EXHIBIT HHH

From: ddglobal
To: Jennifer Lindo
Subject: Meeting
Date: Tuesday, July 14, 2020 9:20:14 AM

Thanks for hosting the very informative meeting yesterday, albeit very long. I vote to increase the upland review to 500ft. Its absurd to think we need scientific evidence to support the fact that less development means cleaner water, not to mention saving wildlife! The vote shouldn't center on how much work it will be for the town to make these changes. This is for the good of the community.

Also, Gary Goeschel's comments in the Day were an abomination as he clearly supports more development, i.e. more money. Does this sway the board unfairly? I think so!

Thanks for listening.
Best,
Deborah Diehl
26 Green Valley Lake Rd
I work at Yale New Haven hospital and run the WIC program since apparently you want to know such things.

Sent from my Verizon, Samsung Galaxy smartphone

EXHIBIT III

From: Gary Goeschel
To: Jennifer Lindo
Subject: FW: To the Inland Wetland Agency and Chairman Gary Upton
Date: Wednesday, July 15, 2020 4:02:45 PM

-----Original Message-----
From: Christie Hayes <christie.hayes1@gmail.com>
Sent: Wednesday, July 15, 2020 4:01 PM
To: Gary Goeschel <ggoeschel@eltownhall.com>
Subject: To the Inland Wetland Agency and Chairman Gary Upton

I was not able to join in the Zoom meeting but wanted to let you know that I am definitely in favor of the extended area in order that we can increase our protection of wetland areas. Our current and future environmental health depends on rulings such as this, and I consider it very important.

Sincerely,
Christie Hayes
97 W Main St.
Niantic

From: Gary Goeschel
To: Jennifer Lindo
Subject: FW: Upland Review change
Date: Thursday, July 16, 2020 3:39:26 PM

From: Thomas Moriarty <tmmoriarty112@gmail.com>
Sent: Wednesday, July 15, 2020 1:25 PM
To: Gary Goeschel <ggoeschel@eltownhall.com>
Subject: Upland Review change

It is my opinion that the proposed expansion of upland review requirements is excessive.
Thomas Moriarty
31 Manwaring Road
Niantic, CT 06357
860-614-8076

From: Gary Goeschel
To: Jennifer Lindo
Subject: FW: To the Inland Wetland Agency and Chairman Gary Upton
Date: Monday, July 20, 2020 10:44:16 AM

From: John C Parker <JohnCParker1@atlanticbb.net>
Sent: Saturday, July 18, 2020 4:00 PM
To: Gary Goeschel <ggoeschel@eltownhall.com>; gary@uptonbass.com
Subject: To the Inland Wetland Agency and Chairman Gary Upton

I **do not support** expanding the Upland review area.

Changing a regulation when scientific findings show the need would be fine.

Changing the scope of an existing regulation as a way to stop commercial development is not appropriate.

I support - following the guidance of professionals. I do not support recommendations based only on "that would be nice".

John C Parker

Niantic CT

From:	Ted Koch
To:	Jennifer Lindo
Cc:	Gary Goeschel
Subject:	Wetlands Regulations Change
Date:	Saturday, July 25, 2020 5:59:31 PM

Dear Ms. Lindo,

Would you kindly add my comments below to the public record in advance of our next wetlands meeting? Thank you.

I have heard the public comment about the proposed increase of our upland review area from 100 feet to 500 feet. The public clearly supports some increase. Support for an increase specifically to 500 feet is less clear.

Some have asked what the scientific support is for an upland review area of 500 feet, as opposed to 200 feet or 1,000. This is a valid concern. I am not aware of much evidence, in our record as it presently stands, specifically supporting 500 feet as the appropriate measure. I am concerned that if our board were to approve a 500 foot upland review area on the record as it stands, we could be vulnerable to the charge that our decision is arbitrary and capricious. I am also concerned that we should notice the public, while public comment is still open, specifically of any intent we might have to increase the upland review area to a distance between 100 and 500 feet.

I have been reviewing the wetlands regulations of our sister towns. Lyme, for example, extends its 100 foot upland review area by different measures, depending upon different activities, and around certain named vulnerable wetlands and watercourses.

The time for public comment gladly remains open. I propose the following:

(1) The board should consider--and the public should know that we will consider--expanding our upland review area only in certains areas. The Pattagansett watershed comes to mind. It impacts our town aquifer and the Long Island Sound. I request that our town planner, Mr. Goeschel, or another appropriately designated person, present to the board a complete list of such particularly vulnerable wetlands and watercourses.

(2) The board should consider--and the public should know that we will consider--different upland review area measurements of less than 500 feet, both as a general proposition for the entire town, and/or as a specific

proposition for particularly vulnerable wetlands and watercourses. This way, we can balance our task to protect the wetlands and watercourses with our ability rigorously to enforce such regulations, and to understand where good environmental protection meets the law of diminishing returns.

W. Theodore Koch III

From: Gary Goeschel
To: Jennifer Lindo
Subject: FW: To the Inland Wetland Agency and Chairman Gary Upton
Date: Monday, July 27, 2020 4:00:08 PM

From: Bdavidia <bdavidia@aol.com>
Sent: Saturday, July 25, 2020 5:48 PM
To: Gary Goeschel <ggoeschel@eltownhall.com>; gary@upto-bass.com
Subject: To the Inland Wetland Agency and Chairman Gary Upton

I am unable to attend the continued hearing on August 10th. So I am sending this e-mail.
I live in Lyme, but care greatly about the environment and how each town's decisions affects its neighbors. I have just "retired" from Lyme's Open Space Commission after about 8 years on it.

You are certainly doing the right thing: having hearings, maybe several, to hear your constituents and consider all sides.
The ultimate goal here is, of course, to protect your town's drinking water and the environment.
I agree that the Town needs to look carefully at the location of its crucial waterbodies and protect them first.
Yes, strict regulations puts a burden on the town, but.....good regulations should strike a balance.
I suggest that you take the time to do careful research: and use good, up to date data. Use your plan of Conservation and Development. If it has not been updated within the last 10 years, then update it!
Think long term: poor regulations can cause problems way into the future, which are expensive, if not impossible to correct.
The town of Lyme makes it VERY hard to develop, or build anything. Over 50% of our Town is in Open Space. Our water is very clean, and it is a desirable place to live. We have strict wetland zoning and our sanitarian is tough.

May I suggest a compromise? Maybe not every house can have a pool. Maybe, in some cases, decks could be exempt: they don't cause as much harm to the environment, in general. Maybe the setback could be changed to 250 feet now and then another 250 feet at a later date. Going from 100' to 500' all at once seems harsh.
Sustainable, long term, carefully thought out regulations that are fair and balanced and will be enforceable are the best!
I wish you a good end result.

Barbara David, 344 Joshuatown Road
Lyme, CT. 06371

bdavidia@aol.com

July 29, 2020

East Lyme Inland Wetland Commission

Chairman Upton and commission members

I'm writing this letter opposing your change to the regulated area from one hundred feet to five hundred feet.

Has the commission determined that developments that have been built under the current regulations are causing an impact to the wetlands and if so where's the data?

Has the commission determined how the roads without any drainage control has an impact on the wetlands compared to the roads that have drainage controls like detention basins or water quality control basins?

If the commission hasn't looked into it then how do you know your current regulations needs to be changed?

Changing the regulation without determining where the problem is will do nothing to improve the wetlands or the quality of the water. There are a lot of roads in town that their drainage goes directly into the wetlands, so in the winter when they're deicing the roads all the chemicals they put down goes into the wetlands which increases the sodium in the water, changing the regulation will not improve this. This change to the regulation puts an impact on most of the town with no evidence showing how it will improve the quality of the wetlands and the water in town.

I'm a second generation developer that's been in the business for over thirty years, and we built two developments in town, Spinnaker and Sea Spray I'm also the developer of Twin Valley Lakes and as a developer we are not looking to build developments that will have an impact on wetlands we build them as to the regulations that the state and towns have adopted.

If the commission wants to change the regulation then they should do some homework and find out where the problem is first and how best to repair it and not assume that changing from 100 feet to 500 feet (a 500% increase) will improve anything. With an impact this large that will effect most land owners in East Lyme the town should wait until you can hold a public meeting in person, I've heard no reason as to why this has to happen now.

Sincerely

Robert Fusari Jr

Liberty Way Partners LLC.

Owner of 22 Liberty Way

Exhibit OOO

Gary Upton, Chairman August 5, 2020
Inland Wetlands Agency
Gary Goeschel, Wetlands Officer
Jennifer Lindo, Administrative Assistant

My name is John Bialowans Jr. of 61 Walnut Hill Road. I would ask that this letter be included in the exhibits for the Public Hearting on Upland Review. We are in opposition to the increase of the Upland review area from one hundred feet (100') to five hundred feet (500'). We feel that its neither legal nor factually supported. This town already has the most restricted regulations, in all of its boards, commissions, and departments. What we need is to enforce the regulations that there are now. Look at a Al Smith property. The permit was given to Al Smith not Pazz Construction. It's been over a year for this dispute to be settled - how much more money and time is the town going to spend? Two construction companies sharing one permit- Is that allowed? Especially, keep the politics out, and favors that have been done in this Town

I am repeating what citizens of East Lyme have been saying about longstanding problems in this town, I will share some examples:

1. Stop & Shop with gas station in the Towns' aquifer
2. Costco with gas station in the Towns' aquifer
3. Huge Gateway Development built above the Towns' aquifers. What about the pipe breakage (fitting) damage to the wetlands, Gordon pond and the Towns' aquifer. At that time, the Wetlands Agency and the CT DEEP enforced their regulations, laws and see how fast the restoration, clean up went and Gateway did everything that was asked of them – with no excuses on the repairs and clean up.
4. My last example is the solar farm on Grassy Hill and Walnut Hill Roads.
    a. Where were all the concerned citizens of East Lyme for the disaster on wetlands, property, watercourses (Cranberry Meadow Brook, Latimer's Brook and the Sound at Golden Spur) when they had a retention pond failure.
    b. Even the solar farms own wetlands, watercourses are still damaged (never vacuumed the silt up, rock dams never done, and the list can go on).
    c. Did anyone clean up or look at a low estimate of 900 tons of silt down these watercourses and into the sound?
    d. Did the CT DEEP and Town of East Lyme Wetlands Agency fully execute their regulations and laws on this matter?
    e. East Lyme would never have another solar farm built here I would imagine from lessons learned.
    f. Look at the CT DEEP on solar farms now (I guess they learned something from their oversight) and the Town too.
    g. What I have heard and been told by CT citizens and East Lyme citizens that a major influence to this project was money, politics and favors.

I would like to know if the Town located all the watercourses, wetlands, vernal pools, etc. that will affect all the citizens of East Lyme with this regulation change. Is this going to be another expense for land owners to live in this town?

I would like to know if the Wetlands Commission members have driven around town roads to see the wetlands, etc. and see the problems with this change to homeowners? Homeowners wouldn't be able to do anything.

That could be a total of 1000 ft – 500 ft on either side of wetlands, etc.

Do you know how much time, money, and lawsuits that will happen with this regulation change?

Did anyone think about the staff at the Town Hall? It's going to end up hiring more people like another wetlands agent, administrative assistance to planning, zoning, building departments and other Town Hall departments, if needed. How much more will the tax payers have to pay?

What's going to happen – people will move out, citizens will say "what can I do on my own property, can I fix anything (from septic systems, additions, a new home or even a little shed, etc.)?

Of course our taxes will go up to pay for the lawsuits, staff hours, and etc.

This is not a quaint little Town anymore and it will never be again. Like I said (and other people to), keep money, politics and favors out of the process. We already had a lot of that happen already in this Town – past, present and we hope not the future.

John Bialowans Jr.
Carol Murcko

Gary Upton-Chairman August 6, 2020
Inland Wetlands Agency
Gary Goeschel – Wetlands Officer
Jennifer Lindo – Administrative Assistant

My name is John Bialowans Jr. of 61 Walnut Hill Road. I got up around 3:00 am Thursday morning and did a little more thinking and research on what I said in my letter of August 5, 2020. I remembered that the Town hired a Massachusetts firm to locate (?) and to drill test holes in the aquifer. They ultimately moved the primary, secondary boundaries of the aquifer. This happened probably more than 5 years ago. Everyone knows that big chain stores (Costco, others) put their scouts, feelers out to find a location for their stores. It could be years before they pick a location. Rumors were going around that Costco said, and I quote "if Costco cannot have a gas station, East Lyme is not their choice for a store". I went to some of those wetlands meetings and listened to the engineers speak….and I'll stop here.

All the other gas stations were there in the 50's and 60's maybe earlier, on Flanders & Chesterfield Roads. I worked at Perry's Esso gas station when I was in high school. I even bought one of the brothers Corvettes when I was 18. I had the Vette for awhile until I got my insurance estimate, and that ended my ownership. The brother took it back, luckily!

Stop and Shop gas station was built on the secondary line of the aquifer. A lot of citizens of East Lyme thought the aquifer line was from the High School, down pass the Middle School, along Flanders Road and to the hillside on Gateway property.

I would like to say something more about the solar farm issue. I know the Wetlands Commission is going to say that they issued a Cease, Desist and Restore order on the property. If you read the regulations, laws, authority of the East Lyme Wetlands Commission (then DEEP got involved) look at the CDR order, what was done. The only thing they said was that it was a civil matter and they did what they could.

Like I heard and have been told by CT citizens and East Lyme citizens that a major influence to this project was money, politics and favors.

Thank you,
John Bialowans, Jr.
Carol Murcko

Ps At least at almost 72 years old I can still admit to my mistakes that I have said and correct them.

Jennifer Lindo

From: Gary Goeschel
Sent: Thursday, August 06, 2020 10:05 AM
To: Jennifer Lindo
Subject: FW: Acquifer Drinking Water CRM:0021070
Attachments: apagencydirectorypdf.pdf; CTSWPfactsheetpdf.pdf; modelmuniregspdf.pdf; modelmuniregsreferencedocpdf.pdf; munregguidancepdf.pdf

We may add this to the IWA public hearing record. I don't think it's relevant so I'm thinking no. Upton may want it.

From: Mark Nickerson <mnickerson@eltownhall.com>
Sent: Wednesday, August 05, 2020 10:03 AM
To: Gary Upton <gary@uptonbass.com>
Cc: Gary Goeschel <ggoeschel@eltownhall.com>
Subject: FW: Acquifer Drinking Water CRM:0021070

Research is back from CCM. Enjoy.

August 3, 2020

The Honorable Mark Nickerson
First Selectman
Town of East Lyme
108 Pennsylvania Ave.
Niantic, CT 06357

Dear Mark,

The following is in response to your request for information regarding what towns in the state have aquifer drinking water.
For those towns that do what are upland review areas, or other protections for the wetlands in those towns.

The phrase "towns that have aquifer drinking water" can mean different things, some of which lead to DEEP and others to DPH.

DEEP has the Aquifer Protection Area Program and, if the focus is on which towns have aquifer protection areas that are regulated that program, you'll want to go there. You can see a map of them at https://ctdeep.maps.arcgis.com/apps/webappviewer/index.html?id=6b33fc05fcce4c5286fafae1b2cccbfb.

If the question focuses on which towns have people or businesses that use water from aquifers, you'll be better off checking with DPH. Its Drinking Water Section regulates public water companies, which include systems at the scale of the MDC all the way down to a Dunkin Donuts served by its own well. But many systems like New Haven's Regional Water Authority, even with all those big reservoirs, also have wells tapping into an aquifer somewhere. DPH also has a private well program. Few of CT's private wells tap into the kind of aquifer regulated by DEEP's APA program, but every well that yields water is producing it from some kind of aquifer. The local and regional health districts do the heavy lifting in dealing with those.

I have attached several documents that help explain the program for municipalities, model regulation, how to develop your own regulation and a fact sheet concerning drinking water sources in Connecticut. Also, each website link includes contact information within DEEP and DPH if you have further questions. At the DEEP website there is a program manual specific to municipalities, it is too large to attach here but you can download straight from the website.

I hope that this information is helpful. Please feel free to contact me directly at (203) 498-3055 or by email at bwest@ccm-ct.org, should you have any further inquiries.

Regards,

Brian

Brian West
Principal Research Analyst
Connecticut Conference of Municipalities (CCM)
545 Long Wharf Drive
8th Floor
New Haven, CT 06511

collaborating for the common good

Connecticut Department of
ENERGY & ENVIRONMENTAL PROTECTION

CONNECTICUT AQUIFER PROTECTION AGENT DIRECTORY 2018

Avon

Aquifer Protection Agency (Planning and Zoning Commission)
Town of Avon
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Avon, CT 06001

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Web: http://www.avonct.gov/planning-community-development/pages/aquifer-protection-regulations-appendix-a-and-permit-informatio

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Beacon Falls

Aquifer Protection Agency (Inland Wetlands and Watercourses Commission)
Beacon Falls Town Hall
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Beacon Falls, CT 06403-1198

David Keating
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Berlin

Aquifer Protection Agency (Inland Wetlands and Watercourses Commission)
Town of Berlin
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James Horbal
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Bethany

Aquifer Protection Agency (Planning and Zoning Commission)
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40 Peck Road
Bethany, CT 06524

Isabel Kearns
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Phone: (203) 393-2100 ext. 1135
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Bethel

Aquifer Protection Agency (Inland Wetlands Agency)
Town of Bethel
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Bethel, CT 06801

Beth Cavagna
Director/Town Planner
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Bethlehem

Aquifer Protection Agency (Inland Wetlands Agency)
Town of Bethlehem
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Bethlehem, CT 06751

Norma Carey/Robert A. Smith
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Bolton

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Town of Bolton
222 Bolton Center Road
Bolton, CT 06043

Jim Rupert
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Bristol

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Robert M. Flanagan AICP, CZEO
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Brookfield

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Brooklyn

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Burlington

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Canterbury

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East Windsor

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Matt Tyksinski
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Essex

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Web: Farmington Aquifer Protection Agency

Glastonbury
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Griswold
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Litchfield

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Town of Litchfield, Town Hall Annex
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Madison

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Manchester

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Environmental Planner
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Mansfield

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Meriden

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Middletown

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DEPARTMENT OF PUBLIC HEALTH
Drinking Water Section

Source Water Protection Unit

The Connecticut Department of Public Health Drinking Water Section created a dedicated functional unit to implement policies and enforce statutes and regulations pertaining specifically to the protection of the sources of public drinking water. The Source Water Protection Unit (SWP) is responsible for the purity and adequacy of Connecticut's approximately 4,000 surface and ground water drinking water supply sources.

The SWP Unit maintains a Strategic Plan for the Implementation of Drinking Water Source Protection in Connecticut. The program elements coordinate, manage, and regulate source protection through the enhancement and oversight of existing source protection laws and regulations, integration with water supply planning, education of local land use officials, and involvement with stakeholders on a continuous basis. This Strategic Plan has two main objectives:

1. Revise and enforce existing public health laws, with an emphasis on education and training, involvement of stakeholders and creation of linkages to all relevant programs in order to effectively and efficiently implement the comprehensive drinking water source protection strategic work plan;
2. Maintain minimized risk to public health for 100 percent of source water areas for community water systems (both surface and groundwater) by substantial implementation of the source water protection actions listed in the Strategic Plan, as well as full application of the federal Ground Water Rule and other laws that are in place to prevent contamination and protect water quality and therefore public health.

Water System Data (as of September, 2012):

System Type	Community	Nontransient Noncommunity	Transient Noncommunity	Groundwater	Surface Water
Number of Systems	556	582	1,454	2,513	79
Population Served	2,714,190	113,320	59,373	429,705	2,447,846

State Definition of Substantial Implementation of the Source Water Protection Program:

The SWP Unit considers substantial implementation as being achieved when all public water systems are in compliance with the objectives in the Strategic Plan. This includes activities and tasks such as:

- implementing continually revised statutes and regulations for source water protection (including the provisions of the federal Groundwater Rule);
- reviewing/approving proposed sources of water supply and proposed sales and proposed changes to the use of water company owned land,
- reviewing/approving permit applications for monitored recreational activities on water company;
- coordinating the process of conducting annual watershed inspections and annual submission of watershed survey reports;
- using and improving the Geographical Information System (GIS) application and database to optimize source assessment and protection;
- working with local, regional and state partnerships on Environmental Impact Review promoting the usage and understanding of source water protection concepts and best management practices to enhance drinking water source protection; .
- working with many diverse groups to enhance drinking water source protection and provide useful educational materials;
- researching and preparing for emerging threats and risks to public water supply sources, and
- working to develop and utilize consistent policies for the use of pesticides and herbicides in public drinking water sources of supply.

Case Studies:

Statutes and Regulations: In 2011, several statutory changes, initiated by the SWP Unit, were passed that: emphasize the importance of maintaining Connecticut's most pristine water bodies for public drinking water use, and strengthen the authority to deny proposed public water supply sources in locations threatened by pollution.

Source Water Area Inspections: In 2013, the SWP Unit worked with a property owner, a water utility, USDA/NRCS and a local health department to develop a manure management plan for a property with historical deficiencies. The SWP Unit ultimately issued a permit for the manure management structure and BMPs that will ensure a minimized risk to the public water supply for years to come. The permit was issued pursuant to Connecticut's 'Sanitation of Watersheds' regulations.

Outreach: The SWP Unit, along with the EPA and US Geological Survey held a stakeholder workshop in October, 2010 to address local source water protection issues. Topics included: cyanotoxins, low impact development and new techniques for water quality protection and management. The SWP Unit has begun an effort to disseminate information on the Drinking Water Section website regarding drinking water supply impacts due to Cyanobacteria, Harmful Algal Blooms (HAB's) and invasive freshwater alga. The SWP Unit participated in a watershed inspector training held in April 2013 to assist personnel of water utilities who annually inspect properties within drinking water watersheds for risks to public water supplies. An additional training is scheduled for spring 2014.

Pesticides and Herbicides: In 2012, the SWP Unit, Department of Public Health toxicologists, and members of CT Department of Energy and Environmental Protection's Water Quality Program, Pesticide Division executed a Memorandum of Agreement that updated the permitting requirements for introducing aquatic pesticides into waters tributary to drinking water supplies.

Stakeholder Involvement: The SWP Unit meets bimonthly with the Connecticut section of the American Water Works Association, Source Water Protection Committee to discuss topics of mutual interest ranging from federal regulations, state statute revisions, local issues. This committee works to develop guidance documents for the annual watershed inspections required by DPH; educational materials for residences and businesses located in public water supply watersheds and sharing information on training events. The SWP Unit also collaborates on a regional and national level (e.g. New England Interstate Water Pollution Control Commission, Ground Water Protection Council, etc.) to ensure that the most effective policies and laws are enacted in Connecticut.

State Policies: The SWP Unit reviewed and offered comments to the State's Office of Policy and Management on the draft State of Connecticut Conservation and Development Policies Plan 2013-2018. One of the key policy recommendations to protect sources of public drinking water that was included in the draft is "utilize an integrated watershed management approach to ensure that high quality existing and potential sources of public drinking water are maintained for human consumption." Projects receiving over $200,000 in state funding must be consistent with the policies in the Plan.

For more information, please see the link below for Connecticut's Source Water Protection Unit:

www.ct.gov/publicdrinkingwater

State of Connecticut

Department of Environmental Protection

Model Municipal Regulations
Aquifer Protection Areas

Effective Date: June 1, 2005
Revised on January 1, 2006
Revised on October 1, 2007
Revised on October 1, 2010

October 1, 2010 revisions

The following revisions made the Model Municipal Regulations consistent with statutory amendments to Public Act No. 10-135, An Act Concerning Brownfield Remediation Liability:

Page 11, Section 4(b)(3) – new, added "a regulated activity which is on any municipally owned site undergoing remedial action pursuant to 40 CFR 271 at the time the applicable aquifer protection area is designated on a municipal zoning district map or inland wetland map, provided: (1) no such regulated activity substantially commenced or was in active operation for the five-year period preceding the date that at the applicable aquifer protection area is designated on a municipal zoning district map or inland wetland map, and (2) any person who engages in such regulated activity within the ten-year period commencing on the date that such applicable aquifer protection area is designated on a municipal zoning district map or inland wetland map registers such regulated activity on a form prescribed by the Commissioner of Environmental Protection and in accordance with the provisions of section 22a-354i-7 of the Regulations of Connecticut State Agencies."

Page 14, Section 8(a) – new, added "… , or for any municipally owned site undergoing remedial action pursuant to 40 CFR 271, any person who engages in a regulated activity within the ten (10) year period commencing on the date the applicable aquifer protection area is designated on a municipal zoning district map or inland wetlands map, …"

Page 14, Section 8(a)(2) – new, added "… Any municipally owned site undergoing remedial action pursuant to 40 CFR 271, the person engaged in such regulated activity shall submit a registration within the ten (10) year period commencing on the date the applicable aquifer protection area is designated on a municipal zoning district map or inland wetlands map. Any person submitting a registration pursuant to the requirements of this subsection …"

State of Connecticut
Department of Environmental Protection

Model Municipal Regulations
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Model Municipal Regulations
Aquifer Protection Areas

SECTION 1. Title and Authority

(a) Aquifers are an essential natural resource and a major source of public drinking water for the State of Connecticut. Use of groundwater will increase as the population grows and opportunities for new surface water supplies diminish due to the rising cost of land and increasingly intense development. At the same time, numerous drinking water wells have been contaminated by certain land use activities, and others are now threatened. To address this problem, Connecticut has established the Aquifer Protection Area Program (Connecticut General Statutes §22a-354a to §22a-354bb) to identify critical water supply aquifers and to protect them from pollution by managing land use. Protection requires coordinated responsibilities shared by the state, municipality and water companies to ensure a plentiful supply of public drinking water for present and future generations. It is therefore the purpose of these regulations to protect aquifer protection areas within the City/Town of ___________ by making provisions for:

(1) implementing regulations consistent with state regulations and An Act Concerning Aquifer Protection Areas, Connecticut General Statutes §22a-354a to §22a-354bb ("the Act");

(2) delineating aquifer protection areas on the city/town zoning or inland wetland and watercourse areas maps;

(3) regulating land use activity within the aquifer protection area including: prohibiting certain new activities; registering existing regulated activities; and issuing permits for new regulated activities at registered facilities; and

(4) administering and enforcing these regulations.

(b) These regulations shall be known as the Aquifer Protection Area Regulations (the "APA Regulations") of the City/Town of ___________.

(c) These regulations were adopted and may be amended, from time to time, in accordance with the provisions of §22a-354p of An Act Concerning Aquifer Protection Areas, the Connecticut General Statutes §22a-354a to §22a-354bb and the Regulations of Connecticut State Agencies §22a-354i-1 through §22a-354i-10.

(d) The ___________________ [board or commission] of the City/Town of ___________ is established as the Aquifer Protection Agency (the "Agency") in accordance with the "Ordinance for the Establishment of an Aquifer Protection Agency," (the "APA Ordinance") effective _________, and shall implement the purposes and provisions of the APA Ordinance and the Act.

(e) The Agency shall administer all provisions of the Act and shall approve or deny registrations, issue permits, issue permits with terms, conditions, limitations or modifications, or deny permits for all regulated activities in aquifer protection areas in the City/Town of ___________ pursuant to the Act.

SECTION 2. Definitions

(a) As used in these regulations, the following definitions apply:

(1) "Affected water company" means "affected water company" as defined in §22a-354h of the Connecticut General Statutes;

(2) "Agency" means the board or commission authorized by the municipality under §22a-354o of the Connecticut General Statutes;

(3) "Agriculture" means "agriculture" as defined in the §1-1(q) of the Connecticut General Statutes;

(4) "Applicant" means, as appropriate in context, a person who applies for an exemption under §22a-354i-6 of the Regulations of Connecticut State Agencies, a permit under §22a-354i-8 of the Regulations of Connecticut State Agencies or a permit under Section 9 of the APA Regulations;

(5) "Application" means, as appropriate in context, an application for an exemption under §22a-354i-6 of the Regulations of Connecticut State Agencies, an application for a permit under §22a-354i-8 of the Regulations of Connecticut State Agencies or an application for a permit under Section 9 of the APA Regulations;

(6) "Aquifer protection area" means "aquifer protection area" as defined in §22a-354h of the Connecticut General Statutes and any extension of such area approved by the Commissioner pursuant to §22a-354i-4 of the Regulations of Connecticut State Agencies;

(7) "Area of contribution" means "area of contribution" as defined in §22a-354h of the Connecticut General Statutes and as mapped in accordance with §22a-354b-1 of the Regulations of Connecticut State Agencies;

(8) "Bulk storage facility" means property where oil or petroleum liquids are received by tank vessel, pipeline, railroad car or tank vehicle for the purpose of storage for wholesale distribution;

(9) "Certified Hazardous Materials Manager" means a hazardous materials manager certified by the Institute of Hazardous Materials Management and who is qualified by reason of relevant specialized training and relevant specialized experience to conduct audits of regulated activities to ensure compliance with applicable laws and identify appropriate pollution prevention practices for such activities;

(10) "Commissioner" means the commissioner of environmental protection, or his or her agent;

(11) "Domestic sewage" means "domestic sewage" as defined in §22a-430-3(a) the Regulations of Connecticut State Agencies;

(12) "Facility" means property where a regulated activity is conducted by any person, including without limitation any buildings located on the property that are owned or leased by that person; and includes contiguous land owned, leased, or for which there is an option to purchase by that person;

(13) "Floor drain" means any opening in a floor or surface which opening or surface receives materials spilled or deposited thereon;

(14) "Hazardous material" means (A) any hazardous substance as defined in 40 CFR 302.4 and listed therein at Table 302.4, excluding mixtures with a total concentration of less than 1% hazardous substances based on volume, (B) any hazardous waste as defined in §22a-449(c)-101 of the Regulations of Connecticut State Agencies, (C) any pesticide as defined in §22a-47 of the Connecticut General Statutes, or (D) any oil or petroleum as defined in §22a-448 of the Connecticut General Statutes;

(15) "Hazardous waste" means "hazardous waste" as defined in §22a-449(c)-101 of the Regulations of Connecticut State Agencies;

(16) "Industrial laundry" means a facility for washing clothes, cloth or other fabric used in industrial operations;

(17) "Infiltration device" means any discharge device installed below or above the ground surface that is designed to discharge liquid to the ground;

(18) "Inland wetland and watercourse areas map" means a map pursuant to §22a-42a of the Connecticut General Statutes;

(19) "ISO 14001 environmental management system certification" means a current ISO 14001 environmental management system certification issued by an ISO 14001 environmental management system registrar that is accredited by the American National Standards Institute (ANSI) - American Society for Quality (ASQ) National Accreditation Board (ANAB);

(20) "Level A mapping" means the lines as shown on Level A maps approved or prepared by the Commissioner pursuant to §22a-354c, §22a-354d or §22a-354z of the Connecticut General Statutes encompassing the area of contribution and recharge areas;

(21) "Lubricating oil" means oil that contains less than 1% chlorinated solvents and is used for the sole purpose of lubricating, cutting, grinding, machining, stamping or quenching metals;

(22) "Municipality" means "municipality" as defined in §22a-354h of the Connecticut General Statutes;

(23) "Owner" means the owner or lessee of the facility in question;

(24) "De-icing chemical" means sodium chloride, calcium chloride, or calcium magnesium acetate;

(25) "Person" means any individual, firm, partnership, association, syndicate, company, trust, corporation, limited liability company, municipality, agency, political or administrative subdivision of the state, or other legal entity of any kind;

(26) "Pollution" means "pollution" as defined in §22a-423 of the Connecticut General Statutes;

(27) "Pollution prevention" means the use of processes and materials so as to reduce or minimize the amount of hazardous materials used or the quantity and concentration of pollutants in waste generated;

(28) "Professional engineer" means a professional engineer licensed in accordance with Chapter 391 of the Connecticut General Statutes, and who is qualified by reason of relevant specialized training and relevant specialized experience to conduct audits of regulated activities to ensure compliance with applicable law and identify appropriate pollution prevention practices for such activities;

(29) "Publicly Owned Treatment Works" means "publicly owned treatment works" as defined in §22a-430-3 of the Regulations of Connecticut State Agencies;

(30) "Public service company" means "public service company" as defined in §16-1 of the Connecticut General Statutes;

(31) "Public supply well" means "public supply well" as defined in §19-13-B51b of the Regulations of Connecticut State Agencies;

(32) "Recharge area" means "recharge area" as defined in §22a-354h of the Connecticut General Statutes and as mapped in accordance with §22a-354b-1 of the Regulations of Connecticut State Agencies;

(33) "Registered regulated activity" means a regulated activity which has been registered under §22a-354i-7 of the Regulations of Connecticut State Agencies or Section 8 of the APA Regulations, and is conducted at the facility identified in such registration;

(34) "Registrant" means a person, who or which, has submitted a registration for an existing regulated activity under §22a-354i-7 of the Regulations of Connecticut State Agencies or Section 4 of the APA Regulations;

(35) "Regulated activity" means any of the following activities, which are located or conducted, wholly or partially, in an aquifer protection area, except as provided for in §22a-354i-5(c) and §22a-354i-6 of the Regulations of Connecticut State Agencies, or Section 4 of the APA Regulations:

(A) underground storage or transmission of oil or petroleum, to the extent such activity is not pre-empted by federal law, or hazardous material, except for (i) an underground storage tank that contains number two (2) fuel oil and is located more than five hundred (500) feet from a public supply well subject to regulation under §22a-354c or §22a-354z of the Connecticut General Statutes, or (ii) underground electrical facilities such as transformers, breakers, or cables containing oil for cooling or insulation purposes which are owned and operated by a public service company,

(B) oil or petroleum dispensing for the purpose of retail, wholesale or fleet use,

(C) on-site storage of hazardous materials for the purpose of wholesale sale,

(D) repair or maintenance of vehicles or internal combustion engines of vehicles, involving the use, storage or disposal of hazardous materials, including solvents, lubricants, paints, brake fluids, transmission fluids or the generation of hazardous wastes,

(E) salvage operations of metal or vehicle parts,

(F) wastewater discharges to ground water other than domestic sewage and stormwater, except for discharges from the following that have received a permit from the Commissioner pursuant to §22a-430 of the Connecticut General Statutes: (i) a pump and treat system for ground water remediation, (ii) a potable water treatment system, (iii) heat pump system, (iv) non-contact cooling water system, (v) swimming pools,

(G) car or truck washing, unless all waste waters from such activity are lawfully disposed of through a connection to a publicly owned treatment works,

(H) production or refining of chemicals, including without limitation hazardous materials or asphalt,

(I) clothes or cloth cleaning service which involves the use, storage or disposal of hazardous materials including without limitation dry-cleaning solvents,

(J) industrial laundry activity that involves the cleaning of clothes or cloth contaminated by hazardous material, unless all waste waters from such activity are lawfully disposed of through a connection to a publicly owned treatment works,

(K) generation of electrical power by means of fossil fuels, except for (i) generation of electrical power by an emergency engine as defined by §22a-174-22(a)(2) of the Regulations of Connecticut State Agencies, or (ii) generation of electrical power by means of natural gas or propane,

(L) production of electronic boards, electrical components, or other electrical equipment involving the use, storage or disposal of any hazardous material or involving metal plating, degreasing of parts or equipment, or etching operations,

(M) embalming or crematory services which involve the use, storage or disposal of hazardous material, unless all waste waters from such activity are lawfully disposed of through a connection to a publicly owned treatment works,

(N) furniture stripping operations which involve the use, storage or disposal of hazardous materials,

(O) furniture finishing operations which involve the use, storage or disposal of hazardous materials, unless all waste waters from such activity are lawfully disposed of through a connection to a publicly owned treatment works,

(P) storage, treatment or disposal of hazardous waste subject to a permit under §22a-449(c)-100 to §22a-449(c)-110, inclusive, of the Regulations of Connecticut State Agencies,

(Q) biological or chemical testing, analysis or research which involves the use, storage or disposal of hazardous material, unless all waste waters from such activity are lawfully disposed of through a connection to a publicly owned treatment works, and provided that on-site testing of a public supply well by a public water utility is not a regulated activity,

(R) pest control services which involve storage, mixing or loading of pesticides or other hazardous materials,

(S) photographic finishing which involves the use, storage or disposal of hazardous materials, unless all waste water from such activity are lawfully disposed of through a connection to a publicly owned treatment works,

(T) production or fabrication of metal products which involves the use, storage or disposal of hazardous materials including (i) metal cleaning or degreasing with industrial solvents, (ii) metal plating, or (iii) metal etching,

(U) printing, plate making, lithography, photoengraving, or gravure, which involves the use, storage or disposal of hazardous materials,

(V) accumulation or storage of waste oil, anti-freeze or spent lead-acid batteries which are subject to a general permit issued by the Commissioner under §22a-208(i) and §22a-454(e)(1) of the Connecticut General Statutes,

(W) production of rubber, resin cements, elastomers or plastic, which involves the use, storage or disposal of hazardous materials,

(X) storage of de-icing chemicals, unless such storage takes place within a weather-tight water-proof structure for the purpose of retail sale or for the purpose of de-icing parking areas or access roads to parking areas,

(Y) accumulation, storage, handling, recycling, disposal, reduction, processing, burning, transfer or composting of solid waste which is subject to a permit issued by the Commissioner pursuant to §22a-207b, §22a-208a, and §22a-208c of the Connecticut General Statute, except for a potable water treatment sludge disposal area,

(Z) dying, coating or printing of textiles, or tanning or finishing of leather, which activity involves the use, storage or disposal of hazardous materials,

(AA) production of wood veneer, plywood, reconstituted wood or pressure-treated wood, which involves the use, storage or disposal of hazardous material, and

(BB) pulp production processes that involve bleaching;

(36) "Release" means "release" as defined in §22a-133k-1 of the Regulations of Connecticut State Agencies;

(37) "State aquifer protection regulations" means §22a-354i-1 to §22a-354i-10, inclusive, of the Regulations of Connecticut State Agencies;

(38) "Storage" means the holding or possession of any hazardous material;

(39) "Storage tank" means a stationary device which is designed to store hazardous materials, and is constructed of non-earthen materials including without limitation concrete, steel, fiberglass or plastic;

(40) "Topographic feature" means an object, whether natural or man-made, located on the earth surface and of sufficient size that it appears on a 1:24,000 scale topographic quadrangle map drawn by the United States Geological Survey;

(41) "Underground" when referring to a storage tank or storage tank component means that ten percent or more of the volumetric capacity of such tank or component is below the surface of the ground and that portion which is below the surface of the ground is not fully visible for inspection;

(42) “Vehicle” or "vehicles" means a “vessel” as defined by §15-170 of the Connecticut General Statutes, and any vehicle propelled or drawn by any non-muscular power, including without limitation an automobile, aircraft, all-terrain vehicle, tractor, lawn mower or snowmobile;

(43) "Waters” means “waters” as defined in §22a-423 of the Connecticut General Statutes;

(44) "Well field" means "well field" as defined in §22a-354h of the Connecticut General Statutes; and

(45) "Zoning district map" means any map showing zoning districts prepared in accordance with maps adopted pursuant to §8-3 of the Connecticut General Statutes.

SECTION 3. Delineation of Aquifer Protection Area Boundaries

(a) The zoning, planning, or planning and zoning commission shall delineate the aquifer protection areas on the City/Town of ____________ zoning district map or, if zoning district maps do not exist, the inland wetland and watercourse areas map adopted pursuant to §22a-42a the Connecticut General Statutes. Such delineation shall consist of the combined areas of contribution and recharge areas as shown on Level A maps approved or prepared by the Commissioner.

(1) Such boundaries shall be delineated within one hundred twenty (120) days after being notified by the Commissioner that an aquifer protection area is located partially or entirely within the City/Town of _________________.

(2) Notice of such delineation shall be published in a newspaper having substantial circulation in the affected area. Such notice shall include at least the following:

(A) a map or detailed description of the subject aquifer protection area; and

(B) the name, telephone number, and address of a representative of the Agency who may be reached for further information.

(b) In order to clarify the location of an aquifer protection area boundary, the Agency may apply to the Commissioner to extend such boundary to coincide with the nearest property line, municipal boundary or topographic feature pursuant to §22a-354i-4 of the Regulations of Connecticut State Agencies. Such extension shall, at a minimum, fully encompass the aquifer protection areas bounded by the approved level A mapping but shall not exceed the distance necessary to clarify the location of the aquifer protection area or to facilitate the administration of regulations pertaining thereto. An aquifer protection area boundary may not be extended without prior written approval of the Commissioner.

(1) Any request by the Agency to the Commissioner for extension of an aquifer protection area boundary shall include at least the following:

(A) A map to scale delineating (i) the aquifer protection area boundary mapped under Section 3(a) of the APA regulations and (ii) the proposed extension of the aquifer protection area boundary;

(B) A certification by the chairperson or duly authorized agent of the Agency that notice of such request has been provided to all owners of property within the proposed extended aquifer protection area and all affected water companies in accordance with the following:

(i) Such notice shall include at least the following:

(aa) A map showing the aquifer protection area boundaries and the proposed extension of such boundaries,

(bb) the name, address, and telephone number of a representative of the Agency who may be contacted for further information, and

(cc) a statement that any person may, not later than thirty (30) days after said notification, submit to the Agency written comments on such proposed boundary extension;

(ii) Such notice shall be effectuated by the following:

(aa) Delivery of notice by certified mail to those individuals and entities identified in Subsection (b)(1)(B) of this Section, or

(bb) the publication of a notice in a newspaper having substantial circulation in the affected area; and posting of notice near the proposed boundaries of the subject aquifer protection area of at least four signs each of which shall be at least four square feet in size (2′ x 2′); and

(C) A summary of comments received by such Agency regarding the proposed boundary extension and the Agency's response.

(2) Not later than sixty (60) days after receiving the Commissioner's written approval of a request to extend an aquifer protection area boundary, the Agency shall cause such boundary to be delineated in accordance with Subsection (a) of this Section.

(c) No person may challenge the boundaries of the aquifer protection area under the APA Regulations unless such challenge is based solely on a failure by the Agency to properly delineate the boundaries in accordance with §22a-354n of the Connecticut General Statutes.

(d) A map of the location and boundaries of the aquifer protection areas, or regulated areas, shall be available for inspection in the Office of the City/Town Clerk or the Agency.

(e) If the Level A mapping is amended in accordance with §22a-354b-1(i) or §22a-354b-1(j) of the Regulations of Connecticut State Agencies, the Agency shall cause the amended aquifer protection area boundary to be delineated in accordance with Subsections (a) or (b) of this Section.

SECTION 4. Prohibited and Regulated Activities

(a) All regulated activities are prohibited in aquifer protection areas, except as specified in Subsection (b) of this Section.

(b) The following regulated activities are not prohibited in aquifer protection areas:

(1) a registered regulated activity which is conducted in compliance with §22a-354i-9 of the Regulations of Connecticut State Agencies or Section 12 of the APA Regulations;

(2) a regulated activity which has received a permit issued pursuant to §22a-354i-8 of the Regulations of Connecticut State Agencies or Section 9 of the APA Regulations; and

(3) a regulated activity which is on any municipally owned site undergoing remedial action pursuant to 40 CFR 271 at the time the applicable aquifer protection area is designated on a municipal zoning district map or inland wetland map, provided: (1) no such regulated activity substantially commenced or was in active operation for the five-year period preceding the date that the applicable aquifer protection area is designated on a municipal zoning district map or inland wetland map, and (2) any person who engages in such regulated activity within the ten-year period commencing on the date that such applicable aquifer protection area is designated on a municipal zoning district map or inland wetland map registers such regulated activity on a form prescribed by the Commissioner of Environmental Protection and in accordance with the provisions of section 22a-354i-7 of the Regulations of Connecticut State Agencies.

(c) The following are not regulated activities:

(1) Any activity conducted at a residence without compensation;

(2) any activity involving the use or storage of no more than two and one-half (2.5) gallons of each type of hazardous material on-site at any one time, provided the total of all hazardous materials on-site does not exceed fifty-five (55) gallons at any one time;

(3) any agricultural activity regulated pursuant to §22a-354m(d) of the Connecticut General Statutes;

(4) any activity provided all the following conditions are satisfied:

(A) such activity takes place solely within an enclosed building in an area with an impermeable floor,

(B) such activity involves no more than 10% of the floor area in the building where the activity takes place,

(C) any hazardous material used in connection with such activity is stored in such building at all times,

(D) all waste waters generated by such activity are lawfully disposed through a connection to a publicly owned treatment works, and

(E) such activity does not involve (i) repair or maintenance of internal combustion engines, including without limitation, vehicles, or equipment associated with such vehicles, (ii) underground storage of any hazardous material, or (iii) above ground storage of more than one hundred and ten (110) gallons of hazardous materials;

(5) any activity solely involving the use of lubricating oil provided all the following conditions are satisfied:

  (A) such activity does not involve cleaning of metals with chlorinated solvents at the facility,

  (B) such activity takes place solely within an enclosed building in an area with an impermeable floor,

  (C) any hazardous material used in connection with such activity is stored in such building at all times, and

  (D) such activity does not involve: (i) repair or maintenance of internal combustion engines, including without limitation, vehicles, or equipment associated with such vehicles, (ii) underground storage of any hazardous material, or (iii) above ground storage of more than one hundred ten (110) gallons of such lubricating oil and associated hazardous waste; and

(6) any activity involving the dispensing of oil or petroleum from an above-ground storage tank or tanks with an aggregate volume of two thousand (2000) gallons or less provided all the following conditions are satisfied:

  (A) such dispensing activity takes place solely on a paved surface which is covered by a roof,

  (B) the above-ground storage tank(s) is a double-walled tank with overfill alarms, and

  (C) all associated piping is either above ground, or has secondary containment.

(d) Determination of a non-regulated activity

  (1) Any person proposing to carry out a non-regulated activity, as set forth in Section 4(c) of these regulations, in an aquifer protection area shall, prior to commencement of such activity, notify the Agency or its duly authorized agent on a form provided by the Agency. Such form shall provide sufficient information to enable the Agency or its duly authorized agent to properly determine that the proposed activity is a regulated activity or a non-regulated activity within the aquifer protection area.

  (2) If such activity is determined to be a non-regulated activity, then no further action under the APA Regulations is necessary.

SECTION 5. Activities Regulated by the State

(a) The Commissioner shall exclusively regulate activities within aquifer protection areas that are specified in §22a-354p(g) of the Connecticut General Statutes. The Agency shall regulate all other regulated activities.

(b) Any person conducting regulated activities that are within the authority of the Commissioner shall submit a registration or obtain a permit or exemption from the Commissioner prior to engaging in such activity. The Commissioner shall process applications for those regulated activities.

(c) The Agency may submit an advisory decision to the Commissioner for consideration on any permit regulated under this Section in accordance with the Connecticut General Statutes §22a-354p(g).

SECTION 6. Application for an Exemption from Prohibition or Regulation

(a) The owner or operator of a regulated activity may seek an exemption from the Commissioner pursuant to §22a-354i-6 of the Regulations of Connecticut State Agencies. Any person seeking an exemption from the Commissioner shall concurrently submit a copy of the application for an exemption to the Agency and any affected water company.

(b) The Agency may submit written comments to the Commissioner on any exemption regulated under this Section in accordance with §22a-354i-6(c) of the Regulations of Connecticut State Agencies within sixty (60) days of the agency receipt of copy of the application.

SECTION 7. General Registration, Permit Application and Transfer Procedures

(a) All applications for permits and registrations shall contain sufficient information for a fair and informed determination of the issues. The Agency may request additional information from the applicant for this purpose.

(b) The day of receipt of a registration, permit application or transfer form shall be the day of the next regularly scheduled meeting of the Agency, immediately following the day of submission of the application to the Agency or its duly authorized agent, or thirty-five (35) days after such submission, whichever is sooner.

(c) At any time during the review period, the Agency may require the applicant or registrant to provide additional information about the regulated activity. Requests for additional information shall not stay the time limitations for registrations and permits as set forth in Sections 8 and 9 of the APA Regulations.

(d) All permit applications and registrations shall be open for public inspection.

(e) Incomplete permit applications and registrations may be denied without prejudice.

(f) No permit or registration issued under Sections 8 or 9 of the APA Regulations shall be assigned or transferred except with written approval by the Agency.

(g) The Agency shall notify the town clerk of any adjoining municipality of the pendency of any application, petition, appeal, request or plan concerning any project on any site in which: (1) any portion of the property affected by a decision of such agency is within five-hundred feet of the boundary of the adjoining municipality; (2) a significant portion of the traffic to the completed project on the site will use streets within the adjoining municipality to enter or exit the site; (3) a significant portion of the sewer or water drainage from the project on the site will flow through and significantly impact the drainage or sewerage system within the adjoining municipality; or (4) water runoff from the improved site will impact streets or other municipal or private property within the adjoining municipality. Such notice shall be made by certified mail, return receipt requested, and shall be mailed within seven days of the date of receipt of the application, petition, request or plan. Such adjoining municipality may, through a representative, appear and be heard at any hearing on any such application, petition, appeal, request or plan.

SECTION 8. Registration Requirements

(a) Any person engaged in a regulated activity which substantially commenced, or was in active operation within the past five (5) years, or with respect to which a municipal building permit was issued, either (A) before the effective date of the state aquifer protection regulations, or (B) before the date an applicable aquifer protection area is designated on a municipal zoning district map or inland wetland and watercourse areas map, whichever occurs later, or for any municipally owned site undergoing remedial action pursuant to 40 CFR 271, any person who engages in a regulated activity within the ten (10) year period commencing on the date the applicable aquifer protection area is designated on a municipal zoning district map or inland wetlands map, shall register the activity in accordance with this Section unless such person has pending an application for an exemption pursuant to §22a-354i-6 of the Regulations of Connecticut State Agencies.

(1) The Commissioner shall process registrations for those regulated activities specified in §22a-354p(g) of the Connecticut General Statutes. The Agency shall process registrations for all other regulated activities.

(2) If the regulated activity is not specified in §22a-354p(g) of the Connecticut General Statutes, the person engaged in such activity shall submit a registration to the Agency not later than one hundred eighty (180) days after adoption of regulations pursuant to §22a-354p of the Connecticut General Statutes, or the designation the aquifer protection area pursuant to §22a-354i-2 of the Regulations of Connecticut State Agencies, whichever occurs later. Any municipally owned site undergoing remedial action pursuant to 40 CFR 271, the person engaged in such regulated activity shall submit a registration within the ten (10) year period commencing on the date the applicable aquifer protection area is designated on a municipal zoning district map or

inland wetlands map. Any person submitting a registration pursuant to the requirements of this subsection shall simultaneously file a copy of the registration with the Commissioner, Commissioner of Public Health and the affected water company.

(b) All registrations shall be provided on a form prescribed by the Agency and shall be accompanied by the correct registration fee in accordance with Section 18 of the APA Regulations. Such registration forms may be obtained from the __________ City/Town Clerk or the Agency. Such registration forms shall include at least the following information in writing or on maps or drawings:

(1) The name, business telephone number, street address and mailing address of the:

(A) Registrant; if the registrant is a corporation or limited partnership, the full name of the facility and such corporation or limited partnership as registered with the Connecticut Secretary of State, and any officer or governing or managing body of any partnership, association, firm or corporation,

(B) owner of such facility if different than the registrant, and

(C) manager or operator overseeing the operations of such facility;

(2) the location of such facility, using street address or other appropriate method of location, and a map showing the property boundaries of the facility on a 1:24,000 scale United States Geological Survey topographic quadrangle base;

(3) an identification of the regulated activity or activities conducted at the facility, as described in Section 2(a)(35) of the APA Regulations, which regulated activity or activities shall consist of any regulated activity which substantially commenced, was in active operation, or with respect to which a municipal building permit was issued within the past five years; and

(4) a certification by the registrant that the subject regulated activity is in compliance with the best management practices set forth in Section 12(a) of the APA Regulations, as follows, signed after satisfying the statements set forth in the following certification:

> "I have personally examined and am familiar with the information submitted in this registration and all attachments, and I certify, based on reasonable investigation, including my inquiry of those individuals responsible for obtaining the information, the submitted information is true, accurate and complete to the best of my knowledge and belief. I understand that any false statement made in this document or certification may be punishable as a criminal offense under §53a-157b of the Connecticut General Statutes and any other applicable law."

(c) When deemed necessary to protect a public supply well subject to regulation under §22a-354c or §22a-354z of the Connecticut General Statutes, the Agency may:

(1) require, by written notice, any registrant to submit for review and written approval a storm water management plan prepared in accordance with Section 12(b) of the APA Regulations. If so required, the storm water management plan shall be implemented by the registrant immediately upon its approval; or

(2) require, by written notice, any registrant to submit for review and written approval the materials management plan prepared in accordance with Section 12(a) of the APA Regulations. If so required, the materials management plan shall be implemented by the registrant immediately upon its approval.

(d) If the Agency determines that a registration is incomplete, it shall reject the registration and notify the registrant of what additional information is required and the date by which it shall be submitted.

(e) If the registration is determined to be complete, and the regulated activity is eligible for registration, the Agency shall send written notification of such registration to the registrant. Such registration shall be determined to be complete and eligible if the registrant has not otherwise received a notice of rejection from the Agency, not later than one hundred and eighty (180) days after the date the registration is received by the Agency.

(f) The following general provisions shall be included in the issuance of all registrations:

(1) The Agency has relied in whole or in part on information provided by the registrant and if such information subsequently proves to be false, deceptive, incomplete or inaccurate, the registration may be modified, suspended or revoked;

(2) all registrations issued by the Agency are subject to and do not derogate any present or future rights or powers of the Commissioner, Agency, or municipality, and convey no rights in real estate or material nor any exclusive privileges, and are further subject to any and all public and private rights and to any federal, state, and municipal laws or regulations pertinent to the subject land or activity;

(3) a complete registration shall expire five (5) years from the date of receipt of such registration by the Agency;

(4) the registrant shall apply to the Agency to renew the registration on a form prescribed by the Agency for a facility prior to expiration of such registration; and

(5) If a registered regulated activity is out of business or inactive when registration renewal is required, a five (5) year allowance shall be in effect from the date the registration expires. If the registrant has not applied to renew the registration within five (5) years of the date the registration expires, the facility is no longer eligible for registration.

(g) If a regulated activity which is eligible for registration in accordance with Subsection (a) of this Section fails to be registered or if the registrant of an active registered activity fails to apply for renewal prior to expiration, the Commissioner or municipal aquifer protection agency, as appropriate, may accept a late registration at their discretion, subject to the limitations in Subsection (f)(5) of this Section.

(h) Any person wishing to assume the benefits under a registration for regulated activities shall apply to transfer such registration on a form prescribed by the Agency and submitted to the Agency.

SECTION 9. Permit Requirements

(a) Any person may apply for a permit to add a regulated activity to a facility where a registered regulated activity occurs.

(b) The Agency shall process permit applications for those registrants that have registered pursuant to Section 8 of the APA Regulations. The Commissioner shall process permit applications for regulated activities specified in §22a-354p(g) of the Connecticut General Statutes and for those registrants that have registered pursuant to §22a-354i-7(b)(1) of the Regulations of Connecticut State Agencies.

(c) Action shall be taken on permit applications within sixty-five (65) days after the completion of a public hearing or in the absence of a public hearing within sixty-five (65) days from the date of receipt of the application. The applicant may consent to one or more extensions of either of these timeframes, provided the total extension of all such periods is sixty-five (65) days or less.

(d) An application for a permit shall be made on a form prescribed by the Agency and shall be accompanied by the correct application fee in accordance with Section 18 of the APA Regulations. Such permit application forms may be obtained from the _______ City/Town Clerk or the Agency. Simultaneously with filing an application, the applicant shall send a copy of the application to the Commissioner, the Commissioner of Public Health and the affected water company. An application shall include the following information:

  (1) The information as required for a registration under Section 8(b) of the APA Regulations shall be provided for the proposed regulated activity;

  (2) a confirmation and certification that the existing and proposed activity:

    (A) remains and shall remain in compliance with Section 12(a) of the APA Regulations,

    (B) shall not increase the number of underground storage tanks used for storage of hazardous materials, and

    (C) remains and shall remain in compliance with all local, state, and federal environmental laws;

  (3) a materials management plan in accordance with Section 12(a) of the APA Regulations;

(4) a storm water management plan in accordance with Section 12(b) of the APA Regulations;

(5) the following environmental compliance information with respect to environmental violations which occurred at the facility where the regulated activities are conducted, within the five years immediately preceding the date of the application:

(A) any criminal conviction involving a violation of any environmental protection law,

(B) any civil penalty imposed in any state or federal judicial proceeding, or any penalty exceeding five thousand dollars imposed in any administrative proceeding, and

(C) any judicial or administrative orders issued regarding any such violation together with the dates, case or docket numbers, or other information which identifies the proceeding. For any such proceeding initiated by the state or federal government, the Agency may require submission of a copy of any official document associated with the proceeding, the final judgment or order;

(6) any additional information deemed necessary by the Agency regarding potential threats to the ground water and proposed safeguards; and

(7) the following certification signed by the applicant and the individual responsible for preparing the application, after satisfying the statements set forth in the certification:

> "I have personally examined and am familiar with the information submitted in this document and all attachments, and I certify, based on reasonable investigation, including my inquiry of those individuals responsible for obtaining the information, the submitted information is true, accurate and complete to the best of my knowledge and belief. I understand that any false statement made in the submitted information is punishable as a criminal offense under §53a-157b of the Connecticut General Statutes and any other applicable law."

(e) The Commissioner, any affected water company or the Commissioner of Public Health may, not later than thirty (30) days after receiving a copy of an application for a permit under this Section, submit to the Agency written comments on such application. The Agency shall give due consideration to any such comments, and shall provide a copy of the decision to the Commissioner, the affected water company and the Commissioner of Public Health.

(f) To carry out the purposes of the Act, the Agency may grant an application as filed, grant it upon such terms, conditions, limitations or modifications necessary, or deny it. The Agency shall state upon the record the reason for its decision.

(g) The Agency may hold a public hearing on an application for a permit in accordance with Section 10 of the APA regulations.

(h) The Agency shall not issue a permit unless a complete application has been received and the applicant demonstrates to the Agency's satisfaction that all requirements of this Section of the APA regulations have been satisfied and all of the following standards and criteria have been met:

(1) the proposed regulated activity shall take place at a facility where a registered regulated activity occurs;

(2) the proposed regulated activity shall not increase the number, or storage capacity of underground storage tanks used for hazardous materials except for the replacement of an existing underground storage tank in accordance with Section 12(a)(3) of the APA Regulations;

(3) the materials management plan and storm water management plan have been satisfactorily prepared in accordance with Sections 12(a) and 12(b) of the APA Regulations;

(4) the applicant has submitted a confirmation and certification that all regulated activities remain and shall remain in compliance with all local, state and federal environmental laws in accordance with Subsection (d)(2) of this Section;

(5) the applicant's compliance record does not indicate (A) that any noncompliance resulted from indifference to or disregard for the legal requirements, (B) an unwillingness or inability to devote the resources necessary to comply and remain in compliance, or (C) that instances of noncompliance have led to serious environmental harm, harm to human health or safety, or a substantial risk of such harm;

(6) the proposed regulated activity shall be conducted in accordance with Section 12 of the APA Regulations;

(7) the existing regulated activity is being conducted in accordance with Section 12 of the APA Regulations; and

(8) the certification required under Subsection (d)(7) of this Section has been signed by the applicant and the individual responsible for preparing the application.

(i) The Agency may impose reasonable conditions or limitations on any permit issued under this Section to assure protection of the ground water, including, but not limited to the following:

(1) best management practices in addition to those set forth in Section 12 of the APA Regulations; and

(2) ground water monitoring.

(j) The following general provisions shall be included in the issuance of all permits:

(1) the Agency has relied in whole or in part on information provided by the applicant

and if such information subsequently proves to be false, deceptive, incomplete or inaccurate, the permit may be modified, suspended or revoked;

(2) all permits issued by the Agency are subject to and do not derogate any present or future rights or powers of the Commissioner, Agency, or municipality, and convey no rights in real estate or material nor any exclusive privileges, and are further subject to any and all public and private rights and to any federal, state, and municipal laws or regulations pertinent to the subject land or activity;

(3) the permit shall expire ten (10) years from the date of issuance of such permit by the Agency; and

(4) a person shall apply to the Agency to renew the permit on a form prescribed by the Agency prior to expiration of such permit. Such renewal shall be granted upon request by the Agency unless a substantial change in the permitted activity is proposed, or enforcement action with regard to the regulated activity has been taken, in which case, a new permit application shall be submitted and reviewed in accordance with the provisions of this Section.

(k) The Agency shall notify the applicant or permittee within fifteen (15) days of the date of the decision by certified mail, return receipt requested, and the Agency shall cause notice of its order in issuance or denial of a permit to be published in a newspaper having a general circulation in the municipality in which the aquifer protection area is located.

(l) A permittee may request a modification of a permit from the Agency. Such request shall be on a form prescribed by the Agency, and shall include the facts and reasons supporting the request. The Agency may require the permittee to submit a new application for a permit or renewal in lieu of a modification request.

(m) A person wishing to assume the benefits under a permit for regulated activities shall apply to transfer such permit on a form prescribed by the Agency and submitted to the Agency.

SECTION 10. Public Hearings Regarding Permit Applications

(a) If the Agency decides to hold a public hearing regarding an application for a permit to conduct a regulated activity within an aquifer protection area, such hearing shall commence no later than sixty-five (65) days after the receipt of such application.

(b) Notice of the hearing shall be published at least twice at intervals of not less than two (2) days, the first not more than fifteen (15) days and not fewer than ten (10) days, and the last not less than two (2) days before the date set for the hearing in a newspaper having a general circulation in each city/town where the affected aquifer, or any part thereof, is located.

(c) The Agency shall send to any affected water company, at least ten (10) days before the hearing, a copy of the notice by certified mail, return receipt requested. Any affected water company may, through a representative, appear and be heard at any such hearing.

(d) All applications, maps and documents relating thereto shall be open for public inspection.

(e) At such hearing any person or persons may appear and be heard.

(f) The hearing shall be completed within thirty-five (35) days of its commencement.

(g) The applicant may consent to an extension of the time frames in Subsections (a) or (f) of this Section, provided the total extension of all such periods, including any extensions provided in Section 9(c), totals sixty-five (65) days or less.

(h) In reaching its decision on any application after a public hearing, the Agency shall base its decision on the record of that hearing. Documentary evidence or other material not in the hearing record shall not be considered by the Agency in its decision.

(i) The applicant or permittee shall be notified of the Agency's decision in accordance with Section 9(k) of the APA Regulations.

SECTION 11. Bond and Insurance Relevant to Permit Applicants

(a) An applicant may be required to file a bond as a condition of the permit.

(b) Any bond or surety shall be conditioned on compliance with all provisions of these regulations and the terms, conditions and limitations established in the permit.

SECTION 12. Best Management Practices

(a) Every regulated activity shall be conducted in accordance with the following:

  (1) hazardous materials may be stored above ground within an aquifer protection area only in accordance with the following conditions:

    (A) hazardous material shall be stored in a building or under a roof that minimizes storm water entry to the hazardous material storage area, except that a roof is not required for a bulk storage facility as defined in Section 2 of the APA Regulations,

    (B) floors within a building or under a roof where hazardous material may be stored shall be constructed or treated to protect the surface of the floor from deterioration due to spillage of any such material,

    (C) a structure which may be used for storage or transfer of hazardous material shall be protected from storm water run-on, and ground water intrusion,

    (D) hazardous material shall be stored within an impermeable containment area which is capable of containing at least the volume of the largest container of such hazardous material present in such area, or 10% of the total volume of all such containers in such area, whichever is larger, without overflow of released hazardous material from the containment area,

(E) hazardous material shall not be stored with other hazardous materials that are incompatible and may create a hazard of fire, explosion or generation of toxic substances,

(F) hazardous material shall be stored only in a container that has been certified to meet state or federal specifications for containers suitable for the transport or storage of such material,

(G) hazardous material shall be stored only in an area that is secured against unauthorized entry by the public, and

(H) the requirements of this subdivision are intended to supplement, and not to supersede, any other applicable requirements of federal, state, or local law, including applicable requirements of the Resource Conservation and Recovery Act of 1976;

(2) no person shall increase the number of underground storage tanks used to store hazardous materials;

(3) an underground storage tank used to store hazardous materials shall not be replaced with a larger tank unless (A) there is no more than a 25% increase in volume of the larger replacement tank, and (B) the larger replacement tank is a double-walled tank with co-axial piping, both meeting new installation component standards pursuant to §22a-449(d)-1(e) and §22a-449(d)-102 of the Regulations of Connecticut State Agencies, and with interstitial monitoring;

(4) no person shall use, maintain or install floor drains, dry wells or other infiltration devices or appurtenances which allow the release of waste waters to the ground, unless such release is permitted by the Commissioner in accordance with §22a-430 or §22a-430b of the Connecticut General Statutes; and

(5) a materials management plan shall be developed and implemented in accordance with the following:

(A) a materials management plan shall contain, at a minimum, the following information with respect to the subject regulated activity:

(i) a pollution prevention assessment consisting of a detailed evaluation of alternatives to the use of hazardous materials or processes and practices that would reduce or eliminate the use of hazardous materials, and implementation of such alternatives where possible and feasible,

(ii) a description of any operations or practices which may pose a threat of pollution to the aquifer, which shall include the following:

        (aa) a process flow diagram identifying where hazardous materials are stored, disposed and used, and where hazardous wastes are generated and subsequently stored and disposed,

        (bb) an inventory of all hazardous materials which are likely to be or will be manufactured, produced, stored, utilized or otherwise handled, and

        (cc) a description of waste, including waste waters generated, and a description of how such wastes are handled, stored and disposed,

    (iii) the name, street address, mailing address, title and telephone number of the individual(s) responsible for implementing the materials management plan and the individual(s) who should be contacted in an emergency,

    (iv) a record-keeping system to account for the types, quantities, and disposition of hazardous materials which are manufactured, produced, utilized, stored, or otherwise handled or which are discharged or emitted; such record-keeping system shall be maintained at the subject facility and shall be made available thereat for inspection during normal business hours by the Commissioner and the municipal aquifer protection agency, and

    (v) an emergency response plan for responding to a release of hazardous materials. Such plan shall describe how each such release could result in pollution to the underlying aquifer and shall set forth the methods used or to be used to prevent and abate any such a release;

(B) when a materials management plan is required under either Section 8(c) or 9(d) of the APA Regulations, such materials management plan shall be completed and certified by a professional engineer or a certified hazardous materials manager, or, if the facility where the regulated activity is conducted has received and maintained an ISO 14001 environmental management system certification, then the registrant may complete and certify the materials management plan; and

(C) the materials management plan shall be maintained at the subject facility and shall be made available thereat for inspection during normal business hours by the Commissioner and the municipal aquifer protection agency.

(b) The development and implementation of a storm water management plan required for regulated activities in accordance with Sections 8(c) and 9(d) of the APA Regulations, shall be as follows: A storm water management plan shall assure that storm water run-off generated by the subject regulated activity is (i) managed in a manner so as to prevent pollution of ground water, and (ii) shall comply with all of the requirements for the General Permit of the Discharge of Storm Water associated with a Commercial Activity issued pursuant to §22a-430b of the Connecticut General Statutes.

SECTION 13. Other State, Federal and Local Laws

(a) Nothing in these regulations shall obviate the requirement for the applicant to obtain any other assents, permits or licenses required by law or regulation by the City/Town of ______________, State of Connecticut and the Government of the United States including any approval required by the Connecticut Department of Environmental Protection and the U.S. Army Corps of Engineers and the United States Environmental Protection Agency. Obtaining such assents, permits or licenses are the sole responsibility of the applicant.

(b) No person shall conduct any regulated activity within an aquifer protection area which requires zoning or subdivision approval without first having obtained a valid certificate of zoning or subdivision approval, special permit, special exception or variance, or other documentation establishing that the proposal complies with the City/Town of ___________ zoning or subdivision regulations.

SECTION 14. Enforcement

(a) The Agency may appoint a duly authorized agent to act in its behalf with the authority to issue notices of violation or cease and desist orders.

(b) If the Agency or its duly authorized agent finds that any person is conducting or maintaining any activity, facility or condition which violates any provision of these regulations, the Agency or its duly authorized agent may:

(1) Issue a notice of violation.

(A) The notice of violation shall state the nature of the violation, the jurisdiction of the Agency, and the necessary action required to correct the violation including without limitation halting the activity in the aquifer protection area.

(B) The Agency may request that the person appear at the next regularly scheduled meeting of the Agency to discuss the unauthorized activity, and/or provide a written reply to the notice or file an application for the necessary permit or registration. Failure to carry out the action(s) directed in a notice of violation may result in issuance of an order under Subsection (2) of this Section or other enforcement proceedings as provided by law.

(2) Issue a written order.

(A) Such order shall be issued by certified mail, return receipt requested to such person conducting such activity or maintaining such facility or condition to cease such activity immediately or to correct such facility or condition. The Agency shall send a copy of such order to any affected water company by certified mail, return receipt requested.

(B) Within ten (10) days of the issuance of such order the Agency shall hold a hearing to provide the person an opportunity to be heard and show cause why the order should not remain in effect. Any affected water company may testify at the hearing. The Agency shall consider the facts presented at the hearing and, within ten (10) days of the completion of the hearing, notify the person by certified mail, return receipt requested, that the original order remains in effect, that a revised order is in effect, or that the order has been withdrawn.

(3) Suspend or revoke registration or permit.

(A) The Agency may suspend or revoke a registration or a permit if it finds, after a hearing, that the registrant or permittee has not complied with the terms, conditions or limitations set forth in the registration or the permit. Prior to revoking or suspending any registration or permit, the Agency shall issue notice to the registrant or the permittee, personally or by certified mail, return receipt requested, setting forth the facts or conduct that warrants the intended action.

(B) The Agency shall hold a hearing to provide the registrant or permittee an opportunity to show that it is in compliance with its registration or permit. The Agency shall notify the registrant or permittee of its decision by certified mail within fifteen (15) days of the date of its decision. The Agency shall publish notice of a suspension or revocation in a newspaper having general circulation in the City/Town of ________________.

(c) An order issued pursuant to Subsection (b)(2) of this Section shall be effective upon issuance, shall remain in effect until the Agency affirms, revises, or withdraws the order, and shall not delay or bar an action pursuant to Subsection (b)(3) of this Section.

(d) A court may assess criminal and or civil penalties to any person who commits, takes part in, or assists in any violation of any provision of the APA regulations in accordance with §22a-354s(b) and §22a-354s(c) of the Connecticut General Statutes.

SECTION 15. Amendments

(a) These regulations may be amended, changed or repealed in accordance with §22a-354p(b) of the Connecticut General Statutes.

(b) If a complete application is filed with the Agency which is in conformance with the APA regulations as of the date of its filing, the permit issued shall not be required to comply with any changes in regulations taking effect on or after the filing date. The provisions of this Section shall not apply to the establishment, amendment, or change of the boundaries of the aquifer protection area or to any changes in the APA Regulations necessary to make the regulations consistent with Chapter 446i of the Connecticut General Statutes as of the date of the Agency's decision.

SECTION 16. Appeals

(a) Appeal of the Agency's regulation, order, decision or action shall be made in accordance with §22a-354q of the Connecticut General Statutes.

SECTION 17. Conflict and Severance

(a) If there is a conflict between the provisions of the APA Regulations, the provision that imposes the most stringent standards shall govern. The invalidity of any word, clause, sentence, section, part, subsection, subdivision or provision of these regulations shall not affect the validity of any other part that can be given effect without such valid part or parts.

(b) If there is a conflict between the provisions of the APA Regulations and the Act, the provisions of the Act shall govern.

SECTION 18. Registration and Permit Application Fees

(a) All fees required by these regulations shall be submitted to the Agency by certified check or money order payable to the City/Town of _____________ at the time the registration or permit application is filed with the Agency.

(b) No registration or permit application shall be granted or approved by the Agency unless the correct registration/application fee is paid in full or unless a waiver has been granted by the Agency pursuant to Subsection (f) of this Section.

(c) The registration or permit application fee is nonrefundable.

(d) Registration or permit application fees shall be based on the following schedule:

Fee Schedule			
	Facility Size		
	Small (< 1 acre)	**Medium (1-5 acres)**	**Large (> 5 acres)**
Registrations:			
Industrial			
Commercial			
Other			
Fee Schedule (continued)			
	Facility Size		
	Small (< 1 acre)	**Medium (1-5 acres)**	**Large (> 5 acres)**
Permits:			
Industrial			
Commercial			

Other			
Materials Management Plan Reviews			
Storm water Management Plan Reviews			
Public Hearing			
Facility Inspection/Monitoring			
Regulation Petition			
Transfer Fee			

(e) Boards, commissions, councils and departments of the City/Town of _________ are exempt from all fee requirements.

(f) The registrant or applicant may petition the Agency to waive, reduce or allow delayed payment of the fee. Such petitions shall be in writing and shall state fully the facts and circumstances the Agency should consider in its determination under this Section. The Agency may waive all or part of the application fee if the Agency determines that:

(1) the activity applied for would clearly result in a substantial public benefit to the environment or to the public health and safety and the registrant or applicant would reasonably be deterred from initiating the activity solely or primarily as a result of the amount of the registration or permit application fee; or

(2) the amount of the registration or permit application fee is clearly excessive in relation to the cost to the City/Town for reviewing and processing the application.

(g) Extra Assessments

In the event that additional expenses, including but not limited to outside consultants, experts, or legal advisors are incurred in processing the registration or permit application the applicant/registrant may be assessed an additional fee not to exceed $___________ to cover said costs. Said fees are to be estimated by the duly authorized agent and submitted with the application fee and held until the application is completely processed after which time any residual funds pertaining to this assessment are to be returned to the applicant/registrant.

For the purpose of this assessment, an "outside consultant" means a professional who is not an employee of the City/Town of _____________ including but not limited to engineering, environmental, hydrogeology and hazardous materials management professionals.

(h) The Agency shall state upon its record the basis for all actions under this Section.

SECTION 19. Effective Date of Regulations

The APA Regulations, APA boundaries and amendments thereto, shall become effective upon (1) the Commissioner's determination that such regulations are reasonably related to the purpose of ground water protection and not inconsistent with the Regulations of Connecticut State Agencies §22a-354i-1 through §22a-354i-10 and (2) filing in the Office of the City/Town Clerk.

Adopted Date: ___________________ (e.g. public hearing date)

DEP Approval Date: ______________ (date of approval letter)

Effective Date: __________________ (e.g. 60 days after hearing date)

Revision Date: ___________________ (as needed)

State of Connecticut
Department of Environmental Protection

Reference Document for Model Municipal Regulations
Aquifer Protection Areas

October 1, 2007
Revised October 1, 2010

The Connecticut Department of Environmental Protection has developed this reference document to provide the reader with a quick reference to the statutory and regulatory citations used in the Model Municipal Aquifer Protection Area Regulations. Additionally, the document provides explanations and clarifications to other citations and references in the regulations. The reference document is arranged by section of the model regulations in which the citation occurs. Municipalities may utilize this document as a companion to the regulations and modify the section numbers to coincide with their local regulations if necessary. DEP will revise this document if there are changes to the statutory and regulatory language of the citations or other references. Municipalities are encouraged to adopt the model regulations with the statutory and regulatory citations and use this document as reference, thereby allowing revisions to the reference document if changes are made to the citations without going through the formal process to revise local regulations.

Model Municipal Regulations Aquifer Protection Areas

Section 1 Title and Authority

Section 2 Definitions

2(a)(1) CGS §22a-354h reads:

"Affected Water Company" means any public or private water company owning or operating a public water supply well within an aquifer protection area.

2(a)(3) CGS §1-1(q) reads:

"Agriculture" means cultivation of the soil, dairying, forestry, raising or harvesting any agricultural or horticultural commodity, including the raising, shearing, feeding, caring for, training and management of livestock, including horses, bees, poultry, fur-bearing animals and wildlife, and the raising or harvesting of oysters, clams, mussels, other molluscan shellfish or fish; the operation, management, conservation, improvement or maintenance of a farm and its buildings, tools and equipment, or salvaging timber or cleared land of brush or other debris left by a storm, as an incident to such farming operations; the production or harvesting of maple syrup or maple sugar, or any agricultural commodity, including lumber, as an incident to ordinary farming operations or the harvesting of mushrooms, the hatching of poultry, or the construction, operation or maintenance of ditches, canals, reservoirs or waterways used exclusively for farming purposes; handling, planting, drying, packing, packaging, processing, freezing, grading, storing or delivering to storage or to market, or to a carrier for transportation to market, or for direct sale any agricultural or horticultural commodity as an incident to ordinary farming operations, or, in the case of fruits and vegetables, as an incident to the preparation of such fruits or vegetables for market or for direct sale.

2(a)(6) CGS §22a-354h reads:

"Aquifer protection area" means any area consisting of well fields, areas of contribution and recharge areas, identified on maps approved by the Commissioner of Environmental Protection pursuant to § 22a-354b to 22a-354d, inclusive, within which land uses or activities shall be required to comply with regulations adopted pursuant to § 22a-354p by the municipality where the aquifer protection area is located.

2(a)(7) CGS §22a-354h reads:

"Area of contribution" means the area where the water table or other potentiometric surface is lowered due to the pumping of a well and groundwater flows directly to the well.

2(a)(9) Institute of Hazardous Materials Managers web site: http://www.ihmm.org

2(a)(11) CGS §22a-430-3(a) reads:

"Domestic sewage" means sewage that consists of water and human excretions or other waterborne wastes incidental to the occupancy of a residential building or a non-residential building but not including manufacturing process water, cooling water, wastewater from water softening equipment, commercial laundry wastewater, blowdown from heating or cooling equipment, water from cellar or floor drains or surface water from roofs, paved surfaces or yard drains.

2(a)(14) Hazardous material broadly includes both raw hazardous chemicals and hazardous wastes.

Hazardous substance means any material, either singularly or in combination, which may pose a present or potential hazard to human health or to the environment if released. The specific hazardous substances are listed in federal regulation 40 CFR 302 (CERCLA list). They generally include substances that are ignitable, corrosive, reactive or toxic. (For full text go to: http://www.epa.gov/epahome/cfr40.htm. The web site contains all of 40 CFR. Navigating to the CERCLA list is as follows: Go to Chapter 1(Parts 1-799); go to Subchapter J (Parts 300-399); go to (Part 302); go to Section 302.4; and finally scroll down to the table.)

CGS §22a-47 reads: "Pesticide" means any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest, or any substance or mixture of substances intended for use as a plant regulator, defoliant or desiccant.

CGS §22a-448 reads: "Oil or petroleum" means oil or petroleum of any kind or in any form including but not limited to waste oils and distillation products such as fuel oil, kerosene, naphtha, gasoline and benzene, or their vapors.

2(a)(15) Hazardous waste means a solid, liquid or gaseous waste that meets one of the following conditions:

1. Is listed in Subpart D of 40 CFR 261(For full text go to: http://www.epa.gov/epahome/cfr40.htm. The web site contains all of 40 CFR. Navigate to Subpart D as follows: Go to Chapter 1(Parts 1-799); go to Subchapter I (Parts 260-265); go to (Part 261); go to Subpart D; and finally to Appendix VIII to Part 261(Hazardous Constituents).)

2. Exhibits a characteristic defined in Subpart C of 40 CFR part 261 that include ignitability, corrosivity, reactivity and toxicity

3. Is a mixture containing a listed hazardous waste and a non-hazardous solid waste

4. Is derived from storage, treatment or disposal of a hazardous waste (For example: leachate is derived from disposal)

5. Is not excluded from regulation as a hazardous waste (Exclusions are limited and include very specific wastes treated in specific ways. For example: wastewater treatment plant sludges generated from electroplating operations and stored in on-site land fill)

For more information, call the DEP's Hazardous Waste Compliance Assistance Program at 1-888-424-4193 (toll free).

2(a)(16) Note: Industrial laundry facilities are regulated in addition to dry cleaners and they may or may not use dry cleaning solvents in their operations.

2(a)(19) For more information on ISO 14001, visit www.anab.org.

2(a)(20) Level A Mapping defines the land area contributing ground water to the public water supply well field. The water company owning the well field maps the area according to the mapping regulations (section 22a-354b-1 of the Regulations of Connecticut State Agencies). DEP approves the mapping.

2(a)(22) CGS §22a-354h reads: "Municipality" means any town, consolidated town and city, consolidated town and borough, city or borough.

For the purposes of these regulations, "Municipality" means the town of

________________.

2(a)(26) CGS §22a-423 reads:

"Pollution" means harmful thermal effect or the contamination or rendering unclean or impure of any waters of the state by reason of any waste or other materials discharged or deposited therein by any public or private sewer or otherwise so directly or indirectly to come in contact with any waters. This includes, but is not limited to, erosion and sedimentation resulting from any filling, land clearing or excavation activity.

2(a)(29) RCSA §22a-430-3 reads:

"Publicly Owned Treatment Works" or "POTW" means a system used for collection, treatment and/or disposal of sewage from more than one lot as defined in section 22a-430-1 of the Regulations of Connecticut State Agencies and which discharges to the waters of the state and which is owned by a municipality or the state.

2(a)(30) CGS §16-1 reads:

"Public service company" means electric, electric distribution, gas, telephone, telegraph, pipeline, sewage, water and community antenna television companies, owning, leasing, maintaining, operating, managing or controlling plants or parts of plants or equipment, and all express companies having special privileges on railroads within this state, but shall not include telegraph company functions concerning intrastate money order service, towns, cities, boroughs, any municipal corporation or department thereof, whether separately incorporated or not, a private power producer, as defined in section 16-243b, or an exempt wholesale generator, as defined in 15 USC 79z-5a.

2(a)(31) RCSA §19-13-B51b reads:

"Public supply well" means a water supply well used or made available by a water company to two or more consumers.

2(a)(32) CGS §22a-354h reads:

"Recharge area" means the area from which groundwater flows directly to the area of contribution.

2(a)(35)(K) RCSA §22a-174-22(a)(2) reads:

"Emergency engine" means a stationary reciprocating engine or a turbine engine which is used as a means of providing mechanical or electrical power only during periods of testing and scheduled maintenance or during either an emergency or in accordance with a contract intended to ensure an adequate supply of electricity for use within the state of Connecticut during the loss of electrical power derived from nuclear facilities. The term does not include an engine for which the owner or operator of such engine is party to any other agreement to sell electrical power from such engine to a electrictricity supplier, or otherwise receives any reduction in the cost of electrical power for agreeing to produce power during periods of reduced voltage or reduced power availability.

RCSA §22a-174-22(a)(3) reads:

"Emergency" means an unforeseeable condition that is beyond the control of the owner or operator of an emergency engine, and that:

> (a) results in an interruption of electrical power from the utility to the premise;
>
> (b) results in a deviation in the voltage from the electricity supplier to the premises of greater than three percent (+3%) above or five percent (-5%) below the standard nominal voltage in accordance with section 16-11-115(a) of the Regulations of Connecticut State Agencies;
>
> (c) requires an interruption of electrical power from the electricitiy supplier to the premises enabling the owner or operator to perform emergency repairs; or
>
> (d) requires the operation of the emergency engine to minimize damage from fire, flood, or any other catastrophic event, natural or man-made.

2(a)(35)(P) Facilities that store, treat or dispose of hazardous waste are subject to a permit under federal and state law. The state laws incorporate the federal laws by reference. Under RCRA, storage means the containment of hazardous wastes either on a temporary basis or for a period of years in such a manner as not to constitute disposal of such hazardous waste; treatment means any method, technique or process including neutralization designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste or so as to render such waste non-hazardous, safer for transport, amenable for recovery, amenable for storage, or reduced in volume; disposal means the discharge, deposit, injection, dumping, spilling, leaking, or placing of waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment.

For more information, call the DEP's Hazardous Waste Compliance Assistance Program at 1-888-424-4193 (toll free).

2(a)(35)(V) Facilities subject to a general permit include transfer stations, solid waste disposal areas, household hazardous waste collection sites, and certain recycling facilities.

2(a)(35)(Y) Solid wastes facilities subject to a permit include solid waste disposal areas, volume reduction plants, transfer stations, wood-burning facilities and biomedical waste treatment facilities. (This does not apply to facilities that only compost leaves.)

CGS §22a-207(3) reads:

"Solid waste" means unwanted or discarded solid, liquid, semisolid or contained gaseous material, including, but not limited to, demolition debris, material burned or otherwise processed at a resources recovery facility or incinerator, material processed at a recycling facility and sludge or other residue from a water pollution abatement facility, water supply treatment plant or air pollution control facility.

2(a)(36) RCSA §22a-133k-1 reads:

"Release" means any spilling, leaking, pumping, pouring, emptying, discharging, injecting, escaping, leaching, dumping or disposing of a hazardous material.

2(a)(42) CGS §15-170 reads:

"Vessel" means every description of watercraft, other than a seaplane on water, used or capable of being used as a means of transportation on water.

2(a)(43) CGS §22a-423 reads:

"Waters" means all tidal waters, harbors, estuaries, rivers, brooks, watercourses, waterways, wells, springs, lakes, ponds, marshes, drainage systems and all other surface or underground streams, bodies or accumulations of water, natural or artificial, public or private, which are contained within, flow through or border upon this state or any portion thereof.

2(a)(44) CGS §22a-354h reads:

"Well field" means the immediate area surrounding a public drinking water supply well or group of wells.

Section 3 Delineation of Aquifer Protection Area Boundaries

3(a) If the Agency is not the zoning commission, planning commission or the planning and zoning commission, then the other agency appointed as the aquifer protection agency must work with those commissions to have the aquifer protection area delineated on the official zoning map in accordance with section 3 of the APA Regulations.

3(b) DEP recommends limiting the extension of the boundary to the absolute minimum required area necessary to administer the program. See guidance for further information.

Section 4 Prohibited and Regulated Activities

4(b)(3) 40 CFR 271 is the section of the federal code that authorizes a memorandum of agreement (MOA) between EPA and the states to have the lead on Hazardous Waste under Section 3006 of RCRA. Under the MOA between CT DEP & EPA, the state has the lead on RCRA Corrective Action where sites are undergoing remedial cleanup of contamination. Our current records show there are 234 sites in CT in RCRA Corrective Action Program and of these, 12 are in APAs. At least 8 sites are active and would be able to register directly under APA program. Of the remaining sites, we are aware of only one site (Century Brass site in New Milford) which is municipally owned and would therefore be allowed the extended time frame to register.

4(c)(3) See definition of agriculture under section 2 of the APA Regulations.

Section 5 Activities Regulated by the State

5(a) CGS §22a-354p(g) gives the Commissioner the sole authority for aquifer protection registrations and permits for:

(A) any person to whom the commissioner has issued an individual permit under the national pollutant discharge elimination system (NPDES) of the federal Clean Water Act (33 USC 1251 et seq.) or under the state pollutant discharge elimination system (SPDES) pursuant to section 22a-430 or any person to whom the commissioner has issued a permit under the provisions of the federal Resource Conservation and Recovery Act (RCRA) (42 USC 6901 et seq.) for a treatment, storage or disposal facility,

(B) any public service company, as defined in section 16-1, providing gas, electric, pipeline, water or telephone service,

(C) any large quantity generator, as defined in regulations adopted by the commissioner under section 22a-449, or

(D) any state department, agency or instrumentality, except any local or regional board of education.

5(c) CGS §22a-354p(g) says:

Such authority may be exercised only after an advisory decision on such permit has been rendered to the commissioner by the aquifer protection agency of the municipality within which such aquifer protection area is located or thirty-five (35) days after receipt by the commissioner of the application for such permit, whichever occurs first.

Section 6 Application for Exemption from Prohibition or Regulation

Section 7 General Registration, Permit Application and Transfer Procedures

7 (b) The time frame is specified by statue under Connecticut General Statute 22a-354p(c).

Section 8 Registration Requirements

8(a) See section 4(b)(3) of this reference document for explanation of 40 CFR 271.

8(a)(1) See section 5(a) of these regulations for explanation of §22a-354p(g).

8(a)(2) See section 4(b)(3) of this reference document for explanation of 40 CFR 271.

8(f)(3) See section 7(b) for definition of date of receipt.

8(h) A transfer in ownership requires submittal of a form to the Agency that changes the name on the registration and the new owner must certify compliance with best management practices. The expiration date of the registration remains the same.

Section 9 Permit Requirements

9(b) See section 5(a) of these regulations for explanation of §22a-354p(g).

9(c) Connecticut General Statutes §22a-354p(c) specifies the number of days to take action on permit applications.

9(e) Please note that the time frame differs from the 60 days allowed in state regulations. The 30-day time period is established due to CGS section 22a-354p(c) requiring all local applications to be acted on by the agency within 65 days of receipt, in the absence of a public hearing.

9(k) The number of days the Agency has to notify the applicant or permittee of the decision of the permit is specified in Connecticut General Statute 22a-354p(d).

9(m) A transfer in ownership requires submittal of a form to the Agency that changes the name on the permit and the new owner must certify compliance with best management practices. The expiration date of the permit remains the same.

Section 10 Public Hearings Regarding Permit Applications

10(a) The number of days is specified in Connecticut General Statute 22a-354p(c). The time frames were intended to be consistent with Inland Wetlands but Inland Wetlands time frames have changed.

Section 11 Bond and Insurance Relevant to Permit Applications

Section 12 Best Management Practices

12(a)(5)(B) ISO 14001 is an internationally accepted specification for an environmental management system. It specifies requirements for establishing an environmental policy, determining environmental aspects & impacts of products/activities/services, planning environmental objectives and measurable targets, implementation & operation of programs to meet objectives & targets, checking & corrective action, and management review. For more information visit their web site at: http://www.iso14000.com.

12(b) A stormwater plan must meet the requirements of the commercial stormwater general permit. The permit requires the plan have the following components: Stormwater conveyance and management, pollution prevention, spill control/response, pavement sweeping, maintenance and inspection. The basic stormwater principals in aquifer protection areas are: prevent illicit discharges or releases to the ground, provide impervious pavement in areas of potential release, and provide measures where possible to infiltrate clean water. See guidance for additional information. The DEP 2004 Connecticut Stormwater Quality Manual provides comprehensive stormwater guidance and is available on the DEP's website at http://www.dep.state.ct.us/wtr/stormwater/strmwtrman.htm

Section 13 Other State, Federal and Local Laws

Section 14 Enforcement

14(d) CGS §22a-354s(b) reads:

(b) Any person who commits, takes part in, or assists in any violation of any provision of sections 22a-354o to 22a-354t, inclusive, or section 14 of public act 89-305* or any ordinance or regulation promulgated by municipalities pursuant to the grant of authority herein contained, shall be assessed a civil penalty of not more than one thousand dollars for each offense. Each violation of said sections shall be a separate and distinct offense, and, in the case of a continuing violation, each day's continuance thereof shall be deemed to be a separate and distinct offense. The Superior Court, in an action brought by the commissioner, municipality, district or any person shall have jurisdiction to restrain a continuing violation of said sections, to issue orders directing that the violation be corrected or removed, and to assess civil penalties pursuant to this section. All costs, fees and expenses in connection with such action shall be assessed as damages against the violator together with reasonable attorney's fees which may be allowed, all of which shall be awarded to the municipality, district or person bringing such action.

(Sections 22a-354o to 22a-354t are the sections of the statute pertaining to municipal regulation of aquifer protection areas. Section 14 of public act 89-305 refers to a transportation study that DEP and Department of Transportation are required to conduct.)

CGS §22a-354s(c) reads:

(c) Any person who wilfully or knowingly violates any provision of sections 22a-354o to 22a-354t, inclusive, or section 14 of public act 89-305* shall be fined not more than one thousand dollars for each day during which such violation continues or be imprisoned not more than six months or both. For a subsequent violation, such person shall be fined not more than two thousand dollars for each day during which such violation continues or be imprisoned not more than one year or both. For the purposes of this subsection, "person" shall be construed to include any responsible corporate officer.

Section 15 Amendments

Section 16 Appeals

16(a) Within fifteen (15) days of publication of the regulation, order, decision or action, the aggrieved person may appeal to superior court.

Section 17 Conflict and Severance

Section 18 Application and Registration Fees

Section 19 Effective Date of Regulations

State of Connecticut
Department of Environmental Protection

Guidance for Adoption of Municipal Regulations

In order to regulate aquifer protection areas, the local aquifer protection agency must adopt aquifer protection regulations in accordance with Connecticut General Statutes (C.G.S.) Section 22a-354p and state regulations. Municipal regulations must provide for:

1. the manner in which the boundaries of aquifer protection areas shall be established and amended or changed;
2. the form for an application to conduct regulated activities within the area;
3. notice and publication requirements;
4. criteria and procedures for the review of applications; and
5. administration and enforcement.

No regulations of an aquifer protection agency shall become effective or be established until after a public hearing, at which interested parties and citizens have an opportunity to be heard. Local aquifer protection regulations must be consistent with the state regulations and the adopted regulations must be approved by the Connecticut Department of Environmental Protection (DEP). The Model Municipal Regulations for Aquifer Protection Areas have been prepared by DEP for use by municipal agencies in adopting regulations consistent with statutory requirements and state regulations.

The Adoption Process

The attached flow chart indicates the required actions and timeframes necessary to complete the regulation adoption process. Care should be taken to ensure that proper DEP, water company and public notices are given.

In particular, the municipality must:

- **send a copy of the hearing notice and proposed regulations to DEP, town clerk and affected water company(s) 35 days prior to hearing**
- **publish proper legal notices**
- **send a copy of the adopted regulations to DEP for final approval**

Send DEP copies to:

Kim Czapla
Environmental Analyst 3
Connecticut Department of Environmental Protection
Bureau of Water Protection and Land Reuse
Aquifer Protection Area Program
79 Elm Street
Hartford, CT 06106-5127

Model Municipal Regulations

CGS Section 22a-354l requires DEP to prepare a model municipal aquifer protection ordinance[1], consistent with regulations adopted under Section 22a-354i. The ordinance may be considered by municipal aquifer protection agencies in adopting regulations pursuant to Section 22a-354p. DEP encourages use of the Model Municipal Aquifer Protection Area Regulations to ensure state regulation consistency.

DEP has also prepared a reference document to provide the reader with a quick reference to the statutory and regulatory citations used in the Model Municipal Aquifer Protection Area Regulations.

Consistency with State Regulations

The adopted regulations shall not be effective unless the Commissioner of the Department of Environmental Protection (DEP) determines that they are reasonably related to the purpose of ground water protection and are not inconsistent with the state regulations. Regulations must be as stringent as state regulations. DEP is required to provide the agency with written notice of approval or the reasons the regulations cannot be approved within sixty days of receipt by DEP in accordance with Connecticut General Statutes (C.G.S.) Section 22a-354p(f).

Considerations for More Stringent Regulations

Although C.G.S. Section 22a-354p(f) allows local aquifer protection regulations to provide a greater level of protection than the state regulations, such authority is limited in scope and must be related to the purpose of ground water protection. Local regulation matters are limited to those matters specified in 22a-354p(a):

(1) the manner in which the boundaries of aquifer protection areas shall be established and amended or changed;
(2) the form for an application to conduct regulated activities within the area;
(3) notice and publication requirements;
(4) criteria and procedures for the review of applications; and
(5) administration and enforcement.

The Aquifer Protection Act does not authorize local regulations to alter the scope of regulated activities. The authority for determining the scope of regulated activities is given solely to the DEP Commissioner under C.G.S. Section 22a-354i. The Commissioner may determine the scope of regulated activities, exceptions or conditions for non-regulated activities, exemptions, and best management practices. When considering more stringent local regulations, care must be taken to ensure they are limited to matters specified in Section 22a-354p(a) and are reasonably related to the protection of ground water. Any municipality considering a greater level of protection than provided in the DEP model municipal regulation is advised to discuss those with the DEP staff first before formally proposing regulations.

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[1] DEP recognizes the ordinance as regulations.

Aquifer Protection Area Regulation Adoption Flow Chart

(CGS Sec. 22a-354p & RCSA Sec. 22a-354i-3)

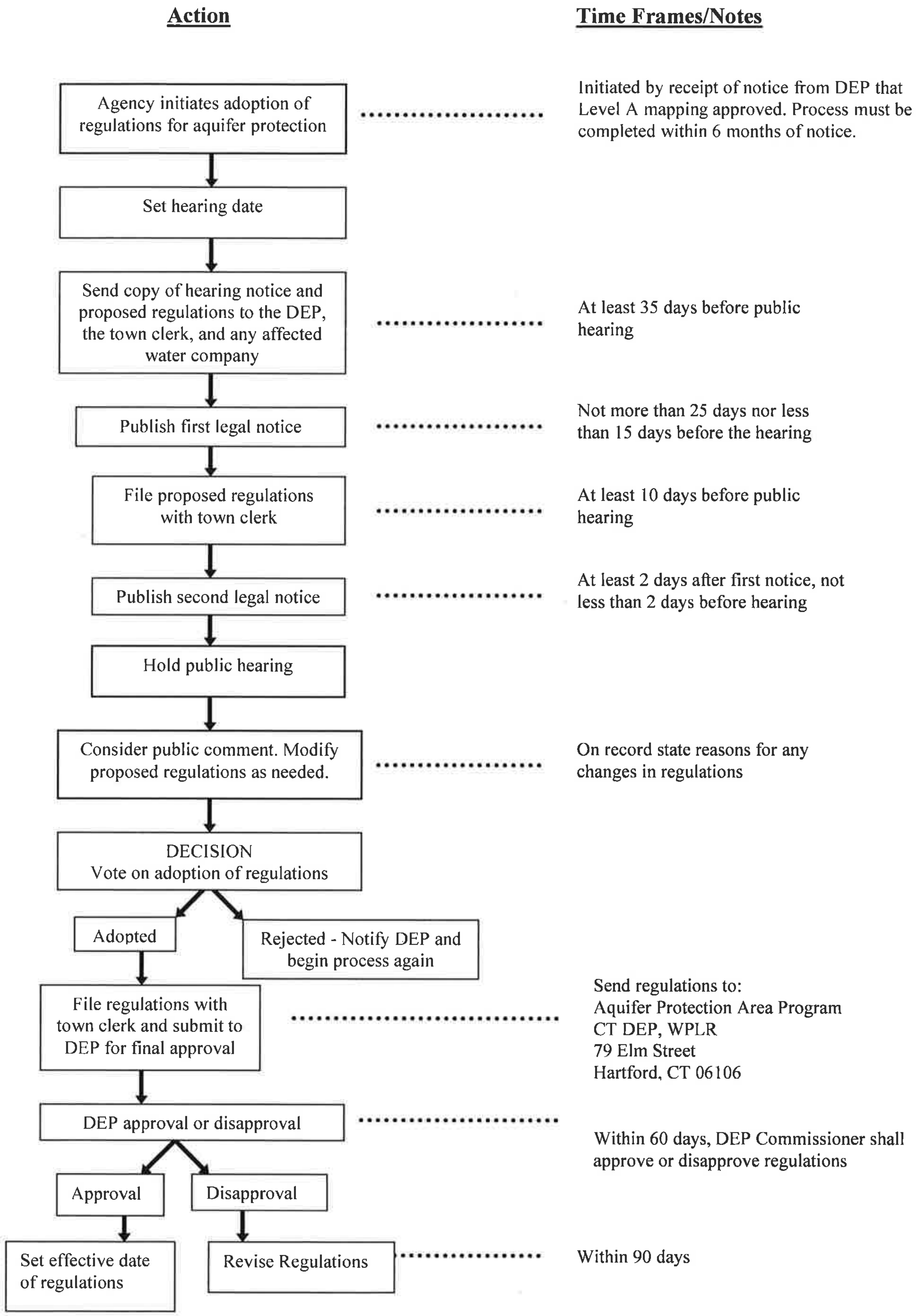

EXHIBIT RRR

EAST LYME INLAND WETLANDS AGENCY
REGUALAR MEETING MINUTES
June 10, 2019
East Lyme Town Hall, 108 Pennsylvania Avenue,
East Lyme, Connecticut
Upper Meeting Room
7:00 p.m.

Present: Peter DeRosa, Phyllis Berger, Rosemary Ostfeld, Ann Cicchiello, Vice Chairman
Absent: Gary Upton, Chairman, Harry Clarke, Jack Chomicz, Theodore Koch, Alt.
Also Present: Gary Goeschel, Director of Planning/Inland Wetlands Agent

Call to Order:
Vice Chairman, Ann Cicchiello called the meeting to order at 7:04

Pledge of Allegiance:
The Pledge of Allegiance was recited.

I. **Additions to the Agenda**-none

II. **Public Hearings:** -none

III. **Public Delegations:** No Public Delegations

IV. **Acceptance of Minutes:**

A. **Meeting Minutes of May 6, 2016 Regular Meeting**

MOTION (Ostfeld/Berger) To approve the minutes of May 6, 2019 Regular Meeting as amended.

- Page 3, ¶ 1-The soils are ~~gravely~~ gravelly and sandy.

V. **Ex-Officio Report**-none

VI. **Pending Applications**

A. **Willow Land LLC, Jodie Chase, Owner, Application for the construction of a new single family residence within an upland review area located at 67 Spring Glen Rd, East Lyme Assessor's Map 01.18, Lot 56.**
Greg Fettus, Fettus Engineering, Mystic, described the property and addressed the comments from town staff. He discussed the drainage path along the wetlands and stated that to avoid footing drains and sub-pumps they flipped the house which moved it more towards the road and eliminated the front steps. The water and sewer will come straight in to the house with less disturbance. Fettus stated the grading has

not changed from the first plan submitted. Any water from the sub-pumps will be directed to a stoned gravel area in the buffer.
The house is 32 X 30 with a single car garage and walk out basement. The lot size is 12,538 sq.ft. There is no additional impact from drainage on neighbors as the grading is not changing.
Fettus informed the commission that when the soil scientist surveyed the property he did not see evidence of a stream, but he acknowledged there is evidence of an intermittent stream. There will be a mulch buffer planted at the edge of the limit of disturbance. The rain garden is the same as first presented. The driveway will be stone with a paved apron.

Jodie Chase stated she is a soil scientist and informed the commission that they are building the smallest house possible but they need to build a house that is marketable and in keeping with the surrounding homes.

G. Goeschel stated the applicant has addressed all staff comments and the town engineer had no issue with the drainage as proposed.

The flow of the water is north to south and goes to a drainage system and then into Long Island Sound.

The application states that there is 2,100 sq. ft. of wetlands areas that will be disturbed and 5,000 sq. ft. of upland review will be disturbed.

MOTION: (Ostfeld/DeRosa) to table until the next meeting, Willow Land LLC, Jodie Chase, Owner, Application for the construction of a new single family residence within an upland review area located at 67 Spring Glen Rd, East Lyme Assessor's Map 01.18, Lot 56. Vote: Approved Unanimously.

B. **Leonard Brian McPartlin, Owner: Application for the repair and construction of a landscape retaining wall down to the bank level at 132 N. Bride Brook Road, East Lyme Assessor's Map 14.0, Lot 56**

G. Goeschel stated the applicant has informed his office he is building the retaining wall according to the sketch provided to him on how to build a, "Landscape Retaining Wall". G. Goeschel is not sure there is the level of stone/crushed rock as the sketch calls for but it appears that the wall is being constructed properly and no water is getting behind wall.

MOTION: (Berger/Ostfeld) to approve Application for the repair and construction of a landscape retaining wall down to the bank level at 132 N. Bride Brook Road, East Lyme Assessor's Map 14.0, Lot 56. Vote: Approved Unanimously.

VII. New Business:

A. **J. Robert Pfanner & Associates, Agent for Roxbury Road, LLC; for the deposition of material on land within 100-feet of a wetlands and watercourse at**

property located on the southwest side of Roxbury Road across from the entrance of the Towns' Municipal Transfer Station, Assessor's Map 16.1Lot 43, Niantic, Connecticut for future septic area as part of a future subdivision.

J. Robert Pfanner gave a background of the previous violation on the property and stated the property owner has retained the services of his company. He informed the members that an 8 lot development is proposed in the future on the 62 acre parcel. He stated most of the back part of the property is wetlands.

Pfanner stated there are two areas that are called out as prep for septic system. He stated there needs to be 4' of cover to a septic system. Due to rock in those areas 2' of fill needs to be brought in to meet septic regulations. He stated the application if just for the stockpile of fill for the septic, not for the development. He cannot get a sanitation report for the potential development until there is a suitable area for the septic. He stated the fill will be closest to the wetlands. The leeching area will be approximately 60" from the wetlands.

Pfanner stated the wetlands report which has been done by a certified soil scientist will be provided to staff and the commission. The commission stated they would like the soil scientist to be at the next meeting.

The application was tabled until the next meeting.

VIII. Old Business: No Old Business

IX. Reports

A. Chairman's Report-no report

B. Inland Wetlands Agent Report-no report

C. Enforcement

1. Cease, Desist and Restore Order, 13 Green Valley Lakes Rd; Thomas and Kristen Chantrell, Owner; Installation of a dock which encroaches approximately 20-feet into a watercourse located on an abutting property and the clearing, grading, removal and deposition of material on the land within 100 ft of a watercourse without an Inland Wetlands Permit. (Agreement to remove by August 31, 2019)

G. Goeschel stated the property owner did remove the additional dock that was on the abutters property. He stated they are in the process of removing the pipe.

G. Goeschel informed the members that the Twin Valley application is now on the court docket and is proceeding forward in the courts.

2. Notice of Violation; 297 Boston Post Road; Al Smith Owner, Jason Pazzaglia, Other; Outside storage of equipment, construction materials, and the stockpiling of earthen materials including but not limited to yard debris within 100 feet of a watercourse without or in violation of an Inland Wetlands Permit.

G. Goeschel stated there was no change from the last time J. Pazzaglia was contacted. He stated he saw J. Pazzaglia recently and told him he needed to get moving on moving the materials outside of the review area. It was the consensus of the commission that a fine should be levied.

Correspondence-none

G. Goeschel included in the packets, the Inland Wetland Commission bylaws for future discussion and possible action. He also supplied their regulations for possible revision.

G. Goeschel informed the members of his discussion with some Board of Selectmen members on the issue of attendance and lack of members on the commission.

X. Adjournment:

MOTION: (Berger/DeRosa) to adjourn at 8:15 Vote: Approved Unanimously.

Respectfully Submitted

Sue Spang
Recording Secretary

EAST LYME INLAND WETLANDS AGENCY
REGUALAR MEETING MINUTES
December 16, 2019
East Lyme Town Hall, 108 Pennsylvania Avenue,
East Lyme, Connecticut
Upper Meeting Room

7:00 p.m.

Present: Gary Upton, Chairman, Phyllis Berger, Rosemary Ostfeld, Theodore Koch, Don Phimister, Kristin Chantrell, Sandy Gignac, Alt., Doreen Rhein, Alt.
Absent: none
Also Present: Gary Goeschel, Director of Planning/Inland Wetlands Agent, Paul Dagle, Selectman

Call to Order:
G. Upton called the meeting to order at 7:01

Pledge of Allegiance:
The Pledge of Allegiance was recited.

FILED
December 20, 20 19 AT 8:38 [✓ AM]/PM
Brooke Stevens ATC
EAST LYME TOWN CLERK

I. **Additions to the Agenda-**none

II. **Public Hearings:** -none

III. **Public Delegations:** none

IV. **Acceptance of Minutes:**
A. **Meeting Minutes of October 21, 2019 Regular Meeting**

MOTION (Berger/ Ostfeld) To approve the minutes of October 21, 2019 Regular Meeting as presented.

Vote: Approved. In favor- Upton, Ostfeld, Berger, Koch, Gignac, Chantrell. Opposed-none. Abstaining-Phimister

V. **Ex-Officio Report-**Selectman Dagle welcomed the new members. He stated that the budget season is starting and the Public Safety Building project is moving along and he does not expect any of the work to affect regulated areas.

VI. **Pending Applications-**none

VII. **New Business:**
A. **2020 Meeting dates**
MOTION: (Chantrell/Gignac) to approve the Inland Wetlands Agency's 2020 meeting dates as presented with changes to the April meeting date from April 13,

2020 to April 6, 2020 and the April site walk date from April 11, 2020 to April 4, 2020. Vote: Approved. In favor- Upton, Ostfeld, Berger, Phimister, Gignac, Chantrell. Opposed-none. Abstaining- Koch

B. **Application of Harry Heller, Attorney/Agent for Pazz & Construction, LLC, Owner to conduct regulated activities in the upland review area in association with a proposed multi-family residential community on property identified in the application as N Bride Brook Rd, East Lyme Assessor's Map 09.0, Lot 37-2.**
Harry Heller, 736 Rt. 32 Uncasville representing Pazz & Construction and the project design engineer, Brandon Handfield, Yantic River Consultants representing the applicant introduced the project.
H. Heller stated the project was a 20-acre parcel located on the westerly side of N. Bride Brook Rd. and the easterly side of Interstate 95. He stated there was no direct impact to the wetlands.
The proposal is to build 108 residential units in 13 buildings. The project has municipal water and sewer access and received approval for sewer capacity to service the project.
H. Heller informed the Agency that the drainage system will be a closed system. The project will be done in phases with the detention basin and access to the project done first. The storm water quality detention basin will be in the southeasterly part of the property. There will be a pretreatment basin in the westerly side of the basin that will handle a 1" rainfall. The water will pass through a permeable berm into the basin which can accommodate all storm events from a two-year storm to the 100-year storm event. There is an outlet culvert from the detention basin to a catch basin in N. Bride Brook Road and then the water will naturally go into Bride Brook.
On the Northeast corner of the parcel the water will sheet off the improved hard surfaces (minus the rooftops in the 3 westerly buildings) and will be picked up by a series of culverts and into the storm water quality detention basin.
The proposed buildings, I, J and M are on the westerly side of the parcel will have indirect activity to the 100 ft. regulated upland review area. Any rainfall other than the rooftops will drain to the paved area and go to the closed drainage system and on to the drainage basin. The rain from the three roofs will drain to a rip rap splash pad along the westerly periphery and to the watercourse and wetlands system to provide recharge to the system.
H. Heller stated the plan is to construct two buildings at a time. He described the erosion and sedimentation plan for the property. The plan calls for sediment vents and wood chip berms on the down gradient side of the property. He stated there will be traps designed to accommodate 134 cubic yards of material for each disturbed acre of the site. The traps have a maintenance plan to be cleared when they are at 50% of capacity. When the area is fully stabilized the area will be graded off.
H. Heller stated the project is an affordable housing project under §8-30g.
There will be curbing to direct storm water to the closed drainage system. He stated he would not be averse to Cape Cod curbing.
Brandon Handfield informed the members that there is an intermittent watercourse on the property which flows onto private property.
The road and cull-d-sac will be private roads.

G. Goeschel reviewed the memo from town engineer Victor Benni, specifically items 5, landscaping plan which H. Heller agrees to, item 8 and item 11, E&S controls and bond.
G. Goeschel read the definition of significant activity and informed the members that if the project is deemed to meet the definition of significant activity, then they can choose to hold a public hearing.

MOTION: (Ostfeld/Chantrell) to hold a Public Hearing for application of Pazz & Construction, LLC, Owner to conduct regulated activities in the upland review area in association with a proposed multi-family residential community on property identified in the application as N Bride Brook Rd, East Lyme Assessor's Map 09.0, Lot 37. Vote: Approved Unanimously.

MOTION: (Chantrell/Phimister) to hold the Public Hearing application of Pazz & Construction, LLC, Owner to conduct regulated activities in the upland review area in association with a proposed multi-family residential community on property identified in the application as N Bride Brook Rd, East Lyme Assessor's Map 09.0, Lot 37, on January 13, 2020 and a site walk on January 11, 2020. Vote: Approved Unanimously.

C. **Application of Mel Wiese, Agent for Roxbury Road LLC, Owner, for a Determination of Permitted/Non-Regulated Activity for a proposed 6-lot residential conservation subdivision at property identified in the application as Roxbury Road, East Lyme Assessor's Map 16.1, Lot 43.**
Kyle Hobbert, CLA Engineers representing the applicant described the property as south of the town's Transfer Station and across from Riverview. He stated the property is 61 acres with a proposal for two frontage lots and 3 lots accessed by a common driveway. There is municipal water access and on site septic systems will be installed. K. Hobbert stated there are no wetland or watercourse or regulated upland review areas that will be disturbed. The area has previously been flagged for wetlands and confirmed by B. Russo, soil scientist at CLA. The perimeter will have hay bales for E&S controls.
Members asked about the history of the property and the loam pile that has been the subject of an enforcement action. K. Hobbert stated that the pile in question was determined to be outside of the upland review area.
The property is proposed as a conservation sub-division, 8.2 acres will be for residential housing and 2.9 acres will be set aside for conservation.
K. Hobbert stated as there was no impact to the wetlands or the upland review area, the applicant was looking for a determination of Permitted/Non-Regulated Activity.

D. **MOTION: (Berger/Upton) to require an application to the Inland Wetlands Agency for Roxbury Road LLC, Owner, for a Determination of Permitted/Non-Regulated Activity for a proposed 6-lot residential conservation subdivision at property identified in the application as Roxbury Road, East Lyme Assessor's Map 16.1, Lot 43. Vote: Approved. In favor-Berger, Upton, Ostfeld, Chantrell. Opposed-Phimister, Koch, Gignac. Abstaining-None.**

VIII. Old Business: None

IX. Reports

A. **Chairman's Report**-none

B. **Inland Wetlands Agent Report**

Redlined version of the Inland Wetlands regulations were given to members.

1) **Administrative Permits Issued-none**
2) **Commission Issued Permits-none**

C. **Enforcement**

1. **Notice of Violation; 297 Boston Post Road; Al Smith Owner, Jason Pazzaglia, Other; Outside storage of equipment, construction materials, and the stockpiling of earthen materials including but not limited to yard debris within 100 feet of a watercourse without or in violation of an Inland Wetlands Permit.**

   Jason Pazzaglia submitted a letter to the Agency stating he would work with G. Goeschel to move equipment and items out of the regulated areas. He would like G. Goeschel to come to the property and consult as to the plan moving forward. He understands this issue has gone on too long and will work to clean up the area in the next 30 days.

   The Agency stated that if not cleaned up to the satisfaction of G. Goeschel an order will be issued.

2. **Notice of Violation: 103 West Main Street, Brookfield Estates Condominiums; C/O Thames Harbor Real Estate, LLC; Removal of vegetation and the deposit of yard and tree waste within 100-feet of an inland wetlands and watercourse.**

   G. Goeschel stated he expects the work to be done by the next meeting.

A. **Correspondence-none**

X. Adjournment

MOTION: (Berger/Chantrell) to adjourn at 8:41 Vote: Approved Unanimously.

Respectfully Submitted

Sue Spang
Recording Secretary

EAST LYME INLAND WETLANDS AGENCY
REGUALAR MEETING MINUTES

February 24, 2020
East Lyme Town Hall, 108 Pennsylvania Avenue,
East Lyme, Connecticut
Upper Meeting Room

7:00 p.m.

FILED Feb 24 20 20 AT 2:00 AM/PM
EAST LYME TOWN CLERK

Present: Gary Upton, Chairman, Phyllis Berger, Rosemary Ostfeld, Theodore Koch, Don Phimister, Kristin Chantrell, David Schmitt, Sandy Gignac, Alt., Doreen Rhein, Alt. Jason Deeble, Alt.
Absent: none
Also Present: Gary Goeschel, Director of Planning/Inland Wetlands Agent, Selectman Paul Dagle

Call to Order:
G. Upton called the meeting to order at 7:09

I. ADDITIONS TO THE AGENDA-T. Koch requested changing the upland review area from 100' to 200' be added to the agenda.

MOTION: (Ostfeld/Chantrell) to add discussion of the proposed change to the agenda Vote: Approved Unanimously.
MOTION: (Koch/Upton) to add review of the proposed regulations to New Business, item B. Vote: Approved Unanimously.

II. PUBLIC HEARINGS

A. Application of Harry Heller, Attorney/Agent for Pazz & Construction, LLC, Owner to conduct regulated activities in the upland review area in association with a proposed multi-family residential community on property identified in the application as N Bride Brook Rd, East Lyme Assessor's Map 09.0, Lot 37-2.

(T. Koch steps down and D. Rhein is seated)
Attorney H. Heller, 736 RT. 32, Uncasville reviewed the application and proposed activity. H. Heller stated the project was a 20-acre parcel located on the westerly side of N. Bride Brook Rd. and the easterly side of Interstate 95. There will be no crossing of a wetland or any activity in the wetlands or watercourse. He stated there was no direct impact to the wetlands.
The proposal is to build 108 residential units in 13 buildings. The project has municipal water and sewer access and received approval for sewer capacity.
H. Heller stated there is an intermittent watercourse that intersects the parcel.
The topography slopes from the northeast to the south corner of North Bride Brook Rd. The site will be built, bottom up-the storm water quality and detention basin will be constructed first.
H. Heller stated there are 2 buildings and part of a 3rd, a cul-de-sac and parking, situated in the upland review area (URA). The runoff from the roofs of the 3 buildings will be captured and eventually directed to the existing watercourse or the drainage basin, and eventually into the towns storm water system. He stated the runoff of the buildings are in

2 different water divides. All the runoff from the paving is contained and captured in the storm water drainage system and goes to the basin where it is treated and discharged into the environment.

James Sipperly, certified soil scientist stated the area had previously been flagged. In 2019 he conducted and delineated the wetlands. He described the wetlands as a narrow, intermittent water course approximately 1-3 feet wide with a depth of 4 inches to a foot. J. Sipperly stated the bedrock is controlling the course of the wetlands and the soils are poorly drained in that area. He described the existing growth in the area as healthy with no invasive species. J. Sipperly stated with the proposed Erosion and Sedimentation controls (E&S) in place there will be no direct impact to the wetlands or upland review area. He has been to the site three times and there has always been flow in the wetland.

Brandon Handfield, project engineer stated that the installation of rain gardens for the 3 buildings in the URA would not work due to the shallow depth to bedrock and could actually cause flooding in that area. He stated there are proposed green spaces placed where possible to provided filtration and recharge.

G. Goeschel stated that he would like to correct a statement he made in a newspaper article in the Day paper. He stated he was quoted as saying a hundred-year storm was 6.6 inches, he clarified that the plan submitted is designed for 7.2 inches for a hundred-year storm.

S. Sipperly does not believe there will be significant impact to the wetlands by any blasting as the make up of the rock ledge is solid, with no fractures or layered rocks.

B. Handfield stated the site runoff minus the 2 ½ buildings in the URA will go to an enclosed system. The first ½ inch of rain will be filtered through the berm and then to the basin which will infiltrate to the ground. The soil types in this area can handle 50 feet per day. The system is designed to handle 5 to 100 year storms. The water will flow out of orifices which are placed at various levels in the detention basin. The overflow will go to a 15'' pipe connection, across the road and into the town storm water system. The 24-hour flow will be at or below the existing conditions.

H. Heller stated the housing will be rental and the property owner will be responsible for maintenance. He did not know what, if any chemicals will be used to power wash the buildings. He stated it is highly unlikely power washing will effect the wetlands. The vegetative buffer along the wetlands will treat runoff from the 3 building roofs and any water from power washing will be absorbed by the buffer.

The snow removal will consist of an 80/20 sand salt mix and in the event of a snow storm a pretreatment is usually put down before it snows.

The agency questioned the water and sewer limit lines and if they or the applicant can request a change in the line to accommodate building in that area which would be outside the URA. G. Goeschel stated it would be a long consuming process which would eventually go to the Board of Selectmen.

J. Sipperly stated that the water and sewer commission probably looked at many factors when deciding the lines, including topography.

G. Upton called for public comment.

Lisa McGowen, 33 Spinnaker, listed a number of affordable housing units in the area such as; Bride Brook nursing and rehab, the prison, HEPA units, and the Rocky Neck Motel. She stated there was plenty of affordable housing in this area. L. McGowen stated that the intermittent stream eventually goes to Bride Brook and eventually to Rocky Neck and should be considered when making a decision. She stated that Bride Brook is an alewife habitat and breeding water.

Nancy Kalal, 80 Grassy Hill Rd. agreed that the URA should be increased. She encouraged the agency to look at the bigger picture and stated that Bride Brook is a spawning ground for the alewife which is a critical food supply for larger fish. N. Kalal discussed the project on Walnut Hill Rd that effected the wetlands farther away in Latimer Brook. She stated detention basins do not work well and referenced the detention basin behind Costco. J. Pazzalia has clear cut a project on Pattagansett Lake and that is a red flag for her and how this project would be managed.

H. Heller reminded the agency of their responsibility and their limits of review. He stated there was expert testimony presented on the absence of adverse impacts on the wetlands. He stated they testified there was no adverse impact and the project was designed to negate environmental impacts. H. Heller stated the project meets the regulations and should be permitted.

J. Sipperly stated the public cannot comment on the affordable housing or the wildlife aspect of the application.

G. Goeschel stated those issues should be presented to the zoning commission. The presentation shows the drainage will ultimately be going to Bride Lake and could potentially impact Rocky Neck, Bride Lake is a reservoir for spawning alewives. Considering the amount of water in Bride Lake does the sand to salt ratio adversely effect the wetlands? He stated that would be a question for an engineer or soil scientist.

H. Heller stated the project was designed and certified by a professional engineer, the E&S controls meet the 2004 storm water standards. There is a comprehensive drainage report submitted and the municipal engineer is satisfied with the report.

B. Handfield stated there are no changes to the storm water leaving the site, it is consistent or less than what is there now. He stated the project is a low impact design which allows the runoff to get to the green areas as fast as possible and into the natural hydrologic conditions. Approximately 90% of the water off the impervious surfaces will get absorbed.

The thermal heat of the rain on the roofs of the 2 ½ buildings in the URA will go back to the ground and into the proposed vegetative buffer before getting to the wetlands. The closest distance to the wetlands from a building is 40'. H. Heller stated the thermal impact is not significant.

The flow of the water on the site pre and post conditions were explained. H. Heller stated that due to the impervious surface post conditions the runoff has been increased. But, because the storm water will be captured in the detention basin the water will be decreased to the town storm water system.

A planting plan will be submitted when the application goes to the planning commission.

MOTION: (Schmitt/Chantrell) to close the public hearing for Application of Harry Heller, Attorney/Agent for Pazz & Construction, LLC, Owner to conduct regulated activities in the upland review area in association with a proposed multi-family residential community on property identified in the application as N Bride Brook Rd, East Lyme Assessor's Map 09.0, Lot 37-2. Vote: Approved Unanimously.

(T. Koch returns to be seated)

III. PUBLIC DELEGATIONS: none

IV. ACCEPTANCE OF MINUTES:

Meeting Minutes of January 27, 2020 Regular Meeting

MOTION (Koch/Berger) To approve the minutes of January 27, 2020 Regular Meeting as presented. Vote: Approved Unanimously.

V. EX-OFFICIO REPORT-Selectman Dagle informed the agency that the Public Safety Building project has gone out to bid. The Harbor Management Plan has been approved and the town is now in budget season.

VI. PENDING APPLICATIONS:

A. Application of Harry Heller, Attorney/Agent for Pazz & Construction, LLC, Owner to conduct regulated activities in the upland review area in association with a proposed multi-family residential community on property identified in the application as N Bride Brook Rd, East Lyme Assessor's Map 09.0, Lot 37-2.

(D. Reich is seated; T. Koch steps down)

K. Chantrell expressed concern about the runoff from the 3 buildings closest to the wetlands. The thermal effect of the runoff from the buildings was discussed. G. Goeschel pointed out that when there is a rain event there will be clouds preceding it and therefore cooling off the roof. The building will provide shade along with the tree canopy on the west side of the wetland.

R. Ostfeld, Earth and Environmental Science, MA, Land Economy, Ph.D. and professor at Wesleyan, stated she is not convinced there will be no environmental impact. She is concerned about the amount of impervious surface on the site. The U.S. Geological Survey states that 10% of impervious surface can lead to negative impacts on water quality. The proposed project has significantly more than that. She stated the water body is already impaired which was stated by H. Heller. It is the agency's duty to protect and insure the water body is not further degraded. She believes the project has the potential to exacerbate water quality issues in the town. According to the East Lyme Water and Sewer Dept., in 2019, well production was 1.783 million gallons per day and 43% of that is contributed by Bride Lake aquifer. The project is located in the Bride Lake aquifer and and that could effectively impact 776,690 gallons of the towns drinking water supply if the project has significant impact. There is discrepancy between the application and what the residents brought up at public hearing. She questioned if the design was sufficient, considering the concerns of the public. She stated the surveys were conducted during the summer when water flow is low. It is likely the project will have significant impact due to the impervious surface.

The issue of sewer and water boundary lines was brought up, G. Goeschel reiterated the process would be cumbersome and the applicant had already asked if the line could be reconsidered.

The conservation and natural resource commission states that the drinking water supplies have sodium levels that are too high. R. Ostfeld stated the salt being applied in snow events could impact those levels.

G. Upton questioned what the project would look like financially if the 3 buildings were not part of the project.

G. Goeschel will draft a resolution considering the concerns of the agency.

B. Application of Toby and Glenn Knowles, Owner; for the proposed construction of a patio, correction of water runoff and wetlands restoration at property identified as 21 Brightwater Road, Niantic, East Lyme Assessor's Map 5.19, lot 58.

(T. Koch returns to be seated)

Glenn Knowles presented plans for a patio, modification of the wetlands and grade to divert water into the wetlands away from the house. They will put gutters on half the house and pipe the water into the wetlands at the low point of the property. A flow diffuser will mitigate the impact to the wetlands from water exiting the pipe. G. Knowles estimates 250 gallons would be directly transiting the pipe in a 1" rain event. The reused topsoil from grading and the patio will be used to grass the area towards the wetland. A gentle swale will be installed to direct water flow. A rain garden will be added to the upland side of the wetland to mitigate additional water flow. The size of the rain garden will be approximately 100 square feet and 8" deep, treating up to 500 gallons of water.

The patio will be directly behind the house and constructed of UNILOCK pavers. A low wall will be constructed at the edge of the wetland to provide a defined border. The modified wetlands will be planted with native wetland plants. There will be approximately 900' of wetlands disturbance.

There is an outside shower that infiltrates to the ground.

G. Goeschel stated the project will enhance the wetlands. He will have the comments from the town engineer for the next meeting.

VII. NEW BUSINESS:

A. Request of John Bialowans for release of $5,000.00 bond for 57 Walnut Hill Road, Est Lyme. Said bond being an erosion and sedimentation control bond.

G. Goeschel stated the work has been completed for a number of years and the site is stable.

MOTION: (Berger/Ostfeld) to release the $5,000.00 bond for John Bialowans, 57 Walnut Hill Road, East Lyme. Said bond being an erosion and sedimentation control bond. Vote: Approved Unanimously.

B. East Lyme Inland Wetlands Agency Regulation Revision Discussion

Members discussed the proposed changes and additional changes they would like to have included in the draft proposal.

- Add provision for signage when there is a public hearing based on the zoning regulation language
- Add provision of notification of abutters when there is an application
- Add a 200 foot URA
- Define vernal pool
- Define minor activities the WEO can approve without agency
- Include language for regulated slope area
- Define minimal impact

G. Goeschel will draft proposed language and asked members to email him any additional requests.

VIII. OLD BUSINESS-none

IX. REPORTS

A. Chairman's Report-none

B. Inland Wetlands Agent Report-no report.

C. Enforcement

Notice of Violation; 297 Boston Post Road; Al Smith Owner, Jason Pazzaglia, Other; Outside storage of equipment, construction materials, and the stockpiling of earthen materials including but not limited to yard debris within 100 feet of a watercourse without or in violation of an Inland Wetlands Permit.

G. Goeschel presented photos of the progress on the property. He stated there was a significant amount of garbage/items moved away from the shore. There is still a stockpile in the middle of the property. G. Goeschel suggested to J. Pazzalia that he should come to the agency with an application requesting a permit.

D. Correspondence-none

X. ADJOURNMENT

MOTION: (Schmitt/Berger) to adjourn at 10:20. Vote: Approved Unanimously.

Respectfully Submitted

Sue Spang
Recording Secretary

EAST LYME INLAND WETLANDS AGENCY
SPECIAL MEETING MINUTES
May 18, 2020
Remote Participation by ZOOM due to Covid 19
7:00 p.m.

Present: Gary Upton, Phyllis Berger, Rosemary Ostfeld, Theodore Koch, Don Phimister, Kristin Chantrell, David Schmitt, Sandy Gignac, Alt., Doreen Rhein, Alt.
Absent: Jason Deeble, Alt.
Also Present: Gary Goeschel, Director of Planning/Inland Wetlands Agent, Jennifer Lindo, Administrative Assistant

Call to Order:
G. Upton called the meeting to order at 7:05. He explained the rules for participation in the remote ZOOM meeting. The materials for the applications are on the town's website.

I. **ADDITIONS TO THE AGENDA**-none

II. **PUBLIC HEARINGS-none**

III. **PUBLIC DELEGATIONS: none**

FILED
May 22, 20 20 AT 8:28 [✓ AM]/P
ATC
EAST LYME TOWN CLERK

IV. **ACCEPTANCE OF MINUTES:**
Meeting Minutes of February 24, 2020 Regular Meeting

MOTION (Ostfeld/Chantrell) To approve the minutes of February 24, 2020 Regular Meeting as presented. Vote: Approved Unanimously.

V. **EX-OFFICIO REPORT**-none

VI. **PENDING APPLICATIONS:**

A. **Application of Harry Heller, Attorney/Agent for Pazz & Construction, LLC, Owner to conduct regulated activities in the upland review area in association with a proposed multi-family residential community on property identified in the application as N Bride Brook Rd, East Lyme Assessor's Map 09.0, Lot 37-2.**
(D. Reich is seated; T. Koch is muted and video disabled)
G. Goeschel gave background on the application, he read his memo dated March 30, 2020.
G. Goeschel stated the application is complete with no significant impacts to the regulated areas.
The Agency asked if there could be an independent expert to assess the impacts on the application site. They noted there was no hydrology report with the application. G. Goeschel informed the agency that the public hearing has been closed so no new information can be added to the record.
G. Upton stated he had concerns about the detention basin and the testimony of a resident concerning flooding that occurs on the site. He noted there are toxins such as, antifreeze, herbicides, oil, etc. that will be running off the site and onto adjacent properties. R. Ostfeld noted that the detention basin is over an aquifer protection zone.

G. Goeschel stated the abutting property owners had all been notified for the public hearing and if there were concerns they had the opportunity to present those concerns during the public hearing. He stated the detention basin is significant as to the volume of runoff from the site and designed for a hundred-year storm. G. Goeschel did not see evidence of flood plain areas.

K. Chantrell voiced concern about the thermal pollution runoff from the roofs of proposed buildings I, J and M. She stated that it will have significant impact to the wetlands that are already degraded. She informed the Agency and public that she has an environmental engineering degree.

K. Chantrell stated she believes there is a prudent and feasible alternative for proposed buildings I, J and M which run parallel to the wetlands and are in or partially in, the upland review area.

G. Goeschel stated there were no other feasible and prudent alternatives for the site due to the boundaries of the water and sewer boundary maps. There was no application by the applicant to move the water and sewer boundary but the applicant did apply for the water and sewer capacity for the proposed site.

G. Upton read section 1 (one) of the East Lyme Wetlands Regulations stating the purpose and role of the Agency.

G. Goeschel reminded the Agency of their authority. He stated that the application as presented meets the 2004 state water quality manual standards. He stated that according to the project engineer's calculations the runoff from the three buildings into the liters, pre-development is the same as post-development.

K. Chantrell reminded the Agency, the applicant stated during the public hearing process that there was going to be an impact from the runoff of buildings I, J and M and it was up to the Agency to determine if it was significant.

MOTION: (Upton/Chantrell) to deny the application without prejudice because the application is incomplete due to several of the buildings need to be relocated or eliminated and the additional information as to water quality leaving the detention pond at the southern end of the site and the lack of a hydrology report.

K. Chantrell stated the the buildings should be removed due to the runoff from the roofs of I, J and M and the runoff should not be going into the watercourse.

Vote: Approved Unanimously.

B. Application of Toby and Glenn Knowles, Owner; for the proposed construction of a patio, correction of water runoff and wetlands restoration at property identified as 21 Brightwater Road, Niantic, East Lyme Assessor's Map 5.19, lot 58.

(T. Koch returns at 8:42)

G. Goeschel informed the Agency that he issued a permit to G. Knowles for work in the upland review area.

G. Knowles updated the Agency on work he is proposing on the site. He stated the large tree in the upland review area has been cut down and the stump has been ground down. Brandon Hyde (contractor) stated there is approximately 20-30 yards of fill proposed which will utilize on site materials. The fill will be used to create a soft gradient for runoff and top dressing. There will be crushed stone under the proposed patio. The water will be absorbed by the turf and then from there any other water will be absorbed into the wetlands. He stated the gradient slopes toward the wetlands.

MOTION: (Chantrell/Ostfeld) to approve the application. Vote: Approved Unanimously.

VII. NEW BUSINESS:

A. East Lyme Inland Wetlands Agency Regulations

The Agency discussed some of the changes to the regulations as well as the process for accepting the changes.
G. Goeschel stated that many of the changes are minor edits for clarification and spelling/grammar. The main changes are the increase of the upland review area and splitting the permit process into three categories; minor, intermediate and significant. G. Goeschel stated the agency may want to consider changing the sub-division and resub-division approvals. Typically, the applicant has to come to the Agency in the proposal phase and then again for each individual lot development. He suggested letting the agent approve each individual lot as the agency has already approved the overall site plan. It was the consensus of the members that they do not want to change the current approval process for sub-divisions and re sub-divisions.
Discussion about what agencies/towns/boards should be notified and given the opportunity to submit comment on the regulation changes. G. Upton informed the agency members that the changes should go to the state. A public hearing is required for proposed regulation changes.
The agency discussed changing the upland review area from 100 ft. to 500 ft.
MOTION: (Ostfeld/Upton) to extend the regulated area to 500 ft.
The members decided to focus on the change in the regulated area. Other areas of concern were signage. The Agency set the Public Hearing for June 8, 2020.
Vote: Approved Unanimously.
G. Upton read Section 15.2 of the regulations.
MOTION: (Upton/) to put a moratorium on any pending and new applications until the 400 ft. increase to the upland review area is enacted.
The legality of a moratorium was discussed.
The MOTION failed due to lack of a second to the motion.

B. Nottingham Hills Re-subdivision; Request of Kristen T. Clarke, P.E. Agent for Owner English Harbor Asset Management, LLC for a Determination of Permitted/Non-Regulated Activity at Upper Kensington Drive, as part of a 4-lot re-subdivision. East Lyme Assessor's Map 40.0, Lot 23 and 22.

Paul Gerahty, representing the applicant gave background on the proposed site. He stated the site is part of a previously approved 16 lot application. The current proposal is Phase III. The agency previously approved this site for 2 lots but the owner has decided to do an additional split into 4 lots. Lot 4 will be donated to the East Lyme Land Trust. There is no proposed activity in any of the regulated areas of the new proposal. P. Gerahty informed the agency that the plan combines 2 driveways into one therefore, reducing the amount of impervious surface.
G. Goeschel noted that the plan shown is different than the one the town engineer had commented on. J. Lindo stated the plan was submitted on Friday and revised April 23, 2020. G. Goeschel stated that according to the new plans there is no regulated activity shown.

P. Gerahty stated that although lot 4 will be donated to the land trust, regulations require that all lots have to show they are a building lot able to have a house and septic system. There will be no house or septic due to the lot being donated to the land trust.

P. Gerahty stated the closest any activity comes to a regulated activity is approximately 30 ft.

The agency scheduled a site walk on June 6, 2020 at 9:00 AM before making a determination.

C. **21 Marshfield Rd, Your Brothers Keeper LLC, Agent for Owner Brandy and Derek Moore, for Determination of a Permitted/Non-Regulated Activity at 21 Marshfield Road, for the clean out of a culvert entrance and exit to maintain the natural flow of water. East Lyme Assessor's Map 04.7, Lot 19.**

(This application was combined with item D)

D. **Creek Road, Giants Neck Heights Club House, your Brothers Keeper LLC, Agent for Owner Giants Neck Heights Association, for Determination of a Permitted/Non-Regulated Activity at 21 Marshfield Road, for the clean out of a culvert entrance and exit to maintain the natural flow of water. East Lyme Assessor's Map 04.7, Lot 18.**

Brian Kennedy stated the road was originally constructed in 1954 with the understanding the town would adopt the road but failed to do so. The association has been maintaining the road. He believes the culvert was filled in during hurricane Sandy. The phragmites on one end of the culvert are slowing the drainage to the creek.

G. Goeschel suggested the Agency combine item C and D as they are technically the same project. He confirmed both applicants agree the work needs to be done and the landowners have given permission. He stated he originally thought the work is exempt, except for the language in section 4.1 (F) that mentions hydrophilic vegetation which would require a permit. He also noted that the town's public works dept. applies for a permit every five years to conduct drainage clearing.

Alisa Lecour representing the property owner of 21 Marshfield Rd. is in favor of the proposed work.

B. Kennedy stated he would need to use a backhoe to accomplish the clearing of the culvert.

The Agency decided to do a site walk on June 6, 2020 before a determination was made.

VIII. OLD BUSINESS-none

The members discussed who would be getting notice of the Public Hearing on the regulation changes and want to see as many as possible be made aware of the Public Hearing.

IX. REPORTS

A. Chairman's Report-none

B. Inland Wetlands Agent Report-no report.

C. Enforcement

Notice of Violation; 297 Boston Post Road; Al Smith Owner, Jason Pazzaglia, Other; Outside storage of equipment, construction materials, and the stockpiling of earthen materials including but not limited to yard debris within 100 feet of a watercourse without or in violation of an Inland Wetlands Permit.

G. Goeschel stated the site has been cleaned up to his satisfaction and many of the old vehicles have been removed. The members can go to the site between 8:00 AM and 4:00 PM with notification to inspect for themselves. The Agency requested the item stay on the agenda

D. Correspondence-none

X. ADJOURNMENT

MOTION: (Schmitt/Chantrell) to adjourn at 10:50. Vote: Approved Unanimously.

Respectfully Submitted

Sue Spang
Recording Secretary

Town of **East Lyme**

P.O. Drawer 519
Department of Planning &
Inland Wetlands Agency
Gary A. Goeschel II, Director of Planning /
Inland Wetlands Agent

108 Pennsylvania Ave
Niantic, Connecticut 06357
Phone: (860) 691-4114
Fax: (860) 860-691-0351

MEMORANDUM

To: East Lyme Inland Wetlands Agency

From: Gary A. Goeschel II, Director of Planning/ Inland Wetlands Agent

Date: March 30, 2020

Re: Re: Inland Wetlands Application – North Bride Brook Multi-Family Development: Application of Pazz & Construction, LLC; Jason Pazzaglia, Applicant; Pazz & Construction, LLC, Owner; to conduct regulated activities in the upland review area in association with a proposed multi-family residential community on property identified in the application as N Bride Brook Rd, East Lyme Assessor's Map 09.0, Lot 37-2.

Upon review of the above referenced application and the proposed plans entitled "North Bride Brook Multi-Family Development, prepared for Pazz & Construction, LLC, Sheets 1 thought 7, dated 9/25/2019 and revised through 1/15/2020," by Brandon J. Hanfield, P.E. of Yantic River Consultants, LLC of 191 Norwich Avenue, Lebanon, CT and several meetings with the Applicant's engineer, Town staff, and four (2) evenings of public hearing, I offer the following:

FINDINGS:

Whereas: In accordance with Section 7, Application Requirements, of the Inland Wetlands Regulations the applicant has provided the all the information required by Section 7.5 and the necessary additional information required by Section 7.6, including but not limited to proposed alternatives, engineering reports and analyses, a description of ecological communities and the functions of the wetlands and watercourse and the effects of the proposed activity on these communities and wetland functions, an alternative which would cause less or no environmental impact to wetlands or watercourses, as well as an operations and maintenance plan for stormwater structures, stormwater management plan, erosion and sedimentation control plan, and site development plans. As such, the application appears to be complete.

Whereas: In accordance with Section 7.6, the Agency required information to be submitted including but not limited to site plans which show the land which will be affected thereby which shows existing and proposed conditions, wetland and watercourse boundaries, contours, and other pertinent features of the land and the proposed activity.

Whereas: The Agency may find this application to be in conformance with the Inland Wetlands Regulations of the Town of East Lyme and more specifically based on the following findings:

Whereas: The Agency received an Inland Wetlands Application from Jason Pazzaglia of Pazz & Construction, LLC November 22, 2019 and the Agency commenced review of the Application at a regular meeting on December 9, 2019.

Whereas: The Agency at their December 9, 2019 meeting, scheduled a Public Hearing to commence on January 27, 2020 and published notice of said hearing in the January 15, 20120 and January 23, 2020 editions of The Day Newspaper.

Whereas: The Agency's commenced a public hearing on January 27, 2020, which was continued to the Agency's meeting of February 24, 2020 and closed that same evening.

Whereas: Town staff provided the Agency with comment concerning this application's compliance with local requirements and regulations as well as received testimony from the Applicant's professionals, and the general public.

Whereas: The Application submitted includes all the information required pursuant to Section 7.5 of the East Lyme Inland Wetlands and Watercourses Regulations and includes site plans, engineering reports, and wetlands delineation by a soil scientist depicted on the site plans. As such, the Application submitted in accordance with Section 7.1 of the East Lyme Inland Wetlands Regulations is complete.

Whereas: There is no direct impact on the wetlands or the watercourse as the all construction activities will be conducted within the 100-foot upland review area from an inland wetland and watercourses. Therefore, there are no irreversible and irretrievable loss of wetlands or watercourse which would be caused by the proposed regulated activity.

Whereas: The project has been designed to protect the wetlands and watercourses as the building structures, driveways, and drainage structures are designed to be situated outside of the wetlands and located in the upland review area as well as the public utilities (sewer, water, electric, etc..) which are being installed within existing upland areas.

Whereas: Mitigation measures to minimize and mitigate potential impacts from the creation of new impervious surfaces on the site and to protect the wetlands and watercourses, such as stormwater management structures (catch basins) and the retention pond, will pre-treat and control runoff, and promote groundwater recharge.

Whereas: Potential impacts are mitigated by the implementation of temporary erosion and sedimentation controls as well as stormwater controls throughout all phases of construction.

Whereas: The upland review process does not forbid activity based solely on proximity to wetlands. Rather, the upland review process merely provides a basis for determining whether activities will have an adverse impact on the adjacent wetland or watercourse, and if necessary, regulating them.

Whereas: Pursuant to Section 10.5 of the East Lyme Inland Wetlands and Watercourses Regulations, for the purpose of those Sections (1) "wetlands and watercourses" includes aquatic, plant or animal life and habitats in wetlands or watercourses, and (2) "habitats" means areas or environments in which an organism or biological population normally lives or occurs.

Whereas: Pursuant to Section 10.5 of the East Lyme Inland Wetlands and Watercourses Regulations, a municipal inland wetlands agency shall not deny or condition an application for a regulated activity in an area outside wetlands or watercourses on the basis of an impact or effect on aquatic, plant, or animal life unless such activity will likely impact or affect the physical characteristics of such wetlands or watercourses.

Whereas: Demonstrated by Exhibit "L", Memorandum from V. Benni, P.E. Town Engineer to G. Goeschel II, Wetlands Officer, dated January 27, 2020 Re: North Bride Brook Multi-Family Development, the Stormwater Management Report prepared in accordance with the 2004 Connecticut Stormwater Quality Manual, verifies that the proposed detention pond attenuates peak flow rates and volumes as compared to the pre-development conditions, resulting in a net zero (0) increase in run off from the development for the 2 through 100-year storm events.

Whereas: The proposed detention pond will enhance stormwater runoff quality and recharge the groundwater as stormwater from the closed drainage system will enter a sediment forebay which, is separated from the detention basin by a "Detention Filter Berm" before passing through the semi-pervious filter berm into the detention basin itself.

Whereas: The E&S Narrative and Construction Details provide construction notes and a long-term maintenance plan for the stormwater detention basin. Moreover, the Erosion and Sediment Control Plan was prepared according to the 2002 Connecticut Guidelines for Soil Erosion and Sediment Control (CT DEEP), and includes a narrative, construction sequence and vegetative turf establishment procedures.

Whereas: Demonstrated by Exhibit "H", plan review comments from B. Kargl, Town Utilities Engineer, dated 12/12/19, found the conceptual layout of the water and sewer utilities to be acceptable.

Whereas: The record before the Agency, which includes Exhibit "B", Wetlands report from James Sipperly, Soil Scientist dated October 3, 2019, states: "The proposed development in the upland review area will not be disturbing any wetlands and/or watercourses on the site. For that reason, the inland wetlands will continue to perform their functions as they currently do." As such, the proposed activity will avoid any direct impacts to the wetlands or watercourses and the design has been prepared to minimize the potential for secondary and indirect impacts through implementation of the Erosion and Sedimentation Control Plan.

Whereas: Demonstrated by Exhibit "L", memorandum from V. Benni, Town Engineer and Exhibit "A" Application and project narrative, and Exhibit "B" the Soils Report by James Sipperly, the project will not significantly change to the hydrology of the wetlands and watercourse in question as the drainage design provides recharge to the on-site wetlands and watercourse by discharging the roof runoff from Building I, J, & M at the westerly corner of each building to a rip-rap splash pad which it then flows overland to the wetland in order to replicate the existing flows which currently reach and contribute to the recharge of the wetlands system.

Whereas: Although the proposed construction would pose an intrusion into the upland area, introducing a new and more intensive use than the present condition (forested land) and risks to the wetlands, there is no substantial evidence in the record to support a likely adverse impact on the wetlands and watercourse from the proposed upland intrusion.

Whereas: The record before the Agency of the current application contains no specific evidence that the impacts on the wetland and watercourse are significant, adverse, and would likely impact or affect the physical characteristics of such wetlands or watercourse.

Whereas: As demonstrated by Exhibit "A" the application and supporting documentation including the proposed plans entitled "North Bride Brook Multi-Family Development, prepared for Pazz & Construction, LLC, Sheets 1 thought 7, dated 9/25/2019 and revised through 1/15/2020," by Brandon J. Hanfield, P.E. of Yantic River Consultants, LLC of 191 Norwich Avenue, Lebanon, C ", there are no other prudent and feasible alternatives yielding a 100-unit multi-family development that would eliminate or further reduce the potential for wetlands impacts. As the proposed activity is of limited duration with no direct or likely adverse impacts to the wetlands or watercourse, it is the preferred alternative.

SUGGESTED RESOLUTION

Based on the Findings in the memorandum from Gary A. Goeschel II, Director of Planning/Inland Wetlands Agent to the Inland Wetlands Agency dated March 30, 2020, and the record before the Agency, I move the Agency APPROVE the Application known as the Application of Pazz & Construction, LLC; Jason Pazzaglia, Applicant; Pazz & Construction, LLC, Owner; Application to conduct regulated activities in the upland review area in association with a proposed 100-unit multi-family residential community on property identified in the Inland Wetlands and Watercourses Agency Application as North Bride Brook Rd, East Lyme Assessor's Map 09.0, Lot 37-2 and the plans entitled "North Bride Brook Multi-Family Development, prepared for Pazz & Construction, LLC, Sheets 1 thought 7, dated 9/25/2019 and revised through 1/15/2020," by Brandon J. Hanfield, P.E. of Yantic River Consultants, LLC of 191 Norwich Avenue, Lebanon, CT, which are further subject to the following administrative requirements and required modifications to the site plan and other materials submitted in support of this application:

1. The Erosion and Sedimentation Control Plan and recommended Construction Sequence shall be followed.
2. Pursuant to the Erosion and Sedimentation Control Plan and construction sequence, notify conservation officer at least 2 days prior to construction to inspect erosion controls.
3. Silt fence and other erosion controls including temporary sediment traps and diversion swales to be installed shall be inspected by the Inland Wetlands Agent and the Town Engineer prior to any site construction, land clearing or other associated construction activities.
4. In areas proposed to be loamed and seeded, a low maintenance lawn such as fescue, which requires minimal application of fertilizers and pesticides, shall be planted.
5. Forested cover within the upland review areas shall be maintained to the extent practicable. The propose Limits of Disturbance (LOD) shall be strictly adhered to though out all phases of lot build out and construction.
6. As indicated in Exhibit "L", memorandum from Victor Benni P.E., Town Engineer dated January 27, 2020, an Erosion and Sedimentation Control Bond (aka financial guarantee)

in the amount of $30,000.00 dollars in a form satisfactory to the Town of East Lyme and the Inland Wetlands Agency, its Agent, and Town Engineer shall be posted with the Town of East Lyme.

7. A copy of each weekly inspection reports for the Stormwater Management Basin shall be furnished to the East Lyme Inland Wetlands Agent within 7-days of conducting said inspection.

8. Failure of the development to adhere to the stormwater management system components of the long-term operations and maintenance plan shall be consider a violation of this permit and the East Lyme Inland Wetlands and Watercourses Regulations.

9. Any proposed Additional work beyond this permit in the wetlands or watercourse or its 100-foot regulated area will require approval from the Inland Wetlands Agency or its certified agent.

10. Any changes to the site plan listed on this permit require notification to the Inland Wetlands Agent and may require commission approval; a new plan shall be given to the Inland Wetlands Agent for review and approval before such work begins.

11. Inland Wetlands Conservation Tags provided by the Wetlands Agency, available in the Land Use Office, Department of Planning & Inland Wetlands, shall be posted along the inland wetlands boundary at 40-50-foot intervals satisfactory to the Inland Wetlands Agent.

12. A 200-foot wide conservation easement, beginning at the limits of clearing and extending north, south and westward along the existing stream corridor, in a form satisfactory to the Inland Wetlands Agency and the Town of East Lyme, shall be filed on the land records in the office of the East Lyme Town Clerk prior to any construction.

13. No site work shall commence until all applicable conditions are satisfied.

14. Notify Inland Wetlands Agent upon completion of all regulated activities for a final inspection and to request the release of any financial guarantees.

This approval is specific to the site development plan submitted as the application of Jason Pazzaglia, Applicant; Pazz & Construction, LLC, Owner; Application to conduct regulated activities in the upland review area in association with a proposed 100-unit multi-family residential community on property identified in the Inland Wetlands and Watercourses Agency Application as North Bride Brook Rd, East Lyme Assessor's Map 09.0, Lot 37-2 and the plans entitled "North Bride Brook Multi-Family Development, prepared for Pazz & Construction, LLC, Sheets 1 thought 7, dated 9/25/2019 and revised through 1/15/2020," by Brandon J. Hanfield, P.E. of Yantic River Consultants, LLC of 191 Norwich Avenue, Lebanon, CT".

Any change or modification in the plan or development plan layout other than those identified herein shall constitute a new application unless prior approval from the Agency or its Agent is granted. The applicant/owner shall be bound by the provisions of this Application and Approval.

N Bride Brook Multi-Family Development
Inland Wetlands
Updated as of 5/11/2020

Exhibit #	Description	Date
A	Wetlands Application	11/22/2019
B	Soils Report, James Sipperly	10/3/2019
C	Authorization Form for Pazz & Construction LLC	11/21/2019
D	Application Narrative by Attorney Heller	11/22/2019
E	State Reporting Form	11/22/2019
F	Memo of Victor Benni	12/13/2019
G	Public Hearing Legal Notice for the Day and Town Clerk	1/15/2020
H	Comments of Brad Kargl, Utility Engineer	12/12/2019
I	Comments of William Mulholland, Zoning Official	12/4/2019
J	Certificates of Mailing provided by Applicant	12/16/2019
K	Yantic River Consultants LLC Comment Response Summary	12/13/2019
L	Memo of Victor Benni	1/27/2020
M	Maps by Yantic River Consultants LLC	1/15/2020
N	Public Hearing Display Plans 1 thru 5	2/24/2020
O		

APPLICATION FOR PERMIT EAST LYME INLAND WETLANDS AGENCY

Check# 38510, 38512 **Office Use Only**

Fee Paid $ 1,210.00 Date Submitted 11/22/2019 Application #__________

Date of Receipt __________ Date Approved __________ Permit Number __________

Major Impact: YES NO Public Hearing: [✓ YES] NO Agent Approved: YES NO

Note: In accordance with the Inland Wetland and Watercourses Regulations, Eleven (11) copies of all application materials must be submitted.

1. SITE LOCATION (Street) and Description: Westerly side North Bride Brook Road (no assigned street number)

   Assessor's Map 9 Lot # 37-2

   Note: It is the applicant's responsibility to provide the correct site address, map/ lot number for the legal notice. Provide a description of the land in sufficient detail to allow identification of the inland wetlands and watercourses, the area(s) (in acres or square feet) of wetlands and watercourses to be disturbed, soil type(s), and wetland vegetation.

2. APPLICANT: Pazz & Construction, LLC ; Jason Pazzaglia

   Address: 21 Darrows Ridge Road
   East Lyme, Connecticut 06333

   Phone: (860) 961-2364

   Fax: n/a

   Business: 21 Darrows Ridge Road
   East Lyme, Connecticut 06333

   Cell: (860) 961-2364

   Email: jpazz17@gmail.com

   Applicant's interest in the land: Owner

   ***If the applicant is a Limited Liability Corporation or a Corporation provide the managing member's or responsible corporate officer's name, address, and telephone number.*

3. OWNER: Pazz & Construction, LLC

   Address: 21 Darrows Ridge Road
   East Lyme, Connecticut 06333

   Phone: (860) 961-2364

   Fax: n/a

   Email: jpazz17@gmail.com

   Cell: (860) 961-2364

   ***As the legal owner of the property listed on this application, I hereby consent to the proposed activities. And I hereby authorize the members and agents of the Agency to inspect the subject land, at reasonable times, during the pendancy of the application and for the life of the permit.*

Owners Printed Name: Pazz & Construction, LLC

Owners Signature: __________ Date: November 21, 2019

Jason Pazzaglia, its Member

Ex "A"

4. Area of wetland to be disturbed: 0 sq. ft. or ac 0

Area of watercourse to be disturbed: 0 sq. ft. or ac 0

Upland review area to be disturbed: 62,530 sq. ft. or ac 1.44

Will fill be needed on site? Yes [✓ No]

If yes, how much fill is needed? n/a Cubic yards

5. The property contains (circle one or more)

[✓ WATERCOURSE] WATERBODY WOODED-WETLAND [✓ SWAMP]

FLOODPLAIN OTHER: ____________

Description of soil types on site: Upland soils are Haven Silt Loam (703A), Charlton-Chatfield Complex (73E) and Charlton-Chatfield Complex (73C); Wetland soils associated with the Bride Brook riparian corridor are Ridgebury LeicesterWhitman soils.

Description of wetland vegetation: Forested wetland (general classification). The vegetative overstory includes Maple, Ash, Black Cherry, Oak and Poplar. Shrub species include Winterbury, Spice Bush, Silky Dog Wood and Mountain Laurel. The herbacious layer includes sensitive fern, poison ivy, wildly grape and skunk cabbage.

Name of Soil Scientist(s) and date of survey:

James Sipperly. Date of Survey: June 29, 2019.

6. Provide a written narrative of the purpose and a description of the proposed activity and proposed erosion and sedimentation controls and other best management practices and mitigation measures which may be considered as a condition of issuing a permit for the proposed regulated activity including, but not limited to, measures to (1) prevent or minimize pollution or other environmental damage, (2) maintain or enhance existing environmental quality, or (3) in the following order of priority: restore, enhance and create productive wetland or watercourse resources. Depending on the complexity of the project, include the following: construction schedule, sequence of operations, drainage computations with pre and post construction runoff quantities and runoff rates, plans clearly showing the drainage areas corresponding to the drainage computation, existing wetland inventory and functional assessment, soils report, construction plans signed by a certified soils scientist, licensed surveyor, and licensed professional engineer.
See Project Narrative submitted with this application.

7. Provide information of all alternatives considered. List all alternatives which would cause less or no environmental impact to wetlands or watercourses and state why the alternative as set forth in the application was chosen. All such alternatives shall be diagramed on a site plan or drawing. (Attach plans showing all alternates considered).
Activities proposed are upland review area activities only, none of which are anticipated to have any adverse impact on the inland wetland/watercourse system which bisects the property in a northwesterly to southeasterly direction. Therefore, the considerations of alternatives is not required.

8. Attach a site plan showing the proposed activity and existing and proposed conditions in relation to wetlands and watercourses and identifying any further activities associated with, or reasonably related to, the proposed regulated activity which are made inevitable by the proposed regulated activity and which may have an impact on wetlands and watercourses. **See site development plan entitled "North Bride Brook Multi-Family Development Prepared For Pazz & Construction, LLC Overall Layout Plan N. Bride Brook (Assessor's Map 9, Lot 37-2) East Lyme, CT" dated September 25, 2019 prepared by Yantic River Consultants, LLC consisting of 7 sheets submitted with this application.**

9. Provide the name and mailing addresses of adjacent landowners (including across a street). Attach additional sheets if necessary.

Name/Address: **SEE ATTACHED SHEET**

Name/Address: ____________

Name/Address: ____________

WETLANDS APPLICATION OF PAZZ & CONSTRUCTION, LLC

LIST OF ABUTTING PROPERTY OWNERS

Name and Mailing Address	Property Address	Parcel Number
Ms. Geraldine J. Dzwilewski 90 North Bride Brook Road East Lyme, CT 06333	90 North Bride Brook Road	09.0/37
Ms. Margaret Berry Balon 86 North Bride Brook Road Niantic, CT 06357	86 North Bride Brook Road	09.0/37-1
State of Connecticut NCI & JB Gates Prison 199 West Main Street Niantic, CT 06357	199 West Main Street	10.0/2
Ms. Alice T. Welsh 102 North Bride Brook Road Niantic, CT 06357	102 North Bride Brook Road	14.0/66
Ms. Alice T. Welsh 102 North Bride Brook Road Niantic, CT 06357	North Bride Brook Road	14.0/67
Niantic Sportsmens Club Inc. P.O. Box 122 Niantic, CT 06357	Plants Dam Road	19.0/58
Mr. Frank Maric Mr. Rajko Maric 26 Johnson Place Ardsley, NY 10502	Spring Rock Road	14.0/45

10. Attach a completed DEP reporting form.

The Agency shall revise or correct the information provided by the applicant and submit the form to the Commissioner of Environmental Protection in accordance with section 22a-30-14 of the Regulations of Connecticut State Agencies.

DEEP Statewide Reporting Form submitted with this application.

11. Name of Erosion Control Agent (Person Responsible for Compliance):

Jason Pazzaglia

Address: 21 Darrows Ridge Road
East Lyme, Connecticut 06333

Phone: (860) 961-2364

Fax: n/a

Email: jpazz17@gmail.com

Cell: (860) 961-2364

12. Are you aware of any wetland violations (past or present) on this property? Yes [✓ No]

If yes, please explain: ______

13. Are there any vernal pools located on or adjacent (within 500') to the property? Yes [✓ No]

14. For projects that do not fall under the ACOE Category I general permit – Have you contacted the Army Corps of Engineers? Yes No **N/A**

15. Is this project within a public water supply aquifer protection area or a watershed area? Yes [✓ No]

16. If so, have you notified the Commissioner of the Connecticut Department of Public Health and the East Lyme Water and Sewer Department? Yes No *(Proof of notification must be submitted with your application).* **N/A**

17. Attach the appropriate filing fee based on the fee schedule established in Section 19 of the Regulations.
Fee: $1,010.00 *(Make checks payable to "Town of East Lyme").*

18. PUBLIC HEARINGS ONLY: The applicant must provide proof of mailing notices to the abutters prior to the hearing date.

The undersigned Applicant hereby consents to necessary and proper inspection of the above mentioned property by the East Lyme Inland Wetlands Agency and/or its agents at reasonable times both before and after the permit in question has been granted.

The Applicant affirms that the information supplied in this application is accurate to the best of his/her knowledge and belief. As the applicant I hereby certify that I am familiar with the information provided in this application and I am aware of the penalties for obtaining a permit through deception or through inaccurate or misleading information.

Printed Name: Pazz & Construction, LLC

Date: November 21, 2019

Signature: By:
Jason Pazzaglia, its Member

Please note:

Above notice to be published in legal section of newspaper having general circulation in the Town of East Lyme. Applicant to pay cost of publication.

You or a representative must attend the Inland Wetlands Agency meeting to present your application.

NORTH BRIDE BROOK MULTI-FAMILY DEVELOPMENT

CHECKLIST FOR A COMPLETE APPLICATION

- ☒ completed application form including Department of Environmental Protection reporting form (green copy)
- ☒ A narrative of the purpose and description and methodology of all propose activities;
- n/a ☐ Alternatives considered by the applicant, reasons for leaving less than a 10' buffer between clearing and the wetlands. Such alternatives to be diagrammed on a site plan or drawing and submitted to the commission as part of the application;
- ☒ Names and mailing addresses of abutting property owners;
- ☒ Three copies of approximately l"=40' scale plans
- ☒ Locations of existing and proposed land uses
- ☒ Locations of existing and proposed buildings
- n/a ☐ Locations of existing and proposed subsurface sewage disposal systems, and test hole descriptions
- ☒ Existing and proposed topographical and man-made features including roads and driveways, on and adjacent to the site
- ☒ Location and diagrams of proposed erosion control structures
- ☒ Assessor map and lot number
- ☒ Key or inset map
- ☒ North arrow
- ☒ Flood zone classification and delineation
- n/a ☐ Use of wetland and watercourse markers where appropriate.
- ☒ Soil types classification and boundary delineation (flagged and numbered boundary), Soil Scientist's original signature and certification on plans
- ☒ Soil Scientist's (or other wetland scientist) report on the function of the wetlands
- ☒ Watercourse channel location and flow direction, where appropriate
- ☒ 100 ft. regulated area depicted on plans
- n/a ☐ Conservation easements where appropriate
- ☒ A detailed erosion and sediment control plan which meets requirements set forth in the most recent revision of the *Connecticut Guidelines for Soil Erosion and Sediment Control,* published by the Connecticut Council on Soil and Water Conservation, including:
- ☒ Location of areas to be stripped of vegetation and other unprotected areas
- ☒ Schedule of operations including starting and completion dates for major development phases
- ☒ Seeding, sodding, or re-vegetation plans for all unprotected or un-vegetated areas
- ☒ Location and design of structural sediment control measures
- ☒ Timing of planned sediment control measures
- n/a ☐ Use of wetland and watercourse markers
- ☒ Proper certification on the application documents and plans

In the case of filling in wetlands, watercourses, or regulated upland areas, the following items are necessary:

- n/a ☐ Area to be filled
- n/a ☐ Volume of requested fill
- ☒ Finished slopes of filled areas
- ☒ Containment and stabilization measures
- ☒ Proposed finished contours
- n/a ☐ Evaluation of the effect of filling the wetlands with respect to storage volume and its impact downstream showing before and after development flows, and the evaluation of storm water detention including the existing need for flood control downstream

Other required items:

- n/a ☐ Proof of adjoining Town notification, where required;
- ☒ All application fees required by Section 16 of these regulations;
- ☒ A written narrative detailing how the effects of the applicant's proposed activities upon wetlands and watercourses shall be mitigated.
- n/a ☐ A written description of any and all future plans which may be linked to the activities proposed in the current application.
- n/a ☐ Address the potential to enhance the current buffer area.
- ☒ Review drainage information with Town Engineering
- ☒ Mailing requirements for abutters (public hearing only)

Appendix D - ORDINANCE ESTABLISHING SCHEDULE OF FEES FOR CONSERVATION, PLANNING AND ZONING COMMISSIONS

1.1 Application Fee **

1.1.1 Residential Uses........... ....$150.00 Plus *$50.00/LOT
Plus Fee from Schedule A

1.1.2 Commercial Uses.......... .... [✓ ....$400.00]
Plus Fee from Schedule A

1.1.3 All Other Uses $200.00
Plus Fee from Schedule A

*Each lot with regulated activities
**$60 fee required by C.G.S 22a-27j will be added to the base fees.

1.2 Approval by Duly Authorized Agent ** $100.00

1.3 Appeal of Duly Authorized Agent Decision........ ....$300.00

1.4 Significant Activity Fee $300.00

1.5 Public Hearing Fee

1.5.1 Single Residential $200.00

1.5.2 Commercial/Industrial/Multi-Family $450.00

1.6 Complex Application Fee ....Actual Cost

The Inland Wetlands Agency may charge an additional fee sufficient to cover the cost of reviewing and acting on complex applications. Such fee may include, but not be limited to, the cost of retaining experts, to advise, analyze, review, and report on issues requiring such experts. The Agency or the duly authorized agent shall estimate the complex application fee, which shall be paid pursuant to section 19.1 of these regulations within 10 days of the applicant's receipt or notice of such estimate. Any portion of the complex application fee in excess of the actual cost shall be refunded to the applicant no later than 30 days after publication of the agency's decision.

1.7 Permitted and Nonregulated Uses :

1.7.1 Permitted Uses as of Right $0.00
1.7.2 Nonregulated $0.00

1.8 Regulation Amendment Petitions $500.00
(Does not include Notices or Regulation Advisories from DEP)

1.8.1 Map Amendment Petitions $500.00
Plus Fee from Schedule B

1.9 Modification of Previous Approval:...... ....$100.00

1.10 Renewal of Previous Approval $100.00

1.11 Monitoring Compliance Fee $100.00

1.12 SCHEDULE A. For the purpose of calculating the permit application fee, the area in schedule A is the total area of wetlands and watercourses and the upland review area upon which a regulated activity is proposed.

SQUARE FEET of AREA
1.12.1. Less than 1,000. ....$0.00
1.12.2. 1,000 to 5,000... ....$250.00
1.12.3. More than 5,000 .... [✓ ....$750.00]

+ 60.

$1,210.00

1.13 SCHEDULE B. For the purpose of calculating the map amendment petition fee, linear feet in schedule B is the total length of wetlands and watercourses boundary subject to the proposed boundary change.

LINEAR FEET
1.13.1. Less than 500.... ....$0.00
1.13.2 500 to 1,000 ....$250.00
1.13.3 More than 1,000...$750.00

JAMES SIPPERLY
CERTIFIED SOIL SCIENTIST
21 CASE STREET
NORWICH, CT 06360
860-334-7073
james.sipperly.js@gmail.com

Brandon Handfield, Professional Engineer
Yantic River Consultants
191 Norwich Avenue
Lebanon, CT 06249

October 3, 2019

RE: INLAND WETLAND SOILS AND WATERCOURSES INVESTIGATION, AND DELINEATION, NORTH BRIDE BROOK MULTI-FAMILY DEVELOPMENT, NORTH BRIDE BOOK ROAD, EAST LYME, CT

Dear Mr. Handfied:

On Saturday, June 29, 2019 I visited the site referenced above to inspect the inland wetlands and watercourses delineation that was originally performed by Michael Schaefer, Soil Scientist quite some time ago. Remarkably, most of his blue flagging was still identifiable in the field on either side of the watercourse that flows through the center of a narrow wetland corridor that bisects the property.

I sampled the soil throughout the site using a soil auger to a depth of two to three feet. Based on my field observations and using the guidelines established by the National Cooperative Soil Survey and as defined by the Connecticut General Statutes I delineated the inland wetland soils and watercourse on the property. I delineated the inland wetlands and watercourses using blue flagging numbered 1-44 and 45-78 respectively.

At many, if not all of Michael Schaefer's flag locations, I conducted a soil transect using my soil auger and in every instance I agreed with his placement of his wetland flags.

The inland wetland soils associated with Bride Brook are classified as a poorly drained and very poorly drained Leicester, Ridgebury Whitman fine sandy loam. These soils are often found in depressions and drainageways on glacial till uplands and are mapped together as a complex due to their similar physical characteristics, use and management.

Bride Brook flows in a southerly direction under Route 95 via a culvert onto the subject property and bisects the property and continues onto the State of Connecticut property to the south. The width of the actual flow is variable from 1 foot to 3 feet and tends to branch out and form mini meanders at times due to the presence of rocks and boulders and the nature of the topography.

Ex "B"

The inland wetlands and watercourses locations are shown correctly on a site plan entitled "North Bride Brook Multi-Family Development, prepared for Pazza Construction, LLC, Overall Layout Plan, sheet 1 of 7, dated 9/25/19, scale 1"= 60'' prepared by Yantic River Consultants, LLC".

All of the wetland areas are classified as a forested wetland general classification. Its functions include: groundwater recharge and discharge, sediment stabilization, nutrient removal and transformation, product export, and wildlife diversity. The vegetative over-story includes maples, ash, black cherry, oak and poplar. Shrub species include winterberry, spice bush, silky dogwood and mountain laurel. The herbaceous layer includes sensitive fern, poison ivy, wildly grape and skunk cabbage. No evidence of invasive species was observed.

The proposed development in the upland review area will not be disturbing any wetlands and/or watercourses on the site. For that reason, the inland wetlands will continue to perform their functions as they currently do.

With any proposed project a comprehensive erosion and sedimentation control plan well designed and properly installed and maintained is the key to a successful project. Regular inspections should occur, especially after storm events of more than 0.1 inches of rain.

After reviewing the erosion and sedimentation control plans and the storm water design features it is my professional opinion that the proposed construction activities will not have a significant adverse effect on the adjacent inland wetlands and/or watercourse on or off the site.

If you have any questions or require additional information, please contact me at the telephone number referenced above.

Very truly yours,

James Sipperly
Certified Soil Scientist, Society of Soil Scientists of Southern New England
Connecticut Wetland Scientist, Connecticut Association of Wetland Scientists

AUTHORIZATION

Pazz & Construction, LLC hereby authorizes the law firm of Heller, Heller & McCoy to submit an application on its behalf to the Town of East Lyme Inlands Wetlands Agency for permits to conduct regulated activities in conjunction with the development of a proposed 108 unit multi-family development on real property located on the westerly side of North Bride Brook Road in the Town of East Lyme, Connecticut as depicted on a plan entitled "North Bride Brook Multi-Family Development Prepared For Pazz & Construction, LLC N. Bride Brook Road (Assessor's Map 9, Lot 37-2) East Lyme, CT Scale: 1" = 40' Sheets 1 of 7 to 7 of 7 Date 9/25/19 Yantic River Consultants, LLC 191 Norwich Avenue Lebanon, Conn 06249 Phone (860) 367-7264 E-mail: yanticriver@gmail.com Web: www.yanticriverconsultants.com".

Pazz & Construction, LLC hereby further authorizes the law firm of Heller, Heller & McCoy, the consulting civil engineering firm of Yantic River Consultants, LLC and James Sipperly, Soil Scientist, to represent its interests in all proceedings before the Town of East Lyme Inland Wetlands Agency with respect to said application for permits to conduct activities in upland review areas adjacent to wetlands and watercourses on the hereinbefore described property.

Dated at Montville, Connecticut this 21st day of November, 2019.

PAZZ & CONSTRUCTION, LLC

By:________________________(L.S.)
Jason Pazzaglia, its Member

Z:\Pazzaglia, Jason\East Lyme Wetlands\Authorization.doc

Ex "C"

APPLICATION OF PAZZ & CONSTRUCTION, LLC ("APPLICANT")
TO
TOWN OF EAST LYME INLAND WETLANDS AND WATERCOURSES COMMISSION

NORTH BRIDE BROOK MULTI-FAMILY RESIDENTIAL DEVELOPMENT
NORTH BRIDE BROOK ROAD, EAST LYME, CONNECTICUT

APPLICATION NARRATIVE
DATE: NOVEMBER 22, 2019

PROJECT OVERVIEW

The Applicant is the owner of a 20.24 acre, more or less, tract of land, located on the westerly side of North Bride Brook Road in the Town of East Lyme, Connecticut (the "Property"). The Property enjoys road frontage both to the north and south of a single family dwelling and appurtenant facilities located at 90 North Bride Brook Road, which parcel is owned of record by Geraldine J. Dzwilewski as shown on the hereinafter referenced plan. The Applicant proposes to develop the easterly portion of the Property for one hundred eight (108) multi-family residential units formulated in an application to be submitted to the East Lyme Zoning Commission pursuant to the provisions of Section 8-30g of the Connecticut General Statutes.

As depicted on the Overall Layout Plan for the project entitled "North Bride Brook Multi-Family Development Prepared For Pazz & Construction, LLC Overall Layout Plan N. Bride Brook Road (Assessor's Map 9, Lot 37-2) East Lyme, CT Scale: 1" = 40' Sheet 1 of 7 Date 9/25/19 Yantic River Consultants, LLC 191 Norwich Avenue Lebanon, Conn 06249 Phone (860) 367-7264 E-mail: yanticriver@gmail.com Web: www.yanticriverconsultants.com" (the "Overall Layout Plan"), the project parcel is bifurcated by a wetland system associated with Bride Brook which flows through the project site in a northwesterly to southeasterly orientation. In conjunction with the instant development initiative, the Applicant is proposing only to develop that portion of the project site which is located easterly of the wetland system. As depicted on the Overall Layout Plan, the project site accommodates 48,970 square feet (1.12 acres) of regulated inland wetland and/or watercourse area, all comprised of the riparian system which incorporates and is adjacent to Bride Brook.

All proposed dwelling units to be constructed in the North Bride Brook Multi-Family Development will interconnect with the municipal sewer system administered by the Town of East Lyme Water and Sewer Commission and will obtain a potable water supply from the East Lyme municipal water system. The East Lyme Water and Sewer Commission has allocated 35,400 gallons of sewer capacity to provide sanitary sewer service to the 108 proposed residential apartment units to be constructed in the North Bride Brook Multi-Family Development.

The project will obtain vehicular and pedestrian access by virtue of a private access road which will intersect North Bride Brook Road adjacent northerly to the Dzwilewski property as depicted on the Overall Layout Plan. All roads interior to the multi-family development will be

Ex "D"

privately owned and maintained by the Applicant/developer. The roadways within the multi-family development will be curbed and will accommodate a closed drainage system which will collect stormwater runoff from impervious and semi-pervious areas within the project development and transmit the same to a stormwater quality/detention basin located in the southeasterly corner of the project site. A swale to be constructed along the northeasterly periphery of the project site will direct stormwater runoff from semi-pervious areas of the project site to Catch Basin #309 which will pick up any overland flow emanating from semi-pervious areas of the project site and introduce the same to the stormwater system incorporated into the project design. Stormwater from the closed drainage system will discharge to a sediment forebay in the detention basin area in the southeasterly corner of the project site. The sediment forebay shall be separated from the detention basin by a filter berm constructed in accordance with the "Detention Filter Berm" detail delineated on Sheet 7 of 7 of the site development plan. The design of the sediment forebay and detention basin has been formulated in order to attain residency time in the sediment forebay for suspended solids in the stormwater stream to filter out and settle before the stormwater passes through the semi-pervious filter berm to the detention basin itself. Stormwater from the detention basin will be released at a controlled rate based upon the orifice sizes in the outlet structure to be located in the northeast corner of the detention basin. Water outletting the detention basin will be introduced to a cross-culvert under North Bride Brook Road and thereafter discharged to the environment. The stormwater design has been formulated in order to attenuate any increase in peak runoff for all design storm events from the 2 year storm to the 100 year storm.

In order to provide recharge to the wetland/watercourse system which bisects the property in a northwesterly to southeasterly direction, the project engineer has provided for roof top runoff from Buildings I, J and M as depicted on the Overall Layout Plan to be discharged to a rip rap splash pad at a westerly corner of each building. These stormwater discharges have been formulated to replicate the existing flows which currently reach and contribute to the recharge of the wetland system associated with Bride Brook.

The Property, with the exclusion of the wetland system which accommodates Bride Brook, is entirely composed of upland soils. A description of the vegetation and soil composition, including a detailed analysis of the characteristics and functions of the wetland and watercourse systems on the Property is contained in a report dated October 3, 2019 prepared on behalf of the Applicant by James Sipperly, certified soil scientist. This report is submitted with and constitutes an integral component of the application for permits to conduct regulated activities which is being submitted contemporaneously herewith to the Town of East Lyme Inland Wetlands and Watercourses Commission.

The Applicant is seeking a permit from the Town of East Lyme Inland Wetlands and Watercourses Commission to conduct regulated activities in the upland review area adjacent easterly to the wetland/watercourse system which bisects the Property in a northwesterly to southeasterly direction in conjunction with the development of its proposed 108 unit multi-family affordable residential development. Activities proposed by the application in the upland review area include the construction of Buildings J and M and a portion of Building I, the construction of a portion of the roadway and parking system which will provide access to and parking for Buildings I, J, K, L and M, grading and landscaping adjacent to Buildings I, J and M and the stormwater discharge of the rooftop stormwater from Buildings I, J and M incorporated into the project design to provide stormwater recharge to the adjacent wetland system. The Applicant, in conjunction with the development of the multi-family residential project, is not proposing any direct disturbance to any inland wetland or watercourse. There are 4.56 acres of upland review area located adjacent to the wetland/watercourse system which bisects the Property. In conjunction with the development of its multi-family residential project, the Applicant is proposing disturbance of 1.44 acres of this upland review area. Through the incorporation of a robust erosion and sediment control program during construction, and well thought out stabilization techniques and a long term maintenance program, it is not anticipated that the activities proposed by the Applicant in the upland review area will have any adverse impact on the adjacent wetland/watercourse system. The statements contained in this Narrative are affirmed by the Evaluation Report of James Sipperly contained in his correspondence to the East Lyme Inland Wetlands and Watercourses Commission dated October 3, 2019.

The design of the stormwater collection, treatment and discharge system for the project was chosen by the Applicant's engineer in order to (i) avoid disturbance in conjunction with the development of the Property in wetlands and limit disturbance to upland review areas, resulting in no direct impact to or disturbance of any regulated inland wetland or watercourse (ii) maintain the existing hydraulic regime on the Property post-development in order to insure that there is adequate recharge for the wetland/watercourse system which bisects the Property in a northwesterly to southeasterly direction and (iii) discharge a highly renovated stormwater to the environment in a location which will not adversely impact wetlands or watercourses.

The development plan for the Property, as well as the development techniques specified by the design engineer, all of which have been incorporated into the site development plan, have been formulated to accomplish the following goals:

1. To avoid, to the maximum extent possible, wetland and environmental resources, and upland review areas adjacent to those resources located on the Property.

2. To provide housing units which will represent a good value to the public.

3. To replicate the pre-development hydrology of the wetland/watercourse system which bisects the Property.

The stormwater quality system which has been incorporated into the project vernacular has been designed by the Applicant's consulting engineer, Yantic River Consultants, LLC, in order to satisfy the goals enunciated in the 2004 Connecticut Department of Environmental Protection Stormwater Quality Manual. The stormwater quality forebay has been designed to receive and detain the water quality volume which will consist of the first one (1") inch of rainfall. The collection, treatment and discharge system has been designed both to meet the stormwater quality goals as well as to provide flood control by the attenuation of peak rates of discharge before the stormwater is released to the environment.

The soil designation for all soils located on the Property are identified on the Overall Layout Plan and their characteristics are set forth in the next section of this Narrative.

Stormwater runoff calculations for the project are contained in a report submitted herewith by Yantic River Consultants, LLC dated November 1, 2019.

SOIL CHARACTERISTICS

Upland areas of the Property are comprised of three (3) soil types designated on the Overall Layout Plan as "Haven Silt Loam 0-3% (Code 703A)", "Charlton-Chatfield Complex, 15-45% (Code 73E)" and "Charlton-Chatfield Complex, 0-15% (Code 73C)". The soil characteristics for each soil type are as follows:

Haven Silt Loam

The Haven Silt Loam soils are located in the southeasterly corner of the project site, primarily in the location of the parking area associated with Building E and the stormwater treatment and detention area. This soil type consists of well drained soils that formed in glacial outwash. Haven soils are found on stream terraces and outwash plains. Haven soils are found in a drainage sequence on the landscape with moderately well-drained Tisbury soils and poorly drained Raypol soils. They are near excessively drained Hinckley soils, well-drained Canton, Charlton, Narragansett and Agawam soils and moderately well-drained Ninigret soils. The typical soil stratification for the Haven soil is as follows:

0" – 7"	Dark brown silty loam; weak fine granular structure; very friable; common fine and medium roots; 5% course fragments; strongly acid; abrupt wavy boundary.
7" – 11"	Brown silty loam; weak medium subangular blocky structure; friable; few fine roots; 5% course fragments; strongly acid; gradual wavy boundary.
11" – 15"	Dark yellowish brown silt loam; weak medium subangular blocky structure; friable; few fine roots; 10% course fragments; strongly acid; gradual wavy boundary.
15" – 23"	Yellowish brown silt loam; weak medium subangular blocky structure; friable; few fine roots; 15% course fragments; strongly acid; clear wavy boundary.
23" – 60"	Light yellowish brown very gravelly sand; single grain; loose; 55% course fragments; medium acid.

Charlton-Chatfield Complex (0-15%)

This soil complex is found on gently sloping to strongly sloping landscapes with bedrock controlled hills and bedrock controlled uplands. 0-3% of the surface area is covered with stones. This complex is comprised of 45% Charlton soils, 30% Chatfield soils and 25% other soils.

The stratification of the Charlton soils is as follows:

0" – 4"	Fine sandy loam.
4" – 7"	Fine sandy loam.
7" – 19"	Fine sandy loam.
19" – 27"	Gravelly fine sandy loam.
27" – 65"	Gravelly fine sandy loam.

The stratification of the Chatfield soils is as follows:

0" – 1"	Highly decomposed plant material.
1" – 6"	Gravelly fine sandy loam.
6" – 15"	Gravelly fine sandy loam.
15" – 29"	Gravelly fine sandy loam.
29" – 80"	Unweathered bedrock.

Permeability in the Charlton-Chatfield complex is well drained. Available water capacity is moderate to high. Depth to restrictive features in the Charlton soils is greater than 72" and 20" to 40" in the Chatfield soil.

Included with these soils and mapping are areas of moderately well-drained Sutton soils and poorly drained Leicester soils. Sutton soils are in slight depressions in the landscape; Leicester soils are in depressions and drainage ways. Also included are small areas of shallow, somewhat excessively drained Hollis soils where bedrock is 10" – 20" below the surface.

This soil group (designated as 73C on the Overall Layout Plan) is located in the northeasterly portion of the proposed to be developed project site and accommodates the entire westerly portion of the Property located westerly of the wetland/watercourse system which bisects the Property.

Charlton-Chatfield Complex (15-45%)

This Charlton-Chatfield complex (15-45%) is found on moderately steep to steep slopes on the landscape with bedrock controlled hills and bedrock controlled hills and uplands. 0-3% of the surface area of this soil is covered by stones. Charlton soils comprise 45% of the Charlton-Chatfield complex, Chatfield soils comprise 30% of the complex and 25% of the complex is comprised of other soils. Depth to bedrock in the Charlton soils is very deep and depth to bedrock in the Chatfield soils is moderately deep or deep. Both soils are well drained soils formed from course-loamy melt-out till derived from granite and/or Schist and/or Gneiss. Both components of the Charlton-Chatfield complex are well-drained soils and permeability in each soil is moderate or moderately rapid. The depth to the restrictive layer in the Charlton soils is greater than 72" and the depth to the restrictive layer in the Chatfield soils is 20" to 40". Depth to seasonal groundwater in both soils is greater than 6'.

The stratification of the Charlton soil is as follows:

0" – 4"	Fine sandy loam.
4" – 7"	Fine sandy loam.
7" – 19"	Fine sandy loam.
19" – 27"	Gravelly fine sandy loam.
27" – 65"	Gravelly fine sandy loam.

The stratification of the Chatfield soils is as follows:

0" – 1"	Highly decomposed plant material.
1" – 6"	Gravelly fine sandy loam.
6" – 15"	Gravelly fine sandy loam.
15" – 29"	Gravelly fine sandy loam.
29" – 80"	Unweathered bedrock.

The Charlton-Chatfield complex is found on the landscape in areas of moderately well-drained Sutton soils and poorly drained Leicester soils. Sutton soils are found in slight depressions on the landscape. Leicester soils are found in depressions and drainage ways. Also included in this complex are small areas of shallow, somewhat excessively drained Hollis soils where bedrock is 10" – 20" below the surface.

WETLAND SOILS

The wetland soils associated with the riparian corridor of Bride Brook extending in a northeasterly to southeasterly orientation through and across the Property are Ridgebury, Leicester, Whitman soils. These nearly level, poorly drained and very poorly drained soils are found in drainage ways and depressions on glacial till, upland hills, ridges, plains and drumloidal landforms. Stones and boulders cover 8-25% of the surface. Slopes range from 0-3%. The mapped acreage of this undifferentiated group is about 35% Ridgebury soil, 30% Leicester soil, 20% Whitman soil and 15% other soils. Some mapped areas consist of one of these soils, and other areas consist of two or three. These soils were mapped together because there are no major differences in use and management.

The soil stratification for the Ridgebury soil is as follows:

0" – 1"	Partly decomposed leaves.
0" – 4"	Black, fine sandy loam; weak medium granular structure; friable; common fine roots; 5% rock fragments; strongly acid; clear wavy boundary.
4" – 13"	Gray fine sandy loam; common medium distinct strong brown mottles and common, medium faint yellowish brown mottles; massive; friable; 5% rock fragments; strongly acid; gradual wavy boundary.
13" – 20"	Brown fine sandy loam; many medium distinct yellowish brown mottles and few fine faint grayish brown mottles; massive; friable; firm in place; 10% rock fragments; slightly acid; clear wavy boundary.
20" – 60"	Grayish brown sandy loam; few fine faint yellowish brown mottles; massive; very firm, brittle; 5% rock fragment; slightly acid.

The stratification of the Leicester soil is as follows:

0" – 2"	Decomposed leaves.
2" – 6"	Very dark gray fine sandy loam; weak fine granular structure; very friable; few fine and medium roots; 5% rock fragments; very strongly acid; abrupt smooth boundary.
6" – 12"	Dark grayish brown, fine sandy loam; few fine faint yellowish-brown mottles and many medium distinct light brownish gray mottles; weak medium subangular blocky structure; very friable; few medium roots; 5% rock fragments; strongly acid; clear wavy boundary.
12" – 24"	Grayish brown, fine sandy loam; few medium distinct yellowish-brown and dark grayish brown mottles; weak medium subangular blocky structure; friable; 10% rock fragments; strongly acid; gradual wavy boundary.
24" – 32"	Pale olive fine sandy loam; many course distinct yellowish brown mottles; weak medium subangular blocky structure; friable; 15% rock fragments; strongly acid; gradual wavy boundary.
32" – 60"	Light olive gray gravelly fine sandy loam; many medium distinct yellowish brown mottles; massive; friable; 25% rock fragment; strongly acid.

The stratification of the Whitman soil is as follows:

0" – 1"	Decomposed leaf litter.
1" – 9"	Black fine sandy loam; weak medium granular structure; friable; common fine and medium roots; strongly acid; abrupt wavy boundary.
9" – 16"	Dark grayish brown fine sandy loam; few fine faint yellowish brown mottles; weak medium subangular blocky structure; friable; few fine roots; 5% rock fragments; medium acid; clear wavy boundary.
16" – 22"	Grayish brown, fine sandy loam; common medium distinct strong brown mottles and few medium light brownish gray mottles; moderate medium platy structure; very firm, brittle; 5% rock fragments; slightly acid; gradual wavy boundary.
22" – 60"	Grayish brown fine sandy loam; common medium distinct strong brown mottles and few medium faint light brownish gray mottles; massive; firm, brittle; 5% rock fragments; slightly acid.

Included with these soils and mapping are small areas of moderately well drained Rainbow, Sutton and Woodbridge soils and very poorly drained Adrian and Palms soils. The Ridgebury soil has a seasonal high water table at a depth of about 6". Permeability is moderate or moderately rapid in the surface layer and subsoil and slow or very slow in the substratum. The Leicester soil has a seasonal high water table at a depth of about 6". Permeability is moderate or moderately rapid. The Whitman soil has a high water table at or near the surface for most of the year. Permeability is moderate or moderately rapid in the surface layer and subsoil and slow or very slow in the substratum.

PROPOSED REGULATED ACTIVITIES

1. The development of proposed Building J and proposed Building M and a portion of proposed Building I in the upland review area adjacent easterly to the wetland system as depicted on the Overall Layout Plan.

2. The construction and use of a portion of the cul-de-sac, secondary access drive and parking in the upland review area adjacent easterly to the wetland system on the Property.

3. Grading and landscaping in the upland review area in conjunction with the development of proposed Buildings I, J and M, the cul-de-sac, secondary access drive and parking in the upland review area adjacent easterly to the wetland system on the Property.

4. The discharge of roof collected stormwater from Buildings I, J and M as depicted on the Overall Layout Plan in the upland review area adjacent easterly to the wetland system on the Property to provide recharge for the adjacent wetlands.

GENERAL PROCEDURES

1. Prior to the conducting any construction activities on the Property, the Applicant, and its contractor, shall meet with the East Lyme Wetlands Enforcement Officer and the East Lyme Zoning Enforcement Officer to discuss and agree upon the method of installation and maintenance of erosion and sediment control measures during construction as well as a construction inspection schedule (the "Preconstruction Meeting").

2. Subsequent to the Preconstruction Meeting, the Applicant's surveyor shall delineate in the field the limits within which construction activities shall occur and shall further delineate the location for the installation of all erosion and sediment control measures as depicted on a plan entitled "North Bride Brook Multi-Family Development Prepared For Pazz & Construction, LLC Erosion & Sedimentation Control Plan N. Bride Brook Road (Assessor's Map 9, Lot 37-2) East Lyme, CT Sheet 5 of 7 Date 9/25/19 Yantic River Consultants, LLC 191 Norwich Avenue Lebanon, Conn 06249 Phone (860) 367-7264 E-mail: yanticriver@gmail.com Web: www.yanticriverconsultants.com" (the "Erosion Control Plan").

3. Upon agreement of the East Lyme Wetlands Enforcement Officer and the East Lyme Zoning Enforcement Officer, the Applicant shall clear (but not grub) the area required for the installation of erosion and sediment control measures as delineated on the Erosion Control Plan.

4. Once clearing of the areas for the installation of erosion and sediment control measures has been accomplished, the Applicant (or its contractor) shall install the erosion and sediment control measures as delineated on the Erosion Control Plan. In no event shall grubbing or soil disturbance (other than that required for the clearing associated with the installation of erosion and sediment control measures) occur until such time as all erosion and sediment control measures have been installed and inspected, as hereinafter provided.

5. At such time as all erosion and sediment control measures have been installed in accordance with the Erosion Control Plan and in accordance with the directives of the East Lyme Wetlands Enforcement Officer and the East Lyme Zoning Enforcement Officer enunciated at the Preconstruction Meeting, the Applicant shall contact the East Lyme Wetlands Enforcement Officer and the East Lyme Zoning Enforcement Officer to perform an on-site inspection of the installation of said erosion and sediment control measures. In no event shall actual construction activities be commenced either with respect to the infrastructure for the project or on any buildings, until such time as the East Lyme Wetlands Enforcement Officer and the East Lyme Zoning Enforcement Officer have reviewed and approved the installation of all applicable erosion and sediment control measures.

6. In conjunction with the development of the North Bride Brook Multi-Family Development, marketable timber removed in conjunction with construction activities shall be removed from the site. Construction debris (i.e. stumps, branches, etc.) shall either be (i) ground in place or (ii) removed to an area approved, in advance, by the East Lyme Zoning Enforcement Officer. In no event shall stumps or construction debris be buried on site.

7. All erosion and sediment control measures shall be inspected at least twice weekly while construction is ongoing and after every storm event resulting in the deposition of in excess of one-tenth of one (0.10") inch of precipitation and repaired and maintained as necessary.

8. If any erosion and sediment control measure fails or is not installed or maintained in accordance with the Erosion Control Plan or the directors of the East Lyme Wetlands Enforcement Officer or the East Lyme Zoning Enforcement Officer, the Applicant shall be required to cease all construction activities with respect to the development of the North Bride Brook Multi-Family Development until such time as said erosion and sediment and control measures have been installed in accordance with the Erosion Control Plan and/or the directives of the East Lyme Wetlands Enforcement Officer or the East Lyme Zoning Enforcement Officer and approval of the same has been certified, in writing, by the East Lyme Wetlands Enforcement Officer and the East Lyme Zoning Enforcement Officer.

9. During the stabilization period (after construction of any area on the Property has been completed, but prior to certification of approval thereof by the East Lyme Wetlands Enforcement Officer and the East Lyme Zoning Enforcement Officer for removal of erosion and sediment control measures) all erosion and sediment control measures shall be maintained in proper working order and condition. Unless notice otherwise is provided to the East Lyme Wetlands Enforcement Officer and the East Lyme Zoning Enforcement Officer, Jason Pazzaglia, 21 Darrows Ridge Road, East Lyme, Connecticut 06333, (860) 961-2364, jpazz17@gmail.com shall be the responsible party for compliance with all erosion and sediment control measures and requirements in conjunction with construction activities on the Property. All erosion and sediment control measures shall be inspected, maintained and/or repaired, as necessary, as set forth above.

10. Subject to permitting requirements, it is anticipated that the construction of infrastructure improvements for the North Bride Brook Multi-Family Development shall commence in the summer of 2020. The project will be constructed in increments and it is anticipated that a 3 – 4 year period will be required for the complete construction and stabilization of the North Bride Brook Multi-Family Development.

11. During the stabilization period, any erosion which occurs shall be immediately repaired by the Applicant, reseeded with the seeding mixes set forth in the Construction Sequencing section of this Narrative and re-stabilized.

12. Once complete site stabilization has been achieved, and certification thereof obtained, in writing, from the East Lyme Wetlands Enforcement Officer and the East Lyme Zoning Enforcement Officer, all erosion and sediment control measures shall be removed by the Applicant.

CONSTRUCTION SEQUENCING

1. The Applicant shall clear the area for the initial phase of construction of the North Bride Brook Multi-Family Development. No grubbing shall occur until subsequent to the installation and inspection of erosion and sediment control measures. Any marketable timber shall be removed from the Property.

2. The Applicant shall install silt fence down gradient of the area of all construction activities as depicted on the Erosion Control Plan. The Applicant may use wood chip berms in lieu of silt fence as an acceptable methodology for sediment and erosion control. Silt fence installation, if utilized, shall be effected in accordance with the "Silt Fence" detail as depicted on Sheet 6 of 7 of the project site plan.

3. The Applicant shall install the anti-tracking apron at the construction interface of the access road to the Property with North Bride Brook Road in accordance with the "Anti-Tracking Pad Detail" as depicted on Sheet 6 of 7 of the project plans.

4. Upon completion of installation of erosion and sediment control measures, the Applicant shall contact the East Lyme Wetlands Enforcement Officer and the East Lyme Zoning Enforcement Officer to perform an inspection of the installation of erosion and sediment control measures. In no event shall mass soil disturbance and/or grubbing occur in the first phase of the project until such time as the installation of erosion and sediment control measures has been approved by the East Lyme Wetlands Enforcement Officer and the East Lyme Zoning Enforcement Officer.

5. Surface soil shall be stripped in the first phase construction area and stockpiled in a surface soil stockpile area as depicted on the Erosion Control Plan. Surface soil stockpiles shall have a slope not exceeding 4:1, and shall be stabilized by seeding with a perennial ryegrass mix and mulch. The perennial ryegrass mix shall be applied at a rate of 40 pounds per acre. Mulch shall be applied at the rate of 80 pounds per 1,000 square feet, and shall be spread by hand or with a mulch blower. Silt fence or staked hay bales shall be installed along the down gradient periphery of each surface stockpile location.

6. Excavation for the installation of the water quality forebay and stormwater detention basin shall be effected at the location delineated on the plans. Excavated materials shall be retained for use as fill in fill areas on the project site as delineated on the project plans. The water quality/detention basin shall be excavated and shaped to the contours and at the depths depicted on the project site development plan. Culvert trenches shall be excavated in order to effect the interconnection of the outlet structure within the detention basin to the catch basin system in North Bride Brook Road.

7. Upon completion of the excavation of the culvert trenches, bedding material, not less than 12" shall be installed and compacted in each trench bed.

8. The outlet structure (OCS #100) shall be installed in the northeasterly corner of the detention basin and interconnected to the 15" HDPE outlet culvert which will extend to and interconnect with an existing CB-C (Type II) catch basin in North Bride Brook Road.

9. Upon placement of the outlet culvert, bedding, not less than 12" in thickness shall be installed over the top of the culvert pipe installation and compacted in place. Thereafter, the culvert trenches shall be backfilled with stored surface soil.

10. The filter berm shall be installed separating the water quality forebay from the detention basin in accordance with the detention filter berm detail as depicted on Sheet 7 of 7 of the site development plan.

11. The water quality-detention basin embankments shall be constructed of silty sand and/or clay material.

12. The stormwater quality forebay shall be loamed with not less than 6" of surface soil containing not less than 8% organic content.

13. The stormwater detention basin shall be loamed with not less than 6" of surface soil containing not less than 8% organic content.

14. The water quality forebay and detention basin shall be planted by installing the New England Erosion Control/Restoration Mix or equal. The New England Erosion Control/Restoration Mix contains a selection of native grasses and wild flowers designed to colonize generally moist, recently disturbed sites where quick growth of vegetation is desired to stabilize the soil surface. This mix is particularly appropriate for water quality/detention basins which do not normally hold standing water. The plants in this mix can tolerate infrequent inundation but not constant flooding. The New England Erosion Control/Restoration Mix contains the following species: Switchgrass, Virginia Wild Rye, Creeping Red Fescue, Fox Sedge, Creeping Bent Grass, Silky Wild Rye, Nodding Bur-marigold, Soft Rush, Grass-Leaved Goldenrod, Sensitive Fern, Jo-Pye Weed, Boneset, Flat-Top Aster, New York Aster and Blue Vervain. The seed mix shall be applied at a rate of 1 pound per 1,245 square feet of disturbed area.

    Disturbed areas on the water quality/detention basin berm and exterior thereto which are not anticipated to contain the hydrology required to support the New England Erosion Control/Restoration Mix shall be prepared by spreading ground limestone equivalent to 50% calcium plus magnesium oxide applied at a rate of 50 pounds per 1,000 square feet. Fertilizer (10-10-10) is to be applied at a rate of 7.5 pounds per 1,000 square feet. Following the initial application of lime and fertilizer, there are to be no periodic applications of lime and fertilizer. Disturbed areas will be seeded with a seeding mixture of Kentucky Bluegrass applied at a rate of 20 pounds per acre, Creeping Red Fescue applied at a rate of 20 pounds per acre and Perennial Ryegrass applied at a rate of 5 pounds per acre for a total application of 45 pounds per acre. In the event that a hydroseed mix is not utilized, after seeding, the areas seeded shall be stabilized with hay mulch immediately applied at a rate of 70 pounds per 1,000 square feet, and anchored by tracking. Seeding shall only occur between April 15 and June 15 and August 15 to October 1.

15. As areas of the project site are cleared and grubbed, the Applicant shall install, in the downgradient locations delineated on the Erosion Control Plan, temporary sediment traps in accordance with the "Temporary Sediment Trap" detail depicted on Sheet 6 of 7 of the site development plan which shall be sized, in the field, by the Applicant's consulting civil engineer in accordance with the "Temporary Sediment Trap (TST) Sizing" chart as depicted on Sheet 6 of 7 of the site development plan.

16. Upon completion of the installation and stabilization of the water quality/stormwater detention basin, construction shall progress sequentially in the first phase of project development in accordance with the site development plan.

17. All utility installations, including stormwater, the potable water distribution system and sanitary sewer facilities shall be installed in accordance with the design plans utilizing the trenching, compaction and cover requirements as hereinbefore set forth.

18. As the stormwater drainage system is being sequentially completed, the Applicant shall install sediment control devices in each installed catch basin in accordance with the "Inlet Sediment Control Device" detail depicted on Sheet 6 of 7 of the project site development plan.

19. Areas for road and parking construction and building construction in the first phase of the project shall be "boxed-out" and/or excavated, as the case may be, in accordance with the specifications, and at the elevations depicted on the project site development plan.

20. Excavated material derived from site development shall either be utilized as structural fill in fill areas in the first phase of the project or stored in soil stockpiles in the soil stockpile locations as depicted on the Erosion Control Plan. Any stockpiled earth product material shall be stabilized and protected by the installation of erosion control devices in accordance with the requirement hereinbefore set forth in this Construction Sequencing Narrative.

21. Each road location shall be boxed out and trenches excavated for the installation of all utilities, including stormwater drainage.

22. Upon the completion of culverting, not less than 12" of clean bedding material shall be installed in each utility trench.

23. Subsequent to the installation of bedding, utilities, including stormwater drainage pipes, shall be installed as delineated on the utilities plan incorporated into the site development plan.

24. Once utilities have been installed, each utility trench shall be backfilled with clean bedding material compacted to a depth of not less than 12" over each utility installation. Areas to be paved will be prepared by installing a compacted gravel subgrade base, overlaid with 8" of processed gravel (compacted) and thereafter by the installation of 3" of compacted Class 2 bituminous concrete placed in 1.5" lifts in accordance with the Bituminous Pavement detail delineated on Sheet 6 of 7 of the project site development plan. Bituminous concrete curbing shall be installed in accordance with the "Bituminous Concrete Curb (BCLC) Detail" as depicted on Sheet 6 of 7 of the project site development plan.

25. Buildings in the first phase of the project shall be constructed in accordance with the architectural plans for the development of the same.

26. Upon completion of construction in the first phase of the project, disturbed areas shall be stabilized by spreading stockpiled surface soil over these areas at a thickness of not less than 4". Areas to be seeded will be prepared by spreading ground limestone equivalent to 50% calcium plus magnesium oxide applied at a rate of 50 pounds per 1,000 square feet. Fertilizer (10-10-10) is to be applied at a rate of 7.5 pounds per 1,000 square feet. Following the initial application of lime and fertilizer, there are to be no periodic applications of lime and fertilizer.

27. All disturbed areas on slopes greater than 6' in height shall be stabilized by the installation of North American Green S150 or approved equal erosion control blanket installed in accordance with the Erosion Control Blanket Slope Installation Detail as depicted on Sheet 6 of 7 of the site development plan. Other disturbed areas will be seeded with a seeding mix of Kentucky Bluegrass applied at a rate of 20 pounds per acre, Creeping Red Fescue applied at a rate of 20 pounds per acre and perennial Ryegrass applied at a rate of 5 pounds per acre for a total application of 45 pounds per acre. A hydroseed mix utilizing comparable cultivars shall be a suitable substitute. In the event that a hydroseed mix is not utilized, after seeding, the areas seeded shall be stabilized with hay mulch immediately applied at a rate of 70 pounds per 1,000 square feet, and anchored by tracking. Seeding shall only occur between April 15 and June 15 and August 15 to October 1.

28. Once all disturbed areas have been thoroughly stabilized, erosion and sediment control measures shall be removed.

29. As the Applicant nears completion of construction of improvements in the first phase of the North Bride Brook Multi-Family Development, the Applicant shall commence construction of the second phase of the project; and, thereafter, sequentially, each additional phase until completion of the project has been achieved.

30. As each sequential phase of the North Bride Brook Multi-Family Development is constructed, the Applicant shall install, maintain and utilize the erosion control measures and structures depicted on the Erosion Control Plan which shall be installed, administered

and utilized in accordance with the procedures set forth in the General Procedures section of this Narrative and, as applicable, the construction sequencing requirements contained in the Construction Sequencing section of this Narrative.

MAINTENANCE REQUIREMENTS

1. As delineated in the General Procedures section of this Narrative, the Applicant shall, during construction of the project, be responsible for inspecting all erosion control measures installed in the active development phase of the project on a twice weekly basis and after each storm event resulting in the deposition of in excess of 0.10" of precipitation.

2. At any time that sediment reaches one-half the height of the silt fence or the wood chip berm, the sediment shall be removed and utilized as site fill on the Property.

3. Temporary sedimentation traps shall be inspected in accordance with the inspection schedule required pursuant to the General Procedures section of this Narrative. At such time as temporary sedimentation traps are filled to 50% of their capacity, excavation equipment shall be introduced into the temporary sediment traps and all collected sediment shall be excavated and removed from the sedimentation traps to restore the temporary sedimentation traps to their designed capacity. Removed sediment shall be utilized as structural site fill on the project site.

4. Check dams and water bars shall be inspected in accordance with the inspection schedule required pursuant to the requirements of the General Procedures section of this Narrative and cleaned and repaired as necessary in order to insure their functional utility.

5. Inlet sediment control devices shall be inspected weekly and after every storm event resulting in more than 0.10" of precipitation and cleaned as necessary. If any inspection discloses any breach in an inlet sediment control device, the inlet sediment control device shall be replaced immediately.

PERMANENT MAINTENANCE SCHEDULE

1. All parking areas, roadways, sidewalks, driveways and other impervious areas (other than rooftops) shall be swept clean of sand, litter and other possible pollutants twice each year, once between November 14 and December 15 (after leaf fall has concluded) and once during the month of April (after the possibility of further sanding has ended). All material accumulated as a result of the sweeping activities shall be disposed of in accordance with law.

2. The Applicant shall utilize a sand/salt mix of 80/20 for winter roadway, parking lot and sidewalk treatments.

3. All catch basin sumps shall be cleaned at least once per year between the period April 15 and May 30. All material cleaned from catch basin sumps shall be disposed of in accordance with law.

4. A monthly inspection of all stormwater structures installed within the project, including the water quality forebay and the stormwater detention basin, and outfalls, shall be conducted for floating or surface debris. Any floating or surface debris encountered shall be removed and properly disposed of.

5. Except during the grow-in period, the water quality forebay shall be inspected once per year. At such time as accumulated sediments attain a depth of 12", accumulated sediment shall be removed and disposed of in accordance with law. The water quality forebay and detention basin shall be mowed once each year at the conclusion of the growing season.

6. The Applicant shall be responsible for compliance with all of the terms and provisions of this Narrative, including adherence to the maintenance requirements contained in this section hereof.

7. During the first two (2) years subsequent to the completion of the project, the Applicant shall inspect all downgradient discharge areas within the project for channelization subsequent to any storm event resulting in the deposition of in excess of 1" of rainfall. If channelization is occurring, the Applicant shall immediately retain the services of a certified soil and erosion control specialist in order to design remedial measures in order to diffuse the flow causing the channelization and shall forthwith implement the remedial measures designed by the certified soil and erosion control specialist.

Connecticut Department of
ENERGY &
ENVIRONMENTAL
PROTECTION

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Statewide Inland Wetlands & Watercourses Activity Reporting Form

Please complete and mail this form in accordance with the instructions on pages 2 and 3 to:
DEEP Land & Water Resources Division, Inland Wetlands Management Program, 79 Elm Street, 3rd Floor, Hartford, CT 06106
Incomplete or incomprehensible forms will be mailed back to the inland wetlands agency.

PART I: Must Be Completed By The Inland Wetlands Agency

1. DATE ACTION WAS TAKEN: year: __________ month: __________
2. ACTION TAKEN (see instructions, only use one code): __________
3. WAS A PUBLIC HEARING HELD (check one)? yes ☐ no ☐
4. NAME OF AGENCY OFFICIAL VERIFYING AND COMPLETING THIS FORM:

(print name) __________ (signature) __________

PART II: To Be Completed By The Inland Wetlands Agency Or The Applicant

5. TOWN IN WHICH THE ACTION IS OCCURRING (print name): East Lyme

does this project cross municipal boundaries (check one)? yes ☐ no ☒

if yes, list the other town(s) in which the action is occurring (print name(s)): __________, __________

6. LOCATION (see instructions for information): USGS quad name: Niantic or number: 101

subregional drainage basin number: Bride Brook 2206

7. NAME OF APPLICANT, VIOLATOR OR PETITIONER (print name): Pazz & Construction, LLC
8. NAME & ADDRESS / LOCATION OF PROJECT SITE (print information): North Bride Brook Multi-Family Development, 90 North Bride Brook Road, East Lyme, CT

briefly describe the action/project/activity (check and print information): temporary ☐ permanent ☒ description:

Construction activities in upland review areas adjacent to wetlands and a watercourse in conjunction with the development of a multi-family affordable housing project.

9. ACTIVITY *PURPOSE* CODE (see instructions, only use one code): C
10. ACTIVITY *TYPE* CODE(S) (see instructions for codes): 9, 12, 14, __________
11. WETLAND / WATERCOURSE AREA ALTERED (must provide acres or linear feet):

wetlands: 0.00 acres open water body: 0.00 acres stream: 0.00 linear feet

12. UPLAND AREA ALTERED (must provide acres): 1.44 acres
13. AREA OF WETLANDS / WATERCOURSES RESTORED, ENHANCED OR CREATED (must provide acres): 0.00 acres

DATE RECEIVED:

PART III: To Be Completed By The DEEP

DATE RETURNED TO DEEP:

FORM COMPLETED: YES NO

FORM CORRECTED / COMPLETED: YES NO

rev. 1/2019 pdf

Ex "E"

Town of East Lyn

P.O. DRAWER 519 NIANTIC, CONNECTICUT 06357

Town Engineer
Victor A. Benni, P.E.

860-691-4112
FAX 860-739-6930

To: Gary A. Goeschel II, Director of Planning

From: Victor Benni, P.E., Town Engineer

Date: December 13, 2019

Re: North Bride Brook Multi-Family Development
Wetlands Application Review

Information submitted by the Applicant which was considered in this review:

- (Drawing Set) North Bride Brook Multi-Family Development, Prepared for: Pazz & Construction, LLC, East Lyme, CT, 7-Sheet Drawing Set, Date: 9/25/19, By: Yantic River Consultants, LLC.
- (Wetlands Report) Inland Wetland Soils and Watercourses Investigation, And Delineation, North Bride Brook Multi-Family Development, North Bride Brook Road, East Lyme, CT, Date: October 3, 2019, By: James Sipperly, Certified Soil Scientist.
- Application Narrative, Application of Pazz & Construction, LLC, North Bride Brook Multi-Family Residential Development, North Bride Brook Road, East Lyme, Connecticut, Date: November 22, 2019.
- Stormwater Management Report, North Bride Brook Multi-Family Development, North Bride Brook Road, East Lyme, CT, Prepared for: Pazz & Construction, LLC, Date November 1, 2019, By: Yantic River Consultants, LLC.

This office has reviewed the above referenced information and has the following comments in regard to that portion of the development pertaining to the Wetlands and the 100' Upland Review Area:

1. The Wetland Report indicates that the proposed development in the upland review area will not be disturbing any wetlands and/or watercourses on the site.
2. Bride Brook and the un-named tributary to Bride Brook are both listed with the CT DEEP as being "impaired" water bodies. The construction and long-term operations & maintenance components of the stormwater management system should be strictly adhered to.
3. As indicated in the Wetlands Report, "All of the wetland areas are classified as a forested wetland general classification. Its functions include: groundwater recharge and discharge, sediment stabilization, nutrient removal and transformation, product export, and wildlife diversity." The Application Narrative indicates that the project engineer has provided for roof top runoff from Buildings I, J & M to be discharged to the westerly corner of each building in order to replicate the existing flows which currently reach and contribute to the recharge of the wetland system associated with Bride Brook.
4. Catch basin #'s 313, 315, & 324 shall be equipped with 4' deep sumps and hooded outlets.
5. A landscaping/planting plan should be considered for the developed area between the Limit of Proposed Tree Clearing and the Secondary Access Drive; between the Cul-de-sac and Building M. A proposed treeline and understory should be established up to the edge of the two parking areas and the Secondary Access Drive.

Ex "F"

6. The Erosion & Sedimentation Control Plan (Sheet 5), and the Details (Sheets 6 & 7) are in compliance with the 2002 Connecticut Guidelines for Soil Erosion and Sediment Control. The Sequence of Construction and E&S Control Narrative notes on Sheet 5 propose that the project will be completed in multiple phases. Inspection and Maintenance notes along with Temporary Sediment Trap sizing and detail have also been included. Provide correction of numbering system for Drawing Set, Sheet Numbers 6 & 7.

7. The Project Narrative calls for all erosion and sediment control measures to be inspected at least twice weekly during construction and following storm events resulting in excess of 0.1" of precipitation. The Wetlands Agency may wish to consider that weekly or monthly reports be submitted to the East Lyme Wetlands Agent during construction; on a weekly or monthly basis.

8. The results of the 5 soil test pits in the vicinity of the water quality-detention basin shall be provided for review to the East Lyme Engineering Department. Construction of the water quality-detention basin requires an approximate 5' cut into existing grades. The CT DEEP 2004 Connecticut Stormwater Quality Manual (11-P3-3) recommends that the bottom of the infiltration facility be located at least 3 feet above the seasonally high water table or bedrock.

9. The CT DOT Drainage Manual (October 2000) recommends that for quantity purposes, dry detention basins shall be designed to be able to pass a 100-year storm safely (Chapter 10.11-2). This is to ensure that the embankment will not be damaged or fail during the passage of the 100-year storm. In addition, the Manual indicates that the crest of the outlet control structure be set be a minimum of 1 foot below the crest of the emergency spillway, that 1 foot of freeboard be provided between the 100-year storm and the top of the embankment elevations, and 4:1 side slope maintenance access. This criteria should be incorporated into the stormwater management, calculations, design plan, and details for the water quality-detention basin.

10. The Stormwater Management Report verifies that the proposed detention pond attenuates peak flow rates and volumes as compared to the pre-development conditions, resulting in a zero-net increase in runoff from the development.

11. An Erosion and Sedimentation bond should be reviewed by the Engineering Department, following the Wetlands Agency's determination as to the addition of the potential planting plan in the upland review area and the decision whether or not to require the submittal of weekly/monthly E&S inspection reports.

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TOWN OF EAST LYME
INLAND WETLANDS AGENCY
Notice of Public Hearing

The East Lyme Inland Wetlands Agency will hold a Public Hearing on January 27, 2020, at 7:00 p.m., at the East Lyme Town Hall, 108 Pennsylvania Avenue, Niantic, CT, to consider the following application:

A. **NORTH BRIDE BROOK MULTI-FAMILY DEVELOPMENT:** Application of Pazz & Construction, LLC; Jason Pazzaglia, Applicant; Pazz & Construction, LLC, Owner; to conduct regulated activities in the upland review area in association with a proposed multi-family residential community on property identified in the application as N Bride Brook Rd, East Lyme Assessor's Map 09.0, Lot 37-2

Copies of specific proposals are available for public viewing in the Land Use Office.

Gary Upton, Chairman

Total Order Price: $424.80

Please call your ad representative by 3PM today with any ad changes.

Salesperson: Michelle Savona | **Printed on:** 1/2/2020
Telephone: 860-701-4276 | **Fax:** 860-442-5443
Email: Legal@theday.com

116"

Town of East Lyme
Inland Wetlands Agency
P.O. Box 519
Niantic, Connecticut 06357

December 19, 2019 Account #D20603

Advertising Department
The Day Publishing Co.
Eugene O'Neill Drive
New London, CT 06320

Please publish the following notice on January 15, 2020 and January 23, 2020

TOWN OF EAST LYME
INLAND WETLANDS AGENCY
Notice of Public Hearing

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Copies of specific proposals are available for public viewing in the Land Use Office.

Gary Upton, Chairman /gg

EAST LYME INLAND WETLAND AGENCY

APPLICATION REVIEW SHEET

Please return comments to Gary Goeschel, Wetlands Enforcement Officer

TITLE OF PLAN:	North Bride Brook Multi-Family Development, Prepared for Pazz & Construction LLC, by Yantic River Consultants, LLC, dated September 25, 2019
DATE RECEIVED:	11/22/2019
DATE DISTRIBUTED:	12/4/2019
REVIEW DEADLINE:	**12/13/2019**

	Reports	**Plans**
Victor Benni, Town Engineer	✓	✓
Brad Kargl, Utility Engineer		✓
Ray Hart, Fire Marshal		✓
William Mulholland, Zoning Official		✓

COMMENTS:
In general, this office finds the conceptual layout for the water & sewer utilities to be acceptable. This office will require detailed design plans, at which time, location of utility structures including hydrants, blowoffs, services and mains will be reviewed and may deviate from that shown on the plans.

REVIEWED BY: B. Karg DATE: 12/12/19

O:\Inland Wetlands Agency\Inland Wetlands Agency 2019\2019 Applications\N Bride Brook Rd MultiFam Development\Staff Review Sheet.doc

Ex "H"

EAST LYME INLAND WETLAND AGENCY

APPLICATION REVIEW SHEET

Please return comments to Gary Goeschel, Wetlands Enforcement Officer

TITLE OF PLAN:	North Bride Brook Multi-Family Development, Prepared for Pazz & Construction LLC, by Yantic River Consultants, LLC, dated September 25, 2019
DATE RECEIVED:	11/22/2019
DATE DISTRIBUTED:	12/4/2019
REVIEW DEADLINE:	**12/13/2019**

	Reports	**Plans**
Victor Benni, Town Engineer	✓	✓
Brad Kargl, Utility Engineer		✓
Ray Hart, Fire Marshal		✓
William Mulholland, Zoning Official		✓

COMMENTS:

application needs a zone change and affordable Housing development approval by the zoning Commission. also needs site plan approval. application will need a storm water management approval as well.

REVIEWED BY: WM DATE: 12/4/19

Ex "I"

O:\Inland Wetlands Agency\Inland Wetlands Agency 2019\2019 Applications\N Bride Brook Rd MultiFam Development\Staff Review Sheet.doc

HELLER, HELLER & McCOY
Attorneys at Law
736 Norwich-New London Turnpike
Uncasville, Connecticut 06382

Sidney F. Heller (1903-1986)
Harry B. Heller
William E. McCoy

Mary Gagne O'Donal

Telephone: (860)-848-1248
Facsimile: (860)-848-4003

RECEIVED
JAN 15 2020
TOWN OF EAST LYME
LAND USE

January 15, 2020

Town of East Lyme Inland Wetlands Agency
108 Pennsylvania Avenue
Niantic, CT 06357

Re: Pazz & Construction, LLC – North Bride Brook Multi-Family Development Wetlands Application

Gentleperson:

Enclosed herewith please find copies of notices which were forwarded to owners of properties located within 200 feet of the property for which the above referenced wetlands application has been filed. These notices have been provided to alert all neighboring property owners of the public hearing that has been scheduled for the above referenced application on January 27, 2020 at 7:00 p.m. in accordance with Section 9.2 of the East Lyme Zoning Regulations.

Also enclosed please find the United States Postal Service Certificate of Mailing – Firm form that has been stamped by the United States Postal Service evidencing that the notices were mailed on January 13, 2020, pursuant to the provisions of Section 9.2 of the East Lyme Zoning Regulations.

Very truly yours,

Harry B Heller

Harry B. Heller

HBH/rmb

Z:\Pazzaglia, Jason\East Lyme Wetlands\ltr.Town re notices.doc

"Ex J"

UNITED STATES
POSTAL SERVICE®

Certificate of Mailing — Firm

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Turnpike Uncasville, Connecticut
06382

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TOTAL NO. of Pieces Received at Post Office™: 8

Postmaster, per (*name of receiving employee*)

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USPS® Tracking Number Firm-specific Identifier	Address (Name, Street, City, State, and ZIP Code™)	Postage	Fee	Special Handling	Parcel Airlift
1.	Ms. Geraldine J. Dzwilewski 90 North Bride Brook Road East Lyme, CT 06333	.55	.41		
2.	Ms. Margaret Berry Balon 86 North Bride Brook Road Niantic, CT 06357	.55	.41		
3.	State of Connecticut NCI & JB Gates Prison 199 West Main Street Niantic, CT 06357	.55	.41		
	Ms. Alice T. Welsh 102 North Bride Brook Road Niantic, CT 06357	.55	.41		
5.	Ms. Alice T. Welsh 102 North Bride Brook Road Niantic, CT 06357	.55	.41		
6.	Mr. William C. Brown P.O. Box 863 Niantic, CT 06357	.55	.41		

PS Form **3665**, January 2017 (Page 1 of 2) PSN 7530-17-000-

See Reverse for Instructions

UNITED STATES POSTAL SERVICE

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UNCASVILLE CT 06382-9998
JAN 2020
USPS

USPS® Tracking Number Firm-specific Identifier	Address (Name, Street, City, State, and ZIP Code™)	Postage	Fee	Special Handling	Parcel Airlift
7.	State of Connecticut Department of Environmental Protection 79 Elm Street Hartford, CT 06106	.55	.41		
8.	Pazz & Construction, LLC Attn: Mr. Jason Pazzaglia 21 Darrows Ridge Road East Lyme, CT 06333	.55	.41		

YRC
YANTIC RIVER
CONSULTANTS, LLC

RECEIVED
JAN 21 [illegible]
TOWN OF EAST LYME
LAND USE

COMMENT RESPONSE SUMMARY

FROM: **Victor Benni, P.E., Town Engineer**
DATE: **December 13, 2019**
RE: **North Bride Brook Multi-Family Development, Wetlands Application Review**

1. The Wetland Report indicates that the proposed development in the upland review area will not be disturbing any wetlands and/or watercourses on the site.

   Response. Confirmed.

2. Bride Brook and the un-named tributary to Bride brook are both listed with the CT DEEP as being "impaired" waterbodies. The construction and long-term operations & maintenance components of the stormwater management system should be strictly adhered to.

   Response. Noted and agree.

3. As indicated in the Wetlands Report, "All of the wetland areas are classified as a forested wetland general classification. Its functions include: groundwater recharge and discharge, sediment stabilization, nutrient removal and transformation, product export, and wildlife diversity." The Application Narrative indicates that the project engineer has provided for roof top runoff from Buildings I, J, & M to be discharged to the westerly corner of each building in order to replicate the existing flows which currently reach and contribute to the recharge of the wetland system associated with Bride Brook.

   Response. Confirmed.

4. Catch basin #'s 313, 315, & 324 shall be equipped with 4' deep sumps and hooded outlets.

   Response. Per our conversation, the overall collection network was evaluated to determine which basins warrant deeper sumps and trap hoods. Catch basins #302, 313, 319 and 324 are the final open-top structures of each intermediate pipe run. These basins were selected as the appropriate structures for 4' sumps and labeled accordingly. All other catch basins will have a 2' deep sump. Drainage note 3B was also added to Sheet 3 for clarity.

5. A landscaping/planting plan should be considered for the developed area between the Limit of Proposed Tree Clearing and the Secondary Access Drive; between the Cul-de-sac and Building M. A proposed tree line and understory should be established up to the edge of the two parking areas and the Secondary Access Drive.

   Response. Proposed landscaping within the 100' Upland Review Area was added to Sheet 2 along the westerly clearing limit parallel with the inland wetlands. The proposed landscaping consists of seeding the bordering upland areas with New England Wetland Plants 'Conservation/wildlife mix'. Once properly established, this seed mix creates a native vegetated buffer that requires no fertilization and minimal maintenance or mowing.

6. The Erosion & Sediment Control Plan (Sheet 5), and the Details (Sheets 6 & 7) are in compliance with the 2002 Connecticut Guidelines for Soil Erosion and Sediment Control. The Sequence of Construction and E&S Control Narrative notes on Sheet 5 proposed that the

Ex. "K"

project will be completed in multiple phases. Inspection and Maintenance notes along with the Temporary Sediment Trap sizing and detail have also been included. Provide correction of numbering system for Drawing Set, Sheet Numbers 6 & 7.

Response. The Sheet Numbers have been corrected as requested.

7. The Project Narrative calls for all erosion and sediment control measures to be inspected at least twice weekly during construction and following storm events resulting in excess of 0.1" of precipitation. The Wetlands Agency may wish to consider that weekly or monthly reposts be submitted to the East Lyme Wetlands Agent during construction; on a weekly or monthly basis.

Response. The project will be registered with the CT DEEP. This registration will include the preparation and implementation of a Stormwater Pollution Control Plan, which includes a requirement for routine inspections and reports. The weekly reports will be transmitted to the Town Wetland Enforcement Officer on a monthly basis.

8. The results of the 5 soil test pits in the vicinity of the water quality-detention basin shall be provided for review to the East Lyme Engineering Department. Construction of the water-quality-detention basin requires an approximate 5' cut into existing grades. The CT DEEP 2004 Connecticut Stormwater Quality Manual (11-P3-3) recommends that the bottom of the infiltration facility be located at least 3 feet above seasonally high-water table or bedrock.

Response. The results of the soil testing have been added to Sheet 3 of the revised plan set. The first round of testing performed on 7/25/19 consisted of test pits excavated to a depth of 7'-8' below existing grade. Groundwater or ledge was not witnessed. Soils below the water quality-detention basin consisted of fine sandy loam (trace silt) over medium to coarse sands and gravels. Falling head permeability tests were conducted on the sands & gravels with an average calculated permeability of 55 to 85 ft/day. The calculated values exceed the NRCS published rate of 25 ft/day for the Haven silt loam soils.

On 1/14/20, 2 additional pits were excavated to a depth of 9'-10'. Groundwater was witnessed at a depth of 114" in TP7, which is 4.5' below the bottom of basin. Standpipes were installed to allow for monitoring.

Given the depth to witnessed groundwater, it is our opinion that sufficient separation has been provided between the bottom of basin and seasonally high groundwater. In addition, to minimize the potential for long-term standing water, a granular filter material and moist site conservation seed mix has been specified for the basin bottom to promote infiltration.

9. The CT DOT Drainage Manual (October 2000) recommends that for quantity purposes, dry detention basins shall be designed to be able to pass a 100-year storm safely (Chapter 10.11-2). This is to ensure that the embankment will not be damaged or fail during the passage of the 100-year storm. In addition, the Manual indicates that the crest of the outlet control structure be set to a minimum of 1 foot below the crest of the emergence spillway, that 1 foot of freeboard be provided between the 100-year storm and the top of the embankment elevations, and 4:1 side slope maintenance access. This criteria should be incorporated into the stormwater management, calculations, design plans, and details for the water quality-detention basin.

Response. A berm will be constructed along the southern and eastern perimeter of the basin to provide a minimum of 1' of freeboard. In addition, a riprap emergency spillway has been added to divert overflow from storms in excess of 100-year towards a secondary overflow catch basin.

10. The stormwater management report verifies that the proposed detention pond attenuates peak flow rates and volumes as compared to the pre-development conditions, resulting in a zero-net increase in runoff from the development.

    Response. Confirmed.

11. An Erosion and Sedimentation bond should be reviewed by the Engineering Department, following the Wetland Agency's determination as to the addition of the potential planting plan in the upland review area and the decision whether or not to require a submittal of weekly/monthly E&S inspection reports.

    Response. A bond estimate spreadsheet is included for erosion and sedimentation controls and restoration activities to be performed within the 100' upland review area.

WESTLEDGE APARTMENT COMMUNITY
2 WESTLEDGE DRIVE
BOND ESTIMATE

BOND QUANTITIES FORM

Project Name: NORTH BRIDE BROOK MULTI-FAMILY DEV.
Address: NORTH BRIDGE BROOK ROAD, EAST LYME, CT
Bond Amount: $28,000.00
Project No.: 00057-00001
Bond Type: E&S CONTROL - IWA ONLY

Owner/Developer: PAZZ & CONSTRUCTION, LLC
Address: 21 DARROWS RIDGE ROAD
EAST LYME, CT 06333
Phone # (860) 961-2364

ITEM NO.	ITEM DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	ITEM AMOUNT
1	Clearing and Grubbing	1.30	ACRE	$2,000.00	$2,600.00
2	Anti-Tracking Pad	1.00	EA	$1,500.00	$1,500.00
3	Sedimentation Control System	1,000.00	LF	$5.00	$5,000.00
4	Sedimentation Control at Catch Basin	4.00	EA	$100.00	$400.00
5	Erosion Control Blanket	3,000.00	SF	$1.50	$4,500.00
6	Riprap Splash Pad @ Roof Leaders	10.00	EA	$200.00	$2,000.00
7	Restoration of Lawn Areas	2,000.00	SY	$3.00	$6,000.00
8	Wildlife/Conservation Areas	1,500.00	SY	$4.00	$6,000.00
				SUBTOTAL	**$28,000.00**

Town of East Lym

P.O. DRAWER 519 NIANTIC, CONNECTICUT 06357

Town Engineer
Victor A. Benni, P.E.

860-691-4112
FAX 860-739-6930

To: Gary A. Goeschel II, Director of Planning

From: Victor Benni, P.E., Town Engineer

Date: January 27, 2020

Re: North Bride Brook Multi-Family Development
Wetlands Application Review

Information submitted by the Applicant which was considered in this review:

- (Drawing Set) North Bride Brook Multi-Family Development, Prepared for: Pazz & Construction, LLC, East Lyme, CT, 7-Sheet Drawing Set, Date: 9/25/19, Revised: 01/15/20, By: Yantic River Consultants, LLC.
- (Wetlands Report) Inland Wetland Soils and Watercourses Investigation, And Delineation, North Bride Brook Multi-Family Development, North Bride Brook Road, East Lyme, CT, Date: October 3, 2019, By: James Sipperly, Certified Soil Scientist.
- Application Narrative, Application of Pazz & Construction, LLC, North Bride Brook Multi-Family Residential Development, North Bride Brook Road, East Lyme, Connecticut, Date: November 22, 2019.
- Stormwater Management Report, North Bride Brook Multi-Family Development, North Bride Brook Road, East Lyme, CT, Prepared for: Pazz & Construction, LLC, Date November 1, 2019, By: Yantic River Consultants, LLC.
- Bond Quantities Form, North Bridebrook Multi-Family Dev., E&S Control – IWA Only, Received by Land Use Department: 01/21/20.

This office has reviewed the above referenced information and has the following comments in regard to that portion of the development pertaining to the Wetlands and the 100' Upland Review Area:

1. The Wetland Report indicates that the proposed development in the upland review area will not be disturbing any wetlands and/or watercourses on the site.

2. Bride Brook and the un-named tributary to Bride Brook are both listed with the CT DEEP as being "impaired" water bodies. The construction and long-term operations & maintenance components of the stormwater management system should be strictly adhered to.

3. As indicated in the Wetlands Report, "All of the wetland areas are classified as a forested wetland general classification. Its functions include: groundwater recharge and discharge, sediment stabilization, nutrient removal and transformation, product export, and wildlife diversity." The Application Narrative providing for roof top runoff from Buildings I, J & M to be discharged to the westerly corner of each building should be adhered to in order to replicate the existing flows which currently reach and contribute to the recharge of the wetland system associated with Bride Brook.

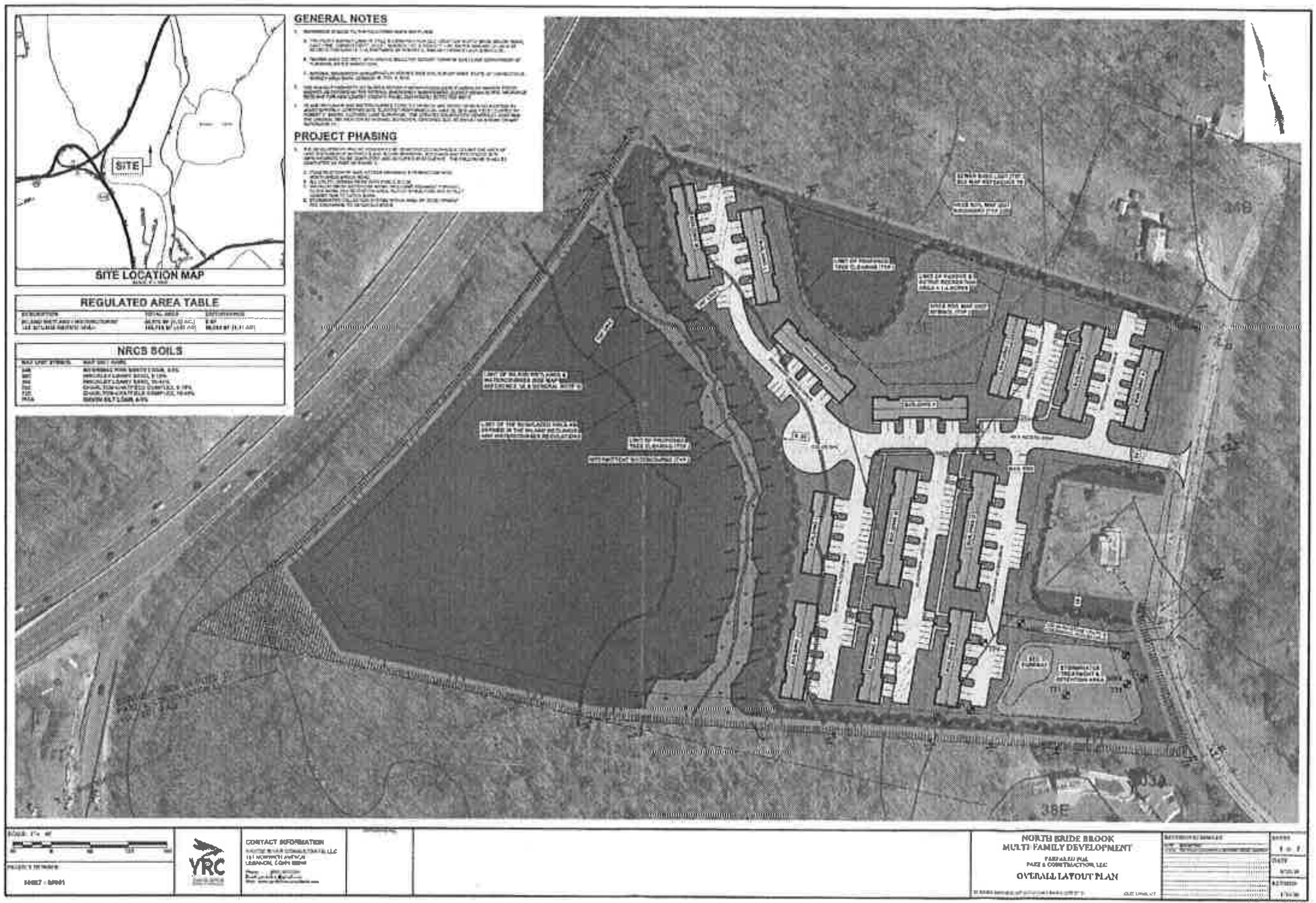
Ex "L"

4. The Erosion & Sedimentation Control Plan (Sheet 5) and the Details (Sheets 6 & 7) provide compliance with the 2002 Connecticut Guidelines for Soil Erosion and Sediment Control. The Sequence of Construction and E&S Control Narrative notes (Sheet 5) propose that the project will be completed in multiple phases; Inspection and Maintenance notes along with Temporary Sediment Trap sizing and detail have also been included.

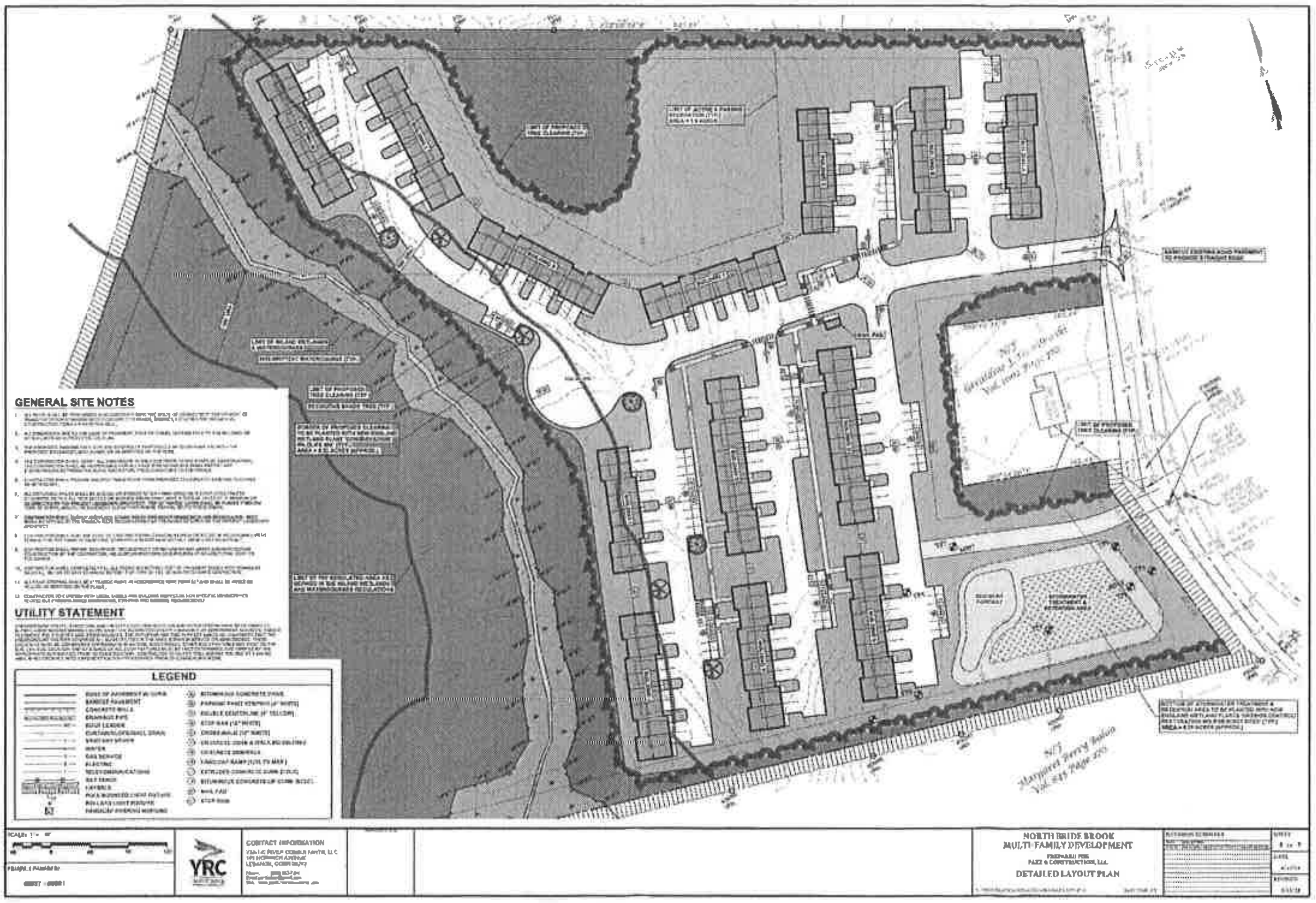
5. The Project Narrative calls for all erosion & sediment control measures to be inspected at least twice weekly during construction and following storm events resulting in excess of 0.1" of precipitation. The Wetlands Agency may wish to consider that the weekly reports required by the CT DEEP Stormwater Pollution Control Plan be submitted to the East Lyme Wetlands Agent.

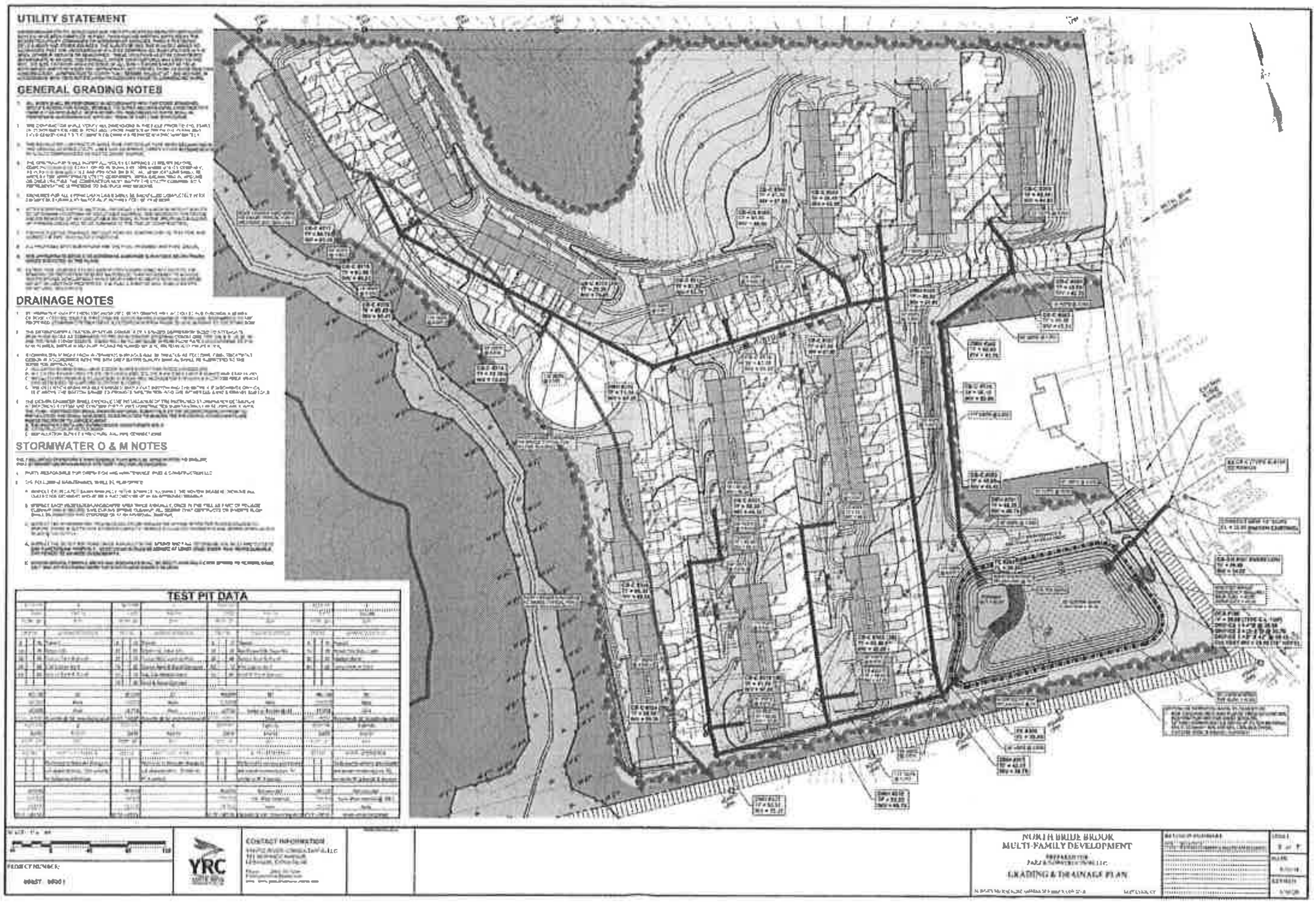
6. The Stormwater Management Report verifies that the proposed detention pond attenuates peak flow rates and volumes as compared to the pre-development conditions, resulting in a zero-net increase in runoff from the development.

7. The East Lyme Engineering Department recommends that the Wetlands Agency consider an Erosion & Sedimentation (E&S) bond in the amount of $30,000 for the installation & maintenance of the E&S control measures.


GENERAL NOTES
PROJECT PHASING
SITE LOCATION MAP
SITE
REGULATED AREA TABLE
NRCS SOILS
34B
73E
38E
STORMWATER TREATMENT & DETENTION AREA
CONTACT INFORMATION
YRC
NORTH BRIDE BROOK
MULTI FAMILY DEVELOPMENT
OVERALL LAYOUT PLAN

Ex "M"


GENERAL SITE NOTES
UTILITY STATEMENT
LEGEND
CONTACT INFORMATION
YRC
NORTH BRIDE BROOK
MULTI-FAMILY DEVELOPMENT
PREPARED FOR
FAZZ & CONSTRUCTION, LLC
DETAILED LAYOUT PLAN


UTILITY STATEMENT
GENERAL GRADING NOTES
DRAINAGE NOTES
STORMWATER O & M NOTES
TEST PIT DATA
PROJECT NUMBER:
YRC
CONTACT INFORMATION
NORTH BRIDE BROOK
MULTI-FAMILY DEVELOPMENT
PREPARED FOR
GRADING & DRAINAGE PLAN
EAST LYME, CT

UTILITY STATEMENT

[illegible]

GENERAL UTILITY NOTES

[illegible]

WATER

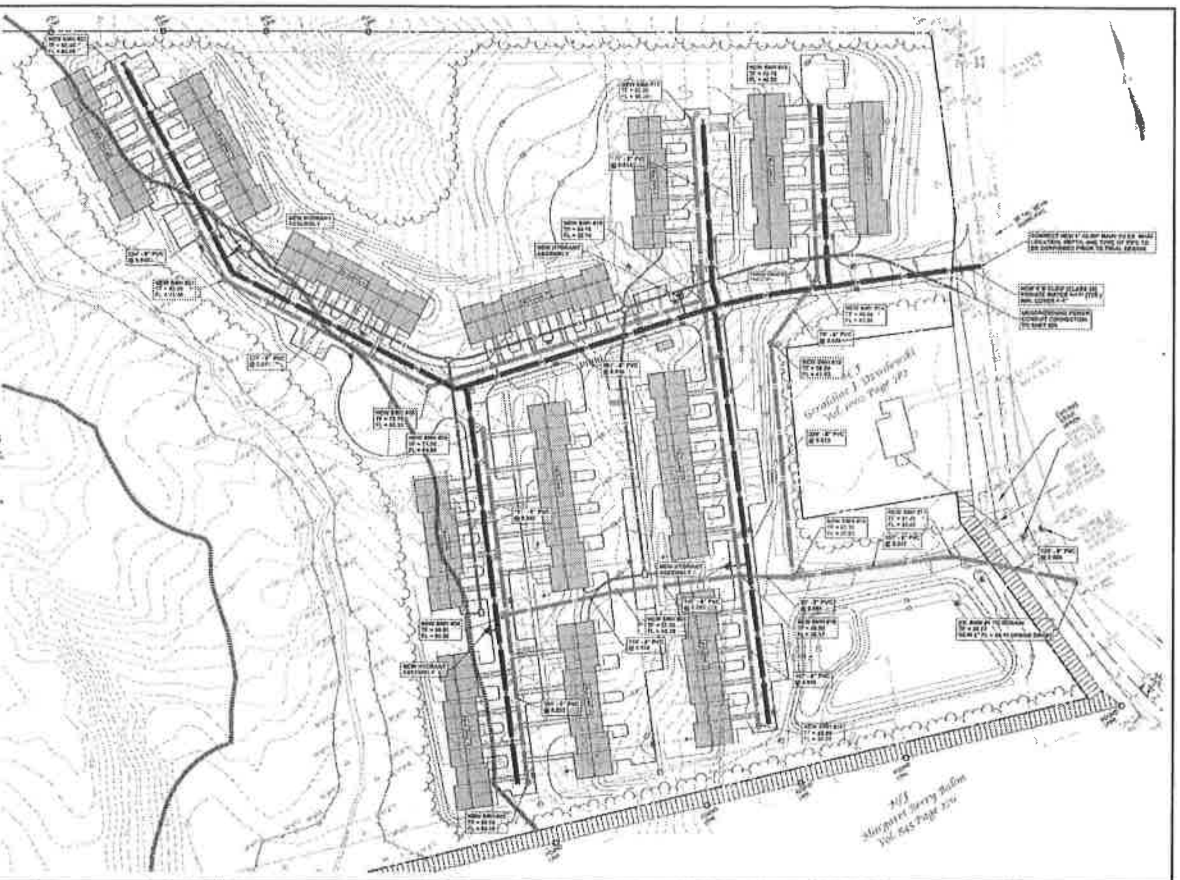
[illegible]

SANITARY

[illegible]

ELECTRIC & TELECOMMUNICATIONS

[illegible]



SCALE: 1" = 40'

PROJECT NUMBER
00657 - 00001

CONTACT INFORMATION
YANTIC RIVER CONSULTANTS LLC

NORTH BRIDE BROOK
MULTI-FAMILY DEVELOPMENT

PREPARED FOR

UTILITY PLAN

REVISION SUMMARY

SHEET
4 of 7

DATE

REVISED

GENERAL CONSTRUCTION NOTES:

1. [illegible]
2. [illegible]

SEQUENCE OF CONSTRUCTION:

1. [illegible]
2. [illegible]

[illegible]

E & S CONTROL NARRATIVE:

[illegible]

E & S CONTROL PLAN:

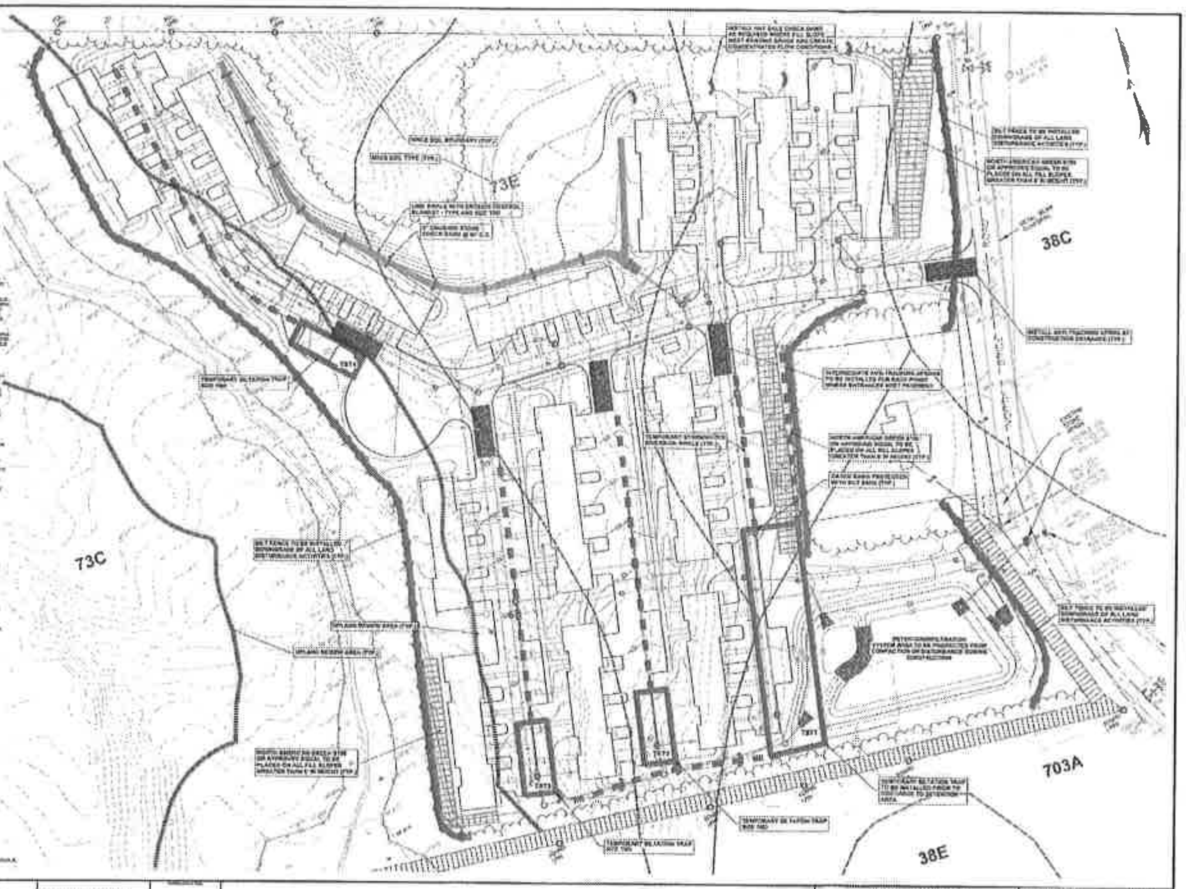
[illegible]

E & S CONTROL NOTES:

[illegible]

INSPECTION AND MAINTENANCE:

[illegible]



SCALE: 1" = 40'

PROJECT NUMBER:

CONTACT INFORMATION

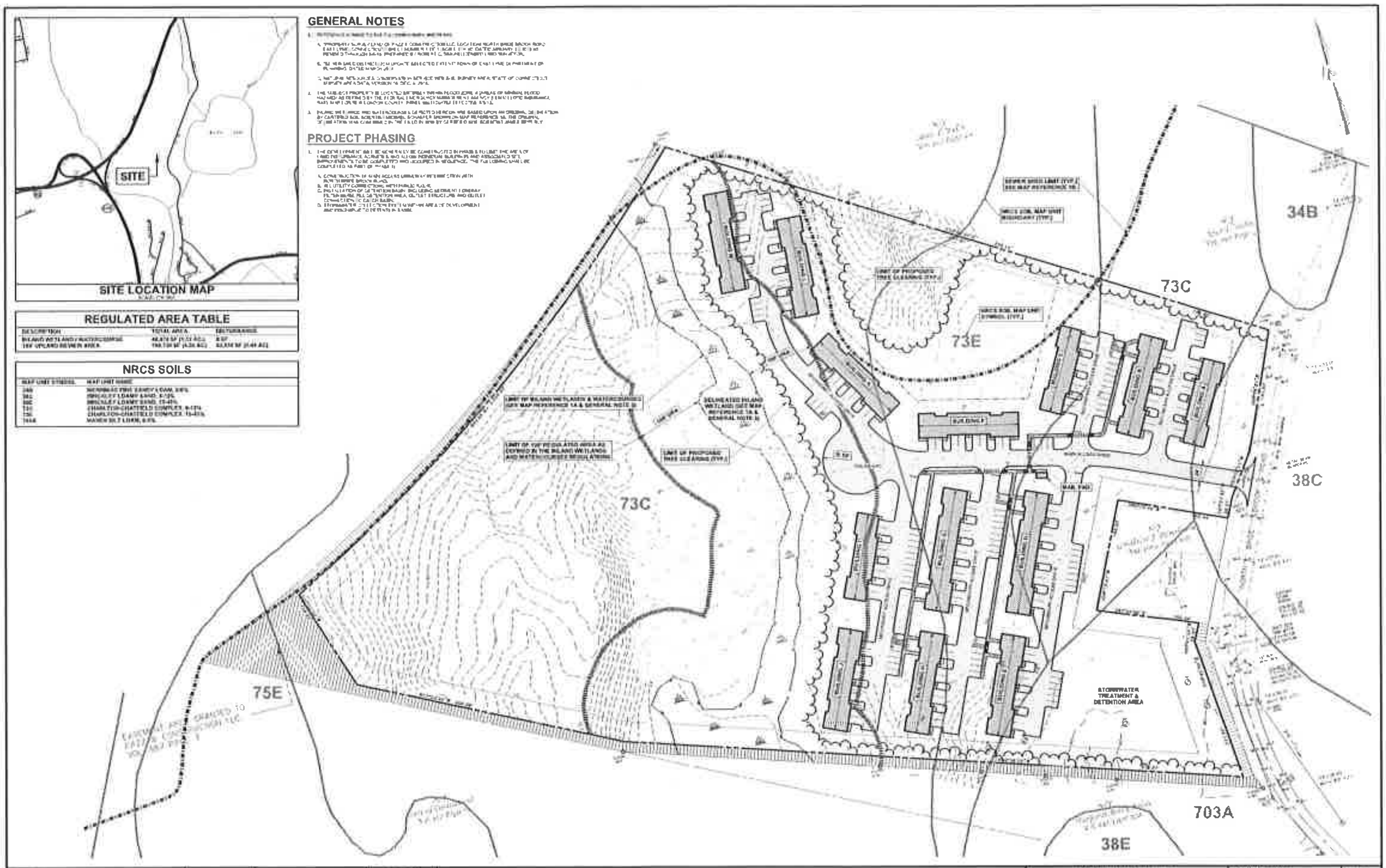
YANTIC RIVER CONSULTANTS, LLC

NORTH BRIDE BROOK
MULTI-FAMILY DEVELOPMENT
PREPARED FOR
[illegible] CONSTRUCTION, LLC
EROSION & SEDIMENTATION CONTROL PLAN

SHEET

DATE

REVISED



GENERAL NOTES

PROJECT PHASING

SITE LOCATION MAP

REGULATED AREA TABLE

DESCRIPTION	TOTAL AREA	DISTURBANCE
INLAND WETLAND / WATERCOURSE	[illegible] SF (1.12 AC)	0 SF
100' UPLAND REVIEW AREA	[illegible] SF (4.3[illegible] AC)	[illegible] SF (1.46 AC)

NRCS SOILS

MAP UNIT SYMBOL	MAP UNIT NAME
[illegible]	MERRIMAC FINE SANDY LOAM, 3-8%
38C	HINCKLEY LOAMY SAND, 3-15%
38E	HINCKLEY LOAMY SAND, 15-45%
73C	CHARLTON-CHATFIELD COMPLEX, 3-15%
73E	CHARLTON-CHATFIELD COMPLEX, 15-45%
[illegible]	HAVEN SILT LOAM, 0-3%

SCALE: 1" = 60'

PROJECT NUMBER

00057 - 0000[illegible]

YRC

CONTACT INFORMATION
YANTIC RIVER CONSULTANTS, LLC
181 NORWICH AVENUE
LEBANON, CONN 06249

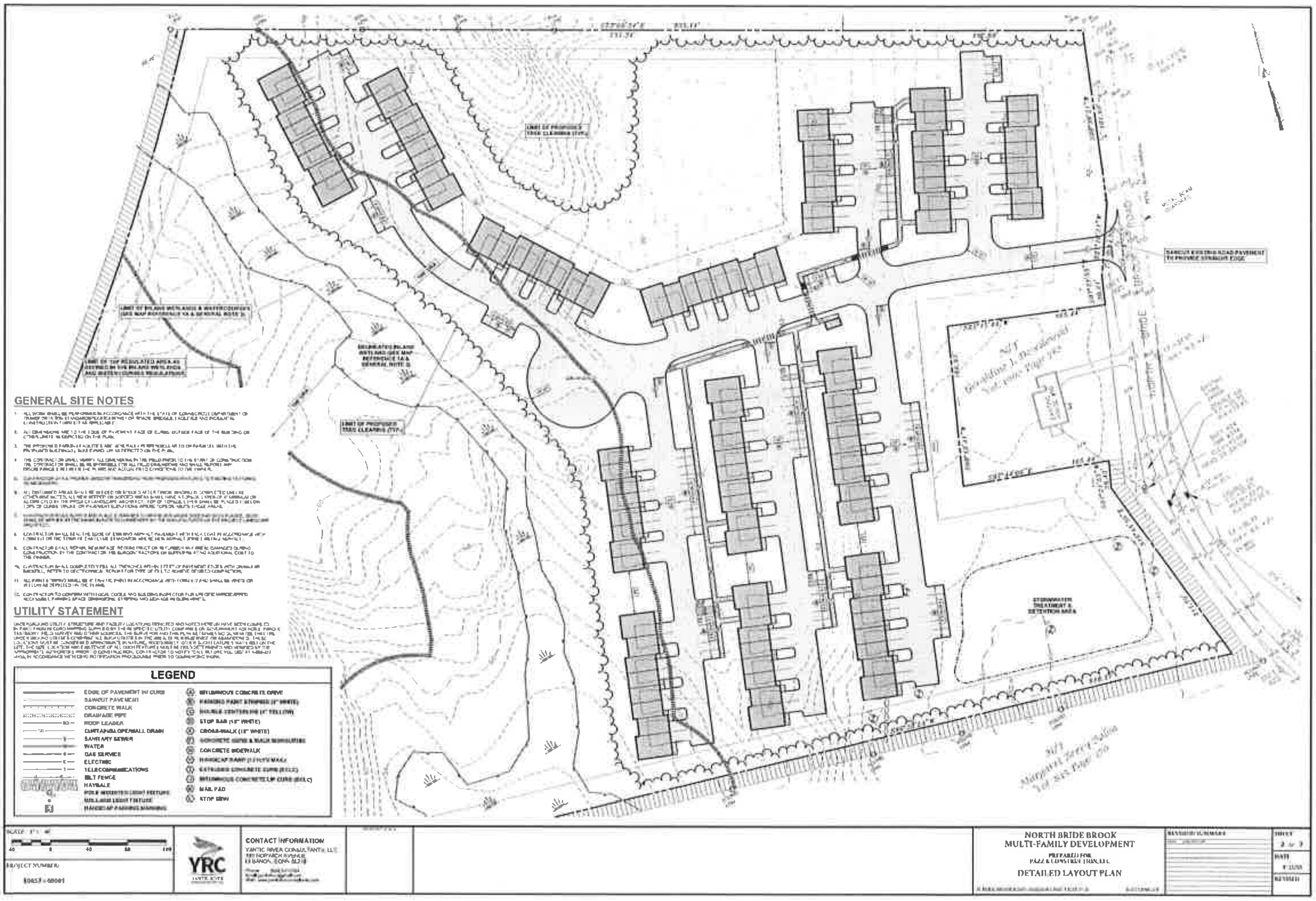
NORTH BRIDE BROOK
MULTI-FAMILY DEVELOPMENT
PREPARED FOR
PAZZ & CONSTRUCTION LLC
OVERALL LAYOUT PLAN

REVISION SUMMARY

SHEET
1 of 1

DATE

REVISION


LIMIT OF PROPOSED TREE CLEARING (TYP.)
LIMIT OF INLAND WETLANDS & WATERCOURSES (SEE MAP REFERENCE 1A & GENERAL NOTE 3)
LIMIT OF 100' REGULATED AREA AS DEFINED IN THE INLAND WETLANDS AND WATERCOURSES REGULATIONS
DELINEATED INLAND WETLAND SEE MAP REFERENCE 1A & GENERAL NOTE 3
LIMIT OF PROPOSED TREE CLEARING (TYP.)
SAWCUT EXISTING ROAD PAVEMENT TO PROVIDE STRAIGHT EDGE
STORMWATER TREATMENT & DETENTION AREA
N/F Margaret Terry Salas
GENERAL SITE NOTES
UTILITY STATEMENT
LEGEND
EDGE OF PAVEMENT W/ CURB
SAWCUT PAVEMENT
CONCRETE WALK
DRAINAGE PIPE
ROOF LEADER
CURTAIN/LOOP/WALL DRAIN
SANITARY SEWER
WATER
GAS SERVICE
ELECTRIC
TELECOMMUNICATIONS
SILT FENCE
HAYBALE
POLE MOUNTED LIGHT FIXTURE
BOLLARD LIGHT FIXTURE
HANDICAP PARKING MARKING
A BITUMINOUS CONCRETE DRIVE
PARKING PAINT STRIPING (4" WHITE)
C DOUBLE CENTERLINE (4" YELLOW)
STOP BAR (18" WHITE)
CROSS-WALK (18" WHITE)
CONCRETE CURB & WALK MONOLITHIC
CONCRETE SIDEWALK
HANDICAP RAMP
EXTRUDED CONCRETE CURB (ECC)
BITUMINOUS CONCRETE LIP CURB (BCLC)
MAIL PAD
STOP SIGN
SCALE: 1" = 40'
40
0
40
80
100
PROJECT NUMBER:
10457 - 00001
YRC
CONTACT INFORMATION
YANTIC RIVER CONSULTANTS, LLC
NORWICH AVENUE
LEBANON, CONN. 06249
NORTH BRIDE BROOK
MULTI-FAMILY DEVELOPMENT
PREPARED FOR
PAZZ & CONSTRUCTION, LLC
DETAILED LAYOUT PLAN
REVISION SUMMARY
SHEET
2 of 3
DATE
REVISED

UTILITY STATEMENT

[illegible]

GENERAL GRADING NOTES

[illegible]

DRAINAGE

[illegible]

STORMWATER O & M NOTES

[illegible]

SCALE: 1" = 40'

PROJECT NUMBER

00057 - 00001

YRC

CONTACT INFORMATION

YANTIC RIVER CONSULTANTS, LLC

[illegible] NORWICH AVENUE

LEBANON, CONN 06249

NORTH BRIDE BROOK
MULTI-FAMILY DEVELOPMENT

PREPARED FOR
PAAZ & CONSTRUCTION, LLC

GRADING & DRAINAGE PLAN

REVISION SUMMARY

SHEET

1 of 1

DATE

REVISED

UTILITY STATEMENT

[illegible]

GENERAL UTILITY NOTES

[illegible]

WATER

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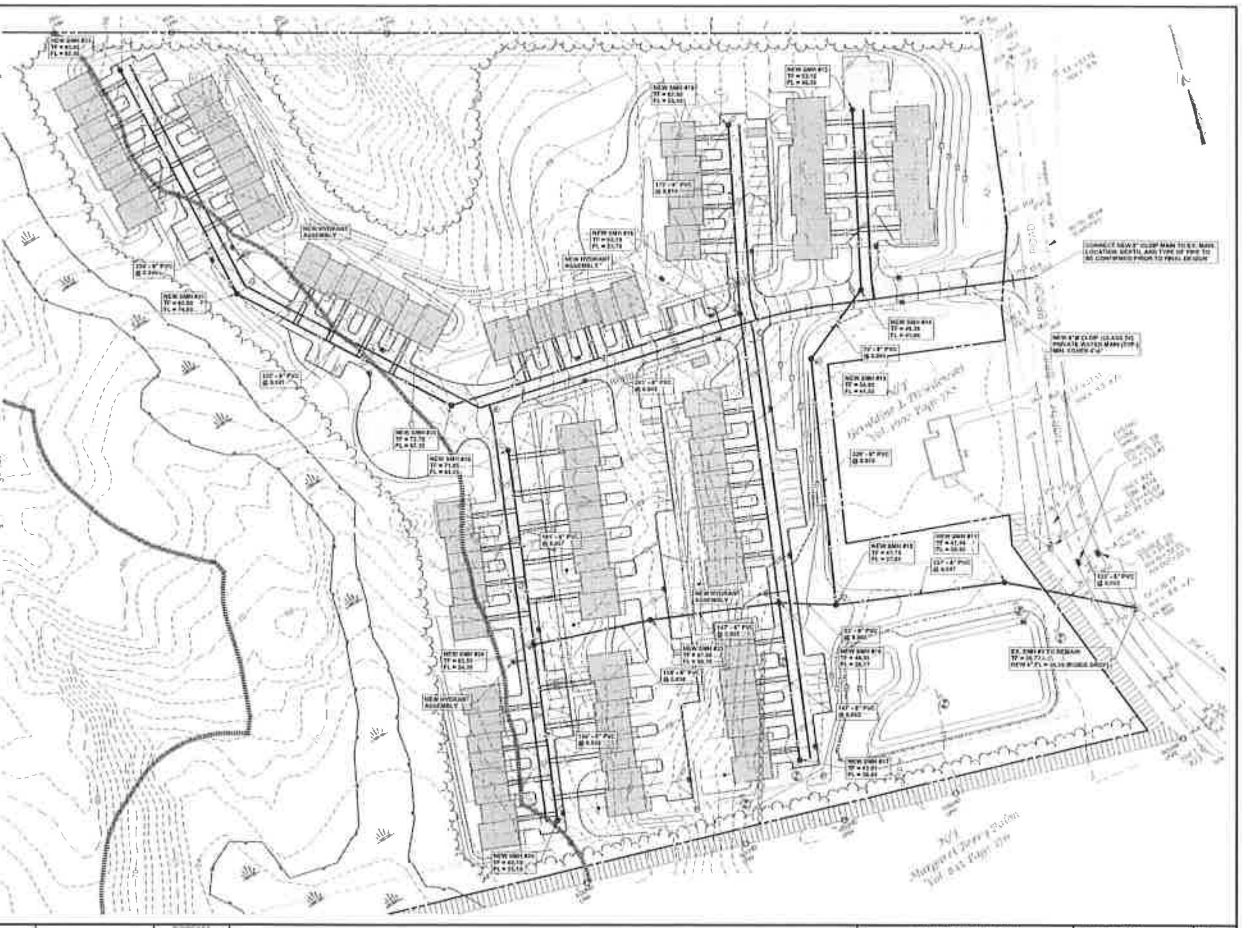
SANITARY

[illegible]

ELECTRIC & TELECOMMUNICATIONS

[illegible]



SCALE: 1" = 40'

PROJECT NUMBER

00057 - 00001

YRC

CONTACT INFORMATION

YANTIC RIVER CONSULTANTS, LLC
181 NORWICH AVENUE
LEBANON, CONN 06249

NORTH BRIDE BROOK
MULTI-FAMILY DEVELOPMENT
PREPARED FOR
FAZZA CONSTRUCTION LLC

UTILITY PLAN

SHEET
4 of 7

DATE

REVISION

GENERAL CONSTRUCTION NOTES:

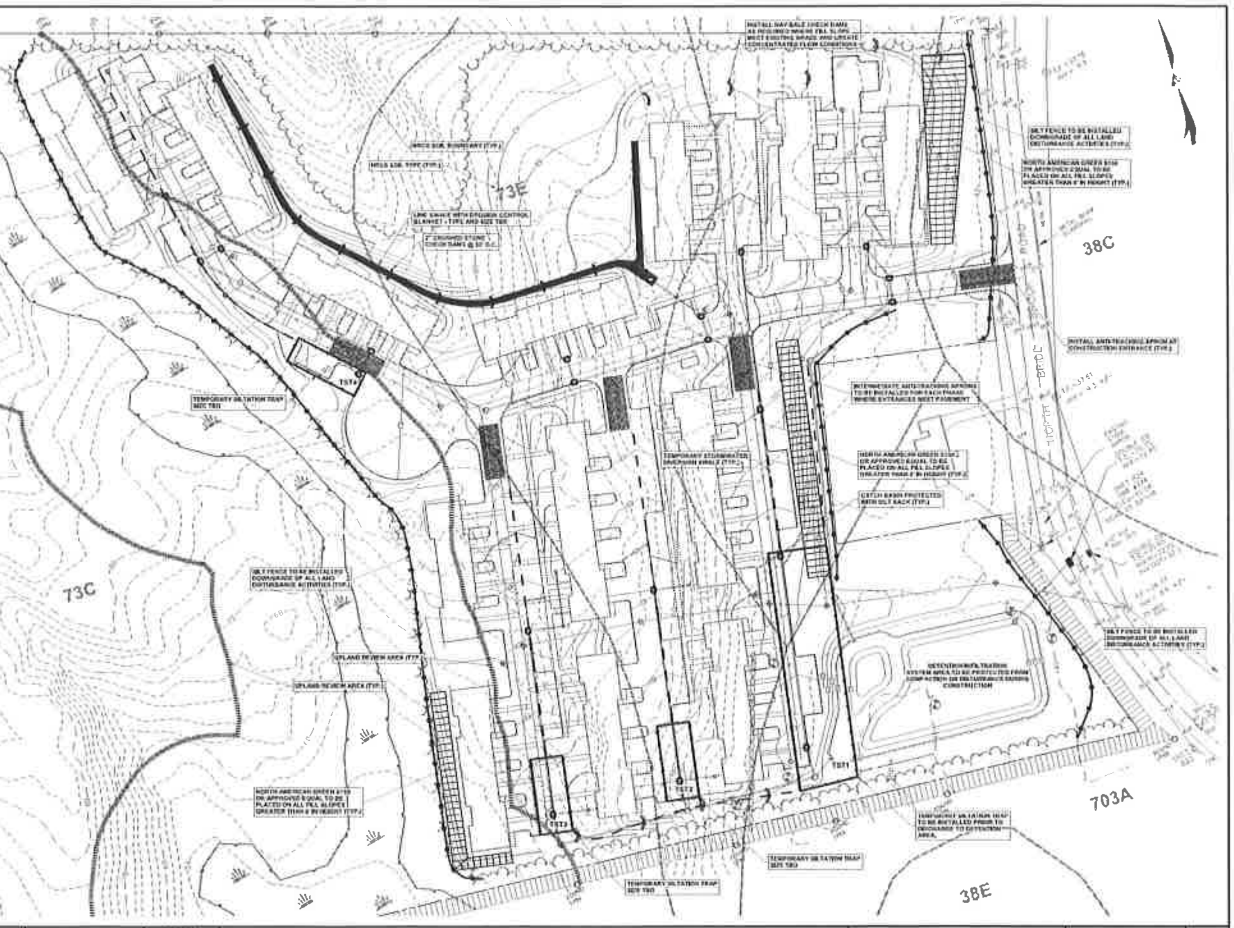
SEQUENCE OF CONSTRUCTION:

E & S CONTROL NARRATIVE:

E & S CONTROL PLAN:

E & S CONTROL NOTES:

INSPECTION AND MAINTENANCE:



SCALE: 1" = 40'

40 0 40 80 120

PROJECT NUMBER:
00057 - 00001

YRC

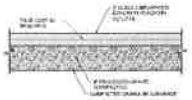
CONTACT INFORMATION
YANTIC RIVER CONSULTANTS, LLC
151 NORWICH AVENUE
LEBANON, CONN 06249

NORTH BRIDE BROOK
MULTI-FAMILY DEVELOPMENT
PREPARED FOR
FAZZ & CONSTRUCTION, LLC
EROSION & SEDIMENTATION CONTROL PLAN

REVISION SUMMARY

SHEET
5 of 7

DATE



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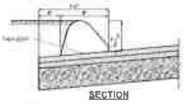

SECTION

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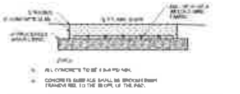

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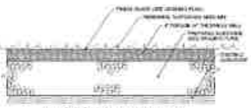

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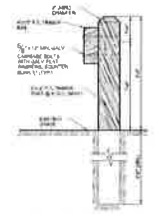

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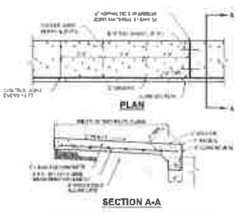

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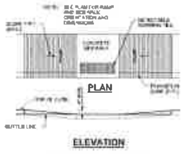

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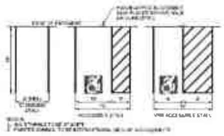

PARKING STALL DETAILS

NOT TO SCALE

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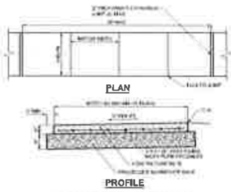
NOT TO SCALE



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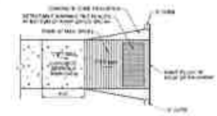

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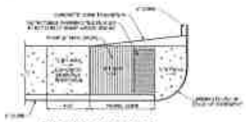

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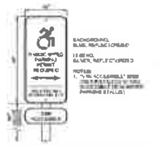

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NOT TO SCALE

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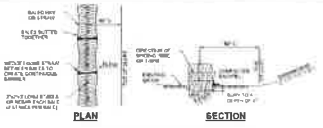

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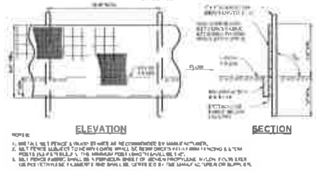

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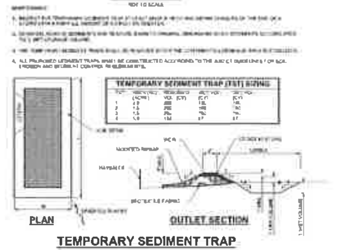

TEMPORARY SEDIMENT TRAP

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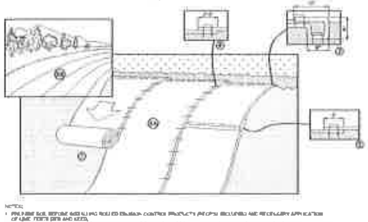

EROSION CONTROL BLANKET SLOPE INSTALLATION

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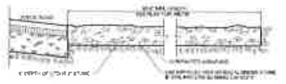
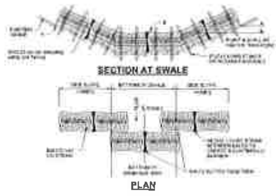


ANTI-TRACKING PAD DETAIL

NOT TO SCALE

SOIL STOCKPILE DETAIL

NOT TO SCALE



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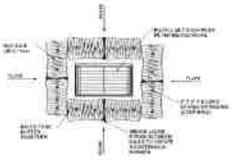

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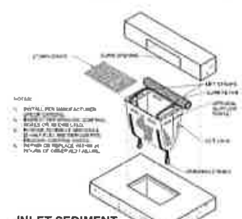


INLET SEDIMENT CONTROL DEVICE

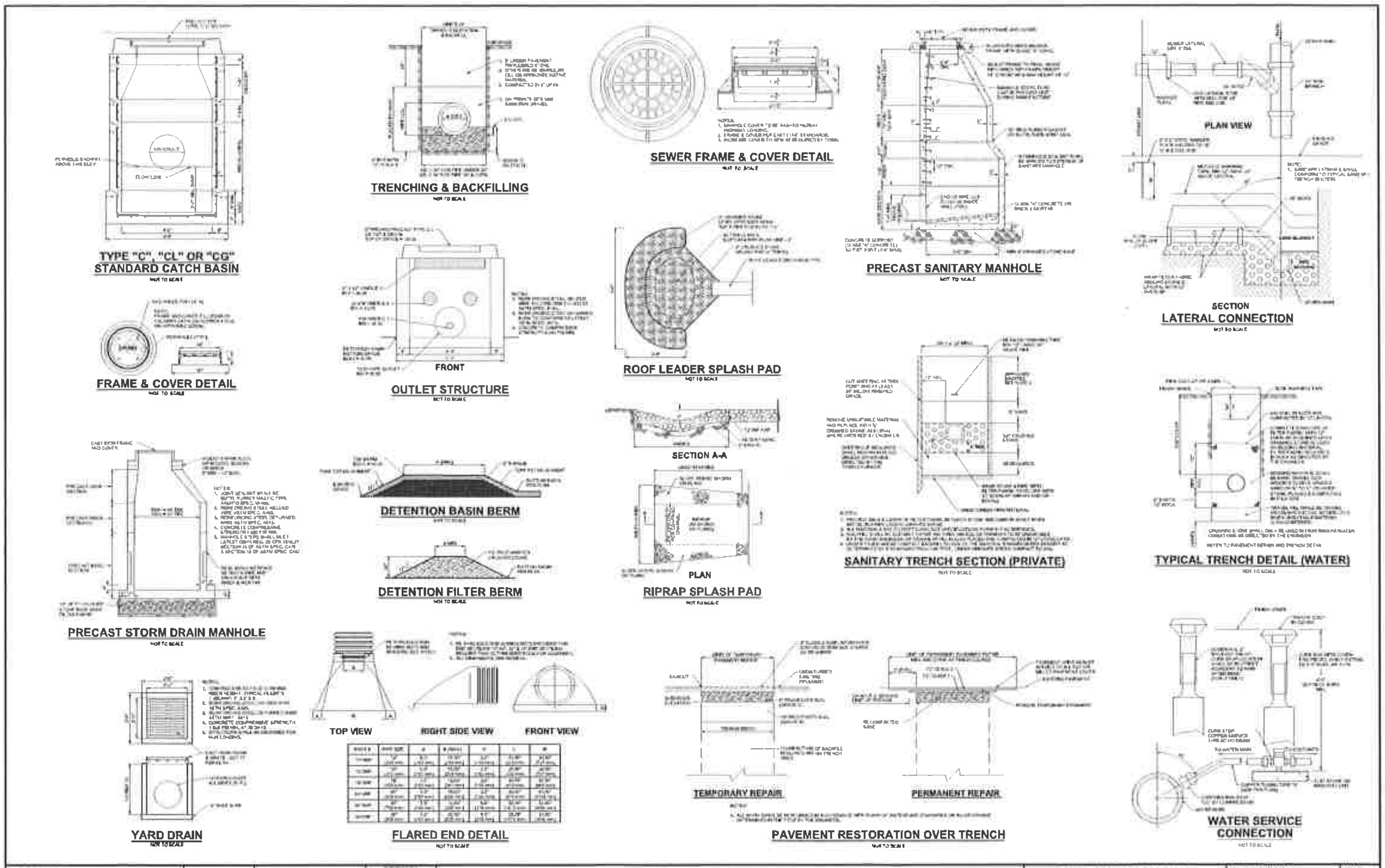
NOT TO SCALE

PROJECT NUMBER:
00057 - 00001

YRC

CONTACT INFORMATION

NORTH BRIDE BROOK ROAD
MULTI-FAMILY DEVELOPMENT
PREPARED FOR
PAZZ & CONSTRUCTION LLC
DETAILS



SCALE: AS SHOWN

PROJECT NUMBER:
00857 - 00001

YRC

CONTACT INFORMATION
YANTIC RIVER CONSULTANTS, LLC
181 NORWICH AVENUE
LEBANON, CONN 06249

NORTH BRIDE BROOK ROAD
MULTI-FAMILY DEVELOPMENT
PREPARED FOR
PAZZ & CONSTRUCTION LLC
DETAILS

REVISION SUMMARY

SHEET
7 OF 7

DATE

REVISION

Town of East Lyme

P.O. Drawer 519
Department of Planning &
Inland Wetlands Agency
Gary A. Goeschel II, Director of Planning /
Inland Wetlands Agent

108 Pennsylvania Ave
Niantic, Connecticut 06357
Phone: (860) 691-4114
Fax: (860) 860-691-0351

MEMORANDUM

To: **East Lyme Inland Wetlands Agency**

From: **Gary A. Goeschel II, Director of Planning/ Inland Wetlands Agent**

Date: **May 18, 2020**

RE: **Inland Wetlands Application – Application of Glenn Knowles, Applicant/Owner,** for the proposed construction of a patio, correction of water runoff and wetlands restoration at property identified as 21 Brightwater Road, Niantic, East Lyme Assessor's Map 5.L9, lot 58.

In regards to the above referenced application, the East Lyme Inland Wetlands Agency at a meeting held on Monday, February 24, 2020, at the East Lyme Town Hall, 108 Pennsylvania Avenue, Niantic, Connecticut, directed me to prepare a draft motion for the above referenced application for discussion and a resolution at their next regularly scheduled meeting which was to be held on March 9, 2020. Unfortunately, due to extenuating circumstance the Agency canceled the meeting and set a Special Meeting to discuss the items that were initially scheduled for the March 9, 2020 Meeting. Subsequently, the Town of East Lyme was forced to close its doors to the public as a result of the COVID-19 Pandemic. As a result, the Inland Wetlands Agency has been unable to meet in a public forum to render a final decision on your application. As such, upon discussing the matter with the Inland Wetlands Agency Chairman, Gary Upton, the Vice Chair, Kristen Chantrell, and First Selectman, Mark Nickerson, it was agreed that I, as Agent for the Commission, would approve the proposed work within the upland review area as it will still be consistent with State Statutes and the East Lyme Inland Wetland and Watercourses Regulations. Upon the opening of the Town Hall to the public or the establishment of virtual meetings pursuant to the criteria provided in the Governor's Executive Orders, the Agency will then be able to act on the portion of work within the on-site inland wetlands.

As such, only the portion of work within the 100-foot upland review area as proposed in the above referenced application known as "Application of Glenn Knowles, Applicant/Owner, for the proposed construction of a patio, correction of water runoff and wetlands restoration at property identified as 21 Brightwater Road, Niantic, East Lyme Assessor's Map 5.19, lot 58 was approved with the following conditions to the site plan;

1. Notify conservation officer at least 2 days prior to sitework in order that they may monitor the work.

2. Any proposed Additional work beyond this permit in the wetlands or watercourse or its 100-foot regulated area will require approval from the Inland Wetlands Agency or its certified Agent.
3. Any changes to the site plan listed on this permit require notification to the Inland Wetlands Agent and may require Agency approval- a new plan incorporating said changes shall be given to the Agent before any work begins.
4. No site work shall commence until all applicable conditions are satisfied.
5. Notify Inland Wetlands Agent upon completion of all regulated activities for final inspection and sign off.

In regards to the work proposed within the on-site wetlands, it may only be permitted by the Agency. Therefore, I offer the following:

FINDINGS:

Whereas: The Agency may find this application to be in conformance with the Inland Wetlands Regulations of the Town of East Lyme and more specifically based on the following:

Whereas: In accordance with Section 7.6, the Agency required information to be submitted including but not limited to site plans which show the land which will be affected thereby which shows existing and proposed conditions, wetland and watercourse boundaries, contours, and other pertinent features of the land and the proposed activity;

Whereas: In accordance with Section 7, Application Requirements, of the Inland Wetlands Regulations the applicant has provided the all the information required by Section 7.5 and the necessary additional information required by Section 7.6, As such, the application appears to be complete.

Whereas: Victor Benni, PE, Town Engineer has reviewed the proposed plans

Whereas: Demonstrated by the Memorandum from Victor Benni, PE, Town Engineer to G. Goeschel II, Director of Planning, dated March 6, 2020 indicates the slight increase in stormwater from the site improvements will be mitigated by the inclusion of the proposed rain garden on the upland side of the wetland and the rock flow diffuser at the low point of the on-site wetland addresses the existing erosion potential.

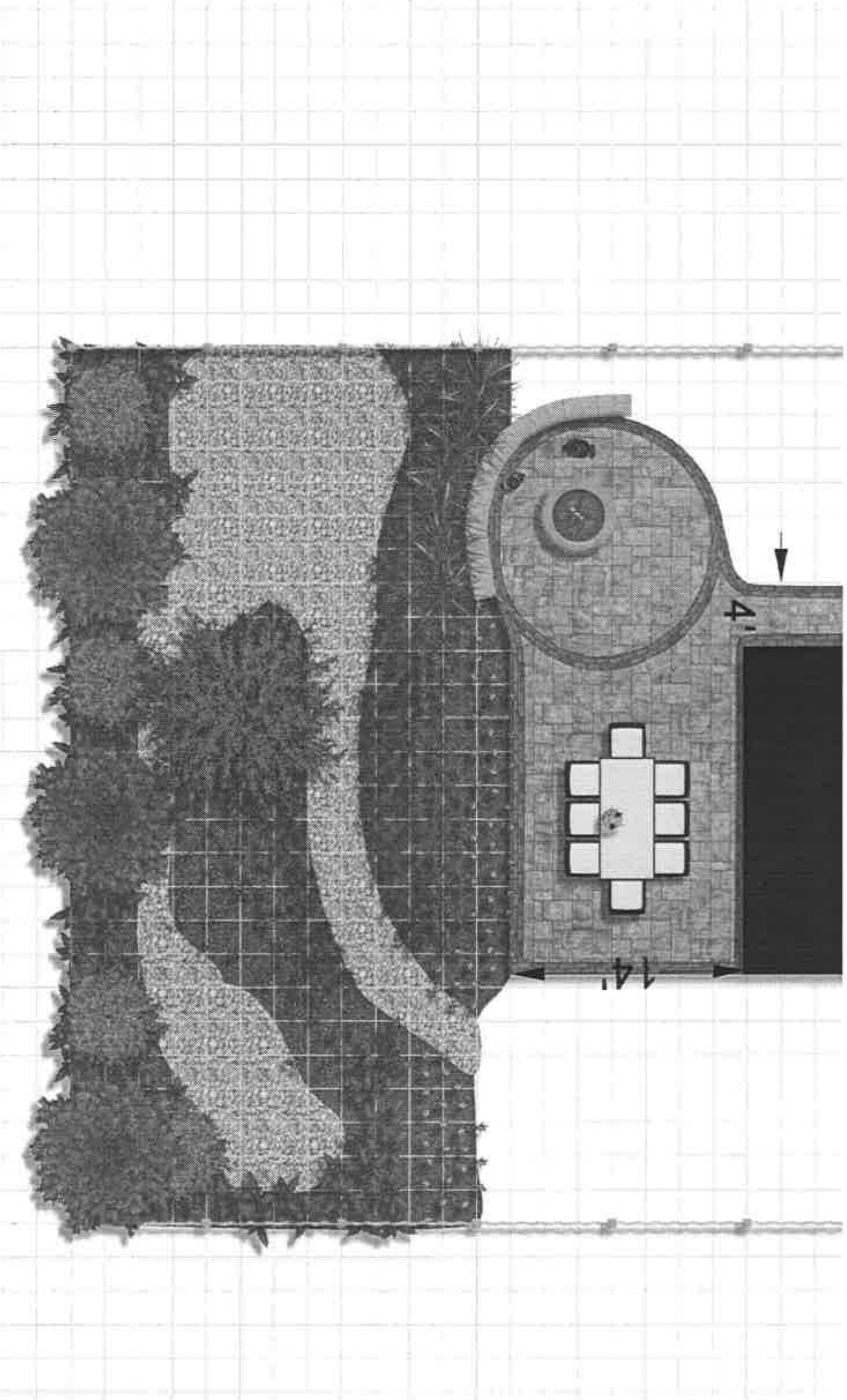
Whereas: Indicated in the memorandum from Victor Benni, PE, Town Engineer to G. Goeschel II, Director of Planning, dated March 6, 2020, the proposed modification to the wetlands will accommodate additional water and restore native wetlands plants; and

Whereas: The proposed improvements do not change the overall surface runoff flow pattern at the rear portion of the property.

SUGGESTED RESOLUTION

Therefore, based on the Findings in the memorandum from Gary A. Goeschel II, Director of Planning/Inland Wetlands Agent to the Inland Wetlands Agency dated March 30, 2020, and the record before the Agency, I move the Agency APPROVE the Application known as the Application of Glenn Knowles, Applicant/Owner, for the proposed construction of a patio, correction of water runoff and wetlands restoration at property identified as 21 Brightwater Road, Niantic, East Lyme Assessor's Map# 5.19, Lot# 58. This approval is specific to the site development plan submitted as the Application of Glenn Knowles, Applicant/Owner, for the proposed construction of a patio, correction of water runoff and wetlands restoration at property identified as 21 Brightwater Road, Niantic, East Lyme Assessor's Map# 5.19, Lot# 58. Any change in the plan, development plan layout, or any modifications of this approval other than those identified herein shall constitute a new application unless prior approval from the Agency or its Agent is granted.

The applicant/owner shall be bound by the provisions of this Application and Approval.


4'
14'

Plant	cont. size		quantity
BETULA NIGRA `HERITAGE` - HEAVY	#15	8-10`	1
ILEX VERT. `JIM DANDY`	#5	18-21``	1
ILEX VERTICILLATA `WINTER RED`	#5	42-48``	3
JUNIPERUS VIRGINIANA	#7	-	3
ASTER NOVAE-ANGLIAE `PURPLE DOME`	#2	-	12
ECHINACEA PURPUREA `HAPPY STAR`	#1	-	15
EUPATORIUM `BABY JOE`	#2	-	6
IRIS VERSICOLOR	#1	-	15
RUDBECKIA FULGIDA `GOLDSTURM`	#1	-	12
OSMUNDA CINNAMOMEA/CINNAMON FERN	#1	-	15
CAREX STRICTA	#1	-	21
PANICUM VIRGATUM `SHENANDOAH`	#2	-	5

Town of East Lyme

P.O. Drawer 519
Department of Planning &
Inland Wetlands Agency
Gary A. Goeschel II, Director of Planning /
Inland Wetlands Agent

108 Pennsylvania Ave
Niantic, Connecticut 06357
Phone: (860) 691-4114
Fax: (860) 860-691-0351

March 27, 2020

Toby & Glenn Knowles
21 Brightwater Road
East Lyme, CT 06375

RE: **Inland Wetlands Application – Application of Glenn Knowles, Applicant/Owner,** for the proposed construction of a patio, correction of water runoff and wetlands restoration at property identified as 21 Brightwater Road, Niantic, East Lyme Assessor's Map 5.L9, lot 58.

Dear Mr. and Mrs. Knowles,

The East Lyme Inland Wetlands Agency at a meeting held on Monday, February 24, 2020, at the East Lyme Town Hall, 108 Pennsylvania Avenue, Niantic, Connecticut, directed me to prepare a draft motion for the above referenced application for discussion and a resolution at their next regularly scheduled meeting which was to be held on March 9, 2020. Unfortunately, due to extenuating circumstance the Agency canceled the meeting and set a Special Meeting to discuss the items that were initially scheduled for the March 9, 2020 Meeting. Subsequently, the Town of East Lyme was forced to close its doors to the public as a result of the COVID-19 Pandemic. As a result, the Inland Wetlands Agency has been unable to meet in a public forum to render a final decision on your application. As such, upon discussing the matter with the Inland Wetlands Agency Chairman, Gary Upton, the Vice Chair, Kristen Chantrell, and First Selectman, Mark Nickerson, it was agreed that I, as Agent for the Commission, would approve the proposed work within the upland review area as it will still be consistent with State Statutes and the East Lyme Inland Wetland and Watercourses Regulations. Upon the opening of the Town Hall to the public or the establishment of virtual meetings pursuant to the criteria provided in the Governor's Executive Orders, the Agency will then be able to act on the portion of work within the on-site inland wetlands.

Therefore, please consider this correspondence as APPROVAL of only the portion of work within the 100-foot upland review area proposed in your application known as "Application of Glenn Knowles, Applicant/Owner, for the proposed construction of a patio, correction of water runoff and wetlands restoration at property identified as 21 Brightwater Road, Niantic, East Lyme Assessor's Map 5.L9, lot 58 which, is further subject to the following administrative requirements and required modifications to the site plan and other materials submitted in support of this application:

1. Notify conservation officer at least 2 days prior to sitework in order that they may monitor the work.
2. Any proposed Additional work beyond this permit in the wetlands or watercourse or its 100-foot regulated area will require approval from the Inland Wetlands Agency or its certified Agent.
3. Any changes to the site plan listed on this permit require notification to the Inland Wetlands Agent and may require Agency approval- a new plan incorporating said changes shall be given to the Agent before any work begins.
4. No site work shall commence until all applicable conditions are satisfied.
5. Notify Inland Wetlands Agent upon completion of all regulated activities for final inspection and sign off.

This approval is specific to the site development plan submitted as the Application of Glenn Knowles, Applicant/Owner, for the proposed construction of a patio, correction of water runoff and wetlands restoration at property identified as 21 Brightwater Road, Niantic, East Lyme Assessor's Map 5.L9, lot 58. Any change in the plan, development plan layout, or any modifications of this approval other than those identified herein shall constitute a new application unless prior approval from the Agency or its Agent is granted.

The applicant/owner shall be bound by the provisions of this Application and Approval.

If you have any further questions regarding this letter or any of the Inland Wetland Regulations, please do not hesitate to contact me at (860) 235-6211 or ggoeschel@eltownhall.com.

Sincerely,

Gary A. Goeschel II
Director of Planning/
Wetlands Enforcement Officer

cc: William Mulholland, Zoning Official
Steven E. Way, Building Official
Victor Benni, Town Engineer
Mark C. Nickerson, First Selectman
Inland Wetlands Agency
File

https://eltownhall-my.sharepoint.com/personal/ggoeschel_eltownhall_com/Documents/21 Brightwater_Notice of Decision_AdminApproval.doc

Town of East Lyme

P.O. DRAWER 519
NIANTIC, CONNECTICUT 06357

Town Engineer
Victor A. Benni, P.E.

860-691-4112
FAX 860-739-6930

To: Gary A. Goeschel II, Director of Planning

From: Victor Benni, P.E., Town Engineer

Date: March 6, 2020

Re: 21 Brightwater Road
Wetlands Application Review

Information submitted by the Applicant which was considered in this review:

- Written Narrative (Narrative), Assessors Map #5.19 Lot 58, 2020, by: Toby and Glenn Knowles.
- Proposed Site Plan Design, Guy Turgeon, 21 Brightwater Road, Scale: 1”=10’, Date: April19, 2002, Revised to: 2/12/09, by: Gerwick-Mereen LLC.
- Sketch Drawings (Sketches), 21 Brightwater Rd, Knowles, GSK1 As Is, GSK 2 Transition, GSK3 Final.

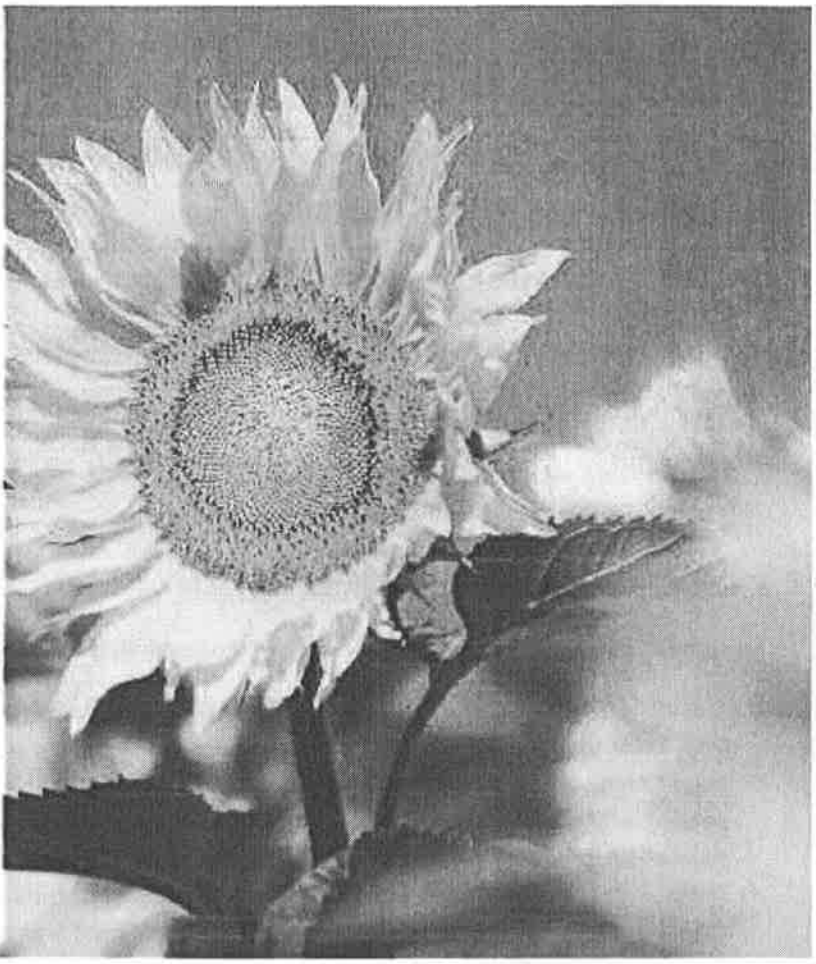
This office has reviewed the above referenced information and has the following comments:

1. The Narrative indicates that the modification to the wetlands will accommodate additional water and restore native wetland plants.
2. The proposed improvements do not change the overall surface runoff flow pattern at the rear portion of the property.
3. The Narrative demonstrates that the slight increase in stormwater from the site improvements will be mitigated by the inclusion of the proposed rain garden on the upland side of the wetland.
4. The proposed rock flow diffuser at the low point of the on-site wetland addresses the already existing erosion potential.
5. The Wetlands Agency may consider having the Wetlands Agent monitor the site as the work progresses; the Engineering Department is available at your disposal to assist in this matter.

Wetlands Narrative

Assessors Map # 5.19 Lot 58

2020



The purpose of this narrative is to provide the East Lyme Wetland Commission the details of our project to correct a water issue, build a patio, and modify the wetland to accommodate additional water and restore it with native plants.

RECEIVED
FEB 14 2020
TOWN OF EAST LYME
LAND USE

Toby and Glenn Knowles
21 Brightwater Rd
Niantic, CT 06357
(860) 334-0199

Assessors Map # 5.19 Lot # 58

Subject: Written Narrative in Support of Application for Permit East Lyme Inland Wetland Agency

The purpose of this permit application is three-fold:

1. Correct water issues in the lawn and around the house and slab
2. Construct a patio in back of the house
3. Modify the wetland to accommodate additional water and restore with native wetland plants

Four drawings have been provided with this permit application

1. GJK 1 – As Is of 21 Brightwater Rd
2. GJK 2 – Transition of 21 Brightwater Rd
3. GJK 3 – Final of 21 Brightwater Rd
4. Original Site Plan Design by Guy Turgeon

Correct water issues in the lawn and around the house slab

Surface water from the upland neighbor, 23 Brightwater Road passes under the properties fence along with water from the roof, causing puddles in the grass on the left side of the property. At the back right corner of the property, water pools against the foundation from runoff of the house roof. The proposed changes are to add gutters to the back half of the house and pipe the water into the wetlands at the low point of the property. A flow diffuser will be used to mitigate impact to the wetlands from water exiting the pipe. It is estimated that 250 gallons would be directly transiting the pipe in a 1" rain storm. A majority of this water would normally end up in the wetlands area as it is the low point of the property (see Drawing # 4). On the upland side of the house reused top soil from grading and top soil will be brought in to grade the grass area towards the wetland. The grade in the transition from the grass to the wetlands will be lowered to allow water to flow into the wetlands. A gentle swale will be installed to direct the flow of water. A rain garden will be added to the upland side of the wetland to mitigate additional flow of water. The size of the rain garden will be approximately 100 square feet and 8" deep, treating up to approximately 500 gallons water.

Construction of a patio

The location of the patio will be placed directly behind the house and flowing to the back and right of the property. The location of the patio is shown on drawing # 3. The patio will be constructed of UNILOCK pavers. A low wall will be constructed at the edge of the wetlands to provide a defined border from the patio to the wetland area.

Modify Wetland Area to accommodate additional water and restore with native wetland plants

Alternative 1:

The existing wetland has a high spot directly in the center. The proposed concept is to better define this high spot and enhance the naturally occurring swales to the north and south of the high spot. A rain garden will be constructed on the upland side of the high spot shown on drawing # 3. The rain garden will extensively be used as a fore bay. The rain garden will be designed and installed using the Nemo.uconn.edu/raingardens/installation.htm web site for rain gardens. There are two naturally occurring swales to the north and south of the high spot. The overflow of the water from the rain garden will be channeled by the existing swale on the north side of the high spot. This will allow the water to flow to the water storage site on the east side of the high spot. The water that flows from the left side of the house via the grass swale will be directed to the existing swale on the southern side of the high spot. This will allow the water to flow to the water storage site of the east side of the high spot as well. Both existing swales in the wetland will be enhanced for better flow and will be filled with river rock. The water storage site will allow rain water to settle and be processed into the ground. The capacity of the water storage site may have to be increased. A flow diffuser of rock approximately 24" wide by 18" deep and 6 feet long will be installed at the low point of the property at the far east point of the wetland. In extreme rainfall it will mitigate any potential erosion to the down land property, 19 Brightwater Road. Sod will be planted on all grass areas that have been disturbed during installation of the patio.

The purpose of the wetland upgrade is to improve wildlife habitat and native vegetation diversity while better managing water runoff. Native wetland plants will be installed to restore, enhance and create productive wetland. Plants such as Winterberry Holly will provide food for birds during the winter. Grasses such as Carex Anphibola (Creek Sedge) will be planted along the water transition sites for erosion control. Cephalanthus Occidentalis (Button Bush) will be planted because it tolerates flooding and some salt and also has a spicy sent that attracts butterflies and bees. The rain garden will have Iris, Cone Flowers and Asters. Evergreens will be planted at the far North of the property to create a blind from the neighbor at 24 Saltaire Ave. This is our initial considerations for this wetland area. As time progresses other productive plants maybe be introduced. We utilized the Connecticut association of conservation and inland wetlands commission web site for potential plantings. A complete list of plantings can be found in appendix A.

Alternative 2:

The do nothing option for this work will not resolve the issues with water in the grass area around the house and water pooling against the slab.

Alternative 3:

I have discussed options of installing galley's in the upland area of the wetland to accommodate water runoff from the roof and from property at 23 Brightwater Road. I have dug test wells in the upland and have hit groundwater approximately 18" below grade. This would render the galley's ineffective.

Appendix A

Property Plantings

Native plants were selected to replant the wetlands area. Plantings were also selected to aid wildlife. The following plants will be introduced into the wetlands:

Wetland area:

Winterberry Holly

Rush Grasses

Pickerelweed

Arrow Arum

Red Star Hibiscus

Cardinal Flower

White Cedar

White Birch

Creek Sage

Button Bush

Rain Garden:

Asters

Iris

Cone Flowers

Day lilies

Sage

Toby and Glenn Knowles

21 Brightwater Rd

Niantic, CT 06357

Assessors Map # 5.19 Lot # 58

Subject: Written Narrative in Support of Application for Permit East Lyme Inland Wetland Agency

The purpose of this permit application is three-fold:

1. Correct water issues in the lawn and around the house and slab
2. Construct a patio in back of the house
3. Modify the wetland to accommodate additional water and restore with native wetland plants

Four drawings have been provided with this permit application

1. GJK 1 – As Is of 21 Brightwater Rd
2. GJK 2 – Transition of 21 Brightwater Rd
3. GJK 3 – Final of 21 Brightwater Rd
4. Original Site Plan Design by Guy Turgeon

Correct water issues in the lawn and around the house slab

Surface water from the upland neighbor, 23 Brightwater Road passes under the properties fence along with water from the roof, causing puddles in the grass on the left side of the property. At the back right corner of the property, water pools against the foundation from runoff of the house roof. The proposed changes are to add gutters to the back half of the house and pipe the water into the wetlands at the low point of the property. A flow diffuser will be used to mitigate impact to the wetlands from water exiting the pipe. It is estimated that 250 gallons would be directly transiting the pipe in a 1" rain storm. A majority of this water would normally end up in the wetlands area as it is the low point of the property (see Drawing # 4). On the upland side of the house top soil will be brought in to grade the grass area towards the wetland. The grade in the transition from the grass to the wetlands will be lowered to allow water to flow into the wetlands. A gentle swale will be installed to direct the flow of water. A rain garden will be added to the upland side of the wetland to mitigate additional flow of water. The size of the rain garden will be approximately 100 square feet and 8" deep, treating up to approximately 500 gallons water.

Construction of a patio

The location of the patio will be placed directly behind the house and flowing to the back and right of the property. The location of the patio is shown on drawing # 3. The patio will be constructed of

UNILOCK pavers. A low wall will be constructed at the edge of the wetlands to provide a defined border from the patio to the wetland area.

Modify Wetland Area to accommodate additional water and restore with native wetland plants

Alternative 1:

The existing wetland has a high spot directly in the center. The proposed concept is to better define this high spot and enhance the naturally occurring swales to the north and south of the high spot. A rain garden will be constructed on the upland side of the high spot shown on drawing # 3. There are two naturally occurring swales to the north and south of the high spot. The overflow of the water from the rain garden will be channeled by the existing swale on the north side of the high spot. This will allow the water to flow to the water storage site on the east side of the high spot. The water that flows from the left side of the house via the grass swale will be directed to the existing swale on the southern side of the high spot. This will allow the water to flow to the water storage site of the east side of the high spot as well. Both existing swales in the wetland will be enhanced for better flow and will be filled with river rock. The water storage site will allow rain water to settle and be processed into the ground. The capacity of the water storage site may have to be increased. A flow diffuser of rock approximately 24" wide by 18" deep and 6 feet long will be installed at the low point of the property at the far east point of the wetland. In extreme rainfall it will mitigate any potential erosion to the down land property, 19 Brightwater Road. Sod will be planted on all grass areas that have been disturbed during installation of the patio.

The purpose of the wetland upgrade is to improve wildlife habitat and native vegetation diversity while better managing water runoff. Native wetland plants will be installed to restore, enhance and create productive wetland. Plants such as Winterberry Holly will provide food for birds during the winter. Grasses such as Carex Anphibola (Creek Sedge) will be planted along the water transition sites for erosion control. Cephalanthus Occidentalis (Button Bush) will be planted because it tolerates flooding and some salt and also has a spicy sent that attracts butterflies and bees. The rain garden will have Iris, Cone Flowers and Asters. Evergreens will be planted at the far North of the property to create a blind from the neighbor at 24 Saltaire Ave. This is our initial considerations for this wetland area. As time progresses other productive plants maybe be introduced.

Alternative 2:

The do nothing option for this work will not resolve the issues with water in the grass area around the house and water pooling against the slab.

Alternative 3:

I have discussed options of installing galley's in the upland area of the wetland to accommodate water runoff from the roof and from property at 23 Brightwater Road. I have dug test wells in the upland and have hit groundwater approximately 18" below grade. This would render the galley's ineffective.

ggoeschele
@townhall.com

APPLICATION FOR PERMIT EAST LYME INLAND WETLANDS AGENCY

CR# 1492

Office Use Only

Fee Paid $210.00

Date Submitted 1/21/2020

Application #

Date of Receipt 2/24/2020

Date Approved

Permit Number

Major Impact: YES NO   Public Hearing: YES NO   Agent Approved: YES NO

Note: In accordance with the Inland Wetland and Watercourses Regulations, Eleven (11) copies of all application materials must be submitted.

1. SITE LOCATION (Street) and Description: 21 BRIGHTWATER RD

Assessor's Map 5.19 Lot # 58

Note: It is the applicant's responsibility to provide the correct site address, map/ lot number for the legal notice. Provide a description of the land in sufficient detail to allow identification of the inland wetlands and watercourses, the area(s) (in acres or square feet) of wetlands and watercourses to be disturbed, soil type(s), and wetland vegetation.

2. APPLICANT: Toby & Glenn Knowles

Address: 21 Brightwater Rd
Niantic CT 06357

Phone:

Fax:

Business:

Cell: 860 334-0199

Email: gknowles1@icloud.com

Applicant's interest in the land:

***If the applicant is a Limited Liability Corporation or a Corporation provide the managing member's or responsible corporate officer's name, address, and telephone number.*

3. OWNER: Toby & Glenn Knowles

Address: 21 Brightwater Rd
Niantic CT 06357

Phone:

Fax:

Email: gKNOWLES1@icloud.com

Cell: 860 334 0199

***As the legal owner of the property listed on this application, I hereby consent to the proposed activities. And I hereby authorize the members and agents of the Agency to inspect the subject land, at reasonable times, during the pendancy of the application and for the life of the permit.*

Owners Printed Name: Glenn J KNOWLES

Owners Signature:

Date: 1/20/20

O:\E&J\Land Use Department Forms\Inland Wetland Forms 2012\Wetlands Application 2012.doc Reviewed and Updated as of 11/18/2019 9:25 AM

4. Area of wetland to be disturbed: 900 sq. ft. or ac

Area of watercourse to be disturbed: sq. ft. or ac

Upland review area to be disturbed: sq. ft. or ac

Will fill be needed on site? [✓ Yes] No

If yes, how much fill is needed? 20 - 30 Cubic yards

5. The property contains (circle one or more)

WATERCOURSE [✓ ~~WATERBODY~~ WOODED-WETLAND] SWAMP

FLOODPLAIN OTHER:

Description of soil types on site:

Description of wetland vegetation: Pepper bush, Blueberry

Name of Soil Scientist(s) and date of survey: Donald Fortunado

6. Provide a written narrative of the purpose and a description of the proposed activity and proposed erosion and sedimentation controls and other best management practices and mitigation measures which may be considered as a condition of issuing a permit for the proposed regulated activity including, but not limited to, measures to (1) prevent or minimize pollution or other environmental damage, (2) maintain or enhance existing environmental quality, or (3) in the following order of priority: restore, enhance and create productive wetland or watercourse resources. Depending on the complexity of the project, include the following: construction schedule, sequence of operations, drainage computations with pre and post construction runoff quantities and runoff rates, plans clearly showing the drainage areas corresponding to the drainage computation, existing wetland inventory and functional assessment, soils report, construction plans signed by a certified soils scientist, licensed surveyor, and licensed professional engineer.

7. Provide information of all alternatives considered. List all alternatives which would cause less or no environmental impact to wetlands or watercourses and state why the alternative as set forth in the application was chosen. All such alternatives shall be diagramed on a site plan or drawing. (Attach plans showing all alternates considered).

Alternative 1: Proposed Plan in narrative
Alternative 2: DO NOTHING
Alternative3: USE OF GALLEY'S in upland

8. Attach a site plan showing the proposed activity and existing and proposed conditions in relation to wetlands and watercourses and identifying any further activities associated with, or reasonably related to, the proposed regulated activity which are made inevitable by the proposed regulated activity and which may have an impact on wetlands and watercourses.

9. Provide the name and mailing addresses of adjacent landowners (including across a street). Attach additional sheets if necessary.

Name/Address: Brian Harrington / 23 Brightwater Rd Niantic CT 06357
Name/Address: Laurene O'LOUGHLIN / 19 Brightwater Rd Niantic CT 06357
Name/Address: Linda Gesualdi / 24 Saltaire Ave Niantic CT 06357
William Molloy / 22 Brightwater Rd, Niantic CT 06357

10. Attach a completed DEP reporting form.

The Agency shall revise or correct the information provided by the applicant and submit the form to the Commissioner of Environmental Protection in accordance with section 22a-30-14 of the Regulations of Connecticut State Agencies.

11. Name of Erosion Control Agent (Person Responsible for Compliance):

Glenn Knowles

Address: 21 Brightwater Rd
Niantic CT 06357
Email: gknowles1@gmail.com

Phone: 860 334-0199
Fax:
Cell:

12. Are you aware of any wetland violations (past or present) on this property? Yes [✓ No]

If yes, please explain:

13. Are there any vernal pools located on or adjacent (within 500') to the property? Yes [✓ No]

14. For projects that do not fall under the ACOE Category I general permit – Have you contacted the Army Corps of Engineers? Yes [✓ No]

15. Is this project within a public water supply aquifer protection area or a watershed area? Yes [✓ No]

16. If so, have you notified the Commissioner of the Connecticut Department of Public Health and the East Lyme Water and Sewer Department? Yes No *(Proof of notification must be submitted with your application).*

17. Attach the appropriate filing fee based on the fee schedule established in Section 19 of the Regulations.
Fee: 210 *(Make checks payable to "Town of East Lyme").*

18. PUBLIC HEARINGS ONLY: The applicant must provide proof of mailing notices to the abutters prior to the hearing date.

The undersigned Applicant hereby consents to necessary and proper inspection of the above mentioned property by the East Lyme Inland Wetlands Agency and/or its agents at reasonable times both before and after the permit in question has been granted.

The Applicant affirms that the information supplied in this application is accurate to the best of his/her knowledge and belief. As the applicant I hereby certify that I am familiar with the information provided in this application and I am aware of the penalties for obtaining a permit through deception or through inaccurate or misleading information.

Printed Name: Glenn Knowles
Date: 1/20/20
Signature:

Please note:

Above notice to be published in legal section of newspaper having general circulation in the Town of East Lyme. Applicant to pay cost of publication.

You or a representative must attend the Inland Wetlands Agency meeting to present your application.

CHECKLIST FOR A COMPLETE APPLICATION

☐ completed application form including Department of Environmental Protection reporting form (green copy)
☐ A narrative of the purpose and description and methodology of all propose activities;
☐ Alternatives considered by the applicant, reasons for leaving less than a 10' buffer between clearing and the wetlands. Such alternatives to be diagrammed on a site plan or drawing and submitted to the commission as part of the application;
☐ Names and mailing addresses of abutting property owners;
☐ Three copies of approximately 1"=40' scale plans
☐ Locations of existing and proposed land uses
☐ Locations of existing and proposed buildings
☐ Locations of existing and proposed subsurface sewage disposal systems, and test hole descriptions
☐ Existing and proposed topographical and man-made features including roads and driveways, on and adjacent to the site
☐ Location and diagrams of proposed erosion control structures
☐ Assessor map and lot number
☐ Key or inset map
☐ North arrow
☐ Flood zone classification and delineation
☐ Use of wetland and watercourse markers where appropriate.
☐ Soil types classification and boundary delineation (flagged and numbered boundary), Soil Scientist's original signature and certification on plans
☐ Soil Scientist's (or other wetland scientist) report on the function of the wetlands
☐ Watercourse channel location and flow direction, where appropriate
☐ 100 ft. regulated area depicted on plans
☐ Conservation easements where appropriate
☐ A detailed erosion and sediment control plan which meets requirements set forth in the most recent revision of the *Connecticut Guidelines for Soil Erosion and Sediment Control*, published by the Connecticut Council on Soil and Water Conservation, including:
☐ Location of areas to be stripped of vegetation and other unprotected areas
☐ Schedule of operations including starting and completion dates for major development phases
☐ Seeding, sodding, or re-vegetation plans for all unprotected or un-vegetated areas
☐ Location and design of structural sediment control measures
☐ Timing of planned sediment control measures
☐ Use of wetland and watercourse markers
☐ Proper certification on the application documents and plans

In the case of filling in wetlands, watercourses, or regulated upland areas, the following items are necessary:

☐ Area to be filled
☐ Volume of requested fill
☐ Finished slopes of filled areas
☐ Containment and stabilization measures
☐ Proposed finished contours
☐ Evaluation of the effect of filling the wetlands with respect to storage volume and its impact downstream showing before and after development flows, and the evaluation of storm water detention including the existing need for flood control downstream

Other required items:

☐ Proof of adjoining Town notification, where required;
☐ All application fees required by Section 16 of these regulations;
☐ A written narrative detailing how the effects of the applicant's proposed activities upon wetlands and watercourses shall be mitigated.
☐ A written description of any and all future plans which may be linked to the activities proposed in the current application.
☐ Address the potential to enhance the current buffer area.
☐ Review drainage information with Town Engineering
☐ Mailing requirements for abutters (public hearing only)

Appendix D - ORDINANCE ESTABLISHING SCHEDULE OF FEES FOR CONSERVATION, PLANNING AND ZONING COMMISSIONS

1.1 Application Fee **
  1.1.1 Residential Uses........... ....$150.00 Plus *$50.00/LOT
    Plus Fee from Schedule A
  1.1.2 Commercial Uses $400.00
    Plus Fee from Schedule A
  1.1.3 All Other Uses............. ....$200.00
    Plus Fee from Schedule A
  *Each lot with regulated activities
  **$60 fee required by C.G.S 22a-27j will be added to the base fees.

1.2 Approval by Duly Authorized Agent ** $100.00

1.3 Appeal of Duly Authorized Agent Decision....... ....$300.00

1.4 Significant Activity Fee $300.00

1.5 Public Hearing Fee

  1.5.1 Single Residential $200.00

  1.5.2 Commercial/Industrial/Multi-Family $450.00

1.6 Complex Application Fee........... ....Actual Cost

The Inland Wetlands Agency may charge an additional fee sufficient to cover the cost of reviewing and acting on complex applications. Such fee may include, but not be limited to, the cost of retaining experts, to advise, analyze, review, and report on issues requiring such experts. The Agency or the duly authorized agent shall estimate the complex application fee, which shall be paid pursuant to section 19.1 of these regulations within 10 days of the applicant's receipt or notice of such estimate. Any portion of the complex application fee in excess of the actual cost shall be refunded to the applicant no later than 30 days after publication of the agency's decision.

1.7 Permitted and Nonregulated Uses :
  1.7.1 Permitted Uses as of-Right $0.00
  1.7.2 Nonregulated $0.00

1.8 Regulation Amendment Petitions........... ....$500.00
  (Does not include Notices or Regulation Advisories from DEP)
  1.8.1 Map Amendment Petitions........ ....$500.00
    Plus Fee from Schedule B

1.9 Modification of Previous Approval: $100.00

1.10 Renewal of Previous Approval $100.00

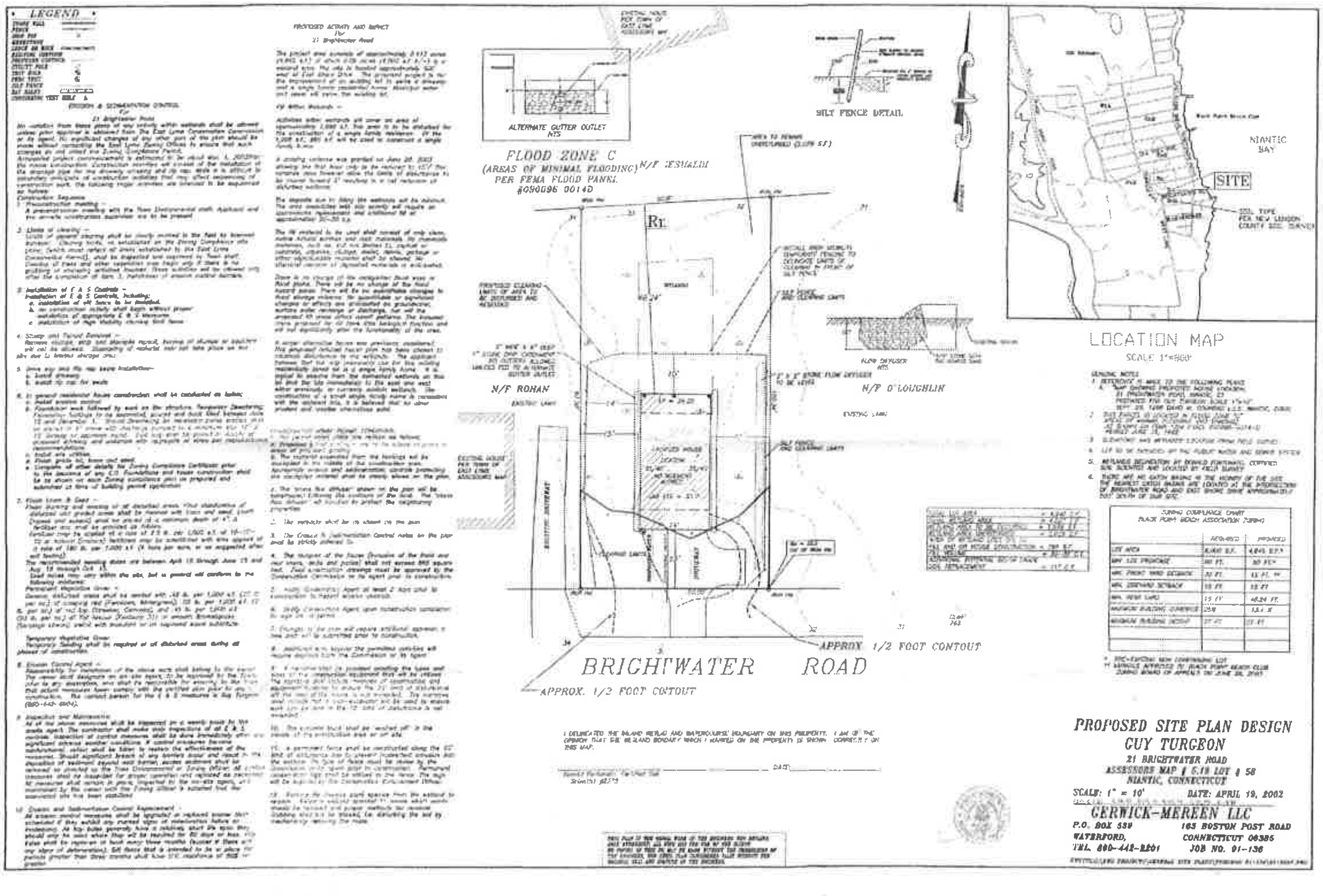
1.11 Monitoring Compliance Fee $100.00

1.12 SCHEDULE A. For the purpose of calculating the permit application fee, the area in schedule A is the total area of wetlands and watercourses and the upland review area upon which a regulated activity is proposed.

SQUARE FEET of AREA
  1.12.1. Less than 1,000 ....$0.00
  1.12.2. 1,000 to 5,000 ....$250.00
  1.12.3. More than 5,000............ ....$750.00

1.13 SCHEDULE B. For the purpose of calculating the map amendment petition fee, linear feet in schedule B is the total length of wetlands and watercourses boundary subject to the proposed boundary change.

LINEAR FEET
  1.13.1. Less than 500 ....$0.00
  1.13.2 500 to 1,000.................. ....$250.00
  1.13.3 More than 1,000 ....$750.00



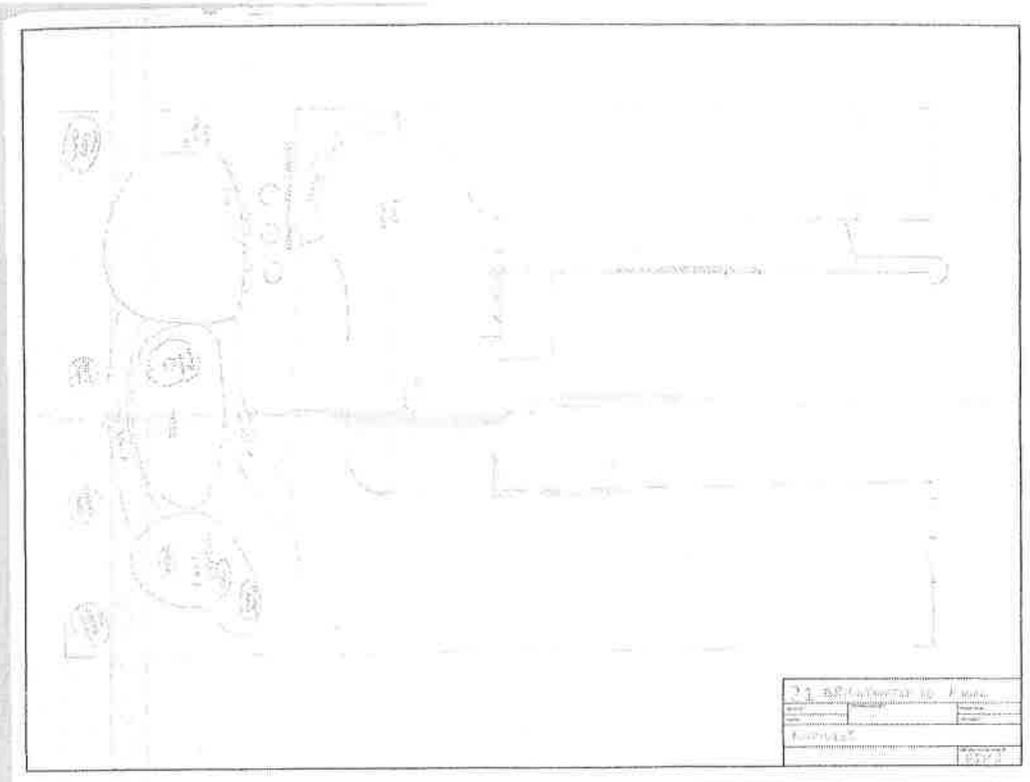
PROPOSED SITE PLAN DESIGN
GUY TURGEON

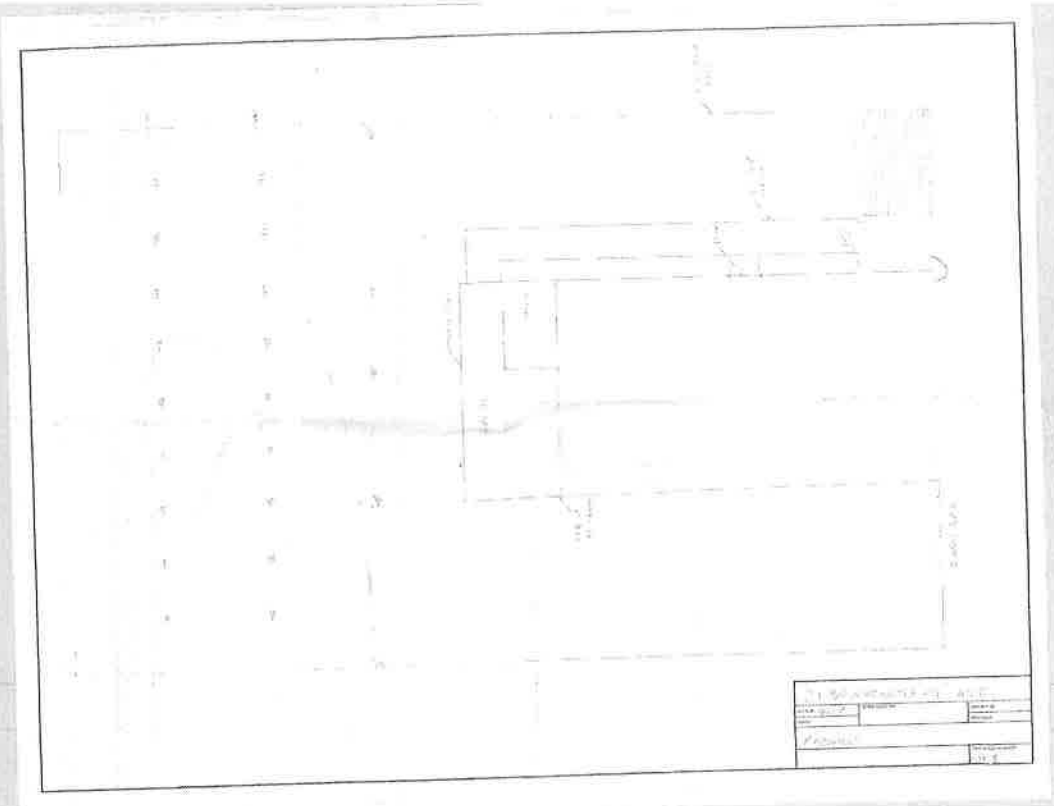
21 BRIGHTWATER ROAD
ASSESSORS MAP # 5.19 LOT # 58
NIANTIC, CONNECTICUT

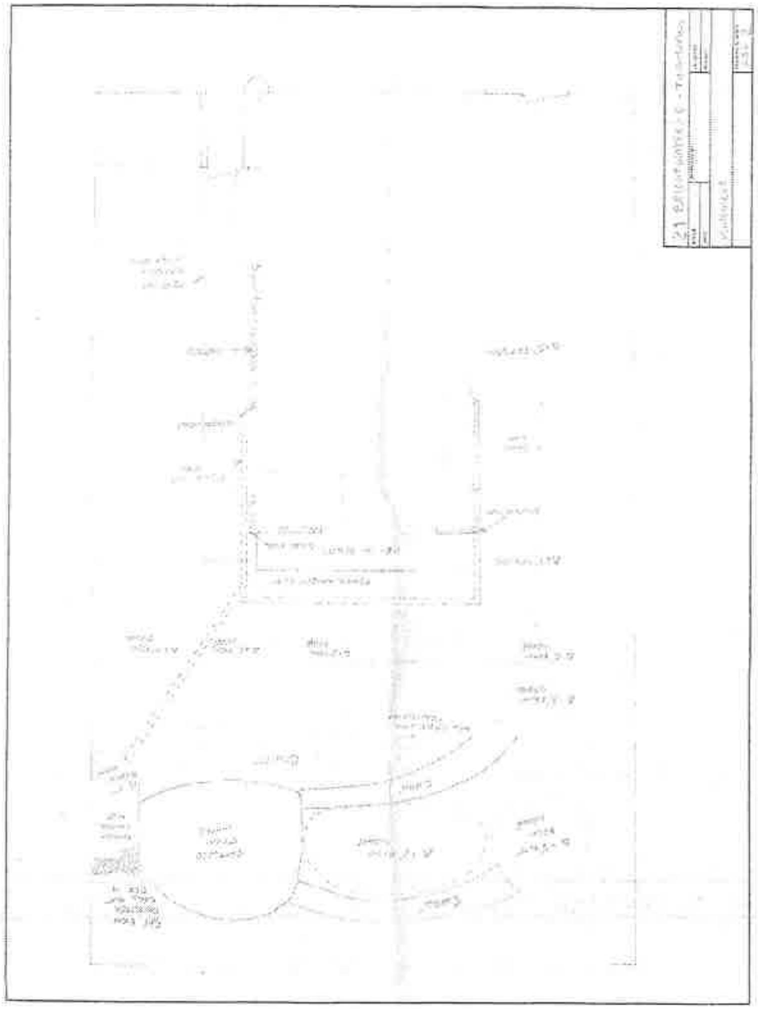
SCALE: 1" = 10' DATE: APRIL 19, 2002

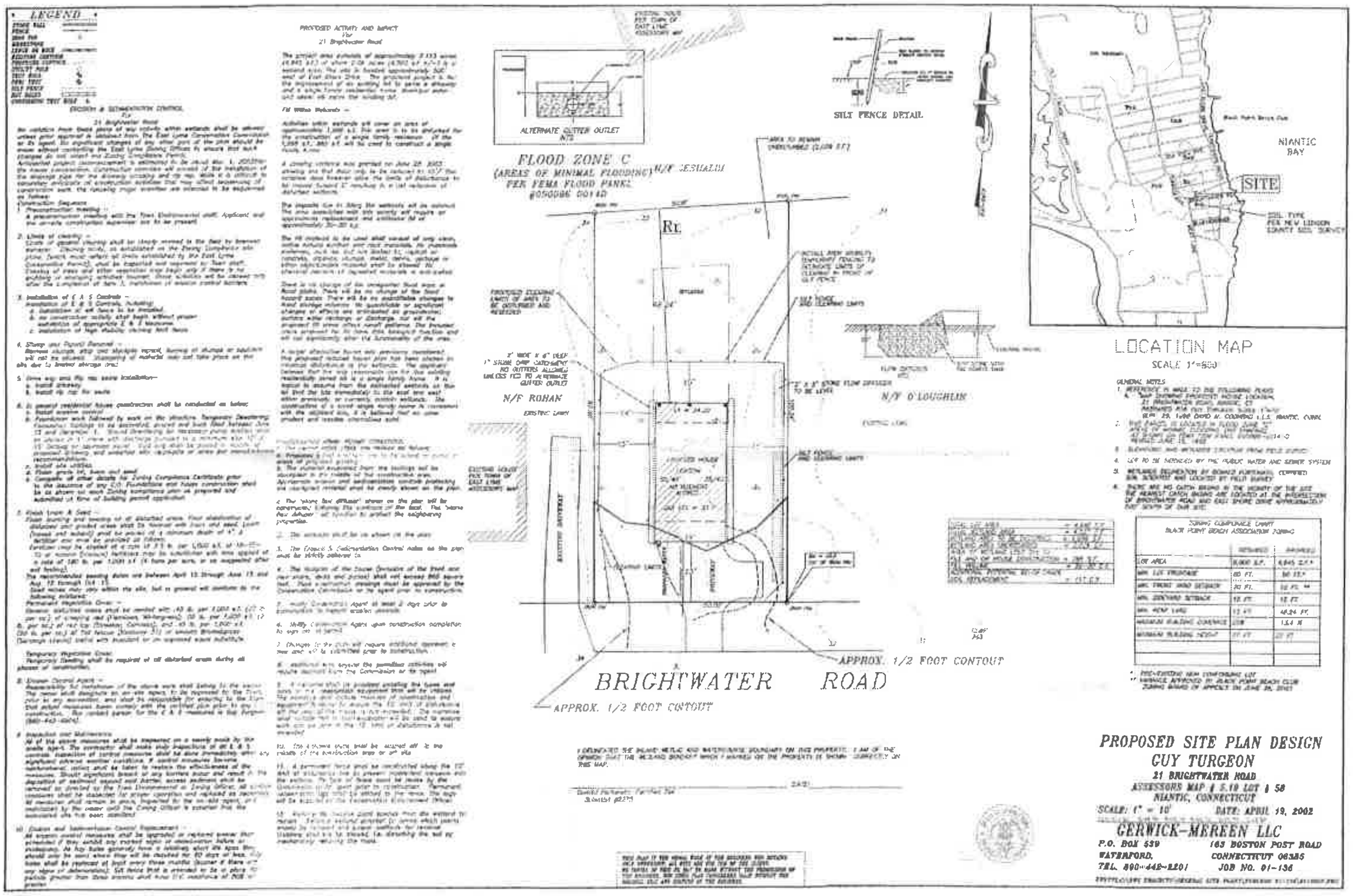
GERWICK-MEREEN LLC

P.O. BOX 539 165 BOSTON POST ROAD
WATERFORD, CONNECTICUT 06385
TEL. 860-442-2201 JOB NO. 01-136






21 Brentwood



PROPOSED SITE PLAN DESIGN
GUY TURGEON
21 BRIGHTWATER ROAD
ASSESSORS MAP # 5.10 LOT # 58
NIANTIC, CONNECTICUT
SCALE: 1" = 10'   DATE: APRIL 19, 2002

GERWICK-MEREEN LLC
P.O. BOX 539   163 BOSTON POST ROAD
WATERFORD,   CONNECTICUT 06385
TEL. 860-442-2201   JOB NO. 01-136

EAST LYME INLAND WETLANDS AGENCY
REGULAR MEETING MINUTES
June 8, 2020
Remote Participation by ZOOM due to Covid 19
7:00 p.m.

Present: Gary Upton, Phyllis Berger, Rosemary Ostfeld, Theodore Koch, Kristin Chantrell, David Schmitt, Doreen Rhein, Alt., Jason Deeble, Alt
Absent: Don Phimister, Sandy Gignac alt.
Also Present: Gary Goeschel, Director of Planning/Inland Wetlands Agent, Jennifer Lindo, Administrative Assistant, Mark S. Zamarka, Town Attorney

Call to Order:

G. Upton called the meeting to order at 7:07. He explained the rules for participation in the remote ZOOM meeting. The materials for the applications are on the town's website.

I. ADDITIONS TO THE AGENDA-none

Attorney Paul Gerahty, representing Nottingham Hills Re-subdivision stated that Town Attorney Zamarka and any attorneys from the law firm Waller Smith and Palmer cannot partake in any conversations or deliberations involving his client or anyone he represents due to a federal consent decree. Attorney Zamarka stated he was not aware of the specifics, but is aware of the existence of an agreement, although it was before his time. He stated that he is not attending the meeting to participate in discussion of issues that are represented by Attorney Gerahty; he will be muted and video turned off during the Nottingham Hills application.

II. PUBLIC HEARINGS-none

III. PUBLIC DELEGATIONS-none

FILED
June 15, 20 20 AT 3:55 AM [✓ PM]
EAST LYME TOWN CLERK

IV. ACCEPTANCE OF MINUTES:

Meeting Minutes of May 18, 2020 Special Meeting

MOTION (Schmitt/Ostfeld) To approve the minutes of May 18, 2020 Special Meeting as presented. Vote: Approved Unanimously.

(D. Rhein is seated for D. Phimister)

V. EX-OFFICIO REPORT-none

VI. PENDING APPLICATIONS:

A. Inland Wetlands Regulations: Changes to regulations and updates

G. Goeschel stated that the Public Hearing for the regulation changes cannot be held on June 8 due to the timing of notifications.

MOTION: (Upton/Ostfeld) to rescind the previous date of June 8, 2020 that was previously set for the Public Hearing to change regulations. Vote: Approved Unanimously.

MOTION: (Upton/Berger) to reschedule the Public Hearing on July 13, 2020. Vote: Approved Unanimously.

B. **Nottingham Hills Re-subdivision; Request of Kristen T. Clarke, P.E. Agent for Owner English Harbor Asset Management, LLC for a Determination of Permitted/Non-Regulated Activity at Upper Kensington Drive, as part of a 4-lot re-subdivision. East Lyme Assessor's Map 40.0, Lot 23 and 22.**

(Attorney Zamarka recused himself from the application discussion)

Attorney Gerahty stated there was a memo submitted from K. Clarke, P.E., who is a member of English Harbor Asset Management LLC, addressing some of the questions the members had at the last meeting. He reminded the agency that they are looking for a determination of no jurisdiction of the agency.

Gerahty explained the reserve septic system which is the closest activity to the wetlands is not to be built, but is reserved. The design is an advanced technology system (GST) which allows for a smaller design. It will be much smaller and farther away from the regulated area. He stated it is a more sophisticated system and is pitched away from the wetlands.

In response to a comment made on the site walk, he stated the rain garden will not be a mosquito breeding ground as the rain garden is not at the lowest point of the slope and will not puddle, therefore creating a breeding ground for mosquitos.

Gerahty stated that due to new regulations the sub-division can now have one driveway as opposed to the two that were originally proposed, therefore reducing the amount of impervious surfaces. He also stated that in addition to the usual E & S controls there will also be staked hay bales as an additional wetlands buffer.

The GST septic system design reduces the leaching fields on all lots by 50% and a note will be added to the final site plans that all the lots in the application will utilize the GST septic system. There is no activity proposed in a protected or endangered species areas according to the NDDB and the tree canopy has not changed or been altered by the proposed application.

Attorney Gerahty stated the applicant has demonstrated the agency has no jurisdiction as there is no proposed activity in a regulated area. In order to call a public hearing, the agency would have to have expert testimony proving there is, "significant activity." He stated that the Planning Commission will have a public hearing as the application is a re-subdivision.

G. Goeschel stated that according to the plan submitted there is no activity proposed in the regulated area and all activity is outside the 100' upland review area. He stated the town engineer and Ledge Light Health District will be reviewing the application.

Attorney Gerahty stated previously there was a wetlands public hearing for the original lots.

The agency asked who would be maintaining the rain garden and how are the wetlands going to be protected during construction. Attorney Gerahty stated there should not be any maintenance for the rain garden and any rights and obligations of the property owners will be clearly drafted and put into the deeds. He stated the wetlands would be marked off during construction and the access for construction purposes will be the proposed driveway.

MOTION: (Schmitt /Koch) there is no need for the agency to require a permit because it is not in its jurisdiction given all the information provided in the application. Vote: Approved Unanimously.

C. **21 Marshfield Rd, Your Brothers Keeper LLC, Agent for Owner Brandy and Derek Moore, for Determination of a Permitted/Non-Regulated Activity at 21 Marshfield Road, for the clean out of a culvert entrance and exit to maintain the natural flow of water. East Lyme Assessor's Map 04.7, Lot 19.**

D. **Creek Road, Giants Neck Heights Club House, your Brothers Keeper LLC, Agent for Owner Giants Neck Heights Association, for Determination of a Permitted/Non-Regulated Activity at 21 Marshfield Road, for the clean out of a culvert entrance and exit to maintain the natural flow of water. East Lyme Assessor's Map 04.7, Lot 18.**

(Items C & D were combined for discussion purposes.)
G. Upton provide photos and gave the history provided at the previous meeting.
G. Goeschel stated the applicants may need a DEEP permit and zoning may require a CAM (Coastal Area Management) review/permit. The question of when the pipe was installed could not be definitely determined.
MOTION: (Upton/Ostfeld) The applicants from 21 Marshfield Rd. and Creek Road need to make an application for a permit to the East Lyme Inland Wetlands Agency for the proposed activity. The applicant only needs to submit one application with the two properties listed. **Vote: Approved Unanimously.**

VII. NEW BUSINESS-none

VIII. OLD BUSINESS-none

IX. REPORTS

A. Chairman's Report

G. Upton shared photos of property along a boat ramp taken during the site walk for 21 Marshfield Rd. He stated there was significant amount of fill. It was determined the property was owned by the railroad. G. Goeschel stated that he had also noticed the fill and has forwarded the issue to B. Mulholland for investigation.

G. Upton had photos of a building (285 Boston Post Rd) which was taken as part of a site walk on 297 Boston Post Rd. He does not remember the agency approving a building that large. G. Goeschel will investigate the as built submitted.

MOTION: (Upton/Ostfeld) to take a 2-5-minute break. The agency went into the break at 9:05 and came back at 9:13. Vote: Approved Unanimously

B. Inland Wetlands Agent Report-

G. Goeschel approved a deck extension in the URA at 21 Fairhaven Rd. and a shed at 16 Egret Rd in the URA.

C. Enforcement

Notice of Violation; 297 Boston Post Road; Al Smith Owner, Jason Pazzaglia, Other; Outside storage of equipment, construction materials, and the stockpiling of earthen materials including but not limited to yard debris within 100 feet of a watercourse without or in violation of an Inland Wetlands Permit.

The members were surprised there were still so many vehicles and equipment on the site. They stated the issue has been before the agency for over a year and wanted to know what other steps can be taken to force the owner to clean up the site. The question of how many vehicles are registered came up.

MOTION: (Upton/Schmitt) to issue a Cease and Desist for the violation at 297 Boston Post Rd and ceasing and desisting any activity that is not permitted. Vote: Approved Unanimously.

D. Correspondence

G. Upton read the letter from the First Selectman which is posted on the town's website as well as his response. K. Chantel's letter is also posted on the website. G. Upton informed the members that he and the First Selectman had a phone conversation in the morning.

X. ADJOURNMENT

MOTION: (Schmitt/Ostfeld) to adjourn at 9:45. Vote: Approved Unanimously.

Respectfully Submitted

Sue Spang
Recording Secretary

EAST LYME INLAND WETLANDS AGENCY
REGULAR MEETING MINUTES
July 13, 2020
Remote Participation by ZOOM due to Covid 19
7:00 p.m.

Present: Gary Upton, Phyllis Berger, Rosemary Ostfeld, Theodore Koch, Kristin Chantrell, Don Phimister, David Schmitt, Doreen Rhein, Alt., Sandy Gignac alt., Jason Deeble, Alt.
Also Present: Gary Goeschel, Director of Planning/Inland Wetlands Agent, Jennifer Lindo, Administrative Assistant, Paul Dagle, Liaison from BOS, Mark Zamarka, town attorney.
Doreen Rhein was seated

CALL TO ORDER:
The meeting started at 7:11

FILED
July 16 2020 AT 11:30 [✓ AM]/PM
EAST LYME TOWN CLERK

G. Upton introduced staff and members. Members introduced themselves and cited their education and qualifications.

I. ADDITIONS TO THE AGENDA

MOTION: (Chantrell/Schmitt) to amend the agenda to only include the public hearing and the Governors order 7M to extend to the 90-day time period for any matters due to COVID19. Vote: Approved Unanimously.
MOTION: (Schmitt/Berger) move that East Lyme Wetlands Agency adopt the Governors regulation, 7M per advice of council to allow the agency to extend to 90 days any matters. Vote: Approved Unanimously.

II. PUBLIC HEARINGS:

1. **Application of the Town of East Lyme Inland Wetland Agency for a text amendment to amend section 2.1 of the East Lyme Inland Wetland Regulations to change the Definition of a "Regulated Activity" by enlarging the distance of the boundary for a regulated activity from 100' from an inland wetlands and/or watercourse to 500'.**
G. Upton stated the rules of the Public Hearing. G. Upton started the public hearing at 7:32. G. Goeschel read the Public Hearing notice (Exhibit C) which was published in the Day paper on July 1, 2020 and July 9, 2020. G. Goeschel listed the agency's public hearing exhibits A-Y:

A	Inland Wetlands Agency Regulation Change Text
B	Inland Wetlands Agency Referral Letter Sent 6/5/2020
C	Public Hearing Legal Notice and Legal for Regulation Change
D	DEEP Receipt of Reg Change and Notice dated 6/5/2020
E	Letter of Support from Natural Resources dated 6/4/2020
F	Map of 100' Upland Review Area
F1	Map of 100' v 500' Upland Review Area
G	Map of 100' v 500' Upland Review Area APA & Aquifer
H	List Serve Responses
I	CT DEEP IWWR 22a-39

J	CT DEEP Enforcement Flowchart 2015
K	CT DEEP Soil Scientist Qualifications
L	CT DEEP Disturbed Soils Guidance 2015 NRCS
M	CT DEEP Application 2015
N	CT DEEP Flowchart Timeline for Regulation Amendments 2015
O	CT DEEP 2006 IW Model Regulations Final 4th Edition
P	CT DEEP 1997 Upland Review Document June 1997
Q	CT DEEP 2015 Regulation Advisory
R	2013 Revised Permit Time Frames Chart
S	CT DEEP 2012 Regulation Advisory PDF
T	CT DEEP 2011 Regulations Advisory
U	Legislation Regulations Advisory Letter
V	CT DEEP 2009 Advisory PDF
W	CT DEEP 2006 Regulations Advisory PDF
X	CT DEEP 2007 Regulations Advisory PDF
Y	Permit Revocation Flow Chart 2015

Town Attorney, Mark Zamarka gave background on the purpose and responsibilities of the Inland Wetlands Agency. He informed the public that there is a legal precedent for increasing the Upland Review Area (URA) but the increase and benefit has to be supported by substantial evidence. He stated there was a procedure for amending the Agency's regulations.
G. Upton read section 1.1 of the East Lyme Inland Wetlands Agency regulations which gives the title and authority to the Agency.
K. Chantrell said the agency has an obligation to protect the wetlands and watercourses and listed other towns that have increased their URA. She believes that vernal pools especially should be protected.
T. Koch stated his reason for wanting to increase the URA was the declining quality of the town's drinking water as the sodium levels are increasing.
R. Ostfeld cited the submission by the town's conservation committee. She stated there are costs for not protecting the town's surface water which is eventually ground water and drinking water. She mentioned the cost for the town's recent remediation of it's drinking supplies/wells from manganese and iron.

Public Comments:
Cheryl Lozanov, 9 West Society Rd, 90 West Rd.- is in favor of the text amendment change.
Robert Pfanner, 2 Surrey Lane-opposed to the text amendment change.
Camile Alberti, 7 Darrows Ct., - supports the agency
Maddie Anthony, 13 Plants Dam Rd-in favor of the text amendment change.
John Anthony, 13 Plants Dam Rd- in favor of the text amendment change.
Tom Kalal, 80 Grassy Hill Rd- in favor of the text amendment change.
Justin Dauber, 21 King James Dr.-ask the agency to go back and look at other options.
Paul Geraghty, attorney for English Harbour Asset Management LLC- opposed to the text amendment change.
Margaret Minor, prior director of the Rivers Alliance- in favor of the text amendment change.

Pat Young, 8 Mile River Watershed-suggested the Agency give more information on why they w the regulation change. She suggested collaboration with the Zoning Commission and possibly usi overlay zones.
Harvey Beeman, member of the East Lyme Commission for Conservation of Natural Resources (CC in favor of the text amendment change.
Brian Lepkowski, 27 Green Valley Lakes Rd.- in favor of the text amendment change.
Joe Mingo- opposed to the text amendment change.
Robert Pfanner, 2 Surrey Lane-submitted additional questions.
Justin Dauber, 21 King James Dr.-is for water quality but has seen no evidence for the increase to 500'

The following exhibits were entered into the record.

Z	Letter from Attorney Timothy Hollister
AA	Memorandum from East Lyme Planning Commission with Minutes of 7/7/2020 meeting
BB	Letter from B Picazio
CC	Letter from J Daubar
DD	Letter from J Mingo
EE	Letter from J Vilcheck
FF	Letter from J Pronsky Brothers
GG	Letter from N Peck
HH	Letter from P Butterfield
II	Letter from G Booth
JJ	Letter from L Higgins
KK	Letter from D Lepkowski
LL	Letter from M & R Goss
MM	Letter from A Lepkowski
NN	Letter from East Lyme Zoning Commission
OO	Letter from R Blatt with Attachments
PP	Letter from R Ambrico
QQ	Letter from C Russell
RR	Letter from N Barwikowski
SS	Letter from D Lepkwoski
TT	Letter from B Lepkowski
UU	Letter from M Anderson
VV	Letter from N Anderson
WW	Letter from Attorney Ted Harris
XX	Letter from M Schmitt
YY	Letter from M Shugrue

ZZ	Letter from L Engelman
AAA	Letter from M Lepkowski
BBB	Letter from A Basu
CCC	2018 Drinking Water Report Natural Resources
DDD	Letter of Margaret Miner
EEE	State Statute
FFF	Letter from M Anthony
GGG	Minutes of the East Lyme Inland Wetlands Agency May 18 and June 8, 2020
HHH	Letter of D Diehl

MOTION: (Berger/Chantrell) to take a short break. Vote: Approved Unanimously. 9:30-9:40.

P. Dagle, BOS liaison thought the URA should have some increase but the justification for the increase is key. He stated the public's questions should be addressed.
Cheryl Lozanov, 9 West Society Rd -stated the agency should look at how this proposed regulation would affect other regulations.

The following exhibits/letters were read into the record:

Attorney Zamarka, referenced R. Blatt's letter which states that Chairman Upton and Vice Chairman Chantrell have a conflict of interest and therefore should recuse themselves. Zamarka stated it was up to the individual member to determine if they can be fair and impartial. G. Upton stated he does not have a predetermined position and has 30 acres in town that would be effected if the text language was adopted. K. Chantrell stated she does not have a predetermined bias and the Cease and Desist order against her was fully satisfied and she restored the area in question.
Attorney Zamarka suggested the Agency take in the information they received from the public and decide if there is sufficient evidence in the record to constitute a change in the regulations and then decide if the Public Hearing stay open or to close it.
MOTION: (Schmitt/Berger) to keep open the Public Hearing until the August 10, meeting. Vote: Approved. In favor-Chantrell, Berger, Ostfeld, Koch, Phimister, Schmitt, Rhein. Opposed-Upton. Abstaining-none.
MOTION: (Upton) to enter minutes from the agency's meetings from January 1, 2019 until the present. Motion failed for lack of a second.
MOTION: (Chantrell/Upton) to enter the minutes from the last two meetings into the Public Hearing. Vote: Approved Unanimously.
MOTION: (Chantrell/Schmitt) to schedule a special meeting for the show cause hearing and the Creek Rd /21 Marshfield Rd application for 6:00 PM, on August 10, 2020. Vote: Approved Unanimously.
G. Upton read Chapter 444, 22A-44A of the Connecticut General Statutes.

2. ADJOURNMENT:
MOTION: (Schmitt/Phimister) to adjourn at 11:35. Vote: Approved Unanimously.

Respectfully Submitted

Sue Spang
Recording Secretary

EXHIBIT SSS

ANNUAL WATER QUALITY REPORT

Water testing performed in 2007

EAST LYME WATER AND
SEWER COMMISSION

PWS ID#: CT0450011

Meeting the Challenge

We once again present to you our annual water quality report. This edition covers all testing completed from January 1 through December 31, 2007. Over the years, we have dedicated ourselves to producing drinking water that meets all state and federal drinking water standards. We continually strive to adopt new and better methods for delivering the best quality drinking water to you. In 2007, we refurbished the 1.3 million gallon water storage tank on Boston Post Road. This included the installation of a passive mixing system to better circulate the water in the tank and improve water quality. An investigation was also conducted to evaluate the feasibility of converting to system-wide chlorine disinfection. Investigations to obtain new water supply sources are also underway. We remain vigilant in meeting the challenges of source water protection, water conservation and community education while continuing to serve the needs of all our water users.

Please share with us your thoughts about the information in this report. After all, well-informed customers are our best allies.

Source Water Assessment

The State of Connecticut Department of Public Health (DPH) in cooperation with the Department of Environmental Protection (DEP) completed source water assessments for all of the East Lyme Water Department's public water supply sources. The sources were rated based on their environmental sensitivity, potential risk factors, and source protection needs. The rating does not necessarily imply poor water quality but indicates susceptibility to potential sources of contamination.

The Bride Lake well field includes Well 2, Well 3, and Well 3A and received a low overall susceptibility rating. The remaining well fields, which include the Gorton Pond well field (Well 1A and Well 6), the Dodge Pond well field (Well 4A), and Well 5, received moderate overall susceptibility ratings. The source water assessments are available on the Connecticut Department of Public Health, Drinking Water Division's Web site at www.dph.state.ct.us/BRS/water/dwd.htm.

Important Health Information

Sources of lead in drinking water includes corrosion of household plumbing systems and erosion of natural deposits. Infants and children who drink water containing lead in excess of the action level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink this water over many years could develop kidney problems or high blood pressure.

Sources of copper in drinking water includes corrosion of household plumbing systems, erosion of natural deposits and leaching from wood preservatives. Copper is an essential nutrient, but some people who drink water containing copper in excess of the action level over a relatively short amount of time could experience gastrointestinal distress. Some people who drink water containing copper in excess of the action level over many years could suffer liver or kidney damage. People with Wilson's Disease should consult their personal doctor.

Some people may be more vulnerable to contaminants in drinking water than the general population. Immunocompromised persons such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants may be particularly at risk from infections. These people should seek advice about drinking water from their health care providers. The U.S. EPA/CDC (Centers for Disease Control and Prevention) guidelines on appropriate means to lessen the risk of infection by *Cryptosporidium* and other microbial contaminants are available from the Safe Drinking Water Hotline at (800) 426-4791.

Source Water Protection

"Level A" aquifer mapping is being developed for all of our water supply sources. The mapping will more accurately identify the zone of influence for our water supply wells and will be used in the future to regulate land use activities that may affect water quality.

Substances That Could Be in Water

To ensure that tap water is safe to drink, the U.S. EPA prescribes regulations limiting the amount of certain contaminants in water provided by public water systems. U.S. Food and Drug Administration regulations establish limits for contaminants in bottled water, which must provide the same protection for public health. Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk.

The sources of drinking water (both tap water and bottled water) include rivers, lakes, streams, ponds, reservoirs, springs, and wells. As water travels over the surface of the land or through the ground, it dissolves naturally occurring minerals, and, in some cases, radioactive material and substances resulting from the presence of animals or from human activity. Substances that may be present in source water include

Microbial Contaminants, such as viruses and bacteria, which may come from sewage treatment plants, septic systems, agricultural livestock operations, or wildlife;

Inorganic Contaminants, such as salts and metals, which can be naturally occurring or may result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining, or farming;

Pesticides and Herbicides, which may come from a variety of sources such as agriculture, urban stormwater runoff, and residential uses;

Organic Chemical Contaminants, including synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production, and may also come from gas stations, urban stormwater runoff, and septic systems;

Radioactive Contaminants, which can be naturally occurring or may be the result of oil and gas production and mining activities.

For more information about contaminants and potential health effects, call the U.S. EPA's Safe Drinking Water Hotline at (800) 426-4791.

MTBE in the News

MTBE (Methyl tert-Butyl Ether) belongs to a group of chemicals commonly known as fuel oxygenates. Oxygenates are added to gasoline to reduce carbon monoxide and ozone levels in the air caused by auto emissions.

MTBE contamination of drinking water sources may result from leaking fuel storage tanks, pipelines, refueling spills, consumer disposal of old gasoline, emissions from older marine engines, and to a lesser degree, stormwater runoff and precipitation mixed with MTBE in the air. Currently, the primary concern about MTBE in drinking water is that it causes taste and odor problems. There are no data showing significant health risks of MTBE at low-exposure levels in drinking water; however, it is a potential human carcinogen at high doses. In December 1997, the U.S. EPA issued a drinking water advisory stating that it is unlikely that MTBE in drinking water at concentrations of 20 to 40 ppb will cause adverse health effects. Continuing research by the U.S. EPA and others is expected to help determine more precisely the potential for adverse health effects from MTBE in drinking water.

In an effort to better balance the air-quality benefits and water-quality concerns associated with oxygenates in gasoline, the U.S. EPA now requires reducing or eliminating MTBE as a fuel oxygenate. Also, the agency is considering setting health standards for MTBE and is currently gathering information from utilities across the country on the occurrence of MTBE. For a more complete discussion, visit the U.S. EPA's MTBE Web site at www.epa.gov/mtbe/faq.htm.

Questions?

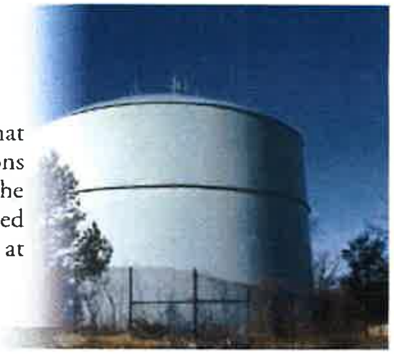
For more information about this report, or for any questions relating to your drinking water, please call Bradford C. Kargl, Municipal Utility Engineer, at (860) 739-6931.

Community Participation

You are invited to participate in our public forum and voice your concerns about your drinking water. We meet the fourth Tuesday of each month beginning at 7:00 p.m. at the East Lyme Town Hall, 108 Pennsylvania Avenue, Niantic, Connecticut.

Where Does My Water Come From?

The Town of East Lyme customers depend on a water supply that comes from seven groundwater sources. Wells are at various locations throughout the town in two separate aquifers. Our water supply is part of the Pattagansett and Bride Brook aquifers. To learn more about our watershed on the Internet, go to the U.S. EPA's Surf Your Watershed Web site at www.epa.gov/surf.



MONITORING AND REPORTING VIOLATION

Regulations of Connecticut State Agencies (RCSA) Section 19-13-B102 requires that suppliers of public water must conduct or have specific laboratory tests to monitor the water quality of their water supply to ensure that it meets with the current drinking water standards. Failure to conduct timely monitoring and/or report results of such monitoring to the State Department of Public Health Drinking Water Section constitutes a violation of the RCSA. As your public water supplier, we must formally notify customers of all monitoring violations, or face additional RCSA violations. Please share this information with all the other people who drink this water, especially those who may have not received this notice directly (for example, people in apartments, nursing homes, schools, and businesses). You can do this by posting this notice in a public place or distributing copies by hand or mail.

We are required to monitor your drinking water for specific contaminants on a regular basis. Results of regular monitoring are an indicator of whether or not our drinking water meets health standards. Due to an administrative oversight, the certified laboratory contracted to do our water quality testing did not complete testing for the parameter listed below:

Gross Beta Particle Activity (WSF ID: 00705; Monitoring Period: 7/1/07–9/30/07).

We have seven active water supply wells that are routinely tested. The well that was not tested for the parameter listed above was Well 4A.

Testing was completed by the next monitoring period and the results were found to meet the current drinking water standards. Steps have been taken to improve the internal tracking of scheduled testing for future monitoring periods.

At this time no precautions by our customers/residents are necessary. We returned to compliance by the next monitoring period, 10/01/2007–12/31/2007.

If you have any questions, please contact the Water Department at (860) 739-6931, Ext. 104 or Ext. 139, or the East Lyme Water and Sewer Commission by mail at PO Box 519, 108 Pennsylvania Avenue, Niantic, CT 06357.

Lead and Drinking Water

If present, elevated levels of lead can cause serious health problems, especially for pregnant women and young children. Lead in drinking water is primarily from materials and components associated with service lines and home plumbing. The East Lyme Water and Sewer Commission is responsible for providing high quality drinking water, but cannot control the variety of materials used in plumbing components. When your water has been sitting for several hours, you can minimize the potential for lead exposure by flushing your tap for 30 seconds to 2 minutes before using water for drinking or cooking. If you are concerned about lead in your water, you may wish to have your water tested. Information on lead in drinking water, testing methods, and steps you can take to minimize exposure is available from the Safe Drinking Water Hotline or at www.epa.gov/safewater/lead.

Sampling Results

During the past year we have taken hundreds of water samples in order to determine the presence of any radioactive, biological, inorganic, volatile organic or synthetic organic contaminants. The table below shows those contaminants that were detected in the water. Although all of the substances listed here are under the Maximum Contaminant Level (MCL), we feel it is important that you know exactly what was detected and how much of the substance was present in the water.

The state requires us to monitor for certain substances less than once per year because the concentrations of these substances do not change frequently. In these cases, the most recent sample data are included, along with the year in which the sample was taken.

REGULATED SUBSTANCES				Distribution		Well 1A		Well 2		Well 3			
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	MCLG [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Combined Radium (pCi/L)	2007	5	0	NA	NA	1.53	NA	0.65	NA	0.46	NA	No	Erosion of natural deposits
Fluoride[1] (ppm)	2007	4	4	NA	NA	1.04	0.70–1.04	1.03	0.72–1.03	1.22	0.90–1.22	No	Erosion of natural deposits; Water additive which promotes strong teeth; Discharge from fertilizer and aluminum factories
Gross Alpha Net (pCi/L)	2007	15	NA	NA	NA	ND	NA	ND	NA	ND	NA	No	Erosion of natural deposits
Gross Beta Particle Activity[2] (pCi/L)	2007	50	NA	NA	NA	NA	NA	NA	NA	NA	NA	No	Decay of natural and man-made deposits
Nickel (ppm)	2005	0.1	NA	NA	NA	ND	NA	ND	NA	ND	NA	No	Naturally occuring
Nitrate (ppm)	2007	10	10	NA	NA	0.59	NA	0.95	NA	0.54	NA	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
Tetrachloroethylene (ppb)	2007	5	0	NA	NA	0.8	ND–0.8	ND	NA	ND	NA	No	Discharge from factories and dry cleaners
Turbidity[3] (NTU)	2007	5	NA	0.7	ND–0.7	1.1	ND–1.1	0.2	ND–0.2	0.2	ND–0.2	No	Soil runoff

REGULATED SUBSTANCES				Well 3A		Well 4A		Well 5		Well 6			
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	MCLG [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Combined Radium (pCi/L)	2007	5	0	0.46	NA	ND	NA	0.92	NA	0.33	NA	No	Erosion of natural deposits
Fluoride[1] (ppm)	2007	4	4	1.08	0.77–1.08	1.15	0.81–1.15	1.71	0.93–1.71	1.25	0.72–1.25	No	Erosion of natural deposits; Water additive which promotes strong teeth; Discharge from fertilizer and aluminum factories
Gross Alpha Net (pCi/L)	2007	15	NA	ND	NA	3.3	ND–3.3	ND	NA	ND	NA	No	Erosion of natural deposits
Gross Beta Particle Activity[2] (pCi/L)	2007	50	NA	NA	NA	31.6	31.5–31.6	NA	NA	NA	NA	No	Decay of natural and man-made deposits
Nickel (ppm)	2005	0.1	NA	0.02	NA	ND	NA	ND	NA	ND	NA	No	Naturally occuring
Nitrate (ppm)	2007	10	10	0.54	NA	3.89	NA	1.44	NA	1.05	NA	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
Tetrachloroethylene (ppb)	2007	5	0	ND	NA	ND	NA	ND	NA	1.3	1.0–1.3	No	Discharge from factories and dry cleaners
Turbidity[3] (NTU)	2007	5	NA	0.4	ND–0.4	0.3	ND–0.3	1.2	ND–1.2	0.2	ND–0.2	No	Soil runoff

Tap water samples were collected from 30 sample sites throughout the community (Lead was not detected at the 90th percentile)

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	ACTION LEVEL	MCLG	AMOUNT DETECTED (90TH%TILE)	SITES ABOVE ACTION LEVEL	VIOLATION	TYPICAL SOURCE
Copper (ppm)	2005	1.3	1.3	0.55	1	No	Corrosion of household plumbing systems; Erosion of natural deposits; Leaching from wood preservatives

UNREGULATED SUBSTANCES[4]		Distribution		Well 1A		Well 2		Well 3		
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Dieldrin (ppb)	2007	NA	NA	ND	NA	0.007	ND–0.007	0.003	0.002–0.003	Runoff from agricultural activity
MTBE (methyl t-butyl ether) (ppb)	2007	NA	NA	11.7	3.1–11.7	ND	NA	ND	NA	Petroleum tanks above and below ground
Sodium (ppm)	2007	24	14–24	21	15–21	23	20–23	20	18–20	Naturally occuring; Road salt
Sulfate (ppm)	2005	NA	NA	10	NA	1	NA	9	NA	Runoff/leaching from natural deposits; Industrial wastes

UNREGULATED SUBSTANCES[4]		Well 3A		Well 4A		Well 5		Well 6		
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Dieldrin (ppb)	2007	0.003	0.002–0.003	0.005	0.002–0.005	ND	NA	0.002	0.002–0.002	Runoff from agricultural activity
MTBE (methyl t-butyl ether) (ppb)	2007	ND	NA	ND	NA	ND	NA	11.0	4.5–11.0	Petroleum tanks above and below ground
Sodium (ppm)	2007	20	19–20	30	18–30	11	10–11	18	17–18	Naturally occuring; Road salt
Sulfate (ppm)	2005	1	NA	11	NA	10	NA	21	NA	Runoff/leaching from natural deposits; Industrial wastes

Definitions

AL (Action Level): The concentration of a contaminant which, if exceeded, triggers treatment or other requirements which a water system must follow.

MCL (Maximum Contaminant Level): The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

MCLG (Maximum Contaminant Level Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

MRDL (Maximum Residual Disinfectant Level): The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

MRDLG (Maximum Residual Disinfectant Level Goal): The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.

NA: Not applicable

ND (Not detected): Indicates that the substance was not found by laboratory analysis.

NTU (Nephelometric Turbidity Units): Measurement of the clarity, or turbidity, of water. Turbidity in excess of 5 NTU is just noticeable to the average person.

pCi/L (picocuries per liter): A measure of radioactivity.

ppb (parts per billion): One part substance per billion parts water (or micrograms per liter).

ppm (parts per million): One part substance per million parts water (or milligrams per liter).

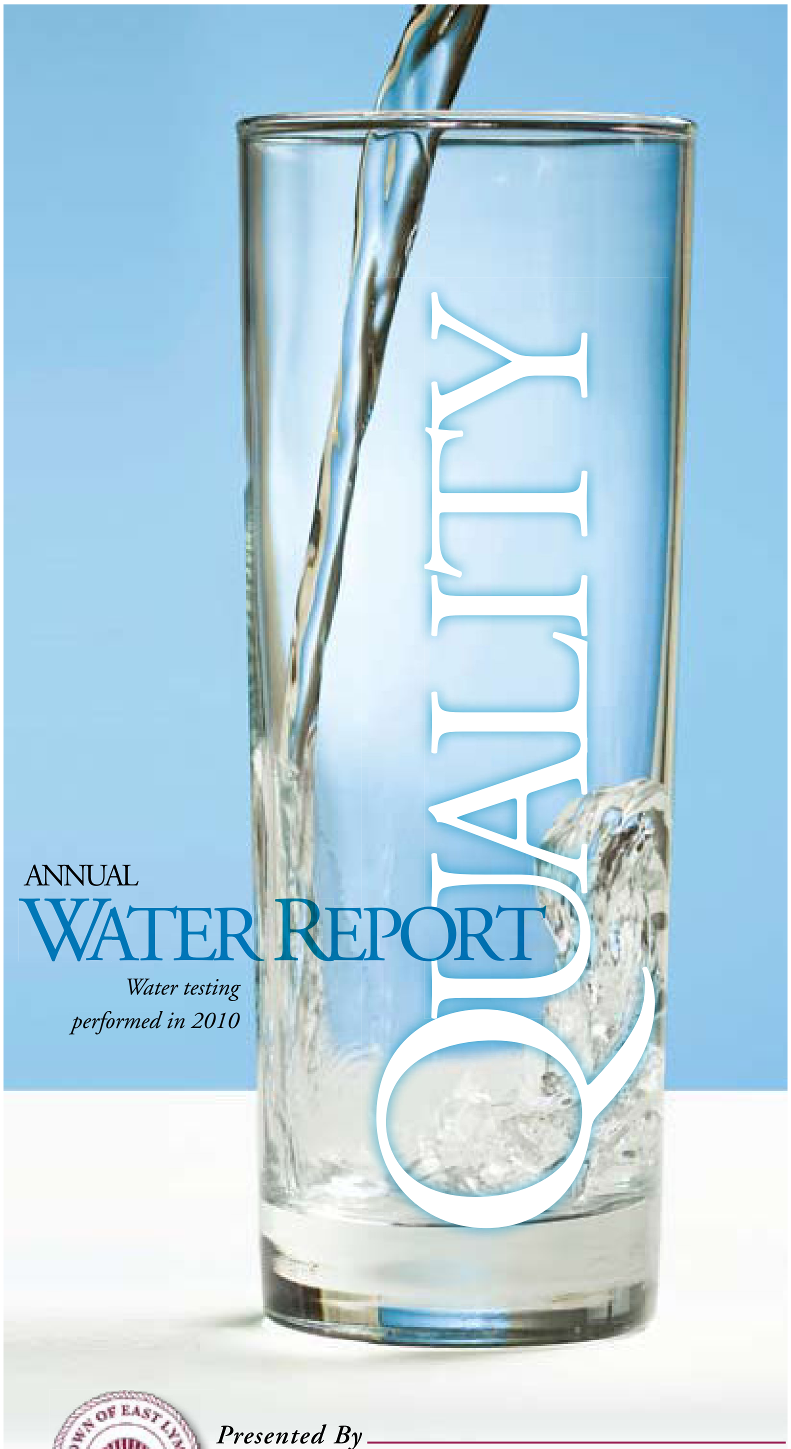
TT (Treatment Technique): A required process intended to reduce the level of a contaminant in drinking water.

[1] The values reported under Amount Detected are the highest monthly averages for the twelve-month period.

[2] The MCL for beta particles is 4 mrem/yr. The U.S. EPA considers 50 pCi/L to be the level of concern for beta particles.

[3] Turbidity is a measure of the cloudiness of the water. It is monitored because it is a good indicator of water quality and the effectiveness of disinfectants.

[4] Unregulated contaminant monitoring helps the U.S. EPA to determine where certain contaminants occur and whether the agency should consider regulating these contaminants in the future.



ANNUAL WATER QUALITY REPORT

Water testing performed in 2010

Presented By

East Lyme Water and Sewer Commission

PWS ID#: CT0450011

Quality First

Once again we present to you our annual water quality report. This report covers all testing performed between January 1 and December 31, 2010. We continue to take steps to improve water supply capacity, water quality, and system reliability. This includes the development of Replacement Wells 2A and 3B, recent completion of the necessary infrastructure for improved chemical handling and storage capabilities, and the installation of system-wide chlorine disinfection facilities. We anticipate that disinfection of the water system will be initiated sometime this summer and phased in over a 12-month period.

Funding is in place for the construction of a regional interconnection between the Town of East Lyme and the New London Water Treatment Plant. The interconnection will improve water supply capacity to meet peak demands that occur during the summertime and will provide system redundancy in the event of a water supply emergency. The funding will be in the form of loans and subsidies that will be made available through the Drinking Water State Revolving Fund.

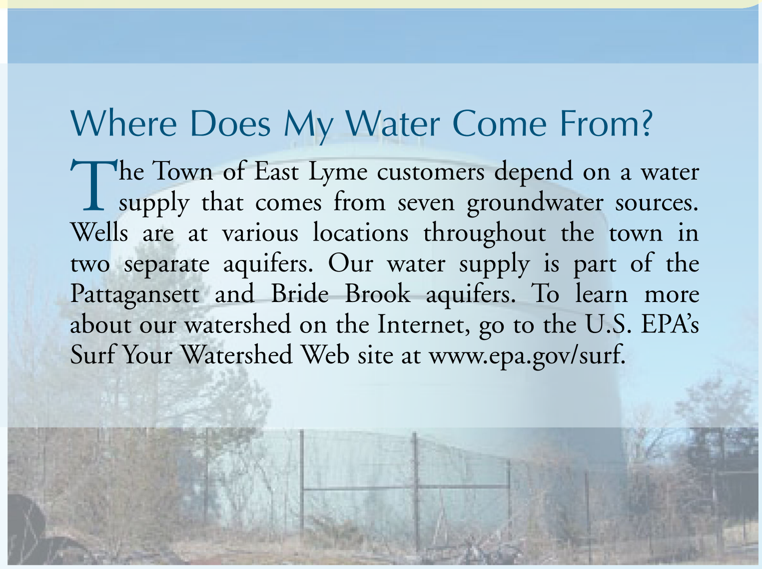
To better manage water demand and improve customer service, we continue to study the implementation of a radio-based meter reading system which can provide daily readings, quickly detect leaks, and analyze consumption patterns.

We appreciate your past efforts to help conserve water, especially during the summer months. While East Lyme has significant water resources, they have to be carefully managed and balanced against competing uses.

We encourage you to share your thoughts with us on the information contained in this report. Should you ever have any questions or concerns, we are always available to assist you.

Where Does My Water Come From?

The Town of East Lyme customers depend on a water supply that comes from seven groundwater sources. Wells are at various locations throughout the town in two separate aquifers. Our water supply is part of the Pattagansett and Bride Brook aquifers. To learn more about our watershed on the Internet, go to the U.S. EPA's Surf Your Watershed Web site at www.epa.gov/surf.



Important Health Information

Sources of lead in drinking water includes corrosion of household plumbing systems and erosion of natural deposits. Infants and children who drink water containing lead in excess of the Action Level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink this water over many years could develop kidney problems or high blood pressure.

Sources of copper in drinking water includes corrosion of household plumbing systems, erosion of natural deposits, and leaching from wood preservatives. Copper is an essential nutrient, but some people who drink water containing copper in excess of the Action Level over a relatively short amount of time could experience gastrointestinal distress. Some people who drink water containing copper in excess of the action level over many years could suffer liver or kidney damage. People with Wilson's Disease should consult their personal doctors.

Some people may be more vulnerable to contaminants in drinking water than the general population. Immunocompromised persons such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants may be particularly at risk from infections. These people should seek advice about drinking water from their health care providers. The U.S. EPA/CDC (Centers for Disease Control and Prevention) guidelines on appropriate means to lessen the risk of infection by Cryptosporidium and other microbial contaminants are available from the Safe Drinking Water Hotline at (800) 426-4791.

Water Conservation

You can play a role in conserving water and save yourself money in the process by becoming conscious of the amount of water your household is using and by looking for ways to use less whenever you can. It is not hard to conserve water. Here are a few tips:

- Automatic dishwashers use 15 gallons for every cycle, regardless of how many dishes are loaded. So get a run for your money and load it to capacity.
- Turn off the tap when brushing your teeth.
- Check every faucet in your home for leaks. Just a slow drip can waste 15 to 20 gallons a day. Fix it and you can save almost 6,000 gallons per year.
- Check your toilets for leaks by putting a few drops of food coloring in the tank. Watch for a few minutes to see if the color shows up in the bowl. It is not uncommon to lose up to 100 gallons a day from an invisible toilet leak. Fix it and you save more than 30,000 gallons a year.
- Use your water meter to detect hidden leaks. Simply turn off all taps and water-using appliances. Then check the meter after 15 minutes. If it moved, you have a leak.

MTBE in the News

MTBE (Methyl tert-Butyl Ether) belongs to a group of chemicals commonly known as fuel oxygenates. Oxygenates are added to gasoline to reduce carbon monoxide and ozone levels in the air caused by auto emissions.

MTBE contamination of drinking water sources may result from leaking fuel storage tanks, pipelines, refueling spills, consumer disposal of old gasoline, emissions from older marine engines, and, to a lesser degree, stormwater runoff and precipitation mixed with MTBE in the air. Currently, the primary concern about MTBE in drinking water is that it causes taste and odor problems. There are no data showing significant health risks of MTBE at low-exposure levels in drinking water; however, it is a potential human carcinogen at high doses. In December 1997, the U.S. EPA issued a drinking water advisory stating that it is unlikely that MTBE in drinking water at concentrations of 20 to 40 ppb will cause adverse health effects. Continuing research by the U.S. EPA and others is expected to help determine more precisely the potential for adverse health effects from MTBE in drinking water.

In an effort to better balance the air-quality benefits and water-quality concerns associated with oxygenates in gasoline, the U.S. EPA now requires reducing or eliminating MTBE as a fuel oxygenate. Also, the agency is considering setting health standards for MTBE and is currently gathering information from utilities across the country on the occurrence of MTBE. For a more complete discussion, visit the U.S. EPA's MTBE Web site at www.epa.gov/mtbe/faq.htm.

Questions?

For more information about this report, or for any questions relating to your drinking water, please call Bradford C. Kargl, Municipal Utility Engineer, at (860) 739-6931.

Lead and Drinking Water

If present, elevated levels of lead can cause serious health problems, especially for pregnant women and young children. Lead in drinking water is primarily from materials and components associated with service lines and home plumbing. The East Lyme Water and Sewer Commission is responsible for providing high-quality drinking water, but we cannot control the variety of materials used in plumbing components. When your water has been sitting for several hours, you can minimize the potential for lead exposure by flushing your tap for 30 seconds to 2 minutes before using water for drinking or cooking. If you are concerned about lead in your water, you may wish to have your water tested. Information on lead in drinking water, testing methods, and steps you can take to minimize exposure is available from the Safe Drinking Water Hotline or at www.epa.gov/safewater/lead.

Community Participation

You are invited to participate in our public forum and voice your concerns about your drinking water. We meet the fourth Tuesday of each month beginning at 7:00 p.m. at the East Lyme Town Hall, 108 Pennsylvania Avenue, Niantic, Connecticut.

Source Water Assessment

The State of Connecticut Department of Public Health (DPH) in cooperation with the Department of Environmental Protection (DEP) completed source water assessments for all of the East Lyme Water Department's public water supply sources. The sources were rated based on their environmental sensitivity, potential risk factors, and source protection needs. The rating does not necessarily imply poor water quality but indicates susceptibility to potential sources of contamination.

The Bride Lake well field includes Well 2, Well 3, and Well 3A; it received a low overall susceptibility rating. The remaining well fields, which include the Gorton Pond well field (Well 1A and Well 6), the Dodge Pond well field (Well 4A), and Well 5 received moderate overall susceptibility ratings. The source water assessments are available on the Connecticut Department of Public Health, Drinking Water Division's Web site at www.dph.state.ct.us/BRS/water/dwd.htm.

Source Water Protection

"Level A" aquifer mapping has been completed for all of our water supply sources and has been approved by the State regulatory agencies. The mapping more accurately identifies the zone of influence for our water supply wells and will be used in the future to regulate land use activities that may affect water quality.

Substances That Could Be in Water

To ensure that tap water is safe to drink, the U.S. EPA prescribes regulations limiting the amount of certain contaminants in water provided by public water systems. U.S. Food and Drug Administration regulations establish limits for contaminants in bottled water, which must provide the same protection for public health. Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk.

The sources of drinking water (both tap water and bottled water) include rivers, lakes, streams, ponds, reservoirs, springs, and wells. As water travels over the surface of the land or through the ground, it dissolves naturally occurring minerals, in some cases, radioactive material, and substances resulting from the presence of animals or from human activity. Substances that may be present in source water include:

Microbial Contaminants, such as viruses and bacteria, which may come from sewage treatment plants, septic systems, agricultural livestock operations, or wildlife;

Inorganic Contaminants, such as salts and metals, which can be naturally occurring or may result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining, or farming;

Pesticides and Herbicides, which may come from a variety of sources such as agriculture, urban stormwater runoff, and residential uses;

Organic Chemical Contaminants, including synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production and may also come from gas stations, urban stormwater runoff, and septic systems;

Radioactive Contaminants, which can be naturally occurring or may be the result of oil and gas production and mining activities.

For more information about contaminants and potential health effects, call the U.S. EPA's Safe Drinking Water Hotline at (800) 426-4791.

Sampling Results

During the past year we have taken hundreds of water samples in order to determine the presence of any radioactive, biological, inorganic, volatile organic, or synthetic organic contaminants. The tables below show only those contaminants that were detected in the water. The State requires us to monitor for certain substances less often than once per year because the concentrations of these substances do not change frequently. In these cases, the most recent sample data are included, along with the year in which the sample was taken.

REGULATED SUBSTANCES

				Distribution		Well 1A		Well 2A		Well 3			
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	MCLG [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Alpha Emitters (pCi/L)	2010	15	0	NA	NA	3.15	NA	ND	NA	ND	NA	No	Erosion of natural deposits
Fluoride[1] (ppm)	2010	4	4	NA	NA	1.08	0.71–1.08	1.24	0.82–1.24	1.4	0.93–1.4	No	Erosion of natural deposits; Water additive that promotes strong teeth; Discharge from fertilizer and aluminum factories
Nitrate (ppm)	2010	10	10	NA	NA	0.66	NA	1.63	NA	0.57	NA	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
Nitrite (ppm)	2010	1	1	NA	NA	ND	NA	0.001	NA	ND	NA	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
Tetrachloroethylene (ppb)	2010	5	0	NA	NA	ND	NA	ND	NA	ND	NA	No	Discharge from factories and dry cleaners
Turbidity[2] (NTU)	2010	5	NA	0.9	ND–0.9	3.7	ND–3.7	0.4	ND–0.4	0.2	ND–0.2	No	Soil runoff

				Well 3A		Well 4A		Well 5		Well 6			
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	MCLG [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Alpha Emitters (pCi/L)	2010	15	0	ND	NA	ND	NA	ND	NA	ND	NA	No	Erosion of natural deposits
Fluoride[1] (ppm)	2010	4	4	1.24	0.97–1.24	1.26	0.85–1.26	1.5	0.80–1.5	1.3	1.1–1.3	No	Erosion of natural deposits; Water additive that promotes strong teeth; Discharge from fertilizer and aluminum factories
Nitrate (ppm)	2010	10	10	0.57	NA	3.62	NA	1.48	NA	1.13	NA	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
Nitrite (ppm)	2010	1	1	ND	NA	ND	NA	0.001	NA	ND	NA	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
Tetrachloroethylene (ppb)	2010	5	0	ND	NA	ND	NA	ND	NA	1.0	0.7–1.0	No	Discharge from factories and dry cleaners
Turbidity[2] (NTU)	2010	5	NA	0.2	ND–0.2	0.4	ND–0.4	0.3	ND–0.3	0.6	ND–0.6	No	Soil runoff

Tap water samples were collected for lead and copper analyses from sample sites throughout the community

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AL	MCLG	AMOUNT DETECTED (90TH%TILE)	SITES ABOVE AL/ TOTAL SITES	VIOLATION	TYPICAL SOURCE
Copper (ppm)	2008	1.3	1.3	0.48	0/30	No	Corrosion of household plumbing systems; Erosion of natural deposits; Leaching from wood preservatives

SECONDARY SUBSTANCES

				Distribution		Well 1A		Well 2A		Well 3			
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	SMCL	MCLG	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Chloride (ppm)	2008	250	NA	NA	NA	18	NA	22	NA	33	NA	No	Runoff/leaching from natural deposits
Sulfate (ppm)	2008	250	NA	ND	NA	ND	NA	ND	NA	12	NA	No	Runoff/leaching from natural deposits; Industrial wastes

				Well 3A		Well 4A		Well 5		Well 6			
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	SMCL	MCLG	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Chloride (ppm)	2008	250	NA	33	NA	30	NA	11	NA	33	NA	No	Runoff/leaching from natural deposits
Sulfate (ppm)	2008	250	NA	12	NA	20	NA	13	NA	19	NA	No	Runoff/leaching from natural deposits; Industrial wastes

UNREGULATED AND OTHER SUBSTANCES

		Distribution		Well 1A		Well 2A		Well 3		
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Dieldrin (ppb)	2009	NA	NA	ND	NA	0.003	ND–0.003	0.002	NA	Runoff from agricultural activity
MTBE (Methyl tert-Butyl Ether) (ppb)	2010	NA	NA	ND	NA	ND	NA	ND	NA	Petroleum tanks above and below ground
Sodium (ppm)	2010	29	15–29	28	16–28	19	18–19	19	19–20	Naturally occurring; Road salt

		Well 3A		Well 4A		Well 5		Well 6		
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Dieldrin (ppb)	2009	0.002	NA	0.004	0.002–0.004	ND	NA	0.002	NA	Runoff from agricultural activity
MTBE (Methyl tert-Butyl Ether) (ppb)	2010	ND	NA	ND	NA	ND	NA	6.2	4.5–6.2	Petroleum tanks above and below ground
Sodium (ppm)	2010	19	19–21	33	27–33	10	10–11	21	19–21	Naturally occurring; Road salt

[1] The values reported under Amount Detected are the highest monthly averages for the twelve-month period.

[2] Turbidity is a measure of the cloudiness of the water. It is monitored because it is a good indicator of water quality and the effectiveness of disinfectants.

Definitions

AL (Action Level): The concentration of a contaminant which, if exceeded, triggers treatment or other requirements that a water system must follow.

MCL (Maximum Contaminant Level): The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology. Secondary MCLs (SMCL) are set for the control of taste and odor.

MCLG (Maximum Contaminant Level Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

MRDL (Maximum Residual Disinfectant Level): The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

MRDLG (Maximum Residual Disinfectant Level Goal): The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.

NA: Not applicable

ND (Not detected): Indicates that the substance was not found by laboratory analysis.

NTU (Nephelometric Turbidity Units): Measurement of the clarity, or turbidity, of water. Turbidity in excess of 5 NTU is just noticeable to the average person.

pCi/L (picocuries per liter): A measure of radioactivity.

ppb (parts per billion): One part substance per billion parts water (or micrograms per liter).

ppm (parts per million): One part substance per million parts water (or milligrams per liter).

TT (Treatment Technique): A required process intended to reduce the level of a contaminant in drinking water.

Annual
WATER QUALITY REPORT

Reporting Year 2013

Presented By
East Lyme
Water and Sewer Commission

PWS ID#: CT0450011

There When You Need Us

Once again we present our annual water quality report covering testing performed between January 1 and December 31, 2013. We are committed to producing drinking water that meets all state and federal standards and continually strive to adopt new methods for delivering the best-quality drinking water to you.

We face new challenges as our community grows, regulatory burden increases, and the water system infrastructure ages. The water interconnection between East Lyme and New London's water treatment plant at Lake Konomac will help to meet those challenges by supplying water to manage peak demands during the summertime and providing system redundancy during water supply emergencies. Also, by sending water in both directions depending on the season, a water balance can be achieved that will minimize the impact on existing water resources. The interconnection will be on line this summer but will not reach full operational capacity until next year.

In the next few years, other initiatives are being considered to improve water quality, customer service, and system reliability. They include filtration at Wells 1A and 2A, implementation of a radio-based meter reading system, and water main rehabilitation.

Please remember that we are always available to assist you should you ever have any questions or concerns about your water.

QUESTIONS?

For more information about this report, or for any questions relating to your drinking water, please call Bradford C. Kargl, Municipal Utility Engineer, at (860) 739-6931.

Substances That Could Be in Water

To ensure that tap water is safe to drink, the U.S. EPA prescribes regulations limiting the amount of certain contaminants in water provided by public water systems. U.S. Food and Drug Administration regulations establish limits for contaminants in bottled water, which must provide the same protection for public health. Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk.

The sources of drinking water (both tap water and bottled water) include rivers, lakes, streams, ponds, reservoirs, springs, and wells. As water travels over the surface of the land or through the ground, it dissolves naturally occurring minerals, in some cases, radioactive material, and substances resulting from the presence of animals or from human activity. Substances that may be present in source water include:

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Pesticides and Herbicides, which may come from a variety of sources such as agriculture, urban stormwater runoff, and residential uses;

Organic Chemical Contaminants, including synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production and may also come from gas stations, urban stormwater runoff, and septic systems;

Radioactive Contaminants, which can be naturally occurring or may be the result of oil and gas production and mining activities.

For more information about contaminants and potential health effects, call the U.S. EPA's Safe Drinking Water Hotline at (800) 426-4791.

How Long Can I Store Drinking Water?

The disinfectant in drinking water will eventually dissipate even in a closed container. If that container housed bacteria before it was filled with the tap water, the bacteria may continue to grow once the disinfectant has dissipated. Some experts believe that water could be stored up to six months before needing to be replaced. Refrigeration will help slow the bacterial growth.

Community Participation

You are invited to participate in our public forum and voice your concerns about your drinking water. We meet the fourth Tuesday of each month beginning at 7:00 pm at the East Lyme Town Hall, 108 Pennsylvania Avenue, Niantic.

Where Does My Water Come From?

The Town of East Lyme customers depend on a water supply that comes from seven groundwater sources. Wells are at various locations throughout the town in two separate aquifers. Our water supply is part of the Pattagansett and Bride Brook aquifers. To learn more about our watershed on the Internet, go to the U.S. EPA's Surf Your Watershed Web site at www.epa.gov/surf.

Lead in Home Plumbing

If present, elevated levels of lead can cause serious health problems, especially for pregnant women and young children. Lead in drinking water is primarily from materials and components associated with service lines and home plumbing. We are responsible for providing high-quality drinking water, but cannot control the variety of materials used in plumbing components. When your water has been sitting for several hours, you can minimize the potential for lead exposure by flushing your tap for 30 seconds to 2 minutes before using water for drinking or cooking. If you are concerned about lead in your water, you may wish to have your water tested. Information on lead in drinking water, testing methods, and steps you can take to minimize exposure is available from the Safe Drinking Water Hotline or at www.epa.gov/safewater/lead.

Benefits of Chlorination

Disinfection, a chemical process used to control disease-causing microorganisms by killing or inactivating them, is unquestionably the most important step in drinking water treatment. By far, the most common method of disinfection in North America is chlorination.

Before communities began routinely treating drinking water with chlorine (starting with Chicago and Jersey City in 1908), cholera, typhoid fever, dysentery, and hepatitis A killed thousands of U.S. residents annually. Drinking water chlorination and filtration have helped to virtually eliminate these diseases in the U.S. Significant strides in public health are directly linked to the adoption of drinking water chlorination. In fact, the filtration of drinking water plus the use of chlorine is probably the most significant public health advancement in human history.

How chlorination works:

Potent Germicide Reduction in the level of many disease-causing microorganisms in drinking water to almost immeasurable levels.

Taste and Odor Reduction of many disagreeable tastes and odors like foul-smelling algae secretions, sulfides, and odors from decaying vegetation.

Biological Growth Elimination of slime bacteria, molds, and algae that commonly grow in water supply reservoirs, on the walls of water mains, and in storage tanks.

Chemical Removal of hydrogen sulfide (which has a rotten egg odor), ammonia, and other nitrogenous compounds that have unpleasant tastes and hinder disinfection. It also helps to remove iron and manganese from raw water.

Source Water Protection

Level A aquifer mapping has been completed for all of our water supply sources and has been approved by the state regulatory agencies. The mapping more accurately identifies the zone of influence for our water supply wells and will be used in the future to regulate land use activities that may affect water quality.

Source Water Assessment

The State of Connecticut Department of Public Health (DPH) in cooperation with the Department of Environmental Protection (DEP) completed source water assessments for all of the East Lyme Water Department's public water supply sources. The sources were rated based on their environmental sensitivity, potential risk factors, and source protection needs. The rating does not necessarily imply poor water quality but indicates susceptibility to potential sources of contamination.

The Bride Lake well field includes Well 2A, Well 3A, and Well 3B and received a low overall susceptibility rating. The remaining well fields, which include the Gorton Pond well field (Well 1A and Well 6), the Dodge Pond well field (Well 4A), and Well 5 received moderate overall susceptibility ratings. The source water assessments are available on the Connecticut Department of Public Health, Drinking Water Division's Web site at www.dph.state.ct.us/BRS/water/dwd.htm.

Important Health Information

Sources of lead in drinking water includes corrosion of household plumbing system and erosion of natural deposits. Infants and children who drink water containing lead in excess of the action level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink this water over many years could develop kidney problems or high blood pressure.

Sources of copper in drinking water include corrosion of household plumbing system, erosion of natural deposits, and leaching from wood preservatives. Copper is an essential nutrient, but some people who drink water containing copper in excess of the action level over a relatively short time could experience gastrointestinal distress. Some people who drink water containing copper in excess of the action level over many years could suffer liver or kidney damage. People with Wilson's disease should consult their personal doctor.

Some people may be more vulnerable to contaminants in drinking water than the general population. Immunocompromised persons such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants may be particularly at risk from infections. These people should seek advice about drinking water from their health care providers. The U.S. EPA/CDC (Centers for Disease Control and Prevention) guidelines on appropriate means to lessen the risk of infection by Cryptosporidium and other microbial contaminants are available from the Safe Drinking Water Hotline at (800) 426-4791.

Sampling Results

During the past year we have taken hundreds of water samples in order to determine the presence of any radioactive, biological, inorganic, volatile organic or synthetic organic contaminants. The table below shows only those contaminants that were detected in the water. The state requires us to monitor for certain substances less than once per year because the concentrations of these substances do not change frequently. In these cases, the most recent sample data are included, along with the year in which the sample was taken.

REGULATED SUBSTANCES

				Distribution		Well 1A		Well 2A		Well 3A/3B		Well 4A		Well 5		Well 6			
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	MCLG [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Alpha Emitters (pCi/L)	2013	15	0	NA	NA	ND	NA	ND	NA	ND	NA	ND	NA	3.00	NA	ND	NA	No	Erosion of natural deposits
Chlorine[1] (ppm)	2013	[4]	[4]	NA	NA	0.65	0.27–0.65	0.35	0.22–0.35	0.56	0.23–0.56	0.53	0.18–0.53	0.54	0.31–0.54	0.44	0.22–0.44	No	Water additive used to control microbes
Combined Radium (pCi/L)	2013	5	0	NA	NA	1.13	NA	0.93	NA	0.53	ND–0.53	0.11	NA	0.81	NA	0.45	NA	No	Erosion of natural deposits
Fluoride[1] (ppm)	2013	4	4	NA	NA	1.00	0.79–1.00	1.48	0.90–1.48	0.86	0.72–0.86	0.94	0.76–0.94	0.94	0.72–0.94	0.94	0.75–0.94	No	Erosion of natural deposits; Water additive which promotes strong teeth; Discharge from fertilizer and aluminum factories
Haloacetic Acids [HAA]–Stage 1 (ppb)	2013	60	NA	3.0	ND–3.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	No	By-product of drinking water disinfection
Nitrate (ppm)	2013	10	10	NA	NA	1.02	NA	0.35	NA	0.28	NA	3.52	NA	1.45	NA	0.98	NA	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
TTHMs [Total Trihalomethanes]–Stage 1 (ppb)	2013	80	NA	15.2	2.5–15.2	9.4	ND–9.4	ND	NA	2.1	1.2–2.1	0.5	ND–0.5	ND	NA	ND	NA	No	By-product of drinking water disinfection
Tetrachloroethylene (ppb)	2013	5	0	NA	NA	0.6	ND–0.6	ND	NA	ND	NA	ND	NA	ND	NA	0.5	0.5–0.6	No	Discharge from factories and dry cleaners
Turbidity[2] (NTU)	2013	5	NA	0.6	ND–0.6	0.7	ND–0.7	0.5	ND–0.5	0.5	ND–0.5	0.5	ND–0.5	0.7	ND–0.7	0.6	ND–0.6	No	Soil runoff

Tap water samples were collected for lead and copper analyses from sample sites throughout the community

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AL	MCLG	AMOUNT DETECTED (90TH%TILE)	SITES ABOVE AL/TOTAL SITES	VIOLATION	TYPICAL SOURCE
Copper (ppm)	2013	1.3	1.3	0.54	0/120	No	Corrosion of household plumbing systems; Erosion of natural deposits
Lead (ppb)	2013	15	0	3	1/120	No	Corrosion of household plumbing systems; Erosion of natural deposits

SECONDARY SUBSTANCES

				Well 1A		Well 2A		Well 3A/3B		Well 4A		Well 5		Well 6			
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	SMCL	MCLG	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Chloride (ppm)	2011	250	NA	35	NA	30	NA	29	NA	41	NA	13	NA	50	NA	No	Runoff/leaching from natural deposits
Sulfate (ppm)	2011	250	NA	ND	NA	ND	NA	11	NA	12	NA	11	NA	18	NA	No	Runoff/leaching from natural deposits; Industrial wastes

OTHER UNREGULATED SUBSTANCES

		Well 1A		Well 2A		Well 3A/3B		Well 4A		Well 5		Well 6		
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
MTBE [Methyl tert-Butyl Ether] (ppb)	2013	ND	NA	ND	NA	ND	NA	ND	NA	ND	NA	2.8	ND–2.8	Petroleum tanks above and below ground
Sodium* (ppm)	2013	34	25–34	28	19–28	18[3]	17–18[3]	41	33–41	17	11–17	32	28–32	Naturally occuring; road salt

***Sodium Notice - Be advised that when the sodium concentration exceeds 28 ppm, anyone who has been placed on a sodium restricted diet should inform their physician**

[1] The values reported under Amount Detected are the highest monthly averages for the 12-month period.

[2] Turbidity is a measure of the cloudiness of the water. It is monitored because it is a good indicator of water quality and the effectiveness of disinfectants.

[3] Sampled in 2012.

Definitions

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ANNUAL WATER QUALITY REPORT

WATER TESTING
PERFORMED
IN 2014

Presented By
East Lyme
Water and Sewer Commission

PWS ID#: CT0450011

Our Mission Continues

Once again we present our annual water quality report covering all testing performed between January 1 and December 31, 2014. Most notably, last year marked the 40th anniversary of the Safe Drinking Water Act (SDWA). This rule was created to protect public health by regulating the nation's drinking water supply. We celebrate this milestone as we continue to manage our water system with a mission to deliver the best-quality drinking water. By striving to meet the requirements of the SDWA, we are ensuring a future of healthy, clean drinking water for years to come.

In keeping with our mission, water system improvements have been made over recent years to keep pace with a growing community, increased demand, and an aging infrastructure. The regional interconnection project, completed in 2014, will allow East Lyme to meet peak demands during the summer months while providing system redundancy in the event of a water supply emergency. System-wide disinfection has been implemented to ensure safe drinking water, and water supply well upgrades have been made to provide a more reliable supply.

Going forward, there is an initiative to investigate filtration alternatives for Wells 1A and 2A to remove naturally occurring iron and manganese and further improve water quality. Implementation of a radio-based meter reading system is also being investigated. The system would provide efficient reading of the meters and provide better customer service.

Please remember that we are always available to assist you should you have any questions about your water.

Community Participation

You are invited to participate in our public forum and voice your concerns about your drinking water. We meet the fourth Tuesday of each month beginning at 7:00 p.m. at the East Lyme Town Hall, 108 Pennsylvania Avenue, Niantic, Connecticut.

Substances That Could Be in Water

To ensure that tap water is safe to drink, the U.S. EPA prescribes regulations limiting the amount of certain contaminants in water provided by public water systems. U.S. Food and Drug Administration regulations establish limits for contaminants in bottled water that must provide the same protection for public health. Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk.

The sources of drinking water (both tap water and bottled water) include rivers, lakes, streams, ponds, reservoirs, springs, and wells. As water travels over the surface of the land or through the ground, it dissolves naturally occurring minerals, in some cases, radioactive material, and substances resulting from the presence of animals or from human activity. Substances that may be present in source water include:

Microbial Contaminants, such as viruses and bacteria, which may come from sewage treatment plants, septic systems, agricultural livestock operations, or wildlife;

Inorganic Contaminants, such as salts and metals, which can be naturally occurring or may result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining, or farming;

Pesticides and Herbicides, which may come from a variety of sources such as agriculture, urban stormwater runoff, and residential uses;

Organic Chemical Contaminants, including synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production and may also come from gas stations, urban stormwater runoff, and septic systems;

Radioactive Contaminants, which can be naturally occurring or may be the result of oil and gas production and mining activities.

For more information about contaminants and potential health effects, call the U.S. EPA's Safe Drinking Water Hotline at (800) 426-4791.

Lead in Home Plumbing

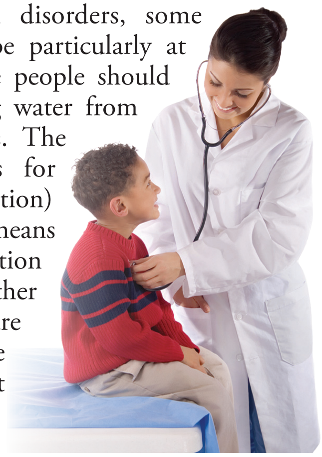
If present, elevated levels of lead can cause serious health problems, especially for pregnant women and young children. Lead in drinking water is primarily from materials and components associated with service lines and home plumbing. We are responsible for providing high-quality drinking water, but we cannot control the variety of materials used in plumbing components. When your water has been sitting for several hours, you can minimize the potential for lead exposure by flushing your tap for 30 seconds to 2 minutes before using water for drinking or cooking. If you are concerned about lead in your water, you may wish to have your water tested. Information on lead in drinking water, testing methods, and steps you can take to minimize exposure is available from the Safe Drinking Water Hotline or at www.epa.gov/safewater/lead.

Important Health Information

Sources of lead in drinking water include corrosion of household plumbing systems and erosion of natural deposits. Infants and children who drink water containing lead in excess of the action level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink this water over many years could develop kidney problems or high blood pressure.

Sources of copper in drinking water includes corrosion of household plumbing systems, erosion of natural deposits, and leaching from wood preservatives. Copper is an essential nutrient, but some people who drink water containing copper in excess of the action level over a relatively short amount of time could experience gastrointestinal distress. Some people who drink water containing copper in excess of the action level over many years could suffer liver or kidney damage. People with Wilson's Disease should consult their personal doctors.

Some people may be more vulnerable to contaminants in drinking water than the general population. Immunocompromised persons such as those with cancer undergoing chemotherapy, those who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants may be particularly at risk from infections. These people should seek advice about drinking water from their health care providers. The U.S. EPA/CDC (Centers for Disease Control and Prevention) guidelines on appropriate means to lessen the risk of infection by Cryptosporidium and other microbial contaminants are available from the Safe Drinking Water Hotline at (800) 426-4791.



Water Conservation

You can play a role in conserving water and save yourself money in the process by becoming conscious of the amount of water your household is using and by looking for ways to use less whenever you can. It is not hard to conserve water. Here are a few tips:

- Automatic dishwashers use 15 gallons for every cycle, regardless of how many dishes are loaded. So get a run for your money and load it to capacity.
- Turn off the tap when brushing your teeth.
- Check every faucet in your home for leaks. Just a slow drip can waste 15 to 20 gallons a day. Fix it and you can save almost 6,000 gallons per year.
- Check your toilets for leaks by putting a few drops of food coloring in the tank. Watch for a few minutes to see if the color shows up in the bowl. It is not uncommon to lose up to 100 gallons a day from an invisible toilet leak. Fix it and you save more than 30,000 gallons a year.
- Use your water meter to detect hidden leaks. Simply turn off all taps and water-using appliances. Then check the meter after 15 minutes. If it moved, you have a leak.

QUESTIONS?

For more information about this report, or for any questions relating to your drinking water, please call Bradford C. Kargl, Municipal Utility Engineer, at (860) 739-6931.

Source Water Assessment

The State of Connecticut Department of Public Health (DPH) in cooperation with the Department of Environmental Protection (DEP) completed source water assessments for all of the East Lyme Water Department's public water supply sources. The sources were rated based on their environmental sensitivity, potential risk factors, and source protection needs. The rating does not necessarily imply poor water quality but indicates susceptibility to potential sources of contamination.

The Bride Lake well field, which includes Well 2A, Well 3A, and Well 3B, received a low overall susceptibility rating. The remaining well fields, which include the Gorton Pond well field (Well 1A and Well 6), the Dodge Pond well field (Well 4A), and Well 5 received moderate overall susceptibility ratings. The source water assessments are available on the Connecticut Department of Public Health, Drinking Water Division's Web site at www.dph.state.ct.us/BRS/water/dwd.htm.

Source Water Protection

Level A aquifer mapping has been completed for all of our water supply sources and has been approved by the State regulatory agencies. The mapping more accurately identifies the zone of influence for our water supply wells and is used to regulate land use activities that may affect water quality.

Where Does My Water Come From?

The Town of East Lyme customers depend on a water supply that comes from seven groundwater sources. Wells are at various locations throughout the town in two separate aquifers. Our water supply is part of the Pattagansett and Bride Brook aquifers. With the completion of the regional interconnection between East Lyme and the New London Water Treatment Plant in 2014, East Lyme will be supplementing its supply during the summer months with water from New London's Lake Konomac Reservoir. To learn more about our watershed on the Internet, go to the U.S. EPA's Surf Your Watershed Web site at www.epa.gov/surf.

Sampling Results

During the past year, we have taken hundreds of water samples in order to determine the presence of any radioactive, biological, inorganic, volatile organic, or synthetic organic contaminants. The tables show only those contaminants that were detected in the water. The State requires us to monitor for certain substances less often than once per year because the concentrations of these substances do not change frequently. In these cases, the most recent sample data are included, along with the year in which the sample was taken.

We participated in the 3rd stage of the EPA's Unregulated Contaminant Monitoring Regulation (UCMR3) program by performing additional tests on our drinking water. UCMR3 benefits the environment and public health by providing the EPA with data on the occurrence of contaminants suspected to be in drinking water, in order to determine if the EPA needs to introduce new regulatory standards to improve drinking water quality.

REGULATED SUBSTANCES

				Distribution		Well 1A		Well 2A		Well 3A/3B			
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	MCLG [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Alpha Emitters (pCi/L)	2013	15	0	NA	NA	ND	NA	ND	NA	ND	NA	No	Erosion of natural deposits
Barium (ppm)	2014	2	2	NA	NA	0.031	NA	0.012	NA	0.015	NA	No	Discharge of drilling wastes; Discharge from metal refineries; Erosion of natural deposits
Chlorine[2] (ppm)	2014	[4]	[4]	NA	NA	0.63	0.41–0.63	0.44	0.11–0.44	0.58	0.35–0.58	No	Water additive used to control microbes
Chromium (ppb)	2014	100	100	NA	NA	2	NA	2	NA	2	NA	No	Discharge from steel and pulp mills; Erosion of natural deposits
Combined Radium (pCi/L)	2014	5	0	NA	NA	1.13[1]	NA	0.93[1]	NA	1.40	0.11–1.40	No	Erosion of natural deposits
Fluoride[2] (ppm)	2014	4	4	NA	NA	1.03	0.78–1.03	1.39	0.89–1.39	1.03	0.71–1.03	No	Erosion of natural deposits; Water additive that promotes strong teeth; Discharge from fertilizer and aluminum factories
Haloacetic Acids [HAAs]–Stage 2 (ppb)	2014	60	NA	2.0	ND–2.0	NA	NA	NA	NA	NA	NA	No	By-product of drinking water disinfection
Nitrate (ppm)	2014	10	10	NA	NA	0.80	NA	2.46	NA	0.65	NA	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
TTHMs [Total Trihalomethanes]–Stage 2 (ppb)	2014	80	NA	9.4	2.4–9.4	1.7	ND–1.7	ND	NA	11.8	ND–11.8	No	By-product of drinking water disinfection
Tetrachloroethylene (ppb)	2014	5	0	NA	NA	ND	NA	ND	NA	ND	NA	No	Discharge from factories and dry cleaners
Turbidity[3] (NTU)	2014	5	NA	1.03	ND–1.03	1.38	ND–1.38	0.6	ND–0.6	0.6	ND–0.6	No	Soil runoff

REGULATED SUBSTANCES

				Well 4A		Well 5		Well 6			
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	MCLG [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Alpha Emitters (pCi/L)	2013	15	0	ND	NA	3.00	NA	ND	NA	No	Erosion of natural deposits
Barium (ppm)	2014	2	2	0.027	NA	0.008	NA	0.058	NA	No	Discharge of drilling wastes; Discharge from metal refineries; Erosion of natural deposits
Chlorine[2] (ppm)	2014	[4]	[4]	0.56	0.25–0.56	0.53	0.21–0.53	0.48	0.23–0.48	No	Water additive used to control microbes
Chromium (ppb)	2014	100	100	4	NA	3	NA	4	NA	No	Discharge from steel and pulp mills; Erosion of natural deposits
Combined Radium (pCi/L)	2014	5	0	0.11[1]	NA	0.81[1]	NA	0.45[1]	NA	No	Erosion of natural deposits
Fluoride[2] (ppm)	2014	4	4	0.99	0.80–0.99	1.04	0.70–1.04	1.25	0.74–1.25	No	Erosion of natural deposits; Water additive that promotes strong teeth; Discharge from fertilizer and aluminum factories
Haloacetic Acids [HAAs]–Stage 2 (ppb)	2014	60	NA	NA	NA	NA	NA	NA	NA	No	By-product of drinking water disinfection
Nitrate (ppm)	2014	10	10	3.46	NA	1.44	NA	1.23	NA	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
TTHMs [Total Trihalomethanes]–Stage 2 (ppb)	2014	80	NA	7.2	ND–7.2	ND	NA	ND	NA	No	By-product of drinking water disinfection
Tetrachloroethylene (ppb)	2014	5	0	ND	NA	ND	NA	0.6	0.5–0.6	No	Discharge from factories and dry cleaners
Turbidity[3] (NTU)	2014	5	NA	0.4	ND–0.4	0.6	ND–0.6	0.5	ND–0.5	No	Soil runoff

Tap water samples were collected for lead and copper analysis from sample sites throughout the distribution system

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AL	MCLG	AMOUNT DETECTED (90TH%TILE)	SITES ABOVE AL/TOTAL SITES	VIOLATION	TYPICAL SOURCE
Copper (ppm)	2014	1.3	1.3	0.70	0/128	No	Corrosion of household plumbing systems; Erosion of natural deposits
Lead (ppb)	2014	15	0	2	3/128	No	Corrosion of household plumbing systems; Erosion of natural deposits

SECONDARY SUBSTANCES

				Well 1A		Well 2A		Well 3A/3B		Well 4A		Well 5		Well 6			
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	SMCL	MCLG	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Chloride (ppm)	2014	250	NA	49.8	NA	32.2	NA	38.4	NA	55.9	NA	50.5	NA	55.9	NA	No	Runoff/leaching from natural deposits
Sulfate (ppm)	2014	250	NA	12.0	NA	9.6	NA	10.9	NA	15.7	NA	12.0	NA	18.2	NA	No	Runoff/leaching from natural deposits; Industrial wastes

UNREGULATED SUBSTANCES

		Distribution		Well 1A		Well 2A		Well 3A/3B		Well 4A		Well 5		Well 6		
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Chlorate[4] (ppb)	2014	160	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	120	NA	By-product of drinking water disinfection
Chromium[4] (ppb)	2014	0.35	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.33	NA	Erosion of natural deposits
Chromium, Hexavalent[4] (ppb)	2014	0.17	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.26	NA	Erosion of natural deposits
MTBE [Methyl-tert-Butyl Ether] (ppb)	2014	NA	NA	ND	NA	ND[1]	NA	ND	NA	ND	NA	ND[1]	NA	2.5	ND–2.5	Petroleum tanks above and below ground
Strontium[4] (ppb)	2014	128	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	128	NA	Erosion of natural deposits
Sodium* (ppm)	2014	NA	NA	34.7	27.9–34.7	29.0	20.2–29.0	30.0	20.0–30.0	41.0	26.5–41.0	15.4	8.6–15.4	37.0	21.6–37.0	Naturally occurring; road salt

*** Sodium Notice: Be advised that when the sodium concentration exceeds 28 ppm, people who have been placed on a sodium-restricted diet should inform their physicians.**

[1] Sampled in 2013.

[2] The values reported under Amount Detected are the highest monthly averages for the 12-month period.

[3] Turbidity is a measure of the cloudiness of the water. It is monitored because it is a good indicator of water quality and the effectiveness of disinfectants.

[4] This substance included in UCMR3 testing program.

Definitions

AL (Action Level): The concentration of a contaminant which, if exceeded, triggers treatment or other requirements that a water system must follow.

MCL (Maximum Contaminant Level): The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

MCLG (Maximum Contaminant Level Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

MRDL (Maximum Residual Disinfectant Level): The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

MRDLG (Maximum Residual Disinfectant Level Goal): The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.

NA: Not applicable

ND (Not detected): Indicates that the substance was not found by laboratory analysis.

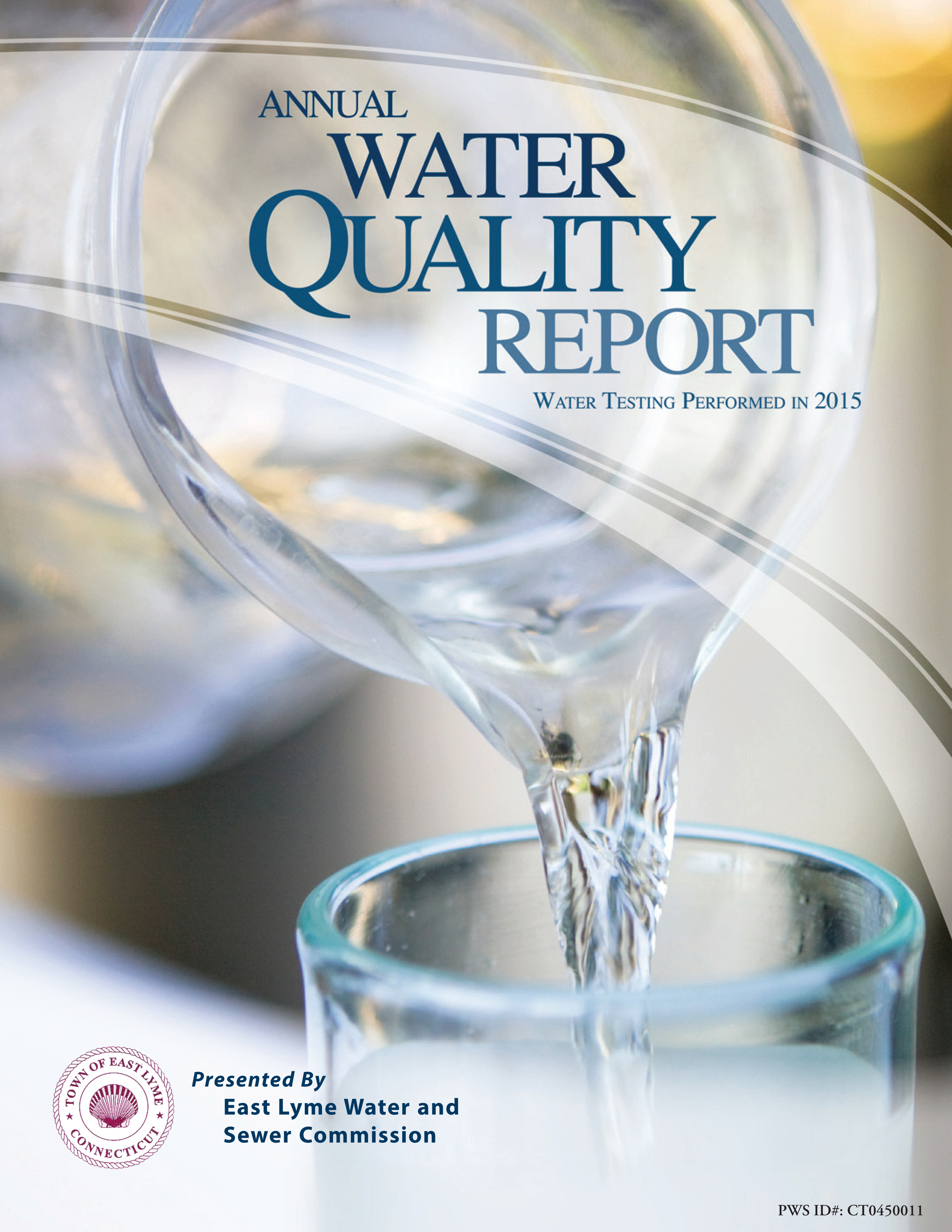
NTU (Nephelometric Turbidity Units): Measurement of the clarity, or turbidity, of water. Turbidity in excess of 5 NTU is just noticeable to the average person.

pCi/L (picocuries per liter): A measure of radioactivity.

ppb (parts per billion): One part substance per billion parts water (or micrograms per liter).

ppm (parts per million): One part substance per million parts water (or milligrams per liter).

SMCL (Secondary Maximum Contaminant Level): SMCLs are established to regulate the aesthetics of drinking water like taste and odor.



ANNUAL WATER QUALITY REPORT

WATER TESTING PERFORMED IN 2015

Presented By

East Lyme Water and Sewer Commission

PWS ID#: CT0450011

Meeting the Challenge

Once again we present our annual drinking water report, covering all drinking water testing performed between January 1 and December 31, 2015. With the many challenges that exist, we have dedicated ourselves to producing drinking water that meets all state and federal standards. We continually strive to adopt new methods for delivering the best quality drinking water to your homes and businesses.

We have made water system improvements in recent years to keep pace with a growing community, increased demand, and an aging infrastructure. Most recently, the regional interconnection with New London was completed, which allows East Lyme to supplement its supply with water from New London primarily during the summer months when East Lyme's demand is the highest. It also provides year-round system redundancy, providing East Lyme with an alternate source of water in the event of a water supply emergency. In addition, systemwide disinfection has been implemented to ensure safe drinking water, and water supply well upgrades have been made to provide a more reliable supply.

A study is currently under way to evaluate filtration alternatives for Wells 1A and 2A to remove naturally occurring iron and manganese and improve water quality. The study should be completed by the end of June 2016. We are currently working with the Connecticut Department of Public Health to obtain funding through the Drinking Water State Revolving Fund to advance the project into the design and construction phase. We continue to investigate the implementation of a radio-based meter reading system that would provide more efficient meter reading capability and better customer service.

Please remember that we are always available to assist you, should you ever have any questions or concerns about your water.

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The Town of East Lyme customers depend on a water supply that comes from seven ground water sources. Wells are at various locations throughout the town in two separate aquifers, which include the Pattagansett and Bride Brook aquifers. The water from five of the wells is filtered to remove iron and manganese, and then treated for pH adjustment, chlorine disinfection, and fluoridation. Two of the wells, Wells 1A and 2A, are similarly treated but are not currently filtered. A sequestering agent is also added to the finished water of Wells 1A and 2A. The finished water is then delivered through an extensive distribution system, including two water storage tanks and 10 booster stations. During the summer months, East Lyme's supply is supplemented with water from the City of New London through a distribution network including more than three miles of water main, an elevated water storage tank, and two pumping stations. New London's water comes from lakes and reservoirs in a protected watershed located in Waterford, Montville, and Salem. The principal reservoir is Lake Konomoc. The water is processed using coagulation, flocculation, sedimentation, and carbon filtration, and then treated for pH adjustment, chlorine disinfection, fluoridation, and corrosion control. To learn more about the watersheds on the Internet, go to the U.S. EPA's Surf Your Watershed Web site at www.epa.gov/surf.

Source Water Assessment

The State of Connecticut Department of Public Health (DPH) in cooperation with the Department of Environmental Protection (DEP) completed source water assessments for all of the East Lyme Water Department's public water supply sources and the New London Lake Konomoc Reservoir System. The sources were rated based on their environmental sensitivity, potential risk factors, and source protection needs. The rating does not necessarily imply poor water quality but indicates susceptibility to potential sources of contamination.

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QUESTIONS?

For more information about this report, or for any questions relating to your drinking water, please call Bradford C. Kargl, Municipal Utility Engineer, at (860) 739-6931.

Water Main Flushing

Distribution mains (pipes) convey water to homes, businesses, and hydrants in your neighborhood. The water entering distribution mains is of very high quality; however, water quality can deteriorate in areas of the distribution mains over time. Water main flushing is the process of cleaning the interior of water distribution mains by sending a rapid flow of water through the mains.

Flushing maintains water quality in several ways. For example, flushing removes sediments like iron and manganese. Although iron and manganese do not pose health concerns, they can affect the taste, clarity, and color of the water. Additionally, sediments can shield microorganisms from the disinfecting power of chlorine, contributing to the growth of microorganisms within distribution mains. Flushing helps remove stale water and ensures the presence of fresh water with sufficient dissolved oxygen, disinfectant levels, and an acceptable taste and smell.

During flushing operations in your neighborhood, some short-term deterioration of water quality, though uncommon, is possible. You should avoid tap water for household uses at that time. If you do use the tap, allow your cold water to run for a few minutes at full velocity before use and avoid using hot water, to prevent sediment accumulation in your hot water tank.

Please contact us if you have any questions or if you would like more information on our water main flushing schedule.

Benefits of Chlorination

Disinfection, a chemical process used to control disease-causing microorganisms by killing or inactivating them, is unquestionably the most important step in drinking water treatment. By far, the most common method of disinfection in North America is chlorination.

Before communities began routinely treating drinking water with chlorine (starting with Chicago and Jersey City in 1908), cholera, typhoid fever, dysentery, and hepatitis A killed thousands of U.S. residents annually. Drinking water chlorination and filtration have helped to virtually eliminate these diseases in the U.S. Significant strides in public health are directly linked to the adoption of drinking water chlorination. In fact, the filtration of drinking water plus the use of chlorine is probably the most significant public health advancement in human history.

How chlorination works:

Potent Germicide Reduction in the level of many disease-causing microorganisms in drinking water to almost immeasurable levels.

Taste and Odor Reduction of many disagreeable tastes and odors like foul-smelling algae secretions, sulfides, and odors from decaying vegetation.

Biological Growth Elimination of slime bacteria, molds, and algae that commonly grow in water supply reservoirs, on the walls of water mains, and in storage tanks.

Chemical Removal of hydrogen sulfide (which has a rotten egg odor), ammonia, and other nitrogenous compounds that have unpleasant tastes and hinder disinfection. It also helps to remove iron and manganese from raw water.

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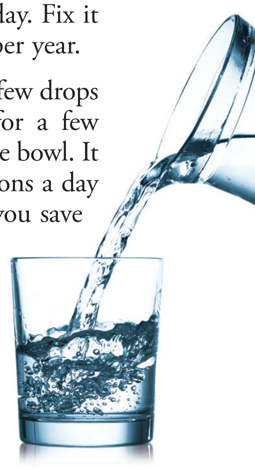
Water Conservation

You can play a role in conserving water and saving yourself money in the process by becoming conscious of the amount of water your household is using and by looking for ways to use less whenever you can. It is not hard to conserve water. Here are a few tips:

- Automatic dishwashers use 15 gallons for every cycle, regardless of how many dishes are loaded. So get a run for your money and load it to capacity.
- Turn off the tap when brushing your teeth.
- Check every faucet in your home for leaks. Just a slow drip can waste 15 to 20 gallons a day. Fix it and you can save almost 6,000 gallons per year.
- Check your toilets for leaks by putting a few drops of food coloring in the tank. Watch for a few minutes to see if the color shows up in the bowl. It is not uncommon to lose up to 100 gallons a day from an invisible toilet leak. Fix it and you save more than 30,000 gallons a year.
- Use your water meter to detect hidden leaks. Simply turn off all taps and water using appliances. Then check the meter after 15 minutes. If it moved, you have a leak.



Sampling Results

During the past year, we have taken hundreds of water samples to determine the presence of any radioactive, biological, inorganic, volatile organic, or synthetic organic contaminants. The table below shows only those contaminants that were detected in the water. The state requires us to monitor for certain substances less than once per year because the concentrations of these substances do not change frequently. In these cases, the most recent sample data are included, along with the year in which the sample was taken.

We participated in the 3rd stage of the EPA's Unregulated Contaminant Monitoring Rule (UCMR3) program by performing additional tests on our drinking water. UCMR3 benefits the environment and public health by providing the EPA with data on the occurrence of contaminants suspected to be in drinking water, in order to determine if EPA needs to introduce new regulatory standards to improve drinking water quality. Contact us for more information on this program.

REGULATED SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	MCLG [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Alpha Emitters (pCi/L)	2014 and 2015	15	0	3.25	3.00–3.25	No	Erosion of natural deposits
Barium (ppm)	2014	2	2	0.058	0.008–0.058	No	Discharge of drilling wastes; Discharge from metal refineries; Erosion of natural deposits
Chlorine[1] (ppm)	2015	[4]	[4]	0.89	0.10–0.89	No	Water additive used to control microbes
Chromium (ppb)	2014	100	100	4	2–4	No	Discharge from steel and pulp mills; Erosion of natural deposits
Combined Radium (pCi/L)	2015	5	0	1.13	ND–1.13	No	Erosion of natural deposits
Fluoride[2] (ppm)	2015	4	4	1.44	0.73–1.44	No	Erosion of natural deposits; Water additive that promotes strong teeth; Discharge from fertilizer and aluminum factories
Haloacetic Acids [HAA] (ppb)	2015	60	NA	6	ND–6	No	By-product of drinking water disinfection
Nitrate (ppm)	2015	10	10	1.93	0.89–1.93	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
TTHMs [Total Trihalomethanes] (ppb)	2015	80	NA	8.8	1.1–35.5	No	By-product of drinking water disinfection
Turbidity[3] (NTU)	2015	5	NA	3.73	ND–3.73	No	Soil runoff

Tap water samples were collected for lead and copper analyses from sample sites throughout the community

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AL	MCLG	AMOUNT DETECTED (90TH%TILE)	SITES ABOVE AL/ TOTAL SITES	VIOLATION	TYPICAL SOURCE
Copper (ppm)	2015	1.3	1.3	0.68	0/122	No	Corrosion of household plumbing systems; Erosion of natural deposits
Lead (ppb)	2015	15	0	2.00	2/122	No	Corrosion of household plumbing systems; Erosion of natural deposits

SECONDARY SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	SMCL	MCLG	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Chloride (ppm)	2014	250	NA	55.9	32.2–55.9	No	Runoff/leaching from natural deposits
Sulfate (ppm)	2014	250	NA	18.2	9.6–18.2	No	Runoff/leaching from natural deposits; Industrial wastes

UNREGULATED AND OTHER SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
MTBE (Methyl-tert-Butyl Ether) (ppb)	2015	2.3	ND–2.3	Petroleum tanks above and below ground
Sodium[4] (ppm)	2015	40.4	9.8–40.4	Naturally occuring; road salt

Sodium Notice – Be advised that when the sodium concentration exceeds 28 ppm, people who have been placed on a sodium-restricted diet should inform their physicians.

UNREGULATED CONTAMINANT MONITORING RULE PART 3 (UCMR3)

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Chlorate (ppb)	2015	710	180–710	By-product of drinking water disinfection
Chromium (ppb)	2015	0.40	0.35–0.40	Erosion of natural deposits
Chromium, Hexavalent (ppb)	2015	0.25	0.07–0.25	Erosion of natural deposits
Strontium (ppb)	2015	131	63–131	Erosion of natural deposits

[1] The values reported under Amount Detected are the highest monthly averages for the 12-month period for the East Lyme treated water sources. When receiving water from New London during the summer months, approximately a three-month period, the highest monthly average is 1.52 ppm.

[2] The values reported under Amount Detected are the highest monthly averages for the 12-month period.

[3] Turbidity is a measure of the cloudiness of the water. It is monitored because it is a good indicator of water quality and the effectiveness of disinfectants.

[4] The average sodium concentration of 144 samples taken was 24.8 ppm.

Definitions

AL (Action Level): The concentration of a contaminant which, if exceeded, triggers treatment or other requirements which a water system must follow.

LRAA (Locational Running Annual Average): The average of sample analytical results for samples taken at a particular monitoring location during the previous four calendar quarters. Amount Detected values for TTHMs and HAAs are reported as LRAAs.

MCL (Maximum Contaminant Level): The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

MCLG (Maximum Contaminant Level Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

MRDL (Maximum Residual Disinfectant Level): The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

MRDLG (Maximum Residual Disinfectant Level Goal): The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.

NA: Not applicable

ND (Not detected): Indicates that the substance was not found by laboratory analysis.

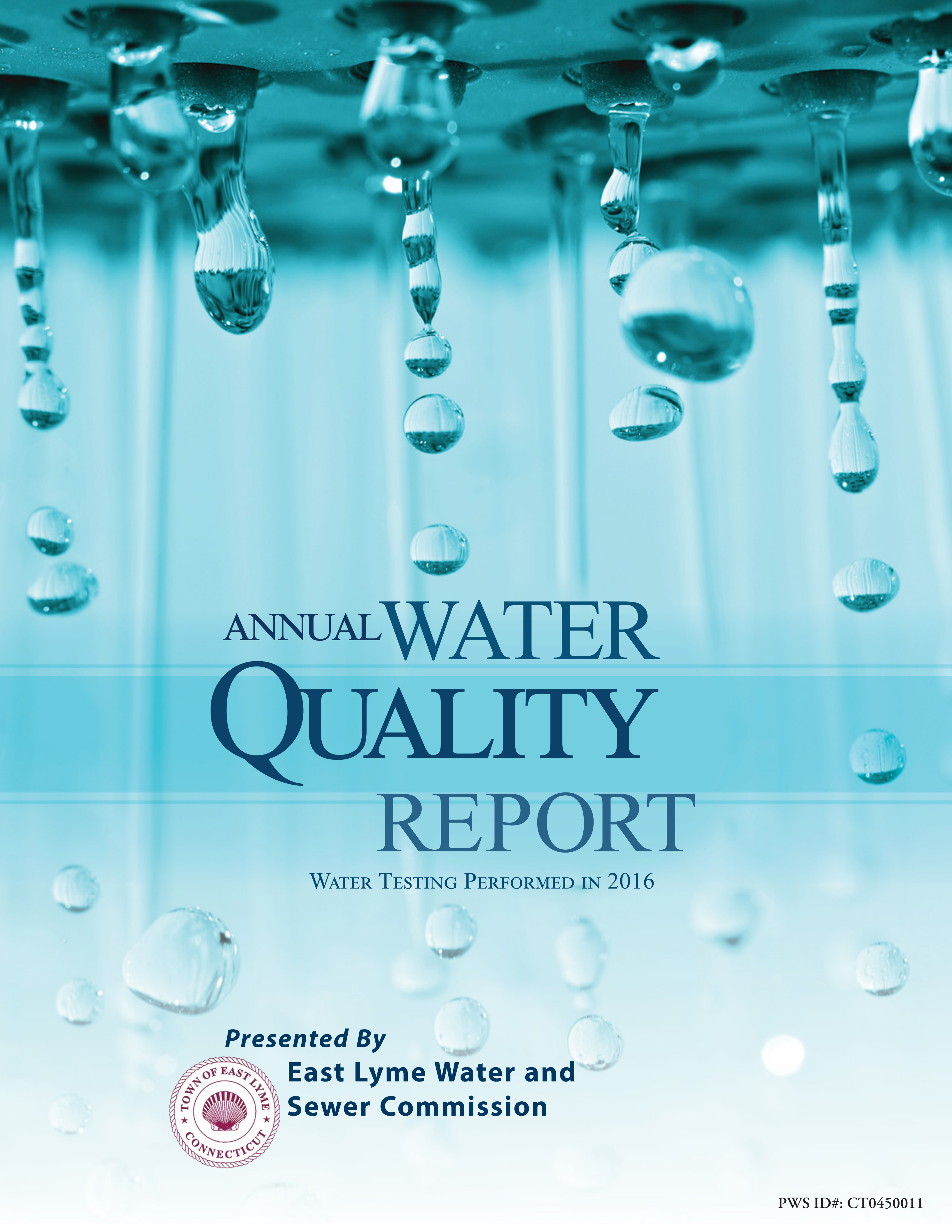
NTU (Nephelometric Turbidity Units): Measurement of the clarity, or turbidity, of water. Turbidity in excess of 5 NTU is just noticeable to the average person.

pCi/L (picocuries per liter): A measure of radioactivity.

ppb (parts per billion): One part substance per billion parts water (or micrograms per liter).

ppm (parts per million): One part substance per million parts water (or milligrams per liter).

SMCL (Secondary Maximum Contaminant Level): SMCLs are established to regulate the aesthetics of drinking water like appearance, taste and odor.



ANNUAL WATER QUALITY REPORT

WATER TESTING PERFORMED IN 2016

Presented By

East Lyme Water and Sewer Commission

PWS ID#: CT0450011

Continuing Our Commitment

Once again we present our annual drinking water report, covering all drinking water testing performed between January 1 and December 31, 2016. We have dedicated ourselves to producing drinking water that meets all state and federal standards. In a matter of only a few decades, drinking water has become exponentially safer and more reliable than at any other point in human history. Although the challenges ahead are many, we continually strive to adopt new methods for delivering the best-quality water without interruption to you and your family.

A study was completed in 2016 to evaluate filtration alternatives for Wells 1A and 2A to remove naturally occurring iron and manganese and improve water quality. Iron and manganese can affect the aesthetic quality of the water and cause discoloration issues. Of the seven wells in the East Lyme system, five are currently filtered to remove iron and manganese. The study recommended that water from Well 1A should be pumped to the existing Well 6 Water Treatment Plant, and the plant upgraded to accommodate the additional flow from Well 1A. The design of the plant upgrades is expected to be completed by December 2017, followed by construction in 2018 and 2019. The total project cost is estimated at $3.1 million. The Connecticut Department of Public Health has made funds available for the design portion of the project through the Drinking Water State Revolving Fund (DWSRF) in the form of a loan paid over twenty years at an interest rate of 2%. The construction phase of the project is also expected to receive DWSRF funding at the appropriate time. Following the completion of the Well 1A project, steps will be taken to secure funding for treatment upgrades to Well 2A in accordance with the recommendations and findings of the study.

We are also working on the implementation of a radio-based meter reading system that would provide more efficient meter reading capability and improve customer service.

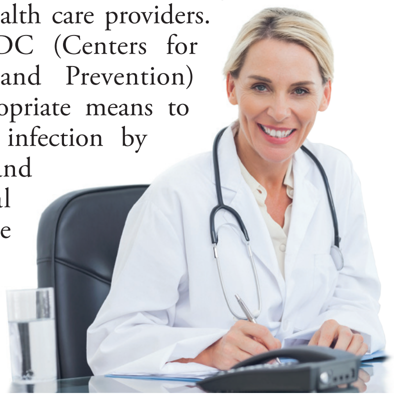
Please remember that we are always available to assist you, should you ever have any questions or concerns about your drinking water.

Important Health Information

Sources of lead in drinking water includes corrosion of household plumbing systems and erosion of natural deposits. Infants and children who drink water containing lead in excess of the action level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink this water over many years could develop kidney problems or high blood pressure.

Sources of copper in drinking water includes corrosion of household plumbing systems, erosion of natural deposits, and leaching from wood preservatives. Copper is an essential nutrient, but some people who drink water containing copper in excess of the action level over a relatively short amount of time could experience gastrointestinal distress. Some people who drink water containing copper in excess of the action level over many years could suffer liver or kidney damage. People with Wilson's Disease should consult their personal doctors.

Some people may be more vulnerable to contaminants in drinking water than the general population. Immunocompromised persons such as those with cancer undergoing chemotherapy, those who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants may be particularly at risk from infections. These people should seek advice about drinking water from their health care providers. The U.S. EPA/CDC (Centers for Disease Control and Prevention) guidelines on appropriate means to lessen the risk of infection by *Cryptosporidium* and other microbial contaminants are available from the Safe Drinking Water Hotline at (800) 426-4791.



Community Participation

You are invited to participate in our public forum and voice your concerns about your drinking water. We meet the fourth Tuesday of each month, beginning at 7:00 p.m., at the East Lyme Town Hall, 108 Pennsylvania Avenue, Niantic, Connecticut.

QUESTIONS?

For more information about this report, or for any questions relating to your drinking water, please call Bradford C. Kargl, Municipal Utility Engineer, at (860) 739-6931.

Substances That Could Be in Water

To ensure that tap water is safe to drink, the U.S. EPA prescribes regulations limiting the amount of certain contaminants in water provided by public water systems. U.S. Food and Drug Administration regulations establish limits for contaminants in bottled water that must provide the same protection for public health. Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk.

The sources of drinking water (both tap water and bottled water) include rivers, lakes, streams, ponds, reservoirs, springs, and wells. As water travels over the surface of the land or through the ground, it dissolves naturally occurring minerals, in some cases, radioactive material, and substances resulting from the presence of animals or from human activity. Substances that may be present in source water include:

Microbial Contaminants, such as viruses and bacteria, which may come from sewage treatment plants, septic systems, agricultural livestock operations, or wildlife;

Inorganic Contaminants, such as salts and metals, which can be naturally occurring or may result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining, or farming;

Pesticides and Herbicides, which may come from a variety of sources such as agriculture, urban stormwater runoff, and residential uses;

Organic Chemical Contaminants, including synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production and may also come from gas stations, urban stormwater runoff, and septic systems;

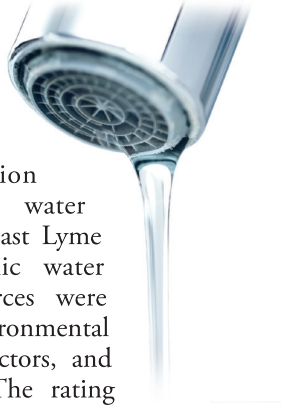
Radioactive Contaminants, which can be naturally occurring or may be the result of oil and gas production and mining activities.

For more information about contaminants and potential health effects, call the U.S. EPA's Safe Drinking Water Hotline at (800) 426-4791.

Lead in Home Plumbing

If present, elevated levels of lead can cause serious health problems, especially for pregnant women and young children. Lead in drinking water is primarily from materials and components associated with service lines and home plumbing. We are responsible for providing high-quality drinking water, but we cannot control the variety of materials used in plumbing components. When your water has been sitting for several hours, you can minimize the potential for lead exposure by flushing your tap for 30 seconds to 2 minutes before using water for drinking or cooking. If you are concerned about lead in your water, you may wish to have your water tested. Information on lead in drinking water, testing methods, and steps you can take to minimize exposure is available from the Safe Drinking Water Hotline or at www.epa.gov/lead.

Source Water Assessment



The State of Connecticut Department of Public Health (DPH) in cooperation with the Department of Environmental Protection (DEP) completed source water assessments for all of the East Lyme Water Department's public water supply sources. The sources were rated based on their environmental sensitivity, potential risk factors, and source protection needs. The rating does not necessarily imply poor water quality but rather indicates susceptibility to potential sources of contamination.

The Bride Lake wellfield, which includes Well 2A, Well 3A, and Well 3B, received a low overall susceptibility rating. The remaining wellfields, which include the Gorton Pond wellfield (Well 1A and Well 6), the Dodge Pond wellfield (Well 4A), and Well 5 received moderate overall susceptibility ratings. New London's Lake Konomoc reservoir received a low susceptibility rating. The source water assessments are available on the CTDPH's Web site at www.ct.gov/dph/publicdrinkingwater. Under Resources, click Source Water Protection, and then Connecticut's SWAP Assessment Reports and Findings.

Source Water Protection

Level A aquifer mapping has been completed for all of our water supply sources and has been approved by the state regulatory agencies. The mapping, which more accurately identifies the zone of influence for our water supply wells, is used to regulate land use activities that may affect water quality.

Important Information About Your Drinking Water

Results of sampling completed in September 2016 were inadvertently not forwarded to the CT Department of Public Health (DPH) in time, thereby triggering the following Monitoring and Reporting Violation Notice:

Our public water system recently violated drinking water monitoring and reporting requirements. As a supplier of public drinking water, we are required to monitor the water quality of our water supply to ensure that it meets the current drinking water standards. Failure to conduct monitoring and/or to report results of such monitoring to the State Department of Public Health Drinking Water Section constitutes a violation. Although the incident was not an emergency, you as our customers, have a right to know what happened and what we did to correct this situation.

We are required to monitor your drinking water for specific contaminants on a regular basis. Results of regular monitoring are an indicator of whether or not our drinking water meets health standards. We did not monitor or test or did not complete all of the monitoring or testing for the requirement(s) listed below and therefore cannot be sure of the quality of our drinking water during that time:

SUBSTANCE	WSF ID	MONITORING PERIOD
Chlorine	00600	September 1, 2016 - September 30, 2016
Total Coliform	00600	September 1, 2016 - September 30, 2016
Physical Parameters	00600	September 1, 2016 - September 30, 2016

What is being done?

The following areas have been affected: entire water distribution system.

The following steps are being taken to correct this violation: the results of the water sampling for chlorine, total coliform, and physical parameters for the September 2016 monitoring period were sent to CTDPH upon notification that they had not been received during the specified time. The contract laboratory is also providing additional internal tracking to assure the timely submittal of results.

We expect to return to compliance or resolve the situation by: 2/13/17 (date when sample results were submitted).

If you have any questions, please contact Brad Kargl at 739-6931, Ext 139 or the East Lyme Water and Sewer Commission by mail at P.O. Box 519, 108 Pennsylvania Avenue, Niantic, CT 06357.

Please share this information with all the other people who drink this water, especially those who may not have received this notice directly (for example, people in apartments, nursing homes, schools, and businesses). You share this information by posting this notice in a public place or distributing copies by hand or mail.

Where Does My Water Come From?

The Town of East Lyme customers depend on a water supply that comes from seven groundwater sources. Wells are at various locations throughout the town in two separate aquifers: the Pattagansett and Bride Brook aquifers. The water from five of the wells is filtered to remove iron and manganese, and then treated for pH adjustment, chlorine disinfection, and fluoridation. Water from the other two wells, Wells 1A and 2A, is similarly treated but not currently filtered. A sequestering agent is also added to the finished water of Well 1A and 2A. The finished water is then delivered through an extensive distribution system, including two water storage tanks and ten booster stations. During the summer months, East Lyme's supply is supplemented with water from the City of New London through a distribution network including over three miles of water mains, an elevated water storage tank, and two pumping stations. New London's water comes from lakes and reservoirs in a protected watershed that is located in Waterford, Montville, and Salem. The principal reservoir is Lake Konomoc. The water is processed using coagulation, flocculation, sedimentation, and carbon filtration, and then treated for pH adjustment, chlorine disinfection, fluoridation, and corrosion control. To learn more about the watersheds on the Internet, go to the U.S. EPA's Surf Your Watershed Web site at www.epa.gov/surf.

Test Results

Our water is monitored for many different kinds of contaminants on a very strict sampling schedule. The information below represents only those substances that were detected; our goal is to keep all detects below their respective maximum allowed levels. The State recommends monitoring for certain substances less often than once per year because the concentrations of these substances do not change frequently. In these cases, the most recent sample data are included, along with the year in which the sample was taken.

We participated in the 3rd stage of the U.S. EPA's Unregulated Contaminant Monitoring Rule (UCMR3) program by performing additional tests on our drinking water. UCMR3 benefits the environment and public health by providing the EPA with data on the occurrence of contaminants suspected to be in drinking water, in order to determine if the EPA needs to introduce new regulatory standards to improve drinking water quality. Contact us for more information on this program.

REGULATED SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	MCLG [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Alpha Emitters (pCi/L)	2015 and 2016	15	0	3.25	ND–3.25	No	Erosion of natural deposits
Barium (ppm)	2014 and 2016	2	2	0.058	0.007–0.058	No	Discharge of drilling wastes; Discharge from metal refineries; Erosion of natural deposits
Chlorine[1] (ppm)	2016	[4]	[4]	1.28	0.26–1.28	No	Water additive used to control microbes
Chromium (ppb)	2014 and 2016	100	100	4	2–4	No	Discharge from steel and pulp mills; Erosion of natural deposits
Combined Radium (pCi/L)	2015 and 2016	5	0	0.93	ND–0.93	No	Erosion of natural deposits
Fluoride[2] (ppm)	2016	4	4	1.25	0.58–1.25	No	Erosion of natural deposits; Water additive that promotes strong teeth; Discharge from fertilizer and aluminum factories
Haloacetic Acids [HAAs] (ppb)	2016	60	NA	31	ND–31	No	By-product of drinking water disinfection
Nitrate (ppm)	2016	10	10	3.51	0.78–3.51	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
TTHMs [Total Trihalomethanes] (ppb)	2016	80	NA	51.7	6.2–51.7	No	By-product of drinking water disinfection
Turbidity[3] (NTU)	2016	5	NA	1.40	ND–1.40	No	Soil runoff

Tap water samples were collected for lead and copper analyses from sample sites throughout the community.

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AL	MCLG	AMOUNT DETECTED (90TH%TILE)	SITES ABOVE AL/TOTAL SITES	VIOLATION	TYPICAL SOURCE
Copper (ppm)	2016	1.3	1.3	0.47	0/33	No	Corrosion of household plumbing systems; Erosion of natural deposits
Lead (ppb)	2016	15	0	2.00	0/33	No	Corrosion of household plumbing systems; Erosion of natural deposits

SECONDARY SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	SMCL	MCLG	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Chloride (ppm)	2014 and 2016	250	NA	55.9	41.0–55.9	No	Runoff/leaching from natural deposits
Sulfate (ppm)	2014 and 2016	250	NA	18.2	9.6–18.2	No	Runoff/leaching from natural deposits; Industrial wastes

UNREGULATED SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Sodium[4] (ppm)	2016	38.8	9.8–38.8	Naturally occurring; road salt

UNREGULATED CONTAMINANT MONITORING RULE - PART 3 (UCMR3)

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Chlorate (ppb)	2015	710	180–710	By-product of drinking water disinfection
Chromium, Hexavalent (ppb)	2015	0.25	0.07–0.25	Erosion of natural deposits
Chromium (ppb)	2015	0.40	0.35–0.40	Erosion of natural deposits
Strontium (ppb)	2015	131	63–131	Erosion of natural deposits

[4] Sodium Notice – Be advised that when the sodium concentration exceeds 28 ppm, people who have been placed on a sodium-restricted diet should inform their physician.

[1] The value reported under Amount Detected is the highest monthly average for the 12-month period for the East Lyme treated water sources. When receiving water from New London during the summer months, approximately a three-month period, the highest monthly average is 1.28 ppm. During the non-summer months, the highest monthly average is 0.66 ppm.

[2] The value reported under Amount Detected is the highest monthly average for the 12-month period.

[3] Turbidity is a measure of the cloudiness of the water. It is monitored because it is a good indicator of water quality and the effectiveness of disinfectants.

Definitions

AL (Action Level): The concentration of a contaminant that, if exceeded, triggers treatment or other requirements that a water system must follow.

LRAA (Locational Running Annual Average): The average of sample analytical results for samples taken at a particular monitoring location during the previous four calendar quarters. Amount Detected values for TTHMs and HAAs are reported as LRAAs.

MCL (Maximum Contaminant Level): The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

MCLG (Maximum Contaminant Level Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

MRDL (Maximum Residual Disinfectant Level): The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

MRDLG (Maximum Residual Disinfectant Level Goal): The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.

NA: Not applicable

ND (Not detected): Indicates that the substance was not found by laboratory analysis.

NTU (Nephelometric Turbidity Units): Measurement of the clarity, or turbidity, of water. Turbidity in excess of 5 NTU is just noticeable to the average person.

pCi/L (picocuries per liter): A measure of radioactivity.

ppb (parts per billion): One part substance per billion parts water (or micrograms per liter).

ppm (parts per million): One part substance per million parts water (or milligrams per liter).

SMCL (Secondary Maximum Contaminant Level): SMCLs are established to regulate the aesthetics of drinking water like appearance, taste and odor.

TT (Treatment Technique): A required process intended to reduce the level of a contaminant in drinking water.

ANNUAL WATER QUALITY REPORT

WATER TESTING PERFORMED IN 2017

Presented By

East Lyme Water and Sewer Commission

PWS ID#: CT0450011

Continuing Our Commitment

Once again, we are pleased to present our annual water quality report. As in years past, we are committed to delivering the best-quality drinking water possible. To that end, we remain vigilant in meeting the challenges of new regulations, source water protection, water conservation, and community outreach and education while continuing to serve the needs of all our water users.

We are currently in the design phase of a project to upgrade the treatment systems at our Well 1A and Well 6 facilities to remove naturally occurring iron and manganese from the ground water and improve overall water quality. Iron and manganese can affect the aesthetic quality of the water and cause discoloration concerns. The design is expected to be completed this summer followed by the start of construction in early 2019. The project is estimated to cost $3.5 million and is eligible for funding from the Connecticut Department of Public Health Drinking Water State Revolving Fund (DWSRF) in the form of a loan paid over 20 years at an interest rate of 2%.

We are also working on the implementation of a radio-based meter reading system that would provide more efficient meter reading capability and improve customer service. This project is also eligible for funding under the DWSRF program. Once completed, billing is expected to be conducted on a quarterly basis rather than biannually.

Please remember that we are always available to assist you, should you have any questions or concerns about your drinking water.

We encourage you to share your thoughts with us on the information contained in this report. After all, well-informed customers are our best allies.

Important Health Information

Sources of lead in drinking water includes corrosion of household plumbing system and erosion of natural deposits. Infants and children who drink water containing lead in excess of the action level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink this water over many years could develop kidney problems or high blood pressure.

Sources of copper in drinking water includes corrosion of household plumbing system, erosion of natural deposits, and leaching from wood preservatives. Copper is an essential nutrient, but some people who drink water containing copper in excess of the action level over a relatively short amount of time could experience gastrointestinal distress. Some people who drink water containing copper in excess of the action level over many years could suffer liver or kidney damage. People with Wilson's disease should consult their personal doctor.

Some people may be more vulnerable to contaminants in drinking water than the general population. Immunocompromised persons such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants may be particularly at risk from infections. These people should seek advice about drinking water from their health care providers. The U.S. EPA/CDC (Centers for Disease Control and Prevention) guidelines on appropriate means to lessen the risk of infection by *Cryptosporidium* and other microbial contaminants are available from the Safe Drinking Water Hotline at (800) 426-4791.

Water Main Flushing

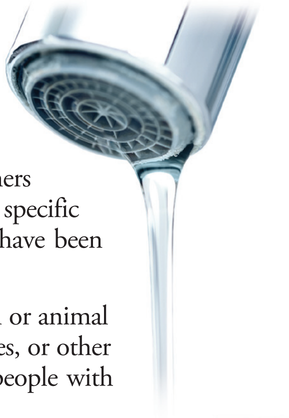
Distribution mains (pipes) convey water to homes, businesses, and hydrants in your neighborhood. The water entering distribution mains is of very high quality; however, water quality can deteriorate in areas of the distribution mains over time. Water main flushing is the process of cleaning the interior of water distribution mains by sending a rapid flow of water through the mains.

Flushing maintains water quality in several ways. For example, flushing removes sediments like iron and manganese. Although iron and manganese do not pose health concerns, they can affect the taste, clarity, and color of the water. Additionally, sediments can shield microorganisms from the disinfecting power of chlorine, contributing to the growth of microorganisms within distribution mains. Flushing helps remove stale water and ensures the presence of fresh water with sufficient dissolved oxygen, disinfectant levels, and an acceptable taste and smell.

During flushing operations in your neighborhood, some short-term deterioration of water quality, though uncommon, is possible. You should avoid tap water for household uses at that time. If you do use the tap, allow your cold water to run for a few minutes at full velocity before use and avoid using hot water, to prevent sediment accumulation in your hot water tank.

Please contact us if you have any questions or if you would like more information on our water main flushing schedule.

Source Water Sampling



On September 19, 2017, we were informed that a routine raw water bacteria sample collected from Well 6 (Source ID 1962) on September 18, 2017, was positive for E. Coli. The raw water is prior to chlorine disinfection, treatment, and entry into the distribution system. We did not detect any coliform or E. Coli positive routine samples collected from the treated water in distribution. As required by the Ground Water Rule, we collected five follow-up samples from Well 6 and three samples from distribution, which were tested for fecal contamination. None of the follow-up samples tested positive for total coliform or fecal indicators. In response, public notification was provided to our customers within 24 hours of learning of this positive sample via Reverse 911 and a website posting. There were no specific deficiencies identified that were attributable to the positive sample and no further positive detections have been found.

Fecal indicators are microbes whose presence indicates that the water may be contaminated with human or animal wastes. Microbes in these wastes can cause short-term effects, such as diarrhea, cramps, nausea, headaches, or other symptoms. They may pose a special health risk for infants, young children, some of the elderly, and people with severely compromised immune systems.

Substances That Could Be in Water

To ensure that tap water is safe to drink, the U.S. EPA prescribes regulations limiting the amount of certain contaminants in water provided by public water systems. U.S. Food and Drug Administration regulations establish limits for contaminants in bottled water, which must provide the same protection for public health. Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk.

The sources of drinking water (both tap water and bottled water) include rivers, lakes, streams, ponds, reservoirs, springs, and wells. As water travels over the surface of the land or through the ground, it dissolves naturally occurring minerals, in some cases, radioactive material, and substances resulting from the presence of animals or from human activity. Substances that may be present in source water include: Microbial Contaminants, such as viruses and bacteria, which may come from sewage treatment plants, septic systems, agricultural livestock operations, or wildlife; Inorganic Contaminants, such as salts and metals, which can be naturally occurring or may result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining, or farming; Pesticides and Herbicides, which may come from a variety of sources such as agriculture, urban stormwater runoff, and residential uses; Organic Chemical Contaminants, including synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production and may also come from gas stations, urban stormwater runoff, and septic systems; Radioactive Contaminants, which can be naturally occurring or may be the result of oil and gas production and mining activities.

For more information about contaminants and potential health effects, call the U.S. EPA's Safe Drinking Water Hotline at (800) 426-4791.

> “Water treatment is a complex, time-consuming process.”

Source Water Protection

Level A aquifer mapping has been completed for all of our water supply sources and has been approved by the state regulatory agencies. The mapping more accurately identifies the zone of influence for our water supply wells and is used to regulate land use activities that may affect water quality.

Source Water Assessment

The State of Connecticut Department of Public Health (DPH) in cooperation with the Department of Environmental Protection (DEP) completed source water assessments for all of the East Lyme Water Department's public water supply sources. The sources were rated based on their environmental sensitivity, potential risk factors, and source protection needs. The rating does not necessarily imply poor water quality but indicates susceptibility to potential sources of contamination.

The Bride Lake well field includes Well 2A, Well 3A, and Well 3B and received a low overall susceptibility rating. The remaining well fields, which include the Gorton Pond well field (Well 1A and Well 6), the Dodge Pond well field (Well 4A), and Well 5 received moderate overall susceptibility ratings. New London's Lake Konomoc reservoir received a low susceptibility rating. The source water assessments are available on the CTDPH's website at www.ct.gov/dph/publicdrinkingwater. Once on the website, go to Source Water Protection, then to Connecticut's SWAP Assessment Reports and Findings.

QUESTIONS?

For more information about this report, or for any questions relating to your drinking water, please call Bradford C. Kargl, Municipal Utility Engineer, at (860) 739-6931.

Community Participation

You are invited to participate in our public forum and voice your concerns about your drinking water. We meet the fourth Tuesday of each month beginning at 7:00 p.m. at the East Lyme Town Hall, 108 Pennsylvania Avenue, Niantic, Connecticut.

Where Does My Water Come From?

The Town of East Lyme customers depend on a water supply that comes from seven ground water sources. Wells are at various locations throughout the town in two separate aquifers, which include the Pattagansett and Bride Brook aquifers. The water from five of the wells are filtered to remove iron and manganese, and then treated for pH adjustment, chlorine disinfection, and fluoridation. Two of the wells, Wells 1A and 2A, are similarly treated but are not currently filtered. A sequestering agent is also added to the finished water of Wells 1A and 2A. The finished water is then delivered through an extensive distribution system including two water storage tanks and ten booster stations. During the summer months, East Lyme's supply is supplemented with water from the City of New London through a distribution network, including more than three miles of water main, an elevated water storage tank, and two pumping stations. New London's water comes from lakes and reservoirs in a protected watershed that is located in Waterford, Montville, and Salem. The principal reservoir is Lake Konomoc. The water is processed using coagulation, flocculation, sedimentation, and carbon filtration, and then treated for pH adjustment, chlorine disinfection, fluoridation, and corrosion control. To learn more about the watersheds on the Internet, go to the U.S. EPA's Surf Your Watershed website at www.epa.gov/surf.

Lead in Home Plumbing

If present, elevated levels of lead can cause serious health problems, especially for pregnant women and young children. Lead in drinking water is primarily from materials and components associated with service lines and home plumbing. We are responsible for providing high-quality drinking water, but cannot control the variety of materials used in plumbing components. When your water has been sitting for several hours, you can minimize the potential for lead exposure by flushing your tap for 30 seconds to 2 minutes before using water for drinking or cooking. If you are concerned about lead in your water, you may wish to have your water tested. Information on lead in drinking water, testing methods, and steps you can take to minimize exposure is available from the Safe Drinking Water Hotline or at www.epa.gov/lead.

Test Results

Our water is monitored for many different kinds of substances on a very strict sampling schedule. The information in the data tables shows only those substances that were detected between January 1 and December 31, 2017. Certain substances, however, are monitored less often than once per year because the concentrations of these substances do not change frequently. In these cases, the most recent sample data are included, along with the year in which the sample was taken.

The concentrations shown in the Amount Detected column represent the highest amounts detected for the range of concentrations found during monitoring.

We participated in the 3rd stage of the U.S. EPA's Unregulated Contaminant Monitoring Rule (UCMR3) program by performing additional tests on our drinking water. UCMR3 benefits the environment and public health by providing the EPA with data on the occurrence of contaminants suspected to be in drinking water, to determine if the EPA needs to introduce new regulatory standards to improve drinking water quality. Contact us for more information on this program.

REGULATED SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	MCLG [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Barium (ppm)	2014, 2016, and 2017	2	2	0.058	0.003–0.058	No	Discharge of drilling wastes; Discharge from metal refineries; Erosion of natural deposits
Chlorine[1] (ppm)	2017	[4]	[4]	0.97	0.25–0.97	No	Water additive used to control microbes
Chromium (ppb)	2014, 2016, and 2017	100	100	4	2–4	No	Discharge from steel and pulp mills; Erosion of natural deposits
Fluoride[2] (ppm)	2017	4	4	0.91	0.48–0.91	No	Erosion of natural deposits; Water additive that promotes strong teeth; Discharge from fertilizer and aluminum factories
Haloacetic Acids [HAA] (ppb)	2017	60	NA	7	ND–7	No	By-product of drinking water disinfection
Nitrate (ppm)	2017	10	10	3.91	0.11–3.91	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
Nitrite (ppm)	2017	1	1	0.24	ND–0.24	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
TTHMs [Total Trihalomethanes] (ppb)	2017	80	NA	26.5	5.5–26.5	No	By-product of drinking water disinfection
Turbidity[3] (NTU)	2017	5 NTU	NA	1.95	ND–1.95	No	Soil runoff

Tap water samples were collected for lead and copper analyses from sample sites throughout the distribution system

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AL	MCLG	AMOUNT DETECTED (90TH%TILE)	SITES ABOVE AL/TOTAL SITES	VIOLATION	TYPICAL SOURCE
Copper (ppm)	2017	1.3	1.3	0.42	0/37	No	Corrosion of household plumbing systems; Erosion of natural deposits
Lead (ppb)	2017	15	0	1.00	0/37	No	Corrosion of household plumbing systems; Erosion of natural deposits

SECONDARY SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	SMCL	MCLG	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Chloride (ppm)	2014, 2016, and 2017	250	NA	70.3	17.9–70.3	No	Runoff/leaching from natural deposits
Sulfate (ppm)	2014, 2016, and 2017	250	NA	18.2	9.6–18.2	No	Runoff/leaching from natural deposits; Industrial wastes

UNREGULATED CONTAMINANT MONITORING RULE - PART 3 (UCMR3)

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Chlorate (ppb)	2015	710	180–710	By-product of drinking water disinfection
Chromium, Hexavalent (ppb)	2015	0.25	0.07–0.25	Erosion of natural deposits
Chromium (ppb)	2015	0.40	0.35–0.40	Erosion of natural deposits
Strontium (ppb)	2015	131	63–131	Erosion of natural deposits

UNREGULATED AND OTHER SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Sodium* (ppm)	2017	46.2	10.2–46.2	Naturally occuring; Road salt
MTBE [Methyl-tert-Butyl Ether] (ppb)	2017	2.5	ND–2.5	Petroleum tanks above and below ground

*Be advised that when the sodium concentration exceeds 28 ppm, people who have been placed on a sodium-restricted diet should inform their physicians.

Definitions

AL (Action Level): The concentration of a contaminant which, if exceeded, triggers treatment or other requirements which a water system must follow.

LRAA (Locational Running Annual Average): The average of sample analytical results for samples taken at a particular monitoring location during the previous four calendar quarters. Amount Detected values for TTHMs and HAAs are reported as the highest LRAAs.

MCL (Maximum Contaminant Level): The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

MCLG (Maximum Contaminant Level Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

MRDL (Maximum Residual Disinfectant Level): The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

MRDLG (Maximum Residual Disinfectant Level Goal): The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.

NA: Not applicable

ND (Not detected): Indicates that the substance was not found by laboratory analysis.

NTU (Nephelometric Turbidity Units): Measurement of the clarity, or turbidity, of water. Turbidity in excess of 5 NTU is just noticeable to the average person.

ppb (parts per billion): One part substance per billion parts water (or micrograms per liter).

ppm (parts per million): One part substance per million parts water (or milligrams per liter).

SMCL (Secondary Maximum Contaminant Level): SMCLs are established to regulate the aesthetics of drinking water like appearance, taste and odor.

TT (Treatment Technique): A required process intended to reduce the level of a contaminant in drinking water.

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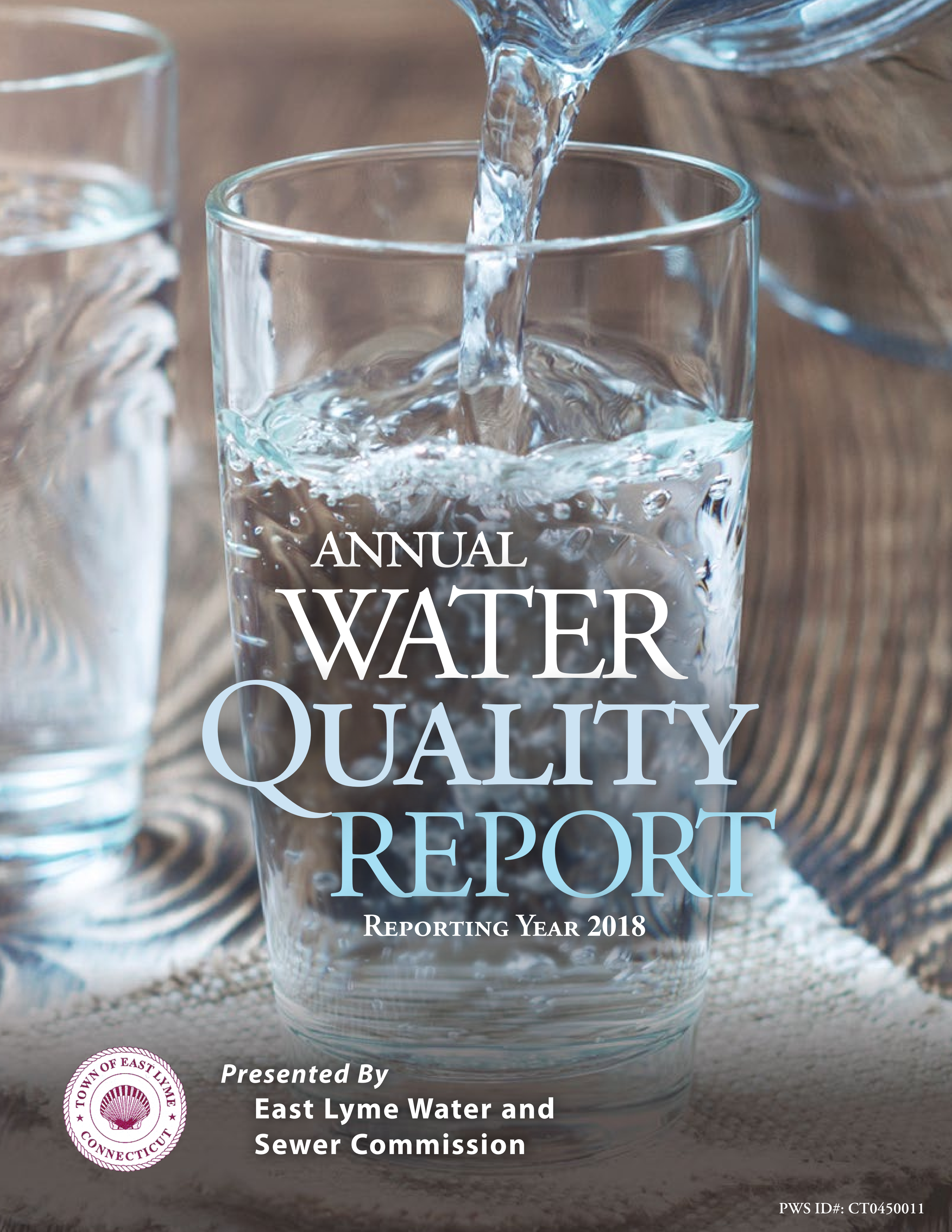
[1] The values reported under Amount Detected are the highest monthly averages for the 12-month period for the East Lyme treated water sources. When receiving water from New London during the summer months, approximately a three-month period, the highest monthly average is 1.16 ppm.

[2] The values reported under Amount Detected are the highest monthly averages for the 12-month period.

[3] Turbidity is a measure of the cloudiness of the water. It is monitored because it is a good indicator of water quality and the effectiveness of disinfectants.



ANNUAL WATER QUALITY REPORT

Reporting Year 2018

Presented By

East Lyme Water and Sewer Commission

PWS ID#: CT0450011

Continuing Our Commitment

Once again we are pleased to present our annual water quality report. As in years past, we are committed to delivering the best-quality drinking water possible. To that end, we remain vigilant in meeting the challenges of new regulations, aging infrastructure, source water protection and water conservation while continuing to serve the needs of all of our water users.

Please remember that we are always available to assist you, should you have any questions or concerns about your drinking water.

We encourage you to share your thoughts with us on the information contained in this report. For more information about this report, or for any questions relating to your drinking water, please call Bradford C. Kargl, Municipal Utility Engineer, at (860) 739-6931.

Community Participation

You are invited to participate in our public forum and voice your concerns about your drinking water. We meet the fourth Tuesday of each month at 7 p.m. at East Lyme Town Hall, 108 Pennsylvania Avenue, Niantic, Connecticut.

Water Conservation Tips

You can play a role in conserving water and save yourself money in the process by becoming conscious of the amount of water your household is using and looking for ways to use less whenever you can. It is not hard to conserve water. Here are a few tips:

- Automatic dishwashers use 15 gallons for every cycle, regardless of how many dishes are loaded. So get a run for your money and load it to capacity.
- Turn off the tap when brushing your teeth.
- Check every faucet in your home for leaks. Just a slow drip can waste 15 to 20 gallons a day. Fix it and you can save almost 6,000 gallons per year.
- Check your toilets for leaks by putting a few drops of food coloring in the tank. Watch for a few minutes to see if the color shows up in the bowl. It is not uncommon to lose up to 100 gallons a day from an invisible toilet leak. Fix it and you save more than 30,000 gallons a year.
- Use your water meter to detect hidden leaks. Simply turn off all taps and water-using appliances. Then check the meter after 15 minutes. If it moved, you have a leak.

Important Health Information

Sources of lead in drinking water include corrosion of household plumbing systems and erosion of natural deposits. Infants and children who drink water containing lead in excess of the action level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink this water over many years could develop kidney problems or high blood pressure.

Sources of copper in drinking water include corrosion of household plumbing systems, erosion of natural deposits, and leaching from wood preservatives. Copper is an essential nutrient, but some people who drink water containing copper in excess of the action level over a relatively short amount of time could experience gastrointestinal distress. Some people who drink water containing copper in excess of the action level over many years could suffer liver or kidney damage. People with Wilson's disease should consult their personal doctor.

Some people may be more vulnerable to contaminants in drinking water than the general population. Immunocompromised persons such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants may be particularly at risk from infections. These people should seek advice about drinking water from their health care providers. The U.S. EPA/CDC (Centers for Disease Control and Prevention) guidelines on appropriate means to lessen the risk of infection by *Cryptosporidium* and other microbial contaminants are available from the Safe Drinking Water Hotline at (800) 426-4791.

Substances That Could Be in Water

To ensure that tap water is safe to drink, the U.S. EPA prescribes regulations limiting the amount of certain contaminants in water provided by public water systems. U.S. Food and Drug Administration regulations establish limits for contaminants in bottled water, which must provide the same protection for public health. Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk.

The sources of drinking water (both tap water and bottled water) include rivers, lakes, streams, ponds, reservoirs, springs, and wells. As water travels over the surface of the land or through the ground, it dissolves naturally occurring minerals, in some cases, radioactive material, and substances resulting from the presence of animals or from human activity. Substances that may be present in source water include: Microbial Contaminants, such as viruses and bacteria, which may come from sewage treatment plants, septic systems, agricultural livestock operations, or wildlife; Inorganic Contaminants, such as salts and metals, which can be naturally occurring or may result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining, or farming; Pesticides and Herbicides, which may come from a variety of sources such as agriculture, urban stormwater runoff, and residential uses; Organic Chemical Contaminants, including synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production and may also come from gas stations, urban stormwater runoff, and septic systems; Radioactive Contaminants, which can be naturally occurring or may be the result of oil and gas production and mining activities.

For more information about contaminants and potential health effects, call the U.S. EPA's Safe Drinking Water Hotline at (800) 426-4791.

Source Water Protection

Level A aquifer mapping has been completed for all our water supply sources and approved by the state regulatory agencies. The mapping more accurately identifies the zone of influence for our water supply wells and is used to regulate land use activities that may affect water quality.

Important Information about Your Drinking Water

Monitoring and/or Reporting Violation

Este informe contiene informacion importante acerca de su agua potable. Haga que alguien lo traduzca para usted, o hable con alguien que lo entienda

Our public water system recently violated drinking water monitoring or reporting requirements. As a supplier of public drinking water, we are required to monitor the quality of our water supply to ensure that it meets the current drinking water standards. Failure to conduct monitoring or report results of such monitoring to the DPH Drinking Water Section constitutes a violation. Although this incident was not an emergency, our customers have a right to know what happened and what we did to correct this situation.

We are required to monitor your drinking water for specific contaminants on a regular basis. Results of regular monitoring are an indicator of whether our drinking water meets health standards. We did not complete the monitoring or did not report the results for the requirement listed below:

Chlorine (WSF ID: 00600; Monitoring Period: September 1 – 30, 2018)

The following area was affected:

Pennsylvania Avenue and adjacent side streets, Niantic.

The following steps were taken to correct this violation:

Three repeat bacteriological samples were inadvertently not tested for chlorine residuals. Instruction was provided and protocols changed to ensure that the chlorine residuals are monitored and properly reported when repeat sampling is required.

We returned to compliance or resolved the situation by October 1, 2018. If you have any questions, please contact Brad Kargl at (860) 739-6931, ext. 1139, or by mail at 108 Pennsylvania Avenue, Niantic, CT 06357.

Please share this information with all other people who drink this water, especially those who may not have received this notice directly (for example, people in apartments, nursing homes, schools, and businesses). You can do this by posting this notice in a public place or distributing copies by hand or mail.

Where Does My Water Come From?

The Town of East Lyme customers depend on a water supply that comes from seven groundwater sources. Wells are at various locations throughout the town and access the Pattagansett and Bride Brook aquifers. The water from five of the wells is filtered to remove iron and manganese and then treated for pH adjustment, chlorine disinfection, and fluoridation. Two of the wells, 1A and 2A, are similarly treated but are not currently filtered. A sequestering agent is also added to the finished water of Wells 1A and 2A. The finished water is then delivered through an extensive distribution system including two water storage tanks and 10 booster stations.

During the summer months, East Lyme's supply is supplemented with water from the City of New London through a distribution network including over 3 miles of water main, an elevated water storage tank, and two pumping stations. New London's water comes from lakes and reservoirs in a protected watershed that is located in Waterford, Montville, and Salem. The principal reservoir is Lake Konomoc. The water is processed using coagulation, flocculation, sedimentation, and carbon filtration and then treated for pH adjustment, chlorine disinfection, fluoridation, and corrosion control. To learn more about our watersheds, visit the U.S. EPA's Surf Your Watershed website at www.epa.gov/surf.

Source Water Assessment

The State of Connecticut Department of Public Health (DPH), in cooperation with the Department of Energy and Environmental Protection, completed source water assessments for all East Lyme Water Department public water supply sources. The sources were rated based on their environmental sensitivity, potential risk factors, and source protection needs. The rating does not necessarily imply poor water quality but indicates susceptibility to potential sources of contamination.

The Bride Lake well field includes Wells 2A, 3A, and 3B and received a low overall susceptibility rating. The remaining well fields, which include Gorton Pond (1A and 6), Dodge Pond (4A), and Well 5, received moderate overall susceptibility ratings. New London's Lake Konomoc reservoir received a low susceptibility rating. The source water assessments are available on the CTDPH website at www.ct.gov/dph/publicdrinkingwater. Go to Source Water Protection, then to Connecticut's SWAP Assessment Reports and Findings.

Lead in Home Plumbing

If present, elevated levels of lead can cause serious health problems, especially for pregnant women and young children. Lead in drinking water is primarily from materials and components associated with service lines and home plumbing. We are responsible for providing high-quality drinking water, but we cannot control the variety of materials used in plumbing components. When your water has been sitting for several hours, you can minimize the potential for lead exposure by flushing your tap for 30 seconds to 2 minutes before using water for drinking or cooking. If you are concerned about lead in your water, you may wish to have your water tested. Information on lead in drinking water, testing methods, and steps you can take to minimize exposure is available from the Safe Drinking Water Hotline at (800) 426-4791 or at www.epa.gov/safewater/lead.

Test Results

Our water is monitored for many different kinds of substances on a very strict sampling schedule. The information in the data tables shows those substances that we are required to monitor that were detected between January 1 and December 31, 2018. Certain substances, however, are monitored less often than once per year because the concentrations of these substances do not change frequently. In these cases, the most recent sample data are included, along with the year in which the sample was taken. Remember that detecting a substance does not mean the water is unsafe to drink; our goal is to keep all detects below their respective maximum allowed levels. The concentrations shown in the Amount Detected column represent the highest amounts detected for the range of concentrations found during monitoring.

We participated in the fourth stage of the U.S. EPA's Unregulated Contaminant Monitoring Rule (UCMR4) program by performing additional tests on our drinking water. If you would like more information on the U.S. EPA's Unregulated Contaminants Monitoring Rule, please call the Safe Drinking Water Hotline at (800) 426-4791.

REGULATED SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	MCLG [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Barium (ppm)	2016, 2017, 2018	2	2	0.088	0.003–0.088	No	Discharge of drilling wastes; Discharge from metal refineries; Erosion of natural deposits
Chlorine[1] (ppm)	2018	[4]	[4]	1.00	0.37–1.00	No	Water additive used to control microbes
Chromium (ppb)	2016, 2017, 2018	100	100	4	2–4	No	Discharge from steel and pulp mills; Erosion of natural deposits
Combined Radium (pCi/L)	2016, 2017, 2018	5	0	0.51	ND–0.51	No	Erosion of natural deposits
Fluoride[2] (ppm)	2018	4	4	0.89	0.67–0.89	No	Erosion of natural deposits; Water additive that promotes strong teeth; Discharge from fertilizer and aluminum factories
Haloacetic Acids [HAAs] (ppb)	2018	60	NA	2	ND–2	No	By-product of drinking water disinfection
Heptachlor (ppt)	2016, 2018	400	0	88	ND–88	No	Residue of banned pesticide
Heptachlor Epoxide (ppt)	2016, 2018	200	0	44	ND–44	No	Breakdown of heptachlor
Nitrate (ppm)	2018	10	10	3.73	0.36–3.73	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
Nitrite (ppm)	2018	1	1	0.03	ND–0.03	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
Selenium (ppb)	2016, 2017, 2018	50	50	7	ND–7	No	Discharge from petroleum and metal refineries; Erosion of natural deposits; Discharge from mines
TTHMs [Total Trihalomethanes] (ppb)	2018	80	NA	14.9	5.2–14.9	No	By-product of drinking water disinfection
Turbidity[3] (NTU)	2018	TT	NA	2.44	ND–2.44	No	Soil runoff

Tap water samples were collected for lead and copper analyses from sample sites throughout the distribution system

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AL	MCLG	AMOUNT DETECTED (90TH %ILE)	SITES ABOVE AL/TOTAL SITES	VIOLATION	TYPICAL SOURCE
Copper (ppm)	2018	1.3	1.3	0.51	0/37	No	Corrosion of household plumbing systems; Erosion of natural deposits
Lead (ppb)	2018	15	0	1	0/37	No	Lead service lines, corrosion of household plumbing systems, including fittings and fixtures; Erosion of natural deposits

UNREGULATED SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Sodium[4] (ppm)	2018	49.7	11.2–49.7	Naturally occurring; Road salt

UNREGULATED CONTAMINANT MONITORING RULE - PART 4 (UCMR4)

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Bromochloroacetic Acid (ppb)	2018	1.5	ND–1.5	By-product of drinking water disinfection
Bromodichloroacetic Acid (ppb)	2018	1.0	ND–1.0	By-product of drinking water disinfection
Chlorodibromoacetic Acid (ppb)	2018	0.9	ND–0.9	By-product of drinking water disinfection
Dibromoacetic Acid (ppb)	2018	1.4	ND–1.4	By-product of drinking water disinfection
Dichloroacetic Acid (ppb)	2018	0.8	0.4–0.8	By-product of drinking water disinfection
HAA5 (ppb)	2018	2.8	0.4–2.8	By-product of drinking water disinfection
HAA6Br (ppb)	2018	4.8	ND–4.8	By-product of drinking water disinfection
HAA9 (ppb)	2018	6.2	0.4–6.2	By-product of drinking water disinfection
Manganese[5] (ppb)	2018	470	0.87–470	Leaching from natural deposits
Trichloroacetic Acid (ppb)	2018	0.6	ND–0.6	By-product of drinking water disinfection

Definitions

90th %ile: The levels reported for lead and copper represent the 90th percentile of the total number of sites tested. The 90th percentile is equal to or greater than 90% of our lead and copper detections.

AL (Action Level): The concentration of a contaminant which, if exceeded, triggers treatment or other requirements which a water system must follow.

LRAA (Locational Running Annual Average): The average of sample analytical results for samples taken at a particular monitoring location during the previous four calendar quarters. Amount Detected values for TTHMs and HAAs are reported as the highest LRAAs.

MCL (Maximum Contaminant Level): The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

MCLG (Maximum Contaminant Level Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

MRDL (Maximum Residual Disinfectant Level): The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

MRDLG (Maximum Residual Disinfectant Level Goal): The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.

NA: Not applicable.

ND (Not detected): Indicates that the substance was not found by laboratory analysis.

NTU (Nephelometric Turbidity Units): Measurement of the clarity, or turbidity, of water. Turbidity in excess of 5 NTU is just noticeable to the average person.

pCi/L (picocuries per liter): A measure of radioactivity.

ppb (parts per billion): One part substance per billion parts water (or micrograms per liter).

ppm (parts per million): One part substance per million parts water (or milligrams per liter).

ppt (parts per trillion): One part substance per trillion parts water (or nanograms per liter).

SMCL (Secondary Maximum Contaminant Level): These standards are developed to protect aesthetic qualities of drinking water and are not health based.

TT (Treatment Technique): A required process intended to reduce the level of a contaminant in drinking water.

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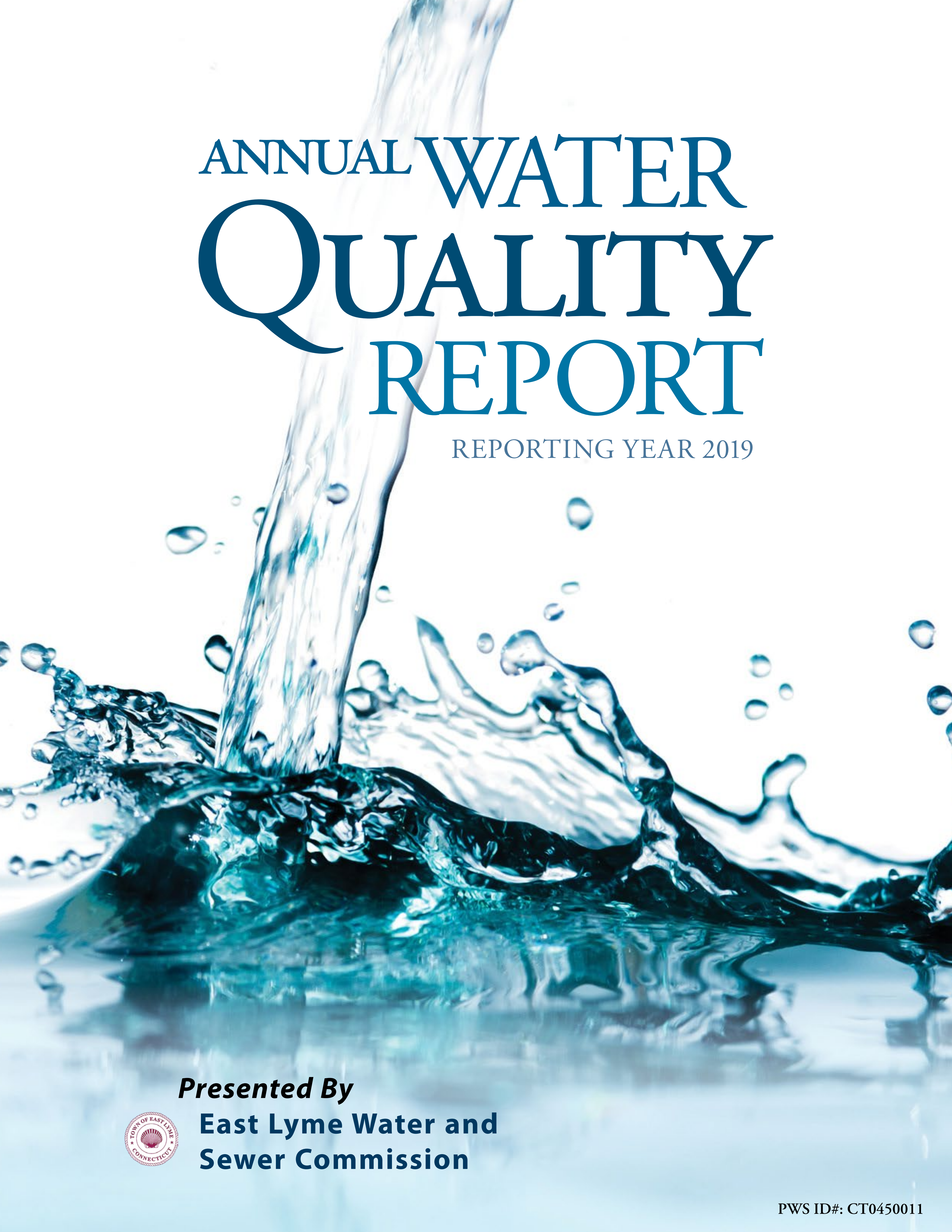
[1] The values reported under Amount Detected are the highest monthly averages for the 12-month period for the East Lyme treated water sources. The highest monthly average for the water received from New London over approximately 5 months was 0.94 ppm.

[2] The values reported under Amount Detected are the highest monthly averages for the 12-month period.

[3] Turbidity is a measure of the cloudiness of the water. It is monitored because it is a good indicator of water quality and the effectiveness of disinfectants.

[4] Be advised that when the sodium concentration exceeds 28 ppm, people who have been placed on a sodium-restricted diet should inform their physicians.

[5] The CTDPH has recently adopted an Action Level of 0.3 ppm (300 ppb) for manganese. Please visit the town website at www.eltownhall.com for more information.



ANNUAL WATER QUALITY REPORT

REPORTING YEAR 2019

Presented By

East Lyme Water and Sewer Commission

PWS ID#: CT0450011

Our Mission Continues

We are once again pleased to present our annual water quality report covering all testing performed between January 1 and December 31, 2019. Over the years, we have dedicated ourselves to producing drinking water that meets all state and federal standards. We continually strive to adopt new methods for delivering the best-quality drinking water to you. As new challenges to drinking water safety emerge, we remain vigilant in meeting the goals of source water protection, water conservation, and community education while continuing to serve the needs of all our water users.

Construction is underway to provide filtration for Well 1A to remove manganese and improve water quality. The project is scheduled to be substantially complete by early spring of 2021. The project will cost $5.59 million and is receiving funding from the Connecticut Department of Public Health (CTDPH) Drinking Water State Revolving Fund (DWSRF). We are also working on the implementation of a radio-based meter reading system that will provide more efficient meter reading capability and improve customer service. This project is also eligible for funding under the DWSRF program. Once completed, billing is expected to be conducted on a quarterly basis rather than bi-annually.

Please remember that we are always available to assist you, should you have any questions or concerns about your drinking water.

Community Participation

You are invited to participate in our public forum and voice your concerns about your drinking water. We meet the fourth Tuesday of each month beginning at 7:00 p.m. at the East Lyme Town Hall, 108 Pennsylvania Avenue, Niantic, Connecticut.

Lead in Home Plumbing

If present, elevated levels of lead can cause serious health problems, especially for pregnant women and young children. Lead in drinking water is primarily from materials and components associated with service lines and home plumbing. We are responsible for providing high-quality drinking water, but we cannot control the variety of materials used in plumbing components. When your water has been sitting for several hours, you can minimize the potential for lead exposure by flushing your tap for 30 seconds to 2 minutes before using water for drinking or cooking. If you are concerned about lead in your water, you may wish to have your water tested. Information on lead in drinking water, testing methods, and steps you can take to minimize exposure is available from the Safe Drinking Water Hotline at (800) 426-4791 or at www.epa.gov/safewater/lead.

Important Health Information

Sources of lead in drinking water include corrosion of household plumbing systems and erosion of natural deposits. Infants and children who drink water containing lead in excess of the action level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink this water over many years could develop kidney problems or high blood pressure.

Sources of copper in drinking water include corrosion of household plumbing systems, erosion of natural deposits, and leaching from wood preservatives. Copper is an essential nutrient, but some people who drink water containing copper in excess of the action level over a relatively short amount of time could experience gastrointestinal distress. Some people who drink water containing copper in excess of the action level over many years could suffer liver or kidney damage. People with Wilson's Disease should consult their personal doctors.

Some people may be more vulnerable to contaminants in drinking water than the general population. Immunocompromised persons such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants may be particularly at risk from infections. These people should seek advice about drinking water from their health care providers. The U.S. EPA/CDC (Centers for Disease Control and Prevention) guidelines on appropriate means to lessen the risk of infection by *Cryptosporidium* and other microbial contaminants are available from the Safe Drinking Water Hotline at (800) 426-4791.

Source Water Protection

Level A aquifer mapping has been completed for all of our water supply sources and has been approved by the state regulatory agencies. The mapping more accurately identifies the zone of influence for our water supply wells and is used to regulate land-use activities that may affect water quality.

Source Water Assessment

The State of Connecticut Department of Public Health (DPH) in cooperation with the Department of Energy and Environmental Protection (DEEP) completed source water assessments for all of the East Lyme Water Department's public water supply sources. The sources were rated based on their environmental sensitivity, potential risk factors, and source protection needs. The rating does not necessarily imply poor water quality but indicates susceptibility to potential sources of contamination.

The Bride Lake wellfield includes Wells 2A, 3A, and 3B and received a low overall susceptibility rating. The remaining wellfields, which include the Gorton Pond wellfield (Wells 1A and 6), the Dodge Pond wellfield (Well 4A), and Well 5, received moderate overall susceptibility ratings. New London's Lake Konomoc reservoir received a low susceptibility rating. The source water assessments are available on the CTDPH's Web site at www.ct.gov/dph/publicdrinkingwater. Once on the Web site, go to Resources, then to Source Water Protection, and then to Connecticut's SWAP Assessment Reports and Findings.

Substances That Could Be in Water

To ensure that tap water is safe to drink, the U.S. EPA prescribes regulations limiting the amount of certain contaminants in water provided by public water systems. U.S. Food and Drug Administration regulations establish limits for contaminants in bottled water, which must provide the same protection for public health. Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk.

> "We remain vigilant in delivering the best-quality drinking water"

The sources of drinking water (both tap water and bottled water) include rivers, lakes, streams, ponds, reservoirs, springs, and wells. As water travels over the surface of the land or through the ground, it dissolves naturally occurring minerals, in some cases, radioactive material, and substances resulting from the presence of animals or from human activity. Substances that may be present in source water include:

Microbial Contaminants, such as viruses and bacteria, which may come from sewage treatment plants, septic systems, agricultural livestock operations, or wildlife;

Inorganic Contaminants, such as salts and metals, which can be naturally occurring or may result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining, or farming;

Pesticides and Herbicides, which may come from a variety of sources such as agriculture, urban stormwater runoff, and residential uses;

Organic Chemical Contaminants, including synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production and may also come from gas stations, urban stormwater runoff, and septic systems;

Radioactive Contaminants, which can be naturally occurring or may be the result of oil and gas production and mining activities.

For more information about contaminants and potential health effects, call the U.S. EPA's Safe Drinking Water Hotline at (800) 426-4791.

Where Does My Water Come From?

The Town of East Lyme customers depend on a water supply that comes from seven groundwater sources. Wells are at various locations throughout the town in two separate aquifers: the Pattagansett and Bride Brook aquifers. The water from five of the wells is filtered to remove iron and manganese and then treated for pH adjustment, chlorine disinfection, and fluoridation. Two of the wells, Wells 1A and 2A, are similarly treated but are not currently filtered. A sequestering agent is also added to the finished water of Wells 1A and 2A. The finished water is then delivered through an extensive distribution system including two water storage tanks and ten booster stations. During the summer months, East Lyme's supply is supplemented with water from the City of New London through a distribution network including over three miles of water main, an elevated water storage tank, and two pumping stations. New London's water comes from lakes and reservoirs in a protected watershed that is located in Waterford, Montville, and Salem. The principal reservoir is Lake Konomoc. The water is processed using coagulation, flocculation, sedimentation, and carbon filtration, and then treated for pH adjustment, chlorine disinfection, fluoridation, and corrosion control. To learn more about the watersheds on the Internet, go to the U.S. EPA's Surf Your Watershed Web site at www.epa.gov/surf.

QUESTIONS?

For more information about this report, or for any questions relating to your drinking water, please call Bradford C. Kargl, Municipal Utility Engineer, at (860) 739-6931.

Test Results

Our water is monitored for many different kinds of substances on a very strict sampling schedule. Also, the water we deliver must meet specific health standards. Here, we show only those substances that were detected in our water during 2019. Certain substances, however, are monitored less often than once per year because the concentrations of these substances do not change frequently. In these cases, the most recent sample data are included, along with the year in which the sample was taken. Remember that detecting a substance does not mean the water is unsafe to drink; our goal is to keep all detects below their respective maximum allowed levels.

The concentrations shown in the Amount Detected column represent the highest amounts detected for the range of concentrations found during monitoring, which are shown in the Range column.

We participated in the 4th stage of the U.S. EPA's Unregulated Contaminant Monitoring Rule (UCMR4) program performing additional tests on our drinking water. UCMR4 benefits the environment and public health by providing the EPA with data on the occurrence of contaminants suspected to be in drinking water, to determine if the EPA needs to introduce new regulatory standards to improve drinking water quality. Contact us for more information on this program.

REGULATED SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	MCLG [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Barium (ppm)	2016, 2017, and 2018	2	2	0.088	0.003–0.088	No	Discharge of drilling wastes; Discharge from metal refineries; Erosion of natural deposits
Chlorine[1] (ppm)	2019	[4]	[4]	1.1	0.48–1.1	No	Water additive used to control microbes
Chromium (ppb)	2016, 2017, and 2018	100	100	4	2–4	No	Discharge from steel and pulp mills; Erosion of natural deposits
Combined Radium (pCi/L)	2017, 2018, and 2019	5	0	0.51	ND–0.51	No	Erosion of natural deposits
Fluoride[1] (ppm)	2019	4	4	0.84	0.54–0.84	No	Erosion of natural deposits; Water additive that promotes strong teeth; Discharge from fertilizer and aluminum factories
Haloacetic Acids [HAAs] (ppb)	2019	60	NA	2.7	ND–2.7	No	By-product of drinking water disinfection
Nitrate (ppm)	2019	10	10	2.96	0.48–2.96	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
Nitrite (ppm)	2019	1	1	0.05	0.01–0.05	No	Runoff from fertilizer use; Leaching from septic tanks, sewage; Erosion of natural deposits
Selenium (ppb)	2016, 2017, and 2018	50	50	7	ND–7	No	Discharge from petroleum and metal refineries; Erosion of natural deposits; Discharge from mines
TTHMs [Total Trihalomethanes] (ppb)	2019	80	NA	14.8	4.4–14.8	No	By-product of drinking water disinfection
Turbidity[2] (NTU)	2019	TT	NA	2.26	ND–2.26	No	Soil runoff

Tap water samples were collected for lead and copper analyses from sample sites throughout the community

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AL	MCLG	AMOUNT DETECTED (90TH %ILE)	SITES ABOVE AL/TOTAL SITES	VIOLATION	TYPICAL SOURCE
Copper (ppm)	2019	1.3	1.3	0.46	0/36	No	Corrosion of household plumbing systems; Erosion of natural deposits
Lead (ppb)	2019	15	0	1	0/36	No	Lead services lines; Corrosion of household plumbing systems including fittings and fixtures; Erosion of natural deposits

SECONDARY SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	SMCL	MCLG	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Chloride (ppm)	2016, 2017, and 2018	250	NA	89.8	17.9–89.8	No	Runoff/leaching from natural deposits
Sulfate (ppm)	2016, 2017, and 2018	250	NA	18.2	9.6–18.2	No	Runoff/leaching from natural deposits; Industrial wastes

UNREGULATED SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Sodium[3] (ppm)	2019	46.5	12.8–46.5	Naturally occurring; Road salt
MTBE [Methyl tert-Butyl Ether] (ppm)	2019	0.0012	ND–0.0012	Petroleum tanks above and below ground

UNREGULATED CONTAMINANT MONITORING RULE - PART 4 (UCMR4)

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH	TYPICAL SOURCE
Bromochloroacetic Acid (ppb)	2019	2.2	0.3–2.2	By-product of drinking water disinfection
Bromodichloroacetic Acid (ppb)	2019	1.3	ND–1.3	By-product of drinking water disinfection
Chlorodibromoacetic Acid (ppb)	2019	1.0	0.4–1.0	By-product of drinking water disinfection
Dibromoacetic Acid (ppb)	2019	2.0	ND–2.0	By-product of drinking water disinfection
Dichloroacetic Acid (ppb)	2019	1.2	ND–1.2	By-product of drinking water disinfection
HAA5 (ppb)	2019	3.6	0.3–3.6	By-product of drinking water disinfection
HAA6Br (ppb)	2019	6.4	1.5–6.4	By-product of drinking water disinfection
HAA9 (ppb)	2019	8.0	1.5–8.0	By-product of drinking water disinfection
Manganese[4] (ppm)	2019	0.462	ND–0.462	Leaching from natural deposits
Trichloroacetic Acid (ppb)	2019	1.0	ND–1.0	By-product of drinking water disinfection

Definitions

90th %ile: The levels reported for lead and copper represent the 90th percentile of the total number of sites tested. The 90th percentile is equal to or greater than 90% of our lead and copper detections.

AL (Action Level): The concentration of a contaminant that, if exceeded, triggers treatment or other requirements that a water system must follow.

LRAA (Locational Running Annual Average): The average of sample analytical results for samples taken at a particular monitoring location during the previous four calendar quarters. Amount Detected values for TTHMs and HAAs are reported as the highest LRAAs.

MCL (Maximum Contaminant Level): The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

MCLG (Maximum Contaminant Level Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

MRDL (Maximum Residual Disinfectant Level): The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

MRDLG (Maximum Residual Disinfectant Level Goal): The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.

NA: Not applicable

ND (Not detected): Indicates that the substance was not found by laboratory analysis.

NTU (Nephelometric Turbidity Units): Measurement of the clarity, or turbidity, of water. Turbidity in excess of 5 NTU is just noticeable to the average person.

pCi/L (picocuries per liter): A measure of radioactivity.

ppb (parts per billion): One part substance per billion parts water (or micrograms per liter).

ppm (parts per million): One part substance per million parts water (or milligrams per liter).

SMCL (Secondary Maximum Contaminant Level): These standards are developed to protect aesthetic qualities of drinking water and are not health based.

TT (Treatment Technique): A required process intended to reduce the level of a contaminant in drinking water.

Water Conservation Tips

You can play a role in conserving water and save yourself money in the process by becoming conscious of the amount of water your household is using and by looking for ways to use less whenever you can. It is not hard to conserve water. Here are a few tips:

- Automatic dishwashers use 15 gallons for every cycle, regardless of how many dishes are loaded. So get a run for your money and load it to capacity.
- Turn off the tap when brushing your teeth.
- Check every faucet in your home for leaks. Just a slow drip can waste 15 to 20 gallons a day. Fix it and you can save almost 6,000 gallons per year.
- Check your toilets for leaks by putting a few drops of food coloring in the tank. Watch for a few minutes to see if the color shows up in the bowl. It is not uncommon to lose up to 100 gallons a day from an invisible toilet leak. Fix it and you save more than 30,000 gallons a year.
- Use your water meter to detect hidden leaks. Simply turn off all taps and water-using appliances. Then check the meter after 15 minutes. If it moved, you have a leak.

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[1] The values reported under the Amount Detected are the highest monthly averages for the 12-month period.

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[4] The CTDPH adopted an Action Level of 0.3 ppm for manganese in 2019. Please visit the town Web site at www.eltownhall.com for more information.

EXHIBIT TTT

EAST LYME PLANNING COMMISSION
EAST LYME PLAN OF CONSERVATION AND DEVELOPMENT SUBCOMMITTEE

FILED
February 3, 2020 AT 11:39 [✓ AM]/PM
Brooke [illegible] ATC
EAST LYME TOWN CLERK

Public Workshop, January 29, 2020. 7:00 PM

East Lyme Town Hall, Upper Meeting Room
108 Pennsylvania Avenue, East Lyme, Connecticut

CHAIRMAN: Michele Williams
PLANNING DIRECTOR: Gary Goeschel II
RECORDING SECRETARY: Sue Spang

CALL TO ORDER 7:00

ROLL CALL

Present: Michelle Williams, Chairman, Kirk Scott, Rosemary Ostfeld, Rich Gordon, Norm Peck

Absent: Peter Lynch, Lawrence Fitzgerald

I. 2020 PLAN OF CONSERVATION AND DEVELOPMENT UPDATE (POCD) PRESENTATION

M. Williams thanked the public for the large turn out and interest in the POCD. She informed the public the POCD is mandated by state statute to be updated every 10-years by the towns in CT. She stated if the POCD is not amended the town will not be eligible for state grants. M. Williams informed the public that the POCD is a vision statement for where the town wants to go in the next 10-years and how they want to manage their resources and future development. M. Williams stated there will be recommendations in the POCD but they will have to go through the normal processes any other regulation or ordinance would go through.

The state is requesting all updated POCD's to include sections on sustainability and resiliency and to identify areas where the town plans on installing sewers and areas of sewer avoidance.

M. Williams presented a timeline, outline, education and outreach of the POCD.

II. OVERVIEW OF PUBLIC FORUM GUIDELINES

M. Williams read the guidelines for participation in the public forum

III. OPEN FOR PUBLIC FEEDBACK

G. Goeschel read into the record a letter from Gretchen Spartz, 38 Hope St., stating that aquaculture belongs in the POCD but she believes aquaculture should not be in the Niantic River. She also wants Oswegatchie Hills preserved.

Geoff Maynard, 9 Woodland Dr. is happy with the towns progress and would like to see the continued development and revitalization. He would like to see more consideration for development of the downtown and thinks some of the properties need to be updated. He would also like to see a recreation center for children. J. Maynard stated the pool at the high school is rundown and always has issues as well as broken gym equipment, he would like to see these issues fixed.

Ed Lilienthal, 21 Haigh Ave., stated he is concerned about the massive traffic congestion from Niantic to Flanders in the next 10-years. He does not think the answer is more roads and parking lots but bike friendly community assets. E. Lilienthal stated statistics show bike friendly communities increase business, increase property values and attract young professionals.

John DeSantis, 7 Corey Lane, asked that an emergency evacuation plan be included in the POCD. He suggested a helicopter landing area when there is an emergency and traffic is backed up.

Deb Moshier-Dunn, 7 Plant Drive, Waterford, Save the River-Save the Hills (STR-STH) read a board approved letter stressing water quality should be a priority and development on the Oswegatchie Hills should be limited. She stated low impact developments standards and low impact best standards be adopted for any development near a stream, wetlands and Niantic River. D. Moshier-Dun stated there should be a mandatory pump out for septic systems every three years. The town should continue efforts to purchase the Oswegatchie Hills property and other open space which would protect the water quality of Niantic River. The town should expand sewer systems, especially in the Saunders Point area. Resiliency and protection of the coast should be addressed.

Thomas Hace, 43 Riverview Rd., stated that zoning seems reactive instead of proactive. He stated the town is caught in a cycle of intense development both commercial and residential and people who have lived in town end up paying the price. People who are developing should be paying an upfront cost so the town does not have to keep bonding. Developers should provide road infrastructure or greenways. T. Hace stated he serves on the agribusiness committee in town and stated there should be a trade system and ask that someone who is going to develop farm land should buy another equal area in town suitable for farming.

Sue Bowes, 61 Pennsylvania Ave., Remax, stated when she started selling houses the town was very desirable but when she looks at the development it scares her. She is against the Type 2 aquaculture in the river because the river is one of the towns best assets and she said it will have an effect on business, recreation and residents. S. Bowes wants to make sure the village of Niantic keeps its charm and should be developed that way by encouraging boutiques, restaurants and other areas that make it walkable.

Dick Waterman, 11 Lake Ave. would like to see the POCD support the arts and culture of East Lyme by funding $2000.00 for 501 (c)(3) organizations. He supports the development of commercial aquaculture in the Niantic River. He stated that the Samuel Smith Farmstead be organized as a commission. The Samuel Smith Farmstead, The Brookside Farm Museum and the East Lyme Historical Society should have a seat on the East Lyme Historic Properties Commission.

Rich Steel, 23 Rose Lane, would like to see permeable ADA compliant walkways in town. The conversion of town vehicles to electric should be considered. R. Steel thinks a trolley service connecting Niantic and Flanders would be a good idea. Rain gardens and walking paths would be of use. He suggested local business could put planters on street corners for beautification. He would like to see the villages of Niantic and Flanders be more integrated. Walking paths throughout town with plaques for education on the history of the town would be nice.

Douglas Schwartz, P.O. Box 7274, Groton, stated the POCD should consider where solar plants should be placed. He informed the members that East Lyme has one of the worst issues of runoff from a solar farm impacting a stream. Solar farms should be placed on rooftops such as COSTCO. The state continues to push solar farms and developers are flooding into the state to make money on these farms. D. Schwartz stated there is no way to decommission the panels and when they are no longer viable they leave behind toxic waste. During high wind events like a hurricane the panels will lift and blow away, possibly catch on fire releasing toxic chemicals. He suggested putting language in the POCD as a way of regulating solar farms.

Mike Dunn,9 King Arthur Drive, Friends of the Oswegatchie Nature Preserve, informed the members of the benefits of open space, he will be providing a study for the appendix of the POCD. He said that even though many acres have been preserved in the Oswegatchie Hills area, it is not good enough. There are 236 acres to the north which has been tied up in litigation and has a mile of frontage on the Niantic River and should not be developed because of terrain and characteristics of the property. This area has been identified as open space for over 30 years and should be noted in the POCD.

John Lombardo, 2 Hillcrest Rd., would like to see more farming and open space that diversifies the economic base of the town. The town should look at demographics of the future. He stated the ages of people moving into the area are getting younger and the town should plan for younger people and their lifestyle which is not suburban models. J. Lombardo suggested partnering with towns around East Lyme for some services.

Sally Uden, 15 Beaver Brook Rd., East Lyme Agricultural Business Group Subcommittee, described the various types of agriculture in East Lyme. She stated if there was more agriculture in town then we would be less reliant on outside sources, especially in an emergency. There are 53 farmers and 2000 acres in East Lyme which help local residents and contribute to clean water. S. Uden mentioned the fishing industry which attracts people to town and helps keep the waters clean, she stated aquaculture should be encouraged. Open space cost less than residential development, more people equals more costs.

Tom Kall, 80 Grassy Hill Rd. stated all lands north of Interstate 95 should be protected for aquifer recharge. He stated the water is a stratified drift aquifer and starts in the north end of town. A few years back the town started buying water from New London which is highly treated. In return for buying the water from New London the town has to supply a certain amount of water in the winter. T. Kall suggested an ordinance limiting the use of fertilizers near aquifer zones, require certification of operation of septic systems, limit paved, impervious surfaces, protect the Four Mile River aquifer and protect beavers.

Ron Luich, 13 Eno Lane, President of the East Lyme Land Trust, stated the land trust had been awarded DEEP grant money for open space purchase. He stated it takes approximately 5 years to acquire land for open space. R. Luich informed the members of other properties the land trust has bought for open space. He stated the land trust has been approached by solar farm developers offering lots of money to install solar farms, the land trust has decided not to allow solar farms on their properties. He stated protecting drinking water should be a priority.

Barbara Harris, 24 Fairhaven Rd., wants to see open space and coastal resources protected. She lives on a tidal marsh and has seen many changes over the years due to climate change. Fairhaven Rd. has become very busy because people use it to get to the Black Point area, this also creates trash along the road which she has noticed is a problem on other town roads. B. Harris also stated that the phragmites should be better controlled.

Kelly Streich, 20 Brook Rd., suggested that the POCD include what has been dropped and what has been added in the POCD. She stated the Pattagansett River estuary is highly developed and the wetlands in the estuary are a unique habitat. The town should protect these areas and consider low impact developments, increased setbacks and a nature center behind the middle school. There should be zoning regulations concerning solar farms.

Doug Dubitsky,690 Boston Post Rd. N. Windham, stated he represents farmers and landowners in East Lyme. He stated farmers are always looking forward and are hard workers who have kept their land as open space for generations. He stated that if a farmer wants to leave land to his children and they want to develop it they should be able to. D. Dubitsky stated that the town should not designate people's property as open space therefore limiting what the farmer can do with the land.

Kate Steel, 23 Rose Lane, suggested integrating the seniors in town with the youth. She also stated there is a large Chinese community in town and they should also be integrated into the community.

Barbara Johnson Low, 3 North Rd., would like the community to be more walkable. She stated that buildings in town could be zoned to allow up to three stories and mixed use should be encouraged. By allowing retail on the lower levels and residential on the top two floors this would encourage a walkable community.

Tim Londgregan, 109-111 Main St., Niantic Bay Shellfish Co. stated there is a vibrant waterfront with a long history of fishing and aquaculture. He stated his strong support for keeping aquaculture in the POCD. T. Londregan would like to see the support of aquaculture in the current POCD remain.

Ruth DeLuca, 10 Bronson St., stated that natural resources are the charm of the town. She stated the town should consider funding of open space and educate residents on the harm of fertilization to the waterways. R. DeLuca stated in the past, the town had set aside a small amount of funding each year for the purchase of opens space, they no longer fund open space. She stated the future depends on the health of its natural resources.

Chris Hoy, 124 North Bride Brook Rd. would like to see condos, and apartment limited. He stated the town cannot keep up with the maintenance and upkeep that comes with the increased development.

Kyle Corey, 75 Holmes Rd., stated the number one priority should be preservation of coastal resources. He stated development is out of control and the traffic is getting much worse. It takes more equipment and taxes to maintain the town and roads.

John Lombardo, 2 Hillcrest Rd., stated East Lyme is no longer a small town but everyone wants that small town feel. He feels the town should consider a fund to purchase farms or buy development rights to help the farmers.

Rich Steel, 23 Rose Lane, would like to see compost pick up, a community garden and he would like to see a grocery store in Niantic.

M. Williams thanked all who came and contributed to the conversation and the POCD.

IX. ADJOURNMENT

MOTION: (Scott/Ostfeld) to adjourn at 8:45. Vote: Approved Unanimously.

Respectfully Submitted,
Sue Spang,
Recording Secretary

Ground Water and Surface Water
A Single Resource

U.S. Geological Survey Circular 1139

by Thomas C. Winter
Judson W. Harvey
O. Lehn Franke
William M. Alley

Denver, Colorado
1998

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Thomas J. Casadevall, Acting Director

MARCH 3, 1849

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FOREWORD

Traditionally, management of water resources has focused on surface water or ground water as if they were separate entities. As development of land and water resources increases, it is apparent that development of either of these resources affects the quantity and quality of the other. Nearly all surface-water features (streams, lakes, reservoirs, wetlands, and estuaries) interact with ground water. These interactions take many forms. In many situations, surface-water bodies gain water and solutes from ground-water systems and in others the surface-water body is a source of ground-water recharge and causes changes in ground-water quality. As a result, withdrawal of water from streams can deplete ground water or conversely, pumpage of ground water can deplete water in streams, lakes, or wetlands. Pollution of surface water can cause degradation of ground-water quality and conversely pollution of ground water can degrade surface water. Thus, effective land and water management requires a clear understanding of the linkages between ground water and surface water as it applies to any given hydrologic setting.

This Circular presents an overview of current understanding of the interaction of ground water and surface water, in terms of both quantity and quality, as applied to a variety of landscapes across the Nation. This Circular is a product of the Ground-Water Resources Program of the U.S. Geological Survey. It serves as a general educational document rather than a report of new scientific findings. Its intent is to help other Federal, State, and local agencies build a firm scientific foundation for policies governing the management and protection of aquifers and watersheds. Effective policies and management practices must be built on a foundation that recognizes that surface water and ground water are simply two manifestations of a single integrated resource. It is our hope that this Circular will contribute to the use of such effective policies and management practices.

(Signed)

Robert M. Hirsch
ChiefHydrologist

CONTENTS

BOXES

PREFACE

- Understanding the interaction of ground water and surface water is essential to water managers and water scientists. Management of one component of the hydrologic system, such as a stream or an aquifer, commonly is only partly effective because each hydrologic component is in continuing interaction with other components. The following are a few examples of common water-resource issues where understanding the interconnections of ground water and surface water is fundamental to development of effective water-resource management and policy.

WATER SUPPLY

- It has become difficult in recent years to construct reservoirs for surface storage of water because of environmental concerns and because of the difficulty in locating suitable sites. An alternative, which can reduce or eliminate the necessity for surface storage, is to use an aquifer system for temporary storage of water. For example, water stored underground during times of high streamflow can be withdrawn during times of low streamflow. The characteristics and extent of the interactions of ground water and surface water affect the success of such conjunctive-use projects.
- Methods of accounting for water rights of streams invariably account for surface-water diversions and surface-water return flows. Increasingly, the diversions from a stream that result from ground-water withdrawals are considered in accounting for water rights as are ground-water return flows from irrigation and other applications of water to the land surface. Accounting for these ground-water components can be difficult and controversial. Another form of water-rights accounting involves the trading of ground-water rights and surface-water rights. This has been proposed as a water-management tool where the rights to the total water resource can be shared. It is an example of the growing realization that ground water and surface water are essentially one resource.
- In some regions, the water released from reservoirs decreases in volume, or is delayed significantly, as it moves downstream because some of the released water seeps into the streambanks. These losses of water and delays in traveltime can be significant, depending on antecedent ground-water and streamflow conditions as well as on other factors such as the condition of the channel and the presence of aquatic and riparian vegetation.
- Storage of water in streambanks, on flood plains, and in wetlands along streams reduces flooding downstream. Modifications of the natural interaction between ground water and surface water along streams, such as drainage of wetlands and construction of levees, can remove some of this natural attenuation of floods. Unfortunately, present knowledge is limited with respect to the effects of land-surface modifications in river valleys on floods and on the natural interaction of ground water and surface water in reducing potential flooding.

WATER QUALITY

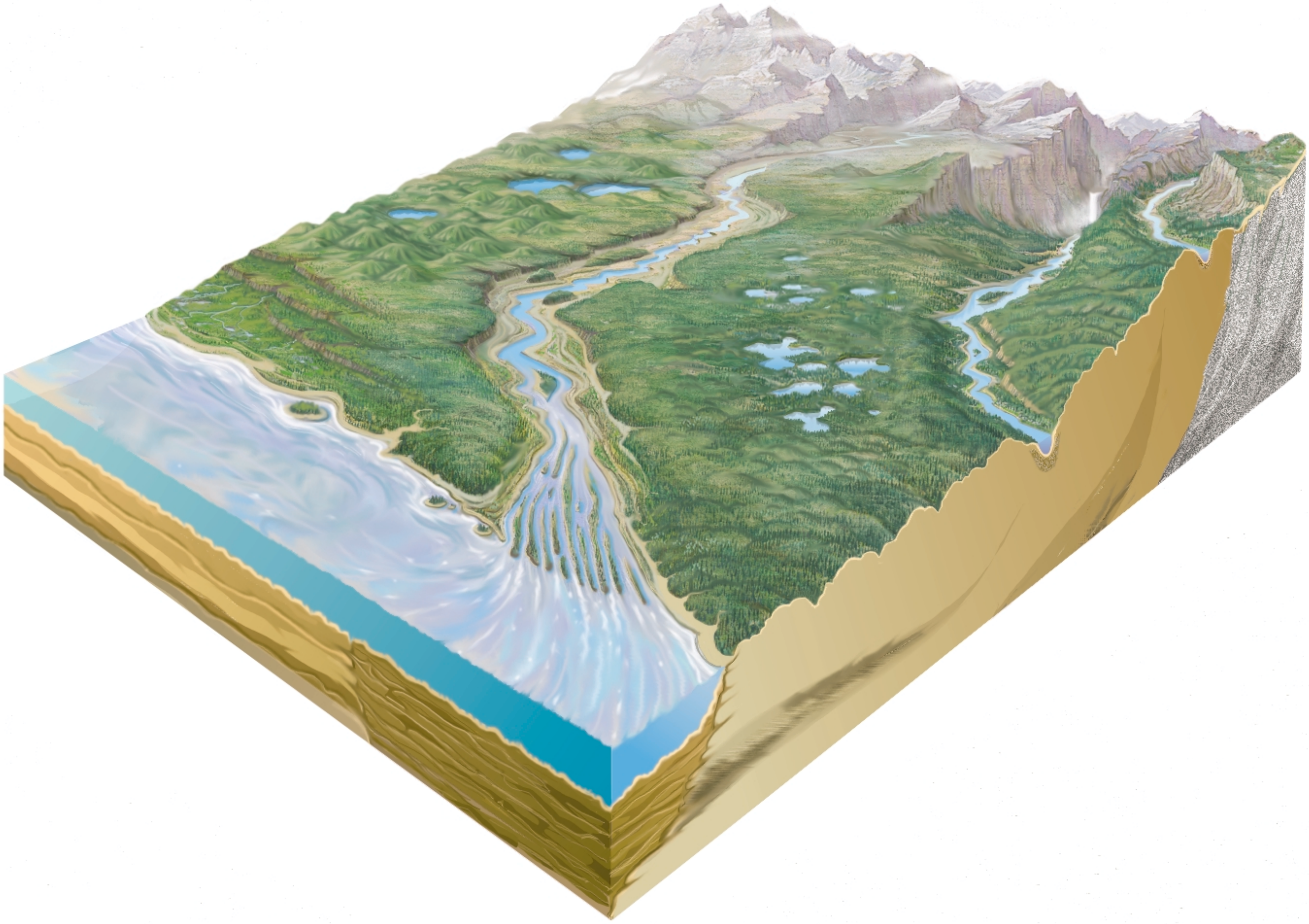
- Much of the ground-water contamination in the United States is in shallow aquifers that are directly connected to surface water. In some settings where this is the case, ground water can be a major and potentially long-term contributor to contamination of surface water. Determining the contributions of ground water to contamination of streams and lakes is a critical step in developing effective water-management practices.
- A focus on watershed planning and management is increasing among government agencies responsible for managing water quality as well as broader aspects of the environment. The watershed approach recognizes that water, starting with precipitation, usually moves

through the subsurface before entering stream channels and flowing out of the watershed. Integrating ground water into this “systems” approach is essential, but challenging, because of limitations in knowledge of the interactions of ground water and surface water. These difficulties are further complicated by the fact that surface-water watersheds and ground-water watersheds may not coincide.

- To meet water-quality standards and criteria, States and local agencies need to determine the amount of contaminant movement (wasteload) to surface waters so they can issue permits and control discharges of waste. Typically, ground-water inputs are not included in estimates of wasteload; yet, in some cases, water-quality standards and criteria cannot be met without reducing contaminant loads from ground-water discharges to streams.
- It is generally assumed that ground water is safe for consumption without treatment. Concerns about the quality of ground water from wells near streams, where contaminated surface water might be part of the source of water to the well, have led to increasing interest in identifying when filtration or treatment of ground water is needed.
- Wetlands, marshes, and wooded areas along streams (riparian zones) are protected in some areas to help maintain wildlife habitat and the quality of nearby surface water. Greater knowledge of the water-quality functions of riparian zones and of the pathways of exchange between shallow ground water and surface-water bodies is necessary to properly evaluate the effects of riparian zones on water quality.

CHARACTERISTICS OF AQUATIC ENVIRONMENTS

- Mixing of ground water with surface water can have major effects on aquatic environments if factors such as acidity, temperature, and dissolved oxygen are altered. Thus, changes in the natural interaction of ground water and surface water caused by human activities can potentially have a significant effect on aquatic environments.
- The flow between surface water and ground water creates a dynamic habitat for aquatic fauna near the interface. These organisms are part of a food chain that sustains a diverse ecological community. Studies indicate that these organisms may provide important indications of water quality as well as of adverse changes in aquatic environments.
- Many wetlands are dependent on a relatively stable influx of ground water throughout changing seasonal and annual weather patterns. Wetlands can be highly sensitive to the effects of ground-water development and to land-use changes that modify the ground-water flow regime of a wetland area. Understanding wetlands in the context of their associated ground-water flow systems is essential to assessing the cumulative effects of wetlands on water quality, ground-water flow, and streamflow in large areas.
- The success of efforts to construct new wetlands that replicate those that have been destroyed depends on the extent to which the replacement wetland is hydrologically similar to the destroyed wetland. For example, the replacement of a wetland that is dependent on ground water for its water and chemical input needs to be located in a similar ground-water discharge area if the new wetland is to replicate the original. Although a replacement wetland may have a water depth similar to the original, the communities that populate the replacement wetland may be completely different from communities that were present in the original wetland because of differences in hydrogeologic setting.



Ground Water and Surface Water

A Single Resource

by T.C. Winter
J.W. Harvey
O.L. Franke
W.M. Alley

INTRODUCTION

As the Nation's concerns over water resources and the environment increase, the importance of considering ground water and surface water as a single resource has become increasingly evident. Issues related to water supply, water quality, and degradation of aquatic environments are reported on frequently. The interaction of ground water and surface water has been shown to be a significant concern in many of these issues. For example, contaminated aquifers that discharge to streams can result in long-term contamination of surface water; conversely, streams can be a major source of contamination to aquifers. Surface water commonly is hydraulically connected to ground water, but the interactions are difficult to observe and measure and commonly have been ignored in water-management considerations and policies. Many natural processes and human activities affect the interactions of ground water and surface water. The purpose of this report is to present our current understanding of these processes and activities as well as limitations in our knowledge and ability to characterize them.

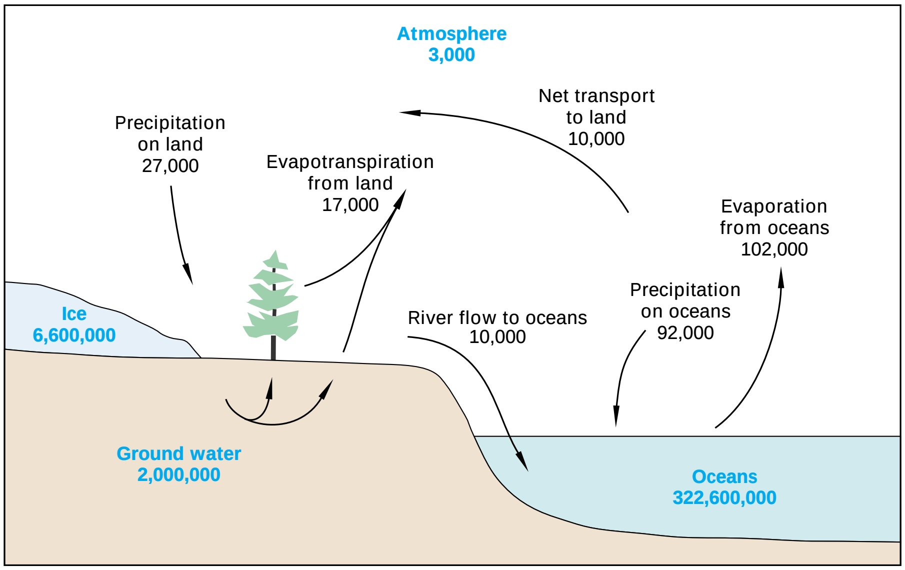
> ***"Surface water commonly is hydraulically connected to ground water, but the interactions are difficult to observe and measure"***

NATURAL PROCESSES OF GROUND-WATER AND SURFACE-WATER INTERACTION

The Hydrologic Cycle and Interactions of Ground Water and Surface Water

The hydrologic cycle describes the continuous movement of water above, on, and below the surface of the Earth. The water on the Earth's surface—surface water—occurs as streams, lakes, and wetlands, as well as bays and oceans. Surface water also includes the solid forms of water—snow and ice. The water below the surface of the Earth primarily is ground water, but it also includes soil water.

The hydrologic cycle commonly is portrayed by a very simplified diagram that shows only major transfers of water between continents and oceans, as in Figure 1. However, for understanding hydrologic processes and managing water resources, the hydrologic cycle needs to be viewed at a wide range of scales and as having a great deal of variability in time and space. Precipitation, which is the source of virtually all freshwater in the hydrologic cycle, falls nearly everywhere, but its distribution is highly variable. Similarly, evaporation and transpiration return water to the atmosphere nearly everywhere, but evaporation and transpiration rates vary considerably according to climatic conditions. As a result, much of the precipitation never reaches the oceans as surface and subsurface runoff before the water is returned to the atmosphere. The relative magnitudes of the individual components of the hydrologic cycle, such as evapotranspiration, may differ significantly even at small scales, as between an agricultural field and a nearby woodland.



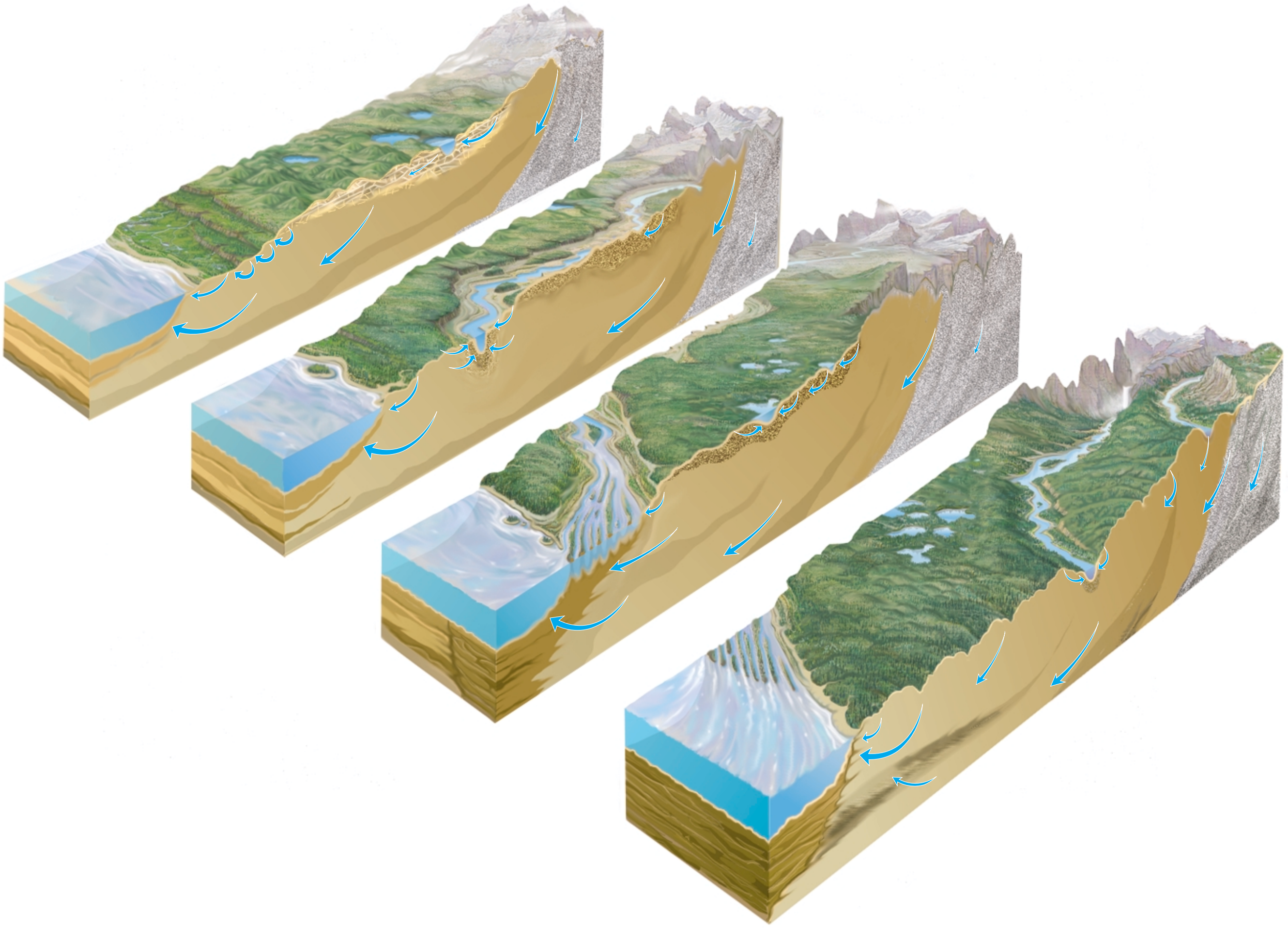
Pools are in cubic miles
Fluxes are in cubic miles per year

Figure ***1.*** *Ground water is the second smallest of the four main pools of water on Earth, and river flow to the oceans is one of the smallest fluxes, yet ground water and surface water are the components of the hydrologic system that humans use most. (Modified from Schelesinger, W.H., 1991, Biogeochemistry–An analysis of global change: Academic Press, San Diego, California.) (Used with permission.)*

To present the concepts and many facets of the interaction of ground water and surface water in a unified way, a conceptual landscape is used (Figure 2). The conceptual landscape shows in a very general and simplified way the interaction of ground water with all types of surface water, such as streams, lakes, and wetlands, in many different terrains from the mountains to the oceans. The intent of Figure 2 is to emphasize that ground water and surface water interact at many places throughout the landscape.

Movement of water in the atmosphere and on the land surface is relatively easy to visualize, but the movement of ground water is not. Concepts related to ground water and the movement of ground water are introduced in Box A. As illustrated in Figure 3, ground water moves along flow paths of varying lengths from areas of recharge to areas of discharge. The generalized flow paths in Figure 3 start at the water table, continue through the ground-water system, and terminate at the stream or at the pumped well. The source of water to the water table (ground-water recharge) is infiltration of precipitation through the unsaturated zone. In the uppermost, unconfined aquifer, flow paths near the stream can be tens to hundreds of feet in length and have corresponding traveltimes of days to a few years. The longest and deepest flow paths in Figure 3 may be thousands of feet to tens of miles in length, and traveltimes may range from decades to millennia. In general, shallow ground water is more susceptible to contamination from human sources and activities because of its close proximity to the land surface. Therefore, shallow, local patterns of ground-water flow near surface water are emphasized in this Circular.

"Ground water moves along flow paths of varying lengths in transmitting water from areas of recharge to areas of discharge"



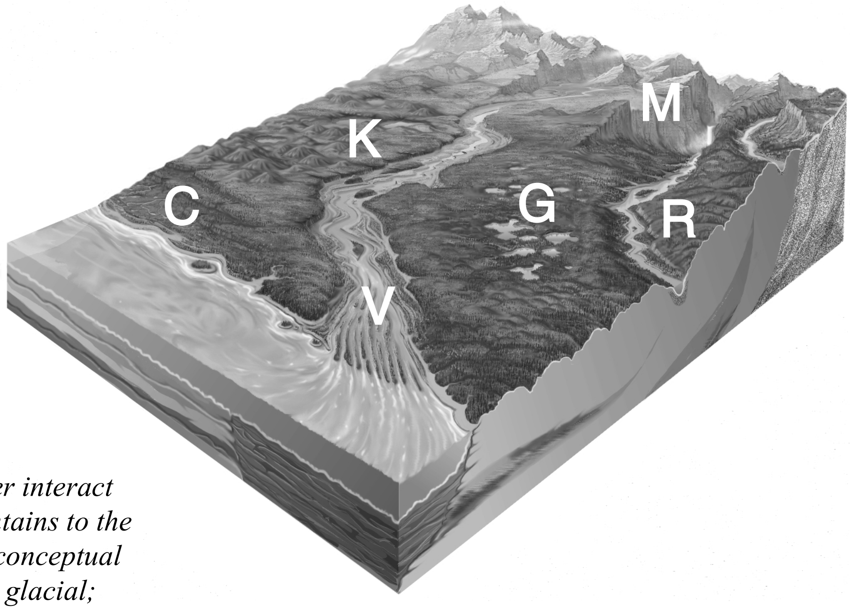


Figure 2. *Ground water and surface water interact throughout all landscapes from the mountains to the oceans, as depicted in this diagram of a conceptual landscape. M, mountainous; K, karst; G, glacial; R, riverine (small); V, riverine (large); C, coastal.*

Small-scale geologic features in beds of surface-water bodies affect seepage patterns at scales too small to be shown in Figure 3. For example, the size, shape, and orientation of the sediment grains in surface-water beds affect seepage patterns. If a surface-water bed consists of one sediment type, such as sand, inflow seepage is greatest at the shoreline, and it decreases in a nonlinear pattern away from the shoreline (Figure 4). Geologic units having different permeabilities also affect seepage distribution in surface-water beds. For example, a highly permeable sand layer within a surface-water bed consisting largely of silt will transmit water preferentially into the surface water as a spring (Figure 5).

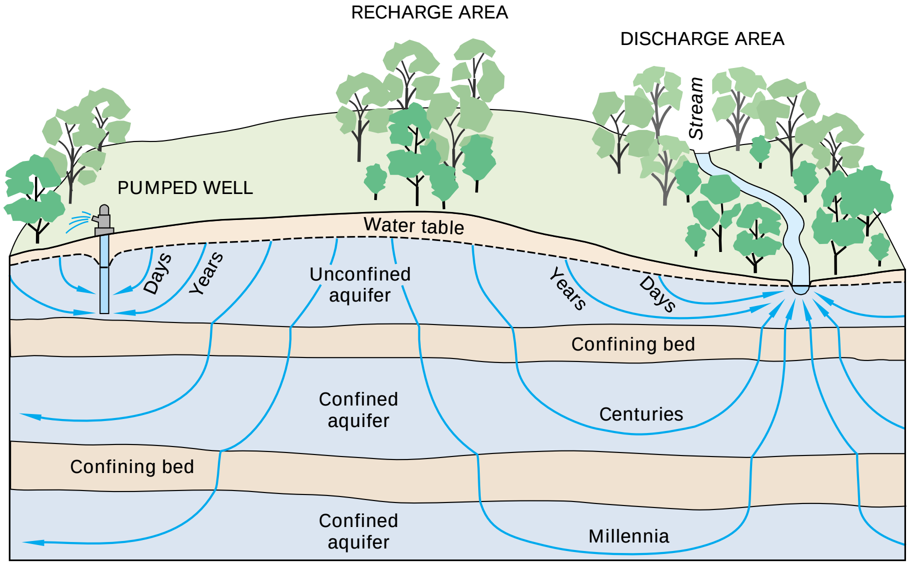


Figure 3. *Ground-water flow paths vary greatly in length, depth, and traveltime from points of recharge to points of discharge in the ground-water system.*

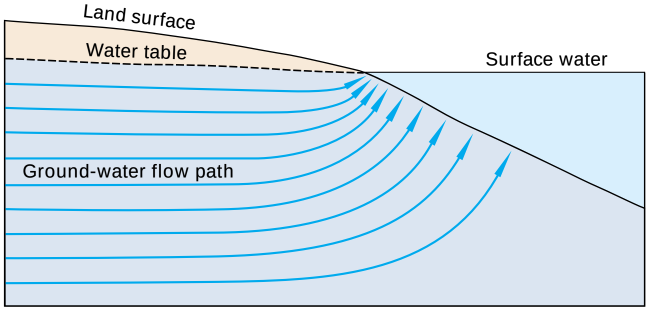


Figure 4. *Ground-water seepage into surface water usually is greatest near shore. In flow diagrams such as that shown here, the quantity of discharge is equal between any two flow lines; therefore, the closer flow lines indicate greater discharge per unit of bottom area.*

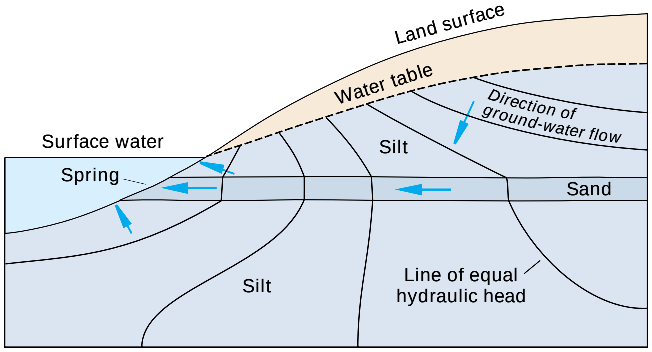


Figure 5. *Subaqueous springs can result from preferred paths of ground-water flow through highly permeable sediments.*

A

Concepts of Ground Water, Water Table, and Flow Systems

SUBSURFACE WATER

Water beneath the land surface occurs in two principal zones, the unsaturated zone and the saturated zone (Figure A–1). In the unsaturated zone, the voids—that is, the spaces between grains of gravel, sand, silt, clay, and cracks within rocks—contain both air and water. Although a considerable amount of water can be present in the unsaturated zone, this water cannot be pumped by wells because it is held too tightly by capillary forces. The upper part of the unsaturated zone is the soil-water zone. The soil zone is crisscrossed by roots, voids left by decayed roots, and animal and worm burrows, which enhance the infiltration of precipitation into the soil zone. Soil water is used by plants in life functions and transpiration, but it also can evaporate directly to the atmosphere.

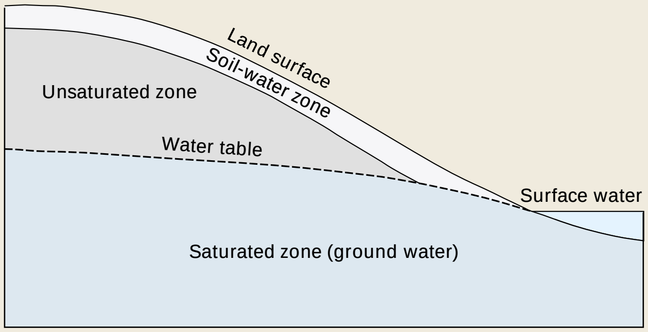


Figure A–1. The water table is the upper surface of the saturated zone. The water table meets surface-water bodies at or near the shoreline of surface water if the surface-water body is connected to the ground-water system.

In contrast to the unsaturated zone, the voids in the saturated zone are completely filled with water. Water in the saturated zone is referred to as ground water. The upper surface of the saturated zone is referred to as the water table. Below the water table, the water pressure is great enough to allow water to enter wells, thus permitting ground water to be withdrawn for use. A well is constructed by inserting a pipe into a drilled hole; a screen is attached, generally at its base, to prevent earth materials from entering the pipe along with the water pumped through the screen.

The depth to the water table is highly variable and can range from zero, when it is at land surface, to hundreds or even thousands of feet in some types of landscapes. Usually, the depth to the water table is small near permanent bodies of surface water such as streams, lakes, and wetlands. An important characteristic of the water table is that its configuration varies seasonally and from year to year because ground-water recharge, which is the accretion of water to the upper surface of the saturated zone, is related to the wide variation in the quantity, distribution, and timing of precipitation.

THE WATER TABLE

The depth to the water table can be determined by installing wells that penetrate the top of the saturated zone just far enough to hold standing water. Preparation of a water-table map requires that only wells that have their well screens placed near the water table be used. If the depth to water is measured at a number of such wells throughout an area of study, and if those water levels are referenced to a common datum such as sea level, the data can be contoured to indicate the configuration of the water table (Figure A–2).

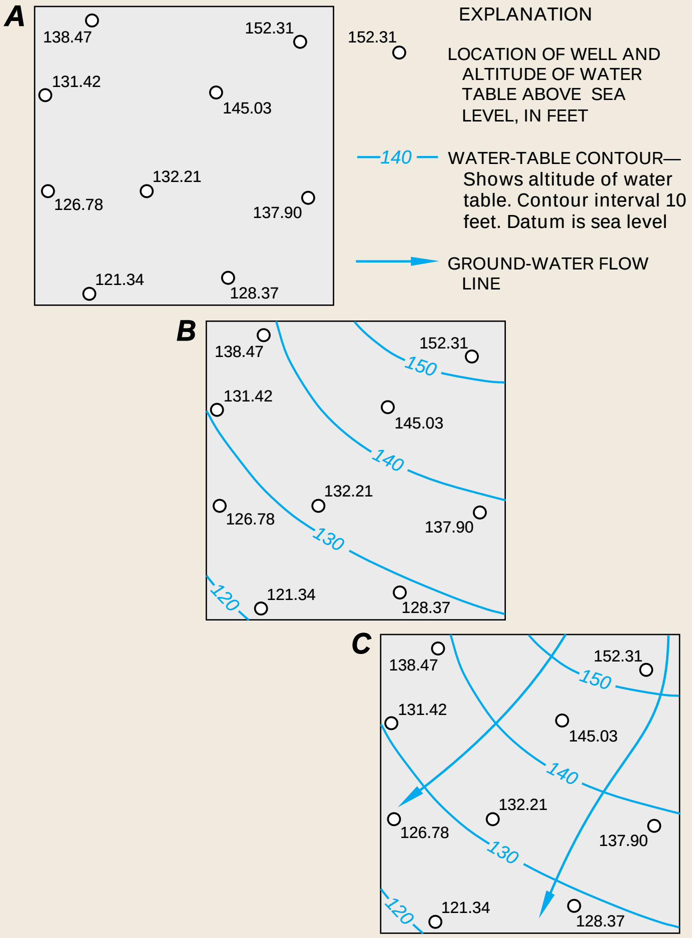


Figure A–2. Using known altitudes of the water table at individual wells (A), contour maps of the water-table surface can be drawn (B), and directions of ground-water flow along the water table can be determined (C) because flow usually is approximately perpendicular to the contours.

In addition to various practical uses of a water-table map, such as estimating an approximate depth for a proposed well, the configuration of the water table provides an indication of the approximate direction of ground-water flow at any location on the water table. Lines drawn perpendicular to water-table contours usually indicate the direction of ground-water flow along the upper surface of the ground-water system. The water table is continually adjusting to changing recharge and discharge patterns. Therefore, to construct a water-table map, water-level measurements must be made at approximately the same time, and the resulting map is representative only of that specific time.

GROUND-WATER MOVEMENT

The ground-water system as a whole is actually a three-dimensional flow field; therefore, it is important to understand how the vertical components of ground-water movement affect the interaction of ground water and surface water. A vertical section of a flow field indicates how potential energy is distributed beneath the water table in the ground-water system and how the energy distribution can be used to determine vertical components of flow near a surface-water body. The term hydraulic head, which is the sum of elevation and water pressure divided by the weight density of water, is used to describe potential energy in ground-water flow systems. For example, Figure A–3 shows a generalized vertical section of subsurface water flow. Water that infiltrates at land surface moves vertically downward to the water table to become ground water. The ground water then moves both vertically and laterally within the ground-water system. Movement is downward and lateral on the right side of the diagram, mostly lateral in the center, and lateral and upward on the left side of the diagram.

Flow fields such as these can be mapped in a process similar to preparing water-table maps, except that vertically distributed piezometers need to be used instead of water-table wells. A piezometer is a well that has a very short screen so the water level represents hydraulic head in only a very small part of the ground-water system. A group of piezometers completed at different depths at the same location is referred to as a piezometer nest. Three such piezometer nests are shown in Figure A–3 (locations A, B, and C). By starting at a water-table contour, and using the water-level data from the piezometer nests, lines of equal hydraulic head can be drawn. Similar to drawing flow direction on water-table maps, flow lines can be drawn approximately perpendicular to these lines of equal hydraulic head, as shown in Figure A–3.

Actual flow fields generally are much more complex than that shown in Figure A–3. For example, flow systems of different sizes and depths can be present, and they can overlie one another, as indicated in Figure A–4. In a local flow system, water that recharges at a water-table high discharges to an adjacent lowland. Local flow systems are the most dynamic and the shallowest flow systems; therefore, they have the greatest interchange with surface water. Local flow systems can be underlain by intermediate and regional flow systems. Water in deeper flow systems have longer flow paths and longer contact time with subsurface materials; therefore, the water generally contains more dissolved chemicals. Nevertheless, these deeper flow systems also eventually discharge to surface water, and they can have a great effect on the chemical characteristics of the receiving surface water.

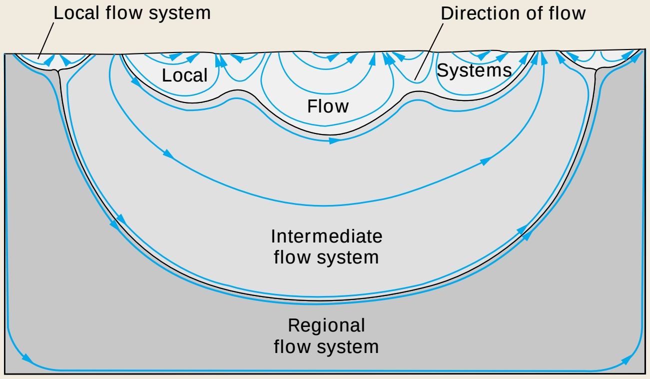


Figure A–4. Ground-water flow systems can be local, intermediate, and regional in scale. Much ground-water discharge into surface-water bodies is from local flow systems. (Figure modified from Toth, J., 1963, A theoretical analysis of groundwater flow in small drainage basins: p. 75–96 in Proceedings of Hydrology Symposium No. 3, Groundwater, Queen's Printer, Ottawa, Canada.)

GROUND-WATER DISCHARGE

The quantity of ground-water discharge (flux) to and from surface-water bodies can be determined for a known cross section of aquifer by multiplying the hydraulic gradient, which is determined from the hydraulic-head measurements in wells and piezometers, by the permeability of the aquifer materials. Permeability is a quantitative measure of the ease of water movement through aquifer materials. For example, sand is more permeable than clay because the pore spaces between sand grains are larger than pore spaces between clay particles.

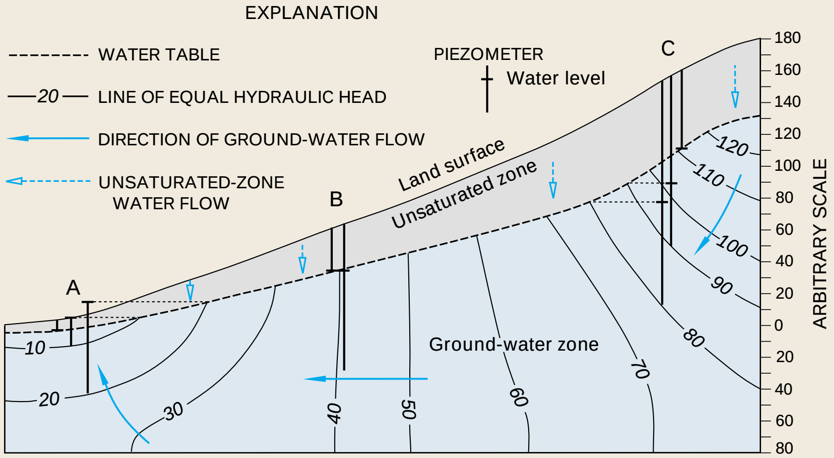


Figure A–3. If the distribution of hydraulic head in vertical section is known from nested piezometer data, zones of downward, lateral, and upward components of ground-water flow can be determined.

Changing meteorological conditions also strongly affect seepage patterns in surface-water beds, especially near the shoreline. The water table commonly intersects land surface at the shoreline, resulting in no unsaturated zone at this point. Infiltrating precipitation passes rapidly through a thin unsaturated zone adjacent to the shoreline, which causes water-table mounds to form quickly adjacent to the surface water (Figure 6). This process, termed focused recharge, can result in increased ground-water inflow to surface-water bodies, or it can cause inflow to surface-water bodies that normally have seepage to ground water. Each precipitation event has the potential to cause this highly transient flow condition near shorelines as well as at depressions in uplands (Figure 6).

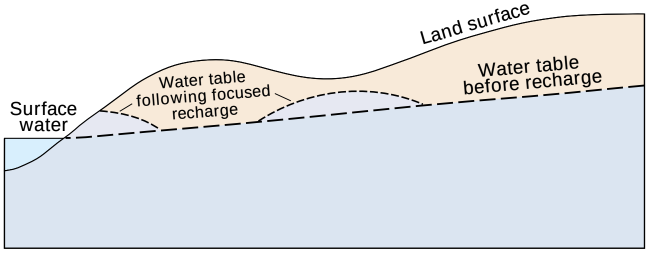


Figure 6. *Ground-water recharge commonly is focused initially where the unsaturated zone is relatively thin at the edges of surface-water bodies and beneath depressions in the land surface.*

Transpiration by nearshore plants has the opposite effect of focused recharge. Again, because the water table is near land surface at edges of surface-water bodies, plant roots can penetrate into the saturated zone, allowing the plants to transpire water directly from the ground-water system (Figure 7). Transpiration of ground water commonly results in a drawdown of the water table much like the effect of a pumped well. This highly variable daily and seasonal transpiration of ground water may significantly reduce ground-water discharge to a surface-water body or even cause movement of surface water into the subsurface. In many places it is possible to measure diurnal changes in the direction of flow during seasons of active plant growth; that is, ground water moves into the surface water during the night, and surface water moves into shallow ground water during the day.

These periodic changes in the direction of flow also take place on longer time scales: focused recharge from precipitation predominates during wet periods and drawdown by transpiration predominates during dry periods. As a result, the two processes, together with the geologic controls on seepage distribution, can cause flow conditions at the edges of surface-water bodies to be extremely variable. These “edge effects” probably affect small surface-water bodies more than large surface-water bodies because the ratio of edge length to total volume is greater for small water bodies than it is for large ones.

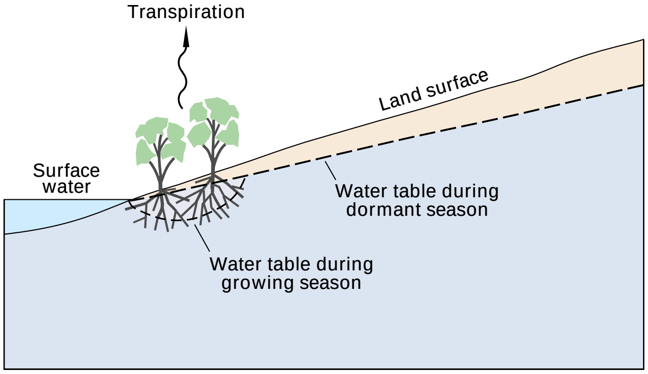


Figure 7. *Where the depth to the water table is small adjacent to surface-water bodies, transpiration directly from ground water can cause cones of depression similar to those caused by pumping wells. This sometimes draws water directly from the surface water into the subsurface.*

INTERACTION OF GROUND WATER AND STREAMS

Streams interact with ground water in all types of landscapes (see Box B). The interaction takes place in three basic ways: streams gain water from inflow of ground water through the streambed (gaining stream, Figure 8*A*), they lose water to ground water by outflow through the streambed (losing stream, Figure 9*A*), or they do both, gaining in some reaches and losing in other reaches. For ground water to discharge into a stream channel, the altitude of the water table in the vicinity of the stream must be higher than the altitude of the stream-water surface. Conversely, for surface water to seep to ground water, the altitude of the water table in the vicinity of the stream must be lower than the altitude of the stream-water surface. Contours of water-table elevation indicate gaining streams by pointing in an upstream direction (Figure 8*B*), and they indicate losing streams by pointing in a downstream direction (Figure 9*B*) in the immediate vicinity of the stream.

Losing streams can be connected to the ground-water system by a continuous saturated zone (Figure 9*A*) or can be disconnected from

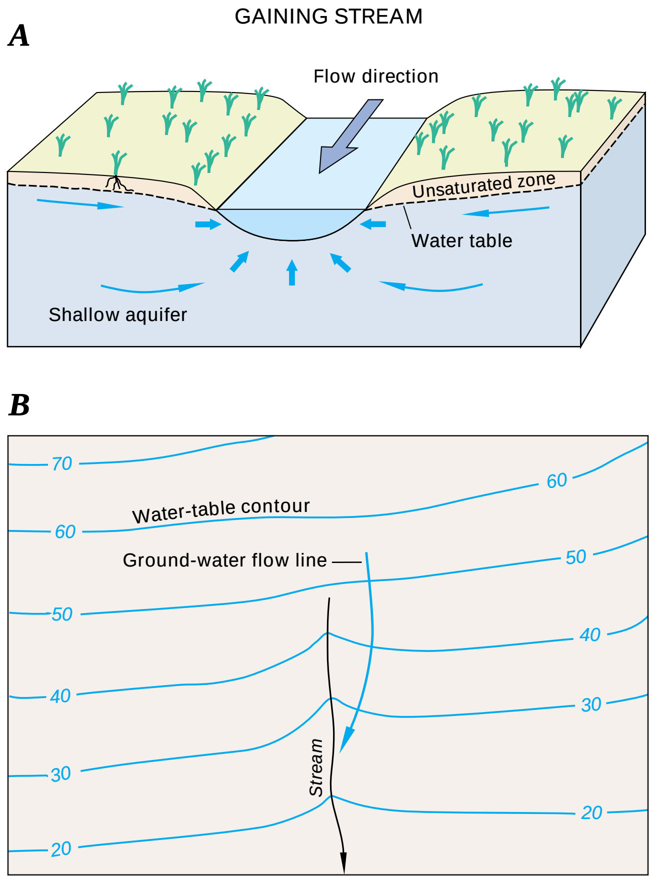


Figure 8. *Gaining streams receive water from the ground-water system (A). This can be determined from water-table contour maps because the contour lines point in the upstream direction where they cross the stream (B).*

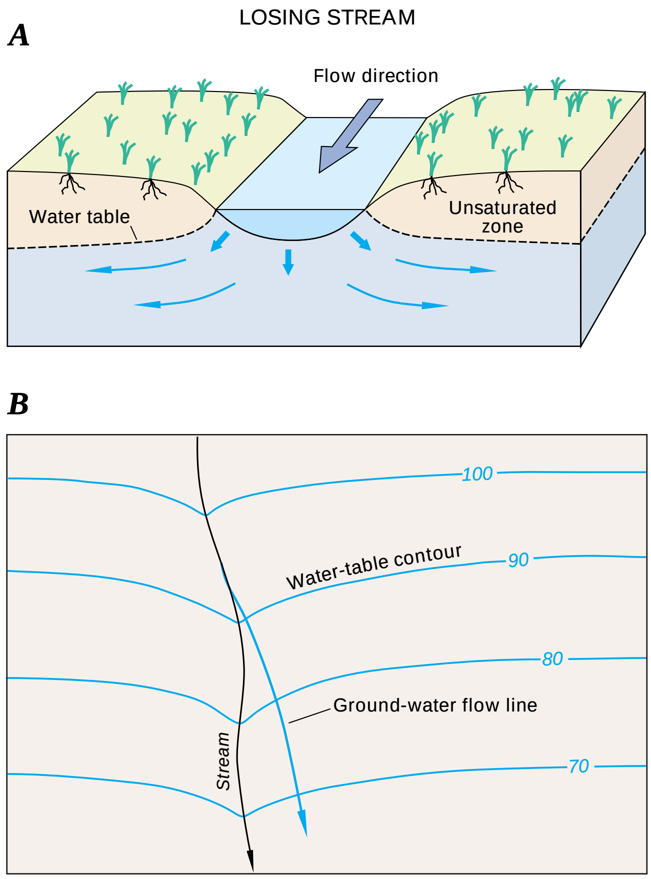


Figure 9. *Losing streams lose water to the ground-water system (A). This can be determined from water-table contour maps because the contour lines point in the downstream direction where they cross the stream (B).*

the ground-water system by an unsaturated zone. Where the stream is disconnected from the ground-water system by an unsaturated zone, the water table may have a discernible mound below the stream (Figure 10) if the rate of recharge through the streambed and unsaturated zone is greater than the rate of lateral ground-water flow away from the water-table mound. An important feature of streams that are disconnected from ground water is that pumping of shallow ground water near the stream does not affect the flow of the stream near the pumped wells.

In some environments, streamflow gain or loss can persist; that is, a stream might always gain water from ground water, or it might always lose water to ground water. However, in other environments, flow direction can vary a great deal along a stream; some reaches receive ground water, and other reaches lose water to ground water. Furthermore, flow direction can change in very short timeframes as a result of individual storms causing focused recharge near the streambank, temporary flood peaks moving down the channel, or transpiration of ground water by streamside vegetation.

A type of interaction between ground water and streams that takes place in nearly all streams at one time or another is a rapid rise in stream stage that causes water to move from the stream into the streambanks. This process, termed bank storage (Figures 11 and 12*B*), usually is caused by storm precipitation, rapid snowmelt, or release of water

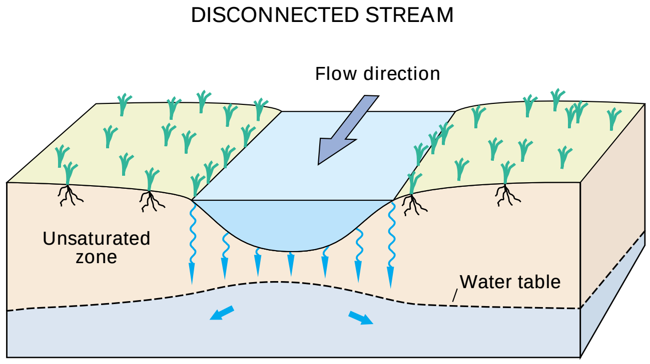


Figure **10.** *Disconnected streams are separated from the ground-water system by an unsaturated zone.*

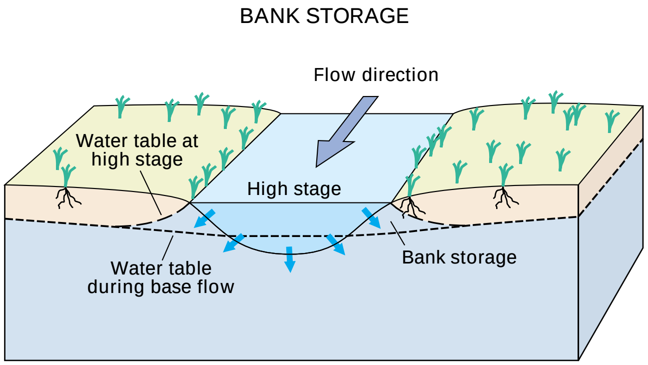


Figure **11**. *If stream levels rise higher than adjacent ground-water levels, stream water moves into the streambanks as bank storage.*

“Streams interact with ground water in three basic ways: streams gain water from inflow of ground water through the streambed (gaining stream), they lose water to ground water by outflow through the streambed (losing stream), or they do both, gaining in some reaches and losing in other reaches”

from a reservoir upstream. As long as the rise in stage does not overtop the streambanks, most of the volume of stream water that enters the streambanks returns to the stream within a few days or weeks. The loss of stream water to bank storage and return of this water to the stream in a period of days or weeks tends to reduce flood peaks and later supplement stream flows. If the rise in stream stage is sufficient to overtop the banks and flood large areas of the land surface, widespread recharge to the water table can take place throughout the flooded area (Figure 12*C*). In this case, the time it takes for the recharged floodwater to return to the stream by ground-water flow may be weeks, months, or years because the lengths of the ground-water flow paths are much longer than those resulting from local bank storage. Depending on the frequency, magnitude, and intensity of storms and on the related magnitude of increases in stream stage, some streams and adjacent shallow aquifers may be in a continuous readjustment from interactions related to bank storage and overbank flooding.

In addition to bank storage, other processes may affect the local exchange of water between streams and adjacent shallow aquifers. Changes in streamflow between gaining and losing conditions can also be caused by pumping ground water near streams (see Box C). Pumping can intercept ground water that would otherwise have discharged to a gaining stream, or at higher pumping rates it can induce flow from the stream to the aquifer.

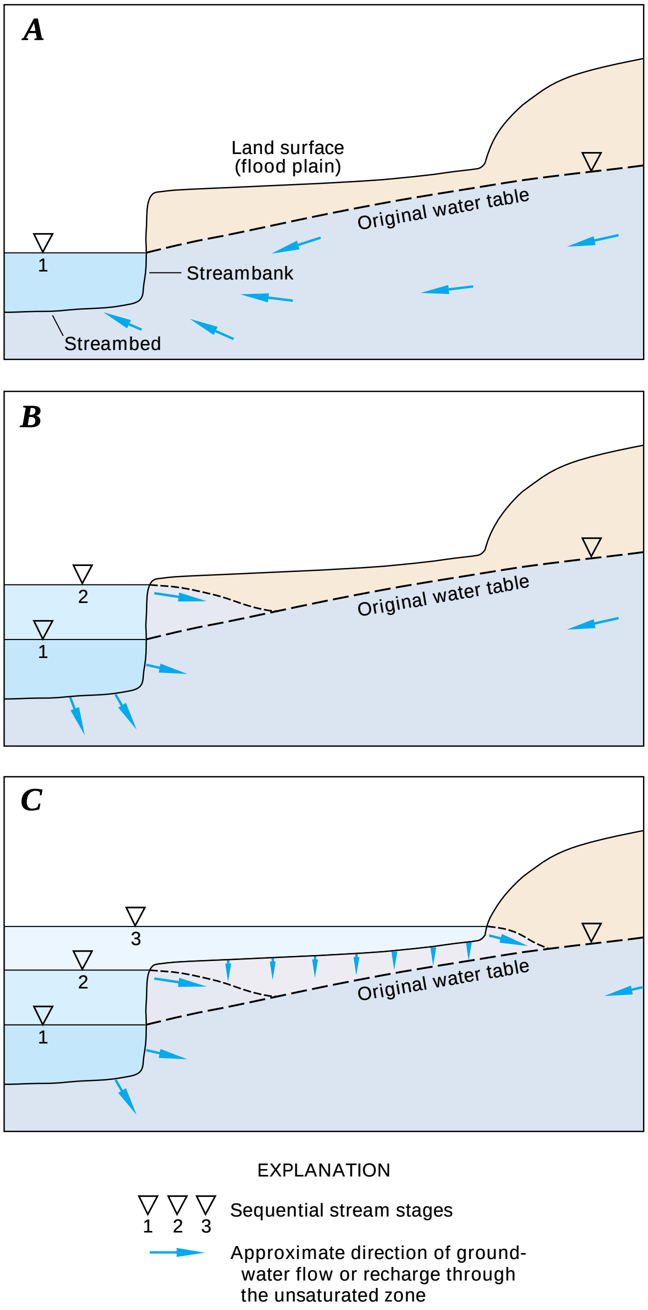


Figure 12. *If stream levels rise higher than their streambanks (C), the floodwaters recharge ground water throughout the flooded areas.*

The Ground-Water Component of Streamflow

Ground water contributes to streams in most physiographic and climatic settings. Even in settings where streams are primarily losing water to ground water, certain reaches may receive ground-water inflow during some seasons. The proportion of stream water that is derived from ground-water inflow varies across physiographic and climatic settings. The amount of water that ground water contributes to streams can be estimated by analyzing streamflow hydrographs to determine the ground-water component, which is termed base flow (Figure B–1). Several different methods of analyzing hydrographs have been used by hydrologists to determine the base-flow component of streamflow.

One of the methods, which provides a conservative estimate of base flow, was used to determine the ground-water contribution to streamflow in 24 regions in the conterminous United States. The regions, delineated on the basis of physiography and climate, are believed to have common characteristics with respect to the interactions of ground water and surface water (Figure B–2). Fifty-four streams were selected for the analysis, at least two in each of the 24 regions. Streams were selected that had drainage basins less than 250 square miles and that had less than 3 percent of the drainage area covered by lakes and wetlands. Daily streamflow values for the 30-year period, 1961–1990, were used for the analysis of each stream. The analysis indicated that, for the 54 streams over the 30-year period, an average of 52 percent of the streamflow was contributed by ground water. Ground-water contributions ranged from 14 percent to 90 percent, and the median was 55 percent. The ground-water contribution to streamflow for selected streams can be compared in Figure B–2. As an example of the effect that geologic setting has on the contribution of ground water to streamflow, the Forest River in North Dakota can be compared to the Sturgeon River in Michigan. The Forest River Basin is underlain by poorly permeable silt and clay deposits, and only about 14 percent of its average annual flow is contributed by ground water; in contrast, the Sturgeon River Basin is underlain by highly permeable sand and gravel, and about 90 percent of its average annual flow is contributed by ground water.

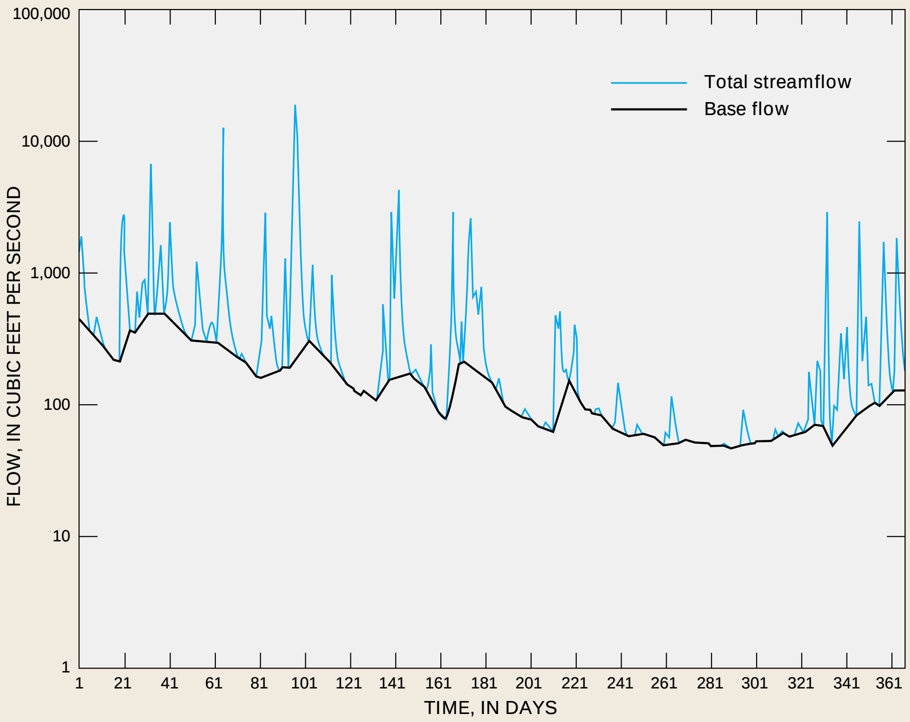


Figure B–1. The ground-water component of streamflow was estimated from a streamflow hydrograph for the Homochitto River in Mississippi, using a method developed by the institute of Hydrology, United Kingdom. (Institute of Hydrology, 1980, Low flow studies: Wallingford, Oxon, United Kingdom, Research Report No. 1.)

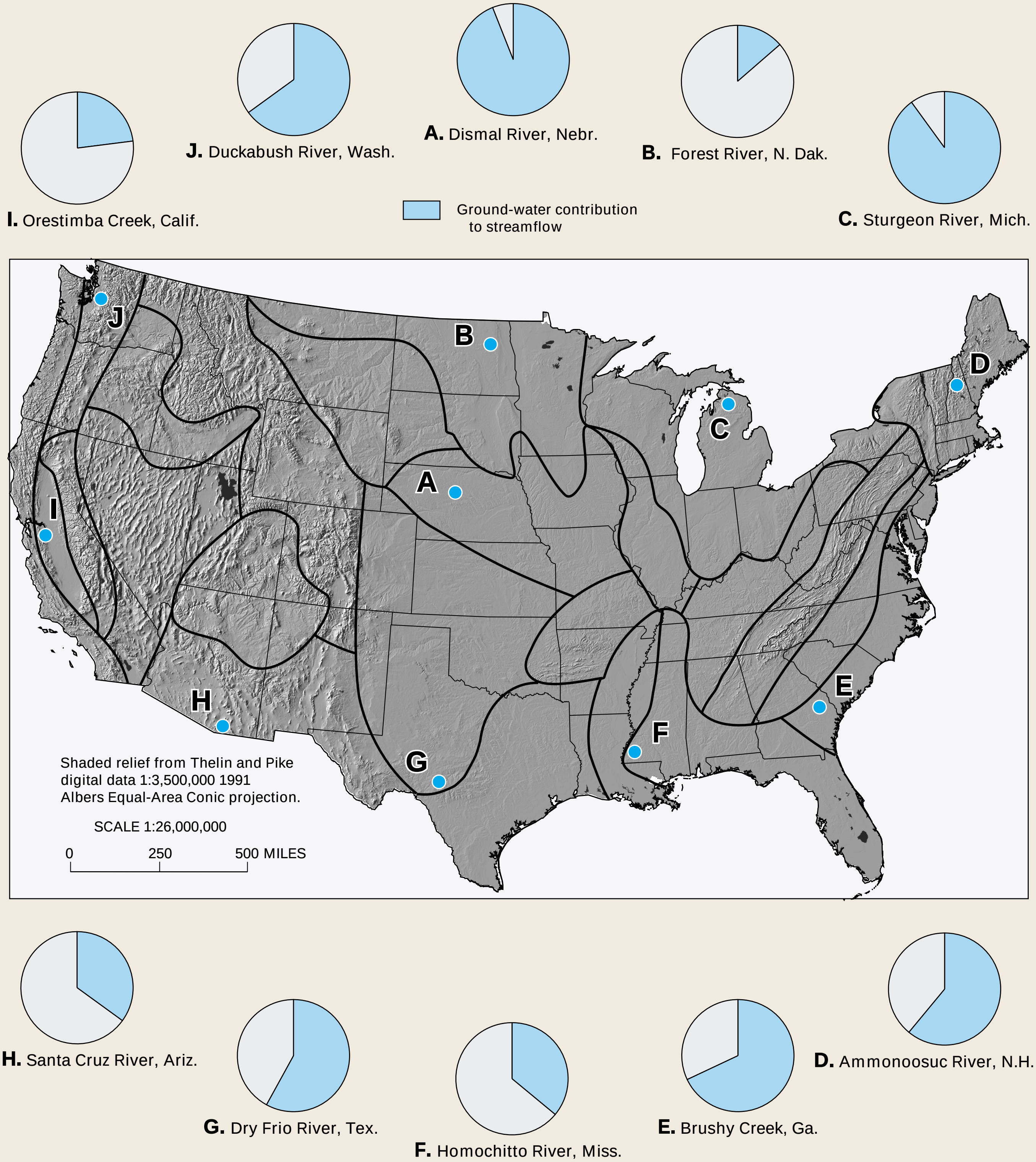


Figure B–2. In the conterminous United States, 24 regions were delineated where the interactions of ground water and surface water are considered to have similar characteristics. The estimated ground-water contribution to streamflow is shown for specific streams in 10 of the regions.

C

The Effect of Ground-Water Withdrawals on Surface Water

Withdrawing water from shallow aquifers that are directly connected to surface-water bodies can have a significant effect on the movement of water between these two water bodies. The effects of pumping a single well or a small group of wells on the hydrologic regime are local in scale. However, the effects of many wells withdrawing water from an aquifer over large areas may be regional in scale.

Withdrawing water from shallow aquifers for public and domestic water supply, irrigation, and industrial uses is widespread. Withdrawing water from shallow aquifers near surface-water bodies can diminish the available surface-water supply by capturing some of the ground-water flow that otherwise would have discharged to surface water or by inducing flow from surface water into the surrounding aquifer system. An analysis of the sources of water to a pumping well in a shallow aquifer that discharges to a stream is provided here to gain insight into how a pumping well can change the quantity and direction of flow between the shallow aquifer and the stream. Furthermore, changes in the direction of flow between the two water bodies can affect transport of contaminants associated with the moving water. Although a stream is used in the example, the results apply to all surface-water bodies, including lakes and wetlands.

A ground-water system under predevelopment conditions is in a state of dynamic equilibrium—for example, recharge at the water table is equal to ground-water discharge to a stream (Figure C–1*A*). Assume a well is installed and is pumped continually at a rate, Q_1. After a new state of dynamic equilibrium is achieved, inflow to the ground-water system from recharge will equal outflow to the stream plus the withdrawal from the well. In this new equilibrium, some of the ground water that would have discharged to the stream is intercepted by the well, and a ground-water divide, which is a line separating directions of flow, is established locally between the well and the stream (Figure C–1*B*). If the well is pumped at a higher rate, Q_2, at a later time a new equilibrium is reached. Under this condition, the ground-water divide between the well and the stream is no longer present and withdrawals from the well induce movement of water from the stream into the aquifer (Figure C–1*C*). Thus, pumpage reverses the hydrologic condition of the stream in this reach from a ground-water discharge feature to a ground-water recharge feature.

In the hydrologic system depicted in Figures C–1*A* and C–1*B*, the quality of the stream water generally will have little effect on the quality of the shallow ground water. However, in the case of the well pumping at the higher rate, Q_2 (Figure C–1*C*), the quality of the stream water, which locally recharges the shallow aquifer, can affect the quality of ground water between the well and the stream as well as the quality of the ground water withdrawn from the well.

This hypothetical withdrawal of water from a shallow aquifer that discharges to a nearby surface-water body is a simplified but compelling illustration of the concept that ground water and surface water are one resource. In the long term, the quantity of ground water withdrawn is approximately equal to the reduction in streamflow that is potentially available to downstream users.

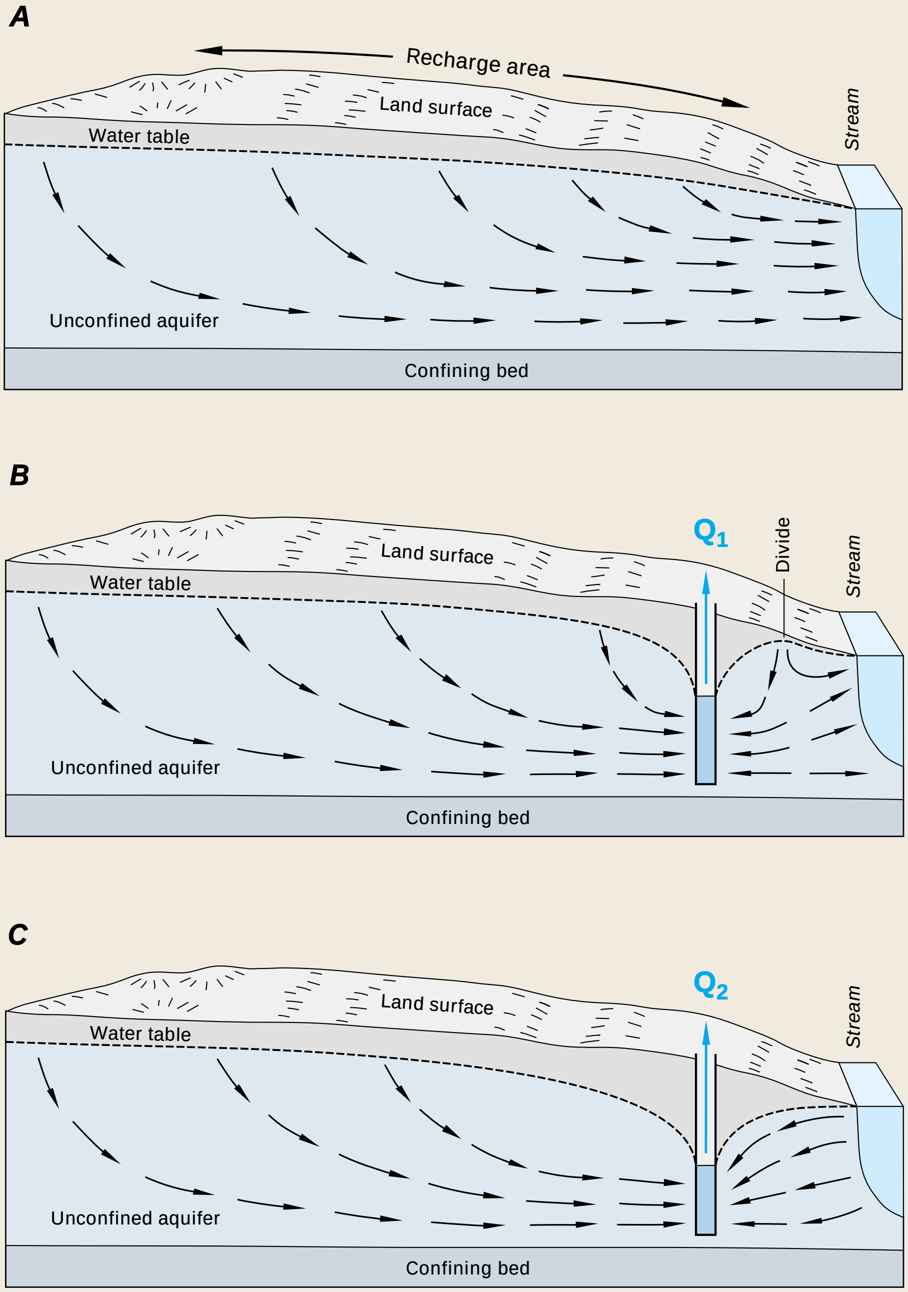


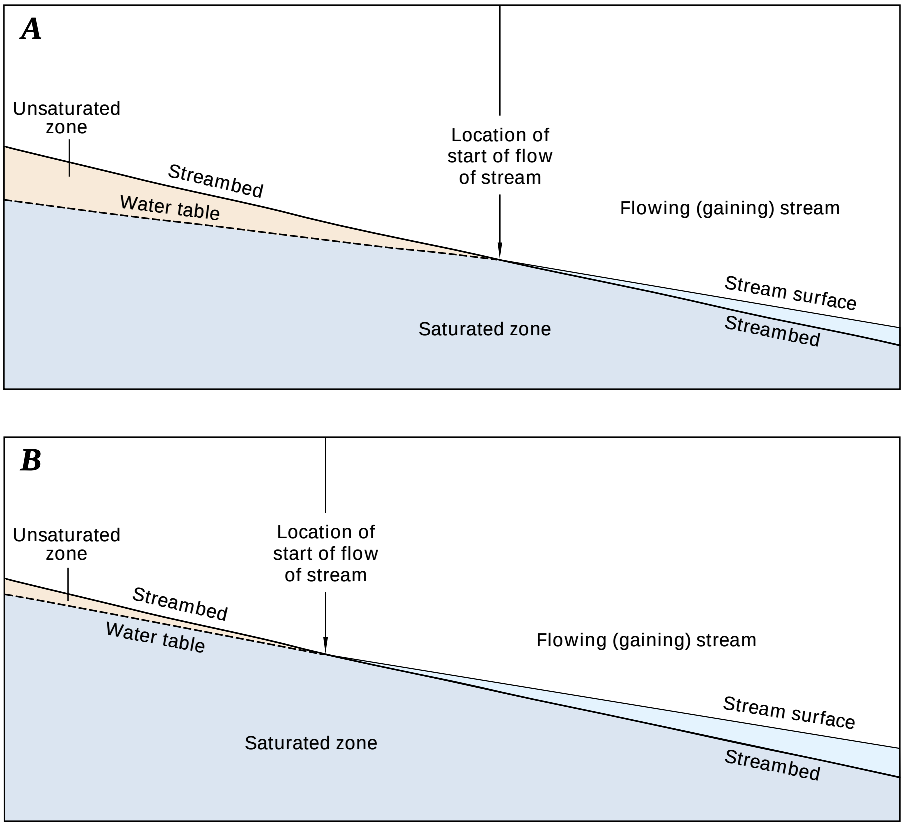
Figure C–1. In a schematic hydrologic setting where ground water discharges to a stream under natural conditions (A), placement of a well pumping at a rate (Q_1) near the stream will intercept part of the ground water that would have discharged to the stream (B). If the well is pumped at an even greater rate (Q_2), it can intercept additional water that would have discharged to the stream in the vicinity of the well and can draw water from the stream to the well (C).

Where streamflow is generated in headwaters areas, the changes in streamflow between gaining and losing conditions may be particularly variable (Figure 13). The headwaters segment of streams can be completely dry except during storm events or during certain seasons of the year when snowmelt or precipitation is sufficient to maintain continuous flow for days or weeks. During these times, the stream will lose water to the unsaturated zone beneath its bed. However, as the water table rises through recharge in the headwaters area, the losing reach may become a gaining reach as the water table rises above the level of the stream. Under these conditions, the point where ground water first contributes to the stream gradually moves upstream.

Some gaining streams have reaches that lose water to the aquifer under normal conditions of streamflow. The direction of seepage through the bed of these streams commonly is related to abrupt changes in the slope of the streambed (Figure 14*A*) or to meanders in the stream channel (Figure 14*B*). For example, a losing stream reach usually is located at the downstream end of pools in pool and riffle streams (Figure 14*A*), or upstream from channel bends in meandering streams (Figure 14*B*). The subsurface zone where stream water flows through short segments of its adjacent bed and banks is referred to as the hyporheic zone. The size and geometry of hyporheic zones surrounding streams vary greatly in time and space. Because of mixing between ground water and surface water in the hyporheic zone, the chemical and biological character of the hyporheic zone may differ markedly from adjacent surface water and ground water.

Ground-water systems that discharge to streams can underlie extensive areas of the land surface (Figure 15). As a result, environmental conditions at the interface between ground water and surface water reflect changes in the broader landscape. For example, the types and numbers of organisms in a given reach of streambed result, in part, from interactions between water in the hyporheic zone and ground water from distant sources.

Figure ***13.*** *The location where perennial streamflow begins in a channel can vary depending on the distribution of recharge in headwaters areas. Following dry periods (A), the start of streamflow will move up-channel during wet periods as the ground-water system becomes more saturated (B).*



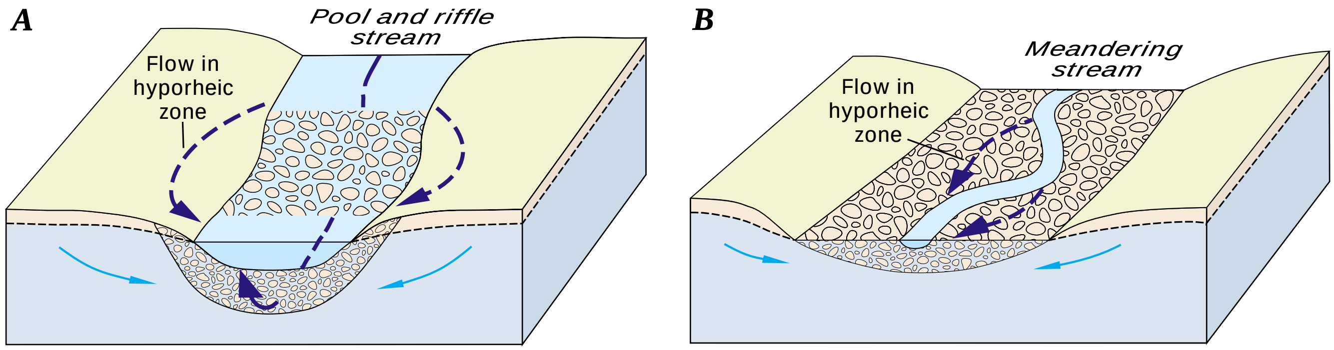


Figure 14. *Surface-water exchange with ground water in the hyporheic zone is associated with abrupt changes in streambed slope (A) and with stream meanders (B).*

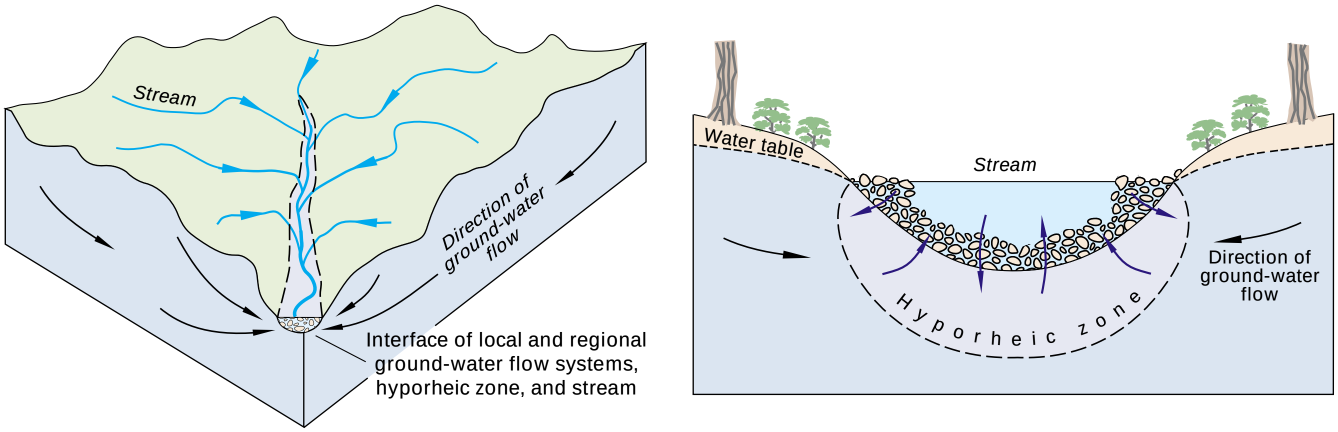


Figure 15. *Streambeds and banks are unique environments because they are where ground water that drains much of the subsurface of landscapes interacts with surface water that drains much of the surface of landscapes.*

INTERACTION OF GROUND WATER AND LAKES

Lakes interact with ground water in three basic ways: some receive ground-water inflow throughout their entire bed; some have seepage loss to ground water throughout their entire bed; but perhaps most lakes receive ground-water inflow through part of their bed and have seepage loss to ground water through other parts (Figure 16). Although these basic interactions are the same for lakes as they are for streams, the interactions differ in several ways.

The water level of natural lakes, that is, those not controlled by dams, generally does not change as rapidly as the water level of streams; therefore, bank storage is of lesser importance in lakes than it is in streams. Evaporation generally has a greater effect on lake levels than on stream levels because the surface area of lakes is generally larger and less shaded than many reaches of streams, and because lake water is not replenished as readily as a reach of a stream. Lakes can be present in many different parts of the landscape and can have complex ground-water flow systems associated with them. This is especially true for lakes in glacial and dune terrain, as is discussed in a later section of this Circular. Furthermore, lake sediments commonly have greater volumes of organic deposits than streams. These poorly permeable organic deposits can affect the distribution of seepage and biogeochemical exchanges of water and solutes more in lakes than in streams.

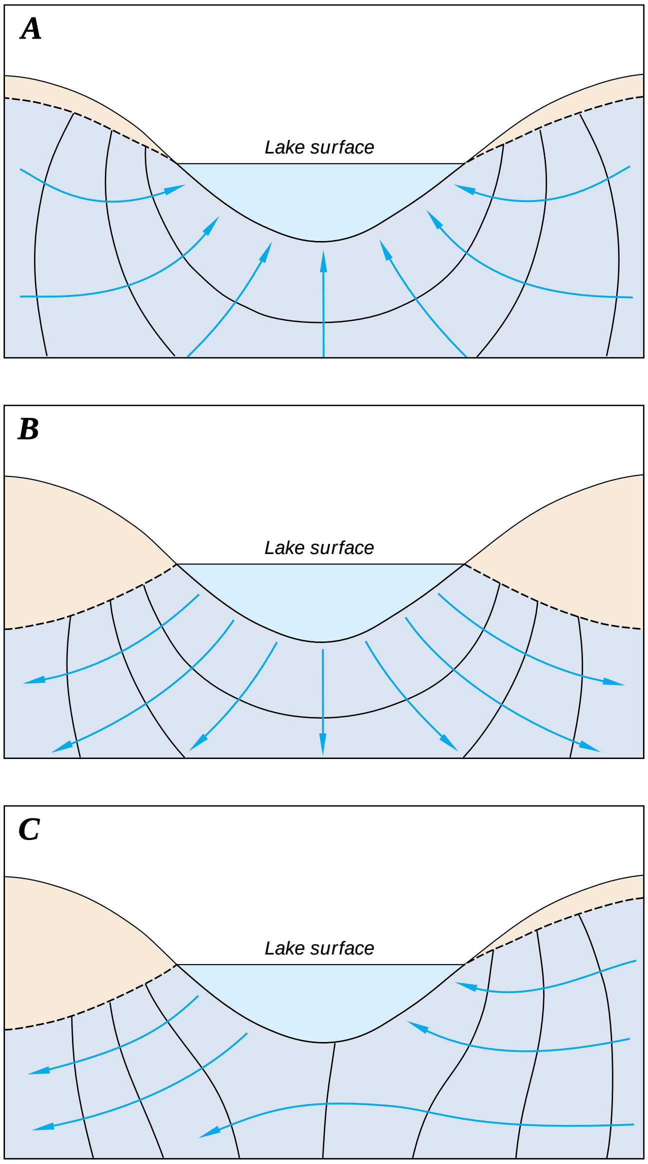


Figure 16. Lakes can receive ground-water inflow (A), lose water as seepage to ground water (B), or both

Reservoirs are human-made lakes that are designed primarily to control the flow and distribution of surface water. Most reservoirs are constructed in stream valleys; therefore, they have some characteristics both of streams and lakes. Like streams, reservoirs can have widely fluctuating levels, bank storage can be significant, and they commonly have a continuous flushing of water through them. Like lakes, reservoirs can have significant loss of water by evaporation, significant cycling of chemical and biological materials within their waters, and extensive biogeochemical exchanges of solutes with organic sediments.

“Lakes and wetlands can receive ground-water inflow throughout their entire bed, have outflow throughout their entire bed, or have both inflow and outflow at different localities”

INTERACTION OF GROUND WATER AND WETLANDS

Wetlands are present in climates and landscapes that cause ground water to discharge to land surface or that prevent rapid drainage of water from the land surface. Similar to streams and lakes, wetlands can receive ground-water inflow, recharge ground water, or do both. Those wetlands that occupy depressions in the land surface have interactions with ground water similar to lakes and streams. Unlike streams and lakes, however, wetlands do not always occupy low points and depressions in the landscape (Figure 17*A*); they also can be present on slopes (such as fens) or even on drainage divides (such as some types of bogs). Fens are wetlands that commonly receive ground-water discharge (Figure 17*B*); therefore, they receive a continuous supply of chemical constituents dissolved in the ground water. Bogs are wetlands that occupy uplands (Figure 17*D*) or extensive flat areas, and they receive much of their water and chemical constituents from precipitation. The distribution of major wetland areas in the United States is shown in Figure 18.

In areas of steep land slopes, the water table sometimes intersects the land surface, resulting in ground-water discharge directly to the land surface. The constant source of water at these seepage faces (Figure 17*B*) permits the growth of wetland plants. A constant source of ground water to wetland plants is also provided to parts of the landscape that are downgradient from breaks in slope of the water table (Figure 17*B*), and where subsurface discontinuities in geologic units cause upward movement of ground water (Figure 17*A*). Many wetlands are present along streams, especially slow-moving streams. Although these riverine wetlands (Figure 17*C*) commonly receive ground-water discharge, they are dependent primarily on the stream for their water supply.

Wetlands in riverine and coastal areas have especially complex hydrological interactions because they are subject to periodic water-level changes. Some wetlands in coastal areas are affected by very predictable tidal cycles. Other coastal wetlands and riverine wetlands are more affected by seasonal water-level changes and by flooding. The combined effects of precipitation, evapotranspiration, and interaction with surface water and ground water result in a pattern of water depths in wetlands that is distinctive.

Hydroperiod is a term commonly used in wetland science that refers to the amplitude and frequency of water-level fluctuations. Hydroperiod affects all wetland characteristics, including the type of vegetation, nutrient cycling, and the types of invertebrates, fish, and bird species present.

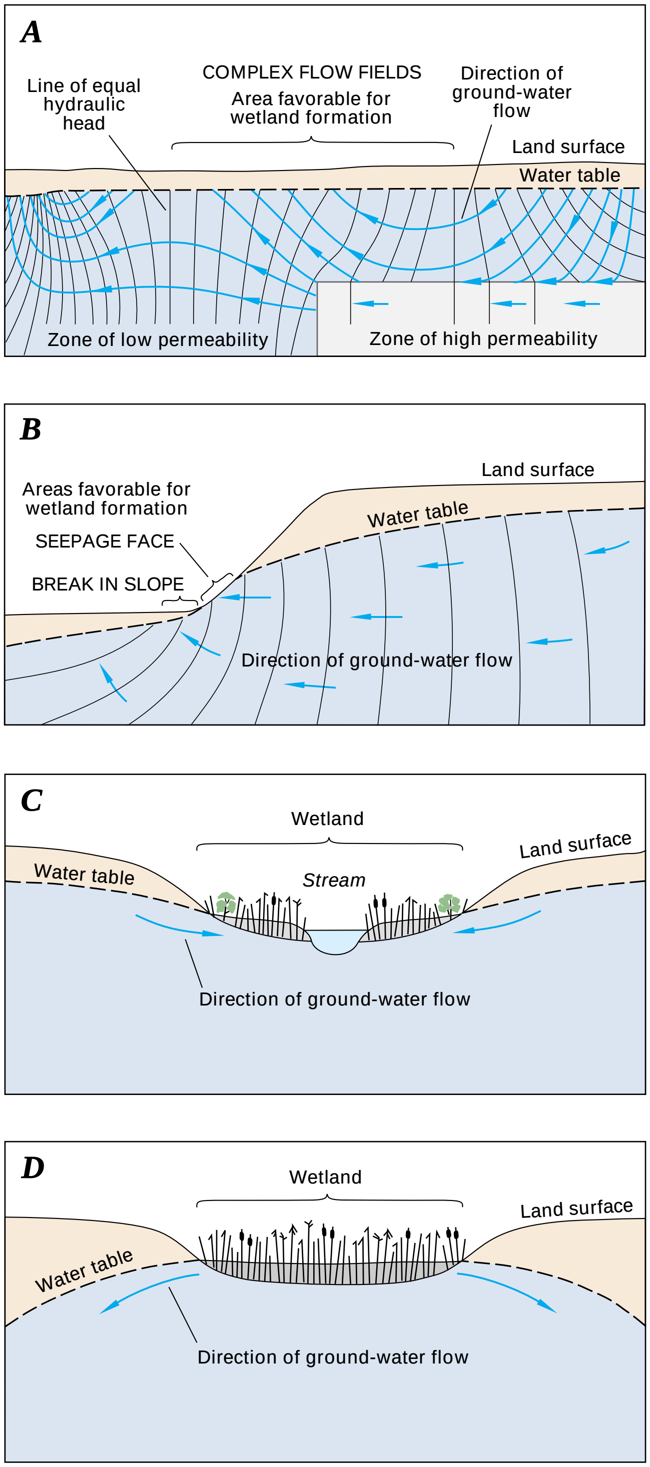


Figure 17. The source of water to wetlands can be from ground-water discharge where the land surface is underlain by complex ground-water flow fields (A), from ground-water discharge at seepage faces and at breaks in slope of the water table (B), from streams (C), and from precipitation in cases where wetlands have no stream inflow and ground-water gradients slope away from the wetland (D).

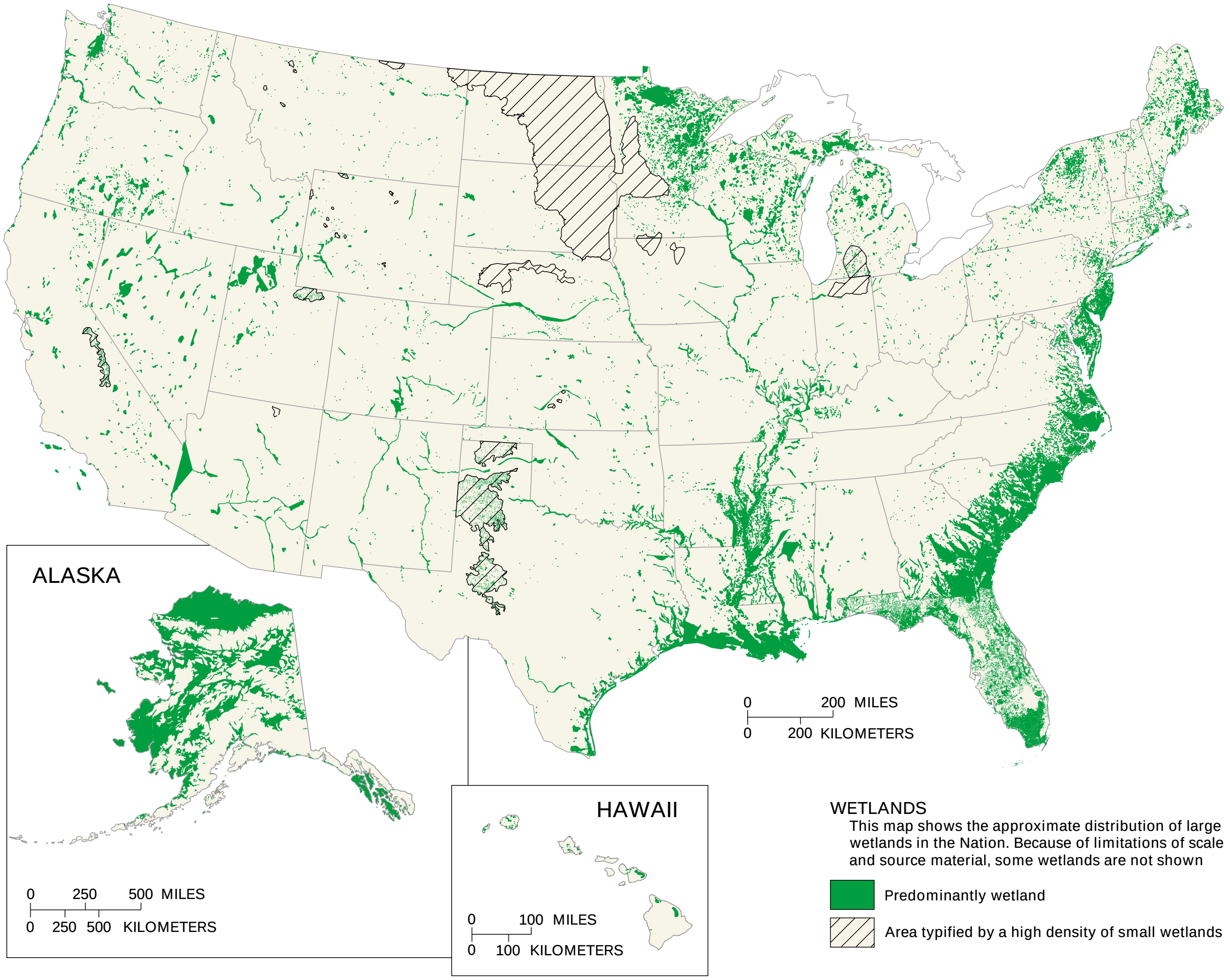


Figure ***18****. Wetlands are present throughout the Nation, but they cover the largest areas in the glacial terrain of the north-central United States, coastal terrain along the Atlantic and gulf coasts, and riverine terrain in the lower Mississippi River Valley.*

A major difference between lakes and wetlands, with respect to their interaction with ground water, is the ease with which water moves through their beds. Lakes commonly are shallow around their perimeter where waves can remove fine-grained sediments, permitting the surface water and ground water to interact freely. In wetlands, on the other hand, if fine-grained and highly decomposed organic sediments are present near the wetland edge, the transfer of water and solutes between ground water and surface water is likely to be much slower.

Another difference in the interaction between ground water and surface water in wetlands compared to lakes is determined by rooted vegetation in wetlands. The fibrous root mat in wetland soils is highly conductive to water flow; therefore, water uptake by roots of emergent plants results in significant interchange between surface water and pore water of wetland sediments. The water exchanges in this upper soil zone even if exchange between surface water and ground water is restricted at the base of the wetland sediments.

Chemical Interactions of Ground Water and Surface Water

EVOLUTION OF WATER CHEMISTRY IN DRAINAGE BASINS

Two of the fundamental controls on water chemistry in drainage basins are the type of geologic materials that are present and the length of time that water is in contact with those materials. Chemical reactions that affect the biological and geochemical characteristics of a basin include (1) acid-base reactions, (2) precipitation and dissolution of minerals, (3) sorption and ion exchange, (4) oxidation-reduction reactions, (5) biodegradation, and (6) dissolution and exsolution of gases (see Box D). When water first infiltrates the land surface, microorganisms in the soil have a significant effect on the evolution of water chemistry. Organic matter in soils is degraded by microbes, producing high concentrations of dissolved carbon dioxide (CO_2). This process lowers the pH by increasing the carbonic acid (H_2CO_3) concentration in the soil water. The production of carbonic acid starts a number of mineral-weathering reactions, which result in bicarbonate (HCO_3^-) commonly being the most abundant anion in the water. Where contact times between water and minerals in shallow ground-water flow paths are short, the dissolved-solids concentration in the water generally is low. In such settings, limited chemical changes take place before ground water is discharged to surface water.

“Two of the fundamental controls on water chemistry in drainage basins are the type of geologic materials that are present and the length of time that water is in contact with those materials”

In deeper ground-water flow systems, the contact time between water and minerals is much longer than it is in shallow flow systems. As a result, the initial importance of reactions relating to microbes in the soil zone may be superseded over time by chemical reactions between minerals and water (geochemical weathering). As weathering progresses, the concentration of dissolved solids increases. Depending on the chemical composition of the minerals that are weathered, the relative abundance of the major inorganic chemicals dissolved in the water changes (see Box E).

Surface water in streams, lakes, and wetlands can repeatedly interchange with nearby ground water. Thus, the length of time water is in contact with mineral surfaces in its drainage basin can continue after the water first enters a stream, lake, or wetland. An important consequence of these continued interchanges between surface water and ground water is their potential to further increase the contact time between water and chemically reactive geologic materials.

CHEMICAL INTERACTIONS OF GROUND WATER AND SURFACE WATER IN STREAMS, LAKES, AND WETLANDS

Ground-water chemistry and surface-water chemistry cannot be dealt with separately where surface and subsurface flow systems interact. The movement of water between ground water and surface water provides a major pathway for chemical transfer between terrestrial and aquatic systems (see Box F). This transfer of chemicals affects the supply of carbon, oxygen, nutrients such as nitrogen and phosphorus, and other chemical constituents that enhance biogeochemical processes on both sides of the interface. This transfer can ultimately affect the biological and chemical characteristics of aquatic systems downstream.

“The movement of water between ground water and surface water provides a major pathway for chemical transfer between terrestrial and aquatic systems”

D

Some Common Types of Biogeochemical Reactions Affecting Transport of Chemicals in Ground Water and Surface Water

ACID-BASE REACTIONS

Acid-base reactions involve the transfer of hydrogen ions (H^+) among solutes dissolved in water, and they affect the effective concentrations of dissolved chemicals through changes in the H^+ concentration in water. A brief notation for H^+ concentration (activity) is pH, which represents a negative logarithmic scale of the H^+ concentration. Smaller values of pH represent larger concentrations of H^+, and larger values of pH represent smaller concentrations of H^+. Many metals stay dissolved when pH values are small; increased pH causes these metals to precipitate from solution.

PRECIPITATION AND DISSOLUTION OF MINERALS

Precipitation reactions result in minerals being formed (precipitated) from ions that are dissolved in water. An example of this type of reaction is the precipitation of iron, which is common in areas of ground-water seeps and springs. At these locations, the solid material iron hydroxide is formed when iron dissolved in ground water comes in contact with oxygen dissolved in surface water. The reverse, or dissolution reactions, result in ions being released into water by dissolving minerals. An example is the release of calcium ions (Ca^{++}) and bicarbonate ions (HCO_3^-) when calcite ($CaCO_3$) in limestone is dissolved.

SORPTION AND ION EXCHANGE

Sorption is a process in which ions or molecules dissolved in water (solutes) become attached to the surfaces (or near-surface parts) of solid materials, either temporarily or permanently. Thus, solutes in ground water and surface water can be sorbed either to the solid materials that comprise an aquifer or streambed or to particles suspended in ground water or surface water. The attachments of positively charged ions to clays and of pesticides to solid surfaces are examples of sorption. Release of sorbed chemicals to water is termed desorption.

When ions attached to the surface of a solid are replaced by ions that were in water, the process is known as ion exchange. Ion exchange is the process that takes place in water softeners; ions that contribute to water hardness—calcium and magnesium—are exchanged for sodium on the surface of the solid. The result of this process is that the amount of calcium and magnesium in the water declines and the amount of sodium increases. The opposite takes place when saltwater enters an aquifer; some of the sodium in the saltwater is exchanged for calcium sorbed to the solid material of the aquifer.

OXIDATION-REDUCTION REACTIONS

Oxidation-reduction (redox) reactions take place when electrons are exchanged among solutes. In these reactions, oxidation (loss of electrons) of certain elements is accompanied by the reduction (gain of electrons) of other elements.

For example, when iron dissolved in water that does not contain dissolved oxygen mixes with water that does contain dissolved oxygen, the iron and oxygen interact by oxidation and reduction reactions. The result of the reactions is that the dissolved iron loses electrons (the iron is oxidized) and oxygen gains electrons (the oxygen is reduced). In this case, the iron is an electron donor and the oxygen is an electron acceptor. Bacteria can use energy gained from oxidation-reduction reactions as they decompose organic material. To accomplish this, bacterially mediated oxidation-reduction reactions use a sequence of electron acceptors, including oxygen, nitrate, iron, sulfate, and carbon dioxide. The presence of the products of these reactions in ground water and surface water can be used to identify the dominant oxidation-reduction reactions that have taken place in those waters. For example, the bacterial reduction of sulfate (SO_4^{2-}) to sulfide (HS^-) can result when organic matter is oxidized to CO_2.

BIODEGRADATION

Biodegradation is the decomposition of organic chemicals by living organisms using enzymes. Enzymes are specialized organic compounds made by living organisms that speed up reactions with other organic compounds. Microorganisms degrade (transform) organic chemicals as a source of energy and carbon for growth. Microbial processes are important in the fate and transport of many organic compounds. Some compounds, such as petroleum hydrocarbons, can be used directly by microorganisms as food sources and are rapidly degraded in many situations. Other compounds, such as chlorinated solvents, are not as easily assimilated. The rate of biodegradation of an organic chemical is dependent on its chemical structure, the environmental conditions, and the types of microorganisms that are present. Although biodegradation commonly can result in complete degradation of organic chemicals to carbon dioxide, water, and other simple products, it also can lead to intermediate products that are of environmental concern. For example, deethylatrazine, an intermediate degradation product of the pesticide atrazine (see Box P), commonly is detected in water throughout the corn-growing areas of the United States.

DISSOLUTION AND EXSOLUTION OF GASES

Gases are directly involved in many geochemical reactions. One of the more common gases is carbon dioxide (CO_2). For example, stalactites can form in caves when dissolved CO_2 exsolves (degasses) from dripping ground water, causing pH to rise and calcium carbonate to precipitate. In soils, the microbial production of CO_2 increases the concentration of carbonic acid (H_2CO_3), which has a major control on the solubility of aquifer materials. Other gases commonly involved in chemical reactions are oxygen, nitrogen, hydrogen sulfide (H_2S), and methane (CH_4). Gases such as chlorofluorocarbons (CFCs) and radon are useful as tracers to determine the sources and rates of ground-water movement (see Box G).

E

Evolution of Ground-Water Chemistry from Recharge to Discharge Areas in the Atlantic Coastal Plain

Changes in the chemical composition of ground water in sediments of the Atlantic Coastal Plain (Figure E–1) provide an example of the chemical evolution of ground water in a regional flow system. In the shallow regime, infiltrating water comes in contact with gases in the unsaturated zone and shallow ground water. As a result of this contact, localized, short-term, fast reactions take place that dissolve minerals and degrade organic material. In the deep regime, long-term, slower chemical reactions, such as precipitation and dissolution of minerals and ion-exchange, add or remove solutes. These natural processes and reactions commonly produce a predictable sequence of hydrochemical facies. In the Atlantic Coastal Plain, ground water evolves from water containing abundant bicarbonate ions and small concentrations of dissolved solids near the point of recharge to water containing abundant chloride ions and large concentrations of dissolved solids where it discharges into streams, estuaries, and the Atlantic Ocean.

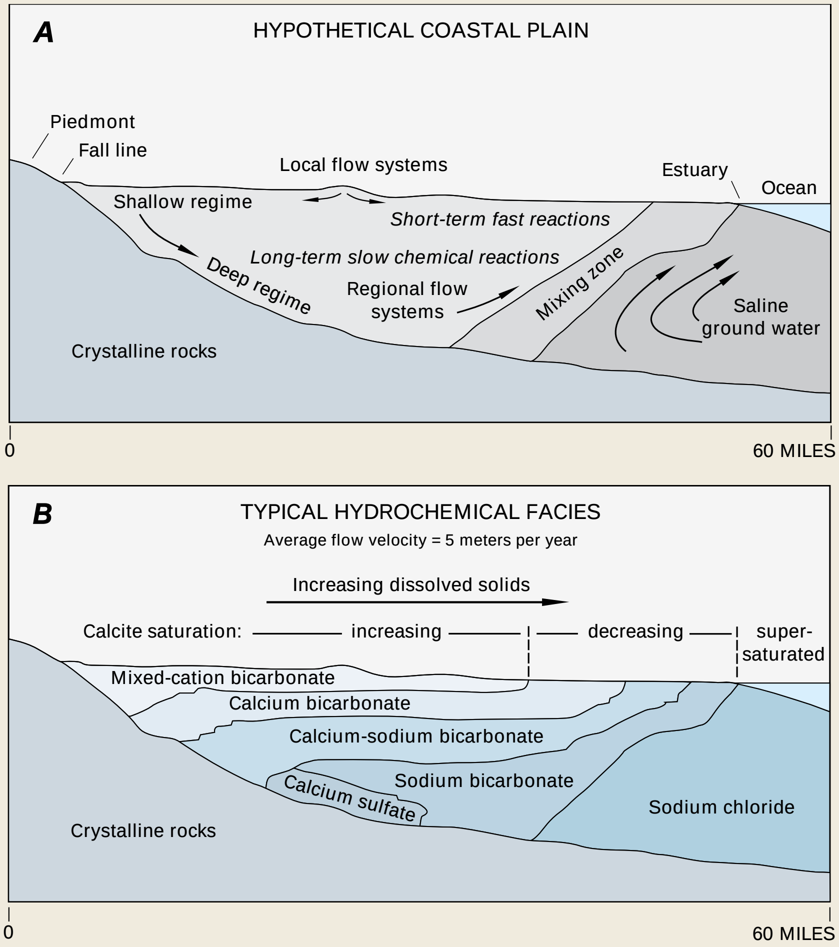


Figure E–1. In a coastal plain, such as along the Atlantic Coast of the United States, the interrelations of different rock types, shallow and deep ground-water flow systems (regimes), and mixing with saline water (A) results in the evolution of a number of different ground-water chemical types (B). (Modified from Back, William, Baedecker, M.J., and Wood, W.W., 1993, Scales in chemical hydrogeology—A historical perspective, in Alley, W.M., ed., Regional Ground-Water Quality: New York, van Nostrand Reinhold, p. 111–129.) (Reprinted by permission of John Wiley & Sons, Inc.)

Many streams are contaminated. Therefore, the need to determine the extent of the chemical reactions that take place in the hyporheic zone is widespread because of the concern that the contaminated stream water will contaminate shallow ground water (see Box G). Streams offer good examples of how interconnections between ground water and surface water affect chemical processes. Rough channel bottoms cause stream water to enter the streambed and to mix with ground water in the hyporheic zone. This mixing establishes sharp changes in chemical concentrations in the hyporheic zone.

A zone of enhanced biogeochemical activity usually develops in shallow ground water as a result of the flow of oxygen-rich surface water into the subsurface environment, where bacteria and geochemically active sediment coatings are abundant (Figure 19). This input of oxygen to the streambed stimulates a high level of activity by aerobic (oxygen-using) microorganisms if dissolved oxygen is readily available. It is not uncommon for dissolved oxygen to be completely used up in hyporheic flow paths at some distance into the streambed, where anaerobic microorganisms dominate microbial activity. Anaerobic bacteria can use nitrate, sulfate, or other solutes in place of oxygen for metabolism. The result of these processes is that many solutes are highly reactive in shallow ground water in the vicinity of streambeds.

The movement of nutrients and other chemical constituents, including contaminants, between ground water and surface water is affected by biogeochemical processes in the hyporheic zone. For example, the rate at which organic contaminants biodegrade in the hyporheic zone can exceed rates in stream water or in ground water away from the stream. Another example is the removal of dissolved metals in the hyporheic zone. As water passes through the hyporheic zone, dissolved metals are removed by precipitation of metal oxide coatings on the sediments.

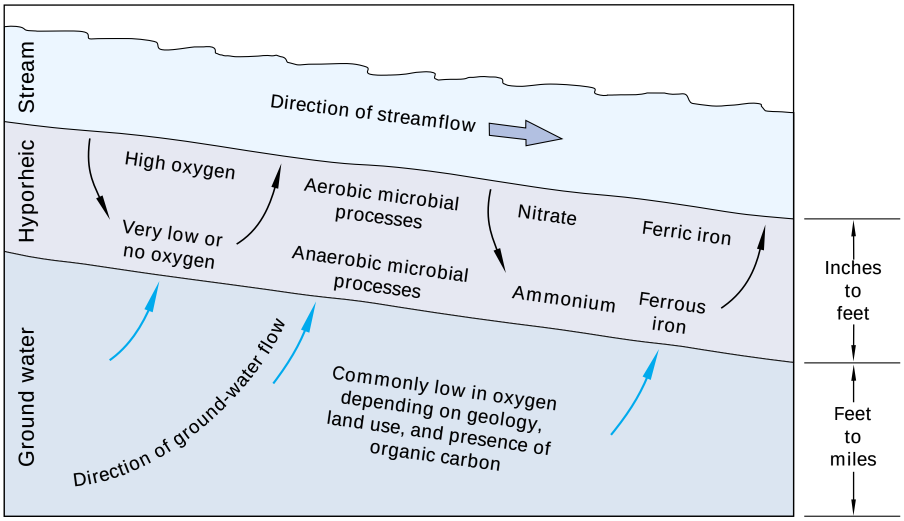


Figure 19. Microbial activity and chemical transformations commonly are enhanced in the hyporheic zone compared to those that take place in ground water and surface water. This diagram illustrates some of the processes and chemical transformations that may take place in the hyporheic zone. Actual chemical interactions depend on numerous factors including aquifer mineralogy, shape of the aquifer, types of organic matter in surface water and ground water, and nearby land use.

The Interface Between Ground Water and Surface Water as an Environmental Entity

In the bed and banks of streams, water and solutes can exchange in both directions across the streambed. This process, termed hyporheic exchange, creates subsurface environments that have variable proportions of water from ground water and surface water. Depending on the type of sediment in the streambed and banks, the variability in slope of the streambed, and the hydraulic gradients in the adjacent ground-water system, the hyporheic zone can be as much as several feet in depth and hundreds of feet in width. The dimensions of the hyporheic zone generally increase with increasing width of the stream and permeability of streambed sediments.

The importance of the hyporheic zone was first recognized when higher than expected abundances of aquatic insects were found in sediments where concentrations of oxygen were high. Caused by stream-water input, the high oxygen concentrations in the hyporheic zone make it possible for organisms to live in the pore spaces in the sediments, thereby providing a refuge for those organisms. Also, spawning success of salmon is greater where flow from the stream brings oxygen into contact with eggs that were deposited within the coarse sediment.

The hyporheic zone also can be a source of nutrients and algal cells to streams that foster the recovery of streams following catastrophic storms. For example, in a study of the ecology of Sycamore Creek in Arizona, it was found that the algae that grew in the top few inches of streambed sediment were quickest to recover following storms in areas where water in the sediments moved upward (Figure F–1). These algae recovered rapidly following storms because concentrations of dissolved nitrogen were higher in areas of the streambed where water moved upward than in areas where water moved downward. Areas of streambed where water moved upward are, therefore, likely to be the first areas to return to more normal ecological conditions following flash floods in desert streams.

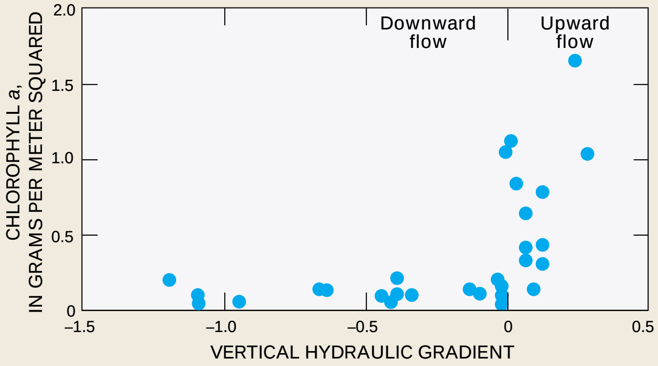


Figure F–1. Abundance of algae in streambed sediments, as indicated by concentration of chlorophyll a, *was markedly greater in areas where water moved upward through the sediments than in areas where water moved downward through the sediments in Sycamore Creek in Arizona. (Modified from Valett, H.M., Fisher, S.G., Grimm, N.B., and Camill, P., 1994, Vertical hydrologic exchange and ecologic stability of a desert stream ecosystem: Ecology, v. 75, p. 548–560.) (Reprinted with permission.)*

Hyporheic zones also serve as sites for nutrient uptake. A study of a coastal mountain stream in northern California indicated that transport of dissolved oxygen, dissolved carbon, and dissolved nitrogen in stream water into the hyporheic zone stimulated uptake of nitrogen by microbes and algae attached to sediment. A model simulation of nitrogen uptake (Figure F–2) indicated that both the physical process of water exchange between the stream and the hyporheic zone and the biological uptake of nitrate in the hyporheic zone affected the concentration of dissolved nitrogen in the stream.

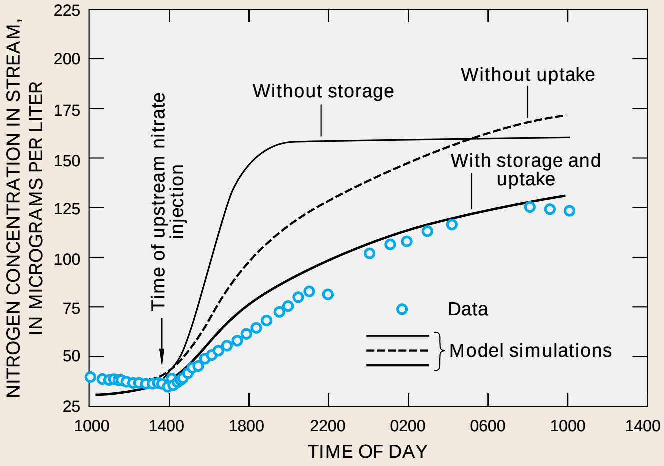


Figure F–2. Nitrate injected into Little Lost Man Creek in northern California was stored and taken up by algae and microbes in the hyporheic zone. (Modified from Kim, B.K.A., Jackman, A.P., and Triska, F.J., 1992, Modeling biotic uptake by periphyton and transient hyporheic storage of nitrate in a natural stream: Water Resources Research, v. 28, no.10, p. 2743–2752.)

The importance of biogeochemical processes that take place at the interface of ground water and surface water in improving water quality for human consumption is shown by the following example. Decreasing metal concentrations (Figure F–3) in drinking-water wells adjacent to the River Glatt in Switzerland was attributed to the interaction of the river with subsurface water. The improvement in ground-water quality started with improved sewage-treatment plants, which lowered phosphate in the river. Lower phosphate concentrations lowered the amount of algal production in the river, which decreased the amount of dissolved organic carbon flowing into the riverbanks. These factors led to a decrease in the bacteria-caused dissolution of manganese and cadmium that were present as coatings on sediment in the aquifer. The result was substantially lower dissolved metal concentrations in ground water adjacent to the river, which resulted in an unexpected improvement in the quality of drinking water.

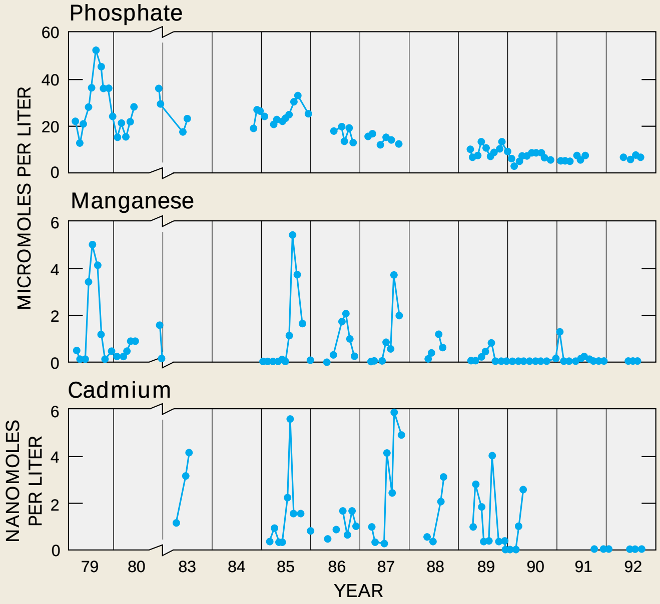
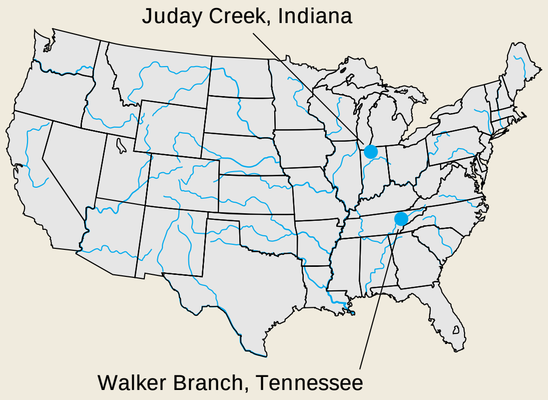


Figure F–3. A decline in manganese and cadmium concentrations after 1990 in drinking-water wells near the River Glatt in Switzerland was attributed to decreased phosphate in the river and hydrologic and biogeochemical interactions between river water and ground water. (Modified from von Gunten, H.R., and Lienert, Ch., 1993, Decreased metal concentrations in ground water caused by controls on phosphate emissions: Nature, v. 364, p. 220–222.) (Reprinted with permission from Nature, Macmillan Magazines Limited.)

Use of Environmental Tracers to Determine the Interaction of Ground Water and Surface Water

Environmental tracers are naturally occurring dissolved constituents, isotopes, or physical properties of water that are used to track the movement of water through watersheds. Useful environmental tracers include (1) common dissolved constituents, such as major cations and anions; (2) stable isotopes of oxygen (^{18}O) and hydrogen (^{2}H) in water molecules; (3) radioactive isotopes such as tritium (^{3}H) and radon (^{222}Rn); and (4) water temperature. When used in simple hydrologic transport calculations, environmental tracers can be used to (1) determine source areas of water and dissolved chemicals in drainage basins, (2) calculate hydrologic and chemical fluxes between ground water and surface water, (3) calculate water ages that indicate the length of time water and dissolved chemicals have been present in the drainage basin (residence times), and (4) determine average rates of chemical reactions that take place during transport. Some examples are described below.



Major cations and anions have been used as tracers in studies of the hydrology of small watersheds to determine the sources of water to streamflow during storms (see Figure G–1). In addition, stable isotopes of oxygen and hydrogen, which are part of water molecules, are useful for determining the mixing of waters from different source areas because of such factors as (1) differences in the isotopic composition of precipitation among recharge areas, (2) changes in the isotopic composition of shallow subsurface water caused by evaporation, and (3) temporal variability in the isotopic composition of precipitation relative to ground water.

Radioactive isotopes are useful indicators of the time that water has spent in the ground-water system. For example, tritium (^{3}H) is a well-known radioactive isotope of hydrogen that had peak concentrations in precipitation in the mid-1960s as a result of above-ground nuclear-bomb testing conducted at that time. Chlorofluorocarbons (CFCs), which are industrial chemicals that are present in ground water less than 50 years old, also can be used to calculate ground-water age in different parts of a drainage basin.

^{222}Radon is a chemically inert, radioactive gas that has a half-life of only 3.83 days. It is produced naturally in ground water as a product of the radioactive decay of ^{226}radium in uranium-bearing rocks and sediment. Several studies have documented that radon can be used to identify locations of

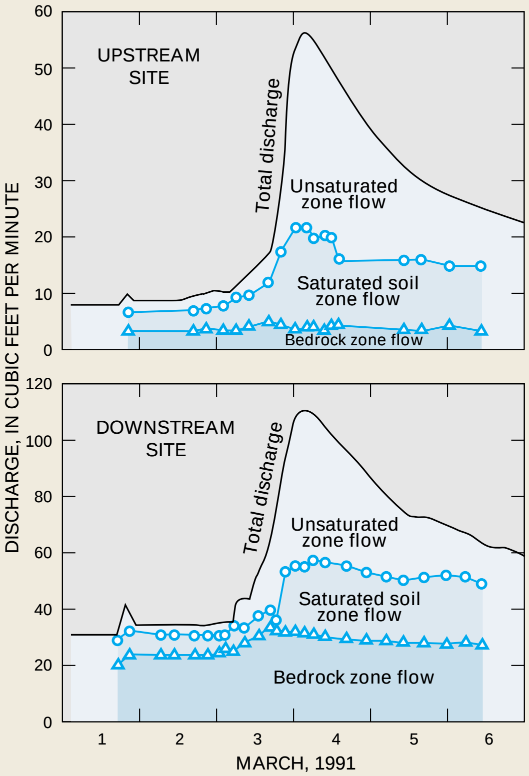


Figure G–1. The relative contributions of different subsurface water sources to streamflow in a stream in Tennessee were determined by analyzing the relative concentrations of calcium and sulfate. Note that increases in bedrock zone (ground water) flow appear to contribute more to the stormflow response at the downstream site than to the stormflow response at the upstream site in this small watershed. (Modified from Mulholland, P.J., 1993, Hydrometric and stream chemistry evidence of three storm flowpaths in Walker Branch Watershed: Journal of Hydrology, v. 151, p. 291–316.) (Reprinted with permission from Elsevier Science-NL, Amsterdam, The Netherlands.)

significant ground-water input to a stream, such as from springs. Radon also has been used to determine stream-water movement to ground water. For example, radon was used in a study in France to determine stream-water loss to ground water as a result of ground-water withdrawals. (See Figure G–2.)

An example of using stream-water temperature and sediment temperature for mapping gaining and losing reaches of a stream is shown in Figure G–3. In gaining reaches of the stream, sediment temperature and stream-water temperature are markedly different. In losing reaches of the stream, the diurnal fluctuations of temperature in the stream are reflected more strongly in the sediment temperature.

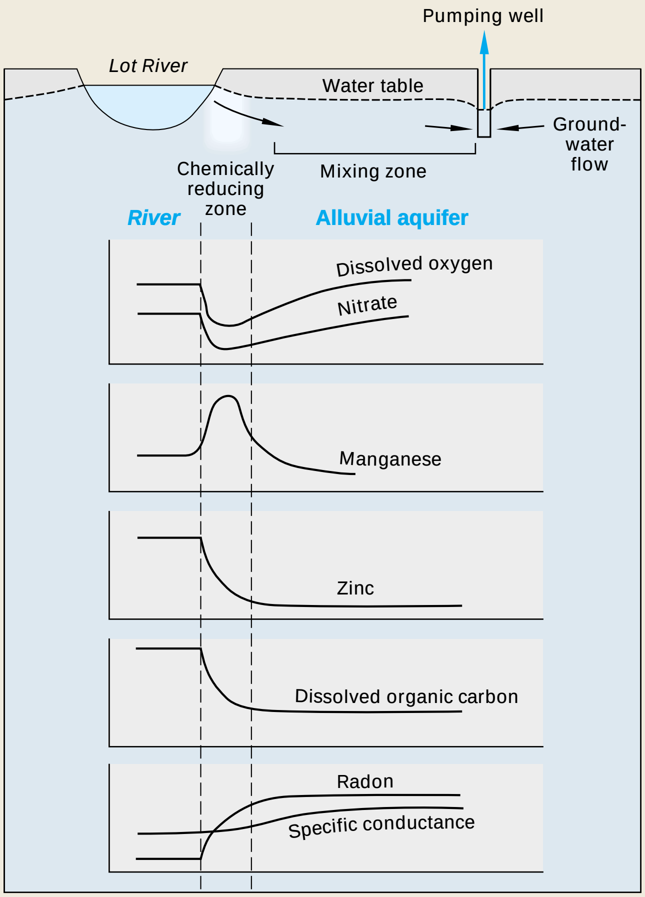


Figure G–2. Sharp changes in chemical concentrations were detected over short distances as water from the Lot River in France moved into its contiguous alluvial aquifer in response to pumping from a well. Specific conductance of water was used as an environmental tracer to determine the extent of mixing of surface water with ground water, and radon was used to determine the inflow rate of stream water. Both pieces of information were then used to calculate the rate at which dissolved metals reacted to form solid phases during movement of stream water toward the pumping well. (Modified from Bourg, A.C.M., and Bertin, C., 1993, Biogeochemical processes during the infiltration of river water into an alluvial aquifer: Environmental Science and Technology, v. 27, p. 661–666.) (Reprinted with permission from the American Chemical Society.)

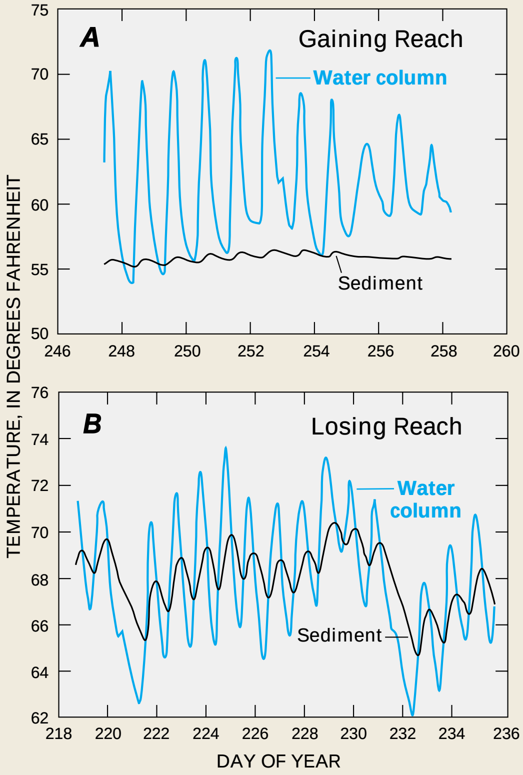


Figure G–3. Ground-water temperatures generally are more stable than surface-water temperatures. Therefore, gaining reaches of Juday Creek in Indiana are characterized by relatively stable sediment temperatures compared to stream-water temperatures (A). Conversely, losing reaches are characterized by more variable sediment temperatures caused by the temperature of the inflowing surface water (B). (Modified from Silliman, S.E., and Booth, D.F., 1993, Analysis of time series measurements of sediment temperature for identification of gaining versus losing portions of Juday Creek, Indiana: Journal of Hydrology, v. 146, p. 131–148.) (Reprinted with permission from Elsevier Science-NL, Amsterdam, The Netherlands.)

Lakes and wetlands also have distinctive biogeochemical characteristics with respect to their interaction with ground water. The chemistry of ground water and the direction and magnitude of exchange with surface water significantly affect the input of dissolved chemicals to lakes and wetlands. In general, if lakes and wetlands have little interaction with streams or with ground water, input of dissolved chemicals is mostly from precipitation; therefore, the input of chemicals is minimal. Lakes and wetlands that have a considerable amount of ground-water inflow generally have large inputs of dissolved chemicals. In cases where the input of dissolved nutrients such as phosphorus and nitrogen exceeds the output, primary production by algae and wetland plants is large. When this large amount of plant material dies, oxygen is used in the process of decomposition. In some cases the loss of oxygen from lake water can be large enough to kill fish and other aquatic organisms.

The magnitude of surface-water inflow and outflow also affects the retention of nutrients in wetlands. If lakes or wetlands have no stream outflow, retention of chemicals is high. The tendency to retain nutrients usually is less in wetlands that are flushed substantially by throughflow of surface water. In general, as surface-water inputs increase, wetlands vary from those that strongly retain nutrients to those that both import and export large amounts of nutrients. Furthermore, wetlands commonly have a significant role in altering the chemical form of dissolved constituents. For example, wetlands that have throughflow of surface water tend to retain the chemically oxidized forms and release the chemically reduced forms of metals and nutrients.

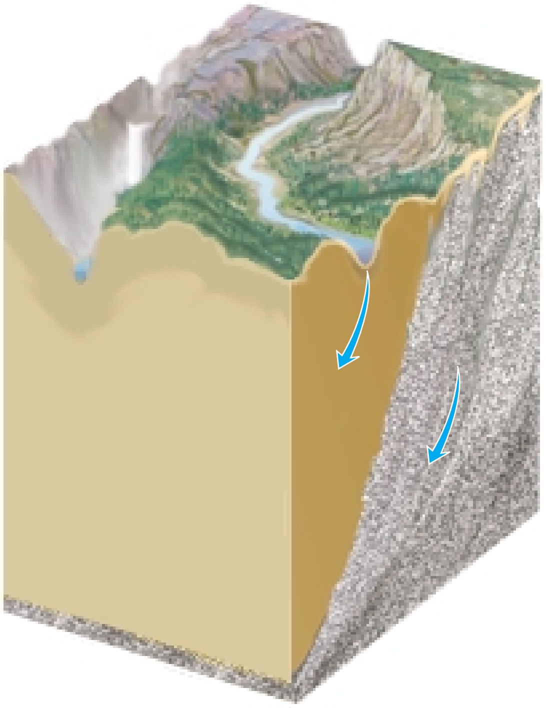
"The chemistry of ground water and the direction and magnitude of exchange with surface water significantly affect the input of dissolved chemicals to lakes and wetlands"

Interaction of Ground Water and Surface Water in Different Landscapes

Ground water is present in virtually all landscapes. The interaction of ground water with surface water depends on the physiographic and climatic setting of the landscape. For example, a stream in a wet climate might receive ground-water inflow, but a stream in an identical physiographic setting in an arid climate might lose water to ground water. To provide a broad and unified perspective of the interaction of ground water and surface water in different landscapes, a conceptual landscape (Figure 2) is used as a reference. Some common features of the interaction for various parts of the conceptual landscape are described below. The five general types of terrain discussed are mountainous, riverine, coastal, glacial and dune, and karst.

MOUNTAINOUS TERRAIN

The hydrology of mountainous terrain (area M of the conceptual landscape, Figure 2) is characterized by highly variable precipitation and water movement over and through steep land slopes. On mountain slopes, macropores created by burrowing organisms and by decay of plant roots have the capacity to transmit subsurface flow downslope quickly. In addition, some rock types underlying soils may be highly weathered or fractured and may transmit significant additional amounts of flow through the subsurface. In some settings this rapid flow of water results in hillside springs.



A general concept of water flow in mountainous terrain includes several pathways by which precipitation moves through the hillside to a stream (Figure 20). Between storm and snowmelt periods, streamflow is sustained by discharge from the ground-water system (Figure 20*A*). During intense storms, most water reaches streams very rapidly by partially saturating and flowing through the highly conductive soils. On the lower parts of hillslopes, the water table sometimes rises to the land surface during storms, resulting in overland flow (Figure 20*B*). When this occurs, precipitation on the saturated area adds to the quantity of overland flow. When storms or snowmelt persist in mountainous areas, near-stream saturated areas can expand outward from streams to include areas higher on the hillslope. In some settings, especially in arid regions, overland flow can be generated when the rate of rainfall exceeds the infiltration capacity of the soil (Figure 20*C*).

Near the base of some mountainsides, the water table intersects the steep valley wall some distance up from the base of the slope (Figure 21, left side of valley). This results in perennial

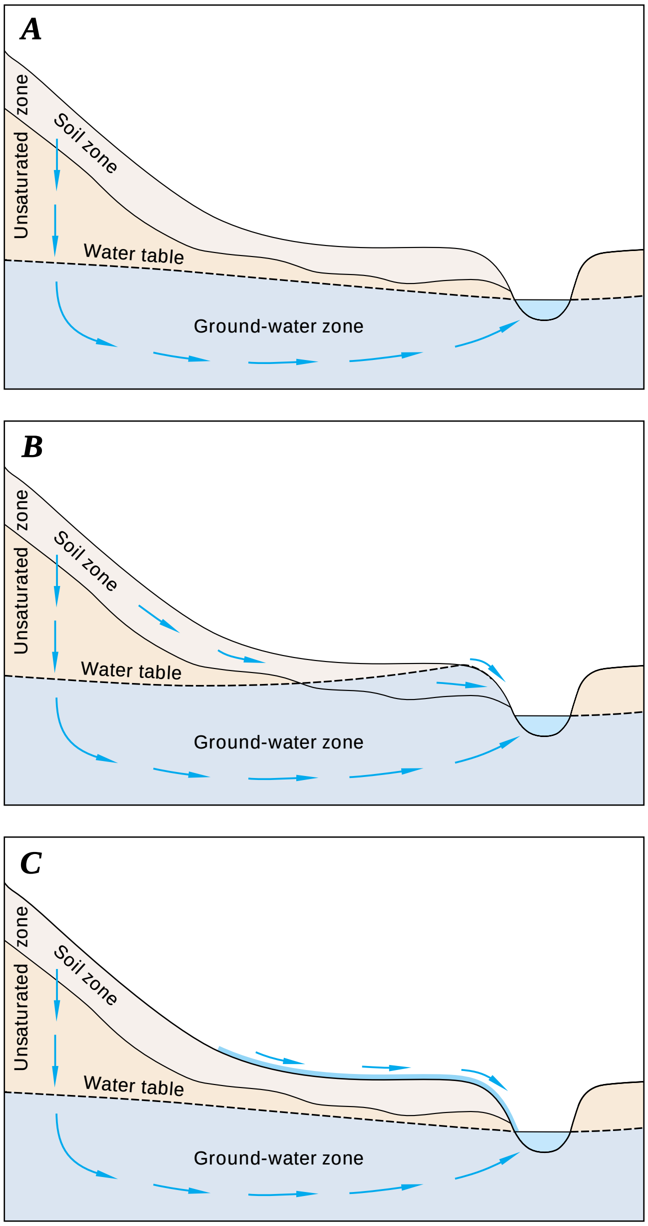


Figure **20**. *Water from precipitation moves to mountain streams along several pathways. Between storms and snowmelt periods, most inflow to streams commonly is from ground water (A). During storms and snowmelt periods, much of the water inflow to streams is from shallow flow in saturated macropores in the soil zone. If infiltration to the water table is large enough, the water table will rise to the land surface and flow to the stream is from ground water, soil water, and overland runoff (B). In arid areas where soils are very dry and plants are sparse, infiltration is impeded and runoff from precipitation can occur as overland flow (C). (Modified from Dunne, T., and Leopold, L.B., 1978, Water in environmental planning: San Francisco, W.H. Freeman.) (Used with permission.)*

discharge of ground water and, in many cases, the presence of wetlands. A more common hydrologic process that results in the presence of wetlands in some mountain valleys is the upward discharge of ground water caused by the change in slope of the water table from being steep on the valley side to being relatively flat in the alluvial valley (Figure 21, right side of valley). Where both of these water-table conditions exist, wetlands fed by ground water, which commonly are referred to as fens, can be present.

Another dynamic aspect of the interaction of ground water and surface water in mountain settings is caused by the marked longitudinal component of flow in mountain valleys. The high gradient of mountain streams, coupled with the coarse texture of streambed sediments, results in a strong down-valley component of flow accompanied by frequent exchange of stream water with water in the hyporheic zone (Figure 14) (see Box H). The driving force for water exchange between a stream and its hyporheic zone is created by the surface water flowing over rough streambeds, through pools and riffles, over cascades, and around boulders and logs. Typically, the stream enters the hyporheic zone at the downstream end of pools and then flows beneath steep sections of the stream (called riffles), returning to the stream at the upstream end of the next pool (Figure 14*A*). Stream water also may enter the hyporheic zone upstream from channel meanders, causing stream water to flow through a gravel bar before reentering the channel downstream (Figure 14*B*).

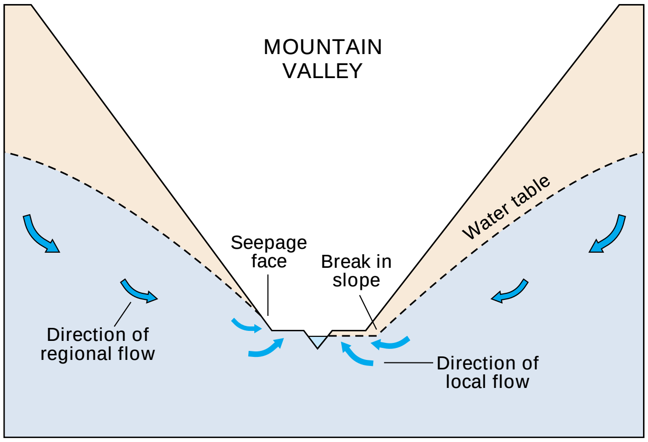


Figure **21**. *In mountainous terrain, ground water can discharge at the base of steep slopes (left side of valley), at the edges of flood plains (right side of valley), and to the stream.*

Streams flowing from mountainous terrain commonly flow across alluvial fans at the edges of the valleys. Most streams in this type of setting lose water to ground water as they traverse the highly permeable alluvial fans. This process has long been recognized in arid western regions, but it also has been documented in humid regions, such as the Appalachian Mountains. In arid and semiarid regions, seepage of water from the stream can be the principal source of aquifer recharge. Despite its importance, ground-water recharge from losing streams remains a highly uncertain part of the water balance of aquifers in these regions. Promising new methods of estimating ground-water recharge, at least locally, along mountain fronts are being developed—these methods include use of environmental tracers, measuring vertical temperature profiles in streambeds, measuring hydraulic characteristics of streambeds, and measuring the difference in hydraulic head between the stream and the underlying aquifer.

The most common natural lakes in mountainous terrain are those that are dammed by rock sills or glacial deposits high in the mountains. Termed cirque lakes, they receive much of their water from snowmelt. However, they interact with ground water much like the processes shown in Figure 21, and they can be maintained by ground water throughout the snow-free season.

The geochemical environment of mountains is quite diverse because of the effects of highly variable climate and many different rock and soil types on the evolution of water chemistry. Geologic materials can include crystalline, volcanic, and sedimentary rocks and glacial deposits. Sediments can vary from those having well-developed soil horizons to stream alluvium that has no soil development. During heavy precipitation, much water flows through shallow flow paths, where it interacts with microbes and soil gases. In the deeper flow through fractured bedrock, longer term geochemical interactions of ground water with minerals determine the chemistry of water that eventually discharges to streams. Base flow of streams in mountainous terrain is derived by drainage from saturated alluvium in valley bottoms and from drainage of bedrock fractures. Mixing of these chemically different water types results in geochemical reactions that affect the chemistry of water in streams. During downstream transport in the channel, stream water mixes with ground water in the hyporheic zone. In some mountain streams, the volume of water in the hyporheic zone is considerably larger than that in the stream channel. Chemical reactions in hyporheic zones can, in some cases, substantially alter the water chemistry of streams (Figure 19).

H

Field Studies of Mountainous Terrain

The steep slopes and rocky characteristics of mountainous terrain make it difficult to determine interactions of ground water and surface water. Consequently, few detailed hydrogeologic investigations of these interactions have been conducted in mountainous areas. Two examples are given below.

A field and modeling study of the Mirror Lake area in the White Mountains of New Hampshire indicated that the sizes of ground-water flow systems contributing to surface-water bodies were considerably larger than their topographically defined watersheds. For example, much of the ground water in the fractured bedrock that discharges to Mirror Lake passes beneath the local flow system associated with Norris Brook (Figure H–1). Furthermore, a more extensive deep ground-water flow system that discharges to the Pemigewasset River passes beneath flow systems associated with both Norris Brook and Mirror Lake.

Studies in mountainous terrain have used tracers to determine sources of ground water to streams (see Box G). In addition to revealing processes of water exchange between ground water and stream water, solute tracers have proven useful for defining the limits of the hyporheic zone surrounding mountain streams. For example, solute tracers such as chloride or bromide ions are injected into the stream to artificially raise concentrations above natural background concentrations. The locations and amounts of ground-water inflow are determined from a simple dilution model. The extent that tracers move into the hyporheic zone can be estimated by the models and commonly is verified by sampling wells placed in the study area.

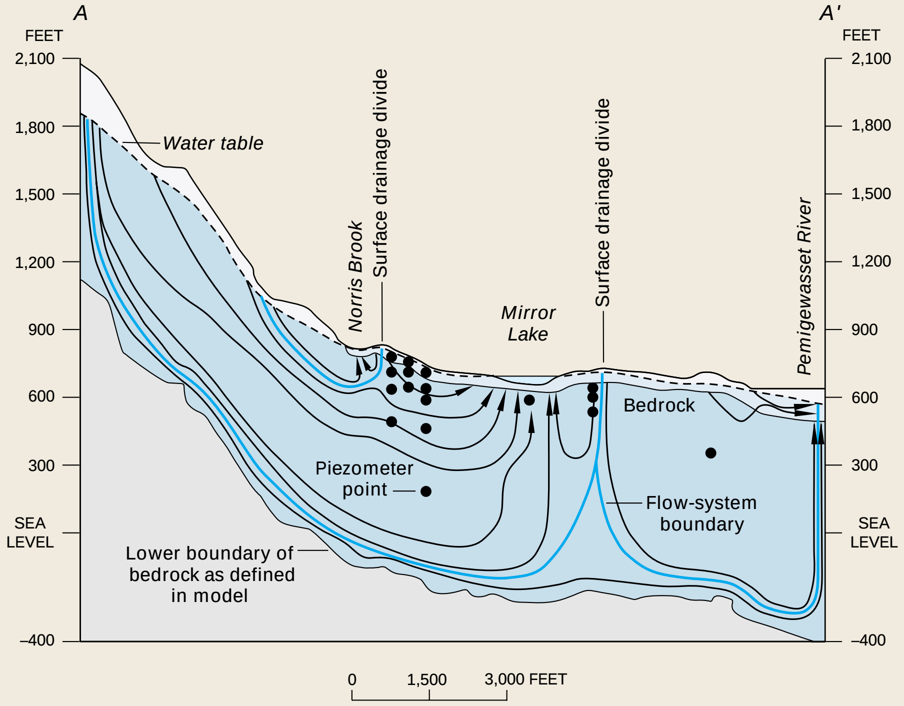


Figure H–1. Ground-water flow systems in the Mirror Lake area extend beyond the topographically defined surface-water watersheds. (Modified from Harte, P.T., and Winter, T.C., 1996, Factors affecting recharge to crystalline rock in the Mirror Lake area, Grafton County, New Hampshire: in Morganwalp, D.W., and Aronson, D.A., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of Technical Meeting, Colorado Springs, Colorado, September 20–24, 1993: U.S. Geological Survey Water-Resources Investigations Report 94–4014, p. 141–150.)

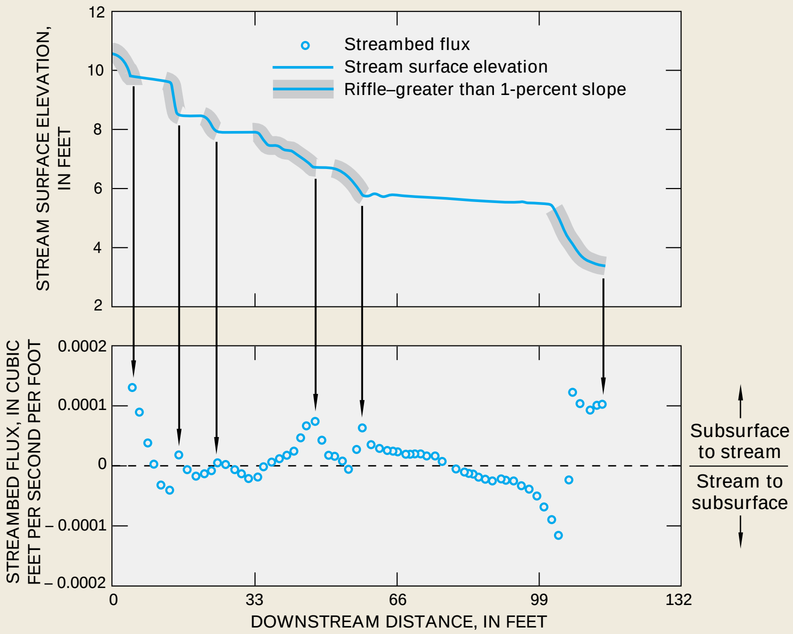


Figure H–2. In mountain streams characterized by pools and riffles, such as at Saint Kevin Gulch in Colorado, inflow of water from the hyporheic zone to the stream was greatest at the downstream end of riffles. (Modified from Harvey, J.W., and Bencala, K.E., 1993, The effect of streambed topography on surface-subsurface water exchange in mountain catchments: Water Resources Research, v. 29, p. 89–98.)

A study in Colorado indicated that hyporheic exchange in mountain streams is caused to a large extent by the irregular topography of the streambed, which creates pools and riffles characteristic of mountain streams. Ground water enters streams most readily at the upstream end of deep pools, and stream water flows into the subsurface beneath and to the side of steep sections of streams (riffles) (Figure H–2). Channel irregularity, therefore, is an important control on the location of ground-water inflow to streams and on the size of the hyporheic zone in mountain streams because changes in slope determine the length and depth of hyporheic flow paths.

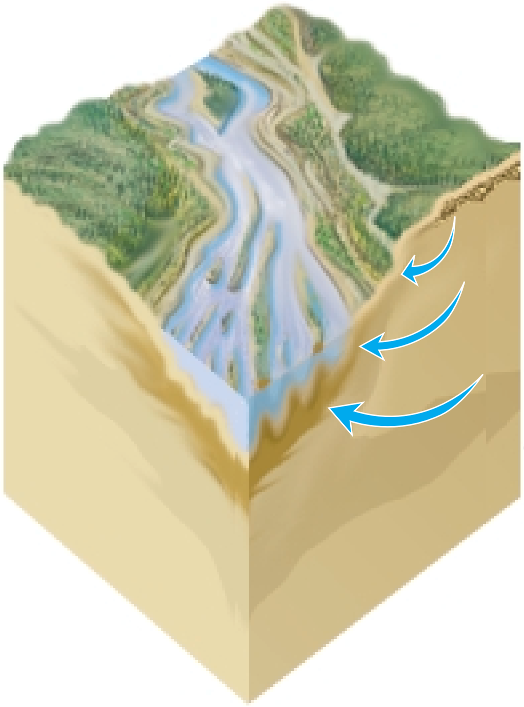
The source and fate of metal contaminants in streams receiving drainage from abandoned mines can be determined by using solute tracers. In addition to surface drainage from mines, a recent study of Chalk Creek in Colorado indicated that contaminants were being brought to the stream by ground-water inflow. The ground water had been contaminated from mining activities in the past and is now a new source of contamination to the stream. This nonpoint ground-water source of contamination will very likely be much more difficult to clean up than the point source of contamination from the mine tunnel.

RIVERINE TERRAIN

In some landscapes, stream valleys are small and they commonly do not have well-developed flood plains (area R of the conceptual landscape, Figure 2) (see Box I). However, major rivers (area V of the reference landscape, Figure 2) have valleys that usually become increasingly wider downstream. Terraces, natural levees, and abandoned river meanders are common landscape features in major river valleys, and wetlands and lakes commonly are associated with these features.

The interaction of ground water and surface water in river valleys is affected by the interchange of local and regional ground-water flow systems with the rivers and by flooding and evapotranspiration. Small streams receive ground-water inflow primarily from local flow systems, which usually have limited extent and are highly variable seasonally. Therefore, it is not unusual for small streams to have gaining or losing reaches that change seasonally.

For larger rivers that flow in alluvial valleys, the interaction of ground water and surface water usually is more spatially diverse than it is for smaller streams. Ground water from regional flow systems discharges to the river as well as at various places across the flood plain (Figure 22). If terraces are present in the alluvial valley, local ground-water flow systems may be associated with each terrace, and lakes and wetlands may be formed because of this source of ground water. At some locations, such as at the valley wall and at the river, local and regional ground-water flow systems may discharge in close proximity. Furthermore, in large alluvial valleys, significant down-valley components of flow in the streambed and in the shallow alluvium also may be present (see Box I).



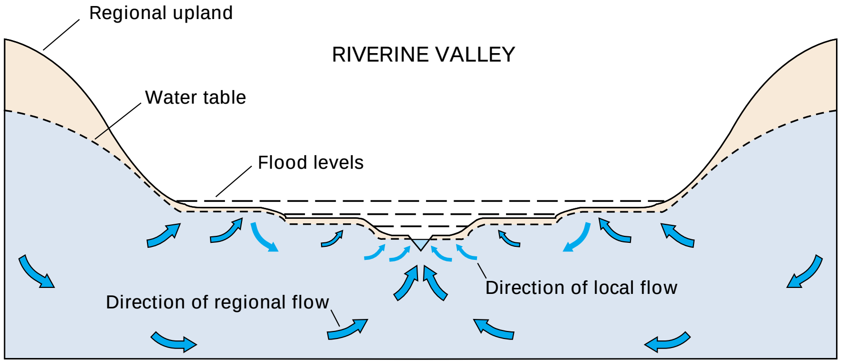


Figure 22. *In broad river valleys, small local ground-water flow systems associated with terraces overlie more regional ground-water flow systems. Recharge from flood waters superimposed on these ground-water flow systems further complicates the hydrology of river*

Added to this distribution of ground-water discharge from different flow systems to different parts of the valley is the effect of flooding. At times of high river flows, water moves into the ground-water system as bank storage (Figure 11). The flow paths can be as lateral flow through the riverbank (Figure 12*B*) or, during flooding, as vertical seepage over the flood plain (Figure 12*C*). As flood waters rise, they cause bank storage to move into higher and higher terraces.

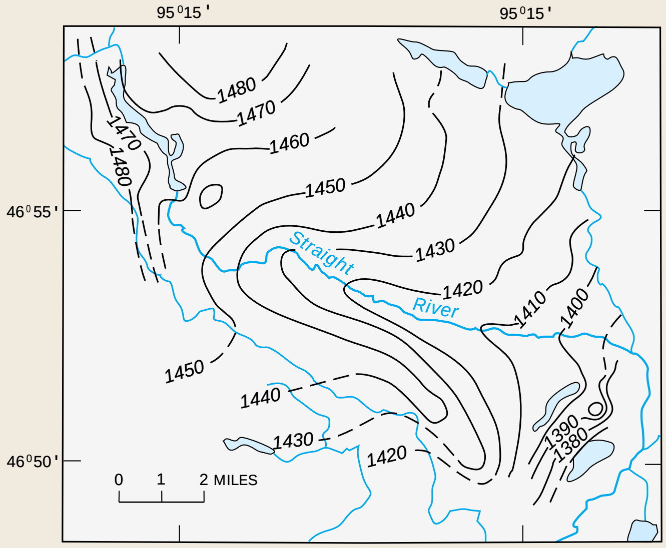
The water table generally is not far below the land surface in alluvial valleys. Therefore, vegetation on flood plains, as well as at the base of some terraces, commonly has root systems deep enough so that the plants can transpire water directly from ground water. Because of the relatively stable source of ground water, particularly in areas of ground-water discharge, the vegetation can transpire water near the maximum potential transpiration rate, resulting in the same effect as if the water were being pumped by a well (see Figure 7). This large loss of water can result in drawdown of the water table such that the plants intercept some of the water that would otherwise flow to the river, wetland, or lake. Furthermore, in some settings it is not uncommon during the growing season for the pumping effect of transpiration to be significant enough that surface water moves into the subsurface to replenish the transpired ground water.

Riverine alluvial deposits range in size from clay to boulders, but in many alluvial valleys, sand and gravel are the predominant deposits. Chemical reactions involving dissolution or precipitation of minerals (see Box D) commonly do not have a significant effect on water chemistry in sand and gravel alluvial aquifers because the rate of water movement is relatively fast compared to weathering rates. Instead, sorption and desorption reactions and oxidation/reduction reactions related to the activity of microorganisms probably have a greater effect on water chemistry in these systems. As in small streams, biogeochemical processes in the hyporheic zone may have a significant effect on the chemistry of ground water and surface water in larger riverine systems. Movement of oxygen-rich surface water into the subsurface, where chemically reactive sediment coatings are abundant, causes increased chemical reactions related to activity of microorganisms. Sharp gradients in concentration of some chemical constituents in water, which delimit this zone of increased biogeochemical activity, are common near the boundary between ground water and surface water. In addition, chemical reactions in the hyporheic zone can cause precipitation of some reactive solutes and contaminants, thereby affecting water quality.

Field Studies of Riverine Terrain

Streams are present in virtually all landscapes, and in some landscapes, they are the principal surface-water features. The interaction of ground water with streams varies in complexity because they vary in size from small streams near headwaters areas to large rivers flowing in large alluvial valleys, and also because streams intersect ground-water flow systems of greatly different scales. Examples of the interaction of ground water and surface water for small and large riverine systems are presented below.

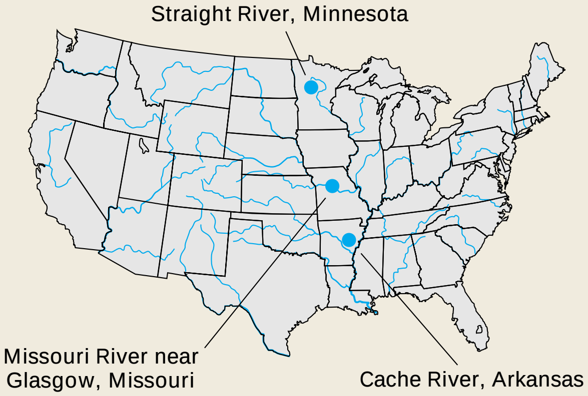
The Straight River, which runs through a sand plain in central Minnesota, is typical of a small stream that does not have a flood plain and that derives most of its water from ground-water inflow. The water-table contours near the river bend sharply upstream (Figure I–1), indicating that ground water moves directly into the river. It is estimated from base-flow studies (see Box B) that, on an annual basis, ground water accounts for more than 90 percent of the water in the river.



EXPLANATION

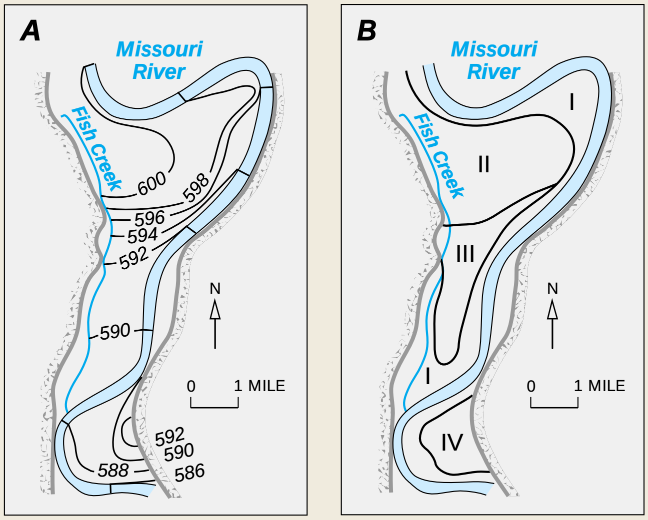
—*1420*— WATER-TABLE CONTOUR—Shows altitude of the water table in feet above sea level. Dashed where approximately located. Contour interval 10 feet

Figure I–1. Small streams, such as the Straight River in Minnesota, commonly do not have flood plains. The flow of ground water directly into the river is indicated by the water-table contours that bend sharply upstream. (Modified from Stark, J.R., Armstrong, D.S., and Zwilling, D.R., 1994, Stream-aquifer interactions in the Straight River area, Becker and Hubbard Counties, Minnesota: U.S. Geological Survey Water-Resources Investigations Report 94–4009, 83 p.)



In contrast, the results of a study of the lower Missouri River Valley indicate the complexity of ground-water flow and its interaction with streams in large alluvial valleys. Configuration of the water table in this area indicates that ground water flows into the river at right angles in some reaches, and it flows parallel to the river in others (Figure I–2*A*). This study also resulted in a map that showed patterns of water-table fluctuations with respect to proximity to the river (Figure I–2*B*). This example shows the wide variety of ground-water flow conditions that can be present in large alluvial valleys.

Another study of part of a large alluvial valley provides an example of the presence of smaller scale flow conditions. The Cache River is a stream within the alluvial valley of the Mississippi River Delta system in eastern Arkansas. In a study of the Black Swamp, which lies along a reach of the river, a number of wells and piezometers were installed to determine the interaction of ground water with the swamp and the river. By measuring hydraulic head at different depths in the



EXPLANATION

—590— WATER-TABLE CONTOUR—Shows altitude of water table in feet above sea level. Contour interval 2 feet

Figure I–2. In flood plains of large rivers, such as the Missouri River near Glasgow, Missouri, patterns of ground-water movement (A) and water-table fluctuations (B) can be complex. Zone I is an area of rapidly fluctuating water levels, zone II is an area of long-term stability, zone III is an area of down-valley flow, and zone IV is a persistent ground-water high. (Modified from Grannemann, N.G., and Sharp, J.M., Jr., 1979, Alluvial hydrogeology of the lower Missouri River: Journal of Hydrology, v. 40, p. 85–99.) (Reprinted with permission from Elsevier Science-NL, Amsterdam, The Netherlands.)

alluvium, it was possible to construct a hydrologic section through the alluvium (Figure I–3), showing that the river receives ground-water discharge from both local and regional ground-water flow systems. In addition, the section also shows the effect of the break in slope associated with the terrace at the edge of the swamp, which causes ground water from a local flow system to discharge into the edge of the swamp rather than to the river.

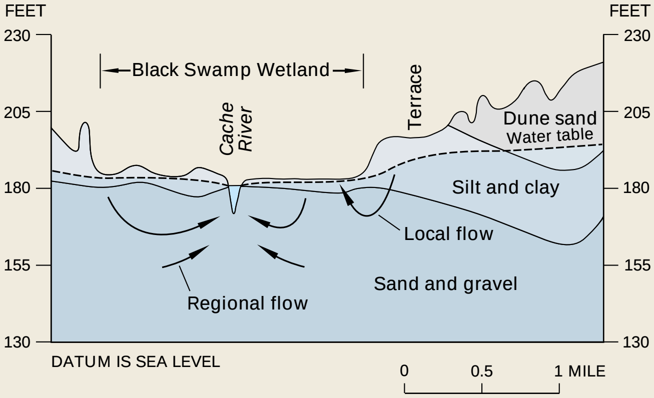


Figure I–3. The Cache River in Arkansas provides an example of contributions to a river from regional and local ground-water flow systems. In addition, a small local ground-water flow system associated with a terrace discharges to the wetland at the edge of the flood plain. (Modified from Gonthier, G.J., 1996, Ground-water flow conditions within a bottomland hardwood wetland, eastern Arkansas: Wetlands, v. 16, no. 3, p. 334–346.) (Used with permission.)

COASTAL TERRAIN

Coastal terrain, such as that along the east-central and southern coasts of the United States, extends from inland scarps and terraces to the ocean (area C of the conceptual landscape, Figure 2). This terrain is characterized by (1) low scarps and terraces that were formed when the ocean was higher than at present; (2) streams, estuaries, and lagoons that are affected by tides; (3) ponds that are commonly associated with coastal sand dunes; and (4) barrier islands. Wetlands cover extensive areas in some coastal terrains (see Figure 18).

The interaction of ground water and surface water in coastal terrain is affected by discharge of ground water from regional flow systems and from local flow systems associated with scarps and terraces (Figure 23), evapotranspiration, and tidal flooding. The local flow systems associated with scarps and terraces are caused by the configuration of the water table near these features (see Box J). Where the water table has a downward break in slope near the top of scarps and terraces, downward components of ground-water flow are present; where the water table has an upward break in slope near the base of these features, upward components of ground-water flow are present.

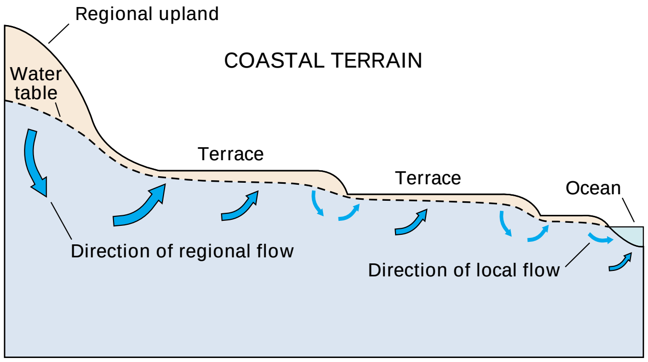
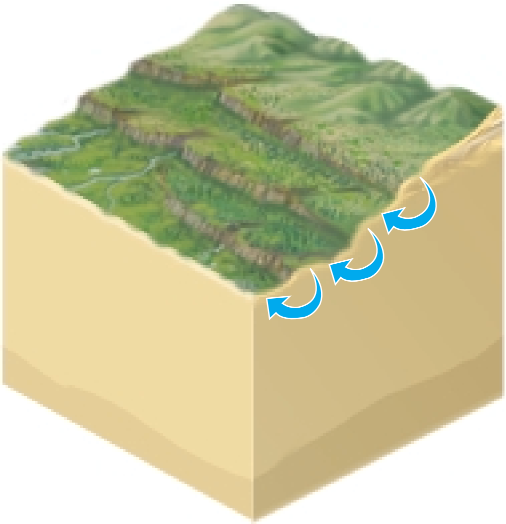


Figure 23. *In coastal terrain, small local ground-water flow cells associated with terraces overlie more regional ground-water flow systems. In the tidal zone, saline and brackish surface water mixes with fresh ground water from local and regional flow systems.*



Evapotranspiration directly from ground water is widespread in coastal terrain. The land surface is flat and the water table generally is close to land surface; therefore, many plants have root systems deep enough to transpire ground water at nearly the maximum potential rate. The result is that evapotranspiration causes a significant water loss, which affects the configuration of ground-water flow systems as well as how ground water interacts with surface water.

In the parts of coastal landscapes that are affected by tidal flooding, the interaction of ground water and surface water is similar to that in alluvial valleys affected by flooding. The principal difference between the two is that tidal flooding is more predictable in both timing and magnitude than river flooding. The other significant difference is in water chemistry. The water that moves into bank storage from rivers is generally fresh, but the water that moves into bank storage from tides generally is brackish or saline.

Estuaries are a highly dynamic interface between the continents and the ocean, where discharge of freshwater from large rivers mixes with saline water from the ocean. In addition, ground water discharges to estuaries and the ocean, delivering nutrients and contaminants directly to coastal waters. However, few estimates of the location and magnitude of ground-water discharge to coasts have been made.

In some estuaries, sulfate-rich regional ground water mixes with carbonate-rich local ground water and with chloride-rich seawater, creating sharp boundaries that separate plant and wildlife communities. Biological communities associated with these sharp boundaries are adapted to different hydrochemical conditions, and they undergo periodic stresses that result from inputs of water having different chemistry. The balance between river inflow and tides causes estuaries to retain much of the particulate and dissolved matter that is transported in surface and subsurface flows, including contaminants.

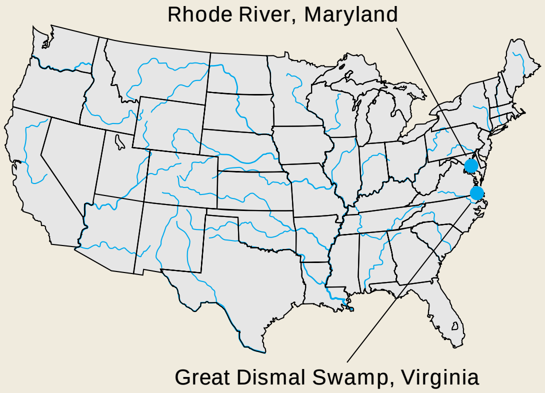
"Ground water discharges to estuaries and the ocean, delivering nutrients and contaminants directly to coastal waters"

Field Studies of Coastal Terrain

Along the Atlantic, Gulf of Mexico, and Arctic Coasts of the United States, broad coastal plains are transected by streams, scarps, and terraces. In some parts of these regions, local ground-water flow systems are associated with scarps and terraces, and freshwater wetlands commonly are present. Other parts of coastal regions are affected by tides, resulting in very complex flow and biogeochemical processes.

Underlying the broad coastal plain of the mid-Atlantic United States are sediments 600 or more feet thick. The sands and clays were deposited in stratigraphic layers that slope gently from west to east. Ground water moves regionally toward the east in the more permeable sand layers. These aquifers are separated by discontinuous layers of clay that restrict vertical ground-water movement. Near land surface, local ground-water flow systems are associated with changes in land slope, such as at major scarps and at streams.

Studies of the Dismal Swamp in Virginia and North Carolina provide examples of the interaction of ground water and wetlands near a coastal scarp. The Suffolk Scarp borders the west side of Great Dismal Swamp. Water-table wells and deeper piezometers placed across the scarp indicated a downward component of ground-water flow in the upland and an upward component of ground-water flow in the lowland at the edge of the swamp (Figure J–1*A*). However, at the edge of the swamp the direction of flow changed several times between May and October in 1982 because transpiration of ground water lowered the water table below the water level of the deep piezometer (Figure J–1*B*).



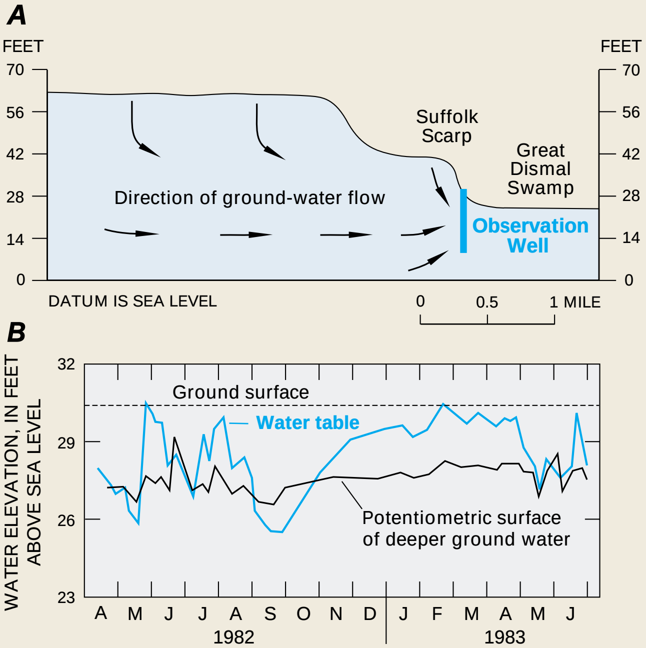


Figure J–1. Ground-water discharge at the edge of the Great Dismal Swamp in Virginia provides an example of local ground-water flow systems associated with coastal scarps (A). The vertical components of flow can change direction seasonally, partly because evapotranspiration discharges shallower ground water during part of the year (B). (Modified from Carter, Virginia, 1990, The Great Dismal Swamp—An illustrated case study, chapter 8, in Lugo, A.E., Brinson, Mark, and Brown, Sandra, eds., Ecosystems of the world, 15: Forested wetlands, Elsevier, Amsterdam, p. 201–211.) (Reprinted with permission from Elsevier Science-NL, Amsterdam, The Netherlands.)

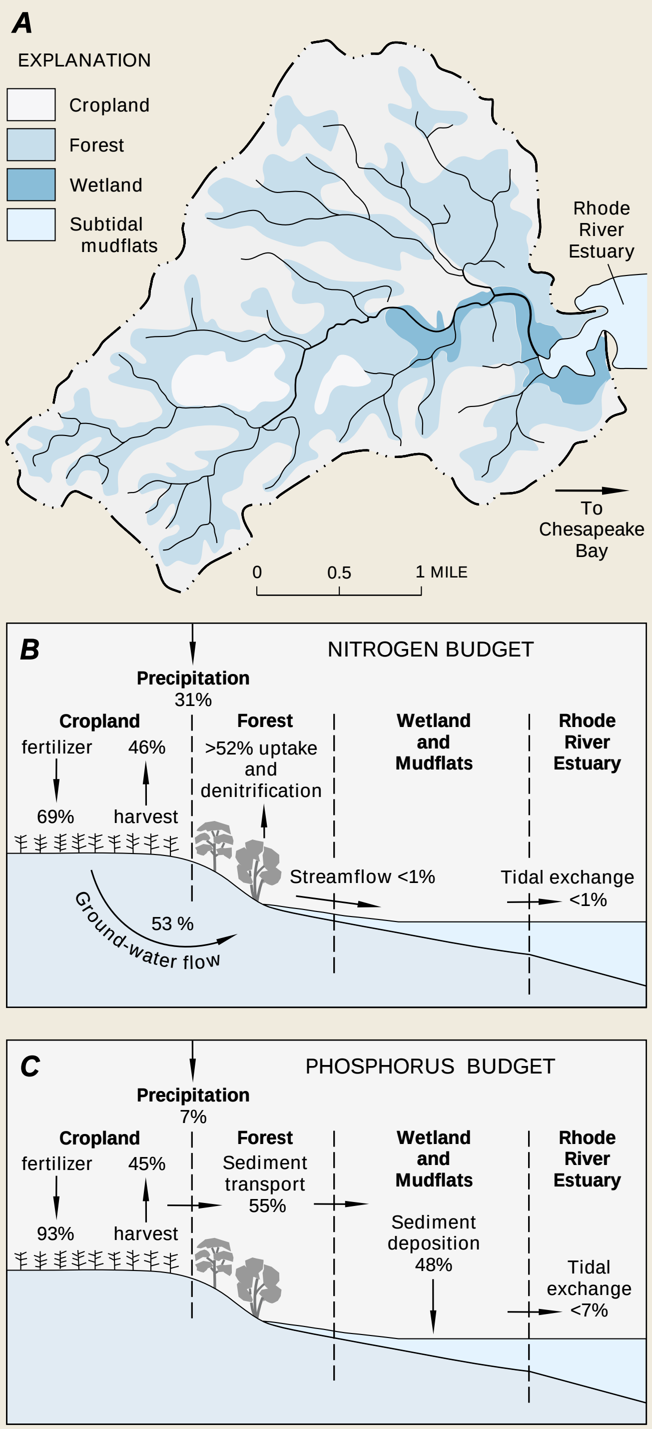


Figure J–2. Forests and wetlands separate cropland from streams in the Rhode River watershed in Maryland (A). More than half of the nitrogen applied to cropland is transported by ground water toward riparian forests and wetlands (B). More than half of the total phosphorus applied to cropland is transported by streams to wetlands and mudflats, where most is deposited in sediments (C). (Modified from Correll, D.L., Jordan, T.E., and Weller, D.E., 1992, Nutrient flux in a landscape—Effects of coastal land use and terrestrial community mosaic on nutrient transport to coastal waters: Estuaries, v. 15, no. 4, p. 431–442.) (Reprinted by permission of the Estuarine Research Federation.)

The gentle relief and sandy, well-drained soils of coastal terrain are ideal for agriculture. Movement of excess nutrients to estuaries are a particular problem in coastal areas because the slow rate of flushing of coastal bays and estuaries can cause them to retain nutrients. At high concentrations, nutrients can cause increased algal production, which results in overabundance of organic matter. This, in turn, can lead to reduction of dissolved oxygen in surface water to the extent that organisms are killed throughout large areas of estuaries and coastal bays.

Movement of nutrients from agricultural fields has been documented for the Rhode River watershed in Maryland (Figure J–2). Application of fertilizer accounts for 69 percent of nitrogen and 93 percent of phosphorus input to this watershed (Figure J–2*B* and J–2*C*). Almost all of the nitrogen that is not removed by harvested crops is transported in ground water and is taken up by trees in riparian forests and wetlands or is denitrified to nitrogen gas in ground water before it reaches streams. On the other hand, most of the phosphorus not removed by harvested crops is attached to soil particles and is transported only during heavy precipitation when sediment from fields is transported into streams and deposited in wetlands and subtidal mudflats at the head of the Rhode River estuary. Whether phosphorus is retained in sediments or is released to the water column depends in part on whether sediments are exposed to oxygen. Thus, the uptake of nutrients and their storage in riparian forests, wetlands, and subtidal mudflats in the Rhode River watershed has helped maintain relatively good water quality in the Rhode River estuary.

In other areas, however, agricultural runoff and input of nutrients have overwhelmed coastal systems, such as in the northern Gulf of Mexico near the mouth of the Mississippi River. The 1993 flood in the Mississippi River system delivered an enormous amount of nutrients to the Gulf of Mexico. Following the flood, oxygen-deficient sediments created areas of black sediment devoid of animal life in parts of the northern Gulf of Mexico.

GLACIAL AND DUNE TERRAIN

Glacial and dune terrain (area G of the conceptual landscape, Figure 2) is characterized by a landscape of hills and depressions. Although stream networks drain parts of these landscapes, many areas of glacial and dune terrain do not contribute runoff to an integrated surface drainage network. Instead, surface runoff from precipitation falling on the landscape accumulates in the depressions, commonly resulting in the presence of lakes and wetlands. Because of the lack of stream outlets, the water balance of these “closed” types of lakes and wetlands is controlled largely by exchange of water with the atmosphere (precipitation and evapotranspiration) and with ground water (see Box K).

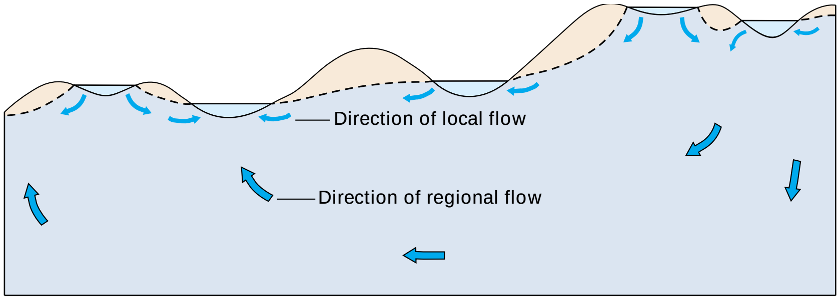
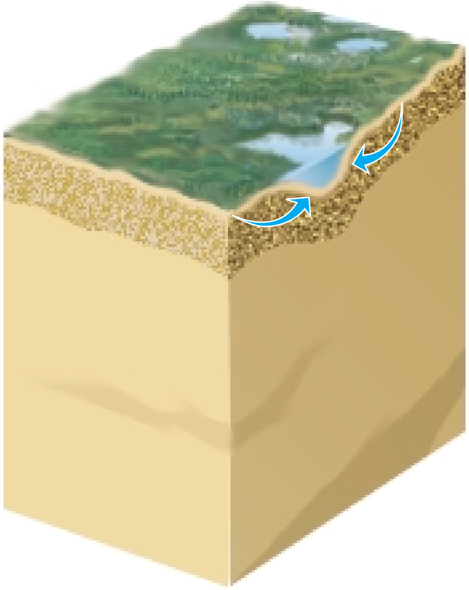


Figure 24. *In glacial and dune terrain, local, intermediate, and regional ground-water flow systems interact with lakes and wetlands. It is not uncommon for wetlands that recharge local ground-water flow systems to be present in lowlands and for wetlands that receive discharge from local ground water to be present in uplands.*



Lakes and wetlands in glacial and dune terrain can have inflow from ground water, outflow to ground water, or both (Figure 16). The interaction between lakes and wetlands and ground water is determined to a large extent by their position with respect to local and regional ground-water flow systems. A common conception is that lakes and wetlands that are present in topographically high areas recharge ground water, and that lakes and wetlands that are present in low areas receive discharge from ground water. However, lakes and wetlands underlain by deposits having low permeability can receive discharge from local ground-water flow systems even if they are located in a regional ground-water recharge area. Conversely, they can lose water to local ground-water flow systems even if they are located in a regional ground-water discharge area (Figure 24).

Lakes and wetlands in glacial and dune terrain underlain by highly permeable deposits commonly have ground-water seepage into one side and seepage to ground water on the other side. This relation is relatively stable because the water-table gradient between surface-water bodies in this type of setting is relatively constant. However, the boundary between inflow to the lake or wetland and outflow from it, termed the hinge line, can move up and down along the shoreline. Movement of the hinge line between inflow and outflow is a result of the changing slope of the water table in response to changes in ground-water recharge in the adjacent uplands.

Transpiration directly from ground water has a significant effect on the interaction of lakes and wetlands with ground water in glacial and dune terrain. Transpiration from ground water (Figure 7) has perhaps a greater effect on lakes and wetlands underlain by low-permeability deposits than in any other landscape. The lateral movement of ground water in low-permeability deposits may not be fast enough to supply the quantity of water at the rate it is removed by transpiration, resulting in deep and steep-sided cones of depression. These cones of depression commonly are present around the perimeter of the lakes and wetlands (Figure 7 and Box K).

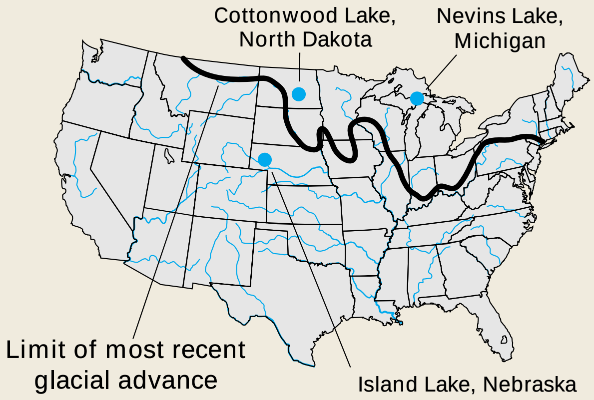
In the north-central United States, cycles in the balance between precipitation and evapotranspiration that range from 5 to 30 years can result in large changes in water levels, chemical concentrations, and major-ion water type of individual wetlands. In some settings, repeated cycling of water between the surface and subsurface in the same locale results in evaporative concentration of solutes and eventually in mineral precipitation in the subsurface. In addition, these dynamic hydrological and chemical conditions can cause significant changes in the types, number, and distribution of wetland plants and invertebrate animals within wetlands. These changing hydrological conditions that range from seasons to decades are an essential process for rejuvenating wetlands that provide ideal habitat and feeding conditions for migratory waterfowl.

> ***“The hydrological and chemical characteristics of lakes and wetlands in glacial and dune terrain are determined to a large extent by their position with respect to local and regional ground-water flow systems”***

Field Studies of Glacial and Dune Terrain

Glacial terrain and dune terrain are characterized by land-surface depressions, many of which contain lakes and wetlands. Although much of the glacial terrain covering the north-central United States (see index map) has low topographic relief, neighboring lakes and wetlands are present at a sufficiently wide range of altitudes to result in many variations in how they interact with ground water, as evidenced by the following examples.

The Cottonwood Lake area, near Jamestown, North Dakota, is within the prairie-pothole region of North America. The hydrologic functions of these small depressional wetlands are highly variable in space and time. With respect to spatial variation, some wetlands recharge ground water, some receive ground-water inflow and have outflow to ground water, and some receive ground-water discharge. Wetland P1 provides an example of how their functions can vary in time. The wetland receives ground-water discharge most of the time; however, transpiration of ground water by plants around the perimeter of the wetland can cause water to seep from the wetland. Seepage from wetlands commonly is assumed to be ground-water recharge, but in cases like Wetland P1, the water is actually lost to transpiration. This process results in depressions in the water table around the perimeter of the wetland at certain times, as shown in



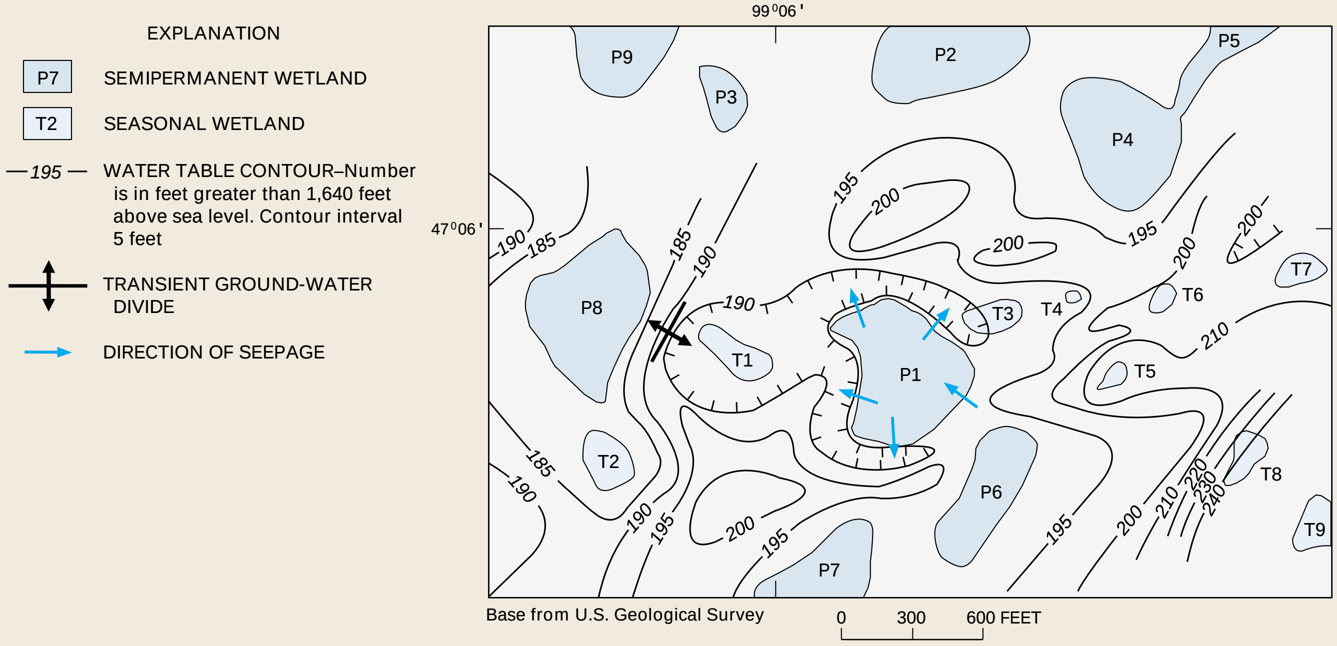


Figure K–1. Transpiration directly from ground water causes cones of depression to form by late summer around the perimeter of prairie pothole Wetland P1 in the Cottonwood Lake area in North Dakota. (Modified from Winter, T.C., and Rosenberry, D.O., 1995, The interaction of ground water with prairie pothole wetlands in the Cottonwood Lake area, east-central North Dakota, 1979–1990: Wetlands, v. 15, no. 3, p. 193–211.) (Used with permission.)

Figure K–1. Transpiration-induced depressions in the water table commonly are filled in by recharge during the following spring, but then form again to some extent by late summer nearly every year.

Nevins Lake, a closed lake in the Upper Peninsula of Michigan, illustrates yet another type of interaction of lakes with ground water in glacial terrain. Water-chemistry studies of Nevins Lake indicated that solutes such as calcium provide an indicator of ground-water inflow to the lake. Immediately following spring snowmelt, the mass of dissolved calcium in the lake increased rapidly because of increased ground-water inflow. Calcium then decreased steadily throughout the summer and early fall as the lake received less ground-water inflow (Figure K–2). This pattern varied annually depending on the amount of ground-water recharge from snowmelt and spring rains. The chemistry of water in the pores of the lake sediments was used to determine the spatial variability in the direction of seepage on the side of the lake that had the most ground-water inflow. Seepage was always out of the lake at the sampling site farthest from shore and was always upward into the lake at the site nearest to shore. Flow reversals were documented at sites located at intermediate distances from shore.

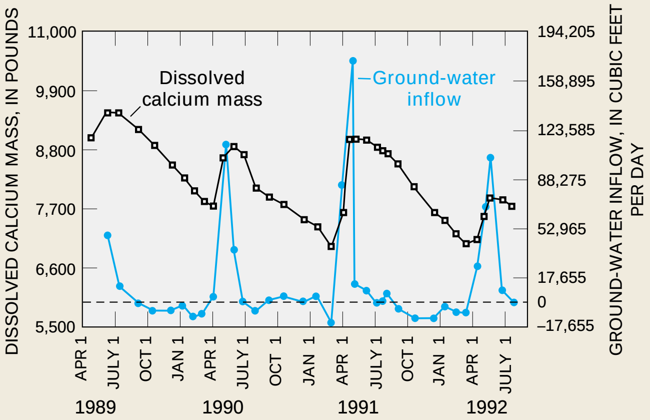


Figure K–2. A large input of ground water during spring supplies the annual input of calcium to Nevins Lake in the Upper Peninsula of Michigan. (Modified from Krabbenhoft, D.P., and Webster, K.E., 1995, Transient hydrogeological controls on the chemistry of a seepage lake: Water Resources Research, v. 31, no. 9, p. 2295–2305.)

Dune terrain also commonly contains lakes and wetlands. Much of the central part of western Nebraska, for example, is covered by sand dunes that have lakes and wetlands in most of the lowlands between the dunes. Studies of the interaction of lakes and wetlands with ground water at the Crescent Lake National Wildlife Refuge indicate that most of these lakes have seepage inflow from ground water and seepage outflow to ground water. The chemistry of inflowing ground water commonly has an effect on lake water chemistry. However, the chemistry of lake water can also affect ground water in areas of seepage from lakes. In the Crescent Lake area, for example, plumes of lake water were detected in ground water downgradient from the lakes, as indicated by the plume of dissolved organic carbon downgradient from Roundup Lake and Island Lake (Figure K–3).

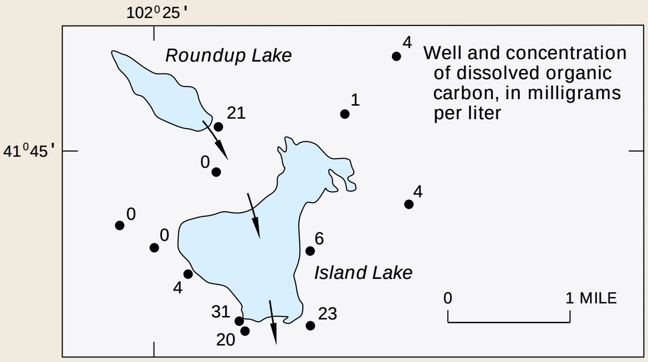
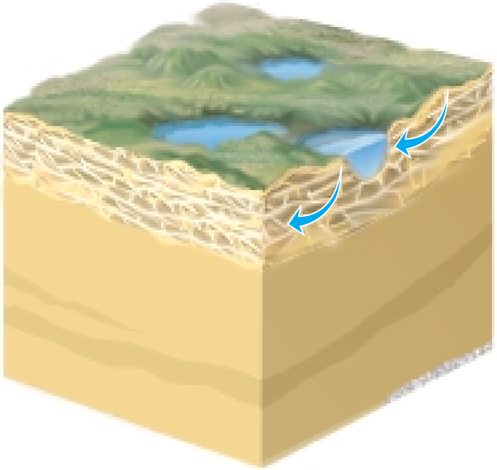


Figure K–3. Seepage from lakes in the sandhills of Nebraska causes plumes of dissolved organic carbon to be present in ground water on the downgradient sides of the lakes. (Modified from LaBaugh, J.W., 1986, Limnological characteristics of selected lakes in the Nebraska sandhills, U.S.A., and their relation to chemical characteristics of adjacent ground water: Journal of Hydrology, v. 86, p. 279–298.) (Reprinted with permission of Elsevier Science-NL, Amsterdam, The Netherlands.)

KARST TERRAIN

Karst may be broadly defined as all landforms that are produced primarily by the dissolution of rocks, mainly limestone and dolomite. Karst terrains (area K of the conceptual landscape, Figure 2) are characterized by (1) closed surface depressions of various sizes and shapes known as sinkholes, (2) an underground drainage network that consists of solution openings that range in size from enlarged cracks in the rock to large caves, and (3) highly disrupted surface drainage systems, which relate directly to the unique character of the underground drainage system.

Dissolution of limestone and dolomite guides the initial development of fractures into solution holes that are diagnostic of karst terrain. Perhaps nowhere else is the complex interplay between hydrology and chemistry so important to changes in landform. Limestone and dolomite weather quickly, producing calcium and magnesium carbonate waters that are relatively high in ionic strength. The increasing size of solution holes allows higher ground-water flow rates across a greater surface area of exposed minerals, which stimulates the dissolution process further, eventually leading to development of caves. Development of karst terrain also involves biological processes. Microbial production of carbon dioxide in the soil affects the carbonate equilibrium of water as it recharges ground water, which then affects how much mineral dissolution will take place before solute equilibrium is reached.



Ground-water recharge is very efficient in karst terrain because precipitation readily infiltrates through the rock openings that intersect the land surface. Water moves at greatly different rates through karst aquifers; it moves slowly through fine fractures and pores and rapidly through solution-enlarged fractures and conduits. As a result, the water discharging from many springs in karst terrain may be a combination of relatively slow-moving water draining from pores and rapidly moving storm-derived water. The slow-moving component tends to reflect the chemistry of the aquifer materials, and the more rapidly moving water associated with recent rainfall tends to reflect the chemical characteristics of precipitation and surface runoff.

Water movement in karst terrain is especially unpredictable because of the many paths ground water takes through the maze of fractures and solution openings in the rock (see Box L). Because of the large size of interconnected openings in well-developed karst systems, karst terrain can have true underground streams. These underground streams can have high rates of flow, in some places as great as rates of flow in surface streams. Furthermore, it is not unusual for medium-sized streams to disappear into the rock openings, thereby completely disrupting the surface drainage system, and to reappear at the surface at another place. Seeps and springs of all sizes are characteristic features of karst terrains. Springs having sufficiently large ground-water recharge areas commonly are the source of small- to medium-sized streams and constitute a large part of tributary flow to larger streams. In addition, the location where the streams emerge can change, depending on the spatial distribution of ground-water recharge in relation to individual precipitation events. Large spring inflows to streams in karst terrain contrast sharply with the generally more diffuse ground-water inflow characteristic of streams flowing across sand and gravel aquifers.

Because of the complex patterns of surface-water and ground-water flow in karst terrain, many studies have shown that surface-water drainage divides and ground-water drainage divides do not coincide. An extreme example is a stream that disappears in one surface-water basin and reappears in another basin. This situation complicates the identification of source areas for water and associated dissolved constituents, including contaminants, in karst terrain.

Water chemistry is widely used for studying the hydrology of karst aquifers. Extensive tracer studies (see Box G) and field mapping to locate points of recharge and discharge have been used to estimate the recharge areas of springs, rates of ground-water movement, and the water balance of aquifers. Variations in parameters such as temperature, hardness, calcium/magnesium ratios, and other chemical characteristics have been used to identify areas of ground-water recharge, differentiate rapid- and slow-moving ground-water flow paths, and compare springflow characteristics in different regions. Rapid transport of contaminants within karst aquifers and to springs has been documented in many locations. Because of the rapid movement of water in karst aquifers, water-quality problems that might be localized in other aquifer systems can become regional problems in karst systems.

Some landscapes considered to be karst terrain do not have carbonate rocks at the land surface. For example, in some areas of the southeastern United States, surficial deposits overlie carbonate rocks, resulting in a “mantled” karst terrain. Lakes and wetlands in mantled karst terrain interact with shallow ground water in a manner similar to that in sandy glacial and dune terrains. The difference between how lakes and wetlands interact with ground water in sandy glacial and dune terrain and how they interact in the mantled karst is related to the buried carbonate rocks. If dissolution of the buried carbonate rocks causes slumpage of an overlying confining bed, such that water can move freely through the confining bed, the lakes and wetlands also can be affected by changing hydraulic heads in the aquifers underlying the confining bed (see Box L).

Field Studies of Karst Terrain

Karst terrain is characteristic of regions that are underlain by limestone and dolomite bedrock. In many karst areas, the carbonate bedrock is present at land surface, but in other areas it may be covered by other deposits and is referred to as "mantled" karst. The Edwards Aquifer in south-central Texas is an example of karst terrain where the limestones and dolomites are exposed at land surface (Figure L–1). In this outcrop area, numerous solution cavities along vertical joints and sinkholes provide an efficient link between the land surface and the water table. Precipitation on the outcrop area tends to infiltrate rapidly into the ground, recharging ground water. In addition, a considerable amount of recharge to the aquifer is provided by losing streams that cross the outcrop area. Even the largest streams that originate to the north are dry in the outcrop area for most of the year. The unusual highway signs in this area go beyond local pride in a prolific water supply—they reflect a clear understanding of how vulnerable this water supply is to contamination by human activities at the land surface.

Just as solution cavities are major avenues for ground-water recharge, they also are focal points for ground-water discharge from karst aquifers. For example, springs near the margin of the Edwards Aquifer provide a continuous source of water for streams to the south.

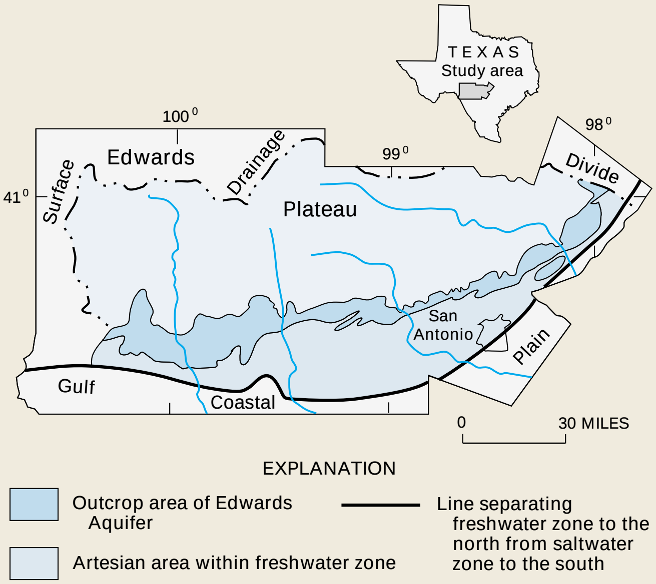
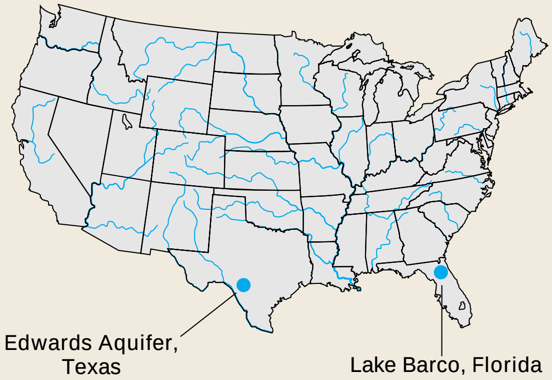


Figure L–1. A large area of karst terrain is associated with the Edwards Aquifer in south-central Texas. Large streams lose a considerable amount of water to ground water as they traverse the outcrop area of the Edwards Aquifer. (Modified from Brown, D.S., and Patton, J.T., 1995, Recharge to and discharge from the Edwards Aquifer in the San Antonio area, Texas, 1995: U.S. Geological Survey Open-File Report 96–181, 2 p.)

An example of mantled karst can be found in north-central Florida, a region that has many sinkhole lakes. In this region, unconsolidated deposits overlie the highly soluble limestone of the Upper Floridan aquifer. Most land-surface depressions containing lakes in Florida are formed when unconsolidated surficial deposits slump into sinkholes that form in the underlying limestone. Thus, although the lakes are not situated directly in limestone, the sinkholes in the bedrock underlying lakes commonly have a significant effect on the hydrology of the lakes.



Lake Barco is one of numerous lakes occupying depressions in northern Florida. Results of a study of the interaction of Lake Barco with ground water indicated that shallow ground water flows into the northern and northeastern parts of the lake, and lake water seeps out to shallow ground water in the western and southern parts (Figure L–2*A*). In addition, ground-water flow is downward beneath most of Lake Barco (Figure L–2*B*).

The studies of lake and ground-water chemistry included the use of tritium, chlorofluorocarbons (CFCs), and isotopes of oxygen (see Box G). The results indicated significant differences in the chemistry of (1) shallow ground water flowing into Lake Barco, (2) Lake Barco water, (3) shallow ground water downgradient from Lake Barco, and (4) deeper ground water beneath Lake Barco. Oxygen-rich lake water moving through the organic-rich lake sediments is reduced, resulting in discharge of oxygen-depleted water into the ground water beneath Lake Barco. This downward-moving ground water may have an undesired effect on the chemical quality of ground water in the underlying Upper Floridan aquifer, which is the principal source of water supply for the region. The patterns of ground-water movement determined from hydraulic-head data were corroborated by chemical tracers. For example, the dates that ground water in different parts of the flow system was recharged, as determined from CFC dating, show a fairly consistent increase in the length of time since recharge with depth (Figure L–2*C*).

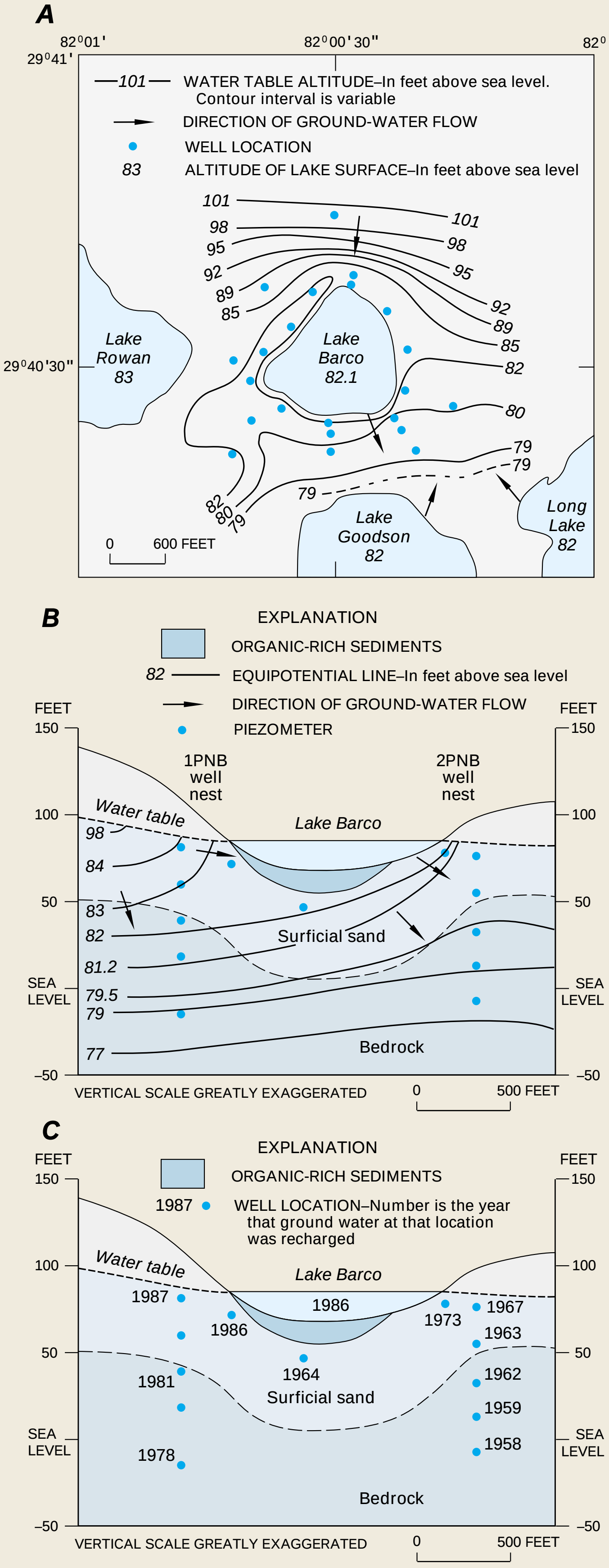


Figure L–2. Lake Barco, in northern Florida, is a flow-through lake with respect to ground water (A and B). The dates that ground water in different parts of the ground-water system was recharged indicate how long it takes water to move from the lake or water table to a given depth (C). (Modified from Katz, B.G., Lee, T.M., Plummer, L.N., and Busenberg, E., 1995, Chemical evolution of groundwater near a sinkhole lake, northern Florida, 1. Flow patterns, age of groundwater, and influence of lake water leakage: Water Resources Research, v. 31, no. 6, p. 1549–1564.)

EFFECTS OF HUMAN ACTIVITIES ON THE INTERACTION OF GROUND WATER AND SURFACE WATER

Human activities commonly affect the distribution, quantity, and chemical quality of water resources. The range in human activities that affect the interaction of ground water and surface water is broad. The following discussion does not provide an exhaustive survey of all human effects but emphasizes those that are relatively widespread. To provide an indication of the extent to which humans affect the water resources of virtually all landscapes, some of the most relevant structures and features related to human activities are superimposed on various parts of the conceptual landscape (Figure 25).

The effects of human activities on the quantity and quality of water resources are felt over a wide range of space and time scales. In the following discussion, “short term” implies time scales from hours to a few weeks or months, and “long term” may range from years to decades. “Local scale” implies distances from a few feet to a few thousand feet and areas as large as a few square miles, and “subregional and regional scales” range from tens to thousands of square miles. The terms point source and nonpoint source with respect to discussions of contamination are used often; therefore, a brief discussion of the meaning of these terms is presented in Box M.

Agricultural Development

Agriculture has been the cause of significant modification of landscapes throughout the world. Tillage of land changes the infiltration and runoff characteristics of the land surface, which affects recharge to ground water, delivery of water and sediment to surface-water bodies, and evapotranspiration. All of these processes either directly or indirectly affect the interaction of ground water and surface water. Agriculturalists are aware of the substantial negative effects of agriculture on water resources and have developed methods to alleviate some of these effects. For example, tillage practices have been modified to maximize retention of water in soils and to minimize erosion of soil from the land into surface-water bodies. Two activities related to agriculture that are particularly relevant to the interaction of ground water and surface water are irrigation and application of chemicals to cropland.

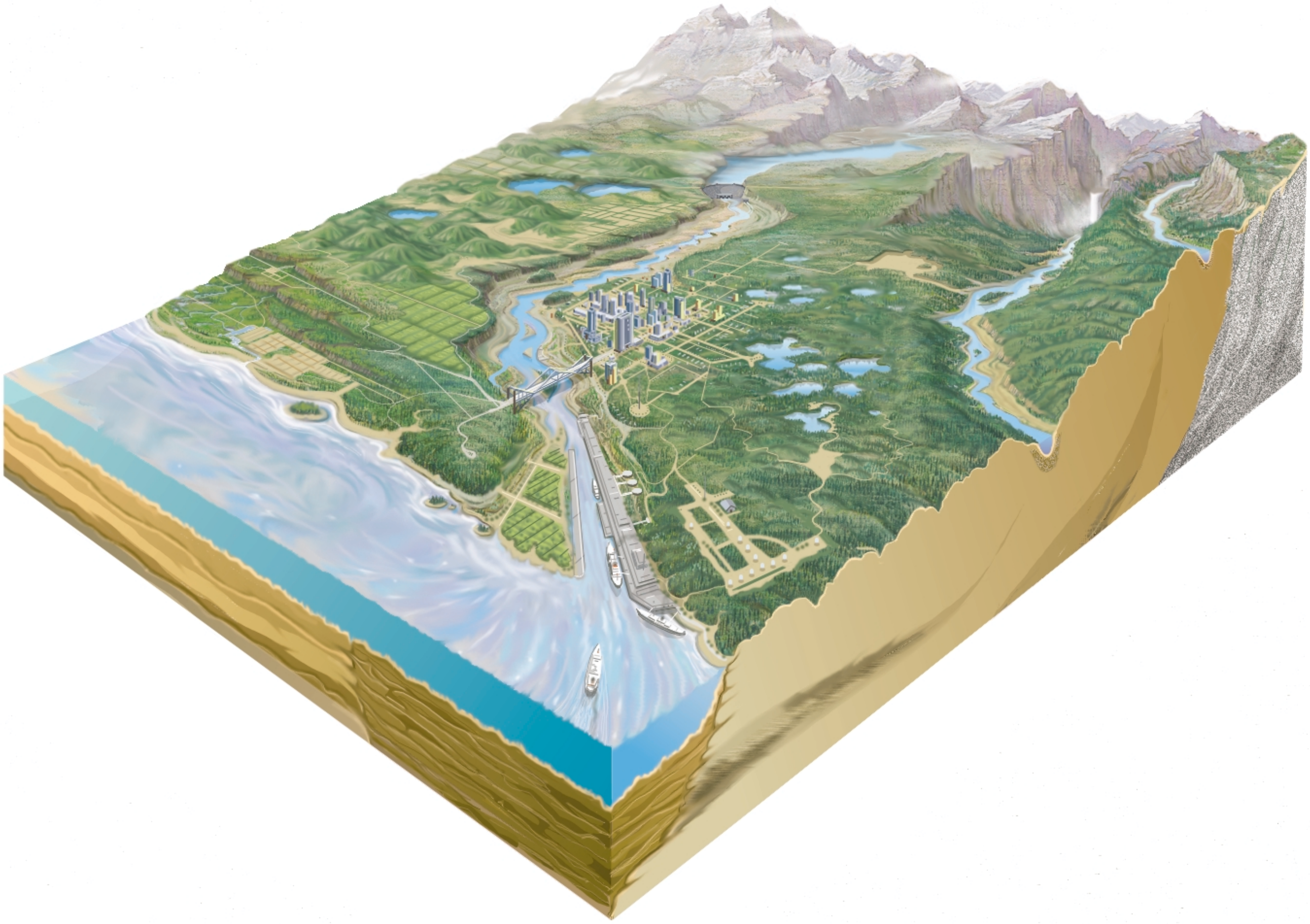


Figure ***25.*** *Human activities and structures, as depicted by the distribution of various examples in the conceptual landscape, affect the interaction of ground water and surface water in all types of landscapes.*

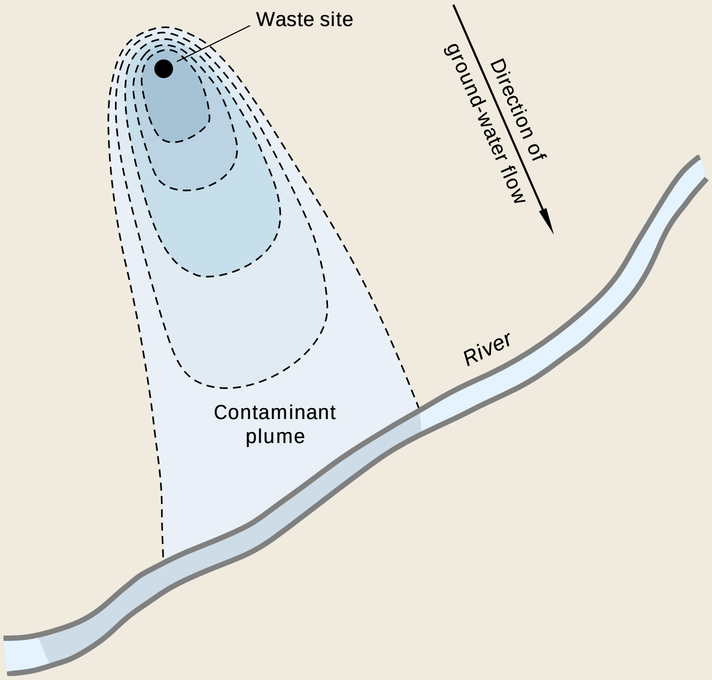
Point and Nonpoint Sources of Contaminants

Contaminants may be present in water or in air as a result of natural processes or through mechanisms of displacement and dispersal related to human activities. Contaminants from point sources discharge either into ground water or surface water through an area that is small relative to the area or volume of the receiving water body. Examples of point sources include discharge from sewage-treatment plants, leakage from gasoline storage tanks, and seepage from landfills (Figure M–1).

Nonpoint sources of contaminants introduce contaminants to the environment across areas that are large compared to point sources, or nonpoint sources may consist of multiple, closely spaced point sources. A nonpoint source of contamination that can be present anywhere, and affect large areas, is deposition from the atmosphere, both by precipitation (wet deposition) or by dry fallout (dry deposition). Agricultural fields, in aggregate, represent large areas through which fertilizers and pesticides can be released to the environment.

The differentiation between point and nonpoint sources of contamination is arbitrary to some extent and may depend in part on the scale at which a problem is considered. For example, emissions from a single smokestack is a point source, but these emissions may be meaningless in a regional analysis of air pollution. However, a fairly even distribution of tens or hundreds of smokestacks might be considered as a nonpoint source. As another example, houses in suburban areas that do not have a combined sewer system have individual septic tanks. At the local scale, each septic tank may be considered as point source of contamination to shallow ground water. At the regional scale, however, the combined contamination of ground water from all the septic tanks in a suburban area may be considered a nonpoint source of contamination to a surface-water body.

Figure M–1. The transport of contamination from a point source by ground water can cause contamination of surface water, as well as extensive contamination of ground water.



IRRIGATION SYSTEMS

Surface-water irrigation systems represent some of the largest integrated engineering works undertaken by humans. The number of these systems greatly increased in the western United States in the late 1840s. In addition to dams on streams, surface-water irrigation systems include (1) a complex network of canals of varying size and carrying capacity that transport water, in many cases for a considerable distance, from a surface-water source to individual fields, and (2) a drainage system to carry away water not used by plants that may be as extensive and complex as the supply system. The drainage system may include underground tile drains. Many irrigation systems that initially used only surface water now also use ground water. The pumped ground water commonly is used directly as irrigation water, but in some cases the water is distributed through the system of canals.

Average quantities of applied water range from several inches to 20 or more inches of water per year, depending on local conditions, over the entire area of crops. In many irrigated areas, about 75 to 85 percent of the applied water is lost to evapotranspiration and retained in the crops (referred to as consumptive use). The remainder of the water either infiltrates through the soil zone to recharge ground water or it returns to a local surface-water body through the drainage system (referred to as irrigation return flow). The quantity of irrigation water that recharges ground water usually is large relative to recharge from precipitation because large irrigation systems commonly are in regions of low precipitation and low natural recharge. As a result, this large volume of artificial recharge can cause the water table to rise (see Box N), possibly reaching the land surface in some areas and waterlogging the fields. For this reason, drainage systems that maintain the level of the water table below the root zone of the crops, generally 4 to 5 feet below the land surface, are an essential component of some irrigation systems. The permanent rise in the water table that is maintained by continued recharge from irrigation return flow commonly results in an increased outflow of shallow ground water to surface-water bodies downgradient from the irrigated area.

Effects of Irrigation Development on the Interaction of Ground Water and Surface Water

Nebraska ranks second among the States with respect to the area of irrigated acreage and the quantity of water used for irrigation. The irrigation water is derived from extensive supply systems that use both surface water and ground water (Figure N–1). Hydrologic conditions in different parts of Nebraska provide a number of examples of the broad-scale effects of irrigation development on the interactions of ground water and surface water. As would be expected, irrigation systems based on surface water are always located near streams. In general, these streams are perennial and (or) have significant flow for at least part of the year. In contrast, irrigation systems based on ground water can be located nearly anywhere that has an adequate ground-water resource. Areas of significant rise and decline in ground-water levels due to irrigation systems are shown in Figure N–2. Ground-water levels rise in some areas irrigated with surface water and decline in some areas irrigated with ground water. Rises in ground-water levels near streams result in increased ground-water inflow to gaining streams or decreased flow from the stream to ground water for losing streams. In some areas, it is possible that a stream that was losing water before development of irrigation could become a gaining stream following irrigation. This effect of surface-water irrigation probably caused the rises in ground-water levels in areas F and G in south-central Nebraska (Figure N–2).

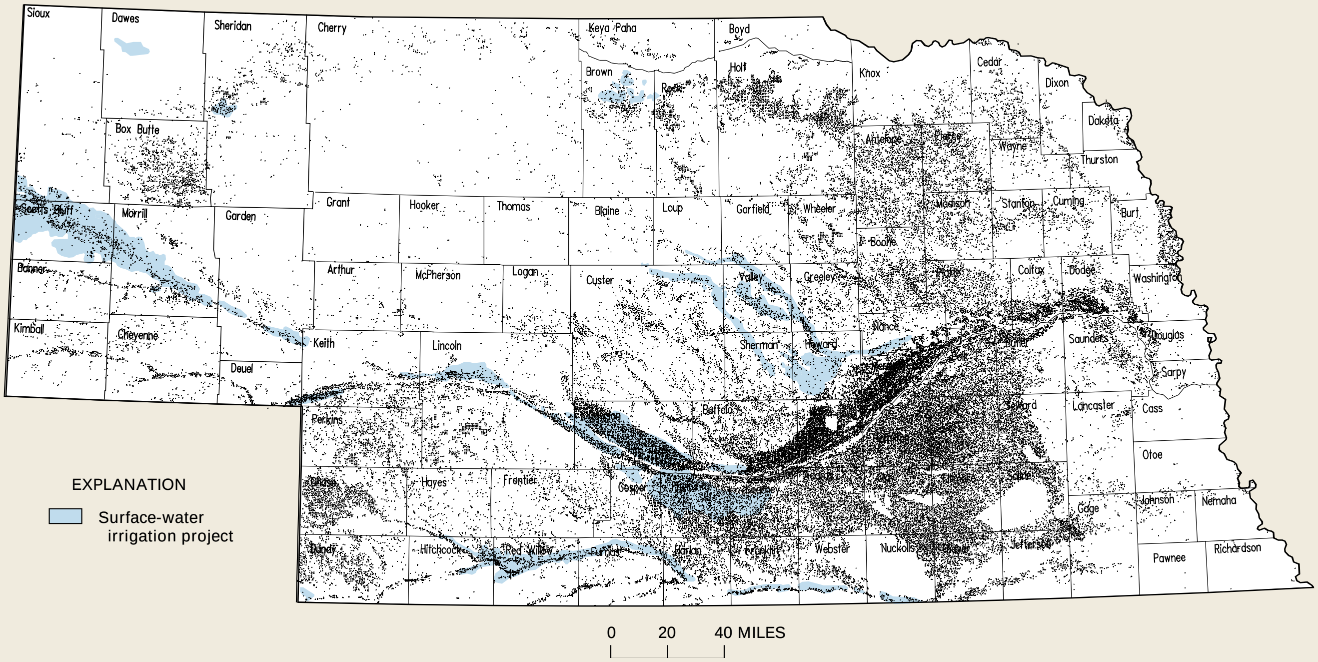


Figure N–1. Nebraska is one of the most extensively irrigated States in the Nation. The irrigation water comes from both ground-water and surface-water sources. Dots are irrigation wells. (Map provided by the University of Nebraska, Conservation and Survey Division.)

Average annual precipitation ranges from less than 15 inches in western Nebraska to more than 30 inches in eastern Nebraska. A large concentration of irrigation wells is present in area E (Figure N–2). The ground-water withdrawals by these wells caused declines in ground-water levels that could not be offset by recharge from precipitation and the presence of nearby flowing streams. In this area, the withdrawals cause decreases in ground-water discharge to the streams and (or) induce flow from the streams to shallow ground water. In contrast, the density of irrigation wells in areas A, B, and C is less than in area E, but water-level declines in these three western areas are similar to area E. The similar decline caused by fewer wells in the west compared to the east is related to less precipitation, less ground-water recharge, and less streamflow available for seepage to ground water.

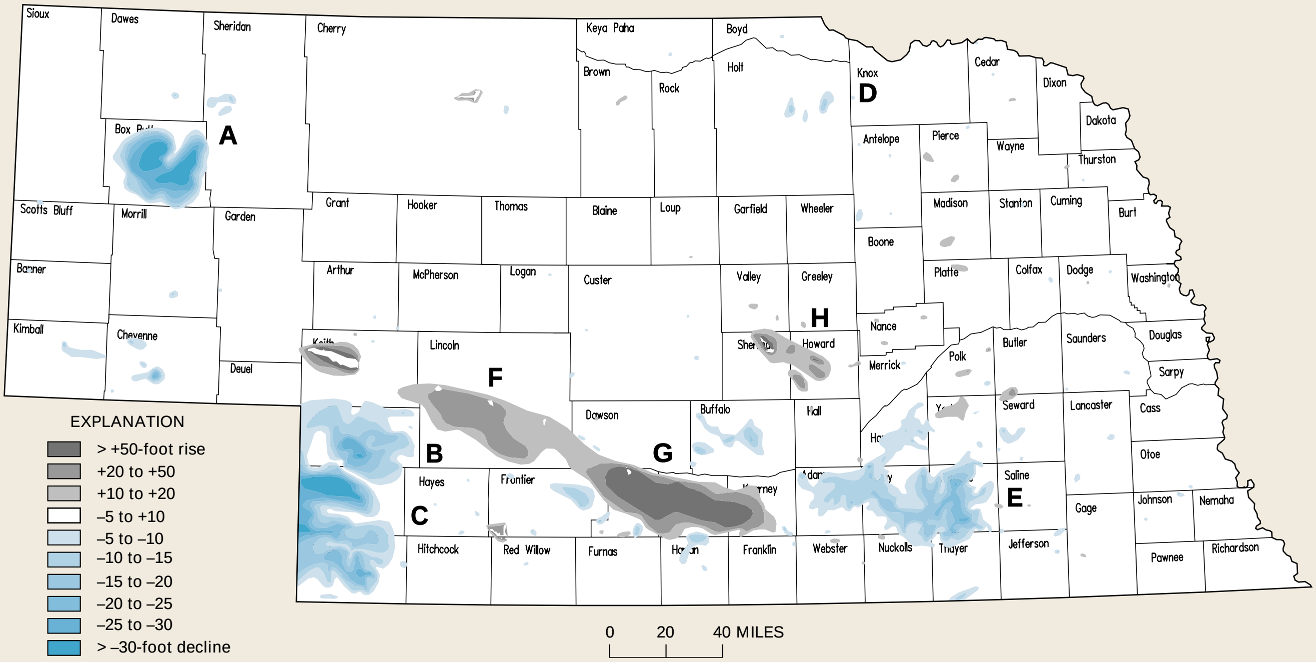


Figure N–2. The use of both ground water and surface water for irrigation in Nebraska has resulted in significant rises and declines of ground-water levels in different parts of the State. (Map provided by the University of Nebraska, Conservation and Survey Division.)

Although early irrigation systems made use of surface water, the development of large-scale sprinkler systems in recent decades has greatly increased the use of ground water for irrigation for several reasons: (1) A system of supply canals is not needed, (2) ground water may be more readily available than surface water, and (3) many types of sprinkler systems can be used on irregular land surfaces; the fields do not have to be as flat as they do for gravity-flow, surface-water irrigation. Whether ground water or surface water was used first to irrigate land, it was not long before water managers recognized that development of either water resource could affect the other. This is particularly true in many alluvial aquifers in arid regions where much of the irrigated land is in valleys.

Significant changes in water quality accompany the movement of water through agricultural fields. The water lost to evapotranspiration is relatively pure; therefore, the chemicals that are left behind precipitate as salts and accumulate in the soil zone. These continue to increase as irrigation continues, resulting in the dissolved-solids concentration in the irrigation return flows being significantly higher in some areas than that in the original irrigation water. To prevent excessive buildup of salts in the soil, irrigation water in excess of the needs of the crops is required to dissolve and flush out the salts and transport them to the ground-water system. Where these dissolved solids reach high concentrations, the artificial recharge from irrigation return flow can result in degradation of the quality of ground water and, ultimately, the surface water into which the ground water discharges.

“Whether ground water or surface water was used first to irrigate land, it was not long before water managers recognized that development of either water resource could affect the other”

USE OF AGRICULTURAL CHEMICALS

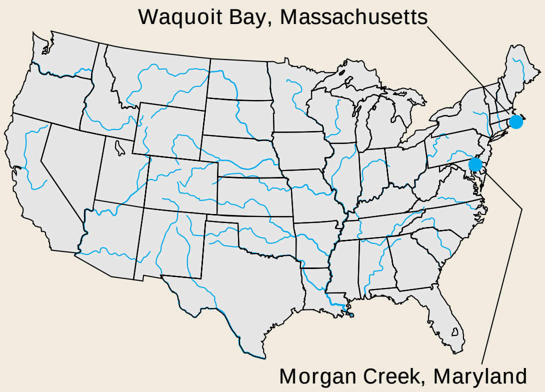
Applications of pesticides and fertilizers to cropland can result in significant additions of contaminants to water resources. Some pesticides are only slightly soluble in water and may attach (sorb) to soil particles instead of remaining in solution; these compounds are less likely to cause contamination of ground water. Other pesticides, however, are detected in low, but significant, concentrations in both ground water and surface water. Ammonium, a major component of fertilizer and manure, is very soluble in water, and increased concentrations of nitrate that result from nitrification of ammonium commonly are present in both ground water and surface water associated with agricultural lands (see Box O). In addition to these nonpoint sources of water contamination, point sources of contamination are common in agricultural areas where livestock are concentrated in small areas, such as feedlots. Whether the initial contamination is present in ground water or surface water is somewhat immaterial because the close interaction of the two sometimes results in both being contaminated (see Box P).

"Whether the initial contamination is present in ground water or surface water is somewhat immaterial because the close interaction of the two sometimes results in both being contaminated"

Effects of Nitrogen Use on the Quality of Ground Water and Surface Water

Nitrate contamination of ground water and surface water in the United States is widespread because nitrate is very mobile in the environment. Nitrate concentrations are increasing in much of the Nation's water, but they are particularly high in ground water in the midcontinent region of the United States. Two principal chemical reactions are important to the fate of nitrogen in water: (1) fertilizer ammonium can be nitrified to form nitrate, which is very mobile as a dissolved constituent in shallow ground water, and (2) nitrate can be denitrified to produce nitrogen gas in the presence of chemically reducing conditions if a source of dissolved organic carbon is available.

High concentrations of nitrate can contribute to excessive growth of aquatic plants, depletion of oxygen, fishkills, and general degradation of aquatic habitats. For example, a study of Waquoit Bay in Massachusetts linked the decline in eelgrass beds since 1950 to a progressive increase in nitrate input due to expansion of domestic septic-field developments in the drainage basin (Figure O–1). Loss of eelgrass is a concern because this aquatic plant stabilizes sediment and provides ideal habitat for juvenile fish and other fauna in coastal bays and estuaries. Larger nitrate concentrations supported algal growth that caused turbidity and shading, which contributed to the decline of eelgrass.



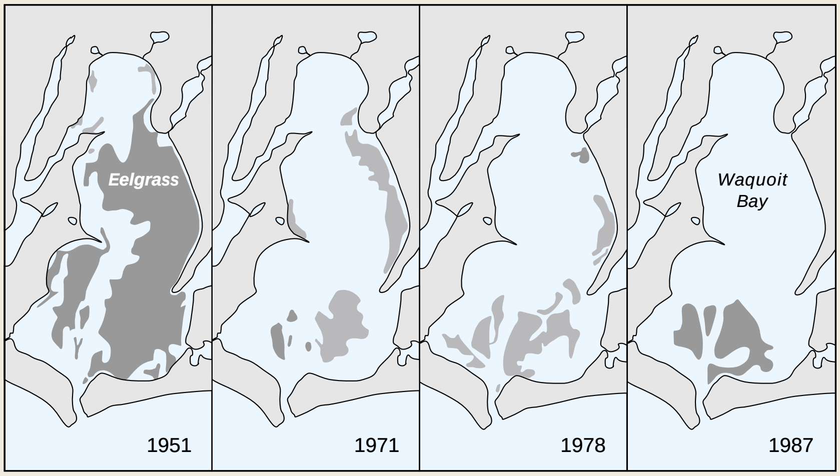


Figure O–1. The areal extent of eelgrass in Waquoit Bay, Massachusetts, decreased markedly between 1951 and 1987 because of increased inputs of nitrogen related to domestic septic-field developments. (Modified from Valiela, I., Foreman, K., LaMontagne, M., Hersh, D., Costa, J., Peckol, P., DeMeo-Andeson, B., D'Avanzo, C., Babione, M., Sham, C.H., Brawley, J., and Lajtha, K., 1992, Couplings of watersheds and coastal waters—Sources and consequences of nutrient enrichment in Waquoit Bay, Massachusetts: Estuaries, v. 15, no. 4, p. 433–457.) (Reprinted by permission of the Estuarine Research Federation.)

Significant denitrification has been found to take place at locations where oxygen is absent or present at very low concentrations and where suitable electron-donor compounds, such as organic carbon, are available. Such locations include the interface of aquifers with silt and clay confining beds and along riparian zones adjacent to streams. For example, in a study on the eastern shore of Maryland, nitrogen isotopes and other environmental tracers were used to show that the degree of denitrification that took place depended on the extent of interaction between ground-water and the chemically reducing sediments near or below the bottom of the Aquia Formation. Two drainage basins were studied: Morgan Creek and Chesterville Branch (Figure O–2). Ground-water discharging beneath both streams had similar nitrate concentration when recharged. Significant denitrification took place in the Morgan Creek basin where a large fraction of local ground-water flow passed through the reducing sediments, which are present at shallow depths (3 to 10 feet) in this area. Evidence for the denitrification included decreases in nitrate concentrations along the flow path to Morgan Creek and enrichment of the ^{15}N isotope. Much less denitrification took place in the Chesterville Branch basin because the top of the reducing sediments are deeper (10 to 20 feet) in this area and a smaller fraction of ground-water flow passed through those sediments.

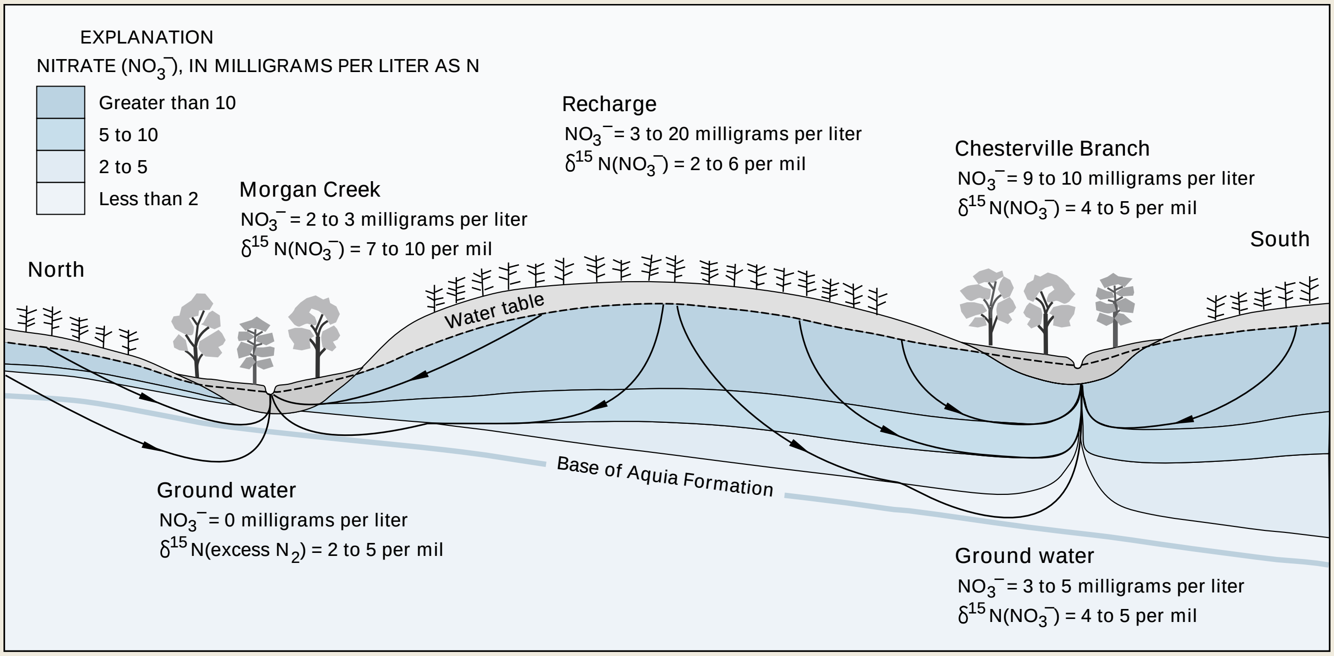


Figure O–2. Denitrification had a greater effect on ground water discharging to Morgan Creek than to Chesterville Branch in Maryland because a larger fraction of the local flow system discharging to Morgan Creek penetrated the reduced calcareous sediments near or below the bottom of the Aquia Formation than the flow system associated with the Chesterville Branch. (Modified from Bolke, J.K., and Denver, J.M., 1995, Combined use of ground-water dating, chemical, and isotopic analyses to resolve the history and fate of nitrate contamination in two agricultural watersheds, Atlantic coastal plain, Maryland: Water Resources Research, v. 31, no. 9, p. 2319–2337.)

P

Effects of Pesticide Application to Agricultural Lands on the Quality of Ground Water and Surface Water

Pesticide contamination of ground water and surface water has become a major environmental issue. Recent studies indicate that pesticides applied to cropland can contaminate the underlying ground water and then move along ground-water flow paths to surface water. In addition, as indicated by the following examples, movement of these pesticides between surface water and ground water can be dynamic in response to factors such as bank storage during periods of high runoff and ground-water withdrawals.

A study of the sources of atrazine, a widely used herbicide detected in the Cedar River and its associated alluvial aquifer in Iowa, indicated that ground water was the major source of atrazine in the river during base-flow conditions. In addition, during periods of high streamflow, surface water containing high concentrations of atrazine moved into the bank sediments and alluvial aquifer, then slowly discharged back to the river as the river level declined. Reversals of flow related to bank storage were documented using data for three sampling periods (Figure P–1). The first sampling (Figure P–1*A*) was before atrazine was applied to cropland, when concentrations in the river and aquifer were relatively low. The second sampling (Figure P–1*B*) was after atrazine was applied to cropland upstream. High streamflow at this time caused the river stage to peak almost 6 feet above its base-flow level, which caused the herbicide to move with the river water into the aquifer. By the third sampling date (Figure P–1*C*), the hydraulic gradient between the river and the alluvial aquifer had reversed again, and atrazine-contaminated water discharged back into the river.

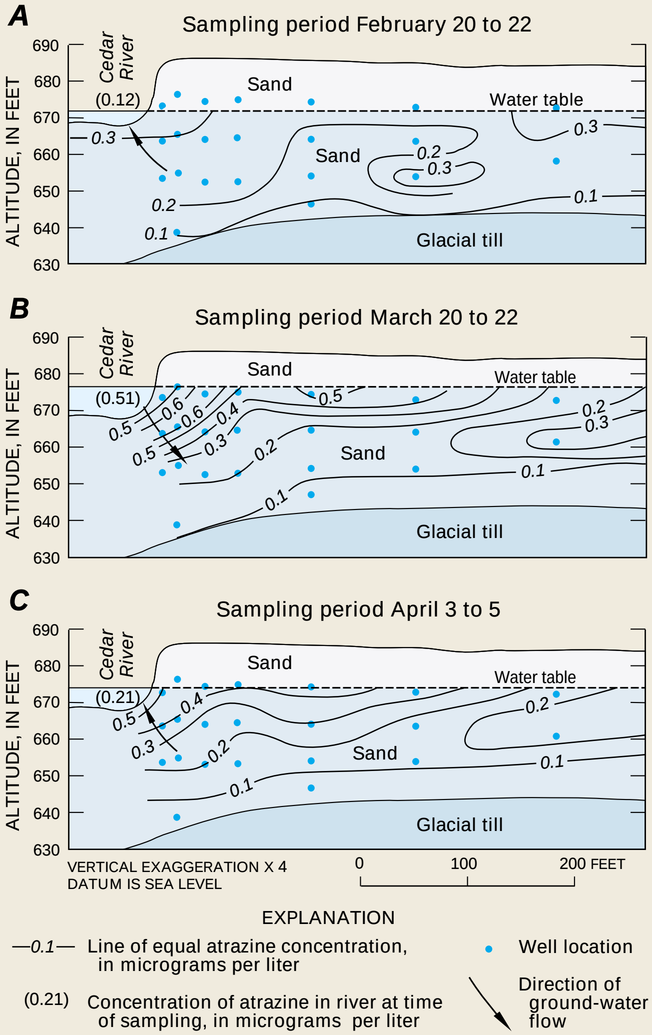


Figure P–1. Concentrations of atrazine increased in the Cedar River in Iowa following applications of the chemical on agricultural areas upstream from a study site. During high streamflow (B), the contaminated river water moved into the alluvial aquifer as bank storage, contaminating ground water. After the river level declined (C), part of the contaminated ground water returned to the river. (Modified from Squillace, P.J., Thurman, E.M., and Furlong, E.T., 1993, Groundwater as a nonpoint source of atrazine and deethylatrazine in a river during base flow conditions: Water Resources Research, v. 29, no. 6, p. 1719–1729.)

In a second study, atrazine was detected in ground water in the alluvial aquifer along the Platte River near Lincoln, Nebraska. Atrazine is not applied in the vicinity of the well field, so it was suspected that ground-water withdrawals at the well field caused contaminated river water to move into the aquifer. To define the source of the atrazine, water samples were collected from monitoring wells located at different distances from the river near the well field. The pattern of concentrations of atrazine in the ground water indicated that peak concentrations of the herbicide showed up sooner in wells close to the river compared to wells farther away (Figure P–2). Peak concentrations of atrazine in ground water were much higher and more distinct during periods of large ground-water withdrawals (July and August) than during periods of much smaller withdrawals (May to early June).

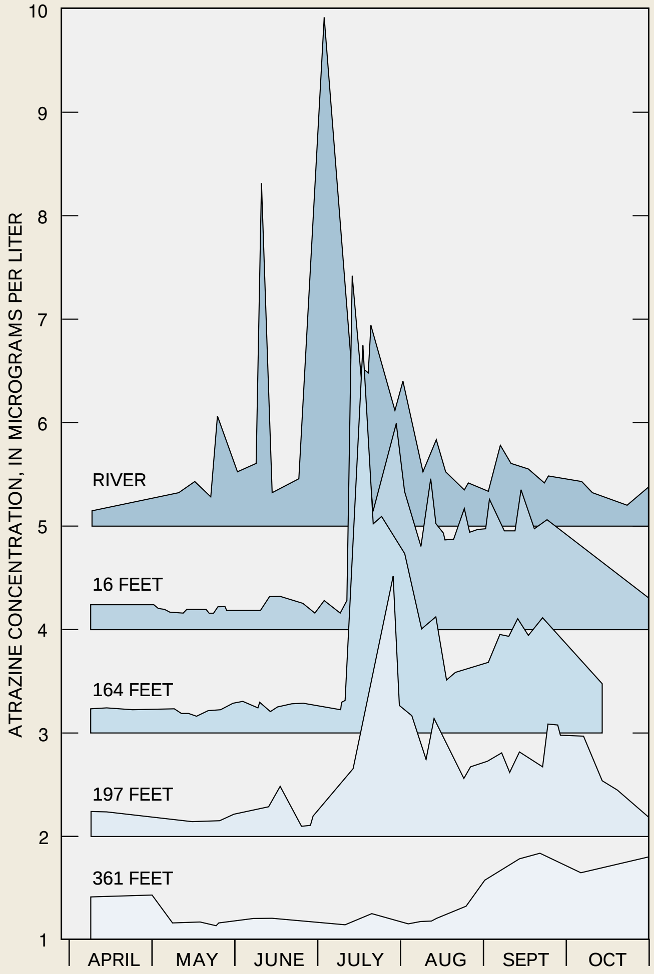


Figure P–2. Pumping of municipal water-supply wells near Lincoln, Nebraska, has induced Platte River water contaminated with atrazine to flow into the aquifer. Distances shown are from river to monitoring well. (Modified from Duncan, D., Pederson, D.T., Shepherd, T.R., and Carr, J.D., 1991, Atrazine used as a tracer of induced recharge: Ground Water Monitoring Review, v. 11, no. 4, p. 144–150.) (Used with permission.)

Urban and Industrial Development

Point sources of contamination to surface-water bodies are an expected side effect of urban development. Examples of point sources include direct discharges from sewage-treatment plants, industrial facilities, and stormwater drains. These facilities and structures commonly add sufficient loads of a variety of contaminants to streams to strongly affect the quality of the stream for long distances downstream. Depending on relative flow magnitudes of the point source and of the stream, discharge from a point source such as a sewage-treatment plant may represent a large percentage of the water in the stream directly downstream from the source. Contaminants in streams can easily affect ground-water quality, especially where streams normally seep to ground water, where ground-water withdrawals induce seepage from the stream, and where floods cause stream water to become bank storage.

Point sources of contamination to ground water can include septic tanks, fluid storage tanks, landfills, and industrial lagoons. If a contaminant is soluble in water and reaches the water table, the contaminant will be transported by the slowly moving ground water. If the source continues to supply the contaminant over a period of time, the distribution of the dissolved contaminant will take a characteristic "plumelike" shape (see Box M). These contaminant plumes commonly discharge into a nearby surface-water body. If the concentration of contaminant is low and the rate of discharge of plume water also is small relative to the volume of the receiving surface-water body, the discharging contaminant plume will have only a small, or perhaps unmeasurable, effect on the quality of the receiving surface-water body. Furthermore, biogeochemical processes may decrease the concentration of the contaminant as it is transported through the shallow ground-water system and the hyporheic zone. On the other hand, if the discharge of the contaminant plume is large or has high concentrations of contaminant, it could significantly affect the quality of the receiving surface-water body.

> ***"Contaminants in streams can easily affect ground-water quality, especially where streams normally seep to ground water, where ground-water withdrawals induce seepage from the stream, and where floods cause stream water to become bank storage"***

Drainage of the Land Surface

In landscapes that are relatively flat, have water ponded on the land surface, or have a shallow water table, drainage of land is a common practice preceding agricultural and urban development. Drainage can be accomplished by constructing open ditches or by burying tile drains beneath the land surface. In some glacial terrain underlain by deposits having low permeability, drainage of lakes and wetlands can change the areal distribution of ground-water recharge and discharge, which in turn can result in significant changes in the biota that are present and in the chemical and biological processes that take place in wetlands. Furthermore, these changes can ultimately affect the baseflow to streams, which in turn affects riverine ecosystems. Drainage also alters the water-holding capacity of topographic depressions as well as the surface runoff rates from land having very low slopes. More efficient runoff caused by drainage systems results in decreased recharge to ground water and greater contribution to flooding.

Drainage of the land surface is common in regions having extensive wetlands, such as coastal, riverine, and some glacial-lake landscapes. Construction of artificial drainage systems is extensive in these regions because wetland conditions generally result in deep, rich, organic soils that are much prized for agriculture. In the most extensive artificially drained part of the Nation, the glacial terrain of the upper Midwest, it is estimated that more than 50 percent of the original wetland areas have been destroyed. In Iowa alone, the destruction exceeds 90 percent. Although some wetlands were destroyed by filling, most were destroyed by drainage.

Modifications to River Valleys

CONSTRUCTION OF LEVEES

Levees are built along riverbanks to protect adjacent lands from flooding. These structures commonly are very effective in containing smaller magnitude floods that are likely to occur regularly from year to year. Large floods that occur much less frequently, however, sometimes overtop or breach the levees, resulting in widespread flooding. Flooding of low-lying land is, in a sense, the most visible and extreme example of the interaction of ground water and surface water. During flooding, recharge to ground water is continuous; given sufficient time, the water table may rise to the land surface and completely saturate the shallow aquifer (see Figure 12). Under these conditions, an extended period of drainage from the shallow aquifer takes place after the floodwaters recede. The irony of levees as a flood protection mechanism is that if levees fail during a major flood, the area, depth, and duration of flooding in some areas may be greater than if levees were not present.

CONSTRUCTION OF RESERVOIRS

The primary purpose of reservoirs is to store water for uses such as public water supply, irrigation, flood attentuation, and generation of electric power. Reservoirs also can provide opportunities for recreation and wildlife habitat. Water needs to be stored in reservoirs because streamflow is highly variable, and the times when streamflow is abundant do not necessarily coincide with the times when the water is needed. Streamflow can vary daily in response to individual storms and seasonally in response to variation in weather patterns.

The effects of reservoirs on the interaction of ground water and surface water are greatest near the reservoir and directly downstream from it. Reservoirs can cause a permanent rise in the water table that may extend a considerable distance from the reservoir, because the base level of the stream, to which the ground-water gradients had adjusted, is raised to the higher reservoir levels. Near the dam, reservoirs commonly lose water to shallow ground water, but this water commonly returns to the river as base flow directly downstream from the dam. In addition, reservoirs can cause temporary bank storage at times when reservoir levels are high. In some cases, this temporary storage of surface water in the ground-water system has been found to be a significant factor in reservoir management (see Box Q).

Human-controlled reservoir releases and accumulation of water in storage may cause high flows and low flows to differ considerably in magnitude and timing compared to natural flows. As a result, the environmental conditions in river valleys downstream from a dam may be altered as organisms try to adjust to the modified flow conditions. For example, the movement of water to and from bank storage under controlled conditions would probably be much more regular in timing and magnitude compared to the highly variable natural flow conditions, which probably would lead to less biodiversity in river systems downstream from reservoirs. The few studies that have been made of riverine ecosystems downstream from a reservoir indicate that they are different from the pre-reservoir conditions, but much more needs to be understood about the effects of reservoirs on stream channels and riverine ecosystems downstream from dams.

REMOVAL OF NATURAL VEGETATION

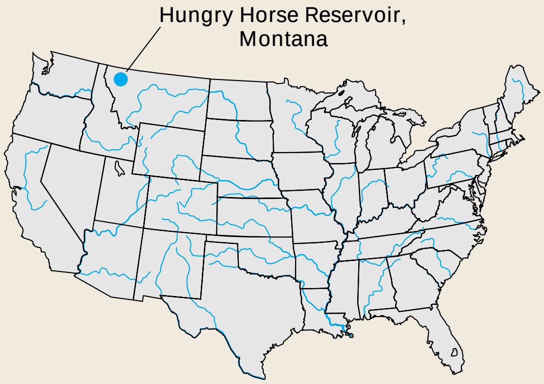
To make land available for agriculture and urban growth, development sometimes involves cutting of forests and removal of riparian vegetation and wetlands. Forests have a significant role in the hydrologic regime of watersheds. Deforestation tends to decrease evapotranspiration, increase storm runoff and soil erosion, and decrease infiltration to ground water and base flow of streams. From the viewpoint of water-resource quality and management, the increase in storm runoff and soil erosion and the decrease in base flow of streams are generally viewed as undesirable.

In the western United States, removal of riparian vegetation has long been thought to result in an increase in streamflow. It commonly is believed that the phreatophytes in alluvial valleys transpire ground water that otherwise would flow to the river and be available for use (see Box R). Some of the important functions of riparian vegetation and riparian wetlands include preservation of aquatic habitat, protection of the land from erosion, flood mitigation, and maintenance of water quality. Destruction of riparian vegetation and wetlands removes the benefits of erosion control and flood mitigation, while altering aquatic habitat and chemical processes that maintain water quality.

Q

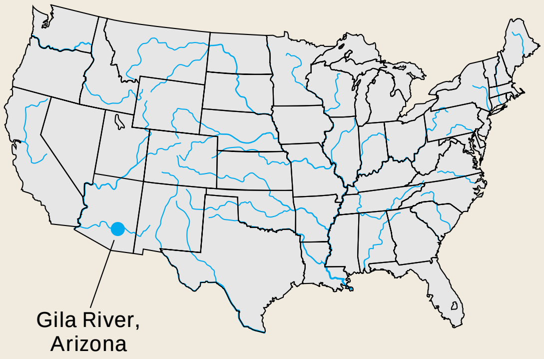
Effects of Surface-Water Reservoirs on the Interaction of Ground Water and Surface Water

The increase of water levels in reservoirs causes the surface water to move into bank storage. When water levels in reservoirs are decreased, this bank storage will return to the reservoir. Depending on the size of the reservoir and the magnitude of fluctuation of the water level of the reservoir, the amount of water involved in bank storage can be large. A study of bank storage associated with Hungry Horse Reservoir in Montana, which is part of the Columbia River system, indicated that the amount of water that would return to the reservoir from bank storage after water levels are lowered is large enough that it needs to be considered in the reservoir management plan for the Columbia River system. As a specific example, if the water level of the reservoir is raised 100 feet, held at that level for a year, then lowered 100 feet, the water that would drain back to the reservoir during a year would be equivalent to an additional 3 feet over the reservoir surface. (Information from Simons, W.D., and Rorabaugh, M.I., 1971, Hydrology of Hungry Horse Reservoir, northwestern Montana: U.S. Geological Survey Professional Paper 682.)



Effects of the Removal of Flood-Plain Vegetation on the Interaction of Ground Water and Surface Water

In low-lying areas where the water table is close to land surface, such as in flood plains, transpiration directly from ground water can reduce ground-water discharge to surface water and can even cause surface water to recharge ground water (see Figure 7). This process has attracted particular attention in arid areas, where transpiration by phreatophytes on flood plains of western rivers can have a significant effect on streamflows. To assess this effect, a study was done on transpiration by phreatophytes along a reach of the Gila River upstream from San Carlos Reservoir in Arizona. During the first few years of the 10-year study, the natural hydrologic system was monitored using observation wells, streamflow gages, and meteorological instruments. Following this initial monitoring period, the phreatophytes were removed from the flood plain and the effects on streamflow were evaluated. The average effect of vegetation removal over the entire study reach was that the Gila River changed from a continually losing river for most years before clearing to a gaining stream during some months for most years following clearing. Specifically, average monthly values of gain or loss from the stream indicated that before clearing, the river lost water to ground water during all months for most years. After clearing, the river gained ground-water inflow during March through June and during September for most years (Figure R–1).



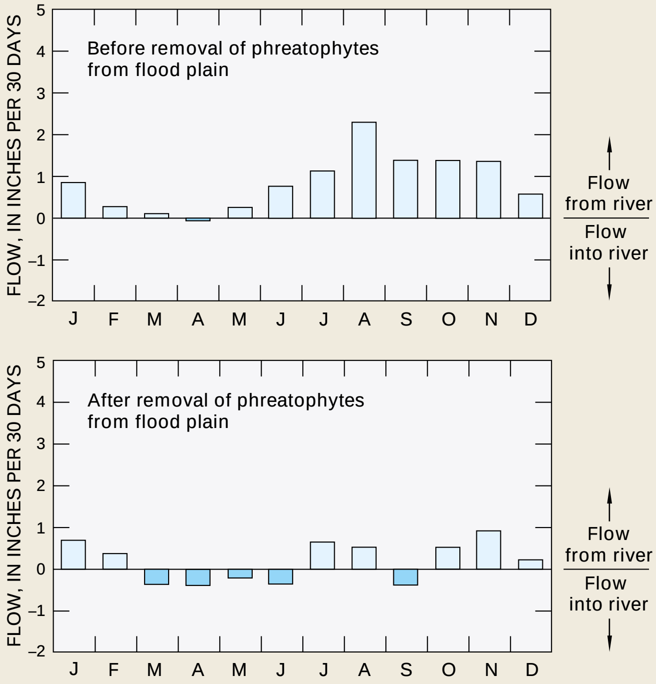


Figure R–1. Removal of phreatophytes from the flood plain along a losing reach of the Gila River in Arizona resulted in the river receiving ground-water inflow during some months of the year. (Modified from Culler, R.C., Hanson, R.L., Myrick, R.M., Turner, R.M., and Kipple, F.P., 1982, Evapotranspiration before and after clearing phreatophytes, Gila River flood plain, Graham County, Arizona: U.S. Geological Professional Paper 655–P.)

Modifications to the Atmosphere

ATMOSPHERIC DEPOSITION

Atmospheric deposition of chemicals, such as sulfate and nitrate, can cause some surface-water bodies to become acidic. Concern about the effects of acidic precipitation on aquatic ecosystems has led to research on the interaction of ground water and surface water, especially in small headwaters catchments. It was clear when the problem was first recognized that surface-water bodies in some environments were highly susceptible to acidic precipitation, whereas in other environments they were not. Research revealed that the interaction of ground water and surface water is important to determining the susceptibility of a surface-water body to acidic precipitation (see Box S). For example, if a surface-water body received a significant inflow of ground water, chemical exchange while the water passed through the subsurface commonly neutralized the acidic water, which can reduce the acidity of the surface water to tolerable levels for aquatic organisms. Conversely, if runoff of acidic precipitation was rapid and involved very little flow through the ground-water system, the surface-water body was highly vulnerable and could become devoid of most aquatic life.

"The interaction of ground water and surface water is important to determining the susceptibility of a surface-water body to acidic precipitation"

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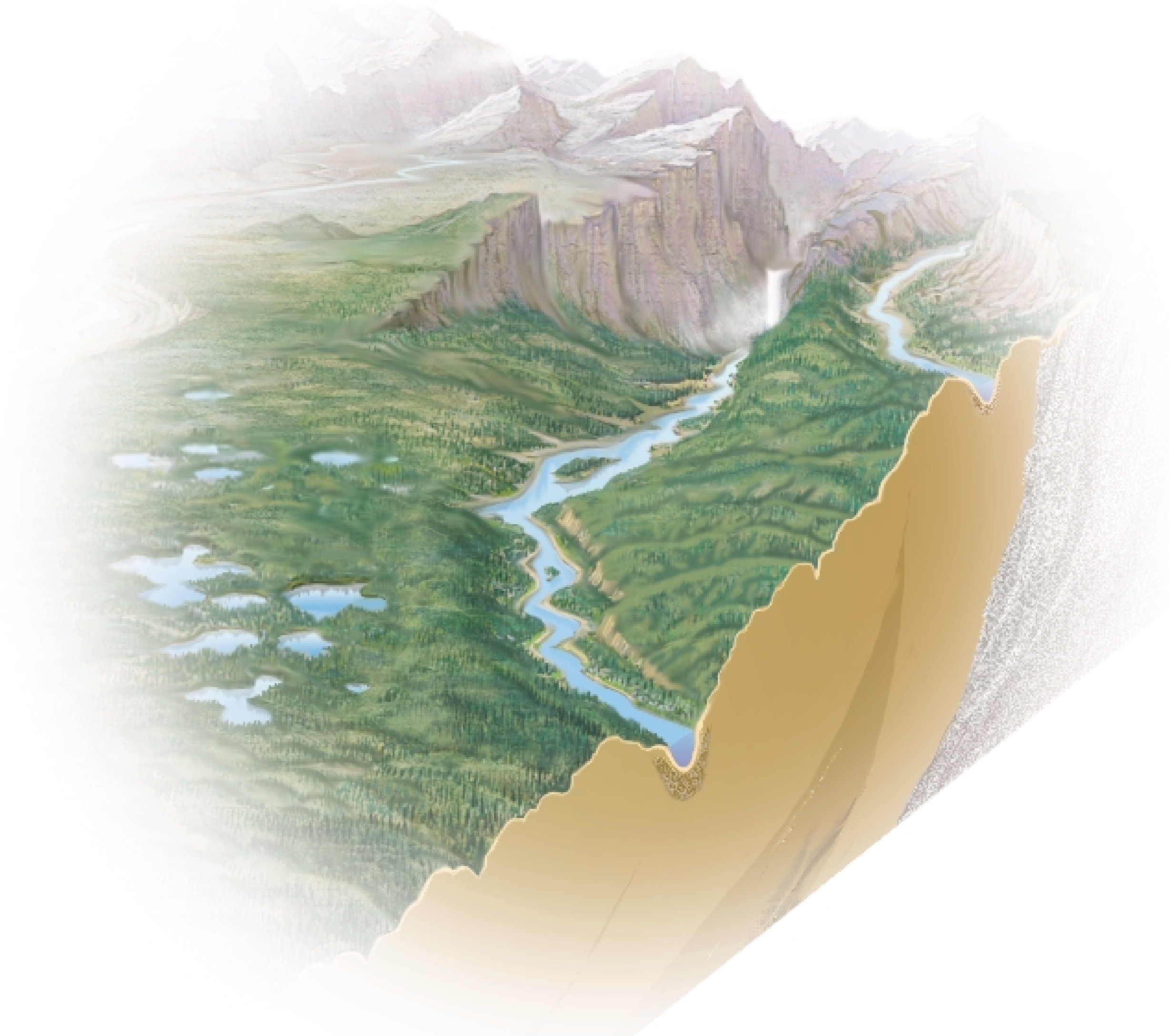
*G*LOBAL WARMING

The concentration of gases, such as carbon dioxide (CO_2) and methane, in the atmosphere has a significant effect on the heat budget of the Earth's surface and the lower atmosphere. The increase in concentration of CO_2 in the atmosphere of about 25 percent since the late 1700s generally is thought to be caused by the increase in burning of fossil fuels. At present, the analysis and prediction of "global warming" and its possible effects on the hydrologic cycle can be described only with great uncertainty. Although the physical behavior of CO_2 and other greenhouse gases is well understood, climate systems are exceedingly complex, and long-term changes in climate are embedded in the natural variability of the present global climate regime.

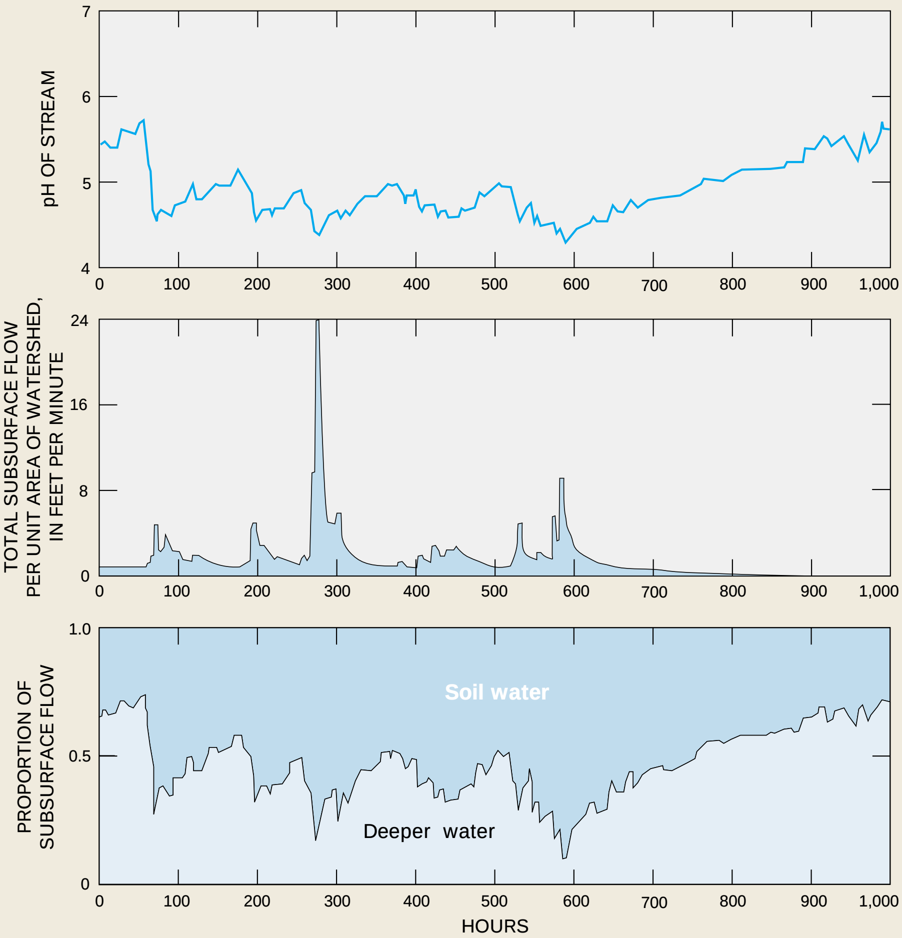
Surficial aquifers, which supply much of the streamflow nationwide and which contribute flow to lakes, wetlands, and estuaries, are the aquifers most sensitive to seasonal and longer term climatic variation. As a result, the interaction of ground water and surface water also will be sensitive to variability of climate or to changes in climate. However, little attention has been directed at determining the effects of climate change on shallow aquifers and their interaction with surface water, or on planning how this combined resource will be managed if climate changes significantly.



Effects of Atmospheric Deposition on the Quality of Ground Water and Surface Water

In areas where soils have little capacity to buffer acids in water, acidic precipitation can be a problem because the infiltrating acidic water can increase the solubility of metals, which results in the flushing of high concentrations of dissolved metals into surface water. Increased concentrations of naturally occurring metals such as aluminum may be toxic to aquatic organisms. Studies of watersheds have indicated that the length of subsurface flow paths has an effect on the degree to which acidic water is buffered by flow through the subsurface. For example, studies of watersheds in England have indicated that acidity was higher in streams during storms when more of the subsurface flow moved through the soil rather than through the deeper flow paths (Figure S–1). Moreover, in a study of the effects of acid precipitation on lakes in the Adirondack Mountains of New York, the length of time that water was in contact with deep subsurface materials was the most important factor affecting acidity because contact time determined the amount of buffering that could take place (Figure S–2).

Figure S–1. Acidity is higher (pH is lower) in streams when most of the flow is contributed by shallow soil water because the water has had less time to be neutralized by contact with minerals compared to water that has traversed deeper flow paths. (Modified from Robson, A., Beven, K.J., and Neal, C., 1992, Towards identifying sources of subsurface flow—A comparison of components identified by a physically based runoff model and those determined by chemical mixing techniques: Hydrological Processes, v. 6, p. 199–214.) (Reprinted with permission from John Wiley & Sons Limited.)



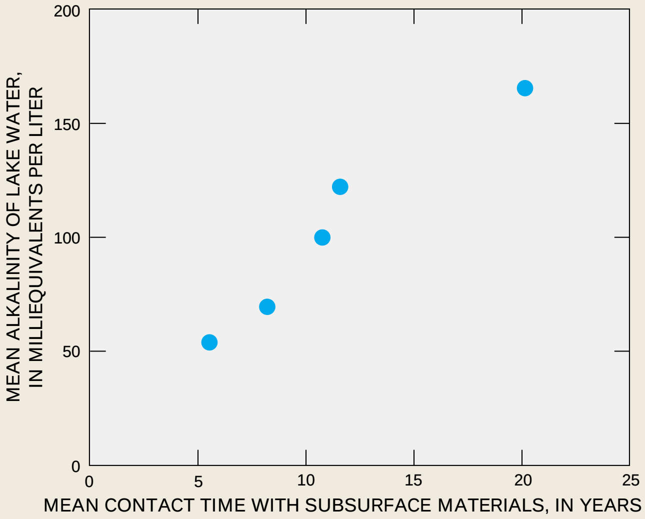


Figure S–2. The longer water is in contact with deep subsurface materials in a watershed, the higher the alkalinity in lakes receiving that water. (Modified from Wolock, D.M., Hornberger, G.M., Beven, K.J., and Campbell, W.G., 1989, The relationship of catchment topography and soil hydraulic characteristics to lake alkalinity in the northeastern United States: Water Resources Research, v. 25, p. 829–837.)

CHALLENGES AND OPPORTUNITIES

The interaction of ground water and surface water involves many physical, chemical, and biological processes that take place in a variety of physiographic and climatic settings. For many decades, studies of the interaction of ground water and surface water were directed primarily at large alluvial stream and aquifer systems. Interest in the relation of ground water to surface water has increased in recent years as a result of widespread concerns related to water supply; contamination of ground water, lakes, and streams by toxic substances (commonly where not expected); acidification of surface waters caused by atmospheric deposition of sulfate and nitrate; eutrophication of lakes; loss of wetlands due to development; and other changes in aquatic environments. As a result, studies of the interaction of ground water and surface water have expanded to include many other settings, including headwater streams, lakes, wetlands, and coastal areas.

Issues related to water management and water policy were presented at the beginning of this report. The following sections address the need for greater understanding of the interaction of ground water and surface water with respect to the three issues of water supply, water quality, and characteristics of aquatic environments.

Water Supply

Water commonly is not present at the locations and times where and when it is most needed. As a result, engineering works of all sizes have been constructed to distribute water from places of abundance to places of need. Regardless of the scale of the water-supply system, development of either ground water or surface water can eventually affect the other. For example, whether the source of irrigation water is ground water or surface water, return flows from irrigated fields will eventually reach surface water either through ditches or through ground-water discharge. Building dams to store surface water or diverting water from a stream changes the hydraulic connection and the hydraulic gradient between that body of surface water and the adjacent ground water, which in turn results in gains or losses of ground water. In some landscapes, development of ground water at even a great distance from surface water can reduce the amount of ground-water inflow to surface water or cause surface water to recharge ground water.

The hydrologic system is complex, from the climate system that drives it, to the earth materials that the water flows across and through, to the modifications of the system by human activities. Much research and engineering has been devoted to the development of water resources for water supply. However, most past work has concentrated on either surface water or ground water without much concern about their interrelations. The need to understand better how development of one water resource affects the other is universal and will surely increase as development intensifies.

Water Quality

For nearly every type of water use, whether municipal, industrial, or agricultural, water has increased concentrations of dissolved constituents or increased temperature following its use. Therefore, the water quality of the water bodies that receive the discharge or return flow are affected by that use. In addition, as the water moves downstream, additional water use can further degrade the water quality. If irrigation return flow, or discharge from a municipal or industrial plant, moves downstream and is drawn back into an aquifer because of ground-water withdrawals, the ground-water system also will be affected by the quality of that surface water.

Application of irrigation water to cropland can result in the return flow having poorer quality because evapotranspiration by plants removes some water but not the dissolved salts. As a result, the dissolved salts can precipitate as solids, increasing the salinity of the soils. Additional application of water dissolves these salts and moves them farther downgradient in the hydrologic system. In addition, application of fertilizers and pesticides to cropland can result in poor-quality return flows to both ground water and surface water. The transport and fate of contaminants caused by agricultural practices and municipal and industrial discharges are a widespread concern that can be addressed most effectively if ground water and surface water are managed as a single resource.

Water scientists and water managers need to design data-collection programs that examine the effects of biogeochemical processes on water quality at the interface between surface water and near-surface sediments. These processes can have a profound effect on the chemistry of ground water recharging surface water and on the chemistry of surface water recharging ground water. Repeated exchange of water between surface water and near-surface sediments can further enhance the importance of these processes. Research on the interface between ground water and surface water has increased in recent years, but only a few stream environments have been studied, and the transfer value of the research results is limited and uncertain.

The tendency for chemical contaminants to move between ground water and surface water is a key consideration in managing water resources. With an increasing emphasis on watersheds as a focus for managing water quality, coordination between watershed-management and ground-water-protection programs will be essential to protect the quality of drinking water. Furthermore, ground-water and surface-water interactions have a major role in affecting chemical and biological processes in lakes, wetlands, and streams, which in turn affect water quality throughout the hydrologic system. Improved scientific understanding of the interconnections between hydrological and biogeochemical processes will be needed to remediate contaminated sites, to evaluate applications for waste-discharge permits, and to protect or restore biological resources.

Characteristics of Aquatic Environments

The interface between ground water and surface water is an areally restricted, but particularly sensitive and critical niche in the total environment. At this interface, ground water that has been affected by environmental conditions on the terrestrial landscape interacts with surface water that has been affected by environmental conditions upstream. Furthermore, the chemical reactions that take place where chemically distinct surface water meets chemically distinct ground water in the hyporheic zone may result in a biogeochemical environment that in some cases could be used as an indicator of changes in either terrestrial or aquatic ecosystems. The ability to understand this interface is challenging because it requires the focusing of many different scientific and technical disciplines at the same, areally restricted locality. The benefit of this approach to studying the interface of ground water and surface water could be the identification of useful biological or chemical indicators of adverse or positive changes in larger terrestrial and aquatic ecosystems.

Wetlands are a type of aquatic environment present in most landscapes; yet, in many areas, their perceived value is controversial. The principal characteristics and functions of wetlands are determined by the water and chemical balances that maintain them. These factors in large part determine the value of a wetland for flood control, nutrient retention, and wildlife habitat. As a result, they are especially sensitive to changing hydrological conditions. When the hydrological and chemical balances of a wetland change, the wetland can take on a completely different function, or it may be destroyed. Generally, the most devastating impacts on wetlands result from changes in land use. Wetlands commonly are drained to make land available for agricultural use or filled to make land available for urban and industrial development. Without understanding how wetlands interact with ground water, many plans to use land formerly occupied by wetlands fail. For example, it is operationally straightforward to fill in or drain a wetland, but the ground-water flow system that maintains many wetlands may continue to discharge at that location. Many structures and roads built on former wetlands and many wetland restoration or construction programs fail for this reason. Saline soils in many parts of the central prairies also result from evaporation of ground water that continues to discharge to the land surface after the wetlands were drained.

Riparian zones also are particularly sensitive to changes in the availability and quality of ground water and surface water because these ecosystems commonly are dependent on both sources of water. If either water source changes, riparian zones may be altered, changing their ability to provide aquatic habitat, mitigate floods and erosion, stabilize shorelines, and process chemicals, including contaminants. Effective management of water resources requires an understanding of the role of riparian zones and their dependence on the interaction of ground water and surface water.

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3

Freshwater Resources

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Frequently Asked Questions

Executive Summary

Key Risks at the Global Scale

Freshwater-related risks of climate change increase significantly with increasing greenhouse gas (GHG) concentrations (*robust evidence*, *high agreement*). {3.4, 3.5} Modeling studies since AR4, with large but better quantified uncertainties, have demonstrated clear differences between global futures with higher emissions, which have stronger adverse impacts, and those with lower emissions, which cause less damage and cost less to adapt to. {Table 3-2} For each degree of global warming, approximately 7% of the global population is projected to be exposed to a decrease of renewable water resources of at least 20% (multi-model mean). By the end of the 21st century, the number of people exposed annually to the equivalent of a 20th-century 100-year river flood is projected to be three times greater for very high emissions (Representative Concentration Pathway 8.5 (RCP8.5)) than for very low emissions (RCP2.6) (multi-model mean) for the fixed population distribution at the level in the year 2005. {Table 3-2, 3.4.8}

Climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions (*robust evidence*, *high agreement*). {3.4, 3.5} This will intensify competition for water among agriculture, ecosystems, settlements, industry, and energy production, affecting regional water, energy, and food security (*limited evidence*, *medium* to *high agreement*). {3.5.1, 3.5.2, Box CC-WE} In contrast, water resources are projected to increase at high latitudes. Proportional changes are typically one to three times greater for runoff than for precipitation. The effects on water resources and irrigation requirements of changes in vegetation due to increasing GHG concentrations and climate change remain uncertain. {Box CC-VW}

So far there are no widespread observations of changes in flood magnitude and frequency due to anthropogenic climate change, but projections imply variations in the frequency of floods (*limited evidence*, *medium agreement*). Flood hazards are projected to increase in parts of South, Southeast, and Northeast Asia; tropical Africa; and South America (*limited evidence*, *medium agreement*). Since the mid-20th century, socioeconomic losses from flooding have increased mainly due to greater exposure and vulnerability (*high confidence*). Global flood risk will increase in the future partly due to climate change (*limited evidence*, *medium agreement*). {3.2.7, 3.4.8}

Climate change is *likely* to increase the frequency of meteorological droughts (less rainfall) and agricultural droughts (less soil moisture) in presently dry regions by the end of the 21st century under the RCP8.5 scenario (*medium confidence*). {WGI AR5 Chapter 12} This is *likely* to increase the frequency of short hydrological droughts (less surface water and groundwater) in these regions (*medium evidence*, *medium agreement*). {3.4.8} Projected changes in the frequency of droughts longer than 12 months are more uncertain, because these depend on accumulated precipitation over long periods. There is no evidence that surface water and groundwater drought frequency has changed over the last few decades, although impacts of drought have increased mostly due to increased water demand. {3.5.1}

Climate change negatively impacts freshwater ecosystems by changing streamflow and water quality (*medium evidence*, *high agreement*). Quantitative responses are known in only a few cases. Except in areas with intensive irrigation, the streamflow-mediated ecological impacts of climate change are expected to be stronger than historical impacts owing to anthropogenic alteration of flow regimes by water withdrawals and the construction of reservoirs. {Box CC-RF, 3.5.2.4}

Climate change is projected to reduce raw water quality, posing risks to drinking water quality even with conventional treatment (*medium evidence*, *high agreement*). The sources of the risks are increased temperature, increases in sediment, nutrient and pollutant loadings due to heavy rainfall, reduced dilution of pollutants during droughts, and disruption of treatment facilities during floods. {3.2.5, Figure 3-2, 3.4.6, 3.5.2.3}

In regions with snowfall, climate change has altered observed streamflow seasonality, and increasing alterations due to climate change are projected (*robust evidence*, *high agreement*). {Table 3-1, 3.2.3, 3.2.7, 3.4.5, 3.4.6, 26.2.2} Except in very cold regions, warming in the last decades has reduced the spring maximum snow depth and brought forward the spring maximum of snowmelt discharge; smaller snowmelt floods, increased winter flows, and reduced summer low flows have all been observed. River ice in Arctic rivers has been observed to break up earlier. {3.2.3, 28.2.1.1}

Because nearly all glaciers are too large for equilibrium with the present climate, there is a committed water resources change during much of the 21st century, and changes beyond the committed change are expected due to continued warming; in glacier-fed rivers, total meltwater yields from stored glacier ice will increase in many regions during the next decades but decrease thereafter (*robust evidence*, *high agreement*). Continued loss of glacier ice implies a shift of peak discharge from summer to spring, except in monsoonal catchments, and possibly a reduction of summer flows in the downstream parts of glacierized catchments. {3.4.3}

There is little or no observational evidence yet that soil erosion and sediment loads have been altered significantly due to changing climate (*limited evidence*, *medium agreement*). However, increases in heavy rainfall and temperature are projected to change soil erosion and sediment yield, although the extent of these changes is highly uncertain and depends on rainfall seasonality, land cover, and soil management practices. {3.2.6, 3.4.7}

Adaptation, Mitigation, and Sustainable Development

Of the global cost of water sector adaptation, most is necessary in developing countries where there are many opportunities for anticipatory adaptation (*medium evidence*, *high agreement*). There is limited published information on the water sector costs of adaptation at the local level. {3.6.1, 3.6.3}

An adaptive approach to water management can address uncertainty due to climate change (*limited evidence*, *high agreement*). Adaptive techniques include scenario planning, experimental approaches that involve learning from experience, and the development of flexible and low-regret solutions that are resilient to uncertainty. Barriers to progress include lack of human and institutional capacity, financial resources, awareness, and communication. {3.6.1, 3.6.2, 3.6.4}

Reliability of water supply, which is expected to suffer from increased variability of surface water availability, may be enhanced by increased groundwater abstractions (*limited evidence*, *high agreement*). This adaptation to climate change is limited in regions where renewable groundwater resources decrease due to climate change. {3.4.5, 3.4.8, 3.5.1}

Some measures to reduce GHG emissions imply risks for freshwater systems (*medium evidence*, *high agreement*). If irrigated, bioenergy crops make water demands that other mitigation measures do not. Hydropower has negative impacts on freshwater ecosystems, which can be reduced by appropriate management. Carbon capture and storage can decrease groundwater quality. In some regions, afforestation can reduce renewable water resources but also flood risk and soil erosion. {3.7.2.1, Box CC-WE}

3.1. Introduction

Changes in the hydrological cycle due to climate change can lead to diverse impacts and risks, and they are conditioned by and interact with non-climatic drivers of change and water management responses (Figure 3-1). Water is the agent that delivers many of the impacts of climate change to society, for example, to the energy, agriculture, and transport sectors. Even though water moves through the hydrological cycle, it is a locally variable resource, and vulnerabilities to water-related hazards such as floods and droughts differ between regions. Anthropogenic climate change is one of many stressors of water resources. Non-climatic drivers such as population increase, economic development, urbanization, and land use or natural geomorphic changes also challenge the sustainability of resources by decreasing water supply or increasing demand. In this context, adaptation to climate change in the water sector can contribute to improving the availability of water.

The key messages with *high* or *very high confidence* from the Working Group II Fourth Assessment Report (AR4; IPCC, 2007) in respect to freshwater resources were:

- The observed and projected impacts of climate change on freshwater systems and their management are due mainly to increases in temperature and sea level, local changes of precipitation, and changes in the variability of those quantities.
- Semiarid and arid areas are particularly exposed.
- Warmer water, more intense precipitation, and longer periods of low flow reduce water quality, with impacts on ecosystems, human health, and reliability and operating costs of water services.
- Climate change affects water management infrastructure and practice.
- Adaptation and risk management practices have been developed for the water sector in some countries and regions.
- The negative impacts of climate change on freshwater systems outweigh its benefits.

This chapter assesses hydrological changes due to climate change, based mainly on research published since AR4. Current gaps in research and data are summarized in Section 3.8. For further information on observed trends in the water cycle, please see Chapter 2 of the Working Group I (WGI) contribution to this assessment. See WGI AR5 Chapter 4 for freshwater in cold regions and WGI AR5 Chapters 10 for detection and attribution, 11 for near-term projections, and 12 for long-term projections of climate change. In this Working Group II contribution, impacts on aquatic ecosystems are discussed in Chapter 4 (see also Section 3.5.2.4). Chapter 7 describes the impacts of climate change on food production (see also Section 3.5.2.1 for the impact of hydrological changes on the agricultural sector). The health effects of changes in water quality and quantity are covered in Chapter 11, and regional vulnerabilities related to freshwater in Chapters 21 to 30. Sections 3.2.7, 3.4.8, and 3.6.3 discuss impact and adaptation costs related to water resources; these costs are assessed more broadly in Chapter 10.

3.2. Observed Hydrological Changes Due to Climate Change

3.2.1. Detection and Attribution

A documented hydrological change is not necessarily due to anthropogenic climate change. Detection entails showing, usually statistically, that part

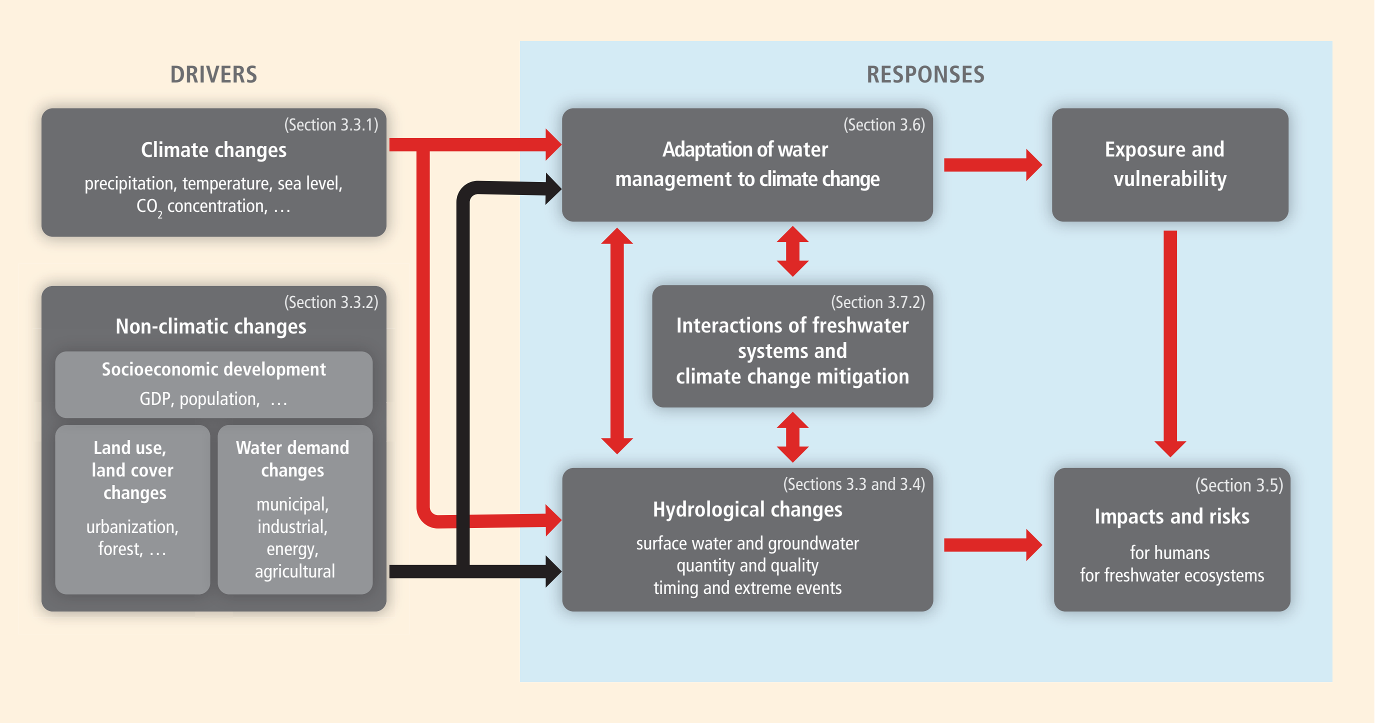
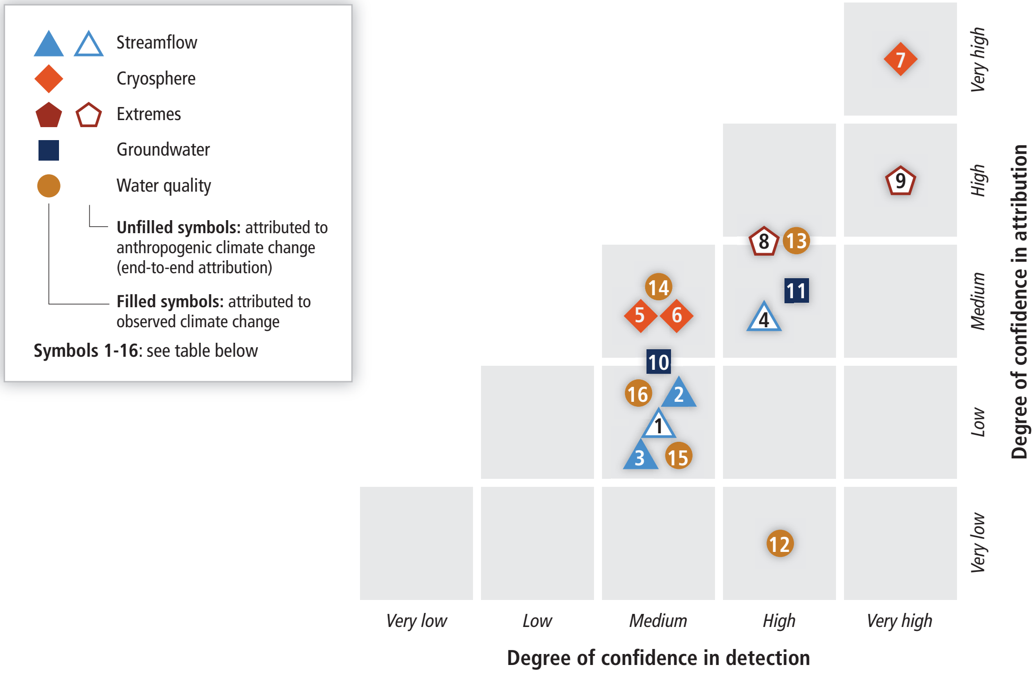


Figure 3-1 | Framework (boxes) and linkages (arrows) for considering impacts of climatic and social changes on freshwater systems, and consequent impacts on and risks for humans and freshwater ecosystems. Both climatic (Section 3.3.1) and non-climatic (Section 3.3.2) drivers have changed natural freshwater systems (Section 3.2) and are expected to continue to do so (Section 3.4). They also stimulate adaptive measures (Section 3.6). Hydrological and water management changes interact with each other and with measures to mitigate climate change (Section 3.7.2). Adaptive measures influence the exposure and vulnerability of human beings and ecosystems to water-related risks (Section 3.5).

Table 3-1 | Selected examples, mainly from Section 3.2, of the observation, detection, and attribution of impacts of climate change on freshwater resources. Observed hydrological changes are attributed here to their climatic drivers, not all of which are necessarily anthropogenic.



	Observed change	Attributed to	Reference
1	Changed runoff (global, 1960–1994)	Mainly climatic change, and to a lesser degree CO_2 increase and land use change	Gerten et al. (2008); Piao et al. (2007); Alkama et al. (2011)
2	Reduced runoff (Yellow River, China)	Increased temperature; only 35% of reduction attributable to human withdrawals	Piao et al. (2010)
3	Earlier annual peak discharge (Russian Arctic, 1960–2001)	Increased temperature and earlier spring thaw	Shiklomanov et al. (2007)
4	Earlier annual peak discharge (Columbia River, western USA, 1950–1999)	Anthropogenic warming	Hidalgo et al. (2009)
5	Glacier meltwater yield greater in 1910–1940 than in 1980–2000 (European Alps)	Glacier shrinkage forced by comparable warming rates in the two periods	Collins (2008)
6	Decreased dry-season discharge (Peru, 1950s–1990s)	Decreased glacier extent in the absence of a clear trend in precipitation	Baraer et al. (2012)
7	Disappearance of Chacaltaya Glacier, Bolivia (2009)	Ascent of freezing isotherm at 50 meters per decade, 1980s–2000s	Rosenzweig et al. (2007)
8	More intense extremes of precipitation (northern tropics and mid-latitudes, 1951–1999)	Anthropogenic greenhouse gas emissions	Min et al. (2011)
9	Fraction of risk of flooding (England and Wales, autumn 2000)	Extreme precipitation attributable to anthropogenic greenhouse radiation	Pall et al. (2011)
10	Decreased recharge of karst aquifers (Spain, 20th century)	Decreased precipitation, and possibly increased temperature; multiple confounding factors	Aguilera and Murillo (2009)
11	Decreased groundwater recharge (Kashmir, 1985–2005)	Decreased winter precipitation	Jeelani (2008)
12	Increased dissolved organic carbon in upland lakes (UK, 1988–2003)	Increased temperature and precipitation; multiple confounding factors	Evans et al. (2005)
13	Increased anoxia in a reservoir, moderated during ENSO (El Niño-Southern Oscillation) episodes (Spain, 1964–1991 and 1994–2007)	Decreased runoff due to decreased precipitation and increased evaporative demand	Marcé et al. (2010)
14	Variable fecal pollution in a saltwater wetland (California, 1969–2000)	Variable storm runoff; 70% of coliform variability attributable to variable precipitation	Pednekar et al. (2005)
15	Nutrient flushing from swamps, reservoirs (North Carolina, 1978–2003)	Hurricanes	Paerl et al. (2006)
16	Increased lake nutrient content (Victoria, Australia, 1984–2000)	Increased air and water temperature	Tibby and Tiller (2007)

of the documented change is not due to natural variability of the water cycle (Chapter 18; WGI AR5 Chapter 10). For robust attribution to climatic change, all the drivers of the hydrological change must be identified, with confidence levels assigned to their contributions. Human contributions such as water withdrawals, land use change, and pollution mean that this is usually difficult. Nevertheless, many hydrological impacts can be attributed confidently to their climatic drivers (Table 3-1). End-to-end attribution, from human climate-altering activities to impacts on freshwater resources, is not attempted in most studies, because it requires experiments with climate models in which the external natural and anthropogenic forcing is "switched off." However, climate models do not currently simulate the water cycle at fine enough resolution for attribution of most catchment-scale hydrological impacts to anthropogenic climate change. Until climate models and impact models become better integrated, it is necessary to rely heavily on multistep attribution, in which hydrological changes are shown to result from climatic changes that may in turn result partly from human activities.

Extreme hydrological events, such as floods, prompt speculation about whether they are "caused" by climate change. Climate change can indeed alter the probability of a particular event. However, to estimate the alteration reliably it is necessary to quantify uncertainties due to natural variability in the changed and the unchanged climates, and also—because of the need for model simulations—uncertainties due to limited ability to simulate the climate.

The probability or risk of the extreme event can be measured by recording the fraction of events beyond some threshold magnitude. Call this fraction r_{ctrl} in the simulated actual climate and r_{expt} in the simulated climate in which there is no anthropogenic forcing, and suppose there are many paired instances of r_{ctrl} and r_{expt}, with the ratio of risks in each pair given by $F = r_{expt} / r_{ctrl}$. The distribution of risk ratios F describes the likelihood that the climate change has altered the risk. Several thousand pairs of such simulations were run to estimate the risk ratio for the floods in England and Wales in autumn 2000 (Pall et al., 2011). Each pair started from a unique initial state that differed slightly from a common reference state, and was obtained with a seasonal forecast model driven by patterns of attributable warming found beforehand from four climate-model simulations of the 20th century. The forecast model was coupled to a model of basin-scale runoff and channel-scale hydraulics. It is not probable that such exercises will become routine for assessing single-event risks in, for example, the insurance industry, because the necessary amount of computation is so formidable. Nevertheless, the result was compelling: in each of the four sets of simulation pairs, the risk increased greatly on average in the runs forced by anthropogenic greenhouse radiation. In aggregate, the most probable amount of increase was two- to threefold, and at most a few percent of the simulation pairs suggested that anthropogenic forcing actually decreased the risk. This summary is worded carefully: the thousands of simulation pairs were needed for quantifying the uncertainties, which led unavoidably to a spread of likelihoods and thus to statements about uncertainty about risk that are themselves uncertain.

3.2.2. Precipitation, Evapotranspiration, Soil Moisture, Permafrost, and Glaciers

Global trends in precipitation from several different datasets during 1901–2005 are statistically insignificant (Bates et al., 2008; WGI AR5 Chapter 2). According to regional observations, most droughts and extreme rainfall events of the 1990s and 2000s have been the worst since the 1950s (Arndt et al., 2010), and certain trends in total and extreme precipitation amounts are observed (WGI AR5 Chapter 2). Most regional changes in precipitation are attributed either to internal variability of the atmospheric circulation or to global warming (Lambert et al., 2004; Stott et al., 2010). It was estimated that the 20th century anthropogenic forcing contributed significantly to observed changes in global and regional precipitation (Zhang et al., 2007). Changes in snowfall amounts are indeterminate, as for precipitation; however, consistent with observed warming, shorter snowfall seasons are observed over most of the Northern Hemisphere, with snowmelt seasons starting earlier (Takala et al., 2009). In Norway, increased temperature at lower altitudes has reduced the snow water equivalent (Skaugen et al., 2012).

Steady decreases since the 1960s of global and regional actual evapotranspiration and pan evaporation have been attributed to changes in precipitation, diurnal temperature range, aerosol concentration, (net) solar radiation, vapor pressure deficit, and wind speed (Fu et al., 2009; McVicar et al., 2010; Miralles et al., 2011; Wang A. et al., 2011). Regional downward and upward trends in soil moisture content have been calculated for China from 1950 to 2006, where longer, more severe, and more frequent soil moisture droughts have been experienced over 37% of the land area (Wang A. et al., 2011). This is supported by detected increases since the 1960s in dry days and a prolongation of dry periods (Gemmer et al., 2011; Fischer et al., 2013), and can be attributed to increases in warm days and warm periods (Fischer et al., 2011).

Decreases in the extent of permafrost and increases in its average temperature are widely observed, for example, in some regions of the Arctic and Eurasia (WGI AR5 Chapter 4) and the Andes (Rabassa, 2009). Active layer depth and permafrost degradation are closely dependent on soil ice content. In steep terrain, slope stability is highly affected by changes in permafrost (Harris et al., 2009). The release of greenhouse gases (GHGs) due to permafrost degradation can have unprecedented impacts on the climate, but these processes are not yet well represented in global climate models (Grosse et al., 2011). In most parts of the world glaciers are losing mass (Gardner et al., 2013). For example, almost all glaciers in the tropical Andes have been shrinking rapidly since the 1980s (Rabassa, 2009; Rabatel et al., 2013); similarly, Himalayan glaciers are losing mass at present (Bolch et al., 2012).

3.2.3. Streamflow

Detected trends in streamflow are generally consistent with observed regional changes in precipitation and temperature since the 1950s. In Europe, streamflow (1962–2004) decreased in the south and east and generally increased elsewhere (Stahl et al., 2010, 2012), particularly in northern latitudes (Wilson et al., 2010). In North America (1951–2002), increases were observed in the Mississippi basin and decreases in the U.S. Pacific Northwest and southern Atlantic–Gulf regions (Kalra et al., 2008). In China, a decrease in streamflow in the Yellow River (1960–2000) is consistent with a reduction of 12% in summer and autumn precipitation, whereas the Yangtze River shows a small increase in annual streamflow driven by an increase in monsoon rains (Piao et al., 2010; see Table 3-1). These and other streamflow trends must be interpreted with caution (Jones, 2011) because of confounding factors such as land use changes (Zhang and Schilling, 2006), irrigation (Kustu et al., 2010), and urbanization (Wang and Cai, 2010).

In a global analysis of simulated streamflows (1948–2004), about one-third of the top 200 rivers (including the Congo, Mississippi, Yenisei, Paraná, Ganges, Columbia, Uruguay, and Niger) showed significant trends in discharge; 45 recorded decreases and only 19 recorded increases (Dai et al., 2009). Decreasing trends in low and mid-latitudes are consistent with recent drying and warming in West Africa, southern Europe, south and east Asia, eastern Australia, western Canada and the USA, and northern South America (Dai, 2013). The contribution to observed streamflow changes due to decreased stomatal opening of many plant species at higher carbon dioxide (CO_2) concentration remains disputed (Box CC-VW).

In regions with seasonal snow storage, warming since the 1970s has led to earlier spring discharge maxima (*robust evidence*, *high agreement*) and has increased winter flows because more winter precipitation falls as rain instead of snow (Clow, 2010; Korhonen and Kuusisto, 2010; Tan et al., 2011). There is *robust evidence* of earlier breakup of river ice in Arctic rivers (de Rham et al., 2008; Smith, 2000). Where streamflow is lower in summer, decrease in snow storage has exacerbated summer dryness (Cayan et al., 2001; Knowles et al., 2006).

3.2.4. Groundwater

Attribution of observed changes in groundwater level, storage, or discharge to climatic changes is difficult owing to additional influences of land use changes and groundwater abstractions (Stoll et al., 2011). Observed trends are largely attributable to these additional influences. The extent to which groundwater abstractions have already been affected by climate change is not known. Both detection of changes in groundwater systems and attribution of those changes to climatic changes are rare owing to a lack of appropriate observation wells and a small number of studies. Observed decreases of the discharge of groundwater-fed springs in Kashmir (India) since the 1980s were attributed to observed precipitation decreases (Jeelani, 2008; Table 3-1). A model-based assessment of observed decreases of groundwater levels in four overexploited karst aquifers in Spain led to the conclusion that groundwater recharge not only decreased strongly during the 20th century due to the decreasing precipitation but also that groundwater recharge as a fraction of observed precipitation declined progressively, possibly indicating an increase in evapotranspiration (Aguilera and Murillo, 2009; Table 3-1).

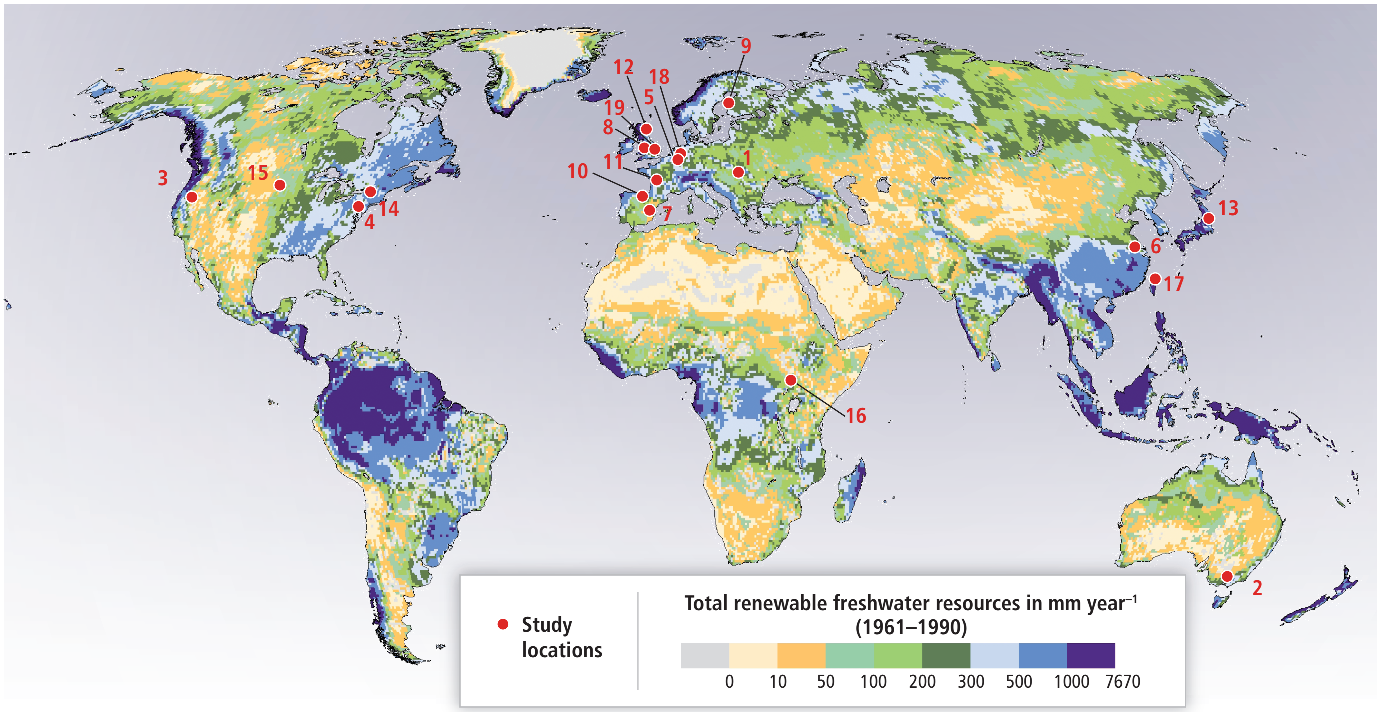
3.2.5. Water Quality

Most observed changes of water quality due to climate change (Table 3-1; Figure 3-2) are known from isolated studies, mostly of rivers or lakes in high-income countries, of a small number of variables. In addition, even though some studies extend over as many as 80 years, most are short term. For lakes and reservoirs, the most frequently reported change is more intense eutrophication and algal blooms at higher temperatures, or shorter hydraulic retention times and higher nutrient loads resulting from increased storm runoff (*medium* to *robust evidence*, *high agreement*). Increased runoff results in greater loads of salts, fecal coliforms, pathogens, and heavy metals (Pednekar et al., 2005; Paerl et al., 2006; Tibby and Tiller, 2007; Boxall et al., 2009) (*robust evidence*, *medium* to *high agreement*, depending on the pollutant). In some cases there are associated impacts on health. For instance, hospital admissions for gastrointestinal illness in elderly people increased by 10% when turbidity increased in the raw water of a drinking water plant even when treated using conventional procedures (Schwartz et al., 2000). However, positive impacts were also reported. For example, the risk of eutrophication was reduced when nutrients were flushed from lakes and estuaries by more frequent storms and hurricanes (Paerl and Huisman, 2008). For rivers, all reported impacts on water quality were negative. Greater runoff, instead of diluting pollution, swept more pollutants from the soil into watercourses (*robust evidence*, *medium* to *high agreement*) (Boxall et al., 2009; Loos et al., 2009; Benítez-Gilabert et al., 2010; Gascuel-Odoux et al., 2010; Howden et al., 2010; Saarinen et al., 2010; Tetzlaff et al., 2010; Macleod et al., 2012). Increased organic matter content impaired the quality of conventionally treated drinking water (Weatherhead and Howden, 2009). In streams in semiarid and arid areas, temperature changes had a stronger influence on the increase of organic matter, nitrates, and phosphorus than precipitation changes (Ozaki et al., 2003; Chang, 2004; Benítez-Gilabert et al., 2010) (*limited evidence*, *medium agreement*). Studies of impacts on groundwater quality are limited and mostly report elevated concentrations of fecal coliforms during the rainy season or after extreme rain events (*medium evidence*, *high agreement*), with varying response times (Curriero et al., 2001; Tumwine et al., 2002, 2003; Auld et al., 2004; Jean et al., 2006; Seidu et al., 2013). Given the widespread use of groundwater for municipal supply and minimal or lacking treatment of drinking water in poor regions, increased pollution is a source of concern (Jean et al., 2006; Seidu et al., 2013). Another concern is the nonlinearity (except for temperature) of relationships between water quality and climatic variables (*limited evidence*, *medium agreement*). In general, the linkages between observed effects on water quality and climate should be interpreted cautiously and at the local level, considering the type of water body, the pollutant of concern, the hydrological regime, and the many other possible sources of pollution (*high confidence*; Senhorst and Zwolsman, 2005; Whitehead et al., 2009a; Benítez-Gilabert et al., 2010; Howden et al., 2010; Kundzewicz and Krysanova, 2010; Ventela et al., 2011).

3.2.6. Soil Erosion and Sediment Load

Precipitation extremes in many regions have increased since 1950 (Seneviratne et al., 2012), which suggests an increase in rainfall erosivity that would enhance soil erosion and stream sediment loads. A warmer climate may affect soil moisture, litter cover, and biomass production and can bring about a shift in winter precipitation from snow to more erosive rainfall (Kundzewicz et al., 2007) or, in semiarid regions, an increase in wildfires with subsequent rainfall leading to intense erosive events (Nyman et al., 2011; Bussi et al., 2013). The effects of climate change on soil erosion and sediment load are frequently obscured by human agricultural and management activities (Walling, 2009).

Only few studies have isolated the contribution of climate change to observed trends in soil erosion and sediment load. In the Yellow River basin, where soil erosion results mostly from heavy rainfall, reduced precipitation (~10%) contributed about 30% to a total reduction in stream sediment loads reaching the sea during 2000–2005, compared to 1950–1968, with the remaining 70% attributable to sediment trapping in reservoirs and soil conservation measures (Wang et al., 2007; Miao et al., 2011). Dai et al. (2008), analyzing the decrease in sediment load of the Yangtze River over 1956–2002, found that climate change was responsible for an increase of about 3 ± 2%; most of the decline in its lower reaches was due to dam construction (Three Gorges Dam) and soil conservation measures.



	Location	Study period	Observation on water quality	Reference
1	Danube River, Bratislava, Slovakia	1926–2005	The water temperature is rising but the trend of the weighted long-term average temperature values resulted close to zero because of the interannual distribution of the mean monthly discharge.	Pekarova et al. (2008)
2	Purrumbete, Colac and Bullen Merri Lakes, Victoria, Australia	1984–2000	The increases in salinity and nutrient content were associated with the air temperature increase; salinity in addition was associated with variations in the effective precipitation.	Tibby and Tiller (2007)
3	Lake Tahoe, California and Nevada States, USA	1970–2007	Thermal stability resulting from a higher ambient temperature decreased the dissolved oxygen content.	Sahoo et al. (2010)
4	Neuse River Estuary, North Carolina, USA	1979–2003	Intense storms and hurricanes flushed nutrients from the estuary, reducing eutrophic conditions and the risk of algal blooms.	Paerl et al., (2006); Paerl and Huisman (2008)
5	River Meuse, western Europe	1976–2003	Increase of water temperature and the content of major elements and some heavy metals were associated with droughts. Algal blooms resulted from a higher nutrient content due to higher water temperature and longer residence time.	van Vliet and Zwolsman (2008)
6	Lake Taihu, Wuxi, Jiangsu, China	2007	The lake, already suffering from periodic cyanobacterial blooms, was affected by a very intensive bloom in May 2007 attributed to an unusually warm spring and leading to the presence of *Microcystis* toxins in the water. This forced two million people to drink bottled water for at least one week.	Qin et al. (2010)
7	Sau Reservoir, Spain	1964–2007	Stream flow variations were of greater significance than temperature increases in the depletion of dissolved oxygen.	Marcé et al. (2010)
8	22 upland waters in UK	1988–2002	Dissolved organic matter increased due to temperature increase but also due to rainfall variations, acid deposition, land use, and CO_2 enrichment.	Evans et al. (2005)
9	Coastal rivers from western Finland	1913–2007	Low pH values are associated with higher rainfall and river discharge in an acid sulfate soil basin.	Saarinen et al. (2010)
		1961–2007	Critical values of dissolved organic carbon is associated with higher rainfall and river discharge.	
10	15 pristine mountain rivers, northern Spain	1973–2005	For a semiarid area, there is a clear relationship between increases in air temperature and a higher nutrient and dissolved organic carbon content.	Benítez-Gilabert et al. (2010)
11	30 coastal rivers and groundwater of western France	1973–2007 (2–6 years)	Interannual variations in the nutrient content associated with air temperature, rainfall, and management practices changes. These effects were not observed in groundwater because of the delay in response time and the depuration of soil on water.	Gascuel-Odoux et al. (2010)
12	Girnock, Scotland	14 months	Higher risks of fecal pollution are clearly related to rainfall during the wet period.	Tetzlaff et al. (2010)
13	27 rivers in Japan	1987–1995	Increases in organic matter and sediment and decreases in the dissolved oxygen content are associated with increases in ambient temperature. Precipitation increases and variations are associated with an increase in the organic matter, sediments, and chemical oxygen demand content in water.	Ozaki et al. (2003)
14	Conestoga River Basin, Pennsylvania, USA	1977–1997	There is a close association between annual loads of total nitrogen and annual precipitation increases.	Chang (2004)
15	USA	1948–1994	Increased rainfall and runoff are associated with site-specific outbreaks of waterborne disease.	Curriero et al. (2001)
16	Northern and eastern Uganda	1999–2001, 2004, 2007	Elevated concentrations of fecal coliforms are observed in groundwater-fed water supplies during the rainy season.	Tumwine et al. (2002, 2003); Taylor et al. (2009)
17	Taiwan, China	1998	The probability of detecting cases of enterovirus infection was greater than 50%, with rainfall rates >31 mm h^{-1}. The higher the rainfall rate, the higher the probability of an enterovirus epidemic.	Jean et al. (2006)
18	Rhine Basin	1980–2001	Nutrient content in rivers followed seasonal variations in precipitation which were also linked to erosion within the basin.	Loos et al. (2009)
19	River Thames, England	1868–2008	Higher nutrient contents were associated to changes in river runoff and land use.	Howden et al. (2010)

Figure 3-2 | Observations of the impacts of climate on water quality.

Potential impacts of climate change on soil erosion and sediment production are of concern in regions with pronounced glacier retreat (Walling, 2009). Glacial rivers are expected to discharge more meltwater, which may increase sediment loads. However, the *limited evidence* is inconclusive for a global diagnosis of sediment load changes; there are both decreasing (e.g., Iceland; Lawler et al., 2003) and increasing trends (Patagonia; Fernandez et al., 2011). So far, there is no clear evidence that the frequency or magnitude of shallow landslides has changed over past decades (Huggel et al., 2012), even in regions with relatively complete event records (e.g., Switzerland; Hilker et al., 2009). Increased landslide impacts (measured by casualties or losses) in south and Southeast Asia, where landslides are triggered predominantly by monsoon and tropical cyclone activity, are largely attributed to population growth leading to increased exposure (Petley, 2012).

In summary, there is *limited evidence* and *low agreement* that anthropogenic climate change has made a significant contribution to soil erosion, sediment loads, and landslides. The available records are limited in space and time, and evidence suggests that, in most cases, the impacts of land use and land cover changes are more significant than those of climate change.

3.2.7. Extreme Hydrological Events and their Impacts

There is *low confidence*, due to *limited evidence*, that anthropogenic climate change has affected the frequency and magnitude of floods at global scale (Kundzewicz et al., 2013). The strength of the evidence is limited mainly by lack of long-term records from unmanaged catchments. Moreover, in the attribution of detected changes it is difficult to distinguish the roles of climate and human activities (Section 3.2.1). However, recent detection of trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at regional scale (*medium confidence*). More locations show increases in heavy precipitation than decreases (Seneviratne et al., 2012). Flood damage costs worldwide have been increasing since the 1970s, although this is partly due to increasing exposure of people and assets (Handmer et al., 2012).

There is no strong evidence for trends in observed flooding in the USA (Hirsch and Ryberg, 2012), Europe (Mudelsee et al., 2003; Stahl et al., 2010; Benito and Machado, 2012; Hannaford and Hall, 2012), South America, and Africa (Conway et al., 2009). However, at smaller spatial scales, an increase in annual maximum discharge has been detected in parts of northwestern Europe (Petrow and Merz, 2009; Giuntoli et al., 2012; Hattermann et al., 2012), while a decrease was observed in southern France (Giuntoli et al., 2012). Flood discharges in the lower Yangtze basin increased over the last 40 years (Jiang et al., 2008; Zhang et al., 2009), and both upward and downward trends were identified in four basins in the northwestern Himalaya (Bhutiyani et al., 2008). In Australia, only 30% of 491 gauge stations showed trends at the 10% significance level, with decreasing magnitudes in southern regions and increasing magnitudes in the northern regions (Ishak et al., 2010). In Arctic rivers dominated by a snowmelt regime, there is no general trend in flood magnitude and frequency (Shiklomanov et al., 2007). In Nordic countries, significant changes since the mid-20th century are mostly toward earlier seasonal flood peaks, but flood magnitudes show contrasting trends, driven by temperature and precipitation, in basins with and without glaciers increasing peaks in the former and decreasing peaks in the latter (Wilson et al., 2010; Dahlke et al., 2012). Significant trends at almost one-fifth of 160 stations in Canada were reported, most of them decreases in snowmelt-flood magnitudes (Cunderlik and Ouarda, 2009). Similar decreases were found for spring and annual maximum flows (Burn et al., 2010).

Attribution has been addressed by Hattermann et al. (2012), who identified parallel trends in precipitation extremes and flooding in Germany, which for the increasing winter floods are explainable in terms of increasing frequency and persistence of circulation patterns favorable to flooding (Petrow et al., 2009). It is *very likely* that the observed intensification of heavy precipitation is largely anthropogenic (Min et al., 2011; see also Section 3.2.1).

Socioeconomic losses from flooding are increasing (*high confidence*), although attribution to anthropogenic climate change is established only seldom (Pall et al., 2011). Reported flood damages (adjusted for inflation) have increased from an average of US$7 billion per year in the 1980s to about US$24 billion per year in 2011 (Kundzewicz et al., 2013). Economic, including insured, flood disaster losses are higher in developed countries, while fatality rates and economic losses expressed as a proportion of gross domestic product are higher in developing countries. Since 1970, the annual number of flood-related deaths has been in the thousands, with more than 95% in developing countries (Handmer et al., 2012). There is *high confidence* (*medium evidence*, *high agreement*) that greater exposure of people and assets, and societal factors related to population and economic growth, contributed to the increased losses (Handmer et al., 2012; Kundzewicz et al., 2013). When damage records are normalized for changes in exposure and vulnerability (Bouwer, 2011), most studies find no contribution of flooding trends to the trend in losses (Barredo, 2009; Hilker et al., 2009; Benito and Machado, 2012), although there are exceptions (Jiang et al., 2005; Chang et al., 2009).

Assessments of observed changes in "drought" depend on the definition of drought (meteorological, agricultural, or hydrological) and the chosen drought index (e.g., consecutive dry days, Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI), Standardized Runoff Index (SRI); see Seneviratne et al., 2012). Meteorological (rainfall) and agricultural (soil moisture) droughts have become more frequent since 1950 (Seneviratne et al., 2012) in some regions, including southern Europe and western Africa, but in others (including the southern USA; Chen et al., 2012) there is no evidence of change in frequency (WGI AR5 Chapter 2).

Very few studies have considered variations over time in hydrological (streamflow) drought, largely because there are few long records from catchments without direct human interventions. A trend was found toward lower summer minimum flows for 1962–2004 in small catchments in southern and Eastern Europe, but there was no clear trend in northern or Western Europe (Stahl et al., 2010). Models can reproduce observed patterns of drought occurrence (e.g., Prudhomme et al., 2011), but as with climate models their outputs can be very divergent. In simulations of drought at the global scale in 1963–2000 with an ensemble of hydrological models, strong correlations were noted between El Niño-

Southern Oscillation (ENSO) events and hydrological droughts, and—particularly in dry regions—low correlations between meteorological and hydrological droughts, which suggests that hydrological droughts cannot necessarily be inferred from rainfall deficits (van Huijgevoort et al., 2013).

3.3. Drivers of Change for Freshwater Resources

3.3.1. Climatic Drivers

Precipitation and potential evaporation are the main climatic drivers controlling freshwater resources. Precipitation is strongly related to atmospheric water vapor content, because saturation specific humidity depends on temperature: warmer air can hold much more water vapor. Temperature has increased in recent decades while surface and tropospheric relative humidity have changed little (WGI AR5 Chapter 2). Among other climatic drivers are atmospheric CO_2, which affects plant transpiration (Box CC-VW), and deposited black carbon and dust, both of which, even in very small concentrations, enhance melting of snow and ice by reducing the surface albedo.

Uncertainty in the climatic drivers is due mainly to internal variability of the atmospheric system, inaccurate modeling of the atmospheric response to external forcing, and the external forcing itself as described by the Representative Concentration Pathways (RCPs; Section 1.1.3). Internal variability and variation between models account for all of the uncertainty in precipitation in the first few decades of the 21st century in Coupled Model Intercomparison Project Phase 3 (CMIP3) projections (Hawkins and Sutton, 2011). The contribution of internal variability diminishes progressively. By no later than mid-century, most of the uncertainty in precipitation is due to discrepancies between models, and divergent scenarios never contribute more than one-third of the uncertainty. In contrast, the uncertainty in temperature (WGI AR5 Chapter 11) is due mostly to divergent scenarios.

CMIP5 simulations of the water cycle during the 21st century (WGI AR5 Chapter 12), with further constraints added here from 20th century observations, can be summarized as follows:

- Surface temperature, which affects the vapor-carrying capacity of the atmosphere and the ratio of snowfall to precipitation, increases non-uniformly (*very high confidence*), probably by about 1.5 times more over land than over ocean.
- Warming is greatest over the Arctic (*very high confidence*), implying latitudinally variable changes in snowmelt and glacier mass budgets.
- Less precipitation falls as snow and snow cover decreases in extent and duration (*high confidence*). In the coldest regions, however, increased winter snowfall outweighs increased summer snowmelt.
- Wet regions and seasons become wetter and dry regions and seasons become drier (*high confidence*), although one observational analysis (Sun et al., 2012) is discordant; moreover the models tend to underestimate observed trends in precipitation (Noake et al., 2012) and its observed sensitivity to temperature (Liu et al., 2012).
- Global mean precipitation increases in a warmer world (*virtually certain*), but with substantial variations, including some decreases, from region to region. Precipitation tends to decrease in subtropical latitudes, particularly in the Mediterranean, Mexico and Central America, and parts of Australia, and to increase elsewhere, notably at high northern latitudes and in India and parts of central Asia (*likely* to *very likely*; WGI AR5 Figure 12-41). However, precipitation changes generally become statistically significant only when temperature rises by at least 1.4°C, and in many regions projected 21st century changes lie within the range of late 20th century natural variability (Mahlstein et al., 2012).
- Changes in evaporation have patterns similar to those of changes in precipitation, with moderate increases almost everywhere, especially at higher northern latitudes (WGI AR5 Figure 12-25). Scenario-dependent decreases of soil moisture are widespread, particularly in central and southern Europe, southwestern North America, Amazonia, and southern Africa (*medium* to *high confidence*; WGI AR5 Figure 12-23; WGI AR5 Section 12.4.5.3).

More intense extreme precipitation events are expected (IPCC, 2012). One proposed reason is the projected increase in specific humidity: intense convective precipitation in short periods (less than 1 hour) tends to "empty" the water vapor from the atmospheric column (Utsumi et al., 2011; Berg et al., 2013). Annual maxima of daily precipitation that are observed to have 20-year return periods in 1986–2005 are projected to have shorter return periods in 2081–2100: about 14 years for RCP2.6, 11 years for RCP4.5, and 6 years for RCP8.5 (Kharin et al., 2013). Unlike annual mean precipitation, for which the simulated sensitivity to warming is typically 1.5 to 2.5% K^{-1}, the 20-year return amount of daily precipitation typically increases at 4 to 10% K^{-1}. Agreement between model-simulated extremes and reanalysis extremes is good in the extratropics but poor in the tropics, where there is *robust evidence* of greater sensitivity (10 ± 4% K^{-1}, O'Gorman, 2012). In spite of the intrinsic uncertainty of sampling infrequent events, variation between models is the dominant contributor to uncertainty. Model-simulated changes in the incidence of meteorological (rainfall) droughts vary widely, so that there is at best *medium confidence* in projections (Seneviratne et al., 2012). Regions where droughts are projected to become longer and more frequent include the Mediterranean, central Europe, central North America, and southern Africa.

3.3.2. Non-Climatic Drivers

In addition to impacts of climate change, the future of freshwater systems will be impacted strongly by demographic, socioeconomic, and technological changes, including lifestyle changes. These change both exposure to hazard and requirements for water resources. A wide range of socioeconomic futures can produce similar climate changes (van Vuuren et al., 2012), meaning that certain projected hydrological changes (Section 3.4) can occur under a wide range of future demographic, social, economic, and ecological conditions. Similarly, the same future socioeconomic conditions can be associated with a range of different climate futures.

Changing land use is expected to affect freshwater systems strongly in the future. For example, increasing urbanization may increase flood hazards and decrease groundwater recharge. Of particular importance for freshwater systems is future agricultural land use, especially irrigation, which accounts for about 90% of global water consumption and severely impacts freshwater availability for humans and ecosystems (Döll, 2009).

Owing mainly to population and economic growth but also to climate change, irrigation may significantly increase in the future. The share of irrigation from groundwater is expected to increase owing to increased variability of surface water supply caused by climate change (Taylor R. et al., 2013a).

3.4. Projected Hydrological Changes

3.4.1. Methodological Developments in Hydrological Impact Assessment

Most recent studies of the potential impact of climate change on hydrological characteristics have used a small number of climate scenarios. An increasing number has used larger ensembles of regional or global models (e.g., Chiew et al., 2009; Gosling et al., 2010; Arnell, 2011; Bae et al., 2011; Jackson et al., 2011; Olsson et al., 2011; Kling et al., 2012; Arnell and Gosling, 2013). Some studies have developed "probability distributions" of future impacts by combining results from multiple climate projections and, sometimes, different emissions scenarios, making different assumptions about the relative weight to give to each scenario (Brekke et al., 2009b; Manning et al., 2009; Christierson et al., 2012; Liu et al., 2013). These studies conclude that the relative weightings given are typically less important in determining the distribution of future impacts than the initial selection of climate models considered. Very few impact studies (Dankers et al., 2013; Hanasaki et al., 2013; Portmann et al., 2013; Schewe et al., 2013) have so far used scenarios based on CMIP5 climate models, and these have used only a small subset.

Most assessments have used a hydrological model with the "delta method" to create scenarios, which applies projected changes in climate derived from a climate model either to an observed baseline or with a stochastic weather generator. Several approaches to the construction of scenarios at the catchment scale have been developed (Fowler et al., 2007), including dynamical downscaling using regional climate models and a variety of statistical approaches (e.g., Fu et al., 2013). Systematic evaluations of different methods have demonstrated that estimated impacts can be very dependent on the approach used to downscale climate model data, and the range in projected change between downscaling approaches can be as large as the range between different climate models (Quintana Segui et al., 2010; Chen J. et al., 2011). An increasing number of studies (e.g., Fowler and Kilsby, 2007; Hagemann et al., 2011; Kling et al., 2012; Teutschbein and Seibert, 2012; Veijalainen et al., 2012; Weiland et al., 2012a) have run hydrological models with bias-corrected input from regional or global climate model output (van Pelt et al., 2009; Piani et al., 2010; Yang et al., 2010), rather than by applying changes to an observed baseline. The range between different bias correction methods can be as large as the range between climate models (Hagemann et al., 2011), although this is not always the case (Chen C. et al., 2011; Muerth et al., 2013). Some studies (e.g., Falloon and Betts, 2006, 2010; Hirabayashi et al., 2008; Nakaegawa et al., 2013) have examined changes in global-scale river runoff as simulated directly by a high-resolution climate model, rather than by an "off-line" hydrological model. Assessments of the ability of climate models directly to simulate current river flow regimes (Falloon et al., 2011; Weiland et al., 2012b) show that performance depends largely on simulated precipitation and is better for large basins, but the *limited evidence* suggests that direct estimates of change are smaller than off-line estimates (Hagemann et al., 2013).

The effects of hydrological model parameter uncertainty on simulated runoff changes are typically small when compared with the range from a large number of climate scenarios (Steele-Dunne et al., 2008; Cloke et al., 2010; Vaze et al., 2010; Arnell, 2011; Lawrence and Haddeland, 2011). However, the effects of hydrological model structural uncertainty on projected changes can be substantial (Dankers et al., 2013; Hagemann et al., 2013; Schewe et al., 2013), owing to differences in the representation of evaporation and snowmelt processes. In some regions (e.g., high latitudes; Hagemann et al., 2013) with reductions in precipitation (Schewe et al., 2013), hydrological model uncertainty can be greater than climate model uncertainty—although this is based on small numbers of climate models. Much of the difference in projected changes in evaporation is due to the use of different empirical formulations (Milly and Dunne, 2011). In a study in southeast Australia, the effects of hydrological model uncertainty were small compared with climate model uncertainty, but all the hydrological models used the same potential evaporation data (Teng et al., 2012).

Among other approaches to impact assessment, an inverse technique (Cunderlik and Simonovic, 2007) starts by identifying the hydrological changes that would be critical for a system and then uses a hydrological model to determine the meteorological conditions that trigger those changes; the future likelihood of these conditions is estimated by inspecting climate model output, as in a catchment study in Turkey (Fujihara et al., 2008a,b). Another approach constructs response surfaces relating sensitivity of a hydrological indicator to changes in climate. Several studies have used a water-energy balance framework (based on Budyko's hypothesis and formula) to characterize the sensitivity of average annual runoff to changes in precipitation and evaporation (Donohue et al., 2011; Renner and Bernhofer, 2012; Renner et al., 2012). A response surface showing change in flood magnitudes was constructed by running a hydrological model with systematically varying changes in climate (Prudhomme et al., 2010). This approach shows the sensitivity of a system to change, and also allows rapid assessment of impacts under specific climate scenarios which can be plotted on the response surface.

3.4.2. Evapotranspiration, Soil Moisture, and Permafrost

Based on global and regional climate models as well as physical principles, potential evapotranspiration over most land areas is *very likely* to increase in a warmer climate, thereby accelerating the hydrologic cycle (WGI AR5 Chapter 12). Long-term projections of actual evapotranspiration are uncertain in both magnitude and sign. They are affected not only by rising temperatures but also by changing net radiation and soil moisture, decreases in bulk canopy conductance associated with rising CO_2 concentrations, and vegetation changes related to climate change (Box CC-VW; Katul and Novick, 2009). Projections of the response of potential evapotranspiration to a warming climate are also uncertain. Based on six different methodologies, an increase in potential evapotranspiration was associated with global warming (Kingston et al., 2009). Regionally, increases are projected in southern Europe, Central America, southern Africa, and Siberia (Seneviratne et al., 2010). The accompanying decrease in soil moisture increases the

Box 3-1 | Case Study: Himalayan Glaciers

The total freshwater resource in the Himalayan glaciers of Bhutan, China, India, Nepal, and Pakistan is known only roughly; estimates range from 2100 to 5800 Gt (Bolch et al., 2012). Their mass budgets have been negative on average for the past 5 decades. The loss rate may have become greater after about 1995, but it has not been greater in the Himalaya than elsewhere. A recent large-scale measurement, highlighted in Figure 3-3, is the first well-resolved, region-wide measurement of any component of the Himalayan water balance. It suggests strongly that the conventional measurements, mostly on small, accessible glaciers, are not regionally representative.

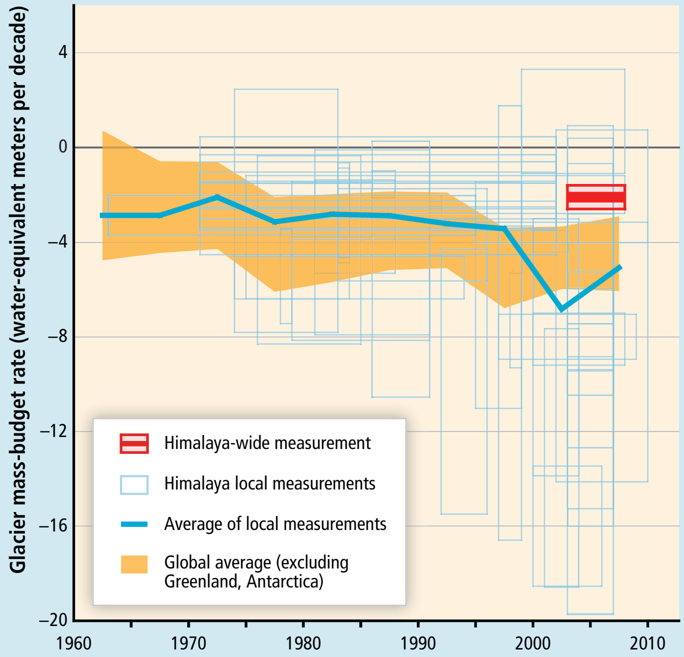


Figure 3-3 | All published glacier mass balance measurements from the Himalaya (based on Bolch et al., 2012). To emphasize the variability of the raw information, each measurement is shown as a box of height ±1 standard deviation centred on the average balance (±1 standard error for multiannual measurements). Region-wide measurement (Kääb et al., 2012) was by satellite laser altimetry. Global average (WGI AR5 Chapter 4) is shown as a 1-sigma confidence region.

Glacier mass changes for 2006–2100 were projected by simulating the response of a glacier model to CMIP5 projections from 14 General Circulation Models (GCMs) (Radić et al., 2013). Results for the Himalaya range between 2% gain and 29% loss to 2035; to 2100, the range of losses is 15 to 78% under RCP4.5. The model-mean loss to 2100 is 45% under RCP4.5 and 68% under RCP8.5 (*medium confidence*). It is *virtually certain* that these projections are more reliable than an earlier erroneous assessment (Cruz et al., 2007) of complete disappearance by 2035.

At the catchment scale, projections do not yet present a detailed region-wide picture. However the GCM-forced simulations of Immerzeel et al. (2013) in Kashmir and eastern Nepal show runoff increasing throughout the century. Peak ice meltwater is reached in mid- to late-century, but increased precipitation overcompensates for the loss of ice.

The growing atmospheric burden of anthropogenic black carbon implies reduced glacier albedo, and measurements in eastern Nepal by Yasunari et al. (2010) suggest that this could yield 70 to 200 mm yr^{-1} of additional meltwater. Deposited soot may outweigh the greenhouse effect as a radiative forcing agent for snowmelt (Qian et al., 2011).

The hazard due to moraine-dammed ice-marginal lakes continues to increase. In the western Himalaya, they are small and stable in size, while in Nepal and Bhutan they are more numerous and larger, and most are growing (Gardelle et al., 2011). There has been little progress on the predictability of dam failure but, of five dams that have failed since 1980, all had frontal slopes steeper than 10° before failure and much gentler slopes afterward (Fujita et al., 2013). This is a promising tool for evaluating the hazard in detail.

The relative importance of Himalayan glacier meltwater decreases downstream, being greatest where the runoff enters dry regions in the west and becoming negligible in the monsoon-dominated east (Kaser et al., 2010). In the mountains, however, dependence on and vulnerability to glacier meltwater are of serious concern when measured per head of population.

risk of extreme hot days (Seneviratne et al., 2006; Hirschi et al., 2011) and heat waves. For a range of scenarios, soil moisture droughts lasting 4 to 6 months double in extent and frequency, and droughts longer than 12 months become three times more common, between the mid-20th century and the end of the 21st century (Sheffield and Wood, 2008). Because of strong natural variability, the generally monotonic projected increases are statistically indistinguishable from the current climate.

Changes consistent with warming are also evident in the freshwater systems and permafrost of northern regions. The area of permafrost is projected to continue to decline over the first half of the 21st century in all emissions scenarios (WGI AR5 Figure 4-18). Under RCP2.6, the permafrost area is projected to stabilize at near 37% less than the 20th century area.

3.4.3. Glaciers

All projections for the 21st century (WGI AR5 Chapter 13) show continued mass loss from glaciers. In glacierized catchments, runoff reaches an annual maximum in summer. As the glaciers shrink, their relative contribution decreases and the annual runoff peak shifts toward spring (e.g., Huss, 2011). This shift is expected with *very high confidence* in most regions, although not, for example, in the eastern Himalaya, where the monsoon and the melt season coincide. The relative importance of high-summer glacier meltwater can be substantial, for example contributing 25% of August discharge in basins draining the European Alps, with area about 105 km^2 and only 1% glacier cover (Huss, 2011). Glacier meltwater also increases in importance during droughts and heat waves (Koboltschnig et al., 2007).

If the warming rate is constant, and if, as expected, ice melting per unit area increases and total ice-covered area decreases, the total annual yield passes through a broad maximum: "peak meltwater." Peak-meltwater dates have been projected between 2010 and 2050 (parts of China, Xie et al., 2006); 2010–2040 (European Alps, Huss, 2011); and mid- to late-century (glaciers in Norway and Iceland, Jóhannesson et al., 2012). Note that the peak can be dated only relative to a specified reference date. Declining yields relative to various dates in the past have been detected in some observational studies (Table 3-1); that is, a peak has been passed already. There is *medium confidence* that the peak response to 20th- and 21st-century warming will fall within the 21st century in many inhabited glacierized basins, where at present society is benefitting from a transitory "meltwater dividend." Variable forcing leads to complex variations of both the melting rate and the extent of ice, which depend on each other.

If they are in equilibrium, glaciers reduce the interannual variability of water resources by storing water during cold or wet years and releasing it during warm years (Viviroli et al., 2011). As glaciers shrink, however, their diminishing influence may make the water supply less dependable.

3.4.4. Runoff and Streamflow

Many of the spatial gaps identified in AR4 have been filled to a very large extent by catchment-scale studies of the potential impacts of climate change on streamflow. The projected impacts in a catchment depend on the sensitivity of the catchment to change in climatic characteristics and on the projected change in the magnitude and seasonal distribution of precipitation, temperature, and evaporation. Catchment sensitivity is largely a function of the ratio of runoff to precipitation: the smaller the ratio, the greater the sensitivity. Proportional changes in average annual runoff are typically between one and three times as large as proportional changes in average annual precipitation (Tang and Lettenmaier, 2012).

Projected scenario-dependent changes in runoff at the global scale, mostly from CMIP3 simulations, exhibit a number of consistent patterns (e.g., Hirabayashi et al., 2008; Döll and Zhang, 2010; Fung et al., 2011; Murray et al., 2012; Okazaki et al., 2012; Tang and Lettenmaier, 2012; Weiland et al., 2012a; Arnell and Gosling, 2013; Nakaegawa et al., 2013; Schewe et al., 2013). Average annual runoff is projected to increase at high latitudes and in the wet tropics, and to decrease in most dry tropical regions. However, for some regions there is very considerable uncertainty in the magnitude and direction of change, specifically in China, south Asia, and large parts of South America. Both the patterns of change and the uncertainty are driven largely by projected changes in precipitation, particularly across south Asia. Figure 3-4 shows the average percentage change in average annual runoff for an increase in global average temperature of 2°C above the 1980–2010 mean, averaged across five CMIP5 climate models and 11 hydrological models. The pattern of change in Figure 3-4 is different in some regions from the pattern shown in WGI AR5 Figure 12-24, largely because it is based on fewer climate models.

The seasonal distribution of change in streamflow varies primarily with the seasonal distribution of change in precipitation, which in turn varies between scenarios. Figure 3-5 illustrates this variability, showing the percentage change in monthly average runoff in a set of catchments from different regions using scenarios from seven climate models, all scaled to represent a 2°C increase in global mean temperature above the 1961–1990 mean. One of the climate models is separately highlighted, and for that model the figure also shows changes with a 4°C rise in temperature. In the Mitano catchment in Uganda, for example, there is a nonlinear relationship between amount of climate change and hydrological response. Incorporating uncertainty in hydrological model structure (Section 3.4.1) would increase further the range in projected impacts at the catchment scale.

There is a much more consistent pattern of future seasonal change in areas currently influenced by snowfall and snowmelt. A global analysis (Adam et al., 2009) with multiple climate scenarios shows a consistent shift to earlier peak flows, except in some regions where increases in precipitation are sufficient to result in increased, rather than decreased, snow accumulation during winter. The greatest changes are found near the boundaries of regions that currently experience considerable snowfall, where the marginal effect of higher temperatures on snowfall and snowmelt is greatest.

3.4.5. Groundwater

While the relation between groundwater and climate change was rarely investigated before 2007, the number of studies and review papers

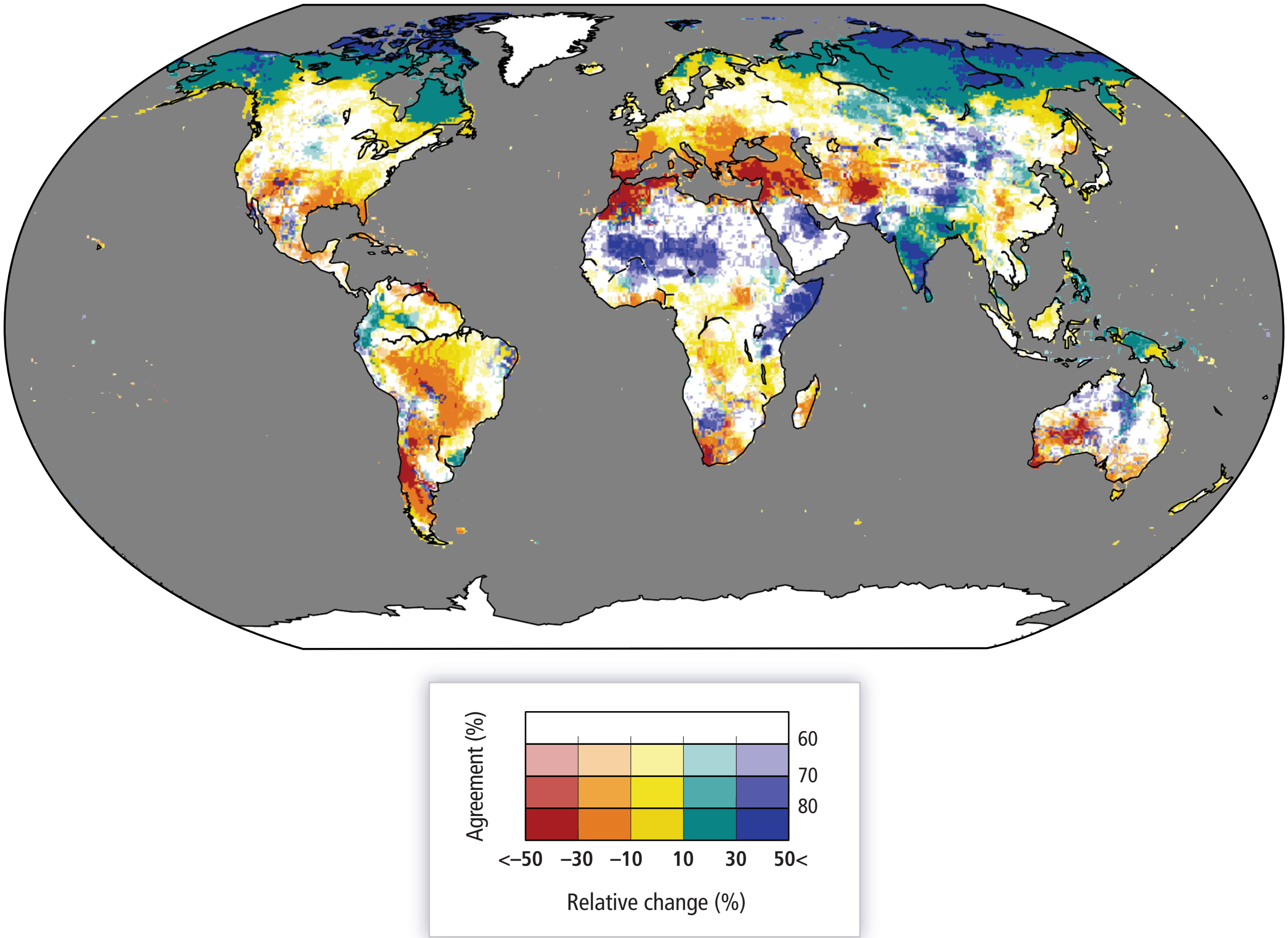


Figure 3-4 | Percentage change of mean annual streamflow for a global mean temperature rise of 2°C above 1980–2010 (2.7°C above pre-industrial). Color hues show the multi-model mean change across 5 General Circulation Models (GCMs) and 11 Global Hydrological Models (GHMs), and saturation shows the agreement on the sign of change across all 55 GHM–GCM combinations (percentage of model runs agreeing on the sign of change) (Schewe et al., 2013).

(Green et al., 2011; Taylor R. et al., 2013a) has increased significantly since then. Ensemble studies, relying on between 4 and 20 climate models, of the impact of climate change on groundwater recharge and partially also on groundwater levels were done for the globe (Portmann et al., 2013), all of Australia (Crosbie et al., 2013a), the German Danube basin (Barthel et al., 2010), aquifers in Belgium and England (Goderniaux et al., 2011; Jackson et al., 2011), the Pacific coast of the USA and Canada (Allen et al., 2010), and the semiarid High Plains aquifer of the USA (Ng et al., 2010; Crosbie et al., 2013b). With three exceptions, simulations were run under only one GHG emissions scenario. The range over the climate models of projected groundwater changes was large, from significant decreases to significant increases for the individual study areas, and the range of percentage changes of projected groundwater recharge mostly exceeded the range of projected precipitation changes. The uncertainties in projected groundwater recharge that originate in the hydrological models have not yet been explored. There are only a few studies of the impacts on groundwater of vegetation changes in response to climate change and CO_2 increase (Box CC-VW). Nor are there any studies on the impact of climate-driven changes of land use on groundwater recharge, even though projected increases in precipitation and streamflow variability due to climate change are expected to lead to increased groundwater abstraction (Taylor R. et al., 2013a), lowering groundwater levels and storage.

Under any particular climate scenario, the areas where total runoff (sum of surface runoff and groundwater recharge) is projected to increase (or decrease) roughly coincide with the areas where groundwater recharge and thus renewable groundwater resources are projected to increase (or decrease) (Kundzewicz and Döll, 2009). Changes in precipitation intensity affect the fraction of total runoff that recharges groundwater. Increased precipitation intensity may decrease groundwater recharge owing to exceedance of the infiltration capacity (typically in humid areas), or may increase it owing to faster percolation through the root zone and thus reduced evapotranspiration (typically in semiarid areas) (Liu, 2011; Taylor R. et al., 2013b). The sensitivity of groundwater recharge and levels to climate change is diminished by perennial vegetation, fine-grained soils, and aquitards and is enhanced by annual cropping, sandy soils, and unconfined (water table) aquifers (van Roosmalen et al., 2007; Crosbie et al., 2013b). The sensitivity of groundwater recharge change to precipitation change was found to be highest for low groundwater

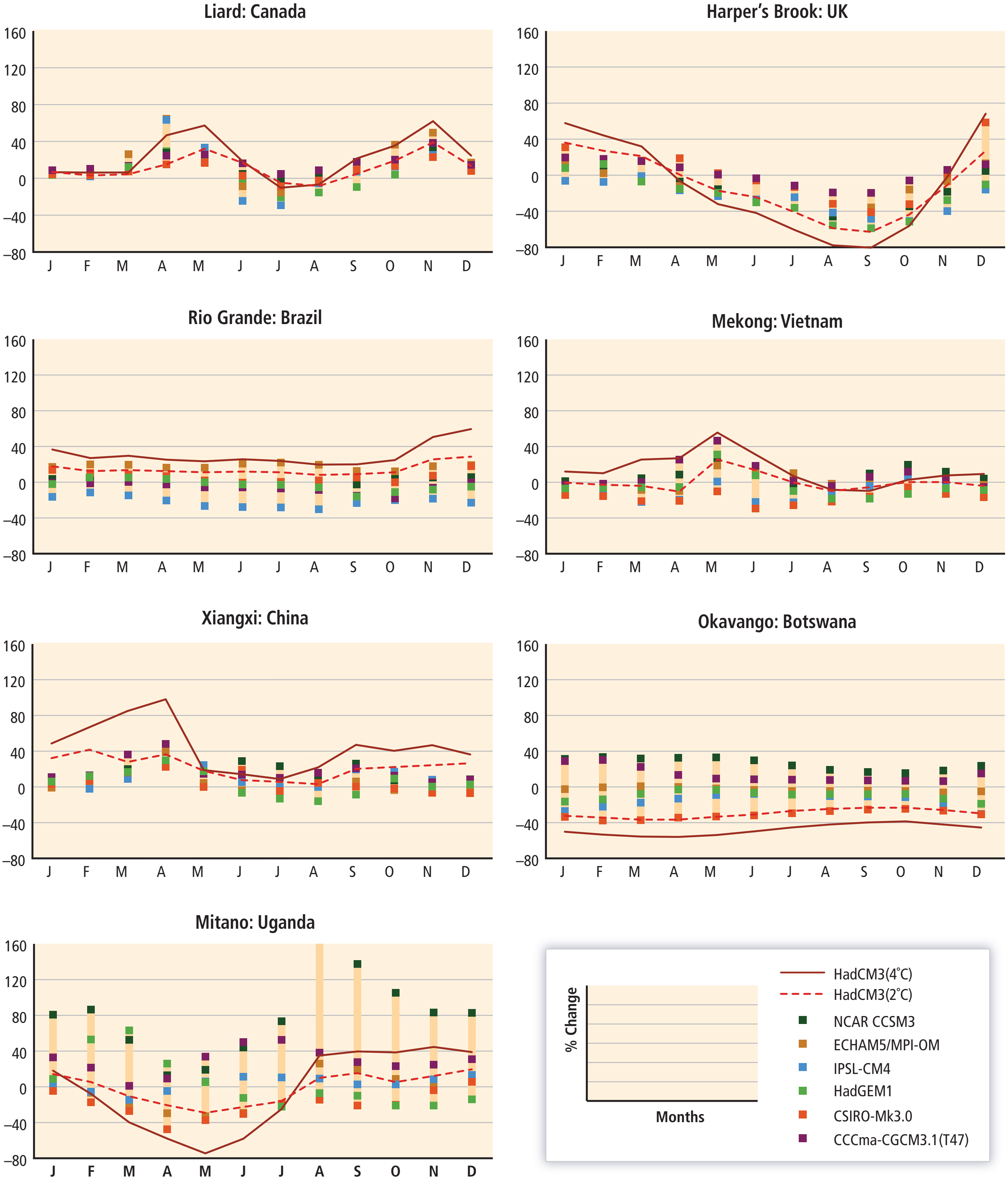


Figure 3-5 | Change in mean monthly runoff across seven climate models in seven catchments, with a 2°C increase in global mean temperature above 1961–1990 (Kingston and Taylor, 2010; Arnell, 2011; Hughes et al., 2011; Kingston et al., 2011; Nobrega et al., 2011; Thorne, 2011; Xu et al., 2011). One of the seven climate models (HadCM3) is highlighted separately, showing changes with both a 2°C increase (dotted line) and a 4°C increase (solid line).

recharge and lowest for high groundwater recharge, the ratio of recharge change to precipitation change ranging from 1.5 to 6.0 in the semiarid High Plains aquifer (Crosbie et al., 2013b). Decreasing snowfall may lead to lower groundwater recharge even if precipitation remains constant; at sites in the southwestern USA, snowmelt provides at least 40 to 70% of groundwater recharge, although only 25 to 50% of average annual precipitation falls as snow (Earman et al., 2006).

Climate change affects coastal groundwater not only through changes in groundwater recharge but also through sea level rise which, together with the rate of groundwater pumping, determines the location of the saltwater/freshwater interface. Although most confined aquifers are expected to be unaffected by sea level rise, unconfined aquifers are expected to suffer from saltwater intrusion (Werner et al., 2012). The volume available for freshwater storage is reduced if the water table cannot rise freely as the sea level rises (Masterson and Garabedian, 2007; Werner et al., 2012). This happens where land surfaces are low lying, for example, on many coral islands and in deltas, but also where groundwater discharges to streams. If the difference between the groundwater table and sea level is decreased by 1 m, the thickness of the unconfined freshwater layer decreases by roughly 40 m (Ghyben-Herzberg relation). Deltas are also affected by storm surges that drive saltwater into stream channels, contaminating the underlying fresh groundwater from above (Masterson and Garabedian, 2007). In three modeling studies, the impact of sea level rise on groundwater levels was found to be restricted to areas within 10 km from the coast (Carneiro et al., 2010; Oude Essink et al., 2010; Yechieli et al., 2010). Saltwater intrusion due to sea level rise is mostly a very slow process that may take several centuries to reach equilibrium (Webb and Howard, 2011). Even small rates of groundwater pumping from coastal aquifers are expected to lead to stronger salinization of the groundwater than sea level rise during the 21st century (Ferguson and Gleeson, 2012; Loaiciga et al., 2012).

Changes in groundwater recharge also affect streamflow. In the Mitano basin in Uganda, mean global temperature increases of 4°C or more with respect to 1961–1990 are projected to decrease groundwater outflow to the river so much that the spring discharge peak disappears and the river flow regime changes from bimodal to unimodal (one seasonal peak only) (Kingston and Taylor, 2010; Figure 3-5). Changing groundwater tables affect land surface energy fluxes, including evaporation, and thus feed back on the climate system, in particular in semiarid areas where the groundwater table is within 2 to 10 m of the surface (Jiang et al., 2009; Ferguson and Maxwell, 2010).

3.4.6. Water Quality

Climate change affects the quality of water through a complex set of natural and anthropogenic mechanisms working concurrently in parallel and in series. Projections under climate change scenarios are difficult, both to perform and interpret, because they require not only integration of the climate models with those used to analyze the transportation and transformation of pollutants in water, soil, and air but also the establishment of a proper baseline (Arheimer et al., 2005; Andersen et al., 2006; Wilby et al., 2006; Ducharne, 2008; Marshall and Randhir, 2008; Bonte and Zwolsman, 2010; Towler et al., 2010; Trolle et al., 2011; Rehana and Mujumdar, 2012). The models have different spatial scales and have to be adapted and calibrated to local conditions for which adequate and appropriate information is needed. In consequence, there are few projections of the impacts of climate change on water quality; where available, their uncertainty is high. It is evident, however, that water quality projections depend strongly on (1) local conditions; (2) climatic and environmental assumptions; and (3) the current or reference pollution state (Chang, 2004; Whitehead et al., 2009a,b; Bonte and Zwolsman, 2010; Kundzewicz and Krysanova, 2010; Sahoo et al., 2010; Trolle et al., 2011). Most projections suggest that future negative impacts will be similar in kind to those already observed in response to change and variability in air and water temperature, precipitation, and storm runoff, and to many confounding anthropogenic factors (Chang, 2004; Whitehead et al., 2009a). This holds for natural and artificial reservoirs (Brikowski, 2008; Ducharne, 2008; Marshall and Randhir, 2008; Loos et al., 2009; Bonte and Zwolsman, 2010; Qin et al., 2010; Sahoo et al., 2010; Trolle et al., 2011), rivers (Andersen et al., 2006; Whitehead et al., 2009a,b; Bowes et al., 2012) and groundwater (Butscher and Huggenberger, 2009; Rozemeijer et al., 2009).

3.4.7. Soil Erosion and Sediment Load

Heavy rainfalls are *likely* to become more intense and frequent during the 21st century in many parts of the world (Seneviratne et al., 2012; WGI AR5 Chapter 11), which may lead to more intense soil erosion even if the total rainfall does not increase. At the global scale, soil erosion simulated assuming doubled CO_2 is projected to increase about 14% by the 2090s, compared to the 1980s (9% attributed to climate change and 5% to land use change), with increases by as much as 40 to 50% in Australia and Africa (Yang et al., 2003). The largest increases are expected in semiarid areas, where extreme events may contribute about half of total erosion; for instance, in Mediterranean Spain 43% of sediment yield over the time period 1990–2009 was produced by a single event (Bussi et al., 2013). In agricultural lands in temperate regions, soil erosion may respond to more intense erosion in complex nonlinear ways; for instance in the UK a 10% increase in winter rainfall (i.e., during early growing season) could increase annual erosion of arable land by up to 150% (Favis-Mortlock and Boardman, 1995), while in Austria a simulation for 2070–2099 projected a decrease of rainfall by 10 to 14% in erosion-sensitive months and thus a decline in soil erosion by 11 to 24% (Scholz et al., 2008). Land management practices are critical for mitigating soil erosion under projected climate change. In China's Loess Plateau, four GCMs coupled to an erosion model show soil erosion increasing by –5 to 195% of soil loss during 2010–2039 under conventional tillage, for three emission scenarios (*Special Report on Emission Scenarios* (SRES) A2 and B2, and IS92a), whereas under conservation tillage they show decreases of 26 to 77% (Li et al., 2011).

Climate change will also affect the sediment load in rivers by altering water discharge and land cover. For example, an increase in water discharge of 11 to 14% in two Danish rivers under the SRES A2 emission scenario was projected to increase the annual suspended sediment load by 9 to 36% during 2071–2100 (Thodsen et al., 2008). Increases in total precipitation, increased runoff from glaciers, permafrost degradation, and the shift of precipitation from snow to rain will further increase soil erosion and sediment loads in colder regions (Lu et al., 2010). In a major

Frequently Asked Questions

FAQ 3.1 | How will climate change affect the frequency and severity of floods and droughts?

Climate change is projected to alter the frequency and magnitude of both floods and droughts. The impact is expected to vary from region to region. The few available studies suggest that flood hazards will increase over more than half of the globe, in particular in central and eastern Siberia, parts of Southeast Asia including India, tropical Africa, and northern South America, but decreases are projected in parts of northern and Eastern Europe, Anatolia, central and East Asia, central North America, and southern South America (*limited evidence*, *high agreement*).The frequency of floods in small river basins is *very likely* to increase, but that may not be true of larger watersheds because intense rain is usually confined to more limited areas. Spring snowmelt floods are *likely* to become smaller, both because less winter precipitation will fall as snow and because more snow will melt during thaws over the course of the entire winter. Worldwide, the damage from floods will increase because more people and more assets will be in harm's way.

By the end of the 21st century meteorological droughts (less rainfall) and agricultural droughts (drier soil) are projected to become longer, or more frequent, or both, in some regions and some seasons, because of reduced rainfall or increased evaporation or both. But it is still uncertain what these rainfall and soil moisture deficits might mean for prolonged reductions of streamflow and lake and groundwater levels. Droughts are projected to intensify in southern Europe and the Mediterranean region, central Europe, central and southern North America, Central America, northeast Brazil, and southern Africa. In dry regions, more intense droughts will stress water supply systems. In wetter regions, more intense seasonal droughts can be managed by current water supply systems and by adaptation; for example, demand can be reduced by using water more efficiently, or supply can be increased by increasing the storage capacity in reservoirs.

headwater basin of the Ganges River, increased precipitation and glacier runoff are projected to increase sediment yield by 26% by 2050 (Neupane and White, 2010). In the tropics, the intensity of cyclones is projected to increase 2 to 11% by 2100, which may increase soil erosion and landslides (Knutson et al., 2010).

In summary, projected increases in heavy rainfall and temperature will lead to changes in soil erosion and sediment load, but owing to the nonlinear dependence of soil erosion on rainfall rate and its strong dependence on land cover there is *low confidence* in projected changes in erosion rates. At the end of the 21st century, the impact of climate change on soil erosion is expected to be twice the impact of land use change (Yang et al., 2003), although management practices may mitigate the problem at catchment scale.

3.4.8. Extreme Hydrological Events (Floods and Droughts)

The *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX; Seneviratne et al., 2012) recognized that projected increases in temperature and heavy precipitation imply regional-scale changes in flood frequency and intensity, but with *low confidence* because these projections were obtained from a single GCM. Global flood projections based on multiple CMIP5 GCM simulations coupled with global hydrology and land surface models (Dankers et al., 2013; Hirabayashi et al., 2013) show flood hazards increasing over about half of the globe, but with great variability at the catchment scale. Projections of increased flood hazard are consistent for parts of south and Southeast Asia, tropical Africa, northeast Eurasia, and South America (Figure 3-6), while decreases are projected in parts of northern and Eastern Europe, Anatolia, central Asia, central North America, and southern South America. This spatial pattern resembles closely that described by Seneviratne et al. (2012), but the latest projections justify *medium confidence* despite new appreciation of the large uncertainty owing to variation between climate models and their coupling to hydrological models.

There have been several assessments of the potential effect of climate change on meteorological droughts (less rainfall) and agricultural droughts (drier soil) (e.g., WGI AR5 Chapter 12; Vidal et al., 2012; Orlowsky and Seneviratne, 2013), but few on hydrological droughts, either in terms of river runoff or groundwater levels. Many catchment-scale studies (Section 3.4.4) consider changes in indicators of low river flow (such as the flow exceeded 95% of the time), but these indicators do not necessarily characterize "drought" as they define neither duration nor spatial extent, and are not necessarily particularly extreme or rare. In an ensemble comparison under SRES A1B of the proportion of the land surface exhibiting significant projected changes in hydrological drought frequency to the proportions exhibiting significant changes in meteorological and agricultural drought frequency, 18 to 30% of the land surface (excluding cold areas) experienced a significant increase in the frequency of 3-month hydrological droughts, while about 15 to 45% saw a decrease (Taylor I. et al., 2013). This is a smaller area with increased frequency, and a larger area with decreased frequency, than for meteorological and agricultural droughts, and is understandable because river flows reflect the accumulation of rainfall over time. Flows during dry periods may be sustained by earlier rainfall. For example, at the catchment scale in the Pacific Northwest (Jung and Chang, 2012),

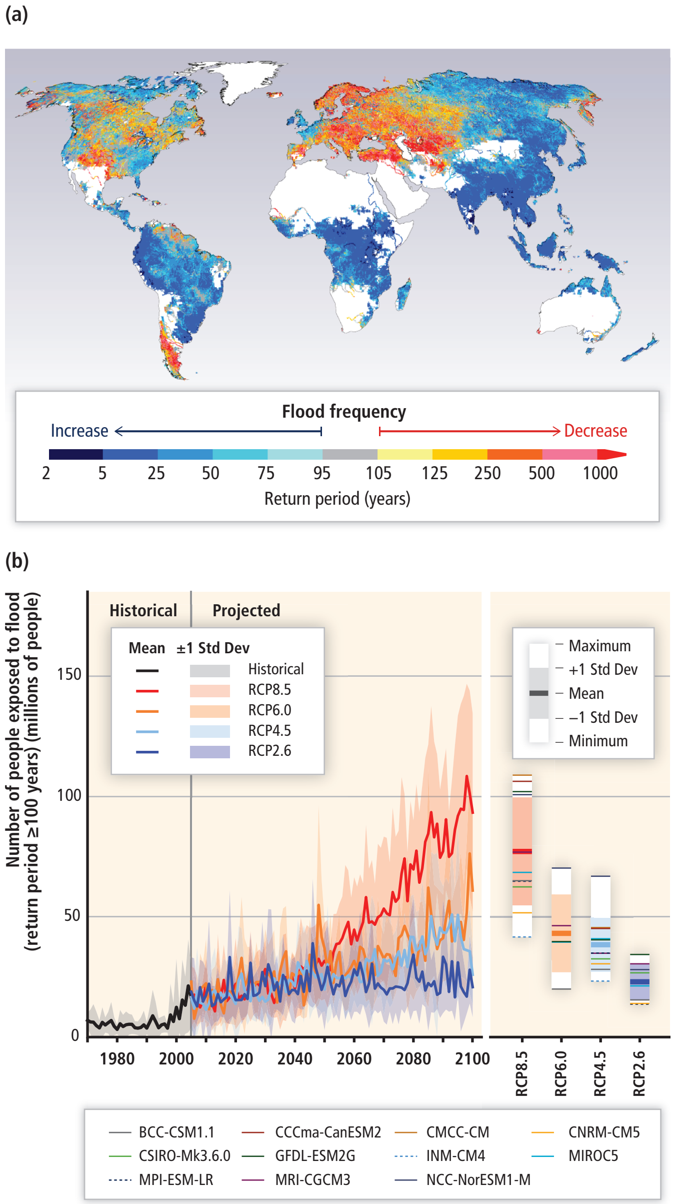


Figure 3-6 | (a) Multi-model median return period (years) in the 2080s for the 20th century 100-year flood (Hirabayashi et al., 2013), based on one hydrological model driven by 11 Coupled Model Intercomparison Project Phase 5 (CMIP5) General Circulation Models (GCMs) under Representative Concentration Pathway 8.5 (RCP8.5). At each location the magnitude of the 100-year flood was estimated by fitting a Gumbel distribution function to time series of simulated annual maximum daily discharge in 1971–2000, and the return period of that flood in 2071–2100 was estimated by fitting the same distribution to discharges simulated for that period. Regions with mean runoff less than 0.01 mm day^{-1}, Antarctica, Greenland, and Small Islands are excluded from the analysis and indicated in white. (b) Global exposure to the 20th-century 100-year flood (or greater) in millions of people (Hirabayashi et al., 2013). Left: Ensemble means of historical (black thick line) and future simulations (colored thick lines) for each scenario. Shading denotes ±1 standard deviation. Right: Maximum and minimum (extent of white), mean (thick colored lines), ±1 standard deviation (extent of shading), and projections of each GCM (thin colored lines) averaged over the 21st century. The impact of 21st century climate change is emphasized by fixing the population to that of 2005. Annual global flood exposure increases over the century by 4 to 14 times as compared to the 20th century (4 ± 3 (RCP2.6), 7 ± 5 (RCP4.5), 7 ± 6 (RCP6.0), and 14 ± 10 (RCP8.5) times, or 0.1% to 0.4 to 1.2% of the global population in 2005). Under a scenario of moderate population growth (UN, 2011), the global number of exposed people is projected to increase by a factor of 7 to 25, depending on the RCP, with strong increases in Asia and Africa due to high population growth.

short hydrological droughts are projected to increase in frequency while longer droughts remain unchanged because, although dry spells last longer, winter rainfall increases.

The impacts of floods and droughts are projected to increase even when the hazard remains constant, owing to increased exposure and vulnerability (Kundzewicz et al., 2013). Projected flood damages vary greatly between models and from region to region, with the largest losses in Asia. Studies of projected flood damages are mainly focused in Europe, the USA, and Australia (Handmer et al., 2012; Bouwer, 2013). In Europe, the annual damage (€6.4 billion) and number of people exposed (200,000) in 1961–1990 are expected to increase about twofold by the 2080s under scenario B2 and about three times under scenario A2 (Feyen et al., 2012). Drought impacts at continental and smaller scales are difficult to assess because they will vary greatly with the local hydrological setting and water management practices (Handmer et al., 2012). More frequent droughts due to climate change may challenge existing water management systems (Kim et al., 2009); together with an increase of population, this may place at risk even the domestic supply in parts of Africa (MacDonald et al., 2009).

3.5. Projected Impacts, Vulnerabilities, and Risks

In general, projections of freshwater-related impacts, vulnerabilities, and risks caused by climate change are evaluated by comparison to historical conditions. Such projections are helpful for understanding human impact on nature and for supporting adaptation to climate change. However, for supporting decisions on climate mitigation, it is more helpful to compare the different hydrological changes that are projected under different future GHG emissions scenarios, or different amounts of global mean temperature rise. One objective of such projections is to quantify what may happen under current water resources management practice, and another is to indicate what actions may be needed to avoid undesirable outcomes (Oki and Kanae, 2006). The studies compiled in Table 3-2 illustrate the benefits of reducing GHG emissions for the Earth's freshwater systems. Emissions scenarios are rather similar until the 2050s. Their impacts, and thus the benefits of mitigation, tend to become more clearly marked by the end of the 21st century. For example, the fraction of the world population exposed to a 20th century 100-year flood is projected to be, at the end of the 21st century, three times higher per year for RCP8.5 than for RCP2.6 (Hirabayashi et al., 2013). Each degree of global warming (up to 2.7°C above preindustrial levels; Schewe et al., 2013) is projected to decrease renewable water resources by at least 20% for an additional 7% of the world population. The number of people with significantly decreased access to renewable groundwater resources is projected to be roughly 50% higher under RCP8.5 than under RCP2.6 (Portmann et al., 2013). The percentage of global population living in river basins with new or aggravated water scarcity is projected to increase with global warming, from 8% at 2°C to 13% at 5°C (Gerten et al., 2013).

3.5.1. Availability of Water Resources

About 80% of the world's population already suffers serious threats to its water security, as measured by indicators including water availability,

Table 3-2 | Effects of different greenhouse gas (GHG) emissions scenarios on hydrological changes and freshwater-related impacts of climate change on humans and ecosystems. Among the Special Report on Emission Scenarios (SRES) scenarios, GHG emissions are highest in A1f and A2, lower in A1 and B2, and lowest in B1. Representative Concentration Pathway 8.5 (RCP8.5) is similar to A2, while the lower emissions scenarios RCP6.0 and RCP4.5 are similar to B1. RCP2.6 is a very low emissions scenario (Figure 1-4 and Section 1.1.3.1 in Chapter 1). The studies in the table give global warming (GW: global mean temperature rise, quantified as the Coupled Model Intercomparison Project Phase 5 (CMIP5) model mean) over different reference periods, typically since pre-industrial. GW since pre-industrial is projected to be, for RCP8.5, approximately 2°C in the 2040s and 4°C in the 2090s. For RCP6.0, GW is 2°C in the 2060s and 2.5°C in the 2090s, while in RCP2.6, GW stays below 1.5°C throughout the 21st century (Figure 1-4 in Chapter 1). Population scenario SSP2 assumes a medium population increase. The number of GCMs that were used in the studies is provided.

Type of hydrological change or impact	Description of indicator	Hydrological change or impact in different emissions scenarios or for different degrees of global warming (GW)	Reference
Decrease of renewable water resources, global scale	Percent of global population affected by a water resource decrease of more than 20% as compared to the 1990s (mean of 5 General Circulation Models (GCMs) and 11 global hydrological models, population scenario SSP2)	Up to 2°C above the 1990s (GW 2.7°C), each degree of GW affects an additional 7%	Schewe et al. (2013)
Decrease of renewable groundwater resources, global scale	Percent of global population affected by a groundwater resource decrease of more than 10% by the 2080s as compared to the 1980s (mean and range of 5 GCMs, population scenario SSP2)	• RCP2.6: 24% (11–39%) • RCP4.5: 26% (23–32%) • RCP6.0: 32% (18–45%) • RCP8.5: 38% (27–50%)	Portmann et al. (2013)
Exposure to floods, global scale	Percent of global population annually exposed, in the 2080s, to a flood corresponding to the 100-year flood discharge for the 1980s (mean and range of 5–11 GCMs, population constant at 2005 values)	• RCP2.6: 0.4% (0.2–0.5%) • RCP4.5: 0.6% (0.4–1.0%) • RCP6.0: 0.7% (0.3–1.1%) • RCP8.5: 1.2% (0.6–1.7%) • GW 2°C: 0.5% (0.3–0.6%) • GW 4°C: 1.2% (0.8–2.2%) • 1980s: 0.1% (0.04–0.16%)	Hirabayashi et al. (2013)
Change in irrigation water demand, global scale	Change of required irrigation water withdrawals by the 2080s (on area irrigated around 2000) as compared to the 1980s (range of 3 GCMs)	• RCP2.6: –0.2 to 1.6% • RCP4.5: 1.9–2.8% • RCP8.5: 6.7–10.0%	Hanasaki et al. (2013)
River flow regime shifts from perennial to intermittent and vice versa, global scale	Percent of global land area (except Greenland and Antarctica) affected by regime shifts between the 1970s and the 2050s (range of 2 GCMs)	• SRES B2: 5.4–6.7% • SRES A2: 6.3–7.0%	Döll and Müller Schmied (2012)
Water scarcity	Percent of global population living in countries with less than 1300 m^3 yr^{-1} of per capita blue water resources in the 2080s (mean of 17 GCMs, population constant at 2000 values)	No significant differences between SRES B1 and A2	Gerten et al. (2011)
New or aggravated water scarcity	Percent of global population living in river basins with new or aggravated water scarcity around 2100 as compared to 2000 (less than 1000 m^3 yr^{-1} of per capita blue water resources) (median of 19 GCMs, population constant at 2000 values)	• GW 2°C: 8% • GW 3.5°C: 11% • GW 5°C: 13%	Gerten et al. (2013)
Exposure to water scarcity	Population in water-stressed watersheds (less than 1000 m^3 yr^{-1} of per capita blue water resources) exposed to an increase in stress (1 GCM)	For emissions scenarios with 2°C target, compared to SRES A1: • 5–8% impact reduction in 2050 • 10–20% reduction in 2100	Arnell et al. (2013)
Change of groundwater recharge in the whole of Australia	Probability that groundwater recharge decreases to less than 50% of the 1990s value by 2050 (16 GCMs)	• GW 1.4°C: close to 0 almost everywhere • GW 2.8°C: in western Australia 0.2–0.6, in central Australia 0.2–0.3, elsewhere close to 1	Crosbie et al. (2013a)
Change in groundwater recharge in East Anglia, UK	Percent change between baseline and future groundwater recharge, in %, by the 2050s (1 GCM)	• SRES B1: –22% • SRES A1f: –26%	Holman et al. (2009)
Change of river discharge, groundwater recharge, and hydraulic head in groundwater in two regions of Denmark	Changes between the 1970s and the 2080s (1 regional climate model)	Differences between SRES B2 and A2 are very small compared to the changes between the 1970s and the 2080s in each scenario.	van Roosmalen et al. (2007)
River flow regime shift for river in Uganda	Shift from bimodal to unimodal (1 GCM)	Occurs in scenarios with GW of at least 4.3°C but not for smaller GW.	Kingston and Taylor (2010)
Agricultural (soil moisture) droughts in France	Mean duration, affected area, and magnitude of short and long drought events throughout the 21st century (1 GCM)	Smaller increases over time for SRES B1 than for A2 and A1B.	Vidal et al. (2012)
Salinization of artificial coastal freshwater lake IJsselmeer in the Netherlands (a drinking water source) due to seawater intrusion	(1) Daily probability of exceedance of maximum allowable concentration (MAC) of chloride (150 mg L^{-1}) (2) Maximum duration of MAC exceedance (2050, 1 GCM)	• Reference period 1997–2007 (GW 0.8°C): (1) 2.5%, (2) 103 days • GW 1.8°C, no change in atmospheric circulation: (1) 3.1%, (2) 124 days • GW 2.8°C and change in atmospheric circulation: (1) 14.3%, (2) 178 days	Bonte and Zwolsman (2010)
Decrease of hydropower production at Lake Nasser, Egypt	Reduction of mean annual hydropower production by the 2080s compared to hydropower production 1950–99 (11 GCMs)	• SRES B1: 8% • SRES A2: 7%	Beyene et al. (2010)
Reduction of usable capacity of thermal power plants in Europe and USA due to low river flow and excessive water temperature	Number of days per year with a capacity reduction of more than 50% (for existing power plants) (2031–2060, 3 GCMs)	• Without climate change: 16 • SRES B1: 22 • SRES A2: 24	van Vliet et al. (2012)
Flood damages in Europe (EU27)	(1) Expected annual damages, in 2006 (2) Expected annual population exposed (2080s, 2 GCMs)	• SRES B2: (1) 14–15 billion € yr^{-1}, (2) 440,000–470,000 people • SRES A2: (1) 18–21 billion € yr^{-1}, (2) 510,000–590,000 people • Reference period: (1) 6.4 billion € yr^{-1}, (2) 200,000 people	Feyen et al. (2012)

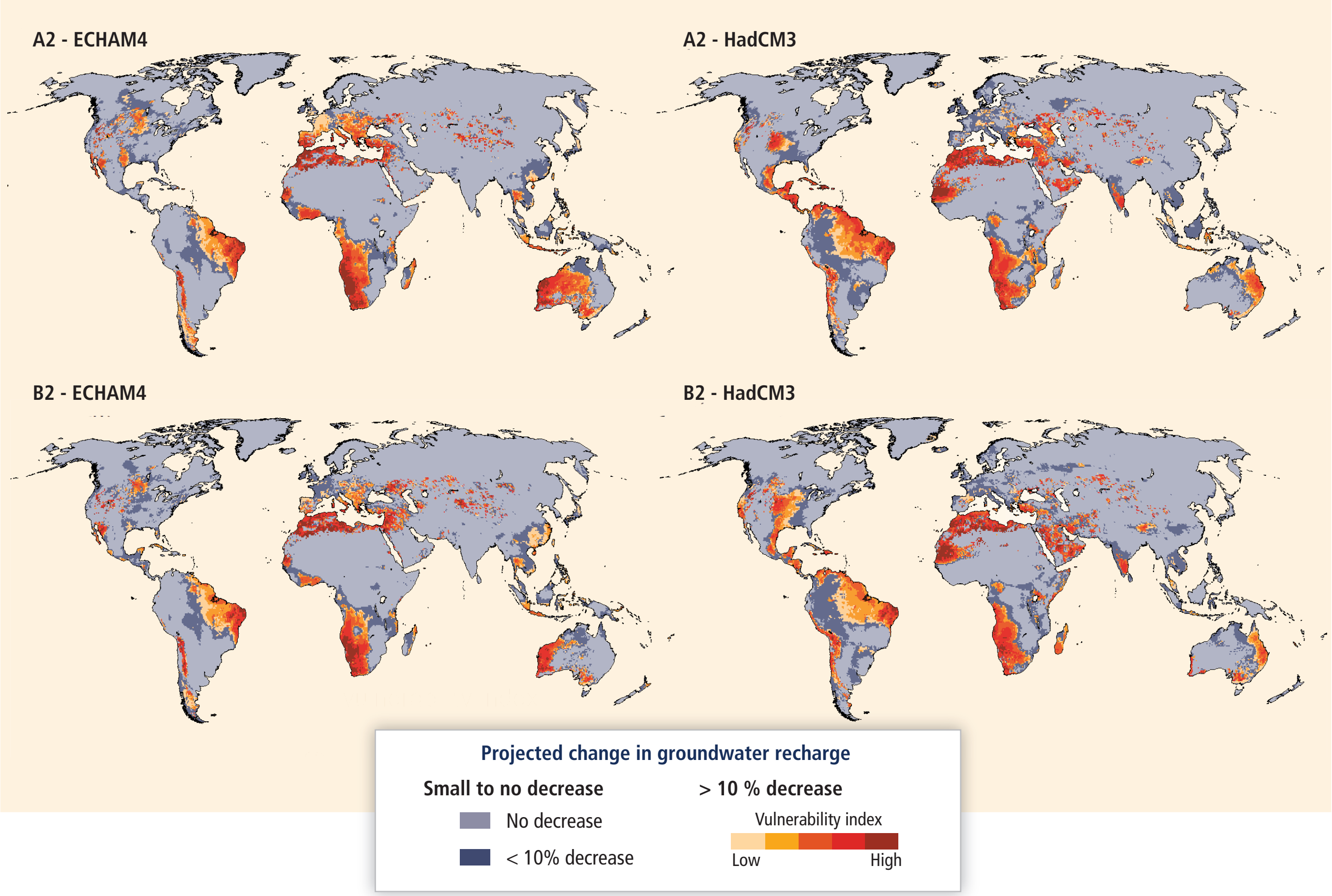


Figure 3-7 | Human vulnerability to climate change–induced decreases of renewable groundwater resources by the 2050s. Lower (Special Report on Emission Scenarios (SRES) B2) and higher (SRES A2) emissions pathways are interpreted by two global climate models. The higher the vulnerability index (computed by multiplying percentage decrease of groundwater recharge by a sensitivity index), the higher is the vulnerability. The index is defined only for areas where groundwater recharge is projected to decrease by at least 10% relative to 1961–1990 (Döll, 2009).

water demand, and pollution (Vörösmarty et al., 2010). Climate change can alter the availability of water and therefore threaten water security as defined by UNESCO (2011).

Global-scale analyses so far have concentrated on measures of resource availability rather than the multi-dimensional indices used in Vörösmarty et al. (2010). All have simulated future river flows or groundwater recharge using global-scale hydrological models. Some have assessed future availability based on runoff per capita (Hayashi et al., 2010; Arnell et al., 2011, 2013; Fung et al., 2011; Murray et al., 2012; Gerten et al., 2013; Gosling and Arnell, 2013; Schewe et al., 2013), whilst others have projected future human withdrawals and characterized availability by the ratio of withdrawals to availability from runoff or recharge (Arnell et al., 2011; Gosling and Arnell, 2013; Hanasaki et al., 2013). A groundwater vulnerability index was constructed that combined future reductions of renewable groundwater resources with water scarcity, dependence on groundwater, and the Human Development Index (Figure 3-7) (Döll, 2009). There are several key conclusions from this set of studies. First, the spatial distribution of the impacts of climate change on resource availability varies considerably between climate models, and strongly with the pattern of projected rainfall change. There is strong consistency in projections of reduced availability around the Mediterranean and parts of southern Africa, but much greater variation in projections for south and East Asia. Second, some water-stressed areas see increased runoff in the future (Section 3.4.4), and therefore less exposure to water resources stress. Third, over the next few decades and for increases in global mean temperature of less than around 2°C above preindustrial, changes in population will generally have a greater effect on changes in resource availability than will climate change. Climate change would, however, regionally exacerbate or offset the effects of population pressures. Fourth, estimates of future water availability are sensitive not only to climate and population projections and population assumptions, but also to the choice of hydrological impact model (Schewe et al., 2013) and to the adopted measure of stress or scarcity. As an indication of the potential magnitude of the impact of climate change, Schewe et al. (2013) estimated that about 8% of the global population would see a severe reduction in water resources (a reduction in runoff either greater than 20% or more than the standard deviation of current annual runoff) with a 1°C rise in global mean temperature (compared to the 1990s), rising to 14% at 2°C and 17% at 3°C; the spread across climate and hydrological models was, however, large.

Under climate change, reliable surface water supply is expected to decrease due to increased variability of river flow that is due in turn to

Frequently Asked Questions

FAQ 3.2 | How will the availability of water resources be affected by climate change?

Climate models project decreases of renewable water resources in some regions and increases in others, albeit with large uncertainty in many places. Broadly, water resources are projected to decrease in many mid-latitude and dry subtropical regions, and to increase at high latitudes and in many humid mid-latitude regions (*high agreement*, *robust evidence*). Even where increases are projected, there can be short-term shortages due to more variable streamflow (because of greater variability of precipitation) and seasonal reductions of water supply due to reduced snow and ice storage. Availability of clean water can also be reduced by negative impacts of climate change on water quality; for instance, the quality of lakes used for water supply could be impaired by the presence of algae-producing toxins.

increased precipitation variability and decreased snow and ice storage. Under these circumstances, it might be beneficial to take advantage of the storage capacity of groundwater and to increase groundwater withdrawals (Kundzewicz and Döll, 2009). However, this option is sustainable only where, over the long term, withdrawals remain well below recharge, while care must also be taken to avoid excessive reduction of groundwater outflow to rivers. Therefore, groundwater cannot be expected to ease freshwater stress where climate change is projected to decrease groundwater recharge and thus renewable groundwater resources (Kundzewicz and Döll, 2009). The percentage of projected global population (SSP2 population scenario) that will suffer from a decrease of renewable groundwater resources of more than 10% between the 1980s and the 2080s was computed to range from 24% (mean based on five GCMs, range 11 to 39%) for RCP2.6 to 38% (range 27 to 50%) for RCP8.5 (Portmann et al., 2013; see also Table 3-2). The land area affected by decreases of groundwater resources increases linearly with global mean temperature rise between 0°C and 3°C. For each degree of global mean temperature rise, an additional 4% of the global land area is projected to suffer a groundwater resources decrease of more than 30%, and an additional 1% to suffer a decrease of more than 70% (Portmann et al., 2013).

3.5.2. Water Uses

3.5.2.1. Agriculture

Water demand and use for food and livestock feed production is governed not only by crop management and its efficiency, but also by the balance between atmospheric moisture deficit and soil water supply. Thus, changes in climate (precipitation, temperature, radiation) will affect the water demand of crops grown in both irrigated and rainfed systems. Using projections from 19 CMIP3 GCMs forced by SRES A2 emissions to drive a global vegetation and hydrology model, climate change by the 2080s would hardly alter the global irrigation water demand of major crops in areas currently equipped for irrigation (Konzmann et al., 2013). However, there is *high confidence* that irrigation demand will increase significantly in many areas (by more than 40% across Europe, USA, and parts of Asia). Other regions—including major irrigated areas in India, Pakistan, and southeastern China—might experience a slight decrease in irrigation demand, due for example to higher precipitation, but only under some climate change scenarios (also see Biemans et al., 2013). Using seven global hydrological models but a limited set of CMIP5 projections, Wada et al. (2013) suggested a global increase in irrigation demand by the 2080s (ensemble average 7 to 21% depending on emissions scenario), with a pronounced regional pattern, a large inter-model spread, and possible seasonal shifts in crop water demand and consumption. By contrast, based on projections from two GCMs and two emissions scenarios, a slight global decrease in crop water deficits was suggested in both irrigated and rainfed areas by the 2080s, which can be explained partly by a smaller difference between daily maximum and minimum temperatures (Zhang and Cai, 2013). As in other studies, region-to-region variations were very heterogeneous.

Where poor soil is not a limiting factor, physiological and structural crop responses to elevated atmospheric CO_2 concentration (CO_2 fertilization) might partly cancel out the adverse effects of climate change, potentially reducing global irrigation water demand (Konzmann et al., 2013; see also Box CC-VW). However, even in this optimistic case, increases in irrigation water demand by >20% are still projected under most scenarios for some regions, such as southern Europe. In general, future irrigation demand is projected to exceed local water availability in many places (Wada et al., 2013). The water demand to produce a given amount of food on either irrigated or rainfed cropland will increase in many regions due to climate change alone (Gerten et al., 2011, projections from 17 CMIP3 GCMs, SRES A2 emissions), but this increase might be moderated by concurrent increases in crop water productivity due to CO_2 effects, that is, decreases in per-calorie water demand. The CO_2 effects may thus lessen the global number of people suffering water scarcity; nonetheless, the effect of anticipated population growth is *likely* to exceed those of climate and CO_2 change on agricultural water demand, use, and scarcity (Gerten et al., 2011).

Rainfed agriculture is vulnerable to increasing precipitation variability. Differences in yield and yield variability between rainfed and irrigated land may increase with changes in climate and its variability (e.g., Finger et al., 2011). Less irrigation water might be required for paddy rice cultivation in monsoon regions where rainfall is projected to increase and the crop growth period to become shorter (Yoo et al., 2013). Water demand for rainfed crops could be reduced by better management (Brauman et al., 2013), but unmitigated climate change may counteract such efforts, as shown in a global modeling study (Rost et al., 2009). In some regions, expansion of irrigated areas or increases of irrigation efficiencies may overcome climate change impacts on agricultural water demand and use (McDonald and Girvetz, 2013).

3.5.2.2. Energy Production

Hydroelectric and thermal power plants, and the irrigation of bioenergy crops (Box CC-WE), require large amounts of water. This section assesses the impact of hydrological changes (as described in Section 3.4) on hydroelectric and thermal power production. The impacts of changes in energy production due to climate change mitigation efforts are discussed in Section 3.7.2.1, while the economic implications of the impact of climate change on thermal power and hydropower production as well as adaptation options are assessed in Chapter 10.

Climate change affects hydropower generation through changes in the mean annual streamflow, shifts of seasonal flows, and increases of streamflow variability (including floods and droughts), as well as by increased evaporation from reservoirs and changes in sediment fluxes. Therefore, the impact of climate change on a specific hydropower plant will depend on the local change of these hydrological characteristics, as well as on the type of hydropower plant and on the (seasonal) energy demand, which will itself be affected by climate change (Golombek et al., 2012). Run-of-river power plants are more susceptible to increased flow variability than plants at dams. Projections of future hydropower generation are subject to the uncertainty of projected precipitation and streamflow. For example, projections to the 2080s of hydropower generation in the Pacific Northwest of the USA range from a decrease of 25% to an increase of 10% depending on the climate model (Markoff and Cullen, 2008). Based on an ensemble of 11 GCMs, hydropower generation at the Aswan High Dam (Egypt) was computed to remain constant until the 2050s but to decrease, following the downward trend of mean annual river discharge, to 90% (ensemble mean) of current mean annual production under both SRES B1 and A2 (Beyene et al., 2010; see also Table 3-2). In snow-dominated basins, increased discharge in winter, smaller and earlier spring floods, and reduced discharge in summer have already been observed (Section 3.2.6) and there is *high confidence* that these trends will continue. In regions with high electricity demands for heating, this makes the annual hydrograph more similar to seasonal variations in electricity demand, reducing required reservoir capacities and providing opportunities for operating dams and power stations to the benefit of riverine ecosystems (Renofalt et al., 2010; Golombek et al., 2012). In regions with high electricity demand for summertime cooling, however, this seasonal streamflow shift is detrimental. In general, climate change requires adaptation of operating rules (Minville et al., 2009; Raje and Mujumdar, 2010) which may, however, be constrained by reservoir capacity. In California, for example, high-elevation hydropower systems with little storage, which rely on storage in the snowpack, are projected to yield less hydropower owing to the increased occurrence of spills, unless precipitation increases significantly (Madani and Lund, 2010). Storage capacity expansion would help increase hydropower generation but might not be cost effective (Madani and Lund, 2010).

Regarding water availability for cooling of thermal power plants, the number of days with a reduced useable capacity is projected to increase in Europe and the USA, owing to increases in stream temperatures and the incidence of low flows (Flörke et al., 2012; van Vliet et al., 2012; see also Table 3-2). Warmer cooling water was computed to lower thermal power plant efficiency and thus electricity production by 1.5 to 3% in European countries by the 2080s under emissions scenario SRES A1B (Golombek et al., 2012).

3.5.2.3. Municipal Services

Under climate change, water utilities are confronted by the following (Bates et al., 2008; Jiménez, 2008; van Vliet and Zwolsman, 2008; Black and King, 2009; Brooks et al., 2009; Whitehead et al., 2009a; Bonte and Zwolsman, 2010; Hall and Murphy, 2010; Mukhopadhyay and Dutta, 2010; Qin et al., 2010; Chakraborti et al., 2011; Major et al., 2011; Thorne and Fenner, 2011; Christierson et al., 2012):

- Higher ambient temperatures, which reduce snow and ice volumes and increase the evaporation rate from lakes, reservoirs, and aquifers. These changes decrease natural storage of water, and hence, unless precipitation increases, its availability. Moreover, higher ambient temperatures increase water demand, and with it the competition for the resource (*medium* to *high agreement*, *limited evidence*).
- Shifts in timing of river flows and possible more frequent or intense droughts, which increase the need for artificial water storage.
- Higher water temperatures, which encourage algal blooms and increase risks from cyanotoxins and natural organic matter in water sources, requiring additional or new treatment of drinking water (*high agreement*, *medium evidence*). On the positive side, biological water and wastewater treatment is more efficient when the water is warmer (Tchobanoglous et al., 2003).
- Possibly drier conditions, which increase pollutant concentrations. This is a concern especially for groundwater sources that are already of low quality, even when pollution is natural as in India and Bangladesh, North and Latin America and Africa; here arsenic, iron, manganese, and fluorides are often a problem (Black and King, 2009).
- Increased storm runoff, which increases loads of pathogens, nutrients, and suspended sediment.
- Sea level rise, which increases the salinity of coastal aquifers, in particular where groundwater recharge is also expected to decrease.

Climate change also impacts water quality indirectly. For instance, at present many cities rely on water from forested catchments that requires very little treatment. More frequent and severe forest wildfires could seriously degrade water quality (Emelko et al., 2011; Smith et al., 2011).

Many drinking water treatment plants—especially small ones—are not designed to handle the more extreme influent variations that are to be expected under climate change. These demand additional or even different infrastructure capable of operating for up to several months per year, which renders wastewater treatment very costly, notably in rural areas (Zwolsman et al., 2010; Arnell et al., 2011).

Sanitation technologies vary in their resilience to climate impacts (Howard et al., 2010). For sewage, three climatic conditions are of interest (NACWA, 2009; Zwolsman et al., 2010):

- Wet weather: heavier rainstorms mean increased amounts of water and wastewater in combined systems for short periods. Current designs, based on critical "design storms" defined through analysis of historical precipitation data, therefore need to be modified. New strategies to adapt to and mitigate urban floods need to be developed, considering not only climate change but also urban design, land use, the "heat island effect," and topography (Changnon, 1969).

- Dry weather: soil shrinks as it dries, causing water mains and sewers to crack and making them vulnerable to infiltration and exfiltration of water and wastewater. The combined effects of higher temperatures, increased pollutant concentrations, longer retention times, and sedimentation of solids may lead to increasing corrosion of sewers, shorter asset lifetimes, more drinking water pollution, and higher maintenance costs.
- Sea level rise: intrusion of brackish or salty water into sewers necessitates processes that can handle saltier wastewater.

Increased storm runoff implies the need to treat additional wastewater when combined sewers are used, as storm runoff adds to sewage; in addition, the resulting mixture has a higher content of pathogens and pollutants. Under drier conditions higher concentrations of pollutants in wastewater, of any type, are to be expected and must be dealt with (Whitehead et al., 2009a,b; Zwolsman et al., 2010). The cost may rule this out in low-income regions (Chakraborti et al., 2011; Jiménez, 2011). The disposal of wastewater or fecal sludge is a concern that is just beginning to be addressed in the literature (Seidu et al., 2013).

3.5.2.4. Freshwater Ecosystems

Freshwater ecosystems are composed of biota (animals, plants, and other organisms) and their abiotic environment in slow-flowing surface waters such as lakes, man-made reservoirs, or wetlands; in fast-flowing surface waters such as rivers and creeks; and in the groundwater. They have suffered more strongly from human activities than have marine and terrestrial ecosystems. Between 1970 and 2000, populations of freshwater species included in the Living Planet Index declined on average by 50%, compared to 30% for marine and also for terrestrial species (Millennium Ecosystem Assessment, 2005). Climate change is an additional stressor of freshwater ecosystems, which it affects not only through increased water temperatures (discussed in Section 4.3.3.3) but also by altered streamflow regimes, river water levels, and extent and timing of inundation (Box CC-RF). Wetlands in dry environments are hotspots of biological diversity and productivity, and their biotas are at risk of extinction if runoff decreases and the wetland dries out (as described for Mediterranean-type temporary ponds by Zacharias and Zamparas, 2010). Freshwater ecosystems are also affected by water quality changes induced by climate change (Section 3.2.5), and by human adaptations to climate change-induced increases of streamflow variability and flood risk, such as the construction of dykes and dams (Ficke et al., 2007; see also Section 3.7.2).

3.5.2.5. Other Uses

In addition to direct impacts, vulnerabilities, and risks in water-related sectors, indirect impacts of hydrological changes are expected for navigation, transportation, tourism, and urban planning (Pinter et al., 2006; Koetse and Rietveld, 2009; Rabassa, 2009; Badjeck et al., 2010; Beniston, 2012). Social and political problems can result from hydrological changes. For example, water scarcity and water overexploitation may increase the risks of violent conflicts and nation-state instability (Barnett and Adger, 2007; Burke et al. 2009; Buhaug et al., 2010; Hsiang et al., 2011). Snowline rise and glacier shrinkage are *very likely* to impact environmental, hydrological, geomorphological, heritage, and tourism resources in cold regions (Rabassa, 2009), as already observed for tourism in the European Alps (Beniston, 2012). Although most impacts will be adverse, some might be beneficial.

3.6. Adaptation and Managing Risks

In the face of hydrological changes and freshwater-related impacts, vulnerability, and risks due to climate change, there is need for adaptation and for increasing resilience. Managing the changing risks due to the impacts of climate change is the key to adaptation in the water sector (IPCC, 2012), and risk management should be part of decision making and the treatment of uncertainty (ISO, 2009). Even to exploit the positive impacts of climate change on freshwater systems, adaptation is generally required.

Frequently Asked Questions

FAQ 3.3 | How should water management be modified in the face of climate change?

Managers of water utilities and water resources have considerable experience in adapting their policies and practices to the weather. But in the face of climate change, long-term planning (over several decades) is needed for a future that is highly uncertain. A flexible portfolio of solutions that produces benefits regardless of the impacts of climate change ("low-regret" solutions) and that can be implemented adaptively, step by step, is valuable because it allows policies to evolve progressively, thus building on—rather than losing the value of—previous investments. Adaptive measures that may prove particularly effective include rainwater harvesting, conservation tillage, maintaining vegetation cover, planting trees in steeply sloping fields, mini-terracing for soil and moisture conservation, improved pasture management, water reuse, desalination, and more efficient soil and irrigation water management. Restoring and protecting freshwater habitats, and managing natural floodplains, are additional adaptive measures that are not usually part of conventional management practice.

3.6.1. Options

There is growing agreement that an adaptive approach to water management can successfully address uncertainty due to climate change. Although there is *limited evidence* of the effectiveness of such an approach, the evidence is growing (Section 3.6.2). Many practices identified as adaptive were originally reactions to climate variability. Climate change provides many opportunities for "low-regret" solutions, capable of yielding social and/or economic benefits and adaptive both to variability and to change (Table 3-3). Adaptive techniques include scenario planning, experimental approaches that involve learning from experience, and the development of flexible solutions that are resilient to uncertainty. A program of adaptation typically mixes "hard" infrastructural and "soft" institutional measures (Bates et al., 2008; Cooley, 2008; Mertz et al., 2009; Sadoff and Muller, 2009; UNECE, 2009; Olhoff and Schaer, 2010).

To avoid adaptation that goes wrong—"maladaptation"—scientific research results should be analyzed during planning. Low-regret solutions, such as those for which moderate investment clearly increases the capacity to cope with projected risks or for which the investment is justifiable under all or almost all plausible scenarios, should be considered explicitly. Involving all stakeholders, reshaping planning processes, coordinating the management of land and water resources, recognizing linkages between water quantity and quality, using surface water and groundwater conjunctively, and protecting and restoring natural systems are examples of principles that can beneficially inform planning for adaptation (World Bank, 2007).

Integrated Water Resource Management continues to be a promising instrument for exploring adaptation to climate change. It can be joined with a Strategic Environmental Assessment to address broader considerations. Attention is currently increasing to "robust measures" (European Communities, 2009), which are measures that perform well under different future conditions and clearly optimize prevailing strategies (Sigel et al., 2010). Barriers to adaptation are discussed in detail in Section 16.4. Barriers to adaptation in the freshwater sector include lack of human and institutional capacity, lack of financial resources, lack of awareness, and lack of communication (Browning-Aiken et al., 2007; Burton, 2008; Butscher and Huggenberger, 2009; Zwolsman et al., 2010). Institutional structures can be major barriers to adaptation (Goulden et al., 2009; Engle and Lemos, 2010; Huntjens et al., 2010; Stuart-Hill and Schulze, 2010; Ziervogel et al., 2010; Wilby and Vaughan, 2011; Bergsma et al., 2012); structures that promote participation of and collaboration between stakeholders tend to encourage adaptation. Some adaptation measures may not pass the test of workability in an uncertain future (Campbell et al., 2008), and uncertainty (Section 3.6.2) can be another significant barrier.

Case studies of the potential effectiveness of adaptation measures are increasing. Changes in operating practices and infrastructure improvements could help California's water managers respond to changes in the volume and timing of supply (Medellin-Azuara et al., 2008; Connell-Buck et al., 2011). Other studies include evaluations of the effectiveness of different adaptation options in Washington state, USA (Miles et al., 2010) and the Murray-Darling basin, Australia (Pittock and Finlayson, 2011), and of two dike-heightening strategies in the Netherlands (Hoekstra and de Kok, 2008). Such studies have demonstrated that it is technically feasible in general to adapt to projected climate changes, but not all have considered how adaptation would be implemented.

3.6.2. Dealing with Uncertainty in Future Climate Change

One of the key challenges in factoring climate change into water resources management lies in the uncertainty. Some approaches (e.g., in England and Wales; Arnell, 2011) use a small set of climate scenarios to characterize the potential range of impacts on water resources and flooding. Others (e.g., Brekke et al., 2008; Lopez et al., 2009; Christierson et al., 2012; Hall et al., 2012) use very large numbers of scenarios to generate likelihood distributions of indicators of impact for use in risk assessment. However, it has been argued (Hall, 2007; Stainforth et al., 2007; Dessai et al., 2009) that attempts to construct probability distributions of impacts are misguided because of "deep" uncertainty, which arises because analysts do not know, or cannot agree on, how the climate system and water management systems may change, how models represent possible changes, or how to value the desirability of different outcomes. Stainforth et al. (2007) therefore argue that it is impossible in practice to construct robust quantitative probability distributions of climate change impacts, and that climate change uncertainty needs to be represented differently, for example by using fewer plausible scenarios and interpreting the outcomes of scenarios less quantitatively.

Some go further, arguing that climate models are not sufficiently robust or reliable to provide the basis for adaptation (Koutsoyiannis et al., 2008; Anagnostopoulos et al., 2010; Blöschl and Montanari, 2010; Wilby, 2010), because they are frequently biased and do not reproduce the temporal characteristics (specifically the persistence or "memory") often found in hydrological records. It has been argued (Lins and Cohn, 2011; Stakhiv, 2011) that existing water resources planning methods are sufficiently robust to address the effects of climate change. This view of climate model performance has been challenged and is the subject of some debate (Koutsoyiannis et al., 2009, 2011; Huard, 2011); the critique also assumes that adaptation assessment procedures would use only climate scenarios derived directly from climate model simulations.

Addressing uncertainty in practice by quantifying it through some form of risk assessment, however, is only one way of dealing with uncertainty. A large and increasing literature recommends that water managers should move from the traditional "predict and provide" approach toward adaptive water management (Pahl-Wostl, 2007; Pahl-Wostl et al., 2008; Matthews and Wickel, 2009; Mysiak et al., 2009; Huntjens et al., 2012; Short et al., 2012; Gersonius et al., 2013) and the adoption of resilient or "no-regrets" approaches (WWAP, 2009; Henriques and Spraggs, 2011). Approaches that are resilient to uncertainty are not entirely technical (or supply-side), and participation and collaboration amongst all stakeholders are central to adaptive water management. However, although climate change is frequently cited as a key motive, there is very little published guidance on how to implement the adaptive water management approach. Some examples are given in Ludwig et al. (2009). The most comprehensive overview of adaptive water

Table 3-3 | Categories of climate change adaptation options for the management of freshwater resources.

Category	Option	May assist both adaptation and mitigation
Institutional	Support integrated water resources management, including the integrated management of land considering specifically negative and positive impacts of climate change	X
	Promote synergy of water and energy savings and efficient use	X
	Identify "low-regret policies" and build a portfolio of relevant solutions for adaptation	X
	Increase resilience by forming water utility network working teams	
	Build adaptive capacity	
	Improve and share information	X
	Adapt the legal framework to make it instrumental for addressing climate change impacts	X
	Develop financial tools (credit, subsidies, and public investment) for the sustainable management of water, and for considering poverty eradication and equity	
Design and operation	Design and apply decision-making tools that consider uncertainty and fulfill multiple objectives	
	Revise design criteria of water infrastructure to optimize flexibility, redundancy, and robustness	
	Ensure plans and services are robust, adaptable, or modular; give good value; are maintainable; and have long-term benefits, especially in low-income countries	X
	Operate water infrastructure so as to increase resilience to climate change for all users and sectors	
	When and where water resources increase, alter dam operations to allow freshwater ecosystems to benefit	
	Take advantage of hard and soft adaptation measures	X
	Carry out programs to protect water resources in quantity and quality	
	Increase resilience to climate change by diversifying water sources[a] and improving reservoir management	X
	Reduce demand by controlling leaks, implementing water-saving programs, cascading and reusing water	X
	Improve design and operation of sewers, sanitation, and wastewater treatment infrastructure to cope with variations in influent quantity and quality	
	Provide universal sanitation with technology locally adapted, and provide for proper disposal and reintegration of used water into the environment or for its reuse	
Reduce impact of natural disasters	Implement monitoring and early warning systems	
	Develop contingency plans	
	Improve defenses and site selection for key infrastructure that is at risk of floods	
	Design cities and rural settlements to be resilient to floods	
	Seek and secure water from a diversity (spatially and source-type) of sources to reduce impacts of droughts and variability in water availability	
	Promote both the reduction of water demand and the efficient use of water by all users	
	Promote switching to more appropriate crops (drought-resistant, salt-resistant; low water demand)	X
	Plant flood- or drought-resistant crop varieties	
Agricultural irrigation	Improve irrigation efficiency and reduce demand for irrigation water	X
	Reuse wastewater to irrigate crops and use soil for carbon sequestration	X
Industrial use	When selecting alternative sources of energy, assess the need for water	X
	Relocate water-thirsty industries and crops to water-rich areas	
	Implement industrial water efficiency certifications	X

[a] This includes water reuse, rain water harvesting, and desalination, among others.

Sources: Vörösmarty et al. (2000); Marsalek et al. (2006); Mogaka et al. (2006); Dillon and Jiménez (2008); Jiménez and Asano (2008); Keller (2008); McCafferty (2008); McGuckin (2008); Seah (2008); UN-HABITAT (2008); Thöle (2008); Andrews (2009); Bahri (2009); Munasinghe (2009); NACWA (2009); OFWAT (2009); Reiter (2009); Whitehead et al. (2009b); de Graaf and der Brugge (2010); Dembo (2010); Godfrey et al. (2010); Howard et al. (2010); Mackay and Last (2010); Mukhopadhyay and Dutta (2010); OECD (2010); Renofalt et al. (2010); Zwolsman et al. (2010); Arkell (2011a, 2011b); Elliott et al. (2011); Emelko et al. (2011); Jiménez (2011); Kingsford (2011); Major et al. (2011); Sprenger et al. (2011); UNESCO (2011); Wang X. et al. (2011); Bowes et al. (2012).

management that explicitly incorporates climate change and its uncertainty is the three-step framework of the U.S. Water Utilities Climate Alliance (WUCA, 2010): system vulnerability assessment, utility planning using decision-support methods, and decision making and implementation. Planning methods for decision support include classic decision analysis, traditional scenario planning, and robust decision making (Lempert et al., 1996, 2006; Nassopoulos et al., 2012). The latter was applied by the Inland Empire Utilities Agency, supplying water to a region in Southern California (Lempert and Groves, 2010). This led to the refinement of the company's water resource management plan, making it more robust to three particularly challenging aspects of climate change that were identified by the scenario analysis. Another framework, based on risk assessment, is the threshold-scenario framework of Freas et al. (2008).

3.6.3. Costs of Adaptation to Climate Change

Calculating the global cost of adaptation in the water sector is a difficult task and results are highly uncertain. Globally, to maintain water services at non-climate change levels to the year 2030 in more than 200 countries, total adaptation costs for additional infrastructure were estimated as US$531 billion for the SRES A1B scenario (Kirshen, 2007). Including two further costs, for reservoir construction because the best locations have already been taken, and for unmet irrigation demands, total water sector adaptation costs were estimated as US$225 billion, or US$11 billion per year for the SRES A1B scenario (UNFCCC, 2007).

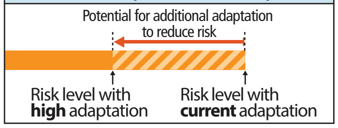
Average annual water supply and flood protection costs to 2050 for restoring service to non-climate change levels were estimated to be US$19.7 billion for a dry GCM projection of the SRES A2 scenario and US$14.4 billion for a wet GCM projection (Ward et al., 2010; World Bank, 2010). Annual urban infrastructure costs, primarily for wastewater treatment and urban drainage, were US$13.0 billion (dry) and US$27.5 billion (wet). Under both GCM projections for the A2 scenario, the water sector accounted for about 50% of total global adaptation cost, which was distributed regionally in the proportions: East Asia/Pacific, 20%; Europe/Central Asia, 10%; Latin America/Caribbean, 20%; Middle East/North Africa, 5%; South Asia, 20%; sub-Saharan Africa, 20%.

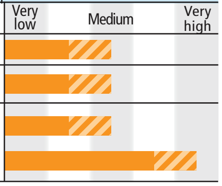
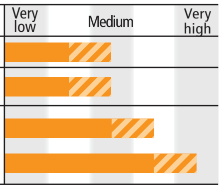
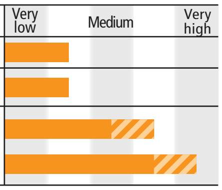
Annual costs for adaptation to climate change in sub-Saharan Africa are estimated as US$1.1 to 2.7 billion for current urban water infrastructure, plus US$1.0 to 2.5 billion for new infrastructure to meet the 2015 Millennium Development Goals (Muller, 2007). These estimates assume a 30% reduction in stream flow and an increase of at least 40% in the unit cost of water. Annual estimates of adaptation costs for urban water storage are US$0.05 to 0.15 billion for existing facilities and US$0.015 to 0.05 billion for new developments. For wastewater treatment, the equivalent estimates are US$0.1 to 0.2 billion and US$0.075 to 0.2 billion.

3.6.4. Adaptation in Practice in the Water Sector

A number of water management agencies are beginning to factor climate change into processes and decisions (Kranz et al., 2010; Krysanova et al., 2010), with the amount of progress strongly influenced by institutional characteristics. Most of the work has involved developing methodologies to be used by water resources and flood managers (e.g., Rudberg et al., 2012), and therefore represents attempts to improve adaptive capacity. In England and Wales, for example, methodologies to gauge the effects of climate change on reliability of water supplies have evolved since the late 1990s (Arnell, 2011), and the strategic plans of water supply companies now generally allow for climate change. Brekke et al. (2009a) describe proposed changes to practices in the USA. Several studies report community-level activities to reduce exposure to current hydrological variability, regarded explicitly as a means of adapting to future climate change (e.g., Barrios et al., 2009; Gujja et al., 2009; Kashaigili et al., 2009; Yu et al., 2009).

Table 3-4 | Key risks from climate change and the potential for reducing risk through mitigation and adaptation. Key risks are identified based on assessment of the literature and expert judgments by chapter authors, with evaluation of evidence and agreement in supporting chapter sections. Each key risk is characterized as very low to very high. Risk levels are presented in three time frames: the present, near term (here assessed over 2030–2040), and longer term (here assessed over 2080–2100). Sources: Xie et al., 2006; Döll, 2009; Kaser et al., 2010; Arnell et al., 2011; Huss, 2011; Jóhannesson et al., 2012; Seneviratne et al., 2012; Arnell and Gosling, 2013; Dankers et al., 2013; Gosling and Arnell, 2013; Hanasaki et al., 2013; Hirabayashi et al., 2013; Kundzewicz et al., 2013; Portmann et al., 2013; Radić et al., 2013; Schewe et al., 2013; WGI AR5 Chapter 13.

Climate-related drivers of impacts			Level of risk & potential for adaptation
🌡 Warming trend	☀ Drying trend	🌧 Extreme precipitation	

Key risk	Adaptation issues & prospects	Climatic drivers	Timeframe	Risk & potential for adaptation
Flood risks associated with climate change increase with increasing greenhouse gas emissions. (*robust evidence, high agreement*) [3.4.8]	By 2100, the number of people exposed annually to a 20th-century 100-year flood is projected to be three times greater for very high emissions (RCP8.5) than for very low emissions (RCP2.6).	🌧	Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	
Climate change is projected to reduce renewable water resources significantly in most dry subtropical regions. (*robust evidence, high agreement*) [3.5.1]	This will exacerbate competition for water among agriculture, ecosystems, settlements, industry and energy production, affecting regional water, energy, and food security.	☀	Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	
Because nearly all glaciers are too large for equilibrium with the present climate, there is a committed water-resources change during much of the 21st century, and changes beyond the committed change are expected due to continued warming; in glacier-fed rivers, total meltwater yields from stored glacier ice will increase in many regions during the next decades but decrease thereafter. (*robust evidence, high agreement*) [3.4.3]	Continued loss of glacier ice implies a shift of peak discharge from summer to spring, except in monsoonal catchments, and possibly a reduction of summer flows in the downstream parts of glacierized catchments.	🌡	Present Near term (2030–2040) Long term (2080–2100) 2°C 4°C	

Frequently Asked Questions

FAQ 3.4 | Does climate change imply only bad news about water resources?

There is good news as well as bad about water resources, but the good news is very often ambiguous. Water may become less scarce in regions that get more precipitation, but more precipitation will probably also increase flood risk; it may also raise the groundwater table, which could lead to damage to buildings and other infrastructure or to reduced agricultural productivity due to wet soils or soil salinization. More frequent storms reduce the risk of eutrophication and algal blooms in lakes and estuaries by flushing away nutrients, but increased storm runoff will carry more of those nutrients to the sea, exacerbating eutrophication in marine ecosystems, with possible adverse impacts as discussed in Chapter 30. Water and wastewater treatment yields better results under warmer conditions, as chemical and biological reactions needed for treatment perform in general better at higher temperatures. In many rivers fed by glaciers, there will be a "meltwater dividend" during some part of the 21st century, due to increasing rates of loss of glacier ice, but the continued shrinkage of the glaciers means that after several decades the total amount of meltwater that they yield will begin to decrease (*medium confidence*). An important point is that often impacts do not become "good news" unless investments are made to exploit them. For instance, where additional water is expected to become available, the infrastructure to capture that resource would need to be developed if it is not already in place.

3.7. Linkages with Other Sectors and Services

3.7.1. Impacts of Adaptation in Other Sectors on Freshwater Systems

Adaptation in other sectors such as agriculture, forestry, and industry might have impacts on the freshwater system, and therefore needs to be considered while planning adaptation in the water sector (Jiang et al., 2013). For example, better agricultural land management practices can also reduce erosion and sedimentation in river channels (Lu et al., 2010), while controlled flooding of agricultural land can alleviate the impacts of urban flooding. Increased irrigation upstream may limit water availability downstream (World Bank, 2007). A project designed for other purposes may also deliver increased resilience to climate change as a co-benefit, even without a specifically identified adaptive component (World Bank, 2007; Falloon and Betts, 2010).

3.7.2. Climate Change Mitigation and Freshwater Systems

3.7.2.1. Impact of Climate Change Mitigation on Freshwater Systems

Many measures for climate change mitigation affect freshwater systems. Afforestation generally increases evapotranspiration and decreases total runoff (van Dijk and Keenan, 2007). Afforestation of areas deemed suitable according to the Clean Development Mechanism–Afforestation/Reforestation provisions of the Kyoto Protocol (7.5 million km^2) would lead to large and spatially extensive decreases of long-term average runoff (Trabucco et al., 2008). On 80% of the area, runoff is computed to decline by more than 40%, while on 27% runoff decreases of 80 to 100% were computed, mostly in semiarid areas (Trabucco et al., 2008). For example, economic incentives for carbon sequestration may encourage the expansion of *Pinus radiata* timber plantations in the Fynbos biome of South Africa, with negative consequences for water supply and biodiversity; afforestation is viable to the forestry industry only because it pays less than 1% of the actual cost of streamflow reduction caused by replacing Fynbos by the plantations (Chisholm, 2010). In general, afforestation has beneficial impacts on soil erosion, local flood risk, water quality (nitrogen, phosphorus, suspended sediments), and stream habitat quality (van Dijk and Keenan, 2007; Trabucco et al., 2008; Wilcock et al., 2008).

Irrigated bioenergy crops and hydropower can have negative impacts on freshwater systems (Jacobson, 2009). In the USA, water use for irrigating biofuel crops could increase from 2% of total water consumption in 2005 to 9% in 2030 (King et al., 2010). Irrigating some bioenergy crops may cost more than the energy thus gained. In dry parts of India, pumping from a depth of 60 m for irrigating jatropha is estimated to consume more energy than that gained from the resulting higher crop yields (Gupta et al., 2010). For a biofuel scenario of the International Energy Agency, global consumptive irrigation water use for biofuel production is projected to increase from 0.5% of global renewable water resources in 2005 to 5.5% in 2030; biofuel production is projected to increase water consumption significantly in some countries (e.g., Germany, Italy, and South Africa), and to exacerbate the already serious water scarcity in others (e.g., Spain and China) (Gerbens-Leenes et al., 2012). Conversion of native Caatinga forest into rainfed fields for biofuels in semiarid northwestern Brazil may lead to a significant increase of groundwater recharge (Montenegro and Ragab, 2010), but there is a risk of soil salinization due to rising groundwater tables.

Hydropower generation leads to alteration of river flow regimes that negatively affect freshwater ecosystems, in particular biodiversity and abundance of riverine organisms (Döll and Zhang, 2010; Poff and Zimmerman, 2010), and to fragmentation of river channels by dams, with negative impacts on migratory species (Bourne et al., 2011). Hydropower operations often lead to discharge changes on hourly timescales that are detrimental to the downstream river ecosystem (Bruno et al., 2009; Zimmerman et al., 2010). However, release management and structural measures like fish ladders can mitigate these negative impacts somewhat (Williams, 2008). In tropical regions, the global warming potential of hydropower, due to methane emissions from man-made reservoirs, may exceed that of thermal power; based on observed emissions of a tropical reservoir, this might be the case where the ratio of hydropower generated to the surface area of the reservoir is less than 1 MW km^{-2} (Gunkel, 2009).

CO_2 leakage to freshwater aquifers from saline aquifers used for carbon capture and storage (CCS) can lower pH by 1 to 2 units and increase concentrations of metals, uranium, and barium (Little and Jackson, 2010). Pressure exerted by gas injection can push brines or brackish water into freshwater parts of the aquifer (Nicot, 2008). Displacement of brine into potable water was not considered in a screening methodology for CCS sites in the Netherlands (Ramírez et al., 2010). Another emergent freshwater-related risk of climate mitigation is increased natural gas extraction from low-permeability rocks. The required hydraulic fracturing process ("fracking") uses large amounts of water (a total of about 9000 to 30,000 m^3 per well, mixed with a number of chemicals), of which a part returns to the surface (Rozell and Reaven, 2012). Fracking is suspected to lead to pollution of the overlying freshwater aquifer or surface waters, but appropriate observations and peer-reviewed studies are still lacking (Jackson et al., 2013). Densification of urban areas to reduce traffic emissions is in conflict with providing additional open space for inundation in case of floods (Hamin and Gurran, 2009).

3.7.2.2. Impact of Water Management on Climate Change Mitigation

A number of water management decisions affect GHG emissions. Water demand management has a significant impact on energy consumption because energy is required to pump and treat water, to heat it, and to treat wastewater. For example, water supply and water treatment were responsible for 1.4% of total electricity consumption in Japan in 2008 (MLIT, 2011). In the USA, total water-related energy consumption was equivalent to 13% of total electricity production in 2005, with 70% for water heating, 14% for wastewater treatment, and only 5% for pumping of irrigation water (Griffiths-Sattenspiel and Wilson, 2009). In China, where agriculture accounts for 62% of water withdrawals, groundwater pumping for irrigation accounted for only 0.6% of China's GHG emissions in 2006, a small fraction of the 17 to 20% share of agriculture as a whole (Wang et al., 2012). Where climate change reduces water resources in dry regions, desalination of seawater as an adaptation option is expected to increase GHG emissions if carbon-based fuels are used as energy source (McEvoy and Wilder, 2012).

In Southeast Asia, emissions due to peatland drainage contribute 1.3 to 3.1% of current global CO_2 emissions from the combustion of fossil fuels (Hooijer et al., 2010), and peatland rewetting could substantially reduce net GHG emissions (Couwenberg et al., 2010). Climate change mitigation by conservation of wetlands will also benefit water quality and biodiversity (House et al., 2010). Irrigation can increase CO_2 storage in soils by reducing water stress and so enhancing biomass production. Irrigation in semiarid California did not significantly increase soil organic carbon (Wu et al., 2008). Water management in rice paddies can reduce methane (CH_4) emissions. If rice paddies are drained at least once during the growing season, with resulting increased water withdrawals, global CH_4 emissions from rice fields could be decreased by 4.1 Tg yr^{-1} (16% around the year 2000), and nitrous oxide (N_2O) emissions would not increase significantly (Yan et al., 2009).

3.8. Research and Data Gaps

Precipitation and river discharge are systematically observed, but data records are unevenly available and unevenly distributed geographically. Information on many other relevant variables, such as soil moisture, snow depth, groundwater depth, and water quality, is particularly limited in developing countries. Relevant socioeconomic data, such as rates of surface water and groundwater withdrawal by each sector, and information on already implemented adaptations for stabilizing water supply, such as long-range diversions, are limited even in developed countries. In consequence, assessment capability is limited in general, and especially so in developing countries.

Modeling studies have shown that the adaptation of vegetation to changing climate may have large impacts on the partitioning of precipitation into evapotranspiration and runoff. This feedback should be investigated more thoroughly (see Box CC-VW).

Relatively little is known about the economic aspects of climate change impacts and adaptation options related to water resources. For example, regional damage curves need to be developed, relating the magnitudes of major water related disasters (such as intense precipitation and surface soil dryness) to the expected costs.

There is a continuing, although narrowing, mismatch between the large scales resolved by climate models and the catchment scale at which water is managed and adaptations must be implemented. Improving the spatial resolution of regional and global climate models, and the accuracy of methods for downscaling their outputs, can produce information more relevant to water management, although the robustness of regional climate projections is still constrained by the realism of GCM simulations of large-scale drivers. More computing capacity is needed to address these problems with more ensemble simulations at high spatial resolution. More research is also needed into novel ways of combining different approaches to projection of plausible changes in relevant climate variables so as to provide robust information to water managers. Robust attribution to anthropogenic climate change of hydrological changes, particularly changes in the frequency of extreme events, is similarly demanding, and further study is required to develop rigorous attribution tools that require less computation. In addition, there is a difficulty to model and interpret results obtained from applying models at different scales and with different logics to follow the future changes on water quality. Moreover, the establishment of a proper baseline to isolate the effects derived from climate change from the anthropogenic cause is a major challenge.

Interactions among socio-ecological systems are not yet well considered in most impact assessments. Particularly, there are few studies on the impacts of mitigation and adaptation in other sectors on the water sector, and conversely. A valuable advance would be to couple hydrological models, or even the land surface components of climate models, to data on water management activities such as reservoir operations, irrigation, and urban withdrawals from surface water or groundwater.

To support adaptation by increasing reliance on groundwater and on the coordinated and combined use of groundwater and surface water, ground-based data are needed in the form of a long-term program to monitor groundwater dynamics and stored groundwater volumes. Understanding of groundwater recharge and groundwater surface water interactions, particularly by the assessment of experiences of conjunctive use of groundwater and surface water, needs to be better developed.

More studies are needed, especially in developing countries, on the impacts of climate change on water quality, and of vulnerability to and ways of adapting to those impacts.

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3

Impacts of 1.5°C of Global Warming on Natural and Human Systems

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Executive Summary

This chapter builds on findings of AR5 and assesses new scientific evidence of changes in the climate system and the associated impacts on natural and human systems, with a specific focus on the magnitude and pattern of risks linked for global warming of 1.5°C above temperatures in the pre-industrial period. Chapter 3 explores observed impacts and projected risks to a range of natural and human systems, with a focus on how risk levels change from 1.5°C to 2°C of global warming. The chapter also revisits major categories of risk (Reasons for Concern, RFC) based on the assessment of new knowledge that has become available since AR5.

1.5°C and 2°C Warmer Worlds

The global climate has changed relative to the pre-industrial period, and there are multiple lines of evidence that these changes have had impacts on organisms and ecosystems, as well as on human systems and well-being (*high confidence*). The increase in global mean surface temperature (GMST), which reached 0.87°C in 2006–2015 relative to 1850–1900, has increased the frequency and magnitude of impacts (*high confidence*), strengthening evidence of how an increase in GMST of 1.5°C or more could impact natural and human systems (1.5°C versus 2°C). {3.3, 3.4, 3.5, 3.6, Cross-Chapter Boxes 6, 7 and 8 in this chapter}

Human-induced global warming has already caused multiple observed changes in the climate system (*high confidence*). Changes include increases in both land and ocean temperatures, as well as more frequent heatwaves in most land regions (*high confidence*). There is also *high confidence* that global warming has resulted in an increase in the frequency and duration of marine heatwaves. Further, there is substantial evidence that human-induced global warming has led to an increase in the frequency, intensity and/or amount of heavy precipitation events at the global scale (*medium confidence*), as well as an increased risk of drought in the Mediterranean region (*medium confidence*). {3.3.1, 3.3.2, 3.3.3, 3.3.4, Box 3.4}

Trends in intensity and frequency of some climate and weather extremes have been detected over time spans during which about 0.5°C of global warming occurred (*medium confidence*). This assessment is based on several lines of evidence, including attribution studies for changes in extremes since 1950. {3.2, 3.3.1, 3.3.2, 3.3.3, 3.3.4}

Several regional changes in climate are assessed to occur with global warming up to 1.5°C as compared to pre-industrial levels, including warming of extreme temperatures in many regions (*high confidence*), increases in frequency, intensity and/or amount of heavy precipitation in several regions (*high confidence*), and an increase in intensity or frequency of droughts in some regions (*medium confidence*). {3.3.1, 3.3.2, 3.3.3, 3.3.4, Table 3.2}

There is no single '1.5°C warmer world' (*high confidence*). In addition to the overall increase in GMST, it is important to consider the size and duration of potential overshoots in temperature. Furthermore, there are questions on how the stabilization of an increase in GMST of 1.5°C can be achieved, and how policies might be able to influence the resilience of human and natural systems, and the nature of regional and subregional risks. Overshooting poses large risks for natural and human systems, especially if the temperature at peak warming is high, because some risks may be long-lasting and irreversible, such as the loss of some ecosystems (*high confidence*). The rate of change for several types of risks may also have relevance, with potentially large risks in the case of a rapid rise to overshooting temperatures, even if a decrease to 1.5°C can be achieved at the end of the 21st century or later (*medium confidence*). If overshoot is to be minimized, the remaining equivalent CO_2 budget available for emissions is very small, which implies that large, immediate and unprecedented global efforts to mitigate greenhouse gases are required (*high confidence*). {3.2, 3.6.2, Cross-Chapter Box 8 in this chapter}

Robust[1] global differences in temperature means and extremes are expected if global warming reaches 1.5°C versus 2°C above the pre-industrial levels (*high confidence*). For oceans, regional surface temperature means and extremes are projected to be higher at 2°C compared to 1.5°C of global warming (*high confidence*). Temperature means and extremes are also projected to be higher at 2°C compared to 1.5°C in most land regions, with increases being 2–3 times greater than the increase in GMST projected for some regions (*high confidence*). Robust increases in temperature means and extremes are also projected at 1.5°C compared to present-day values (*high confidence*) {3.3.1, 3.3.2}. There are decreases in the occurrence of cold extremes, but substantial increases in their temperature, in particular in regions with snow or ice cover (*high confidence*) {3.3.1}.

Climate models project robust[1] differences in regional climate between present-day and global warming up to 1.5°C[2], and between 1.5°C and 2°C[2] *(high confidence)*, depending on the variable and region in question *(high confidence)*. Large, robust and widespread differences are expected for temperature extremes (*high confidence*). Regarding hot extremes, the strongest warming is expected to occur at mid-latitudes in the warm season (with increases of up to 3°C for 1.5°C of global warming, i.e., a factor of two) and at high latitudes in the cold season (with increases of up to 4.5°C at 1.5°C of global warming, i.e., a factor of three) (*high confidence*). The strongest warming of hot extremes is projected to occur in central and eastern North America, central and southern Europe, the Mediterranean region (including southern Europe, northern Africa and the Near East), western and central Asia, and southern Africa (*medium confidence*). The number of exceptionally hot days are expected to increase the most in the tropics, where interannual temperature variability is lowest; extreme heatwaves are thus projected to emerge earliest in these regions, and they are expected to already become widespread there at 1.5°C global warming (*high confidence*). Limiting global warming to 1.5°C instead of 2°C could result in around 420

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[1] Robust is used here to mean that at least two thirds of climate models show the same sign of changes at the grid point scale, and that differences in large regions are statistically significant.

[2] Projected changes in impacts between different levels of global warming are determined with respect to changes in global mean near-surface air temperature.

million fewer people being frequently exposed to extreme heatwaves, and about 65 million fewer people being exposed to exceptional heatwaves, assuming constant vulnerability (*medium confidence*). {3.3.1, 3.3.2, Cross-Chapter Box 8 in this chapter}

Limiting global warming to 1.5°C would limit risks of increases in heavy precipitation events on a global scale and in several regions compared to conditions at 2°C global warming (*medium confidence*). The regions with the largest increases in heavy precipitation events for 1.5°C to 2°C global warming include: several high-latitude regions (e.g. Alaska/western Canada, eastern Canada/Greenland/Iceland, northern Europe and northern Asia); mountainous regions (e.g., Tibetan Plateau); eastern Asia (including China and Japan); and eastern North America (*medium confidence*). Tropical cyclones are projected to decrease in frequency but with an increase in the number of very intense cyclones (*limited evidence, low confidence*). Heavy precipitation associated with tropical cyclones is projected to be higher at 2°C compared to 1.5°C of global warming (*medium confidence*). Heavy precipitation, when aggregated at a global scale, is projected to be higher at 2°C than at 1.5°C of global warming (*medium confidence*) {3.3.3, 3.3.6}

Limiting global warming to 1.5°C is expected to substantially reduce the probability of extreme drought, precipitation deficits, and risks associated with water availability (i.e., water stress) in some regions (*medium confidence*). In particular, risks associated with increases in drought frequency and magnitude are projected to be substantially larger at 2°C than at 1.5°C in the Mediterranean region (including southern Europe, northern Africa and the Near East) and southern Africa (*medium confidence*). {3.3.3, 3.3.4, Box 3.1, Box 3.2}

Risks to natural and human systems are expected to be lower at 1.5°C than at 2°C of global warming (*high confidence*). This difference is due to the smaller rates and magnitudes of climate change associated with a 1.5°C temperature increase, including lower frequencies and intensities of temperature-related extremes. Lower rates of change enhance the ability of natural and human systems to adapt, with substantial benefits for a wide range of terrestrial, freshwater, wetland, coastal and ocean ecosystems (including coral reefs) (*high confidence*), as well as food production systems, human health, and tourism (*medium confidence*), together with energy systems and transportation (*low confidence*). {3.3.1, 3.4}

Exposure to multiple and compound climate-related risks is projected to increase between 1.5°C and 2°C of global warming with greater proportions of people both exposed and susceptible to poverty in Africa and Asia (*high confidence*). For global warming from 1.5°C to 2°C, risks across energy, food, and water sectors could overlap spatially and temporally, creating new – and exacerbating current – hazards, exposures, and vulnerabilities that could affect increasing numbers of people and regions (*medium confidence*). Small island states and economically disadvantaged populations are particularly at risk (*high confidence*). {3.3.1, 3.4.5.3, 3.4.5.6, 3.4.11, 3.5.4.9, Box 3.5}

Global warming of 2°C would lead to an expansion of areas with significant increases in runoff, as well as those affected by flood hazard, compared to conditions at 1.5°C (*medium confidence*). Global warming of 1.5°C would also lead to an expansion of the global land area with significant increases in runoff (*medium confidence*) and an increase in flood hazard in some regions (*medium confidence*) compared to present-day conditions. {3.3.5}

The probability of a sea-ice-free Arctic Ocean[3] during summer is substantially higher at 2°C compared to 1.5°C of global warming (*medium confidence*). Model simulations suggest that at least one sea-ice-free Arctic summer is expected every 10 years for global warming of 2°C, with the frequency decreasing to one sea-ice-free Arctic summer every 100 years under 1.5°C (*medium confidence*). An intermediate temperature overshoot will have no long-term consequences for Arctic sea ice coverage, and hysteresis is not expected (*high confidence*). {3.3.8, 3.4.4.7}

Global mean sea level rise (GMSLR) is projected to be around 0.1 m (0.04 – 0.16 m) less by the end of the 21st century in a 1.5°C warmer world compared to a 2°C warmer world (*medium confidence*). Projected GMSLR for 1.5°C of global warming has an indicative range of 0.26 – 0.77m, relative to 1986–2005, (*medium confidence*). A smaller sea level rise could mean that up to 10.4 million fewer people (based on the 2010 global population and assuming no adaptation) would be exposed to the impacts of sea level rise globally in 2100 at 1.5°C compared to at 2°C. A slower rate of sea level rise enables greater opportunities for adaptation (*medium confidence*). There is *high confidence* that sea level rise will continue beyond 2100. Instabilities exist for both the Greenland and Antarctic ice sheets, which could result in multi-meter rises in sea level on time scales of century to millennia. There is *medium confidence* that these instabilities could be triggered at around 1.5°C to 2°C of global warming. {3.3.9, 3.4.5, 3.6.3}

The ocean has absorbed about 30% of the anthropogenic carbon dioxide, resulting in ocean acidification and changes to carbonate chemistry that are unprecedented for at least the last 65 million years (*high confidence*). Risks have been identified for the survival, calcification, growth, development and abundance of a broad range of marine taxonomic groups, ranging from algae to fish, with substantial evidence of predictable trait-based sensitivities (*high confidence*). There are multiple lines of evidence that ocean warming and acidification corresponding to 1.5°C of global warming would impact a wide range of marine organisms and ecosystems, as well as sectors such as aquaculture and fisheries (*high confidence*). {3.3.10, 3.4.4}

Larger risks are expected for many regions and systems for global warming at 1.5°C, as compared to today, with adaptation required now and up to 1.5°C. However, risks would be larger at 2°C of warming and an even greater effort would be needed for adaptation to a temperature increase of that magnitude (*high confidence*). {3.4, Box 3.4, Box 3.5, Cross-Chapter Box 6 in this chapter}

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[3] Ice free is defined for the Special Report as when the sea ice extent is less than 106 km^2. Ice coverage less than this is considered to be equivalent to an ice-free Arctic Ocean for practical purposes in all recent studies.

Future risks at 1.5°C of global warming will depend on the mitigation pathway and on the possible occurrence of a transient overshoot (*high confidence*). The impacts on natural and human systems would be greater if mitigation pathways temporarily overshoot 1.5°C and return to 1.5°C later in the century, as compared to pathways that stabilize at 1.5°C without an overshoot (*high confidence*). The size and duration of an overshoot would also affect future impacts (e.g., irreversible loss of some ecosystems) (*high confidence*). Changes in land use resulting from mitigation choices could have impacts on food production and ecosystem diversity. {3.6.1, 3.6.2, Cross-Chapter Boxes 7 and 8 in this chapter}

Climate Change Risks for Natural and Human systems

Terrestrial and Wetland Ecosystems

Risks of local species losses and, consequently, risks of extinction are much less in a 1.5°C versus a 2°C warmer world (*high confidence*). The number of species projected to lose over half of their climatically determined geographic range at 2°C global warming (18% of insects, 16% of plants, 8% of vertebrates) is projected to be reduced to 6% of insects, 8% of plants and 4% of vertebrates at 1.5°C warming (*medium confidence*). Risks associated with other biodiversity-related factors, such as forest fires, extreme weather events, and the spread of invasive species, pests and diseases, would also be lower at 1.5°C than at 2°C of warming (*high confidence*), supporting a greater persistence of ecosystem services. {3.4.3, 3.5.2}

Constraining global warming to 1.5°C, rather than to 2°C and higher, is projected to have many benefits for terrestrial and wetland ecosystems and for the preservation of their services to humans (*high confidence*). Risks for natural and managed ecosystems are higher on drylands compared to humid lands. The global terrestrial land area projected to be affected by ecosystem transformations (13%, interquartile range 8–20%) at 2°C is approximately halved at 1.5°C global warming to 4% (interquartile range 2–7%) (*medium confidence*). Above 1.5°C, an expansion of desert terrain and vegetation would occur in the Mediterranean biome (*medium confidence*), causing changes unparalleled in the last 10,000 years (*medium confidence*). {3.3.2.2, 3.4.3.2, 3.4.3.5, 3.4.6.1, 3.5.5.10, Box 4.2}

Many impacts are projected to be larger at higher latitudes, owing to mean and cold-season warming rates above the global average (*medium confidence*). High-latitude tundra and boreal forest are particularly at risk, and woody shrubs are already encroaching into tundra (*high confidence*) and will proceed with further warming. Constraining warming to 1.5°C would prevent the thawing of an estimated permafrost area of 1.5 to 2.5 million km^2 over centuries compared to thawing under 2°C (*medium confidence*). {3.3.2, 3.4.3, 3.4.4}

Ocean Ecosystems

Ocean ecosystems are already experiencing large-scale changes, and critical thresholds are expected to be reached at 1.5°C and higher levels of global warming (*high confidence*). In the transition to 1.5°C of warming, changes to water temperatures are expected to drive some species (e.g., plankton, fish) to relocate to higher latitudes and cause novel ecosystems to assemble (*high confidence*). Other ecosystems (e.g., kelp forests, coral reefs) are relatively less able to move, however, and are projected to experience high rates of mortality and loss (*very high confidence*). For example, multiple lines of evidence indicate that the majority (70–90%) of warm water (tropical) coral reefs that exist today will disappear even if global warming is constrained to 1.5°C (*very high confidence*). {3.4.4, Box 3.4}

Current ecosystem services from the ocean are expected to be reduced at 1.5°C of global warming, with losses being even greater at 2°C of global warming (*high confidence*). The risks of declining ocean productivity, shifts of species to higher latitudes, damage to ecosystems (e.g., coral reefs, and mangroves, seagrass and other wetland ecosystems), loss of fisheries productivity (at low latitudes), and changes to ocean chemistry (e.g., acidification, hypoxia and dead zones) are projected to be substantially lower when global warming is limited to 1.5°C (*high confidence*). {3.4.4, Box 3.4}

Water Resources

The projected frequency and magnitude of floods and droughts in some regions are smaller under 1.5°C than under 2°C of warming (*medium confidence*). Human exposure to increased flooding is projected to be substantially lower at 1.5°C compared to 2°C of global warming, although projected changes create regionally differentiated risks (*medium confidence*). The differences in the risks among regions are strongly influenced by local socio-economic conditions (*medium confidence*). {3.3.4, 3.3.5, 3.4.2}

Risks of water scarcity are projected to be greater at 2°C than at 1.5°C of global warming in some regions (*medium confidence*). Depending on future socio-economic conditions, limiting global warming to 1.5°C, compared to 2°C, may reduce the proportion of the world population exposed to a climate change-induced increase in water stress by up to 50%, although there is considerable variability between regions (*medium confidence*). Regions with particularly large benefits could include the Mediterranean and the Caribbean (*medium confidence*). Socio-economic drivers, however, are expected to have a greater influence on these risks than the changes in climate (*medium confidence*). {3.3.5, 3.4.2, Box 3.5}

Land Use, Food Security and Food Production Systems

Limiting global warming to 1.5°C, compared with 2°C, is projected to result in smaller net reductions in yields of maize, rice, wheat, and potentially other cereal crops, particularly in sub-Saharan Africa, Southeast Asia, and Central and South America; and in the CO_2-dependent nutritional quality of rice and wheat (*high confidence*). A loss of 7–10% of rangeland livestock globally is projected for approximately 2°C of warming, with considerable economic consequences for many communities and regions (*medium confidence*). {3.4.6, 3.6, Box 3.1, Cross-Chapter Box 6 in this chapter}

Reductions in projected food availability are larger at 2°C than at 1.5°C of global warming in the Sahel, southern Africa, the Mediterranean, central Europe and the Amazon (*medium confidence*). This suggests a transition from medium to high risk of regionally differentiated impacts on food security between 1.5°C and 2°C (*medium confidence*). Future economic and trade environments and their response to changing food availability (*medium confidence*) are important potential adaptation options for reducing hunger risk in low- and middle-income countries. {Cross-Chapter Box 6 in this chapter}

Fisheries and aquaculture are important to global food security but are already facing increasing risks from ocean warming and acidification (*medium confidence*). These risks are projected to increase at 1.5°C of global warming and impact key organisms such as fin fish and bivalves (e.g., oysters), especially at low latitudes (*medium confidence*). Small-scale fisheries in tropical regions, which are very dependent on habitat provided by coastal ecosystems such as coral reefs, mangroves, seagrass and kelp forests, are expected to face growing risks at 1.5°C of warming because of loss of habitat (*medium confidence*). Risks of impacts and decreasing food security are projected to become greater as global warming reaches beyond 1.5°C and both ocean warming and acidification increase, with substantial losses likely for coastal livelihoods and industries (e.g., fisheries and aquaculture) (*medium to high confidence*). {3.4.4, 3.4.5, 3.4.6, Box 3.1, Box 3.4, Box 3.5, Cross-Chapter Box 6 in this chapter}

Land use and land-use change emerge as critical features of virtually all mitigation pathways that seek to limit global warming to 1.5°C (*high confidence*). Most least-cost mitigation pathways to limit peak or end-of-century warming to 1.5°C make use of carbon dioxide removal (CDR), predominantly employing significant levels of bioenergy with carbon capture and storage (BECCS) and/or afforestation and reforestation (AR) in their portfolio of mitigation measures (*high confidence*). {Cross-Chapter Box 7 in this chapter}

Large-scale deployment of BECCS and/or AR would have a far-reaching land and water footprint (*high confidence*). Whether this footprint would result in adverse impacts, for example on biodiversity or food production, depends on the existence and effectiveness of measures to conserve land carbon stocks, measures to limit agricultural expansion in order to protect natural ecosystems, and the potential to increase agricultural productivity (*medium agreement*). In addition, BECCS and/or AR would have substantial direct effects on regional climate through biophysical feedbacks, which are generally not included in Integrated Assessments Models (*high confidence*). {3.6.2, Cross-Chapter Boxes 7 and 8 in this chapter}

The impacts of large-scale CDR deployment could be greatly reduced if a wider portfolio of CDR options were deployed, if a holistic policy for sustainable land management were adopted, and if increased mitigation efforts were employed to strongly limit the demand for land, energy and material resources, including through lifestyle and dietary changes (*medium confidence*). In particular, reforestation could be associated with significant co-benefits if implemented in a manner than helps restore natural ecosystems (*high confidence*). {Cross-Chapter Box 7 in this chapter}

Human Health, Well-Being, Cities and Poverty

Any increase in global temperature (e.g., +0.5°C) is projected to affect human health, with primarily negative consequences (*high confidence*). Lower risks are projected at 1.5°C than at 2°C for heat-related morbidity and mortality (*very high confidence*), and for ozone-related mortality if emissions needed for ozone formation remain high (*high confidence*). Urban heat islands often amplify the impacts of heatwaves in cities (*high confidence*). Risks for some vector-borne diseases, such as malaria and dengue fever are projected to increase with warming from 1.5°C to 2°C, including potential shifts in their geographic range (*high confidence*). Overall for vector-borne diseases, whether projections are positive or negative depends on the disease, region and extent of change (*high confidence*). Lower risks of undernutrition are projected at 1.5°C than at 2°C (*medium confidence*). Incorporating estimates of adaptation into projections reduces the magnitude of risks (*high confidence*). {3.4.7, 3.4.7.1, 3.4.8, 3.5.5.8}

Global warming of 2°C is expected to pose greater risks to urban areas than global warming of 1.5°C (*medium confidence*). The extent of risk depends on human vulnerability and the effectiveness of adaptation for regions (coastal and non-coastal), informal settlements and infrastructure sectors (such as energy, water and transport) (*high confidence*). {3.4.5, 3.4.8}

Poverty and disadvantage have increased with recent warming (about 1°C) and are expected to increase for many populations as average global temperatures increase from 1°C to 1.5°C and higher (*medium confidence*). Outmigration in agricultural-dependent communities is positively and statistically significantly associated with global temperature (*medium confidence*). Our understanding of the links of 1.5°C and 2°C of global warming to human migration are limited and represent an important knowledge gap. {3.4.10, 3.4.11, 5.2.2, Table 3.5}

Key Economic Sectors and Services

Risks to global aggregated economic growth due to climate change impacts are projected to be lower at 1.5°C than at 2°C by the end of this century (*medium confidence*). {3.5.2, 3.5.3}

The largest reductions in economic growth at 2°C compared to 1.5°C of warming are projected for low- and middle-income countries and regions (the African continent, Southeast Asia, India, Brazil and Mexico) (*low to medium confidence*). Countries in the tropics and Southern Hemisphere subtropics are projected to experience the largest impacts on economic growth due to climate change should global warming increase from 1.5°C to 2°C (*medium confidence*). {3.5}

Global warming has already affected tourism, with increased risks projected under 1.5°C of warming in specific geographic regions and for seasonal tourism including sun, beach and snow sports destinations (*very high confidence*). Risks will be lower for tourism markets that are less climate sensitive, such as gaming and large hotel-based activities (*high confidence*). Risks for coastal tourism, particularly in subtropical and tropical regions, will increase with temperature-related degradation (e.g., heat extremes, storms) or loss of beach and coral reef assets (*high confidence*). {3.3.6, 3.4.4.12, 3.4.9.1, Box 3.4}

Small Islands, and Coastal and Low-lying areas

Small islands are projected to experience multiple inter-related risks at 1.5°C of global warming that will increase with warming of 2°C and higher levels (*high confidence*). Climate hazards at 1.5°C are projected to be lower compared to those at 2°C (*high confidence*). Long-term risks of coastal flooding and impacts on populations, infrastructures and assets (*high confidence*), freshwater stress (*medium confidence*), and risks across marine ecosystems (*high confidence*) and critical sectors (*medium confidence*) are projected to increase at 1.5°C compared to present-day levels and increase further at 2°C, limiting adaptation opportunities and increasing loss and damage (*medium confidence*). Migration in small islands (internally and internationally) occurs for multiple reasons and purposes, mostly for better livelihood opportunities (*high confidence*) and increasingly owing to sea level rise (*medium confidence*). {3.3.2.2, 3.3.6–9, 3.4.3.2, 3.4.4.2, 3.4.4.5, 3.4.4.12, 3.4.5.3, 3.4.7.1, 3.4.9.1, 3.5.4.9, Box 3.4, Box 3.5}

Impacts associated with sea level rise and changes to the salinity of coastal groundwater, increased flooding and damage to infrastructure, are projected to be critically important in vulnerable environments, such as small islands, low-lying coasts and deltas, at global warming of 1.5°C and 2°C (*high confidence*). Localized subsidence and changes to river discharge can potentially exacerbate these effects. Adaptation is already happening (*high confidence*) and will remain important over multi-centennial time scales. {3.4.5.3, 3.4.5.4, 3.4.5.7, 5.4.5.4, Box 3.5}

Existing and restored natural coastal ecosystems may be effective in reducing the adverse impacts of rising sea levels and intensifying storms by protecting coastal and deltaic regions (*medium confidence*). Natural sedimentation rates are expected to be able to offset the effect of rising sea levels, given the slower rates of sea level rise associated with 1.5°C of warming (*medium confidence*). Other feedbacks, such as landward migration of wetlands and the adaptation of infrastructure, remain important (*medium confidence*). {3.4.4.12, 3.4.5.4, 3.4.5.7}

Increased Reasons for Concern

There are multiple lines of evidence that since AR5 the assessed levels of risk increased for four of the five Reasons for Concern (RFCs) for global warming levels of up to 2°C (*high confidence*). The risk transitions by degrees of global warming are now: from high to very high between 1.5°C and 2°C for RFC1 (Unique and threatened systems) (*high confidence*); from moderate to high risk between 1°C and 1.5°C for RFC2 (Extreme weather events) (*medium confidence*); from moderate to high risk between 1.5°C and 2°C for RFC3 (Distribution of impacts) (*high confidence*); from moderate to high risk between 1.5°C and 2.5°C for RFC4 (Global aggregate impacts) (*medium confidence*); and from moderate to high risk between 1°C and 2.5°C for RFC5 (Large-scale singular events) (*medium confidence*). {3.5.2}

1. **The category 'Unique and threatened systems' (RFC1) display a transition from high to very high risk which is now located between 1.5°C and 2°C of global warming** as opposed to at 2.6°C of global warming in AR5, owing to new and multiple lines of evidence for changing risks for coral reefs, the Arctic and biodiversity in general (*high confidence*). {3.5.2.1}

2. **In 'Extreme weather events' (RFC2), the transition from moderate to high risk is now located between 1.0°C and 1.5°C of global warming,** which is very similar to the AR5 assessment but is projected with greater confidence (*medium confidence*). The impact literature contains little information about the potential for human society to adapt to extreme weather events, and hence it has not been possible to locate the transition from 'high' to 'very high' risk within the context of assessing impacts at 1.5°C versus 2°C of global warming. There is thus *low confidence* in the level at which global warming could lead to very high risks associated with extreme weather events in the context of this report. {3.5}

3. **With respect to the 'Distribution of impacts' (RFC3) a transition from moderate to high risk is now located between 1.5°C and 2°C of global warming,** compared with between 1.6°C and 2.6°C global warming in AR5, owing to new evidence about regionally differentiated risks to food security, water resources, drought, heat exposure and coastal submergence (*high confidence*). {3.5}

4. **In 'global aggregate impacts' (RFC4) a transition from moderate to high levels of risk is now located between 1.5°C and 2.5°C of global warming,** as opposed to at 3.6°C of warming in AR5, owing to new evidence about global aggregate economic impacts and risks to Earth's biodiversity (*medium confidence*). {3.5}

5. **Finally, 'large-scale singular events' (RFC5), moderate risk is now located at 1°C of global warming and high risk is located at 2.5°C of global warming,** as opposed to at 1.6°C (moderate risk) and around 4°C (high risk) in AR5, because of new observations and models of the West Antarctic ice sheet (*medium confidence*). {3.3.9, 3.5.2, 3.6.3}

3.1 About the Chapter

Chapter 3 uses relevant definitions of a potential 1.5°C warmer world from Chapters 1 and 2 and builds directly on their assessment of gradual versus overshoot scenarios. It interacts with information presented in Chapter 2 via the provision of specific details relating to the mitigation pathways (e.g., land-use changes) and their implications for impacts. Chapter 3 also includes information needed for the assessment and implementation of adaptation options (presented in Chapter 4), as well as the context for considering the interactions of climate change with sustainable development and for the assessment of impacts on sustainability, poverty and inequalities at the household to subregional level (presented in Chapter 5).

This chapter is necessarily transdisciplinary in its coverage of the climate system, natural and managed ecosystems, and human systems and responses, owing to the integrated nature of the natural and human experience. While climate change is acknowledged as a centrally important driver, it is not the only driver of risks to human and natural systems, and in many cases, it is the interaction between these two broad categories of risk that is important (Chapter 1).

The flow of the chapter, linkages between sections, a list of chapter- and cross-chapter boxes, and a content guide for reading according to focus or interest are given in Figure 3.1. Key definitions used in the chapter are collected in the Glossary. Confidence language is used throughout this chapter and likelihood statements (e.g., *likely*, *very likely*) are provided when there is *high confidence* in the assessment.

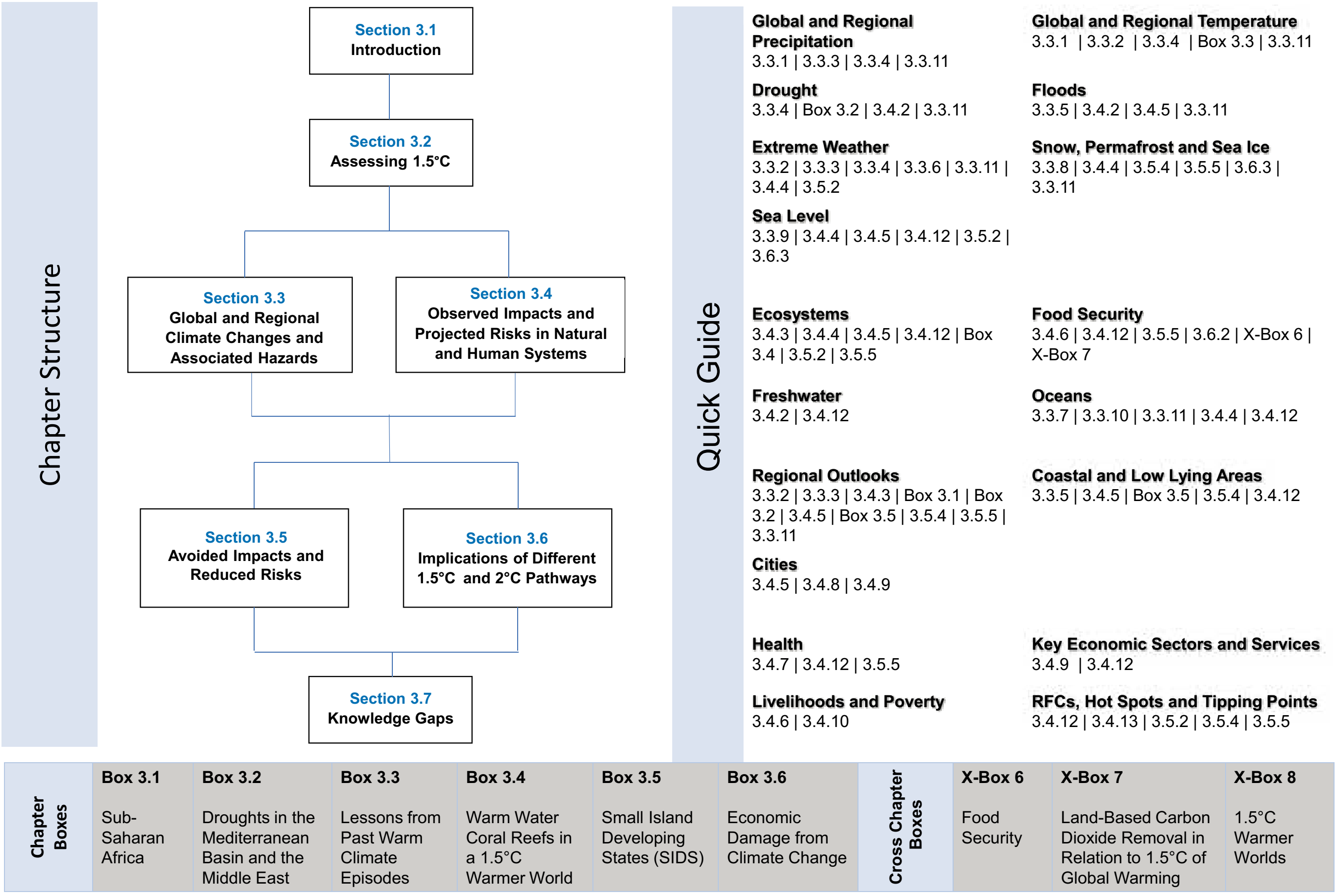


Figure 3.1 | Chapter 3 structure and quick guide.

The underlying literature assessed in Chapter 3 is broad and includes a large number of recent publications specific to assessments for 1.5°C of warming. The chapter also utilizes information covered in prior IPCC special reports, for example the Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX; IPCC, 2012), and many chapters from the IPCC WGII Fifth Assessment Report (AR5) that assess impacts on natural and managed ecosystems and humans, as well as adaptation options (IPCC, 2014b). For this reason, the chapter provides information based on a broad range of assessment methods. Details about the approaches used are presented in Section 3.2.

Section 3.3 gives a general overview of recent literature on observed climate change impacts as the context for projected future risks. With a few exceptions, the focus here is the analysis of transient responses at 1.5°C and 2°C of global warming, with simulations *of short-term stabilization scenarios* (Section 3.2) also assessed in some cases. In general, *long-term equilibrium stabilization responses* could not be assessed owing to a lack of data and analysis. A detailed analysis of detection and attribution is not provided but will be the focus of the next IPCC assessment report (AR6). Furthermore, possible interventions in the climate system through radiation modification measures, which are not tied to reductions of greenhouse gas emissions or concentrations, are not assessed in this chapter.

Understanding the observed impacts and projected risks of climate change is crucial to comprehending how the world is likely to change under global warming of 1.5°C above temperatures in the pre-industrial period (with reference to 2°C). Section 3.4 explores the new literature and updates the assessment of impacts and projected risks for a large number of natural and human systems. By also exploring adaptation opportunities, where the literature allows, the section prepares the reader for discussions in subsequent chapters about opportunities to tackle both mitigation and adaptation. The section is mostly globally focused because of limited research on regional risks and adaptation options at 1.5°C and 2°C. For example, the risks of 1.5°C and 2°C of warming in urban areas, as well as the risks of health outcomes under these two warming scenarios (e.g. climate-related diseases, air quality impacts and mental health problems), were not considered because of a lack of projections of how these risks might change in a 1.5°C or 2°C warmer world. In addition, the complexity of many interactions of climate change with drivers of poverty, along with a paucity of relevant studies, meant it was not possible to detect and attribute many dimensions of poverty and disadvantage to climate change. Even though there is increasing documentation of climate-related impacts on places where indigenous people live and where subsistence-oriented communities are found, relevant projections of the risks associated with warming of 1.5°C and 2°C are necessarily limited.

To explore avoided impacts and reduced risks at 1.5°C compared with at 2°C of global warming, the chapter adopts the AR5 'Reasons for Concern' aggregated projected risk framework (Section 3.5). Updates in terms of the aggregation of risks are informed by the most recent literature and the assessments offered in Sections 3.3 and 3.4, with a focus on the impacts at 2°C of warming that could potentially be avoided if warming were constrained to 1.5°C. Economic benefits that would be obtained (Section 3.5.3), climate change 'hotspots' that could be avoided or reduced (Section 3.5.4 as guided by the assessments of Sections 3.3, 3.4 and 3.5), and tipping points that could be circumvented (Section 3.5.5) at 1.5°C compared to higher degrees of global warming are all examined. The latter assessments are, however, constrained to regional analyses, and hence this particular section does not include an assessment of specific losses and damages.

Section 3.6 provides an overview on specific aspects of the mitigation pathways considered compatible with 1.5°C of global warming, including some scenarios involving temperature overshoot above 1.5°C global warming during the 21st century. Non-CO_2 implications and projected risks of mitigation pathways, such as changes to land use and atmospheric compounds, are presented and explored. Finally, implications for sea ice, sea level and permafrost beyond the end of the century are assessed.

The exhaustive assessment of literature specific to global warming of 1.5°C above the pre-industrial period, presented across all the sections in Chapter 3, highlights knowledge gaps resulting from the heterogeneous information available across systems, regions and sectors. Some of these gaps are described in Section 3.7.

3.2 How are Risks at 1.5°C and Higher Levels of Global Warming Assessed in this Chapter?

The methods that are applied for assessing observed and projected changes in climate and weather are presented in Section 3.2.1, while those used for assessing the observed impacts on and projected risks to natural and managed systems, and to human settlements, are described in Section 3.2.2. Given that changes in climate associated with 1.5°C of global warming were not the focus of past IPCC reports, dedicated approaches based on recent literature that are specific to the present report are also described. Background on specific methodological aspects (climate model simulations available for assessments at 1.5°C global warming, attribution of observed changes in climate and their relevance for assessing projected changes at 1.5°C and 2°C global warming, and the propagation of uncertainties from climate forcing to impacts on ecosystems) are provided in the Supplementary Material 3.SM.

3.2.1 How are Changes in Climate and Weather at 1.5°C versus Higher Levels of Warming Assessed?

Evidence for the assessment of changes to climate at 1.5°C versus 2°C can be drawn both from observations and model projections. Global mean surface temperature (GMST) anomalies were about +0.87°C (±0.10°C likely range) above pre-industrial industrial (1850–1900) values in the 2006-–2015 decade, with a recent warming of about 0.2°C (±0.10°C) per decade (Chapter 1). Human-induced global warming reached approximately 1°C (±0.2°C *likely* range) in 2017 (Chapter 1). While some of the observed trends may be due to internal climate variability, methods of detection and attribution can be applied to assess which part of the observed changes may be attributed to anthropogenic forcing (Bindoff et al., 2013b). Hence, evidence from attribution studies can be used to assess changes in the climate system that are already detectable at lower levels of global warming and would thus continue to change with a further 0.5°C or 1°C of global warming (see Supplementary Material 3.SM.1 and Sections 3.3.1, 3.3.2, 3.3.3, 3.3.4 and 3.3.11). A recent study identified significant changes in extremes for a 0.5°C difference in global warming based on the historical record (Schleussner et al., 2017). It should also be noted that attributed changes in extremes since 1950 that were reported in the IPCC AR5 report (IPCC, 2013) generally correspond to changes in global warming of about 0.5°C (see 3.SM.1)

Climate model simulations are necessary for the investigation of the response of the climate system to various forcings, in particular to forcings associated with higher levels of greenhouse gas concentrations. Model simulations include experiments with global and regional climate models, as well as impact models – driven with output from climate models – to evaluate the risk related to climate change for natural and human systems (Supplementary Material 3.SM.1). Climate model simulations were generally used in the context of particular 'climate scenarios' from previous IPCC reports (e.g., IPCC, 2007, 2013). This means that emissions scenarios (IPCC, 2000) were used to drive climate models, providing different projections for given emissions pathways. The results were consequently used in a 'storyline' framework, which presents the development of climate in the course of the 21st century and beyond for a given emissions pathway. Results were assessed for different time slices within the model projections such as 2016–2035 ('near term', which is slightly below a global warming of 1.5°C according to most scenarios, Kirtman et al., 2013), 2046–2065 (mid-21st century, Collins et al., 2013), and 2081–2100 (end of 21st century, Collins et al., 2013). Given that this report focuses on climate change for a given mean global temperature response (1.5°C or 2°C), methods of analysis had to be developed and/or adapted from previous studies in order to provide assessments for the specific purposes here.

A major challenge in assessing climate change under 1.5°C, or 2°C (and higher levels), of global warming pertains to the **definition of a '1.5°C or 2°C climate projection'** (see also Cross-Chapter Box 8 in this chapter). Resolving this challenge includes the following considerations:

A. The need to distinguish between (i) **transient climate responses** (i.e., those that 'pass through' 1.5°C or 2°C of global warming), (ii) **short-term stabilization responses** (i.e., scenarios for the late 21st century that result in stabilization at a mean global warming of 1.5°C or 2°C by 2100), and (iii) **long-term equilibrium stabilization responses** (i.e., those occurring after several millennia once climate (temperature) equilibrium at 1.5°C or 2°C is reached). These responses can be very different in terms of climate variables and the inertia associated with a given climate forcing. A striking example is sea level rise (SLR). In this case, projected increases within the 21st century are minimally dependent on the scenario considered, yet they stabilize at very different levels for a long-term warming of 1.5°C versus 2°C (Section 3.3.9).

B. The '1.5°C or 2°C emissions scenarios' presented in Chapter 2 are targeted to hold warming below 1.5°C or 2°C with a certain probability (generally two-thirds) over the course, or at the end, of the 21st century. These scenarios should be seen as the operationalization of 1.5°C or 2°C warmer worlds. However, when these emission scenarios are used to drive climate models, some of the resulting simulations lead to warming above these respective thresholds (typically with a probability of one-third, see Chapter 2 and Cross-Chapter Box 8 in this chapter). This is due both to discrepancies between models and to internal climate variability. For this reason, the climate outcome for any of these scenarios, even those excluding an overshoot (see next point, C.), include some probability of reaching a global climate warming of more than 1.5°C or 2°C. Hence, a comprehensive assessment of climate risks associated with '1.5°C or 2°C climate scenarios' needs to include consideration of higher levels of warming (e.g., up to 2.5°C to 3°C, see Chapter 2 and Cross-Chapter Box 8 in this chapter).

C. Most of the '1.5°C scenarios', and some of the '2°C emissions scenarios' presented in Chapter 2 include a temperature overshoot during the course of the 21st century. This means that median temperature projections under these scenarios exceed the target warming levels over the course of the century (typically 0.5°C–1°C higher than the respective target levels at most), before warming returns to below 1.5°C or 2°C by 2100. During the overshoot phase, impacts would therefore correspond to higher transient temperature increases than 1.5°C or 2°C. For this reason, impacts of transient responses at these higher warming levels are also partly addressed in Cross-Chapter Box 8 in this chapter (on a 1.5°C warmer world), and some analyses for changes in extremes are also presented for higher levels of warming in Section 3.3 (Figures 3.5, 3.6, 3.9, 3.10, 3.12 and 3.13). Most importantly, different overshoot scenarios may have very distinct impacts depending on (i) the peak temperature of the overshoot, (ii) the length of the overshoot period, and (iii) the associated rate of change in global temperature over the time period of the overshoot. While some of these issues are briefly addressed in Sections 3.3 and 3.6, and in the Cross-Chapter Box 8, the definition of overshoot and related questions will need to be more comprehensively addressed in the IPCC AR6 report.

D. The levels of global warming that are the focus of this report (1.5°C and 2°C) are measured relative to the pre-industrial period. This definition requires an agreement on the exact reference time period (for 0°C of warming) and the time frame over which the global warming is assessed, typically 20 to 30 years in length. As discussed in Chapter 1, a climate with 1.5°C global warming is one in which temperatures averaged over a multi-decade time scale are 1.5°C above those in the pre-industrial reference period. Greater detail is provided in Cross-Chapter Box 8 in this chapter. Inherent to this is the observation that the mean temperature of a '1.5°C warmer world' can be regionally and temporally much higher (e.g., with regional annual temperature extremes involving warming of more than 6°C; see Section 3.3 and Cross-Chapter Box 8 in this chapter).

E. The interference of factors unrelated to greenhouse gases with mitigation pathways can strongly affect regional climate. For example, biophysical feedbacks from changes in land use and irrigation (e.g., Hirsch et al., 2017; Thiery et al., 2017), or projected changes in short-lived pollutants (e.g., Z. Wang et al., 2017), can have large influences on local temperatures and climate conditions. While these effects are not explicitly integrated into the scenarios developed in Chapter 2, they may affect projected changes in climate under 1.5°C of global warming. These issues are addressed in more detail in Section 3.6.2.2.

The assessment presented in the current chapter largely focuses on the analysis of **transient responses in climate at 1.5°C versus 2°C** and higher levels of global warming (see point A. above and Section 3.3). It generally uses the empirical scaling relationship (ESR) approach (Seneviratne et al., 2018c), also termed the 'time sampling' approach (James et al., 2017), which consists of sampling the response at 1.5°C and other levels of global warming from all available global climate model scenarios for the 21st century (e.g., Schleussner et al., 2016b;

Seneviratne et al., 2016; Wartenburger et al., 2017). The ESR approach focuses more on the derivation of a continuous relationship, while the term 'time sampling' is more commonly used when comparing a limited number of warming levels (e.g., 1.5°C versus 2°C). A similar approach in the case of regional climate model (RCM) simulations consists of sampling the RCM model output corresponding to the time frame at which the driving general circulation model (GCM) reaches the considered temperature level, for example, as done within IMPACT2C (Jacob and Solman, 2017), see description in Vautard et al. (2014). As an alternative to the ESR or time sampling approach, pattern scaling may be used. Pattern scaling is a statistical approach that describes relationships of specific climate responses as a function of global temperature change. Some assessments presented in this chapter are based on this method. The disadvantage of pattern scaling, however, is that the relationship may not perfectly emulate the models' responses at each location and for each global temperature level (James et al., 2017). Expert judgement is a third methodology that can be used to assess probable changes at 1.5°C or 2°C of global warming by combining changes that have been attributed to the observed time period (corresponding to warming of 1°C or less if assessed over a shorter period) with known projected changes at 3°C or 4°C above pre-industrial temperatures (Supplementary Material 3.SM.1). In order to assess effects induced by a 0.5°C difference in global warming, the historical record can be used at first approximation as a proxy, meaning that conditions are compared for two periods that have a 0.5°C difference in GMST warming (such as 1991–2010 and 1960–1979, e.g., Schleussner et al., 2017). This in particular also applies to attributed changes in extremes since 1950 that were reported in the IPCC AR5 report (IPCC, 2013; see also 3.SM.1). Using observations, however, it is not possible to account for potential non-linear changes that could occur above 1°C of global warming or as 1.5°C of warming is reached.

In some cases, assessments of **short-term stabilization responses** are also presented, derived using a subset of model simulations that reach a given temperature limit by 2100, or driven by sea surface temperature (SST) values consistent with such scenarios. This includes new results from the 'Half a degree additional warming, prognosis and projected impacts' (HAPPI) project (Section 1.5.2; Mitchell et al., 2017). Notably, there is evidence that for some variables (e.g., temperature and precipitation extremes), responses after short-term stabilization (i.e., approximately equivalent to the RCP2.6 scenario) are very similar to the transient response of higher-emissions scenarios (Seneviratne et al., 2016, 2018c; Wartenburger et al., 2017; Tebaldi and Knutti, 2018). This is, however, less the case for mean precipitation (e.g., Pendergrass et al., 2015), for which other aspects of the emissions scenarios appear relevant.

For the assessment of **long-term equilibrium stabilization responses**, this chapter uses results from existing simulations where available (e.g., for sea level rise), although the available data for this type of projection is limited for many variables and scenarios and will need to be addressed in more depth in the IPCC AR6 report.

Supplementary Material 3.SM.1 of this chapter includes further details of the climate models and associated simulations that were used to support the present assessment, as well as a background on detection and attribution approaches of relevance to assessing changes in climate at 1.5°C of global warming.

3.2.2 How are Potential Impacts on Ecosystems Assessed at 1.5°C versus Higher Levels of Warming?

Considering that the impacts observed so far are for a global warming lower than 1.5°C (generally up to the 2006–2015 decade, i.e., for a global warming of 0.87°C or less; see above), direct information on the impacts of a global warming of 1.5°C is not yet available. The global distribution of observed impacts shown in AR5 (Cramer et al., 2014), however, demonstrates that methodologies now exist which are capable of detecting impacts on systems strongly influenced by factors (e.g., urbanization and human pressure in general) or where climate may play only a secondary role in driving impacts. Attribution of observed impacts to greenhouse gas forcing is more rarely performed, but a recent study (Hansen and Stone, 2016) shows that most of the detected temperature-related impacts that were reported in AR5 (Cramer et al., 2014) can be attributed to anthropogenic climate change, while the signals for precipitation-induced responses are more ambiguous.

One simple approach for assessing possible impacts on natural and managed systems at 1.5°C versus 2°C consists of identifying impacts of a global 0.5°C of warming in the observational record (e.g., Schleussner et al., 2017) assuming that the impacts would scale linearly for higher levels of warming (although this may not be appropriate). Another approach is to use conclusions from analyses of past climates combined with modelling of the relationships between climate drivers and natural systems (Box 3.3). A more complex approach relies on laboratory or field experiments (Dove et al., 2013; Bonal et al., 2016), which provide useful information on the causal effect of a few factors, which can be as diverse as climate, greenhouse gases (GHG), management practices, and biological and ecological variables, on specific natural systems that may have unusual physical and chemical characteristics (e.g., Fabricius et al., 2011; Allen et al., 2017). This last approach can be important in helping to develop and calibrate impact mechanisms and models through empirical experimentation and observation.

Risks for natural and human systems are often assessed with impact models where climate inputs are provided by representative concentration pathway (RCP)-based climate projections. The number of studies projecting impacts at 1.5°C or 2°C of global warming has increased in recent times (see Section 3.4), even if the four RCP scenarios used in AR5 are not strictly associated with these levels of global warming. Several approaches have been used to extract the required climate scenarios, as described in Section 3.2.1. As an example, Schleussner et al. (2016b) applied a time sampling (or ESR) approach, described in Section 3.2.1, to estimate the differential effect of 1.5°C and 2°C of global warming on water availability and impacts on agriculture using an ensemble of simulations under the RCP8.5 scenario. As a further example using a different approach, Iizumi et al. (2017) derived a 1.5°C scenario from simulations with a crop model using an interpolation between the no-change (approximately 2010) conditions and the RCP2.6 scenario (with a global warming of 1.8°C in 2100), and they derived the corresponding 2°C scenario from RCP2.6 and RCP4.5 simulations in 2100. The Inter-Sectoral Impact Model

Integration and Intercomparison Project Phase 2 (ISIMIP2; Frieler et al., 2017) extended this approach to investigate a number of sectoral impacts on terrestrial and marine ecosystems. In most cases, risks are assessed by impact models coupled offline to climate models after bias correction, which may modify long-term trends (Grillakis et al., 2017).

Assessment of local impacts of climate change necessarily involves a change in scale, such as from the global scale to that of natural or human systems (Frieler et al., 2017; Reyer et al., 2017d; Jacob et al., 2018). An appropriate method of downscaling (Supplementary Material 3.SM.1) is crucial for translating perspectives on 1.5°C and 2°C of global warming to scales and impacts relevant to humans and ecosystems. A major challenge associated with this requirement is the correct reproduction of the variance of local to regional changes, as well as the frequency and amplitude of extreme events (Vautard et al., 2014). In addition, maintaining physical consistency between downscaled variables is important but challenging (Frost et al., 2011).

Another major challenge relates to the propagation of the uncertainties at each step of the methodology, from the global forcings to the global climate and from regional climate to impacts at the ecosystem level, considering local disturbances and local policy effects. The risks for natural and human systems are the result of complex combinations of global and local drivers, which makes quantitative uncertainty analysis difficult. Such analyses are partly done using multimodel approaches, such as multi-climate and multi-impact models (Warszawski et al., 2013, 2014; Frieler et al., 2017). In the case of crop projections, for example, the majority of the uncertainty is caused by variation among crop models rather than by downscaling outputs of the climate models used (Asseng et al., 2013). Error propagation is an important issue for coupled models. Dealing correctly with uncertainties in a robust probabilistic model is particularly important when considering the potential for relatively small changes to affect the already small signal associated with 0.5°C of global warming (Supplementary Material 3.SM.1). The computation of an impact per unit of climatic change, based either on models or on data, is a simple way to present the probabilistic ecosystem response while taking into account the various sources of uncertainties (Fronzek et al., 2011).

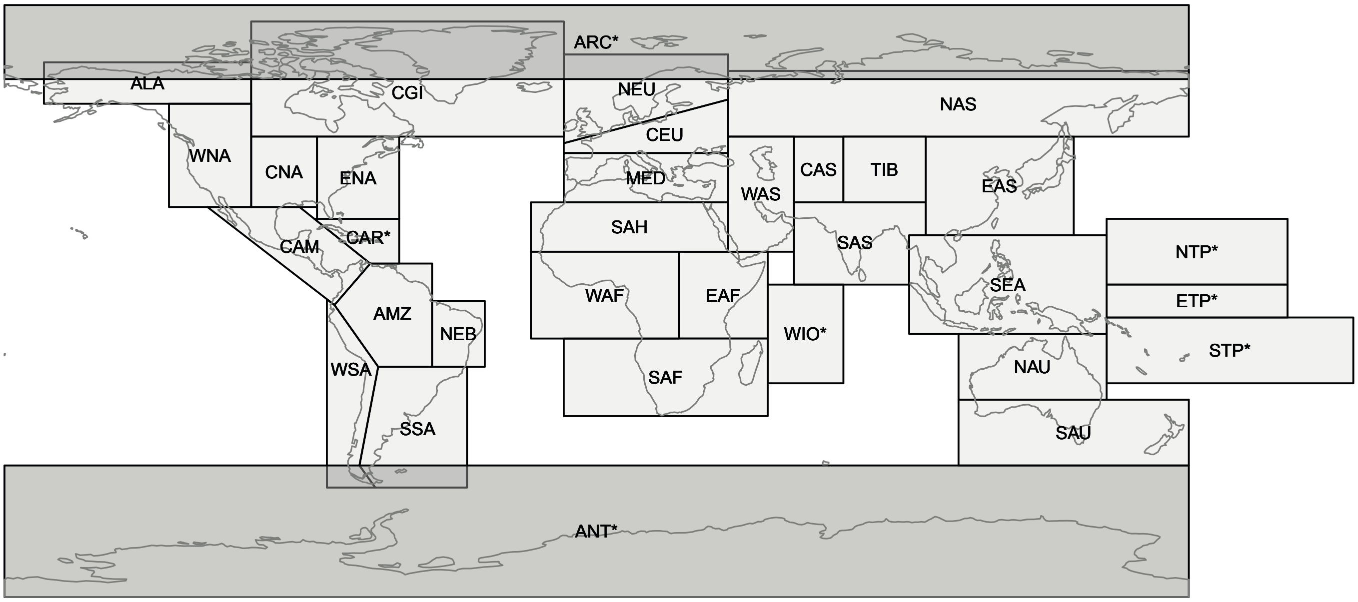
In summary, in order to assess risks at 1.5°C and higher levels of global warming, several things need to be considered. Projected climates under 1.5°C of global warming differ depending on temporal aspects and emission pathways. Considerations include whether global temperature is (i) temporarily at this level (i.e., is a transient phase on its way to higher levels of warming), (ii) arrives at 1.5°C, with or without overshoot, after stabilization of greenhouse gas concentrations, or (iii) is at this level as part of long-term climate equilibrium (complete only after several millennia). Assessments of impacts of 1.5°C of warming are generally based on climate simulations for these different possible pathways. Most existing data and analyses focus on transient impacts (i). Fewer data are available for dedicated climate model simulations that are able to assess pathways consistent with (ii), and very few data are available for the assessment of changes at climate equilibrium (iii). In some cases, inferences regarding the impacts of further warming of 0.5°C above present-day temperatures (i.e., 1.5°C of global warming) can also be drawn from observations of similar sized changes (0.5°C) that have occurred in the past, such as during the last 50 years. However, impacts can only be partly inferred from these types of observations, given the strong possibility of non-linear changes, as well as lag effects for some climate variables (e.g., sea level rise, snow and ice melt). For the impact models, three challenges are noted about the coupling procedure: (i) the bias correction of the climate model, which may modify the simulated response of the ecosystem, (ii) the necessity to downscale the climate model outputs to reach a pertinent scale for the ecosystem without losing physical consistency of the downscaled climate fields, and (iii) the necessity to develop an integrated study of the uncertainties.

3.3 Global and Regional Climate Changes and Associated Hazards

This section provides the assessment of changes in climate at 1.5°C of global warming relative to changes at higher global mean temperatures. Section 3.3.1 provides a brief overview of changes to global climate. Sections 3.3.2–3.3.11 provide assessments for specific aspects of the climate system, including regional assessments for temperature (Section 3.3.2) and precipitation (Section 3.3.3) means and extremes. Analyses of regional changes are based on the set of regions displayed in Figure 3.2. A synthesis of the main conclusions of this section is provided in Section 3.3.11. The section builds upon assessments from the IPCC AR5 WGI report (Bindoff et al., 2013a; Christensen et al., 2013; Collins et al., 2013; Hartmann et al., 2013; IPCC, 2013) and Chapter 3 of the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX; Seneviratne et al., 2012), as well as a substantial body of new literature related to projections of climate at 1.5°C and 2°C of warming above the pre-industrial period (e.g., Vautard et al., 2014; Fischer and Knutti, 2015; Schleussner et al., 2016b, 2017; Seneviratne et al., 2016, 2018c; Déqué et al., 2017; Maule et al., 2017; Mitchell et al., 2017, 2018a; Wartenburger et al., 2017; Zaman et al., 2017; Betts et al., 2018; Jacob et al., 2018; Kharin et al., 2018; Wehner et al., 2018b). The main assessment methods are as already detailed in Section 3.2.

3.3.1 Global Changes in Climate

There is *high confidence* that the increase in global mean surface temperature (GMST) has reached 0.87°C (±0.10°C *likely* range) above pre-industrial values in the 2006–2015 decade (Chapter 1). AR5 assessed that the globally averaged temperature (combined over land and ocean) displayed a warming of about 0.85°C [0.65°C to 1.06°C] during the period 1880–2012, with a large fraction of the detected global warming being attributed to anthropogenic forcing (Bindoff et al., 2013a; Hartmann et al., 2013; Stocker et al., 2013). While new evidence has highlighted that sampling biases and the choice of approaches used to estimate GMST (e.g., using water versus air temperature over oceans and using model simulations versus observations-based estimates) can affect estimates of GMST increase (Richardson et al., 2016; see also Supplementary Material 3.SM.2), the present assessment is consistent with that of AR5 regarding a detectable and dominant effect of anthropogenic forcing on observed trends in global temperature (also confirmed in Ribes et al., 2017). As highlighted in Chapter 1, human-induced warming



Abbreviation	Name	Abbreviation	Name	Abbreviation	Name	Abbreviation	Name
ALA	Alaska/N.W. Canada	CNA	Central North America	NEU	North Europe	TIB	Tibetan Plateau
AMZ	Amazon	EAF	East Africa	NTP*	Pacific Islands region[2]	WAF	West Africa
ANT*	Antarctica	EAS	East Asia	SAF	Southern Africa	WAS	West Asia
ARC*	Arctic	ENA	East North America	SAH	Sahara	WIO*	West Indian Ocean
CAM	Central America/Mexico	ETP*	Pacific Islands region[3]	SAS	South Asia	WNA	West North America
CAR*	small islands regions Caribbean	MED	South Europe/Mediterranean	SAU	South Australia/New Zealand	WSA	West Coast South America
CAS	Central Asia	NAS	North Asia	SEA	Southeast Asia		
CEU	Central Europe	NAU	North Australia	SSA	Southeastern South America		
CGI	Canada/Greenland/Iceland	NEB	North−East Brazil	STP*	Southern Topical Pacific		

Figure 3.2 | Regions used for regional analyses provided in Section 3.3. The choice of regions is based on the IPCC Fifth Assessment Report (AR5, Chapter 14, Christensen et al., 2013 and Annex 1: Atlas) and the Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX, Chapter 3, Seneviratne et al., 2012), with seven additional regions in the Arctic, Antarctic and islands not included in the IPCC SREX report (indicated with asterisks). Analyses for regions with asterisks are provided in the Supplementary Material 3.SM.2

reached approximately 1°C (±0.2°C *likely* range) in 2017. More background on recent observed trends in global climate is provided in the Supplementary Material 3.SM.2.

A global warming of 1.5°C implies higher mean temperatures compared to during pre-industrial times in almost all locations, both on land and in oceans (*high confidence*) (Figure 3.3). In addition, a global warming of 2°C versus 1.5°C results in robust differences in the mean temperatures in almost all locations, both on land and in the ocean (*high confidence*). The land–sea contrast in warming is important and implies particularly large changes in temperature over land, with mean warming of more than 1.5°C in most land regions (*high confidence;* see Section 3.3.2 for more details). The largest increase in mean temperature is found in the high latitudes of the Northern Hemisphere (*high confidence*; Figure 3.3, see Section 3.3.2 for more details). Projections for precipitation are more uncertain, but they highlight robust increases in mean precipitation in the Northern Hemisphere high latitudes at 1.5°C global warming versus pre-industrial conditions, as well as at 2°C global warming versus pre-industrial conditions (*high confidence*) (Figure 3.3). There are consistent but less robust signals when comparing changes in mean precipitation at 2°C versus 1.5°C of global warming. Hence, it is assessed that there is *medium confidence* in an increase of mean precipitation in high-latitudes at 2°C versus 1.5°C of global warming (Figure 3.3). For droughts, changes in evapotranspiration and precipitation timing are also relevant (see Section 3.3.4). Figure 3.4 displays changes in temperature extremes (the hottest daytime temperature of the year, TXx, and the coldest night-time temperature of the year, TNn) and heavy precipitation (the annual maximum 5-day precipitation, Rx5day). These analyses reveal distinct patterns of changes, with the largest changes in TXx occurring on mid-latitude land and the largest changes in TNn occurring at high latitudes (both on land and in oceans). Differences in TXx and TNn compared to pre-industrial climate are robust at both global warming levels. Differences in TXx and TNn at 2°C versus 1.5°C of global warming are robust across most of the globe. Changes in heavy precipitation

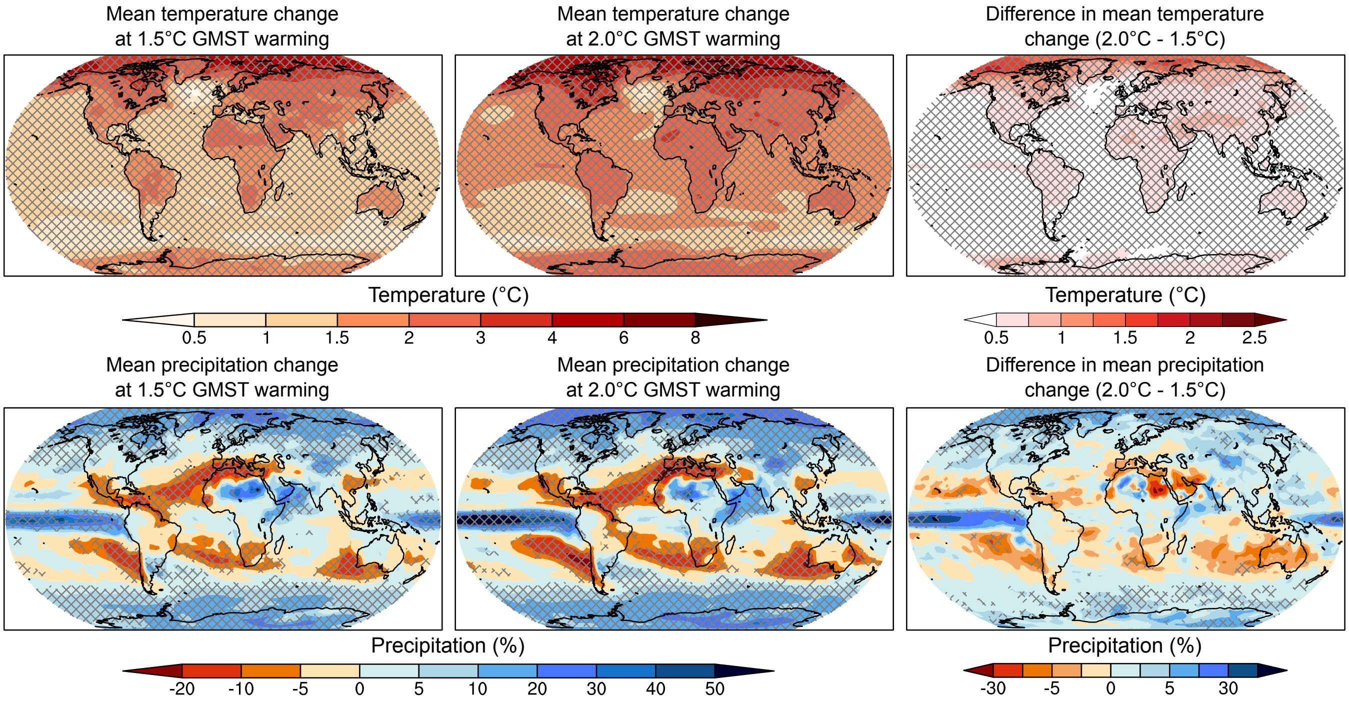


Figure 3.3 | Projected changes in mean temperature (top) and mean precipitation (bottom) at 1.5°C (left) and 2°C (middle) of global warming compared to the pre-industrial period (1861–1880), and the difference between 1.5°C and 2°C of global warming (right). Cross-hatching highlights areas where at least two-thirds of the models agree on the sign of change as a measure of robustness (18 or more out of 26). Values were assessed from the transient response over a 10-year period at a given warming level, based on Representative Concentration Pathway (RCP)8.5 Coupled Model Intercomparison Project Phase 5 (CMIP5) model simulations (adapted from Seneviratne et al., 2016 and Wartenburger et al., 2017, see Supplementary Material 3.SM.2 for more details). Note that the responses at 1.5°C of global warming are similar for RCP2.6 simulations (see Supplementary Material 3.SM.2). Differences compared to 1°C of global warming are provided in the Supplementary Material 3.SM.2.

are less robust, but particularly strong increases are apparent at high latitudes as well as in the tropics at both 1.5°C and 2°C of global warming compared to pre-industrial conditions. The differences in heavy precipitation at 2°C versus 1.5°C global warming are generally not robust at grid-cell scale, but they display consistent increases in most locations (Figure 3.4). However, as addressed in Section 3.3.3, statistically significant differences are found in several large regions and when aggregated over the global land area. We thus assess that there is *high confidence* regarding global-scale differences in temperature means and extremes at 2°C versus 1.5°C global warming, and *medium confidence* regarding global-scale differences in precipitation means and extremes. Further analyses, including differences at 1.5°C and 2°C global warming versus 1°C (i.e., present-day) conditions are provided in the Supplementary Material 3.SM.2.

These projected changes at 1.5°C and 2°C of global warming are consistent with the attribution of observed historical global trends in temperature and precipitation means and extremes (Bindoff et al., 2013a), as well as with some observed changes under the recent global warming of 0.5°C (Schleussner et al., 2017). These comparisons are addressed in more detail in Sections 3.3.2 and 3.3.3. Attribution studies have shown that there is *high confidence* that anthropogenic forcing has had a detectable influence on trends in global warming (*virtually certain* since the mid-20th century), in land warming on all continents except Antarctica (*likely* since the mid-20th century), in ocean warming since 1970 (*very likely*), and in increases in hot extremes and decreases in cold extremes since the mid-20th century (*very likely*) (Bindoff et al., 2013a). In addition, there is *medium confidence* that anthropogenic forcing has contributed to increases in mean precipitation at high latitudes in the Northern Hemisphere since the mid-20th century and to global-scale increases in heavy precipitation in land regions with sufficient observations over the same period (Bindoff et al., 2013a). Schleussner et al. (2017) showed, through analyses of recent observed tendencies, that changes in temperature extremes and heavy precipitation indices are detectable in observations for the 1991–2010 period compared with those for 1960–1979, with a global warming of approximately 0.5°C occurring between these two periods (*high confidence*). The observed tendencies over that time frame are thus consistent with attributed changes since the mid-20th century (*high confidence*).

The next sections assess changes in several different types of climate-related hazards. It should be noted that the different types of hazards are considered in isolation but some regions are projected to be affected by collocated and/or concomitant changes in several types of hazards (*high confidence*). Two examples are sea level rise and heavy precipitation in some regions, possibly leading together to more flooding, and droughts and heatwaves, which can together increase the risk of fire occurrence. Such events, also called compound events, may substantially increase risks in some regions (e.g., AghaKouchak et al., 2014; Van Den Hurk et al., 2015; Martius et al., 2016; Zscheischler et al., 2018). A detailed assessment of physically-defined compound events was not possible as part of this report, but aspects related to overlapping multi-sector risks are highlighted in Sections 3.4 and 3.5.

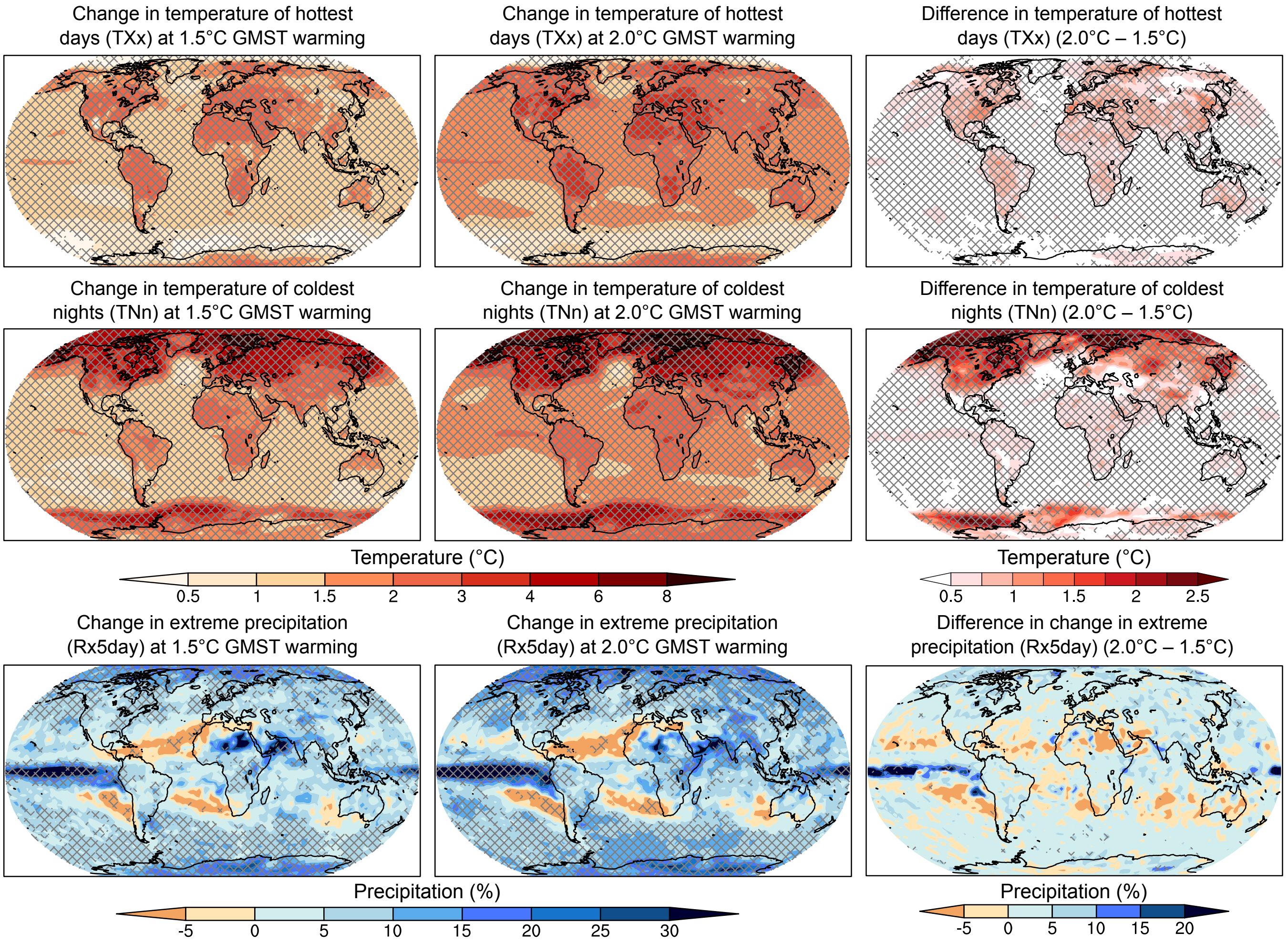


Figure 3.4 | Projected changes in extremes at 1.5°C (left) and 2°C (middle) of global warming compared to the pre-industrial period (1861–1880), and the difference between 1.5°C and 2°C of global warming (right). Cross-hatching highlights areas where at least two-thirds of the models agree on the sign of change as a measure of robustness (18 or more out of 26): temperature of annual hottest day (maximum temperature), TXx (top), and temperature of annual coldest night (minimum temperature), TNn (middle), and annual maximum 5-day precipitation, Rx5day (bottom). The underlying methodology and data basis are the same as for Figure 3.3 (see Supplementary Material 3.SM.2 for more details). Note that the responses at 1.5°C of global warming are similar for Representative Concentration Pathway (RCP)2.6 simulations (see Supplementary Material 3.SM.2). Differences compared to 1°C of global warming are provided in the Supplementary Material 3.SM.2.

3.3.2 Regional Temperatures on Land, Including Extremes

3.3.2.1 Observed and attributed changes in regional temperature means and extremes

While the quality of temperature measurements obtained through ground observational networks tends to be high compared to that of measurements for other climate variables (Seneviratne et al., 2012), it should be noted that some regions are undersampled. Cowtan and Way (2014) highlighted issues regarding undersampling, which is most problematic at the poles and over Africa, and which may lead to biases in estimated changes in GMST (see also Supplementary Material 3.SM.2 and Chapter 1). This undersampling also affects the confidence of assessments regarding regional observed and projected changes in both mean and extreme temperature. Despite this partly limited coverage, the attribution chapter of AR5 (Bindoff et al., 2013a) and recent papers (e.g., Sun et al., 2016; Wan et al., 2018) assessed that, over every continental region and in many sub-continental regions, anthropogenic influence has made a substantial contribution to surface temperature increases since the mid-20th century.

Based on the AR5 and SREX, as well as recent literature (see Supplementary Material 3.SM), there is *high confidence* (*very likely*) that there has been an overall decrease in the number of cold days and nights and an overall increase in the number of warm days and nights at the global scale on land. There is also *high confidence* (*likely*) that consistent changes are detectable on the continental scale in North America, Europe and Australia. There is *high confidence* that these observed changes in temperature extremes can be attributed to anthropogenic forcing (Bindoff et al., 2013a). As highlighted in Section 3.2, the observational record can be used to assess past changes associated with a global warming of 0.5°C. Schleussner et al. (2017) used this approach to assess observed changes in extreme indices for the 1991–2010 versus the 1960–1979 period, which corresponds to just about a 0.5°C GMST difference in the observed record (based on the Goddard Institute for Space Studies Surface Temperature Analysis

(GISTEMP) dataset, Hansen et al., 2010). They found that substantial changes due to 0.5°C of warming are apparent for indices related to hot and cold extremes, as well as for the Warm Spell Duration Indicator (WSDI). In particular, they identified that one-quarter of the land has experienced an intensification of hot extremes (maximum temperature on the hottest day of the year, TXx) by more than 1°C and a reduction in the intensity of cold extremes by at least 2.5°C (minimum temperature on the coldest night of the year, TNn). In addition, the same study showed that half of the global land mass has experienced changes in WSDI of more than six days, as well as an emergence of extremes outside the range of natural variability (Schleussner et al., 2017). Analyses from Schleussner et al. (2017) for temperature extremes are provided in the Supplementary Material 3.SM, Figure 3.SM.6. It should be noted that assessments of attributed changes in the IPCC SREX and AR5 reports were generally provided since 1950, for time frames also approximately corresponding to a 0.5°C global warming (3.SM).

3.3.2.2 Projected changes in regional temperature means and extremes at 1.5°C versus 2°C of global warming

There are several lines of evidence available for providing a regional assessment of projected changes in temperature means and extremes at 1.5°C versus 2°C of global warming (see Section 3.2). These include: analyses of changes in extremes as a function of global warming based on existing climate simulations using the empirical scaling relationship (ESR) and variations thereof (e.g., Schleussner et al., 2017; Dosio and Fischer, 2018; Seneviratne et al., 2018c; see Section 3.2 for details about the methodology); dedicated simulations of 1.5°C versus 2°C of global warming, for instance based on the Half a degree additional warming, prognosis and projected impacts (HAPPI) experiment (Mitchell et al., 2017) or other model simulations (e.g., Dosio et al., 2018; Kjellström et al., 2018); and analyses based on statistical pattern scaling approaches (e.g., Kharin et al., 2018). These different lines of evidence lead to qualitatively consistent results regarding changes in temperature means and extremes at 1.5°C of global warming compared to the pre-industrial climate and 2°C of global warming.

There are statistically significant differences in temperature means and extremes at 1.5°C versus 2°C of global warming, both in the global average (Schleussner et al., 2016b; Dosio et al., 2018; Kharin et al., 2018), as well as in most land regions (*high confidence*) (Wartenburger et al., 2017; Seneviratne et al., 2018c; Wehner et al., 2018b). Projected temperatures over oceans display significant increases in means and extremes between 1.5°C and 2°C of global warming (Figures 3.3 and 3.4). A general background on the available evidence on regional changes in temperature means and extremes at 1.5°C versus 2°C of global warming is provided in the Supplementary Material 3.SM.2. As an example, Figure 3.5 shows regionally-based analyses for the IPCC SREX regions (see Figure 3.2) of changes in the temperature of hot extremes as a function of global warming (corresponding analyses for changes in the temperature of cold extremes are provided in the Supplementary Material 3.SM.2). As demonstrated in these analyses, the mean response of the intensity of temperature extremes in climate models to changes in the global mean temperature is approximately linear and independent of the considered emissions scenario (Seneviratne et al., 2016; Wartenburger et al., 2017). Nonetheless, in the case of changes in the number of days exceeding a given threshold, changes are approximately exponential, with higher increases for rare events (Fischer and Knutti, 2015; Kharin et al., 2018); see also Figure 3.6. This behaviour is consistent with a linear increase in absolute temperature for extreme threshold exceedances (Whan et al., 2015).

As mentioned in Section 3.3.1, there is an important land–sea warming contrast, with stronger warming on land (see also Christensen et al., 2013; Collins et al., 2013; Seneviratne et al., 2016), which implies that regional warming on land is generally more than 1.5°C even when mean global warming is at 1.5°C. As highlighted in Seneviratne et al. (2016), this feature is generally stronger for temperature extremes (Figures 3.4 and 3.5; Supplementary Material 3.SM.2). For differences in regional temperature extremes at a mean global warming of 1.5°C versus 2°C, that is, a difference of 0.5°C in global warming, this implies differences of as much as 1°C–1.5°C in some locations, which are two to three times larger than the differences in global mean temperature. For hot extremes, the strongest warming is found in central and eastern North America, central and southern Europe, the Mediterranean, western and central Asia, and southern Africa (Figures 3.4 and 3.5) (*medium confidence*). These regions are all characterized by a strong soil-moisture–temperature coupling and projected increased dryness (Vogel et al., 2017), which leads to a reduction in evaporative cooling in the projections. Some of these regions also show a wide range of responses to temperature extremes, in particular central Europe and central North America, owing to discrepancies in the representation of the underlying processes in current climate models (Vogel et al., 2017). For mean temperature and cold extremes, the strongest warming is found in the northern high-latitude regions (*high confidence*). This is due to substantial ice-snow-albedo-temperature feedbacks (Figure 3.3 and Figure 3.4, middle) related to the known 'polar amplification' mechanism (e.g., IPCC, 2013; Masson-Delmotte et al., 2013).

Figure 3.7 displays maps of changes in the number of hot days (NHD) at 1.5°C and 2°C of GMST increase. Maps of changes in the number of frost days (FD) can be found in Supplementary Material 3.SM.2. These analyses reveal clear patterns of changes between the two warming levels, which are consistent with analysed changes in heatwave occurrence (e.g., Dosio et al., 2018). For the NHD, the largest differences are found in the tropics (*high confidence*), owing to the low interannual temperature variability there (Mahlstein et al., 2011), although absolute changes in hot temperature extremes tended to be largest at mid-latitudes (*high confidence*) (Figures 3.4 and 3.5). Extreme heatwaves are thus projected to emerge earliest in the tropics and to become widespread in these regions already at 1.5°C of global warming (*high confidence*). These results are consistent with other recent assessments. Coumou and Robinson (2013) found that 20% of the global land area, centred in low-latitude regions, is projected to experience highly unusual monthly temperatures during Northern Hemisphere summers at 1.5°C of global warming, with this number nearly doubling at 2°C of global warming.

Figure 3.8 features an objective identification of 'hotspots' / key risks in temperature indices subdivided by region, based on the ESR approach applied to Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations (Wartenburger et al., 2017). Note that results based on the HAPPI multimodel experiment (Mitchell et al., 2017) are similar (Seneviratne et al., 2018c). The considered regions follow the classification used in Figure 3.2 and also include the global land areas. Based on these analyses, the following can be stated: significant changes in responses are found in all regions for most temperature indices, with the exception of i) the diurnal temperature range (DTR) in most regions, ii) ice days (ID), frost days (FD) and growing season length (GSL) (mostly in regions where differences are zero, because, e.g., there are no ice or frost days), iii) the minimum yearly value of the maximum daily temperature (TXn) in very few regions. In terms of the sign of the changes, warm extremes display an increase in intensity, frequency and duration (e.g., an increase in the temperature of the hottest day of the year (TXx) in all regions, an increase in the proportion of days with a maximum temperature above the 90th percentile of Tmax (TX90p) in all regions, and an increase in the length of the WSDI in all regions), while cold extremes display a decrease in intensity, frequency and duration (e.g., an increase in the temperature of the coldest night of the year (TNn) in all regions, a decrease in the proportion of days with a minimum temperature below the 10th percentile of Tmin (TN10p), and a decrease in the cold spell duration index (CSDI) in all regions). Hence, while warm extremes are intensified, cold extremes become less intense in affected regions.

Overall, large increases in hot extremes occur in many densely inhabited regions (Figure 3.5), for both warming scenarios compared to pre-industrial and present-day climate, as well as for 2°C versus 1.5°C GMST warming. For instance, Dosio et al. (2018) concluded, based on a modelling study, that 13.8% of the world population would be exposed to 'severe heatwaves' at least once every 5 years under 1.5°C of global warming, with a threefold increase (36.9%) under 2°C of GMST warming, corresponding to a difference of about 1.7 billion people between the two global warming levels. They also concluded that limiting global warming to 1.5°C would result in about 420 million fewer people being frequently exposed to extreme heatwaves, and about 65 million fewer people being exposed to 'exceptional heatwaves' compared to conditions at 2°C GMST warming. However, changes in vulnerability were not considered in their study. For this reason, we assess that there is *medium confidence* in their conclusions.

In summary, there is *high confidence* that there are robust and statistically significant differences in the projected temperature means and extremes at 1.5°C versus 2°C of global warming, both in the global average and in nearly all land regions[4] (*likely*). Further, the observational record reveals that substantial changes due to a 0.5°C GMST warming are apparent for indices related to hot and cold extremes, as well as for the WSDI (*likely*). A global warming of 2°C versus 1.5°C would lead to more frequent and more intense hot extremes in all land regions[4], as well as longer warm spells, affecting many densely inhabited regions (*very likely*). The strongest increases in the frequency of hot extremes are projected for the rarest events (*very likely*). On the other hand, cold extremes would become less intense and less frequent, and cold spells would be shorter (*very likely*). Temperature extremes on land would generally increase more than the global average temperature (*very likely*). Temperature increases of extreme hot days in mid-latitudes are projected to be up to two times the increase in GMST, that is, 3°C at 1.5°C GMST warming (*high confidence*). The highest levels of warming for extreme hot days are expected to occur in central and eastern North America, central and southern Europe, the Mediterranean, western and central Asia, and southern Africa (*medium confidence*). These regions have a strong soil-moisture-temperature coupling in common as well as increased dryness and, consequently, a reduction in evaporative cooling. However, there is a substantial range in the representation of these processes in models, in particular in central Europe and central North America (*medium confidence*). The coldest nights in high latitudes warm by as much as 1.5°C for a 0.5°C increase in GMST, corresponding to a threefold stronger warming (*high confidence*). NHD shows the largest differences between 1.5°C and 2°C in the tropics, because of the low interannual temperature variability there (*high confidence*); extreme heatwaves are thus projected to emerge earliest in these regions, and they are expected to become widespread already at 1.5°C of global warming (*high confidence*). Limiting global warming to 1.5°C instead of 2°C could result in around 420 million fewer people being frequently exposed to extreme heatwaves, and about 65 million fewer people being exposed to exceptional heatwaves, assuming constant vulnerability (*medium confidence*).

3.3.3 Regional Precipitation, Including Heavy Precipitation and Monsoons

This section addresses regional changes in precipitation on land, with a focus on heavy precipitation and consideration of changes to the key features of monsoons.

3.3.3.1 Observed and attributed changes in regional precipitation

Observed global changes in the water cycle, including precipitation, are more uncertain than observed changes in temperature (Hartmann et al., 2013; Stocker et al., 2013). There is *high confidence* that mean precipitation over the mid-latitude land areas of the Northern Hemisphere has increased since 1951 (Hartmann et al., 2013). For other latitudinal zones, area-averaged long-term positive or negative trends have *low confidence* because of poor data quality, incomplete data or disagreement amongst available estimates (Hartmann et al., 2013). There is, in particular, *low confidence* regarding observed trends in precipitation in monsoon regions, according to the SREX report (Seneviratne et al., 2012) and AR5 (Hartmann et al., 2013), as well as more recent publications (Singh et al., 2014; Taylor et al., 2017; Bichet and Diedhiou, 2018; see Supplementary Material 3.SM.2).

For heavy precipitation, AR5 (Hartmann et al., 2013) assessed that observed trends displayed more areas with increases than decreases in the frequency, intensity and/or amount of heavy precipitation (*likely*). In addition, for land regions where observational coverage is sufficient for evaluation, it was assessed that there is *medium confidence* that anthropogenic forcing has contributed to a global-scale intensification of heavy precipitation over the second half of the 20th century (Bindoff et al., 2013a).

Regarding changes in precipitation associated with global warming of 0.5°C, the observed record suggests that increases in precipitation extremes can be identified for annual maximum 1-day precipitation

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[4] Using the SREX definition of regions (Figure 3.2)

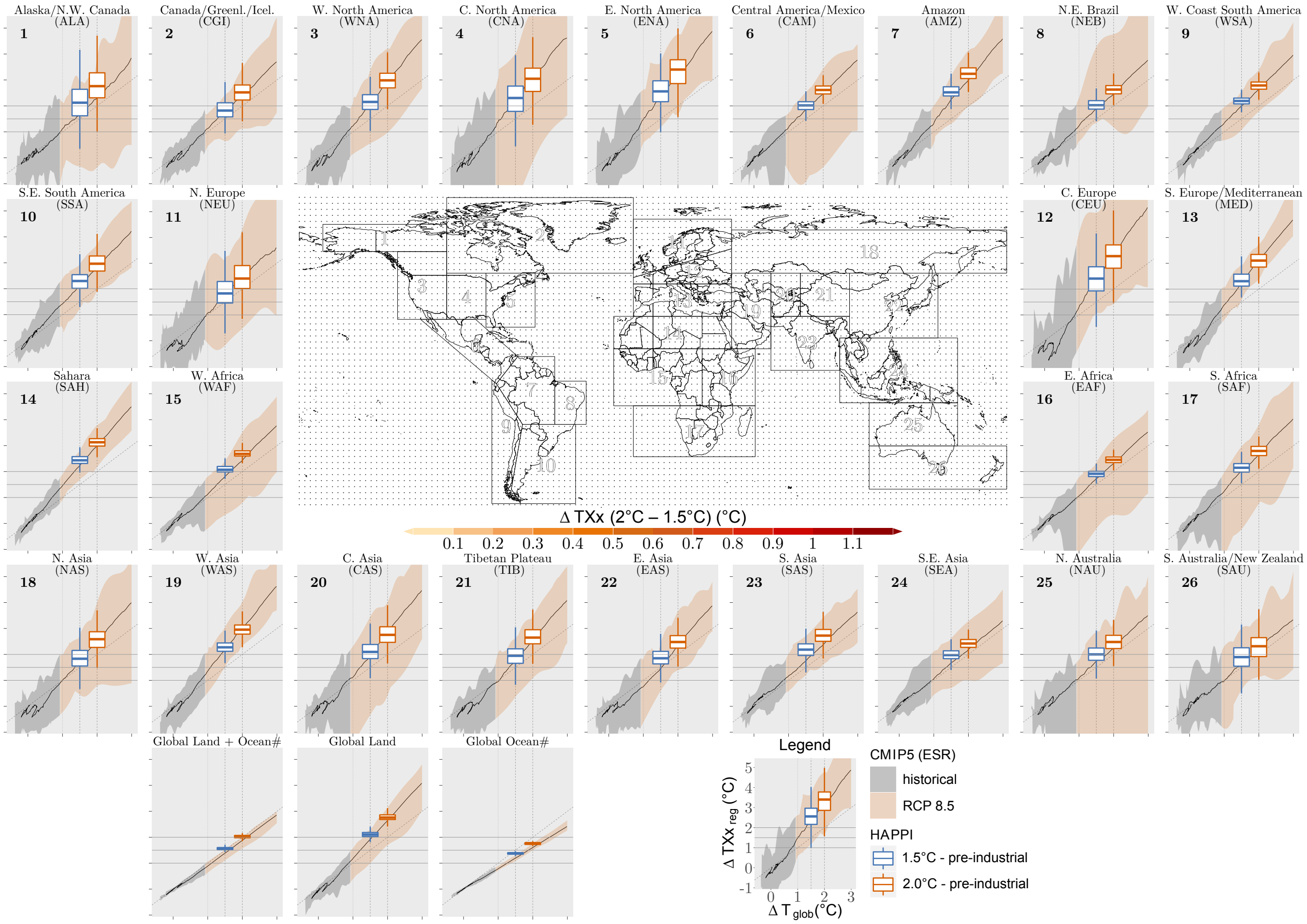


Figure 3.5 | Projected changes in annual maximum daytime temperature (TXx) as a function of global warming for IPCC Special Report on Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) regions (see Figure 3.2), based on an empirical scaling relationship applied to Coupled Model Intercomparison Project Phase 5 (CMIP5) data (adapted from Seneviratne et al., 2016 and Wartenburger et al., 2017) together with projected changes from the Half a degree additional warming, prognosis and projected impacts (HAPPI) multimodel experiment (Mitchell et al., 2017; based on analyses in Seneviratne et al., 2018c) (bar plots on regional analyses and central plot, respectively). For analyses for other regions from Figure 3.2 (with asterisks), see Supplementary Material 3.SM.2. (The stippling indicates significance of the differences in changes between 1.5°C and 2°C of global warming based on all model simulations, using a two-sided paired Wilcoxon test (P = 0.01, after controlling the false discovery rate according to Benjamini and Hochberg, 1995). See Supplementary Material 3.SM.2 for details.

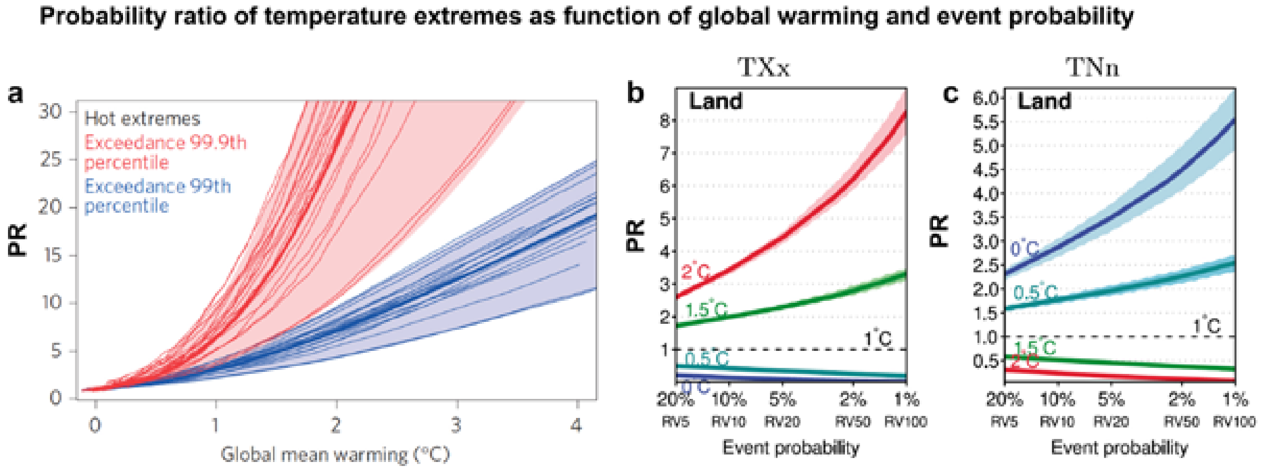


Figure 3.6 | Probability ratio (PR) of exceeding extreme temperature thresholds. (a) PR of exceeding the 99th (blue) and 99.9th (red) percentile of pre-industrial daily temperatures at a given warming level, averaged across land (from Fischer and Knutti, 2015). (b) PR for the hottest daytime temperature of the year (TXx). (c) PR for the coldest night of the year (TNn) for different event probabilities (with RV indicating return values) in the current climate (1°C of global warming). Shading shows the interquartile (25–75%) range (from Kharin et al., 2018).

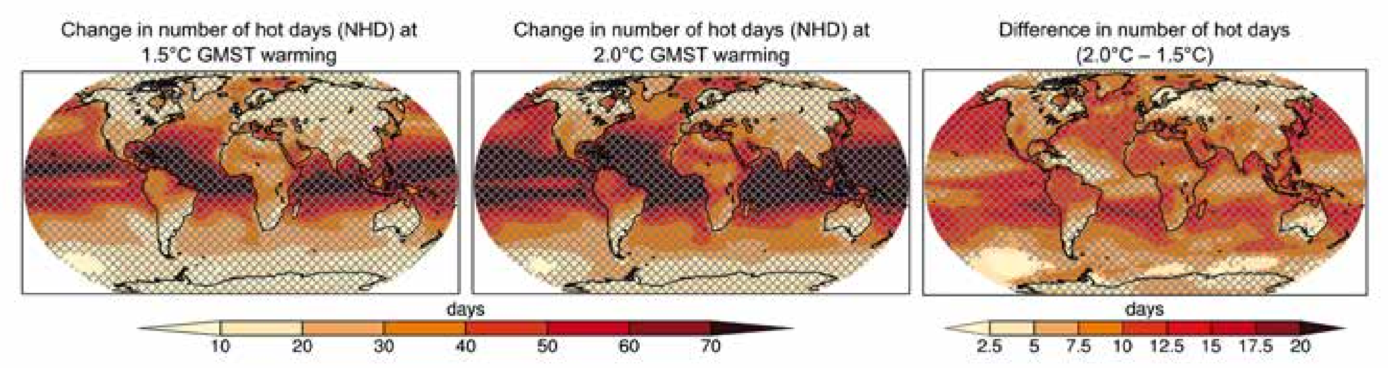
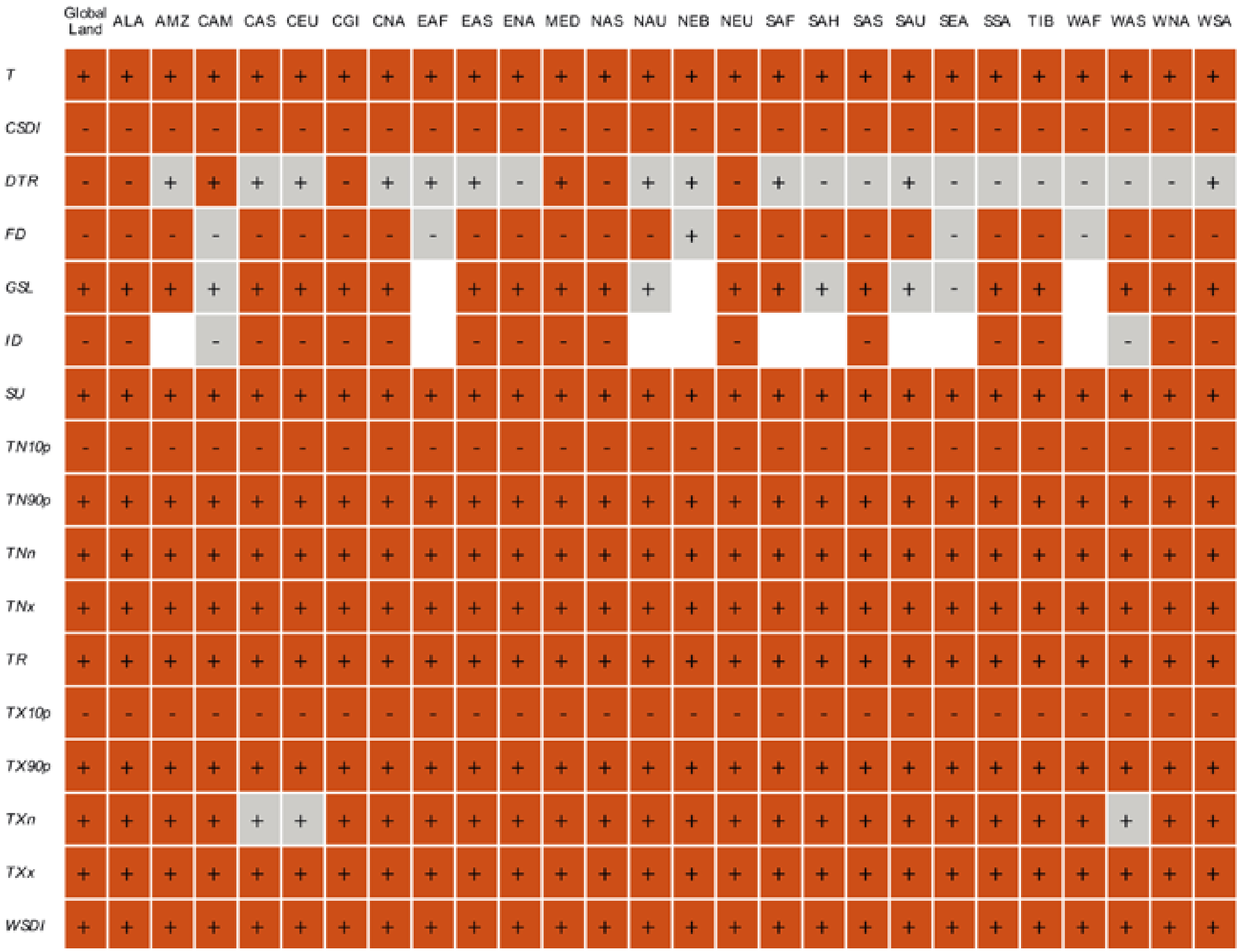


Figure 3.7 | Projected changes in the number of hot days (NHD; 10% warmest days) at 1.5°C (left) and at 2°C (middle) of global warming compared to the pre-industrial period (1861–1880), and the difference between 1.5°C and 2°C of warming (right). Cross-hatching highlights areas where at least two-thirds of the models agree on the sign of change as a measure of robustness (18 or more out of 26). The underlying methodology and the data basis are the same as for Figure 3.2 (see Supplementary Material 3.SM.2 for more details). Differences compared to 1°C global warming are provided in the Supplementary Material 3.SM.2.



	Global Land	ALA	AMZ	CAM	CAS	CEU	CGI	CNA	EAF	EAS	ENA	MED	NAS	NAU	NEB	NEU	SAF	SAH	SAS	SAU	SEA	SSA	TIB	WAF	WAS	WNA	WSA
T	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
CSDI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DTR	-	-	+	+	+	+	-	+	+	+	-	+	-	+	+	-	+	-	-	+	-	-	-	-	-	-	+
FD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
GSL	+	+	+	+	+	+	+	+		+	+	+	+	+		+	+	+	+	+	-	+	+		+	+	+
ID	-	-		-	-	-	-	-		-	-	-	-			-			-			-	-		-	-	-
SU	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
TN10p	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TN90p	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
TNn	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
TNx	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
TR	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
TX10p	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TX90p	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
TXn	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
TXx	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
WSDI	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Figure 3.8 | Significance of differences in regional mean temperature and range of temperature indices between the 1.5°C and 2°C global mean temperature targets (rows). Definitions of indices: T: mean temperature; CSDI: cold spell duration index; DTR: diurnal temperature range; FD: frost days; GSL: growing season length; ID: ice days; SU: summer days; TN10p: proportion of days with a minimum temperature (TN) lower than the 10th percentile of TN; TN90p: proportion of days with TN higher than the 90th percentile of TN; TNn: minimum yearly value of TN; TNx: maximum yearly value of TN; TR: tropical nights; TX10p: proportion of days with a maximum temperature (TX) lower than the 10th percentile of TX; TX90p: proportion of days with TX higher than the 90th percentile of TX; TXn: minimum yearly value of TX; TXx: maximum yearly value of TX; WSDI: warm spell duration index. Columns indicate analysed regions and global land (see Figure 3.2 for definitions). Significant differences are shown in red shading, with increases indicated with + and decreases indicated with –, while non-significant differences are shown in grey shading. White shading indicates when an index is the same at the two global warming levels (i.e., zero changes). Note that decreases in CSDI, FD, ID, TN10p and TX10p are linked to increased temperatures on cold days or nights. Significance was tested using a two-sided paired Wilcoxon test (*P*=0.01, after controlling the false discovery rate according to Benjamini and Hochberg, 1995) (adapted from Wartenburger et al., 2017).

3.3.3.1 (continued)

(RX1day) and consecutive 5-day precipitation (RX5day) for GMST changes of this magnitude (Supplementary Material 3.SM.2, Figure 3.SM.7; Schleussner et al., 2017). It should be noted that assessments of attributed changes in the IPCC SREX and AR5 reports were generally provided since 1950, for time frames also approximately corresponding to a 0.5°C global warming (3.SM).

3.3.3.2 Projected changes in regional precipitation at 1.5°C versus 2°C of global warming

Figure 3.3 in Section 3.3.1 summarizes the projected changes in mean precipitation at 1.5°C and 2°C of global warming. Both warming levels display robust differences in mean precipitation compared to the pre-industrial period. Regarding differences at 2°C vs 1.5°C global warming, some regions are projected to display changes in mean precipitation at 2°C compared with that at 1.5°C of global warming in the CMIP5 multimodel average, such as decreases in the Mediterranean area, including southern Europe, the Arabian Peninsula and Egypt, or increases in high latitudes. The results, however, are less robust across models than for mean temperature. For instance, Déqué et al. (2017) investigated the impact of 2°C of global warming on precipitation over tropical Africa and found that average precipitation does not show a significant response, owing to two phenomena: (i) the number of days with rain decreases whereas the precipitation intensity increases, and (ii) the rainy season occurs later during the year, with less precipitation in early summer and more precipitation in late summer. The results from Déqué et al. (2017) regarding insignificant differences between 1.5°C and 2°C scenarios for tropical Africa are consistent with the results presented in Figure 3.3. For Europe, recent studies (Vautard et al., 2014; Jacob et al., 2018; Kjellström et al., 2018) have shown that 2°C of global warming was associated with a robust increase in mean precipitation over central and northern Europe in winter but only over northern Europe in summer, and with decreases in mean precipitation in central/southern Europe in summer. Precipitation changes reaching 20% have been projected for the 2°C scenario (Vautard et al., 2014) and are overall more pronounced than with 1.5°C of global warming (Jacob et al., 2018; Kjellström et al., 2018).

Regarding changes in heavy precipitation, Figure 3.9 displays projected changes in the 5-day maximum precipitation (Rx5day) as a function of global temperature increase, using a similar approach as in Figure 3.5. Further analyses are available in Supplementary Material 3.SM.2. These analyses show that projected changes in heavy precipitation are more uncertain than those for temperature extremes. However, the mean response of model simulations is generally robust and linear (see also Fischer et al., 2014; Seneviratne et al., 2016). As observed for temperature extremes, this response is also mostly independent of the considered emissions scenario (e.g., RCP2.6 versus RCP8.5; see also Section 3.2). This feature appears to be specific to heavy precipitation, possibly due to a stronger coupling with temperature, as the scaling of projections of mean precipitation changes with global warming shows some scenario dependency (Pendergrass et al., 2015).

Robust changes in heavy precipitation compared to pre-industrial conditions are found at both 1.5°C and 2°C global warming (Figure 3.4). This is also consistent with results for, for example, the European continent, although different indices for heavy precipitation changes have been analysed. Based on regional climate simulations, Vautard et al. (2014) found a robust increase in heavy precipitation everywhere in Europe and in all seasons, except southern Europe in summer at 2°C versus 1971–2000. Their findings are consistent with those of Jacob et al. (2014), who used more recent downscaled climate scenarios (EURO-CORDEX) and a higher resolution (12 km), but the change is not so pronounced in Teichmann et al. (2018). There is consistent agreement in the direction of change in heavy precipitation at 1.5°C of global warming over much of Europe, compared to 1971–2000 (Jacob et al., 2018).

Differences in heavy precipitation are generally projected to be small between 1.5°C and 2°C GMST warming (Figure 3.4 and 3.9 and Supplementary Material 3.SM.2, Figure 3.SM.10). Some regions display substantial increases, for instance southern Asia, but generally in less than two-thirds of the CMIP5 models (Figure 3.4, Supplementary Material 3.SM.2, Figure 3.SM.10). Wartenburger et al. (2017) suggested that there are substantial differences in heavy precipitation in eastern Asia at 1.5°C versus 2°C. Overall, while there is variation among regions, the global tendency is for heavy precipitation to increase at 2°C compared with at 1.5°C (see e.g., Fischer and Knutti, 2015 and Kharin et al., 2018, as illustrated in Figure 3.10 from this chapter; see also Betts et al., 2018).

AR5 assessed that the global monsoon, aggregated over all monsoon systems, is *likely* to strengthen, with increases in its area and intensity, while the monsoon circulation weakens (Christensen et al., 2013). A few publications provide more recent evaluations of projections of changes in monsoons for high-emission scenarios (e.g., Jiang and Tian, 2013; Jones and Carvalho, 2013; Sylla et al., 2015, 2016; Supplementary Material 3.SM.2). However, scenarios at 1.5°C or 2°C global warming would involve a substantially smaller radiative forcing than those assessed in AR5 and these more recent studies, and there appears to be no specific assessment of changes in monsoon precipitation at 1.5°C versus 2°C of global warming in the literature. Consequently, the current assessment is that there is *low confidence* regarding changes in monsoons at these lower global warming levels, as well as regarding differences in monsoon responses at 1.5°C versus 2°C.

Similar to Figure 3.8, Figure 3.11 features an objective identification of 'hotspots' / key risks outlined in heavy precipitation indices subdivided by region, based on the approach by Wartenburger et al. (2017). The considered regions follow the classification used in Figure 3.2 and also include global land areas. Hotspots displaying statistically significant changes in heavy precipitation at 1.5°C versus 2°C global warming are located in high-latitude (Alaska/western Canada, eastern Canada/Greenland/Iceland, northern Europe, northern Asia) and high-elevation (e.g., Tibetan Plateau) regions, as well as in eastern Asia (including China and Japan) and in eastern North America. Results are less consistent for other regions. Note that analyses for meteorological drought (lack of precipitation) are provided in Section 3.3.4.

In summary, observations and projections for mean and heavy precipitation are less robust than for temperature means and extremes (*high confidence*). Observations show that there are more areas with increases than decreases in the frequency, intensity and/or amount of

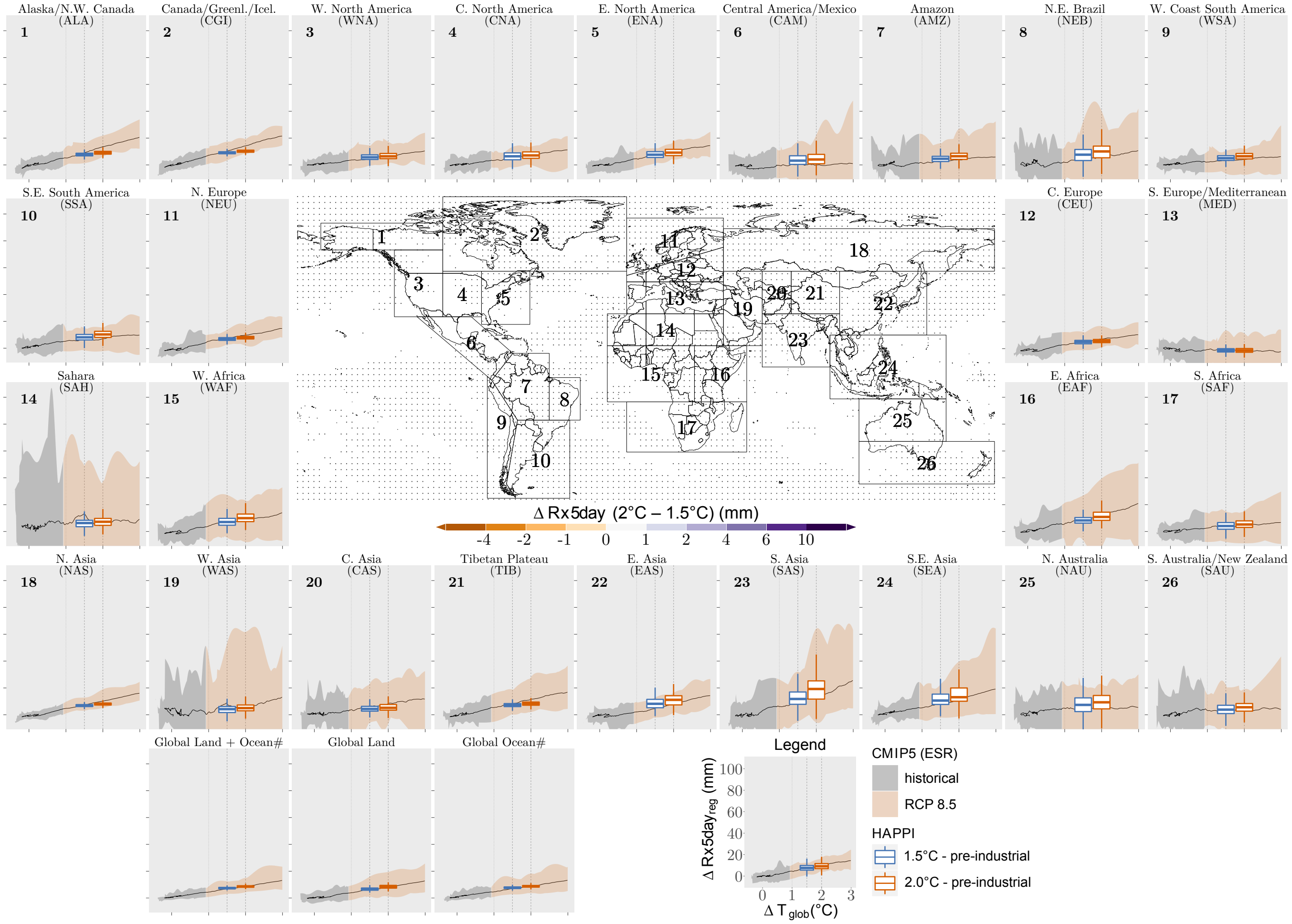


Figure 3.9 | Projected changes in annual 5-day maximum precipitation (Rx5day) as a function of global warming for IPCC Special Report on the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) regions (see Figure 3.2), based on an empirical scaling relationship applied to Coupled Model Intercomparison Project Phase 5 (CMIP5) data together with projected changes from the HAPPI multimodel experiment (bar plots on regional analyses and central plot). The underlying methodology and data basis are the same as for Figure 3.5 (see Supplementary Material 3.SM.2 for more details).

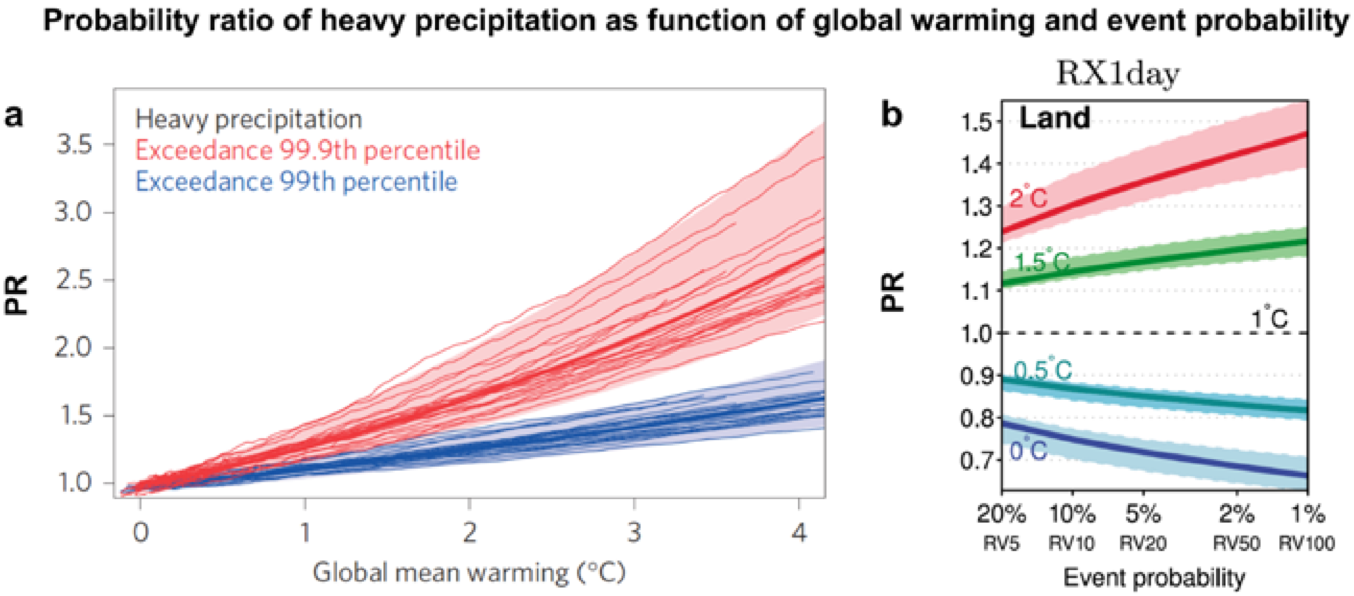
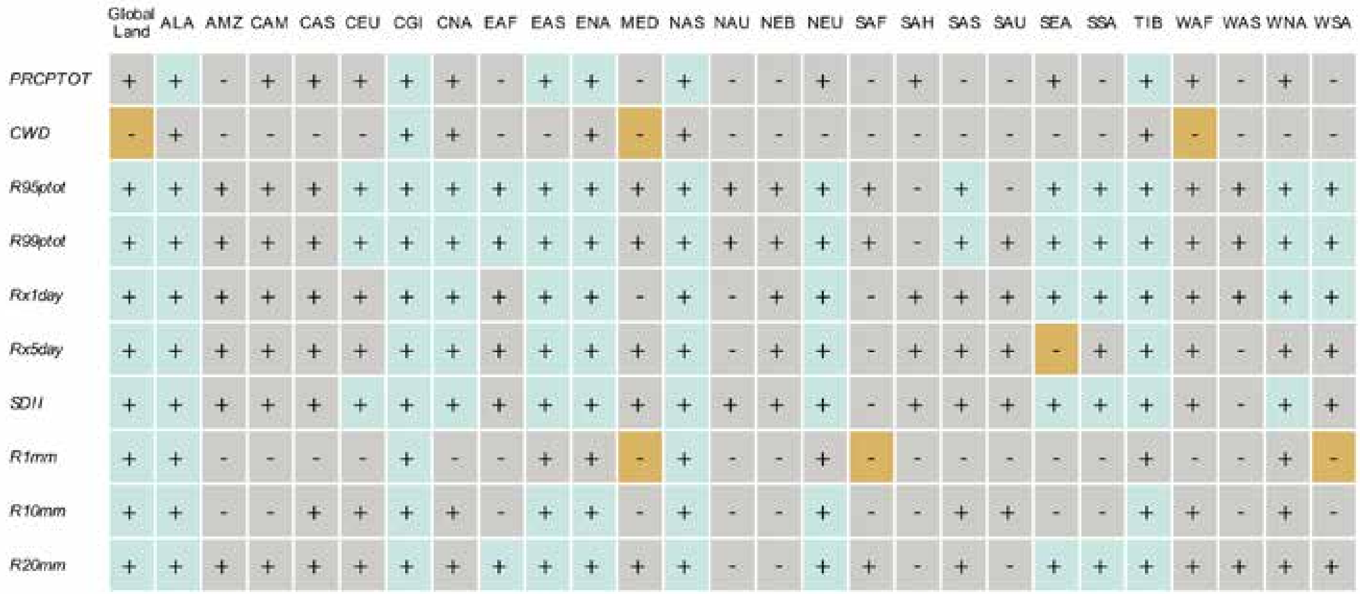


Figure 3.10 | Probability ratio (PR) of exceeding (heavy precipitation) thresholds. (a) PR of exceeding the 99th (blue) and 99.9th (red) percentile of pre-industrial daily precipitation at a given warming level, averaged across land (from Fischer and Knutti, 2015). (b) PR for precipitation extremes (RX1day) for different event probabilities (with RV indicating return values) in the current climate (1°C of global warming). Shading shows the interquartile (25–75%) range (from Kharin et al., 2018).

3.3.3.2 (continued)

heavy precipitation (*high confidence*). Several large regions display statistically significant differences in heavy precipitation at 1.5°C versus 2°C GMST warming, with stronger increases at 2°C global warming, and there is a global tendency towards increases in heavy precipitation on land at 2°C compared with 1.5°C warming (*high confidence*). Overall, regions that display statistically significant changes in heavy precipitation between 1.5°C and 2°C of global warming are located in high latitudes (Alaska/western Canada, eastern Canada/Greenland/Iceland, northern Europe, northern Asia) and high elevation (e.g., Tibetan Plateau), as well as in eastern Asia (including China and Japan) and in eastern North America (*medium confidence*). There is *low confidence* in projected changes in heavy precipitation in other regions.



	Global Land	ALA	AMZ	CAM	CAS	CEU	CGI	CNA	EAF	EAS	ENA	MED	NAS	NAU	NEB	NEU	SAF	SAH	SAS	SAU	SEA	SSA	TIB	WAF	WAS	WNA	WSA
PRCPTOT	+	+	-	+	+	+	+	+	-	+	+	-	+	-	-	+	-	+	-	-	+	-	+	+	-	+	-
CWD	-	+	-	-	-	-	+	+	-	-	+	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-
R95ptot	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	-	+	+	+	+	+	+	+
R99ptot	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+
Rx1day	+	+	+	+	+	+	+	+	+	+	+	-	+	-	+	+	-	+	+	+	+	+	+	+	+	+	+
Rx5day	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	-	+	+	+	-	+	+	+	-	+	+
SDII	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	-	+	+
R1mm	+	+	-	-	-	-	+	-	-	+	+	-	+	-	-	+	-	-	-	-	-	-	+	-	-	+	-
R10mm	+	+	-	-	+	+	+	+	-	+	+	-	+	-	-	+	-	-	+	+	-	-	+	+	-	+	-
R20mm	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	+	+	-	+	-	+	+	+	+	+	+	+

Figure 3.11 | Significance of differences in regional mean precipitation and range of precipitation indices between the 1.5°C and 2°C global mean temperature targets (rows). Definition of indices: PRCPTOT: mean precipitation; CWD: consecutive wet days; R10mm: number of days with precipitation >10 mm; R1mm: number of days with precipitation >1 mm; R20mm: number of days with precipitation >20 mm; R95ptot: proportion of rain falling as 95th percentile or higher; R99ptot: proportion of rain falling as 99th percentile or higher; RX1day: intensity of maximum yearly 1-day precipitation; RX5day: intensity of maximum yearly 5-day precipitation; SDII: Simple Daily Intensity Index. Columns indicate analysed regions and global land (see Figure 3.2 for definitions). Significant differences are shown in light blue (wetting tendency) or brown (drying tendency) shading, with increases indicated with '+' and decreases indicated with '–', while non-significant differences are shown in grey shading. The underlying methodology and the data basis are the same as in Figure 3.8 (see Supplementary Material 3.SM.2 for more details).

3.3.4 Drought and Dryness

3.3.4.1 Observed and attributed changes

The IPCC AR5 assessed that there was *low confidence* in the sign of drought trends since 1950 at the global scale, but that there was *high confidence* in observed trends in some regions of the world, including drought increases in the Mediterranean and West Africa and drought decreases in central North America and northwest Australia (Hartmann et al., 2013; Stocker et al., 2013). AR5 assessed that there was *low confidence* in the attribution of global changes in droughts and did not provide assessments for the attribution of regional changes in droughts (Bindoff et al., 2013a).

The recent literature does not suggest that the SREX and AR5 assessment of drought trends should be revised, except in the Mediterranean region. Recent publications based on observational and modelling evidence suggest that human emissions have substantially increased the probability of drought years in the Mediterranean region (Gudmundsson and Seneviratne, 2016; Gudmundsson et al., 2017). Based on this evidence, there is *medium confidence* that enhanced greenhouse forcing has contributed to increased drying in the Mediterranean region (including southern Europe, northern Africa and the Near East) and that this tendency will continue to increase under higher levels of global warming.

3.3.4.2 Projected changes in drought and dryness at 1.5°C versus 2°C

There is *medium confidence* in projections of changes in drought and dryness. This is partly consistent with AR5, which assessed these projections as being '*likely* (*medium confidence*)' (Collins et al., 2013; Stocker et al., 2013). However, given this *medium confidence*, the current assessment does not include a likelihood statement, thereby maintaining consistency with the IPCC uncertainty guidance document (Mastrandrea et al., 2010) and the assessment of the IPCC SREX report (Seneviratne et al., 2012). The technical summary of AR5 (Stocker et al., 2013) assessed that soil moisture drying in the Mediterranean, southwestern USA and southern African regions was consistent with projected changes in the Hadley circulation and increased surface temperatures, and it concluded that there was *high confidence* in *likely* surface drying in these regions by the end of this century

Box 3.1 | Sub-Saharan Africa: Changes in Temperature and Precipitation Extremes

Sub-Saharan Africa has experienced the dramatic consequences of climate extremes becoming more frequent and more intense over the past decades (Paeth et al., 2010; Taylor et al., 2017). In order to join international efforts to reduce climate change, all African countries signed the Paris Agreement. In particular, through their nationally determined contributions (NDCs), they committed to contribute to the global effort to mitigate greenhouse gas (GHG) emissions with the aim to constrain global temperature increases to 'well below 2°C' and to pursue efforts to limit warming to '1.5°C above pre-industrial levels'. The target of limiting global warming to 1.5°C above pre-industrial levels is useful for conveying the urgency of the situation. However, it focuses the climate change debate on a temperature threshold (Section 3.3.2), while the potential impacts of these global warming levels on key sectors at local to regional scales, such as agriculture, energy and health, remain uncertain in most regions and countries of Africa (Sections 3.3.3, 3.3.4, 3.3.5 and 3.3.6).

Weber et al. (2018) found that at regional scales, temperature increases in sub-Saharan Africa are projected to be higher than the global mean temperature increase (at global warming of 1.5°C and at 2°C; see Section 3.3.2 for further background and analyses of climate model projections). Even if the mean global temperature anomaly is kept below 1.5°C, regions between 15°S and 15°N are projected to experience an increase in hot nights, as well as longer and more frequent heatwaves (e.g., Kharin et al., 2018). Increases would be even larger if the global mean temperature were to reach 2°C of global warming, with significant changes in the occurrence and intensity of temperature extremes in all sub-Saharan regions (Sections 3.3.1 and 3.3.2; Figures 3.4, 3.5 and 3.8).

West and Central Africa are projected to display particularly large increases in the number of hot days, both at 1.5°C and 2°C of global warming (Section 3.3.2). This is due to the relatively small interannual present-day variability in this region, which implies that climate-change signals can be detected earlier there (Section 3.3.2; Mahlstein et al., 2011). Projected changes in total precipitation exhibit uncertainties, mainly in the Sahel (Section 3.3.3 and Figure 3.8; Diedhiou et al., 2018). In the Guinea Coast and Central Africa, only a small change in total precipitation is projected, although most models (70%) indicate a decrease in the length of wet periods and a slight increase in heavy rainfall. Western Sahel is projected by most models (80%) to experience the strongest drying, with a significant increase in the maximum length of dry spells (Diedhiou et al., 2018). Above 2°C, this region could become more vulnerable to drought and could face serious food security issues (Cross-Chapter Box 6 and Section 3.4.6 in this chapter; Salem et al., 2017; Parkes et al., 2018). West Africa has thus been identified as a climate-change hotspot with negative impacts from climate change on crop yields and production (Cross-Chapter Box 6 and Section 3.4.6; Sultan and Gaetani, 2016; Palazzo et al., 2017). Despite uncertainty in projections for precipitation in West Africa, which is essential for rain-fed agriculture, robust evidence of yield loss might emerge. This yield loss is expected to be mainly driven by increased mean temperature, while potential wetter or drier conditions – as well as elevated CO_2 concentrations – could modulate this effect (Roudier et al., 2011; see also Cross-Chapter Box 6 and Section 3.4.6). Using Representative Concentration Pathway (RCP)8.5 Coordinated Regional Climate Downscaling Experiment (CORDEX) scenarios from 25 regional climate models (RCMs) forced with different general circulation models (GCMs), Klutse et al. (2018) noted a decrease in mean rainfall over West Africa in models with stronger warming for this region at 1.5°C of global warming (Section 3.3.4). Mba et al. (2018) used a similar approach and found a lack of consensus in the changes in precipitation over Central Africa (Figure 3.8 and Section 3.3.4), although there was a tendency towards a decrease in the maximum number of consecutive wet days (CWD) and a significant increase in the maximum number of consecutive dry days (CDD).

Over southern Africa, models agree on a positive sign of change for temperature, with temperature rising faster at 2°C (1.5°C–2.5°C) as compared to 1.5°C (0.5°C–1.5°C) of global warming. Areas in the south-western region, especially in South Africa and parts of Namibia and Botswana, are expected to experience the largest increases in temperature (Section 3.3.2; Engelbrecht et al., 2015; Maúre et al., 2018). The western part of southern Africa is projected to become drier with increasing drought frequency and number of heatwaves towards the end of the 21st century (Section 3.3.4; Engelbrecht et al., 2015; Dosio, 2017; Maúre et al., 2018). At 1.5°C, a robust signal of precipitation reduction is found over the Limpopo basin and smaller areas of the Zambezi basin in Zambia, as well as over parts of Western Cape in South Africa, while an increase is projected over central and western South Africa, as well as in southern Namibia (Section 3.3.4). At 2°C, the region is projected to face robust precipitation decreases of about 10–20% and increases in the number of CDD, with longer dry spells projected over Namibia, Botswana, northern Zimbabwe and southern Zambia. Conversely, the number of CWD is projected to decrease, with robust signals over Western Cape (Maúre et al., 2018). Projected reductions in stream flow of 5–10% in the Zambezi River basin have been associated with increased evaporation and transpiration rates resulting from a rise in temperature (Section 3.3.5; Kling et al., 2014), with issues for hydroelectric power across the region of southern Africa.

For Eastern Africa, Osima et al. (2018) found that annual rainfall projections show a robust increase in precipitation over Somalia and a less robust decrease over central and northern Ethiopia (Section 3.3.3). The number of CDD and CWD are projected to increase and decrease, respectively (Section 3.3.4). These projected changes could impact the agricultural and water sectors in the region (Cross-Chapter Box 6 in this chapter and Section 3.4.6).

under the RCP8.5 scenario. However, more recent assessments have highlighted uncertainties in dryness projections due to a range of factors, including variations between the drought and dryness indices considered, and the effects of enhanced CO_2 concentrations on plant water-use efficiency (Orlowsky and Seneviratne, 2013; Roderick et al., 2015). Overall, projections of changes in drought and dryness for high-emissions scenarios (e.g., RCP8.5, corresponding to about 4°C of global warming) are uncertain in many regions, although a few regions display consistent drying in most assessments (e.g., Seneviratne et al., 2012; Orlowsky and Seneviratne, 2013). Uncertainty is expected to be even larger for conditions with a smaller signal-to-noise ratio, such as for global warming levels of 1.5°C and 2°C.

Some published literature is now available on the evaluation of differences in drought and dryness occurrence at 1.5°C and 2°C of global warming for (i) precipitation minus evapotranspiration (P–E, a general measure of water availability; Wartenburger et al., 2017; Greve et al., 2018), (ii) soil moisture anomalies (Lehner et al., 2017; Wartenburger et al., 2017), (iii) consecutive dry days (CDD) (Schleussner et al., 2016b; Wartenburger et al., 2017), (iv) the 12-month standardized precipitation index (Wartenburger et al., 2017), (v) the Palmer drought severity index (Lehner et al., 2017), and (vi) annual mean runoff (Schleussner et al., 2016b, see also next section). These analyses have produced consistent findings overall, despite the known sensitivity of drought assessments to chosen drought indices (see above paragraph). These analyses suggest that increases in drought, dryness or precipitation deficits are projected at 1.5°C or 2°C global warming in some regions compared to the pre-industrial or present-day conditions, as well as between these two global warming levels, although there is substantial variability in signals depending on the considered indices or climate models (Lehner et al., 2017; Schleussner et al., 2017; Greve et al., 2018) (*medium confidence*). Generally, the clearest signals are found for the Mediterranean region (*medium confidence*).

Greve et al. (2018, Figure 3.12) derives the sensitivity of regional changes in precipitation minus evapotranspiration to global temperature changes. The simulations analysed span the full range of available emission scenarios, and the sensitivities are derived using a modified pattern scaling approach. The applied approach assumes linear dependencies on global temperature changes while thoroughly addressing associated uncertainties via resampling methods. Northern high-latitude regions display robust responses tending towards increased wetness, while subtropical regions display a tendency towards drying but with a large range of responses. While the internal variability and the scenario choice play an important role in the overall spread of the simulations, the uncertainty stemming from the climate model choice usually dominates, accounting for about half of the total uncertainty in most regions (Wartenburger et al., 2017; Greve et al., 2018). The sign of projections, that is, whether there might be increases or decreases in water availability under higher global warming levels, is particularly uncertain in tropical and mid-latitude regions. An assessment of the implications of limiting the global mean temperature increase to values below (i) 1.5°C or (ii) 2°C shows that constraining global warming to the 1.5°C target might slightly influence the mean

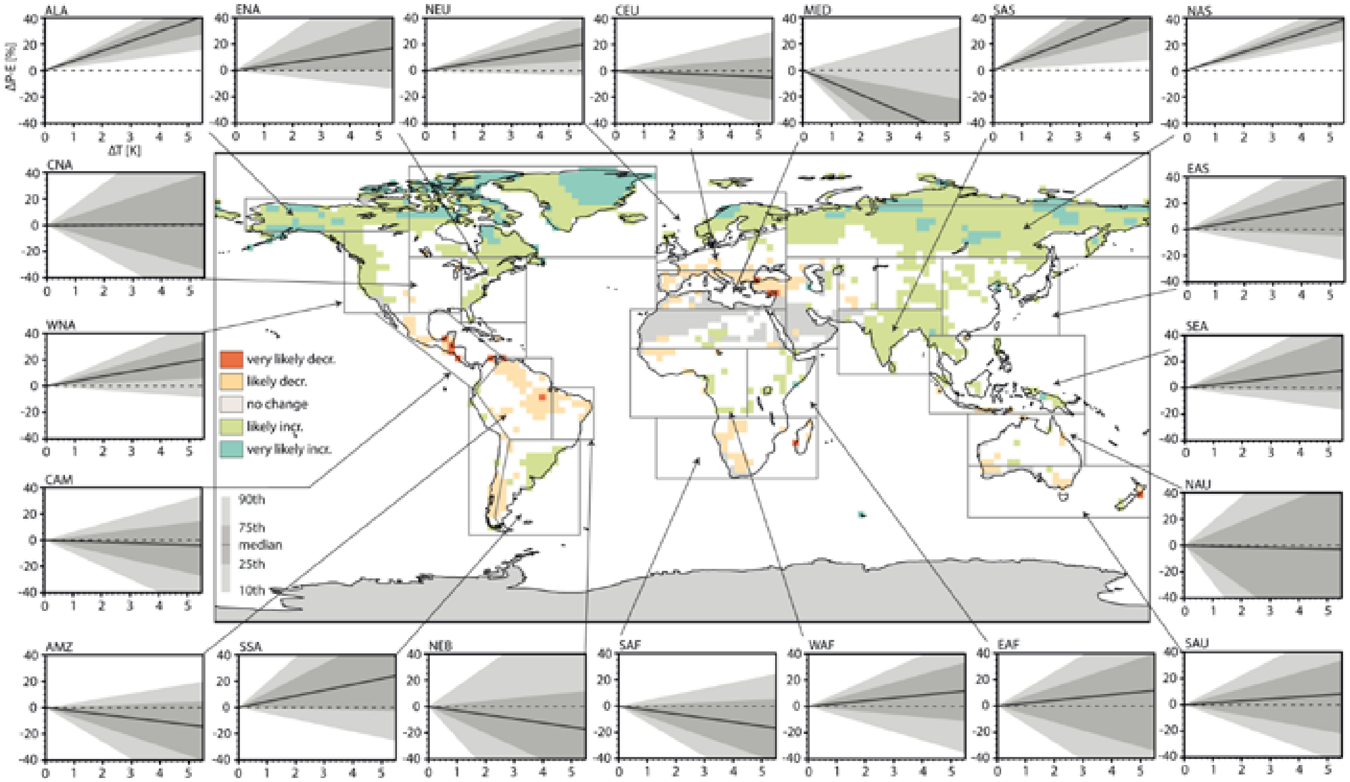


Figure 3.12 | Summary of the likelihood of increases/decreases in precipitation minus evapotranspiration (P–E) in Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations considering all scenarios and a representative subset of 14 climate models (one from each modelling centre). Panel plots show the uncertainty distribution of the sensitivity of P–E to global temperature change, averaged for most IPCC Special Report on Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) regions (see Figure 3.2) outlined in the map (from Greve et al., 2018).

response but could substantially reduce the risk of experiencing extreme changes in regional water availability (Greve et al., 2018).

The findings from the analysis for the mean response by Greve et al. (2018) are qualitatively consistent with results from Wartenburger et al. (2017), who used an ESR (Section 3.2) rather than a pattern scaling approach for a range of drought and dryness indices. They are also consistent with a study by Lehner et al. (2017), who assessed changes in droughts based on soil moisture changes and the Palmer-Drought Severity Index. Notably, these two publications do not provide a specific assessment of changes in the tails of the drought and dryness distribution. The conclusions of Lehner et al. (2017) are that (i) 'risks of consecutive drought years show little change in the US Southwest and Central Plains, but robust increases in Europe and the Mediterranean', and that (ii) 'limiting warming to 1.5°C may have benefits for future drought risk, but such benefits are regional, and in some cases highly uncertain'.

Figure 3.13 features projected changes in CDD as a function of global temperature increase, using a similar approach as for Figures 3.5 (based

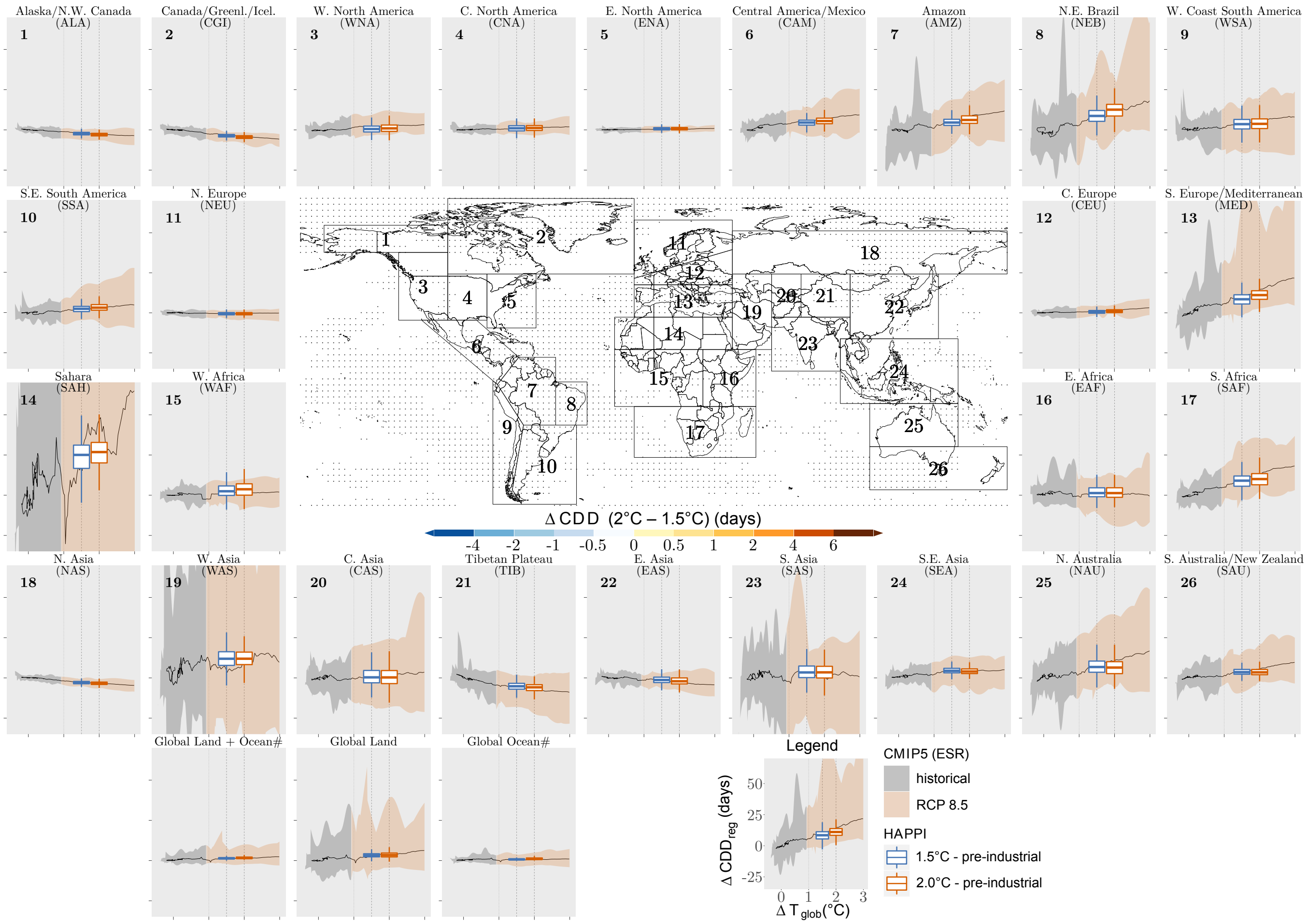
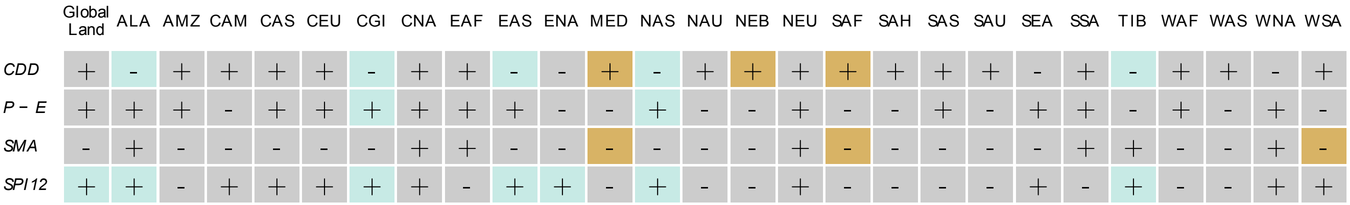


Figure 3.13 | Projected changes in consecutive dry days (CDD) as a function of global warming for IPCC Special Report on Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) regions, based on an empirical scaling relationship applied to Coupled Model Intercomparison Project Phase 5 (CMIP5) data together with projected changes from the HAPPI multimodel experiment (bar plots on regional analyses and central plot, respectively). The underlying methodology and the data basis are the same as for Figure 3.5 (see Supplementary Material 3.SM.2 for more details).



	Global Land	ALA	AMZ	CAM	CAS	CEU	CGI	CNA	EAF	EAS	ENA	MED	NAS	NAU	NEB	NEU	SAF	SAH	SAS	SAU	SEA	SSA	TIB	WAF	WAS	WNA	WSA
CDD	+	-	+	+	+	+	-	+	+	-	-	+	-	+	+	+	+	+	+	+	-	+	-	+	+	-	+
P − E	+	+	+	-	+	+	+	+	+	+	-	-	+	-	-	+	-	-	+	-	+	+	-	+	-	+	-
SMA	-	+	-	-	-	-	-	+	+	-	-	-	-	-	-	+	-	-	-	-	-	+	+	-	-	+	-
SPI12	+	+	-	+	+	+	+	+	-	+	+	-	+	-	-	+	-	-	-	-	+	-	+	-	-	+	+

Figure 3.14 | Significance of differences in regional drought and dryness indices between the 1.5°C and 2°C global mean temperature targets (rows). Definition of indices: CDD: consecutive dry days; P–E: precipitation minus evapotranspiration; SMA: soil moisture anomalies; SPI12: 12-month Standarized Precipitation Index. Columns indicate analysed regions and global land (see Figure 3.2 for definitions). Significant differences are shown in light blue/brown shading (increases indicated with +, decreases indicated with –; light blue shading indicates decreases in dryness (decreases in CDD, or increases in P–E, SMA or SPI12) and light brown shading indicates increases in dryness (increases in CDD, or decreases in P–E, SMA or SPI12). Non-significant differences are shown in grey shading. The underlying methodology and the data basis are the same as for Figure 3.7 (see Supplementary Material 3.SM.2 for more details).

on Wartenburger et al., 2017). The figure also include results from the HAPPI experiment (Mitchell et al., 2017). Again, the CMIP5-based ESR estimates and the results of the HAPPI experiment agree well. Note that the responses vary widely among the considered regions.

Similar to Figures 3.8 and 3.11, Figure 3.14 features an objective identification of 'hotspots' / key risks in dryness indices subdivided by region, based on the approach by Wartenburger et al. (2017). This analysis reveals the following hotspots of drying (i.e. increases in CDD and/or decreases in P–E, soil moisture anomalies (SMA) and 12-month Standardized Precipitation Index (SPI12), with at least one of the indices displaying statistically significant drying): the Mediterranean region (MED; including southern Europe, northern Africa, and the Near East), northeastern Brazil (NEB) and southern Africa.

Consistent with this analysis, the available literature particularly supports robust increases in dryness and decreases in water availability in southern Europe and the Mediterranean with a shift from 1.5°C to 2°C of global warming (*medium confidence*) (Figure 3.13; Schleussner et al., 2016b; Lehner et al., 2017; Wartenburger et al., 2017; Greve et al., 2018; Samaniego et al., 2018). This region is already displaying substantial drying in the observational record (Seneviratne et al., 2012; Sheffield et al., 2012; Greve et al., 2014; Gudmundsson and Seneviratne, 2016; Gudmundsson et al., 2017), which provides additional evidence supporting this tendency and suggests that it will be a hotspot of dryness change at global warming levels beyond 1.5°C (see also Box 3.2). The other identified hotspots, southern Africa and northeastern Brazil, also consistently display drying trends under higher levels of forcing in other publications (e.g., Orlowsky and Seneviratne, 2013), although no published studies could be found reporting observed drying trends in these regions. There are substantial increases in the risk of increased dryness (*medium confidence*) in both the Mediterranean region and Southern Africa at 2°C versus 1.5°C of global warming because these regions display significant changes in two dryness indicators (CDD and SMA) between these two global warming levels (Figure 3.14); the strongest effects are expected for extreme droughts (*medium confidence*) (Figure 3.12). There is *low confidence* elsewhere, owing to a lack of consistency in analyses with different models or different dryness indicators. However, in many regions there is *medium confidence* that most extreme risks of changes in dryness are avoided if global warming is constrained at 1.5°C instead of 2°C (Figure 3.12).

In summary, in terms of drought and dryness, limiting global warming to 1.5°C is expected to substantially reduce the probability of extreme changes in water availability in some regions compared to changes under 2°C of global warming (*medium confidence*). For shift from 1.5°C to 2°C of GMST warming, the available studies and analyses suggest strong increases in the probability of dryness and reduced water availability in the Mediterranean region (including southern Europe, northern Africa and the Near East) and in southern Africa (*medium confidence*). Based on observations and modelling experiments, a drying trend is already detectable in the Mediterranean region, that is, at global warming of less than 1°C (*medium confidence*).

Box 3.2 | Droughts in the Mediterranean Basin and the Middle East

Human society has developed in tandem with the natural environment of the Mediterranean basin over several millennia, laying the groundwork for diverse and culturally rich communities. Even if advances in technology may offer some protection from climatic hazards, the consequences of climatic change for inhabitants of this region continue to depend on the long-term interplay between an array of societal and environmental factors (Holmgren et al., 2016). As a result, the Mediterranean is an example of a region with high vulnerability where various adaptation responses have emerged. Previous IPCC assessments and recent publications project regional changes in climate under increased temperatures, including consistent climate model projections of increased precipitation deficit amplified by strong regional warming (Section 3.3.3; Seneviratne et al., 2012; Christensen et al., 2013; Collins et al., 2013; Greve and Seneviratne, 2015).

The long history of resilience to climatic change is especially apparent in the eastern Mediterranean region, which has experienced a strong negative trend in precipitation since 1960 (Mathbout et al., 2017) and an intense and prolonged drought episode between 2007 and 2010 (Kelley et al., 2015). This drought was the longest and most intense in the last 900 years (Cook et al., 2016). Some authors (e.g., Trigo et al., 2010; Kelley et al., 2015) assert that very low precipitation levels have driven a steep decline in agricultural productivity in the Euphrates and Tigris catchment basins, and displaced hundreds of thousands of people, mainly in Syria. Impacts on the water resources (Yazdanpanah et al., 2016) and crop performance in Iran have also been reported (Saeidi et al., 2017). Many historical periods of turmoil have coincided with severe droughts, for example the drought which occurred at the end of the Bronze Age approximately 3200 years ago (Kaniewski et al., 2015). In this instance, a number of flourishing eastern Mediterranean civilizations collapsed, and rural settlements re-emerged with agro-pastoral activities and limited long-distance trade. This illustrates how some vulnerable regions are forced to pursue drastic adaptive responses, including migration and societal structure changes.

The potential evolution of drought conditions under 1.5°C or 2°C of global warming (Section 3.3.4) can be analysed by comparing the 2008 drought (high temperature, low precipitation) with the 1960 drought (low temperature, low precipitation) (Kelley et al., 2015). Though the precipitation deficits were comparable, the 2008 drought was amplified by increased evapotranspiration induced by much higher temperatures (a mean increase of 1°C compared with the 1931–2008 period in Syria) and a large population increase (from

Box 3.2 (continued)

5 million in 1960 to 22 million in 2008). Koutroulis et al. (2016) reported that only 6% out of the total 18% decrease in water availability projected for Crete under 2°C of global warming at the end of the 21st century would be due to decreased precipitation, with the remaining 12% due to an increase in evapotranspiration. This study and others like it confirm an important risk of extreme drought conditions for the Middle East under 1.5°C of global warming (Jacob et al., 2018), with risks being even higher in continental locations than on islands; these projections are consistent with current observed changes (Section 3.3.4; Greve et al., 2014). Risks of drying in the Mediterranean region could be substantially reduced if global warming is limited to 1.5°C compared to 2°C or higher levels of warming (Section 3.4.3; Guiot and Cramer, 2016). Higher warming levels may induce high levels of vulnerability exacerbated by large changes in demography.

3.3.5 Runoff and Fluvial Flooding

3.3.5.1 Observed and attributed changes in runoff and river flooding

There has been progress since AR5 in identifying historical changes in streamflow and continental runoff. Using the available streamflow data, Dai (2016) showed that long-term (1948–2012) flow trends are statistically significant only for 27.5% of the world's 200 major rivers, with negative trends outnumbering the positive ones. Although streamflow trends are mostly not statistically significant, they are consistent with observed regional precipitation changes. From 1950 to 2012, precipitation and runoff have increased over southeastern South America, central and northern Australia, the central and northeastern United States, central and northern Europe, and most of Russia, and they have decreased over most of Africa, East and South Asia, eastern coastal Australia, the southeastern and northwestern United States, western and eastern Canada, the Mediterranean region and some regions of Brazil (Dai, 2016).

A large part of the observed regional trends in streamflow and runoff might have resulted from internal multi-decadal and multi-year climate variations, especially the Pacific decadal variability (PDV), the Atlantic Multi-Decadal Oscillation (AMO) and the El Niño–Southern Oscillation (ENSO), although the effect of anthropogenic greenhouse gases and aerosols could also be important (Hidalgo et al., 2009; Gu and Adler, 2013, 2015; Chiew et al., 2014; Luo et al., 2016; Gudmundsson et al., 2017). Additionally, other human activities can influence the hydrological cycle, such as land-use/land-cover change, modifications in river morphology and water table depth, construction and operation of hydropower plants, dikes and weirs, wetland drainage, and agricultural practices such as water withdrawal for irrigation. All of these activities can also have a large impact on runoff at the river basin scale, although there is less agreement over their influence on global mean runoff (Gerten et al., 2008; Sterling et al., 2012; Hall et al., 2014; Betts et al., 2015; Arheimer et al., 2017). Some studies suggest that increases in global runoff resulting from changes in land cover or land use (predominantly deforestation) are counterbalanced by decreases resulting from irrigation (Gerten et al., 2008; Sterling et al., 2012). Likewise, forest and grassland fires can modify the hydrological response at the watershed scale when the burned area is significant (Versini et al., 2013; Springer et al., 2015; Wine and Cadol, 2016).

Few studies have explored observed changes in extreme streamflow and river flooding since the IPCC AR5. Mallakpour and Villarini (2015) analysed changes of flood magnitude and frequency in the central United States by considering stream gauge daily records with at least 50 years of data ending no earlier than 2011. They showed that flood frequency has increased, whereas there was limited evidence of a decrease in flood magnitude in this region. Stevens et al. (2016) found a rise in the number of reported floods in the United Kingdom during the period 1884–2013, with flood events appearing more frequently towards the end of the 20th century. A peak was identified in 2012, when annual rainfall was the second highest in over 100 years. Do et al. (2017) computed the trends in annual maximum daily streamflow data across the globe over the 1966–2005 period. They found decreasing trends for a large number of stations in western North America and Australia, and increasing trends in parts of Europe, eastern North America, parts of South America, and southern Africa.

In summary, streamflow trends since 1950 are not statistically significant in most of the world's largest rivers (*high confidence*), while flood frequency and extreme streamflow have increased in some regions (*high confidence*).

3.3.5.2 Projected changes in runoff and river flooding at 1.5°C versus 2°C of global warming

Global-scale assessments of projected changes in freshwater systems generally suggest that areas with either positive or negative changes in mean annual streamflow are smaller for 1.5°C than for 2°C of global warming (Betts et al., 2018; Döll et al., 2018). Döll et al. (2018) found that only 11% of the global land area (excluding Greenland and Antarctica) shows a statistically significantly larger hazard at 2°C than at 1.5°C. Significant decreases are found for 13% of the global land area for both global warming levels, while significant increases are projected to occur for 21% of the global land area at 1.5°C, and rise to between 26% (Döll et al., 2018) and approximately 50% (Betts et al., 2018) at 2°C.

At the regional scale, projected runoff changes generally follow the spatial extent of projected changes in precipitation (see Section 3.3.3). Emerging literature includes runoff projections for different warming levels. For 2°C of global warming, an increase in runoff is projected for much of the high northern latitudes, Southeast Asia, East Africa, northeastern Europe, India, and parts of, Austria, China, Hungary, Norway, Sweden, the northwest Balkans and Sahel (Schleussner et al., 2016b; Donnelly et al., 2017; Döll et al., 2018; Zhai et al., 2018). Additionally, decreases are projected in the Mediterranean region, southern Australia, Central America, and central and southern South

America (Schleussner et al., 2016b; Donnelly et al., 2017; Döll et al., 2018). Differences between 1.5°C and 2°C would be most prominent in the Mediterranean, where the median reduction in annual runoff is expected to be about 9% (likely range 4.5–15.5%) at 1.5°C, while at 2°C of warming runoff could decrease by 17% (likely range 8–25%) (Schleussner et al., 2016b). Consistent with these projections, Döll et al. (2018) found that statistically insignificant changes in the mean annual streamflow around the Mediterranean region became significant when the global warming scenario was changed from 1.5°C to 2°C, with decreases of 10–30% between these two warming levels. Donnelly et al. (2017) found an intense decrease in runoff along both the Iberian and Balkan coasts with an increase in warming level.

Basin-scale projections of river runoff at different warming levels are available for many regions. Betts et al. (2018) assessed runoff changes in 21 of the world's major river basins at 1.5°C and 2°C of global warming (Figure 3.15). They found a general tendency towards increased runoff, except in the Amazon, Orange, Danube and Guadiana basins where the range of projections indicate decreased mean flows (Figure 3.13). In the case of the Amazon, mean flows are projected to decline by up to 25% at 2°C global warming (Betts et al., 2018). Gosling et al. (2017) analysed the impact of global warming of 1°C, 2°C and 3°C above pre-industrial levels on river runoff at the catchment scale, focusing on eight major rivers in different continents: Upper Amazon, Darling, Ganges, Lena, Upper Mississippi, Upper Niger, Rhine and Tagus. Their results show that the sign and magnitude of change with global warming for the Upper Amazon, Darling, Ganges, Upper Niger and Upper Mississippi is unclear, while the Rhine and Tagus may experience decreases in projected runoff and the Lena may experience increases. Donnelly et al. (2017) analysed the mean flow response to different warming levels for six major European rivers: Glomma, Wisla, Lule, Ebro, Rhine and Danube. Consistent with the increases in mean runoff projected for large parts of northern Europe, the Glomma, Wisla and Lule rivers could experience increased discharges with global warming while discharges from the Ebro could decrease, in part due to a decrease in runoff in southern Europe. In the case of the Rhine and Danube rivers, Donnelly et al. (2017) did not find clear results. Mean annual runoff of the Yiluo River catchment in northern China is projected to decrease by 22% at 1.5°C and by 21% at 2°C, while the mean annual runoff for the Beijiang River catchment in southern China is projected to increase by less than 1% at 1.5°C and 3% at 2°C in comparison to the studied baseline period (L. Liu et al., 2017).

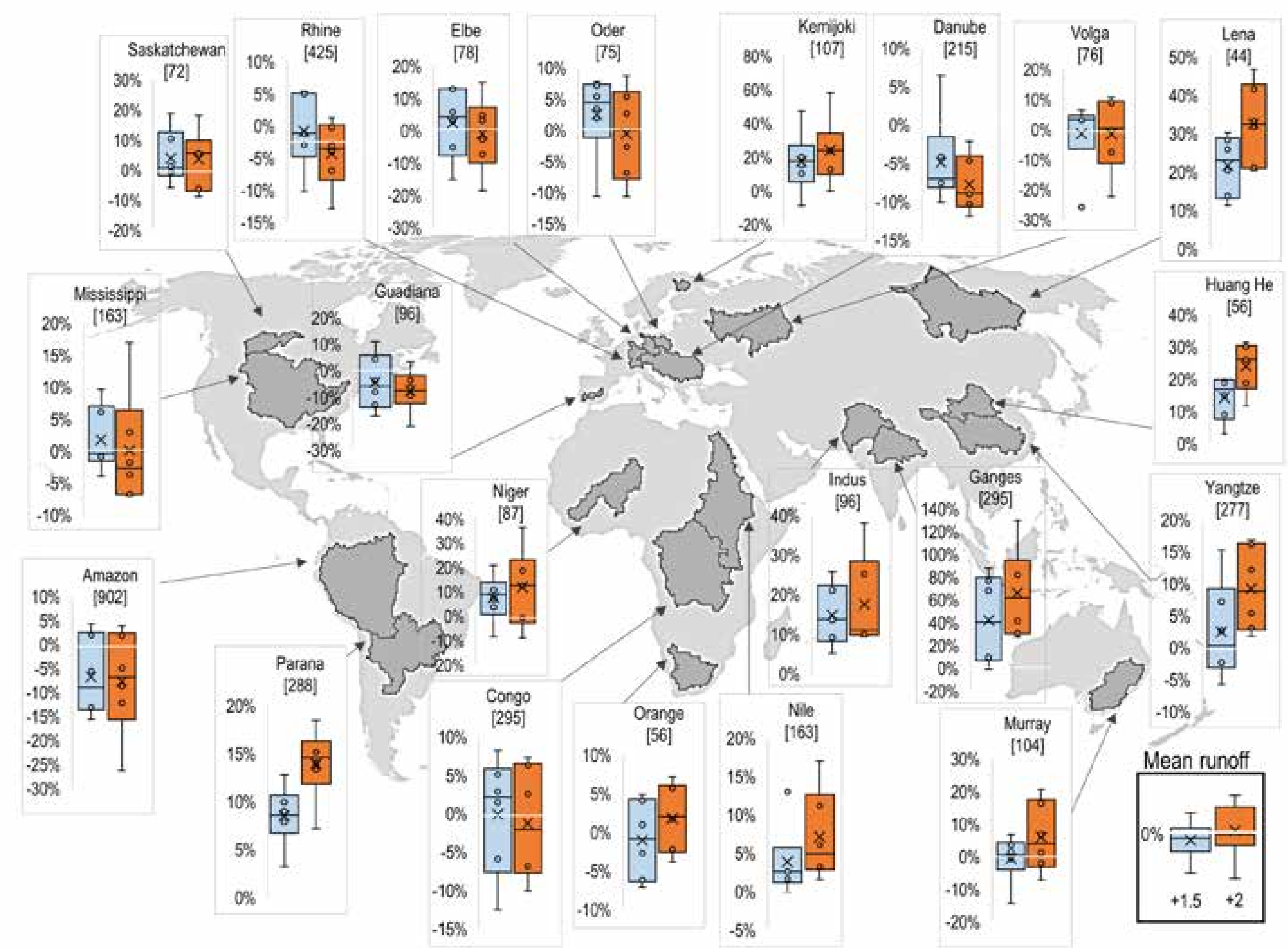


Figure 3.15 | Runoff changes in twenty-one of the world's major river basins at 1.5°C (blue) and 2°C (orange) of global warming, simulated by the Joint UK Land Environment Simulator (JULES) ecosystem–hydrology model under the ensemble of six climate projections. Boxes show the 25th and 75th percentile changes, whiskers show the range, circles show the four projections that do not define the ends of the range, and crosses show the ensemble means. Numbers in square brackets show the ensemble-mean flow in the baseline (millimetres of rain equivalent) (Source: Betts et al., 2018).

Chen et al. (2017) assessed the future changes in water resources in the Upper Yangtze River basin for the same warming levels and found a slight decrease in the annual discharge at 1.5°C but a slight increase at 2°C. Montroull et al. (2018) studied the hydrological impacts of the main rivers (Paraguay, Paraná, Iguazú and Uruguay) in La Plata basin in South America under 1.5°C and 2°C of global warming and for two emissions scenarios. The Uruguay basin shows increases in streamflow for all scenarios/warming targets except for the combination of RCP8.5/1.5°C of warming. The increase is approximately 15% above the 1981–2000 reference period for 2°C of global warming and the RCP4.5 scenario. For the other three rivers the sign of the change in mean streamflow depends strongly on the RCP and GCM used.

Marx et al. (2018) analysed how hydrological low flows in Europe are affected under different global warming levels (1.5°C, 2°C and 3°C). The Alpine region showed the strongest low flow increase, from 22% at 1.5°C to 30% at 2°C, because of the relatively large snow melt contribution, while in the Mediterranean low flows are expected to decrease because of the decreases in annual precipitation projected for that region. Döll et al. (2018) found that extreme low flows in the tropical Amazon, Congo and Indonesian basins could decrease by 10% at 1.5°C, whereas they could increase by 30% in the southwestern part of Russia under the same warming level. At 2°C, projected increases in extreme low flows are exacerbated in the higher northern latitudes and in eastern Africa, India and Southeast Asia, while projected decreases intensify in the Amazon basin, western United States, central Canada, and southern and western Europe, although not in the Congo basin or Indonesia, where models show less agreement.

Recent analyses of projections in river flooding and extreme runoff and flows are available for different global warming levels. At the global scale, Alfieri et al. (2017) assessed the frequency and magnitude of river floods and their impacts under 1.5°C, 2°C and 4°C global warming scenarios. They found that flood events with an occurrence interval longer than the return period of present-day flood protections are projected to increase in all continents under all considered warming levels, leading to a widespread increment in the flood hazard. Döll et al. (2018) found that high flows are projected to increase significantly on 11% and 21% of the global land area at 1.5°C and 2°C, respectively. Significantly increased high flows are expected to occur in South and Southeast Asia and Central Africa at 1.5°C, with this effect intensifying and including parts of South America at 2°C.

Regarding the continental scale, Donnelly et al. (2017) and Thober et al. (2018) explored climate change impacts on European high flows and/or floods under 1.5°C, 2°C and 3°C of global warming. Thober et al. (2018) identified the Mediterranean region as a hotspot of change, with significant decreases in high flows of –11% and –13% at 1.5°C and 2°C, respectively, mainly resulting from reduced precipitation (Box 3.2). In northern regions, high flows are projected to rise by 1% and 5% at 1.5°C and 2°C, respectively, owing to increasing precipitation, although floods could decrease by 6% in both scenarios because of less snowmelt. Donnelly et al. (2017) found that high runoff levels could rise in intensity, robustness and spatial extent over large parts of continental Europe with an increasing warming level. At 2°C, flood magnitudes are expected to increase significantly in Europe south of 60°N, except for some regions (Bulgaria, Poland and southern Spain); in contrast, they are projected to decrease at higher latitudes (e.g., in most of Finland, northwestern Russia and northern Sweden), with the exception of southern Sweden and some coastal areas in Norway where flood magnitudes may increase (Roudier et al., 2016). At the basin scale, Mohammed et al. (2017) found that floods are projected to be more frequent and flood magnitudes greater at 2°C than at 1.5°C in the Brahmaputra River in Bangladesh. In coastal regions, increases in heavy precipitation associated with tropical cyclones (Section 3.3.6) combined with increased sea levels (Section 3.3.9) may lead to increased flooding (Section 3.4.5).

In summary, there is *medium confidence* that global warming of 2°C above the pre-industrial period would lead to an expansion of the area with significant increases in runoff, as well as the area affected by flood hazard, compared to conditions at 1.5°C of global warming. A global warming of 1.5°C would also lead to an expansion of the global land area with significant increases in runoff (*medium confidence*) and to an increase in flood hazard in some regions (*medium confidence*) compared to present-day conditions.

3.3.6 Tropical Cyclones and Extratropical Storms

Most recent studies on observed trends in the attributes of tropical cyclones have focused on the satellite era starting in 1979 (Rienecker et al., 2011), but the study of observed trends is complicated by the heterogeneity of constantly advancing remote sensing techniques and instrumentation during this period (e.g., Landsea, 2006; Walsh et al., 2016). Numerous studies leading up to and after AR5 have reported a decreasing trend in the global number of tropical cyclones and/or the globally accumulated cyclonic energy (Emanuel, 2005; Elsner et al., 2008; Knutson et al., 2010; Holland and Bruyère, 2014; Klotzbach and Landsea, 2015; Walsh et al., 2016). A theoretical physical basis for such a decrease to occur under global warming was recently provided by Kang and Elsner (2015). However, using a relatively short (20 year) and relatively homogeneous remotely sensed record, Klotzbach (2006) reported no significant trends in global cyclonic activity, consistent with more recent findings of Holland and Bruyère (2014). Such contradictions, in combination with the fact that the almost four-decade-long period of remotely sensed observations remains relatively short to distinguish anthropogenically induced trends from decadal and multi-decadal variability, implies that there is only *low confidence* regarding changes in global tropical cyclone numbers under global warming over the last four decades.

Studies in the detection of trends in the occurrence of very intense tropical cyclones (category 4 and 5 hurricanes on the Saffir-Simpson scale) over recent decades have yielded contradicting results. Most studies have reported increases in these systems (Emanuel, 2005; Webster et al., 2005; Klotzbach, 2006; Elsner et al., 2008; Knutson et al., 2010; Holland and Bruyère, 2014; Walsh et al., 2016), in particular for the North Atlantic, North Indian and South Indian Ocean basins (e.g., Singh et al., 2000; Singh, 2010; Kossin et al., 2013; Holland and Bruyère, 2014; Walsh et al., 2016). In the North Indian Ocean over the Arabian Sea, an increase in the frequency of extremely severe cyclonic storms has been reported and attributed to anthropogenic warming (Murakami et al., 2017). However, to the east over the Bay of Bengal, tropical cyclones and severe tropical cyclones have exhibited decreasing trends over the period 1961–2010, although the ratio between severe tropical cyclones and all tropical cyclones is increasing (Mohapatra et al., 2017). Moreover, studies that have used more homogeneous records, but were consequently limited to rather short periods of 20 to 25 years, have reported no statistically significant trends or decreases in the global number of these systems (Kamahori et al., 2006; Klotzbach and Landsea, 2015). Likewise, CMIP5 model simulations of the historical period have not produced anthropogenically induced trends in very intense tropical cyclones (Bender et al., 2010; Knutson et al., 2010, 2013; Camargo, 2013; Christensen et al., 2013), consistent with the findings of Klotzbach and Landsea (2015). There is consequently *low confidence* in the conclusion that the number of very intense cyclones is increasing globally.

General circulation model (GCM) projections of the changing attributes of tropical cyclones under high levels of greenhouse gas forcing (3°C to 4°C of global warming) consistently indicate decreases in the global number of tropical cyclones (Knutson et al., 2010, 2015; Sugi and Yoshimura, 2012; Christensen et al., 2013; Yoshida et al., 2017). A smaller number of studies based on statistical downscaling methodologies contradict these findings, however, and indicate increases in the global number of tropical cyclones under climate change (Emanuel, 2017). Most studies also indicate increases in the global number of very intense tropical cyclones under high levels of global warming (Knutson et al., 2015; Sugi et al., 2017), consistent with dynamic theory (Kang and Elsner, 2015), although a few studies contradict this finding (e.g., Yoshida et al., 2017). Hence, it is assessed that under 3°C to 4°C of warming that the global number of tropical cyclones would decrease whilst the number of very intense cyclones would increase (*medium confidence*).

To date, only two studies have directly explored the changing tropical cyclone attributes under 1.5°C versus 2°C of global warming. Using a high resolution global atmospheric model, Wehner et al. (2018a) concluded that the differences in tropical cyclone statistics under 1.5°C versus 2°C stabilization scenarios, as defined by the HAPPI protocols (Mitchell et al., 2017) are small. Consistent with the majority of studies performed for higher degrees of global warming, the total number of tropical cyclones is projected to decrease under global warming, whilst the most intense (categories 4 and 5) cyclones are projected to occur more frequently. These very intense storms are projected to be associated with higher peak wind speeds and lower central pressures under 2°C versus 1.5°C of global warming. The accumulated cyclonic energy is projected to decrease globally from 1.5°C to 2°C, in association with a decrease in the global number of tropical cyclones under progressively higher levels of global warming. It is also noted that heavy rainfall associated with tropical cyclones was assessed in the IPCC SREX as *likely* to increase under increasing global warming (Seneviratne et al., 2012). Two recent articles suggest that there is *high confidence* that the current level of global warming (i.e., about 1°C, see Section 3.3.1) increased the heavy precipitation associated with the 2017 Hurricane Harvey by about 15% or more (Risser and Wehner, 2017; van Oldenborgh et al., 2017). Hence, it can be inferred, under the assumption of linear dynamics, that further increases in heavy precipitation would occur under 1.5°C, 2°C and higher levels of global warming (*medium confidence*). Using a high resolution regional climate model, Muthige et al. (2018) explored the effects of different degrees of global warming on tropical cyclones over the southwest Indian Ocean, using transient simulations that downscaled a number of RCP8.5 GCM projections. Decreases in tropical cyclone frequencies are projected under both 1.5°C and 2°C of global warming. The decreases in cyclone frequencies under 2°C of global warming are somewhat larger than under 1.5°C, but no further decreases are projected under 3°C. This suggests that 2°C of warming, at least in these downscaling simulations, represents a type of stabilization level in terms of tropical cyclone formation over the southwest Indian Ocean and landfall over southern Africa (Muthige et al., 2018). There is thus *limited evidence* that the global number of tropical cyclones will be lower under 2°C compared to 1.5°C of global warming, but with an increase in the number of very intense cyclones (*low confidence*).

The global response of the mid-latitude atmospheric circulation to 1.5°C and 2°C of warming was investigated using the HAPPI ensemble with a focus on the winter season (Li et al., 2018). Under 1.5°C of global warming a weakening of storm activity over North America, an equatorward shift of the North Pacific jet exit and an equatorward intensification of the South Pacific jet are projected. Under an additional 0.5°C of warming a poleward shift of the North Atlantic jet exit and an intensification on the flanks of the Southern Hemisphere storm track are projected to become more pronounced. The weakening of the Mediterranean storm track that is projected under low mitigation emerges in the 2°C warmer world (Li et al., 2018). AR5 assessed that under high greenhouse gas forcing (3°C or 4°C of global warming) there is *low confidence* in projections of poleward shifts of the Northern Hemisphere storm tracks, while there is *high confidence* that there would be a small poleward shift of the Southern Hemisphere storm tracks (Stocker et al., 2013). In the context of this report, the assessment is that there is *limited evidence* and *low confidence* in whether any projected signal for higher levels of warming would be clearly manifested under 2°C of global warming.

3.3.7 Ocean Circulation and Temperature

It is *virtually certain* that the temperature of the upper layers of the ocean (0–700 m in depth) has been increasing, and that the global mean for sea surface temperature (SST) has been changing at a rate just behind that of GMST. The surfaces of three ocean basins has warmed over the period 1950–2016 (by 0.11°C, 0.07°C and 0.05°C per decade for the Indian, Atlantic and Pacific Oceans, respectively; Hoegh-Guldberg et al., 2014), with the greatest changes occurring at the highest latitudes. Isotherms (i.e., lines of equal temperature) of sea surface temperature (SST) are shifting to higher latitudes at rates of up to 40 km per year (Burrows et al., 2014; García Molinos et al., 2015). Long-term patterns of variability make detecting signals due to climate change complex, although the recent acceleration of changes to the temperature of the surface layers of the ocean has made the climate signal more distinct (Hoegh-Guldberg et al., 2014). There is also evidence of significant increases in the frequency of marine heatwaves in the observational record (Oliver et al., 2018), consistent with changes in mean ocean temperatures (*high confidence*). Increasing climate extremes in the ocean are associated with the general rise in global average surface temperature, as well as more intense patterns of climate variability (e.g., climate change intensification of ENSO) (Section 3.5.2.5). Increased heat in the upper layers of the ocean is also driving more intense storms and greater rates of inundation in some regions, which, together with sea level rise, are already driving significant impacts to sensitive coastal and low-lying areas (Section 3.3.6).

Increasing land–sea temperature gradients have the potential to strengthen upwelling systems associated with the eastern boundary currents (Benguela, Canary, Humboldt and Californian Currents; Bakun, 1990). Observed trends support the conclusion that a general strengthening of longshore winds has occurred (Sydeman et al., 2014), but the implications of trends detected in upwelling currents themselves are unclear (Lluch-Cota et al., 2014). Projections of the scale of changes between 1°C and 1.5°C of global warming and between 1.5°C and 2°C are only informed by the changes during the past increase in GMST of 0.5°C (*low confidence*). However, evidence from GCM projections of future climate change indicates that a general strengthening of the Benguela, Canary and Humboldt upwelling systems under enhanced anthropogenic forcing (D. Wang et al., 2015) is projected to occur (*medium confidence*). This strengthening is projected to be stronger at higher latitudes. In fact, evidence from regional climate modelling is supportive of an increase in long-shore winds at higher latitudes, whereas long-shore winds may decrease at lower latitudes as a consequence of the poleward displacement of the subtropical highs under climate change (Christensen et al., 2007; Engelbrecht et al., 2009).

It is more likely than not that the Atlantic Meridional Overturning Circulation (AMOC) has been weakening in recent decades, given the detection of the cooling of surface waters in the North Atlantic and evidence that the Gulf Stream has slowed since the late 1950s (Rahmstorf et al., 2015b; Srokosz and Bryden, 2015; Caesar et al., 2018). There is only *limited evidence* linking the current anomalously weak state of AMOC to anthropogenic warming (Caesar et al., 2018). It is *very likely* that the AMOC will weaken over the 21st century. The best estimates and ranges for the reduction based on CMIP5 simulations are 11% (1– 24%) in RCP2.6 and 34% (12– 54%) in RCP8.5 (AR5). There is *no evidence* indicating significantly different amplitudes of AMOC weakening for 1.5°C versus 2°C of global warming.

3.3.8 Sea Ice

Summer sea ice in the Arctic has been retreating rapidly in recent decades. During the period 1997 to 2014, for example, the monthly mean sea ice extent during September (summer) decreased on average by 130,000 km² per year (Serreze and Stroeve, 2015). This is about four times as fast as the September sea ice loss during the period 1979 to 1996. Sea ice thickness has also decreased substantially, with an estimated decrease in ice thickness of more than 50% in the central Arctic (Lindsay and Schweiger, 2015). Sea ice coverage and thickness also decrease in CMIP5 simulations of the recent past, and are projected to decrease in the future (Collins et al., 2013). However, the modelled sea ice loss in most CMIP5 models is much smaller than observed losses. Compared to observations, the simulations are less sensitive to both global mean temperature rise (Rosenblum and Eisenman, 2017) and anthropogenic CO_2 emissions (Notz and Stroeve, 2016). This mismatch between the observed and modelled sensitivity of Arctic sea ice implies that the multi-model-mean responses of future sea ice evolution probably underestimates the sea ice loss for a given amount of global warming. To address this issue, studies estimating the future evolution of Arctic sea ice tend to bias correct the model simulations based on the observed evolution of Arctic sea ice in response to global warming. Based on such bias correction, pre-AR5 and post-AR5 studies generally agree that for 1.5°C of global warming relative to pre-industrial levels, the Arctic Ocean will maintain a sea ice cover throughout summer in most years (Collins et al., 2013; Notz and Stroeve, 2016; Screen and Williamson, 2017; Jahn, 2018; Niederdrenk and Notz, 2018; Sigmond et al., 2018). For 2°C of global warming, chances of a sea ice-free Arctic during summer are substantially higher (Screen and Williamson, 2017; Jahn, 2018; Niederdrenk and Notz, 2018; Screen et al., 2018; Sigmond et al., 2018). Model simulations suggest that there will be at least one sea ice-free Arctic[5] summer after approximately 10 years of stabilized warming at 2°C, as compared to one sea ice-free summer after 100 years of stabilized warming at 1.5°C above pre-industrial temperatures (Jahn, 2018; Screen et al., 2018; Sigmond et al., 2018). For a specific given year under stabilized warming of 2°C, studies based on large ensembles of simulations with a single model estimate the likelihood of ice-free conditions as 35% without a bias correction of the underlying model (Sanderson et al., 2017; Jahn, 2018); as between 10% and >99% depending on the observational record used to correct the sensitivity of sea ice decline to global warming in the underlying model (Niederdrenk and Notz, 2018); and as 19% based on a procedure to correct for biases in the climatological sea ice coverage in the underlying model (Sigmond et al., 2018). The uncertainty of the first year of the occurrence of an ice-free Arctic Ocean arising from internal variability is estimated to be about 20 years (Notz, 2015; Jahn et al., 2016).

The more recent estimates of the warming necessary to produce an ice-free Arctic Ocean during summer are lower than the ones given in AR5 (about 2.6°C–3.1°C of global warming relative to pre-industrial levels or 1.6°C–2.1°C relative to present-day conditions), which were similar to the estimate of 3°C of global warming relative to pre-industrial levels (or 2°C relative to present-day conditions) by Mahlstein and Knutti (2012) based on bias-corrected CMIP3 models. Rosenblum and Eisenman (2016) explained why the sensitivity estimated by Mahlstein and Knutti (2012) might be too low, estimating instead that September sea ice in the Arctic would disappear at 2°C of global warming relative to pre-industrial levels (or about 1°C relative to present-day conditions), in line with the other recent estimates. Notz and Stroeve (2016) used the observed correlation between September sea ice extent and cumulative CO_2 emissions to estimate that the Arctic Ocean would become nearly free of sea ice during September with a further 1000 Gt of emissions, which also implies a sea ice loss at about 2°C of global warming. Some of the uncertainty in these numbers stems from the possible impact of aerosols (Gagne et al., 2017) and of volcanic forcing (Rosenblum and Eisenman, 2016). During winter, little Arctic sea ice is projected to be lost for either 1.5°C or 2°C of global warming (Niederdrenk and Notz, 2018).

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[5] Ice free is defined for the Special Report as when the sea ice extent is less than 106 km². Ice coverage less than this is considered to be equivalent to an ice-free Arctic Ocean for practical purposes in all recent studies.

A substantial number of pre-AR5 studies found that there is no indication of hysteresis behaviour of Arctic sea ice under decreasing temperatures following a possible overshoot of a long-term temperature target (Holland et al., 2006; Schröder and Connolley, 2007; Armour et al., 2011; Sedláček et al., 2011; Tietsche et al., 2011; Boucher et al., 2012; Ridley et al., 2012). In particular, the relationship between Arctic sea ice coverage and GMST was found to be indistinguishable between a warming scenario and a cooling scenario. These results have been confirmed by post-AR5 studies (Li et al., 2013; Jahn, 2018), which implies *high confidence* that an intermediate temperature overshoot has no long-term consequences for Arctic sea ice coverage.

In the Antarctic, sea ice shows regionally contrasting trends, such as a strong decrease in sea ice coverage near the Antarctic peninsula but increased sea ice coverage in the Amundsen Sea (Hobbs et al., 2016). Averaged over these contrasting regional trends, there has been a slow long-term increase in overall sea ice coverage in the Southern Ocean, although with comparably low ice coverage from September 2016 onwards. Collins et al. (2013) assessed *low confidence* in Antarctic sea ice projections because of the wide range of model projections and an inability of almost all models to reproduce observations such as the seasonal cycle, interannual variability and the long-term slow increase. No existing studies have robustly assessed the possible future evolution of Antarctic sea ice under low-warming scenarios.

In summary, the probability of a sea-ice-free Arctic Ocean during summer is substantially higher at 2°C compared to 1.5°C of global warming relative to pre-industrial levels, and there is *medium confidence* that there will be at least one sea ice-free Arctic summer after about 10 years of stabilized warming at 2°C, while about 100 years are required at 1.5°C. There is *high confidence* that an intermediate temperature overshoot has no long-term consequences for Arctic sea ice coverage with regrowth on decadal time scales.

3.3.9 Sea Level

Sea level varies over a wide range of temporal and spatial scales, which can be divided into three broad categories. These are global mean sea level (GMSL), regional variation about this mean, and the occurrence of sea-level extremes associated with storm surges and tides. GMSL has been rising since the late 19th century from the low rates of change that characterized the previous two millennia (Church et al., 2013). Slowing in the reported rate over the last two decades (Cazenave et al., 2014) may be attributable to instrumental drift in the observing satellite system (Watson et al., 2015) and increased volcanic activity (Fasullo et al., 2016). Accounting for the former results in rates (1993 to mid-2014) between 2.6 and 2.9 mm yr^{-1} (Watson et al., 2015). The relative contributions from thermal expansion, glacier and ice-sheet mass loss, and freshwater storage on land are relatively well understood (Church et al., 2013; Watson et al., 2015) and their attribution is dominated by anthropogenic forcing since 1970 (15 ± 55% before 1950, 69 ± 31% after 1970) (Slangen et al., 2016).

There has been a significant advance in the literature since AR5, which has included the development of semi-empirical models (SEMs) into a broader emulation-based approach (Kopp et al., 2014; Mengel et al., 2016; Nauels et al., 2017) that is partially based on the results from more detailed, process-based modelling Church et al. (2013) assigned *low confidence* to SEMs because these models assume that the relation between climate forcing and GMSL is the same in the past (calibration) and future (projection). Probable future changes in the relative contributions of thermal expansion, glaciers and (in particular) ice sheets invalidate this assumption. However, recent emulation-based studies overcame this shortcoming by considering individual GMSL contributors separately, and they are therefore employed in this assessment. In this subsection, the process-based literature of individual contributors to GMSL is considered for scenarios close to 1.5°C and 2°C of global warming before emulation-based approaches are assessed.

A limited number of processes-based studies are relevant to GMSL in 1.5°C and 2°C worlds. Marzeion et al. (2018) used a global glacier model with temperature-scaled scenarios based on RCP2.6 to investigate the difference between 1.5°C and 2°C of global warming and found little difference between scenarios in the glacier contribution to GMSL for the year 2100 (54–97 mm relative to present-day levels for 1.5°C and 63–112 mm for 2°C, using a 90% confidence interval). This arises because glacier melt during the remainder of the century is dominated by the response to warming from pre-industrial to present-day levels, which is in turn a reflection of the slow response times of glaciers. Fürst et al. (2015) made projections of the Greenland ice sheet's contribution to GMSL using an ice-flow model forced by the regional climate model Modèle Atmosphérique Régional (MAR; considered by Church et al. (2013) to be the 'most realistic' such model). They projected an RCP2.6 range of 24–60 mm (1 standard deviation) by the end of the century (relative to the year 2000 and consistent with the assessment of Church et al. (2013); however, their projections do not allow the difference between 1.5°C and 2°C worlds to be evaluated.

The Antarctic ice sheet can contribute both positively, through increases in outflow (solid ice lost directly to the ocean), and negatively, through increases in snowfall (owing to the increased moisture-bearing capacity of a warmer atmosphere), to future GMSL rise. Frieler et al. (2015) suggested a range of 3.5–8.7% °C^{-1} for this effect, which is consistent with AR5. Observations from the Amundsen Sea sector of Antarctica suggest an increase in outflow (Mouginot et al., 2014) over recent decades associated with grounding line retreat (Rignot et al., 2014) and the influx of relatively warm Circumpolar Deepwater (Jacobs et al., 2011). Literature on the attribution of these changes to anthropogenic forcing is still in its infancy (Goddard et al., 2017; Turner et al., 2017a). RCP2.6-based projections of Antarctic outflow (Levermann et al., 2014; Golledge et al., 2015; DeConto and Pollard, 2016, who include snowfall changes) are consistent with the AR5 assessment of Church et al. (2013) for end-of-century GMSL for RCP2.6, and do not support substantial additional GMSL rise by Marine Ice Sheet Instability or associated instabilities (see Section 3.6). While agreement is relatively good, concerns about the numerical fidelity of these models still exist, and this may affect the quality of their projections (Drouet et al., 2013; Durand and Pattyn, 2015). An assessment of Antarctic contributions beyond the end of the century, in particular related to the Marine Ice Sheet Instability, can be found in Section 3.6.

While some literature on process-based projections of GMSL for the period up to 2100 is available, it is insufficient for distinguishing between emissions scenarios associated with 1.5°C and 2°C warmer worlds. This literature is, however, consistent with the assessment by Church et al. (2013) of a *likely* range of 0.28–0.61 m in 2100 (relative to 1986–2005), suggesting that the AR5 assessment is still appropriate.

Recent emulation-based studies show convergence towards this AR5 assessment (Table 3.1) and offer the advantage of allowing a comparison between 1.5°C and 2°C warmer worlds. Table 3.1 features a compilation of recent emulation-based and SEM studies.

Table 3.1 | Compilation of recent projections for sea level at 2100 (in cm) for Representative Concentration Pathway (RCP)2.6, and 1.5°C and 2°C scenarios. Upper and lower limits are shown for the 17-84% and 5-95% confidence intervals quoted in the original papers.

Study	Baseline	RCP2.6		1.5°C		2°C	
		67%	90%	67%	90%	67%	90%
AR5	1986–2005	28–61					
Kopp et al. (2014)	2000	37–65	29–82				
Jevrejeva et al. (2016)	1986–2005		29–58				
Kopp et al. (2016)	2000	28–51	24–61				
Mengel et al. (2016)	1986–2005	28–56					
Nauels et al. (2017)	1986–2005	35–56					
Goodwin et al. (2017)	1986–2005		31–59 45–70 45–72				
Schaeffer et al. (2012)	2000		52–96		54–99		56–105
Schleussner et al. (2016b)	2000			26–53		36–65	
Bittermann et al. (2017)	2000				29–46		39–61
Jackson et al. (2018)	1986–2005			30–58 40–77	20–67 28–93	35–64 47–93	24–74 32–117
Sanderson et al. (2017)					50–80		60–90
Nicholls et al. (2018)	1986–2005				24–54		31–65
Rasmussen et al. (2018)	2000			35–64	28–82	39–76	28–96
Goodwin et al. (2018)	1986–2005				26–62		30–69

There is little consensus between the reported ranges of GMSL rise (Table 3.1). Projections vary in the range 0.26–0.77 m and 0.35–0.93 m for 1.5°C and 2°C respectively for the 17–84% confidence interval (0.20–0.99 m and 0.24–1.17 m for the 5–95% confidence interval). There is, however, *medium agreement* that GMSL in 2100 would be 0.04–0.16 m higher in a 2°C warmer world compared to a 1.5°C warmer world based on the 17–84% confidence interval (0.00–0.24 m based on 5–95% confidence interval) with a value of around 0.1 m. There is *medium confidence* in this assessment because of issues associated with projections of the Antarctic contribution to GMSL that are employed in emulation-based studies (see above) and the issues previously identified with SEMs (Church et al., 2013).

Translating projections of GMSL to the scale of coastlines and islands requires two further steps. The first step accounts for regional changes associated with changing water and ice loads (such as Earth's gravitational field and rotation, and vertical land movement), as well as spatial differences in ocean heat uptake and circulation. The second step maps regional sea level to changes in the return periods of particular flood events to account for effects not included in global climate models, such as tides, storm surges, and wave setup and runup. Kopp et al. (2014) presented a framework to do this and gave an example application for nine sites located in the US, Japan, northern Europe and Chile. Of these sites, seven (all except those in northern Europe) were found to experience at least a quadrupling in the number of years in the 21st century with 1-in-100-year floods under RCP2.6 compared to under no future sea level rise. Rasmussen et al. (2018) used this approach to investigate the difference between 1.5°C and 2°C warmer worlds up to 2200. They found that the reduction in the frequency of 1-in-100-year floods in a 1.5°C compared to a 2°C warmer world would be greatest in the eastern USA and Europe, with ESL event frequency amplification being reduced by about a half and with smaller reductions for small island developing states (SIDS). This last result contrasts with the finding of Vitousek et al. (2017) that regions with low variability in extreme water levels (such as SIDS in the tropics) are particularly sensitive to GMSL rise, such that a doubling of frequency may be expected for even small (0.1–0.2 m) rises. Schleussner et al. (2011) emulated the AMOC based on a subset of CMIP-class climate models. When forced using global temperatures appropriate for the CP3-PD scenario (1°C of warming in 2100 relative to 2000 or about 2°C of warming relative to pre-industrial) the emulation suggests an 11% median reduction in AMOC strength at 2100 (relative to 2000) with an associated 0.04 m dynamic sea level rise along the New York City coastline.

In summary, there is *medium confidence* that GMSL rise will be about 0.1 m (within a 0.00–0.20 m range based on 17–84% confidence-interval projections) less by the end of the 21st century in a 1.5°C compared to a 2°C warmer world. Projections for 1.5°C and 2°C global warming cover the ranges 0.2–0.8 m and 0.3–1.00 m relative to 1986–2005, respectively (*medium confidence*). Sea level rise beyond 2100 is discussed in Section 3.6; however, recent literature strongly supports the assessment by Church et al. (2013) that sea level rise will continue well beyond 2100 (*high confidence*).

Box 3.3 | Lessons from Past Warm Climate Episodes

Climate projections and associated risk assessments for a future warmer world are based on climate model simulations. However, Coupled Model Intercomparison Project Phase 5 (CMIP5) climate models do not include all existing Earth system feedbacks and may therefore underestimate both rates and extents of changes (Knutti and Sedláček, 2012). Evidence from natural archives of three moderately warmer (1.5°C–2°C) climate episodes in Earth's past help to assess such long-term feedbacks (Fischer et al., 2018).

While evidence over the last 2000 years and during the Last Glacial Maximum (LGM) was discussed in detail in the IPCC Fifth Assessment Report (Masson-Delmotte et al., 2013), the climate system response during past warm intervals was the focus of a recent review paper (Fischer et al., 2018) summarized in this Box. Examples of past warmer conditions with essentially modern physical geography include the Holocene Thermal Maximum (HTM; broadly defined as about 10–5 kyr before present (BP), where present is defined as 1950), the Last Interglacial (LIG; about 129–116 kyr BP) and the Mid Pliocene Warm Period (MPWP; 3.3–3.0 Myr BP).

Changes in insolation forcing during the HTM (Marcott et al., 2013) and the LIG (Hoffman et al., 2017) led to a global temperature up to 1°C higher than that in the pre-industrial period (1850–1900); high-latitude warming was 2°C–4°C (Capron et al., 2017), while temperature in the tropics changed little (Marcott et al., 2013). Both HTM and LIG experienced atmospheric CO_2 levels similar to pre-industrial conditions (Masson-Delmotte et al. 2013). During the MPWP, the most recent time period when CO_2 concentrations were similar to present-day levels, the global temperature was >1°C and Arctic temperatures about 8°C warmer than pre-industrial (Brigham-Grette et al., 2013).

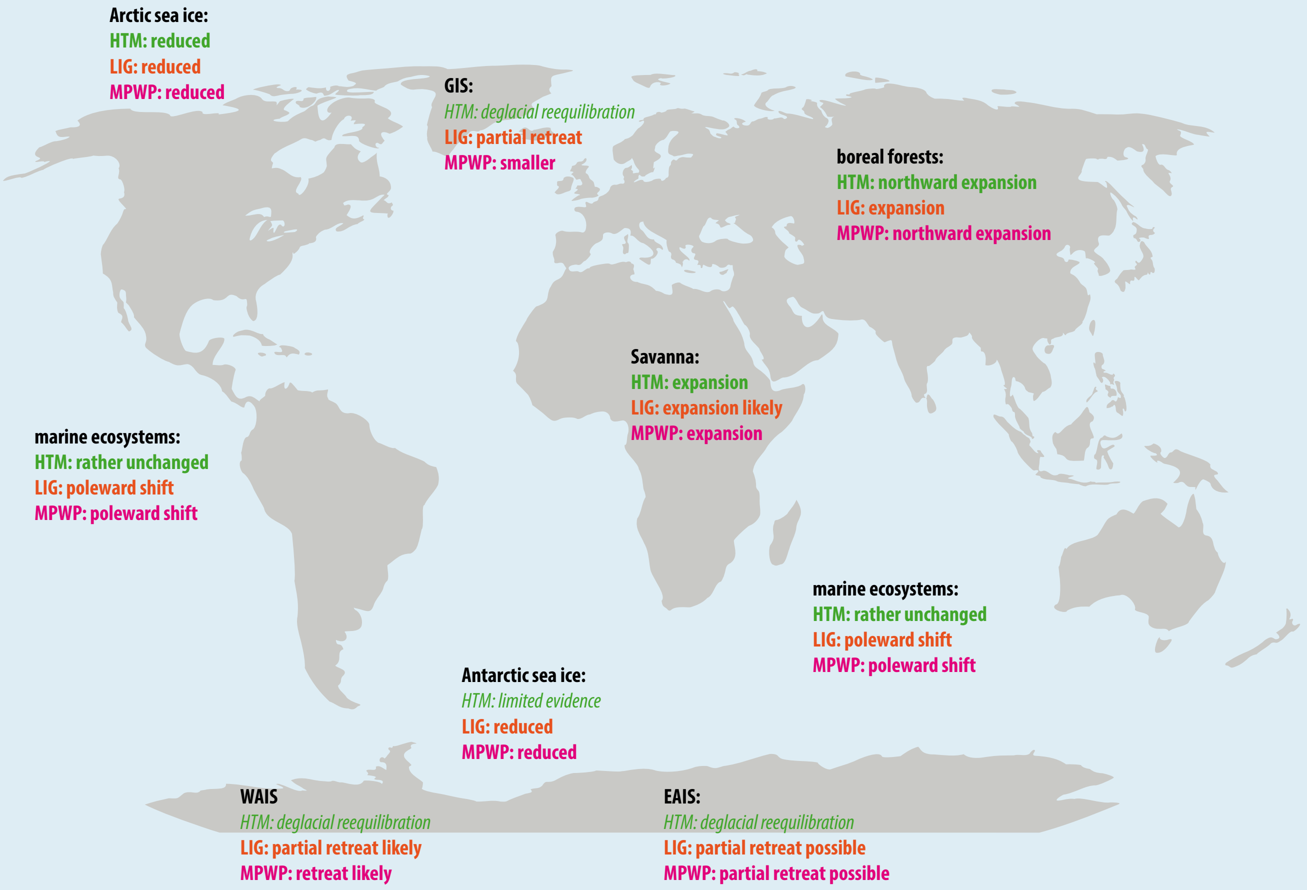
Although imperfect as analogues for the future, these regional changes can inform risk assessments such as the potential for crossing irreversible thresholds or amplifying anthropogenic changes (Box 3.3, Figure 1). For example, HTM and LIG greenhouse gas (GHG) concentrations show no evidence of runaway greenhouse gas releases under limited global warming. Transient releases of CO_2 and CH_4 may follow permafrost melting, but these occurrences may be compensated by peat growth over longer time scales (Yu et al., 2010). Warming may release CO_2 by enhancing soil respiration, counteracting CO_2 fertilization of plant growth (Frank et al., 2010). Evidence of a collapse of the Atlantic Meridional Overturning Circulation (AMOC) during these past events of limited global warming could not be found (Galaasen et al., 2014).

The distribution of ecosystems and biomes (major ecosystem types) changed significantly during past warming events, both in the ocean and on land. For example, some tropical and temperate forests retreated because of increased aridity, while savannas expanded (Dowsett et al., 2016). Further, poleward shifts of marine and terrestrial ecosystems, upward shifts in alpine regions, and reorganizations of marine productivity during past warming events are recorded in natural archives (Williams et al., 2009; Haywood et al., 2016). Finally, past warming events are associated with partial sea ice loss in the Arctic. The limited amount of data collected so far on Antarctic sea ice precludes firm conclusions about Southern Hemisphere sea ice losses (de Vernal et al., 2013).

Reconstructed global sea level rise of 6–9 m during the LIG and possibly >6 m during the MPWP requires a retreat of either the Greenland or Antarctic ice sheets or both (Dutton et al., 2015). While ice sheet and climate models suggest a substantial retreat of the West Antarctic ice sheet (WAIS) and parts of the East Antarctic ice sheet (DeConto and Pollard, 2016) during these periods, direct observational evidence is still lacking. Evidence for ice retreat in Greenland is stronger, although a complete collapse of the Greenland ice sheet during the LIG can be excluded (Dutton et al., 2015). Rates of past sea level rises under modest warming were similar to or up to two times larger than rises observed over the past two decades (Kopp et al., 2013). Given the long time scales required to reach equilibrium in a warmer world, sea level rise will likely continue for millennia even if warming is limited to 2°C.

Finally, temperature reconstructions from these past warm intervals suggest that current climate models underestimate regional warming at high latitudes (polar amplification) and long-term (multi-millennial) global warming. None of these past warm climate episodes involved the high rate of change in atmospheric CO_2 and temperatures that we are experiencing today (Fischer et al., 2018).

Box 3.3 (continued)



Box 3.3, Figure 1 | Impacts and responses of components of the Earth System. Summary of typical changes found for warmer periods in the paleorecord, as discussed by Fischer et al. (2018). All statements are relative to pre-industrial conditions. Statements in italics indicate that no conclusions can be drawn for the future. Note that significant spatial variability and uncertainty exists in the assessment of each component, and this figure therefore should not be referred to without reading the publication in detail. HTM: Holocene Thermal Maximum, LIG: Last Interglacial, MPWP: Mid Pliocene Warm Period. (Adapted from Fischer et al., 2018).

3.3.10 Ocean Chemistry

Ocean chemistry includes pH, salinity, oxygen, CO_2, and a range of other ions and gases, which are in turn affected by precipitation, evaporation, storms, river runoff, coastal erosion, up-welling, ice formation, and the activities of organisms and ecosystems (Stocker et al., 2013). Ocean chemistry is changing alongside increasing global temperature, with impacts projected at 1.5°C and, more so, at 2°C of global warming (Doney et al., 2014) (*medium to high confidence*). Projected changes in the upper layers of the ocean include altered pH, oxygen content and sea level. Despite its many component processes, ocean chemistry has been relatively stable for long periods of time prior to the industrial period (Hönisch et al., 2012). Ocean chemistry is changing under the influence of human activities and rising greenhouse gases (*virtually certain*; Rhein et al., 2013; Stocker et al., 2013). About 30% of CO_2 emitted by human activities, for example, has been absorbed by the upper layers of the ocean, where it has combined with water to produce a dilute acid that dissociates and drives ocean acidification (*high confidence*) (Cao et al., 2007; Stocker et al., 2013). Ocean pH has decreased by 0.1 pH units since the pre-industrial period, a shift that is unprecedented in the last 65 Ma (*high confidence*) (Ridgwell and Schmidt, 2010) or even 300 Ma of Earth's history (*medium confidence*) (Hönisch et al., 2012).

Ocean acidification is a result of increasing CO_2 in the atmosphere (*very high confidence*) and is most pronounced where temperatures are lowest (e.g., polar regions) or where CO_2-rich water is brought to the ocean surface by upwelling (Feely et al., 2008). Acidification can also be influenced by effluents from natural or disturbed coastal land use (Salisbury et al., 2008), plankton blooms (Cai et al., 2011), and the atmospheric deposition of acidic materials (Omstedt et al., 2015). These sources may not be directly attributable to climate change, but they may amplify the impacts of ocean acidification (Bates and Peters, 2007; Duarte et al., 2013). Ocean acidification also influences the ionic composition of seawater by changing the organic and inorganic speciation of trace metals (e.g., 20-fold increases in free ion concentrations of metals such as aluminium) – with changes expected to have impacts although they are currently poorly documented and understood (*low confidence*) (Stockdale et al., 2016).

Oxygen varies regionally and with depth; it is highest in polar regions and lowest in the eastern basins of the Atlantic and Pacific Oceans and in the northern Indian Ocean (Doney et al., 2014; Karstensen et al., 2015; Schmidtko et al., 2017). Increasing surface water temperatures have reduced oxygen in the ocean by 2% since 1960, with other variables such as ocean acidification, sea level rise, precipitation, wind and storm patterns playing roles (Schmidtko et al., 2017). Changes to ocean mixing and metabolic rates, due to increased temperature and greater supply of organic carbon to deep areas, has increased the frequency of 'dead zones', areas where oxygen levels are so low that they no longer support oxygen dependent life (Diaz and Rosenberg, 2008). The changes are complex and include both climate change and other variables (Altieri and Gedan, 2015), and are increasing in tropical as well as temperate regions (Altieri et al., 2017).

Ocean salinity is changing in directions that are consistent with surface temperatures and the global water cycle (i.e., precipitation versus evaporation). Some regions, such as northern oceans and the Arctic, have decreased in salinity, owing to melting glaciers and ice sheets, while others have increased in salinity, owing to higher sea surface temperatures and evaporation (Durack et al., 2012). These changes in salinity (i.e., density) are also potentially contributing to large-scale changes in water movement (Section 3.3.8).

3.3.11 Global Synthesis

Table 3.2 features a summary of the assessments of global and regional climate changes and associated hazards described in this chapter, based on the existing literature. For more details about observation and attribution in ocean and cryosphere systems, please refer to the upcoming IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) due to be released in 2019.

Table 3.2 | Summary of assessments of global and regional climate changes and associated hazards. Confidence and likelihood statements are quoted from the relevant chapter text and are omitted where no assessment was made, in which case the IPCC Fifth Assessment Report (AR5) assessment is given where available. GMST: global mean surface temperature, AMOC: Atlantic Meridional Overturning Circulation, GMSL: global mean sea level.

	Observed change (recent past versus pre-industrial)	Attribution of observed change to human-induced forcing (present-day versus pre-industrial)	Projected change at 1.5°C of global warming compared to pre-industrial (1.5°C versus 0°C)	Projected change at 2°C of global warming compared to pre-industrial (2°C versus 0°C)	Differences between 2°C and 1.5°C of global warming
GMST anomaly	GMST anomalies were 0.87°C (±0.10°C *likely* range) above pre-industrial (1850–1900) values in the 2006–2015 decade, with a recent warming of about 0.2°C (±0.10°C) per decade (*high confidence*) [Chapter 1]	The observed 0.87°C GMST increase in the 2006–2015 decade compared to pre-industrial (1850–1900) conditions was mostly human-induced (*high confidence*) Human-induced warming reached about 1°C (±0.2°C *likely* range) above pre-industrial levels in 2017 [Chapter 1]	1.5°C	2°C	0.5°C
Temperature extremes	Overall decrease in the number of cold days and nights and overall increase in the number of warm days and nights at the global scale on land (*very likely*) Continental-scale increase in intensity and frequency of hot days and nights, and decrease in intensity and frequency of cold days and nights, in North America, Europe and Australia (*very likely*) Increases in frequency or duration of warm spell lengths in large parts of Europe, Asia and Australia (*high confidence* (*likely*)), as well as at the global scale (*medium confidence*) [Section 3.3.2]	Anthropogenic forcing has contributed to the observed changes in frequency and intensity of daily temperature extremes on the global scale since the mid-20th century (*very likely*) [Section 3.3.2]	Global-scale increased intensity and frequency of hot days and nights, and decreased intensity and frequency of cold days and nights (*very likely*) Warming of temperature extremes highest over land, including many inhabited regions (*high confidence*), with increases of up to 3°C in the mid-latitude warm season and up to 4.5°C in the high-latitude cold season (*high confidence*) Largest increase in frequency of unusually hot extremes in tropical regions (*high confidence*) [Section 3.3.2]	Global-scale increased intensity and frequency of hot days and nights, and decreased intensity and frequency of cold days and nights (*very likely*) Warming of temperature extremes highest over land, including many inhabited regions (*high confidence*), with increases of up to 4°C in the mid-latitude warm season and up to 6°C in the high-latitude cold season (*high confidence*) Largest increase in frequency of unusually hot extremes in tropical regions (*high confidence*) [Section 3.3.2]	Global-scale increased intensity and frequency of hot days and nights, and decreased intensity and frequency of cold days and nights (*high confidence*) Global-scale increase in length of warm spells and decrease in length of cold spells (*high confidence*) Strongest increase in frequency for the rarest and most extreme events (*high confidence*) Particularly large increases in hot extremes in inhabited regions (*high confidence*) [Section 3.3.2]

Table 3.2 (continued)

	Observed change (recent past versus pre-industrial)	Attribution of observed change to human-induced forcing (present-day versus pre-industrial)	Projected change at 1.5°C of global warming compared to pre-industrial (1.5°C versus 0°C)	Projected change at 2°C of global warming compared to pre-industrial (2°C versus 0°C)	Differences between 2°C and 1.5°C of global warming
Heavy precipitation	More areas with increases than decreases in the frequency, intensity and/or amount of heavy precipitation (*likely*) [Section 3.3.3]	Human influence contributed to the global-scale tendency towards increases in the frequency, intensity and/or amount of heavy precipitation events (*medium confidence*) [Section 3.3.3; AR5 Chapter 10 (Bindoff et al., 2013a)]	Increases in frequency, intensity and/or amount heavy precipitation when averaged over global land, with positive trends in several regions (*high confidence*) [Section 3.3.3]	Increases in frequency, intensity and/or amount heavy precipitation when averaged over global land, with positive trends in several regions (*high confidence*) [Section 3.3.3]	Higher frequency, intensity and/or amount of heavy precipitation when averaged over global land, with positive trends in several regions (*medium confidence*) Several regions are projected to experience increases in heavy precipitation at 2°C versus 1.5°C (*medium confidence*), in particular in high-latitude and mountainous regions, as well as in eastern Asia and eastern North America (*medium confidence*) [Section 3.3.3]
Drought and dryness	*High confidence* in dryness trends in some regions, especially drying in the Mediterranean region (including southern Europe, northern Africa and the Near East) *Low confidence* in drought and dryness trends at the global scale [Section 3.3.4]	*Medium confidence* in attribution of drying trends in southern Europe (Mediterranean region) *Low confidence* elsewhere, in part due to large interannual variability and longer duration (and thus lower frequency) of drought events, as well as to dependency on the dryness index definition applied [Section 3.3.4]	*Medium confidence* in drying trends in the Mediterranean region *Low confidence* elsewhere, in part due to large interannual variability and longer duration (and thus lower frequency) of drought events, as well as to dependency on the dryness index definition applied Increases in drought, dryness or precipitation deficits projected in some regions compared to the pre-industrial or present-day conditions, but substantial variability in signals depending on considered indices or climate model (*medium confidence*) [Section 3.3.4]	*Medium confidence* in drying trends in the Mediterranean region and Southern Africa *Low confidence* elsewhere, in part due to large interannual variability and longer duration (and thus lower frequency) of drought events, as well as to dependency on the dryness index definition applied Increases in drought, dryness or precipitation deficits projected in some regions compared to the pre-industrial or present-day conditions, but substantial variability in signals depending on considered indices or climate model (*medium confidence*). [Section 3.3.4]	*Medium confidence* in stronger drying trends in the Mediterranean region and Southern Africa *Low confidence* elsewhere, in part due to large interannual variability and longer duration (and thus lower frequency) of drought events, as well as to dependency on the dryness index definition applied [Section 3.3.4]
Runoff and river flooding	Streamflow trends mostly not statistically significant (*high confidence*) Increase in flood frequency and extreme streamflow in some regions (*high confidence*) [Section 3.3.5]	Not assessed in this report	Expansion of the global land area with a significant increase in runoff (*medium confidence*) Increase in flood hazard in some regions (*medium confidence*) [Section 3.3.5]	Expansion of the global land area with a significant increase in runoff (*medium confidence*) Increase in flood hazard in some regions (*medium confidence*) [Section 3.3.5]	Expansion of the global land area with significant increase in runoff (*medium confidence*) Expansion in the area affected by flood hazard (*medium confidence*) [Section 3.3.5]
Tropical and extra-tropical cyclones	*Low confidence* in the robustness of observed changes [Section 3.3.6]	Not meaningful to assess given *low confidence* in changes, due to large interannual variability, heterogeneity of the observational record and contradictory findings regarding trends in the observational record	Increases in heavy precipitation associated with tropical cyclones (*medium confidence*)	Further increases in heavy precipitation associated with tropical cyclones (*medium confidence*)	Heavy precipitation associated with tropical cyclones is projected to be higher at 2°C compared to 1.5°C global warming (*medium confidence*). Limited evidence that the global number of tropical cyclones will be lower under 2°C of global warming compared to under 1.5°C of warming, but an increase in the number of very intense cyclones (*low confidence*)

Table 3.2 (continued)

	Observed change (recent past versus pre-industrial)	Attribution of observed change to human-induced forcing (present-day versus pre-industrial)	Projected change at 1.5°C of global warming compared to pre-industrial (1.5°C versus 0°C)	Projected change at 2°C of global warming compared to pre-industrial (2°C versus 0°C)	Differences between 2°C and 1.5°C of global warming
Ocean circulation and temperature	Observed warming of the upper ocean, with slightly lower rates than global warming (*virtually certain*) Increased occurrence of marine heatwaves (*high confidence*) AMOC has been weakening over recent decades (*more likely than not*) [Section 3.3.7]	*Limited evidence* attributing the weakening of AMOC in recent decades to anthropogenic forcing [Section 3.3.7]	Further increases in ocean temperatures, including more frequent marine heatwaves (*high confidence*) AMOC will weaken over the 21st century and substantially so under high levels (more than 2°C) of global warming (*very likely*) [Section 3.3.7]		
Sea ice	Continuing the trends reported in AR5, the annual Arctic sea ice extent decreased over the period 1979–2012. The rate of this decrease was *very likely* between 3.5 and 4.1% per decade (0.45 to 0.51 million km^2 per decade) [AR5 Chapter 4 (Vaughan et al., 2013)]	Anthropogenic forcings are *very likely* to have contributed to Arctic sea ice loss since 1979 [AR5 Chapter 10 (Bindoff et al., 2013a)]	At least one sea-ice-free Arctic summer after about 100 years of stabilized warming (*medium confidence*) [Section 3.3.8]	At least one sea-ice-free Arctic summer after about 10 years of stabilized warming (*medium confidence*) [Section 3.3.8]	Probability of sea-ice-free Arctic summer greatly reduced at 1.5°C versus 2°C of global warming (*medium confidence*) [Section 3.3.8]
			Intermediate temperature overshoot has no long-term consequences for Arctic sea ice cover (*high confidence*) [3.3.8]		
Sea level	It is *likely* that the rate of GMSL rise has continued to increase since the early 20th century, with estimates that range from 0.000 [–0.002 to 0.002] mm yr^{-2} to 0.013 [0.007 to 0.019] mm yr^{-2} [AR5 Chapter 13 (Church et al., 2013)]	It is very *likely* that there is a substantial contribution from anthropogenic forcings to the global mean sea level rise since the 1970s [AR5 Chapter 10 (Bindoff et al., 2013a)]	Not assessed in this report	Not assessed in this report	GMSL rise will be about 0.1 m (0.00–0.20 m) less at 1.5°C versus 2°C global warming (*medium confidence*) [Section 3.3.9]
Ocean chemistry	Ocean acidification due to increased CO_2 has resulted in a 0.1 pH unit decrease since the pre-industrial period, which is unprecedented in the last 65 Ma (*high confidence*) [Section 3.3.10]	The oceanic uptake of anthropogenic CO_2 has resulted in acidification of surface waters (*very high confidence*). [Section 3.3.10]	Ocean chemistry is changing with global temperature increases, with impacts projected at 1.5°C and, more so, at 2°C of warming (*high confidence*) [Section 3.3.10]		

3.4 Observed Impacts and Projected Risks in Natural and Human Systems

3.4.1 Introduction

In Section 3.4, new literature is explored and the assessment of impacts and projected risks is updated for a large number of natural and human systems. This section also includes an exploration of adaptation opportunities that could be important steps towards reducing climate change, thereby laying the ground for later discussions on opportunities to tackle both mitigation and adaptation while at the same time recognising the importance of sustainable development and reducing the inequities among people and societies facing climate change.

Working Group II (WGII) of the IPCC Fifth Assessment Report (AR5) provided an assessment of the literature on the climate risk for natural and human systems across a wide range of environments, sectors and greenhouse gas scenarios, as well as for particular geographic regions (IPCC, 2014a, b). The comprehensive assessment undertaken by AR5 evaluated the evidence of changes to natural systems, and the impact on human communities and industry. While impacts varied substantially among systems, sectors and regions, many changes over the past 50 years could be attributed to human driven climate change and its impacts. In particular, AR5 attributed observed impacts in natural ecosystems to anthropogenic climate change, including changes in phenology, geographic and altitudinal range shifts in flora and fauna, regime shifts and increased tree mortality, all of which can reduce ecosystem functioning and services thereby impacting people. AR5 also reported increasing evidence of changing patterns of disease and invasive species, as well as growing risks for communities and industry, which are especially important with respect to sea level rise and human vulnerability.

One of the important themes that emerged from AR5 is that previous assessments may have under-estimated the sensitivity of natural and human systems to climate change. A more recent analysis of attribution to greenhouse gas forcing at the global scale (Hansen and Stone, 2016) confirmed that many impacts related to changes in regional atmospheric and ocean temperature can be confidently attributed to anthropogenic forcing, while attribution to anthropogenic forcing of changes related to precipitation are by comparison less clear. Moreover, there is no strong direct relationship between the robustness of climate attribution and that of impact attribution (Hansen and Stone, 2016). The observed changes in human systems are amplified by the loss of ecosystem services (e.g., reduced access to safe water) that are supported by biodiversity (Oppenheimer et al., 2014). Limited research on the risks of warming of 1.5°C and 2°C was conducted following AR5 for most key economic sectors and services, for livelihoods and poverty, and for rural areas. For these systems, climate is one of many drivers that result in adverse outcomes. Other factors include patterns of demographic change, socio-economic development, trade and tourism. Further, consequences of climate change for infrastructure, tourism, migration, crop yields and other impacts interact with underlying vulnerabilities, such as for individuals and communities engaged in pastoralism, mountain farming and artisanal fisheries, to affect livelihoods and poverty (Dasgupta et al., 2014).

Incomplete data and understanding of these lower-end climate scenarios have increased the need for more data and an improved understanding of the projected risks of warming of 1.5°C and 2°C for reference. In this section, the available literature on the projected risks, impacts and adaptation options is explored, supported by additional information and background provided in Supplementary Material 3.SM.3.1, 3.SM.3.2, 3.SM.3.4, and 3.SM.3.5. A description of the main assessment methods of this chapter is given in Section 3.2.2.

3.4.2 Freshwater Resources (Quantity and Quality)

3.4.2.1 Water availability

Working Group II of AR5 concluded that about 80% of the world's population already suffers from serious threats to its water security, as measured by indicators including water availability, water demand and pollution (Jiménez Cisneros et al., 2014). UNESCO (2011) concluded that climate change can alter the availability of water and threaten water security.

Although physical changes in streamflow and continental runoff that are consistent with climate change have been identified (Section 3.3.5), water scarcity in the past is still less well understood because the scarcity assessment needs to take into account various factors, such as the operations of water supply infrastructure and human water use behaviour (Mehran et al., 2017), as well as green water, water quality and environmental flow requirements (J. Liu et al., 2017). Over the past century, substantial growth in populations, industrial and agricultural activities, and living standards have exacerbated water stress in many parts of the world, especially in semi-arid and arid regions such as California in the USA (AghaKouchak et al., 2015; Mehran et al., 2015). Owing to changes in climate and water consumption behaviour, and particularly effects of the spatial distribution of population growth relative to water resources, the population under water scarcity increased from 0.24 billion (14% of the global population) in the 1900s to 3.8 billion (58%) in the 2000s. In that last period (2000s), 1.1 billion people (17% of the global population) who mostly live in South and East Asia, North Africa and the Middle East faced serious water shortage and high water stress (Kummu et al., 2016).

Over the next few decades, and for increases in global mean temperature less than about 2°C, AR5 concluded that changes in population will generally have a greater effect on water resource availability than changes in climate. Climate change, however, will regionally exacerbate or offset the effects of population pressure (Jiménez Cisneros et al., 2014).

The differences in projected changes to levels of runoff under 1.5°C and 2°C of global warming, particularly those that are regional, are described in Section 3.3.5. Constraining warming to 1.5°C instead of 2°C might mitigate the risks for water availability, although socio-economic drivers could affect water availability more than the risks posed by variation in warming levels, while the risks are not homogeneous among regions (*medium confidence*) (Gerten et al., 2013; Hanasaki et al., 2013; Arnell and Lloyd-Hughes, 2014; Schewe et al., 2014; Karnauskas et al., 2018). Assuming a constant population in the models used in his study, Gerten et al. (2013) determined that an additional 8% of the world population in 2000 would be exposed to new or aggravated water scarcity at 2°C of global warming. This value was almost halved – with 50% greater reliability – when warming was constrained to 1.5°C. People inhabiting river basins, particularly in the Middle East and Near East, are projected to become newly exposed to chronic water scarcity even if global warming is constrained to less than 2°C. Many regions, especially those in Europe, Australia and southern Africa, appear to be affected at 1.5°C if the reduction in water availability is computed for non-water-scarce basins as well as for water-scarce regions. Out of a contemporary population of approximately 1.3 billion exposed to water scarcity, about 3% (North America) to 9% (Europe) are expected to be prone to aggravated scarcity at 2°C of global warming (Gerten et al., 2013). Under the Shared Socio-Economic Pathway (SSP)2 population scenario, about 8% of the global population is projected to experience a severe reduction in water resources under warming of 1.7°C in 2021–2040, increasing to 14% of the population under 2.7°C in 2043–2071, based on the criteria of discharge reduction of either >20% or >1 standard deviation (Schewe et al., 2014). Depending on the scenarios of SSP1–5, exposure to the increase in water scarcity in 2050 will be globally reduced by 184–270 million people at about 1.5°C of warming compared to the impacts at about 2°C. However, the variation between socio-economic levels is larger than the variation between warming levels (Arnell and Lloyd-Hughes, 2014).

On many small islands (e.g., those constituting SIDS), freshwater stress is expected to occur as a result of projected aridity change. Constraining warming to 1.5°C, however, could avoid a substantial fraction of water stress compared to 2°C, especially across the Caribbean region, particularly on the island of Hispaniola (Dominican Republic and Haiti) (Karnauskas et al., 2018). Hanasaki et al. (2013) concluded that the projected range of changes in global irrigation water withdrawal (relative to the baseline of 1971–2000), using human configuration fixing non-meteorological variables for the period around 2000, are 1.1–2.3% and 0.6–2.0% lower at 1.5°C and 2°C, respectively. In the same study, Hanasaki et al. (2013) highlighted the importance of water use scenarios in water scarcity assessments, but neither quantitative nor qualitative information regarding water use is available.

When the impacts on hydropower production at 1.5°C and 2°C are compared, it is found that mean gross potential increases in northern, eastern and western Europe, and decreases in southern Europe (Jacob et al., 2018; Tobin et al., 2018). The Baltic and Scandinavian countries are projected to experience the most positive impacts on hydropower production. Greece, Spain and Portugal are expected to be the most negatively impacted countries, although the impacts could be reduced by limiting warming to 1.5°C (Tobin et al., 2018). In Greece, Spain and Portugal, warming of 2°C is projected to decrease hydropower potential below 10%, while limiting global warming to 1.5°C would keep the reduction to 5% or less. There is, however, substantial uncertainty associated with these results due to a large spread between the climate models (Tobin et al., 2018).

Due to a combination of higher water temperatures and reduced summer river flows, the usable capacity of thermoelectric power plants using river water for cooling is expected to reduce in all European countries (Jacob et al., 2018; Tobin et al., 2018), with the magnitude of decreases being about 5% for 1.5°C and 10% for 2°C of global warming for most European countries (Tobin et al., 2018). Greece, Spain and Bulgaria are projected to have the largest reduction at 2°C of warming (Tobin et al., 2018).

Fricko et al. (2016) assessed the direct water use of the global energy sector across a broad range of energy system transformation pathways in order to identify the water impacts of a 2°C climate policy. This study revealed that there would be substantial divergence in water withdrawal for thermal power plant cooling under conditions in which the distribution of future cooling technology for energy generation is fixed, whereas adopting alternative cooling technologies and water resources would make the divergence considerably smaller.

3.4.2.2 Extreme hydrological events (floods and droughts)

Working Group II of AR5 concluded that socio-economic losses from flooding since the mid-20th century have increased mainly because of greater exposure and vulnerability (*high confidence*) (Jiménez Cisneros et al., 2014). There was *low confidence* due to limited evidence, however, that anthropogenic climate change has affected the frequency and magnitude of floods. WGII AR5 also concluded that there is no evidence that surface water and groundwater drought frequency has changed over the last few decades, although impacts of drought have increased mostly owing to increased water demand (Jiménez Cisneros et al., 2014).

Since AR5, the number of studies related to fluvial flooding and meteorological drought based on long-term observed data has been gradually increasing. There has also been progress since AR5 in identifying historical changes in streamflow and continental runoff (Section 3.3.5). As a result of population and economic growth, increased exposure of people and assets has caused more damage due to flooding. However, differences in flood risks among regions reflect the balance among the magnitude of the flood, the populations, their vulnerabilities, the value of assets affected by flooding, and the capacity to cope with flood risks, all of which depend on socio-economic development conditions, as well as topography and hydro-climatic conditions (Tanoue et al., 2016). AR5 concluded that there was *low confidence* in the attribution of global changes in droughts (Bindoff et al., 2013b). However, recent publications based on observational and modelling evidence assessed that human emissions have substantially increased the probability of drought years in the Mediterranean region (Section 3.3.4).

WGII AR5 assessed that global flood risk will increase in the future, partly owing to climate change (*low to medium confidence*), with projected changes in the frequency of droughts longer than 12 months being more uncertain because of their dependence on accumulated precipitation over long periods (Jiménez Cisneros et al., 2014).

Increases in the risks associated with runoff at the global scale (*medium confidence*), and in flood hazard in some regions (*medium confidence*), can be expected at global warming of 1.5°C, with an overall increase in the area affected by flood hazard at 2°C (*medium confidence*) (Section 3.3.5). There are studies, however, that indicate that socio-economic conditions will exacerbate flood impacts more than global climate change, and that the magnitude of these impacts could be larger in some regions (Arnell and Lloyd-Hughes, 2014; Winsemius et al., 2016; Alfieri et al., 2017; Arnell et al., 2018; Kinoshita et al., 2018). Assuming constant population sizes, countries representing 73% of the world population will experience increasing flood risk, with an average increase of 580% at 4°C compared to the impact simulated over the baseline period 1976–2005. This impact is projected to be reduced to a 100% increase at 1.5°C and a 170% increase at 2°C (Alfieri et al., 2017). Alfieri et al. (2017) additionally concluded that the largest increases in flood risks would be found in the US, Asia, and Europe in general, while decreases would be found in only a few countries in eastern Europe and Africa. Overall, Alfieri et al. (2017) reported that the projected changes are not homogeneously distributed across the world land surface. Alfieri et al. (2018) studied the population affected by flood events using three case studies in European states, specifically central and western Europe, and found that the population affected could be limited to 86% at 1.5°C of warming compared to 93% at 2°C. Under the SSP2 population scenario, Arnell et al. (2018) found that 39% (range 36–46%) of impacts on populations exposed to river flooding globally could be avoided at 1.5°C compared to 2°C of warming.

Under scenarios SSP1–5, Arnell and Lloyd-Hughes (2014) found that the number of people exposed to increased flooding in 2050 under warming of about 1.5°C could be reduced by 26–34 million compared to the number exposed to increased flooding associated with 2°C of warming. Variation between socio-economic levels, however, is projected to be larger than variation between the two levels of global warming. Kinoshita et al. (2018) found that a serious increase in potential flood fatality (5.7%) is projected without any adaptation if global warming increases from 1.5°C to 2°C, whereas the projected increase in potential economic loss (0.9%) is relatively small. Nevertheless, their study indicates that socio-economic changes make a larger contribution to the potentially increased consequences of future floods, and about half of the increase in potential economic losses could be mitigated by autonomous adaptation.

There is limited information about the global and regional projected risks posed by droughts at 1.5°C and 2°C of global warming. However, hazards by droughts at 1.5°C could be reduced compared to the hazards at 2°C in some regions, in particular in the Mediterranean region and southern Africa (Section 3.3.4). Under constant socio-economic conditions, the population exposed to drought at 2°C of warming is projected to be larger than at 1.5°C (*low to medium confidence*) (Smirnov et al., 2016; Sun et al., 2017; Arnell et al., 2018; Liu et al., 2018). Under the same scenario, the global mean monthly number of people expected to be exposed to extreme drought at 1.5°C in 2021–2040 is projected to be 114.3 million, compared to 190.4 million at 2°C in 2041–2060 (Smirnov et al., 2016). Under the SSP2 population scenario, Arnell et al. (2018) projected that 39% (range 36–51%) of impacts on populations exposed to drought could be globally avoided at 1.5°C compared to 2°C warming.

Liu et al. (2018) studied the changes in population exposure to severe droughts in 27 regions around the globe for 1.5°C and 2°C of warming using the SSP1 population scenario compared to the baseline period of 1986–2005 based on the Palmer Drought Severity Index (PDSI). They concluded that the drought exposure of urban populations in most regions would be decreased at 1.5°C (350.2 ± 158.8 million people) compared to 2°C (410.7 ± 213.5 million people). Liu et al. (2018) also suggested that more urban populations would be exposed to severe droughts at 1.5°C in central Europe, southern Europe, the Mediterranean, West Africa, East and West Asia, and Southeast Asia, and that number of affected people would increase further in these regions at 2°C. However, it should be noted that the PDSI is known to have limitations (IPCC SREX, Seneviratne et al., 2012), and drought projections strongly depend on considered indices (Section 3.3.4); thus only *medium confidence* is assigned to these projections. In the Haihe River basin in China, a study has suggested that the proportion of the population exposed to droughts is projected to be reduced by 30.4% at 1.5°C but increased by 74.8% at 2°C relative to the baseline value of 339.65 million people in the 1986–2005 period, when assessing changes in droughts using the Standardized Precipitation-Evaporation Index, using a Penman–Monteith estimate of potential evaporation (Sun et al., 2017) .

Alfieri et al. (2018) estimated damage from flooding in Europe for the baseline period (1976–2005) at 5 billion euro of losses annually, with projections of relative changes in flood impacts that will rise with warming levels, from 116% at 1.5°C to 137% at 2°C.

Kinoshita et al. (2018) studied the increase of potential economic loss under SSP3 and projected that the smaller loss at 1.5°C compared to 2°C (0.9%) is marginal, regardless of whether the vulnerability is fixed at the current level or not. By analysing the differences in results with and without flood protection standards, Winsemius et al. (2016) showed that adaptation measures have the potential to greatly reduce present-day and future flood damage. They concluded that increases in flood-induced economic impacts (% gross domestic product, GDP) in African countries are mainly driven by climate change and that Africa's growing assets would become increasingly exposed to floods. Hence, there is an increasing need for long-term and sustainable investments in adaptation in Africa.

3.4.2.3 Groundwater

Working Group II of AR5 concluded that the detection of changes in groundwater systems, and attribution of those changes to climatic changes, are rare, owing to a lack of appropriate observation wells and an overall small number of studies (Jiménez Cisneros et al., 2014).

Since AR5, the number of studies based on long-term observed data continues to be limited. The groundwater-fed lakes in northeastern central Europe have been affected by climate and land-use changes, and they showed a predominantly negative lake-level trend in 1999–2008 (Kaiser et al., 2014).

WGII AR5 concluded that climate change is projected to reduce groundwater resources significantly in most dry subtropical regions (*high confidence*) (Jiménez Cisneros et al., 2014).

In some regions, groundwater is often intensively used to supplement the excess demand, often leading to groundwater depletion. Climate change adds further pressure on water resources and exaggerates human water demands by increasing temperatures over agricultural lands (Wada et al., 2017). Very few studies have projected the risks of groundwater depletion under 1.5°C and 2°C of global warming. Under 2°C of warming, impacts posed on groundwater are projected to be greater than at 1.5°C (*low confidence*) (Portmann et al., 2013; Salem et al., 2017).

Portmann et al. (2013) indicated that 2% (range 1.1–2.6%) of the global land area is projected to suffer from an extreme decrease in renewable groundwater resources of more than 70% at 2°C, with a clear mitigation at 1.5°C. These authors also projected that 20% of the global land surface would be affected by a groundwater reduction of more than 10% at 1.5°C of warming, with the percentage of land impacted increasing at 2°C. In a groundwater-dependent irrigated region in northwest Bangladesh, the average groundwater level during the major irrigation period (January–April) is projected to decrease in accordance with temperature rise (Salem et al., 2017).

3.4.2.4 Water quality

Working Group II of AR5 concluded that most observed changes to water quality from climate change are from isolated studies, mostly of rivers or lakes in high-income countries, using a small number of variables (Jiménez Cisneros et al., 2014). AR5 assessed that climate change is projected to reduce raw water quality, posing risks to drinking water quality with conventional treatment (*medium to high confidence*) (Jiménez Cisneros et al., 2014).

Since AR5, studies have detected climate change impacts on several indices of water quality in lakes, watersheds and regions (e.g., Patiño et al., 2014; Aguilera et al., 2015; Watts et al., 2015; Marszelewski and Pius, 2016; Capo et al., 2017). The number of studies utilising RCP scenarios at the regional or watershed scale have gradually increased since AR5 (e.g., Boehlert et al., 2015; Teshager et al., 2016; Marcinkowski et al., 2017). Few studies, have explored projected impacts on water quality under 1.5°C versus 2°C of warming, however, the differences are unclear (*low confidence*) (Bonte and

Zwolsman, 2010; Hosseini et al., 2017). The daily probability of exceeding the chloride standard for drinking water taken from Lake IJsselmeer (Andijk, the Netherlands) is projected to increase by a factor of about five at 2°C relative to the present-day warming level of 1°C since 1990 (Bonte and Zwolsman, 2010). Mean monthly dissolved oxygen concentrations and nutrient concentrations in the upper Qu'Appelle River (Canada) in 2050–2055 are projected to decrease less at about 1.5°C of warming (RCP2.6) compared to concentrations at about 2°C (RCP4.5) (Hosseini et al., 2017). In three river basins in Southeast Asia (Sekong, Sesan and Srepok), about 2°C of warming (corresponding to a 1.05°C increase in the 2030s relative to the baseline period 1981–2008, RCP8.5), impacts posed by land-use change on water quality are projected to be greater than at 1.5°C (corresponding to a 0.89°C increase in the 2030s relative to the baseline period 1981–2008, RCP4.5) (Trang et al., 2017). Under the same warming scenarios, Trang et al. (2017) projected changes in the annual nitrogen (N) and phosphorus (P) yields in the 2030s, as well as with combinations of two land-use change scenarios: (i) conversion of forest to grassland, and (ii) conversion of forest to agricultural land. The projected changes in N (P) yield are +7.3% (+5.1%) under a 1.5°C scenario and –6.6% (–3.6%) under 2°C, whereas changes under the combination of land-use scenarios are (i) +5.2% (+12.6%) at 1.5°C and +8.8% (+11.7%) at 2°C, and (ii) +7.5% (+14.9%) at 1.5°C and +3.7% (+8.8%) at 2°C (Trang et al., 2017).

3.4.2.5 Soil erosion and sediment load

Working Group II of AR5 concluded that there is little or no observational evidence that soil erosion and sediment load have been altered significantly by climate change (*low to medium confidence*) (Jiménez Cisneros et al., 2014). As the number of studies on climate change impacts on soil erosion has increased where rainfall is an important driver (Lu et al., 2013), studies have increasingly considered other factors, such as rainfall intensity (e.g., Shi and Wang, 2015; Li and Fang, 2016), snow melt, and change in vegetation cover resulting from temperature rise (Potemkina and Potemkin, 2015), as well as crop management practices (Mullan et al., 2012). WGII AR5 concluded that increases in heavy rainfall and temperature are projected to change soil erosion and sediment yield, although the extent of these changes is highly uncertain and depends on rainfall seasonality, land cover, and soil management practices (Jiménez Cisneros et al., 2014).

While the number of published studies of climate change impacts on soil erosion have increased globally since 2000 (Li and Fang, 2016), few articles have addressed impacts at 1.5°C and 2°C of global warming. The existing studies have found few differences in projected risks posed on sediment load under 1.5°C and 2°C (*low confidence*) (Cousino et al., 2015; Shrestha et al., 2016). The differences between average annual sediment load under 1.5°C and 2°C of warming are not clear, owing to complex interactions among climate change, land cover/surface and soil management (Cousino et al., 2015; Shrestha et al., 2016). Averages of annual sediment loads are projected to be similar under 1.5°C and 2°C of warming, in particular in the Great Lakes region in the USA and in the Lower Mekong region in Southeast Asia (Cross-Chapter Box 6 in this chapter, Cousino et al., 2015; Shrestha et al., 2016).

3.4.3 Terrestrial and Wetland Ecosystems

3.4.3.1 Biome shifts

Latitudinal and elevational shifts of biomes (major ecosystem types) in boreal, temperate and tropical regions have been detected (Settele et al., 2014) and new studies confirm these changes (e.g., shrub encroachment on tundra; Larsen et al., 2014). Attribution studies indicate that anthropogenic climate change has made a greater contribution to these changes than any other factor (*medium confidence*) (Settele et al., 2014).

An ensemble of seven Dynamic Vegetation Models driven by projected climates from 19 alternative general circulation models (GCMs) (Warszawski et al., 2013) shows 13% (range 8–20%) of biomes transforming at 2°C of global warming, but only 4% (range 2–7%) doing so at 1°C, suggesting that about 6.5% may be transformed at 1.5°C; these estimates indicate a doubling of the areal extent of biome shifts between 1.5°C and 2°C of warming (*medium confidence*) (Figure 3.16a). A study using the single ecosystem model LPJmL (Gerten et al., 2013) illustrated that biome shifts in the Arctic, Tibet, Himalayas, southern Africa and Australia would be avoided by constraining warming to 1.5°C compared with 2°C (Figure 3.16b). Seddon et al. (2016) quantitatively identified ecologically sensitive regions to climate change in most of the continents from tundra to tropical rainforest. Biome transformation may in some cases be associated with novel climates and ecological communities (Prober et al., 2012).

3.4.3.2 Changes in phenology

Advancement in spring phenology of 2.8 ± 0.35 days per decade has been observed in plants and animals in recent decades in most Northern Hemisphere ecosystems (between 30°N and 72°N), and these shifts have been attributed to changes in climate (*high confidence*) (Settele et al., 2014). The rates of change are particularly high in the Arctic zone owing to the stronger local warming (Oberbauer et al., 2013), whereas phenology in tropical forests appears to be more responsive to moisture stress (Zhou et al., 2014). While a full review cannot be included here, trends consistent with this earlier finding continue to be detected, including in the flowering times of plants (Parmesan and Hanley, 2015), in the dates of egg laying and migration in birds (newly reported in China; Wu and Shi, 2016), in the emergence dates of butterflies (Roy et al., 2015), and in the seasonal greening-up of vegetation as detected by satellites (i.e., in the normalized difference vegetation index, NDVI; Piao et al., 2015).

The potential for decoupling species–species interactions owing to differing phenological responses to climate change is well established (Settele et al., 2014), for example for plants and their insect pollinators (Willmer, 2012; Scaven and Rafferty, 2013). Mid-century projections of plant and animal phenophases in the UK clearly indicate that the timing of phenological events could change more for primary consumers (6.2 days earlier on average) than for higher trophic levels (2.5–2.9 days earlier on average) (Thackeray et al., 2016). This indicates the potential for phenological mismatch and associated risks for ecosystem functionality in the future under global warming of 2.1°C–2.7°C above pre-industrial levels. Further, differing responses

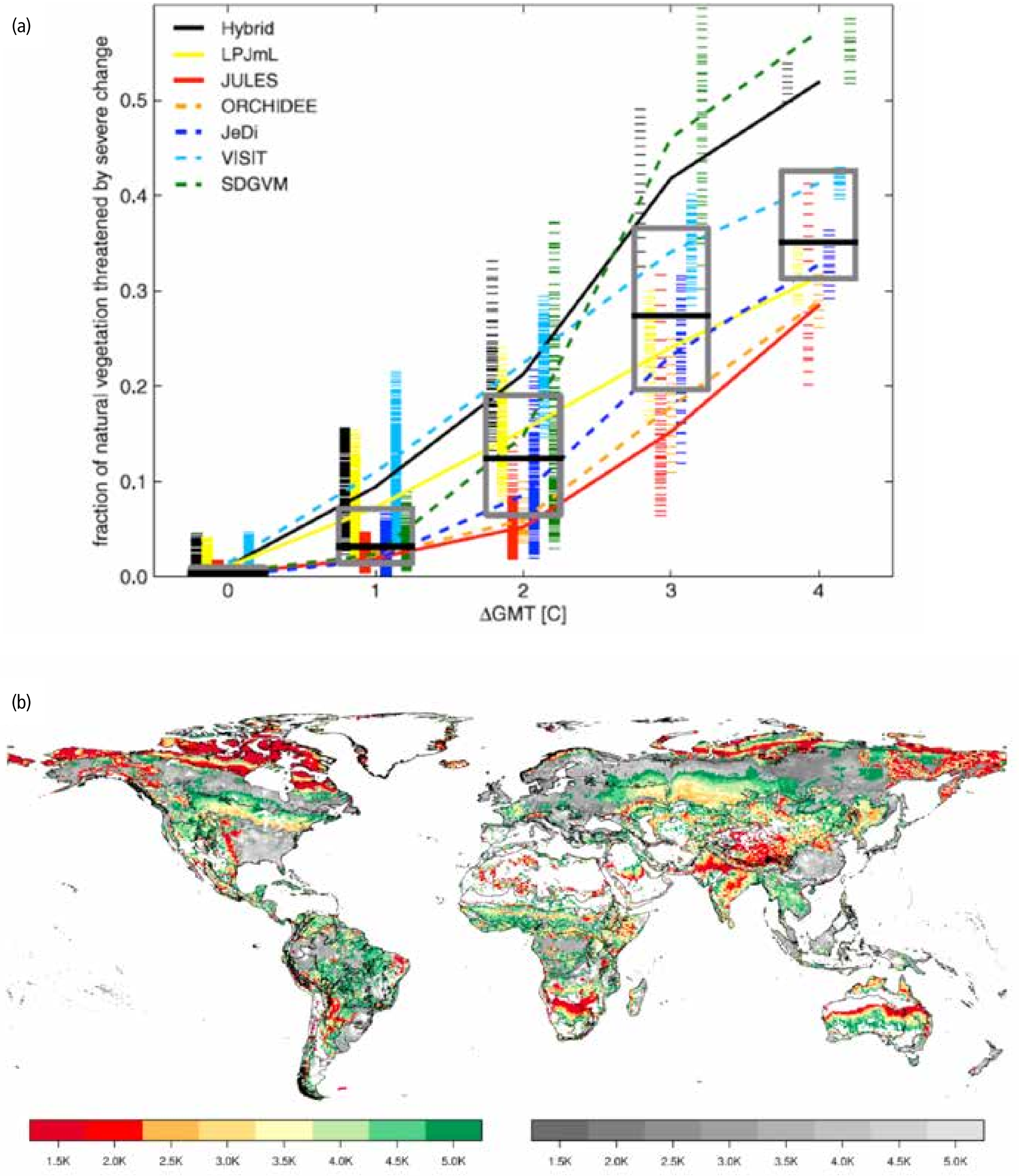


Figure 3.16 | (a) Fraction of global natural vegetation (including managed forests) at risk of severe ecosystem change as a function of global mean temperature change for all ecosystems, models, global climate change models and Representative Concentration Pathways (RCPs). The colours represent the different ecosystem models, which are also horizontally separated for clarity. Results are collated in unit-degree bins, where the temperature for a given year is the average over a 30-year window centred on that year. The boxes span the 25th and 75th percentiles across the entire ensemble. The short, horizontal stripes represent individual (annual) data points, the curves connect the mean value per ecosystem model in each bin. The solid (dashed) curves are for models with (without) dynamic vegetation composition changes. Source: (Warszawski et al., 2013) (b) Threshold level of global temperature anomaly above pre-industrial levels that leads to significant local changes in terrestrial ecosystems. Regions with severe (coloured) or moderate (greyish) ecosystem transformation; delineation refers to the 90 biogeographic regions. All values denote changes found in >50% of the simulations. Source: (Gerten et al., 2013). Regions coloured in dark red are projected to undergo severe transformation under a global warming of 1.5°C while those coloured in light red do so at 2°C; other colours are used when there is no severe transformation unless global warming exceeds 2°C.

could alter community structure in temperate forests (Roberts et al., 2015). Specifically, temperate forest phenology is projected to advance by 14.3 days in the near term (2010–2039) and 24.6 days in the medium term (2040–2069), so as a first approximation the difference between 2°C and 1.5°C of global warming is about 10 days (Roberts et al., 2015). This phenological plasticity is not always adaptive and must be interpreted cautiously (Duputié et al., 2015), and considered in the context of accompanying changes in climate variability (e.g., increased risk of frost damage for plants or earlier emergence of insects resulting in mortality during cold spells). Another adaptive response of some plants is range expansion with increased vigour and altered herbivore resistance in their new range, analogous to invasive plants (Macel et al., 2017).

In summary, limiting warming to 1.5°C compared with 2°C may avoid advance in spring phenology (*high confidence*) by perhaps a few days (*medium confidence*) and hence decrease the risks of loss of ecosystem functionality due to phenological mismatch between trophic levels, and also of maladaptation coming from the sensitivity of many species to increased climate variability. Nevertheless, this difference between 1.5°C and 2°C of warming might be limited for plants that are able to expand their range.

3.4.3.3 Changes in species range, abundance and extinction

AR5 (Settele et al., 2014) concluded that the geographical ranges of many terrestrial and freshwater plant and animal species have moved over the last several decades in response to warming: approximately 17 km poleward and 11 m up in altitude per decade. Recent trends confirm this finding; for example, the spatial and interspecific variance in bird populations in Europe and North America since 1980 were found to be well predicted by trends in climate suitability (Stephens et al., 2016). Further, a recent meta-analysis of 27 studies concerning a total of 976 species (Wiens, 2016) found that 47% of local extinctions (extirpations) reported across the globe during the 20th century could be attributed to climate change, with significantly more extinctions occurring in tropical regions, in freshwater habitats and for animals. IUCN (2018) lists 305 terrestrial animal and plant species from Pacific Island developing nations as being threatened by climate change and severe weather. Owing to lags in the responses of some species to climate change, shifts in insect pollinator ranges may result in novel assemblages with unknown implications for biodiversity and ecosystem function (Rafferty, 2017).

Warren et al. (2013) simulated climatically determined geographic range loss under 2°C and 4°C of global warming for 50,000 plant and animal species, accounting for uncertainty in climate projections and for the potential ability of species to disperse naturally in an attempt to track their geographically shifting climate envelope. This earlier study has now been updated and expanded to incorporate 105,501 species, including 19,848 insects, and new findings indicate that warming of 2°C by 2100 would lead to projected bioclimatic range losses of >50% in 18% (6–35%) of the 19,848 insects species, 8% (4–16%) of the 12,429 vertebrate species, and 16% (9–28%) of the 73,224 plant species studied (Warren et al., 2018a). At 1.5°C of warming, these values fall to 6% (1–18%) of the insects, 4% (2–9%) of the vertebrates and 8% (4–15%) of the plants studied. Hence, the number of insect species projected to lose over half of their geographic range is reduced by two-thirds when warming is limited to 1.5°C compared with 2°C, while the number of vertebrate and plant species projected to lose over half of their geographic range is halved (Warren et al., 2018a) (*medium confidence*). These findings are consistent with estimates made from an earlier study suggesting that range losses at 1.5°C were significantly lower for plants than those at 2°C of warming (Smith et al., 2018). It should be noted that at 1.5°C of warming, and if species' ability to disperse naturally to track their preferred climate geographically is inhibited by natural or anthropogenic obstacles, there would still remain 10% of the amphibians, 8% of the reptiles, 6% of the mammals, 5% of the birds, 10% of the insects and 8% of the plants which are projected to lose over half their range, while species on average lose 20–27% of their range (Warren et al., 2018a). Given that bird and mammal species can disperse more easily than amphibians and reptiles, a small proportion can expand their range as climate changes, but even at 1.5°C of warming the total range loss integrated over all birds and mammals greatly exceeds the integrated range gain (Warren et al., 2018a).

A number of caveats are noted for studies projecting changes to climatic range. This approach, for example, does not incorporate the effects of extreme weather events and the role of interactions between species. As well, trophic interactions may locally counteract the range expansion of species towards higher altitudes (Bråthen et al., 2018). There is also the potential for highly invasive species to become established in new areas as the climate changes (Murphy and Romanuk, 2014), but there is no literature that quantifies this possibility for 1.5°C of global warming.

Pecl et al. (2017) summarized at the global level the consequences of climate-change-induced species redistribution for economic development, livelihoods, food security, human health and culture. These authors concluded that even if anthropogenic greenhouse gas emissions stopped today, the effort for human systems to adapt to the most crucial effects of climate-driven species redistribution will be far-reaching and extensive. For example, key insect crop pollinator families (Apidae, Syrphidae and Calliphoridae; i.e., bees, hoverflies and blowflies) are projected to retain significantly greater geographic ranges under 1.5°C of global warming compared with 2°C (Warren et al., 2018a). In some cases, when species (such as pest and disease species) move into areas which have become climatically suitable they may become invasive or harmful to human or natural systems (Settele et al., 2014). Some studies are beginning to locate 'refugial' areas where the climate remains suitable in the future for most of the species currently present. For example, Smith et al. (2018) estimated that 5.5–14% more of the globe's terrestrial land area could act as climatic refugia for plants under 1.5°C of warming compared to 2°C.

There is no literature that directly estimates the proportion of species at increased risk of global (as opposed to local) commitment to extinction as a result of climate change, as this is inherently difficult to quantify. However, it is possible to compare the proportions of species at risk of very high range loss; for example, a discernibly smaller number of terrestrial species are projected to lose over 90% of their range at 1.5°C of global warming compared with 2°C (Figure 2 in Warren et al., 2018a). A link between very high levels of range loss and greatly increased extinction risk may be inferred (Urban, 2015). Hence, limiting global warming to 1.5°C compared with 2°C would be expected to reduce both range losses and associated extinction risks in terrestrial species (*high confidence*).

3.4.3.4 Changes in ecosystem function, biomass and carbon stocks

Working Group II of AR5 (Settele et al., 2014) concluded that there is *high confidence* that net terrestrial ecosystem productivity at the global scale has increased relative to the pre-industrial era and that rising CO_2 concentrations are contributing to this trend through stimulation of photosynthesis. There is, however, no clear and consistent signal of a climate change contribution. In northern latitudes, the change in productivity has a lower velocity than the warming, possibly because of a lack of resource and vegetation acclimation mechanisms (M. Huang et al., 2017). Biomass and soil carbon stocks in terrestrial ecosystems are currently increasing (*high confidence*), but they are vulnerable to loss of carbon to the atmosphere as a result of projected increases in the intensity of storms, wildfires, land degradation and pest outbreaks (Settele et al., 2014; Seidl et al., 2017). These losses are expected to contribute to a decrease in the terrestrial carbon sink. Anderegg et al. (2015) demonstrated that total ecosystem respiration at the global scale has increased in response to increases in night-time temperature (1 PgC yr^{-1} $°C^{-1}$, P=0.02).

The increase in total ecosystem respiration in spring and autumn, associated with higher temperatures, may convert boreal forests from carbon sinks to carbon sources (Hadden and Grelle, 2016). In boreal peatlands, for example, increased temperature may diminish carbon storage and compromise the stability of the peat (Dieleman et al., 2016). In addition, J. Yang et al. (2015) showed that fires reduce the carbon sink of global terrestrial ecosystems by 0.57 PgC yr^{-1} in ecosystems with large carbon stores, such as peatlands and tropical forests. Consequently, for adaptation purposes, it is necessary to enhance carbon sinks, especially in forests which are prime regulators within the water, energy and carbon cycles (Ellison et al., 2017). Soil can also be a key compartment for substantial carbon sequestration (Lal, 2014; Minasny et al., 2017), depending on the net biome productivity and the soil quality (Bispo et al., 2017).

AR5 assessed that large uncertainty remains regarding the land carbon cycle behaviour of the future (Ciais et al., 2013), with most, but not all, CMIP5 models simulating continued terrestrial carbon uptake under all four RCP scenarios (Jones et al., 2013). Disagreement between models outweighs differences between scenarios even up to the year 2100 (Hewitt et al., 2016; Lovenduski and Bonan, 2017). Increased atmospheric CO_2 concentrations are expected to drive further increases in the land carbon sink (Ciais et al., 2013; Schimel et al., 2015), which could persist for centuries (Pugh et al., 2016). Nitrogen, phosphorus and other nutrients will limit the terrestrial carbon cycle response to both elevated CO_2 and altered climate (Goll et al., 2012; Yang et al., 2014; Wieder et al., 2015; Zaehle et al., 2015; Ellsworth et al., 2017). Climate change may accelerate plant uptake of carbon (Gang et al., 2015) but also increase the rate of decomposition (Todd-Brown et al., 2014; Koven et al., 2015; Crowther et al., 2016). Ahlström et al. (2012) found a net loss of carbon in extra-tropical regions and the largest spread across model results in the tropics. The projected net effect of climate change is to reduce the carbon sink expected under CO_2 increase alone (Settele et al., 2014). Friend et al. (2014) found substantial uptake of carbon by vegetation under future scenarios when considering the effects of both climate change and elevated CO_2.

There is limited published literature examining modelled land carbon changes specifically under 1.5°C of warming, but existing CMIP5 models and published data are used in this report to draw some conclusions. For systems with significant inertia, such as vegetation or soil carbon stores, changes in carbon storage will depend on the rate of change of forcing and thus depend on the choice of scenario (Jones et al., 2009; Ciais et al., 2013; Sihi et al., 2017). To avoid legacy effects of the choice of scenario, this report focuses on the response of gross primary productivity (GPP) – the rate of photosynthetic carbon uptake – by the models, rather than by changes in their carbon store.

Figure 3.17 shows different responses of the terrestrial carbon cycle to climate change in different regions. The models show a consistent response of increased GPP in temperate latitudes of approximately 2 GtC yr^{-1} $°C^{-1}$. Similarly, Gang et al. (2015) projected a robust increase in the net primary productivity (NPP) of temperate forests. However, Ahlström et al. (2012) showed that this effect could be offset or reversed by increases in decomposition. Globally, most models project that GPP will increase or remain approximately unchanged (Hashimoto et al., 2013). This projection is supported by findings by Sakalli et al. (2017) for Europe using Euro-CORDEX regional models under a 2°C global warming for the period 2034–2063, which indicated that storage will increase by 5% in soil and by 20% in vegetation. However, using the same models Jacob et al. (2018) showed that limiting warming to 1.5°C instead of 2°C avoids an increase in ecosystem vulnerability (compared to a no-climate change scenario) of 40–50%.

At the global level, linear scaling is acceptable for net primary production, biomass burning and surface runoff, and impacts on terrestrial carbon storage are projected to be greater at 2°C than at 1.5°C (Tanaka et al., 2017). If global CO_2 concentrations and temperatures stabilize, or peak and decline, then both land and ocean carbon sinks – which are primarily driven by the continued increase in atmospheric CO_2 – will also decline and may even become carbon sources (Jones et al., 2016). Consequently, if a given amount of anthropogenic CO_2 is removed from the atmosphere, an equivalent amount of land and ocean anthropogenic CO_2 will be released to the atmosphere (Cao and Caldeira, 2010).

In conclusion, ecosystem respiration is expected to increase with increasing temperature, thus reducing soil carbon storage. Soil carbon storage is expected to be larger if global warming is restricted to 1.5°C, although some of the associated changes will be countered by enhanced gross primary production due to elevated CO_2 concentrations (i.e., the 'fertilization effect') and higher temperatures, especially at mid- and high latitudes (*medium confidence*).

3.4.3.5 Regional and ecosystem-specific risks

A large number of threatened systems, including mountain ecosystems, highly biodiverse tropical wet and dry forests, deserts, freshwater systems and dune systems, were assessed in AR5. These include Mediterranean areas in Europe, Siberian, tropical and desert ecosystems in Asia, Australian rainforests, the Fynbos and succulent Karoo areas of South Africa, and wetlands in Ethiopia, Malawi, Zambia and Zimbabwe. In all these systems, it has been shown that impacts accrue with greater warming, and thus impacts at 2°C are expected to be greater than those at 1.5°C (*medium confidence*).

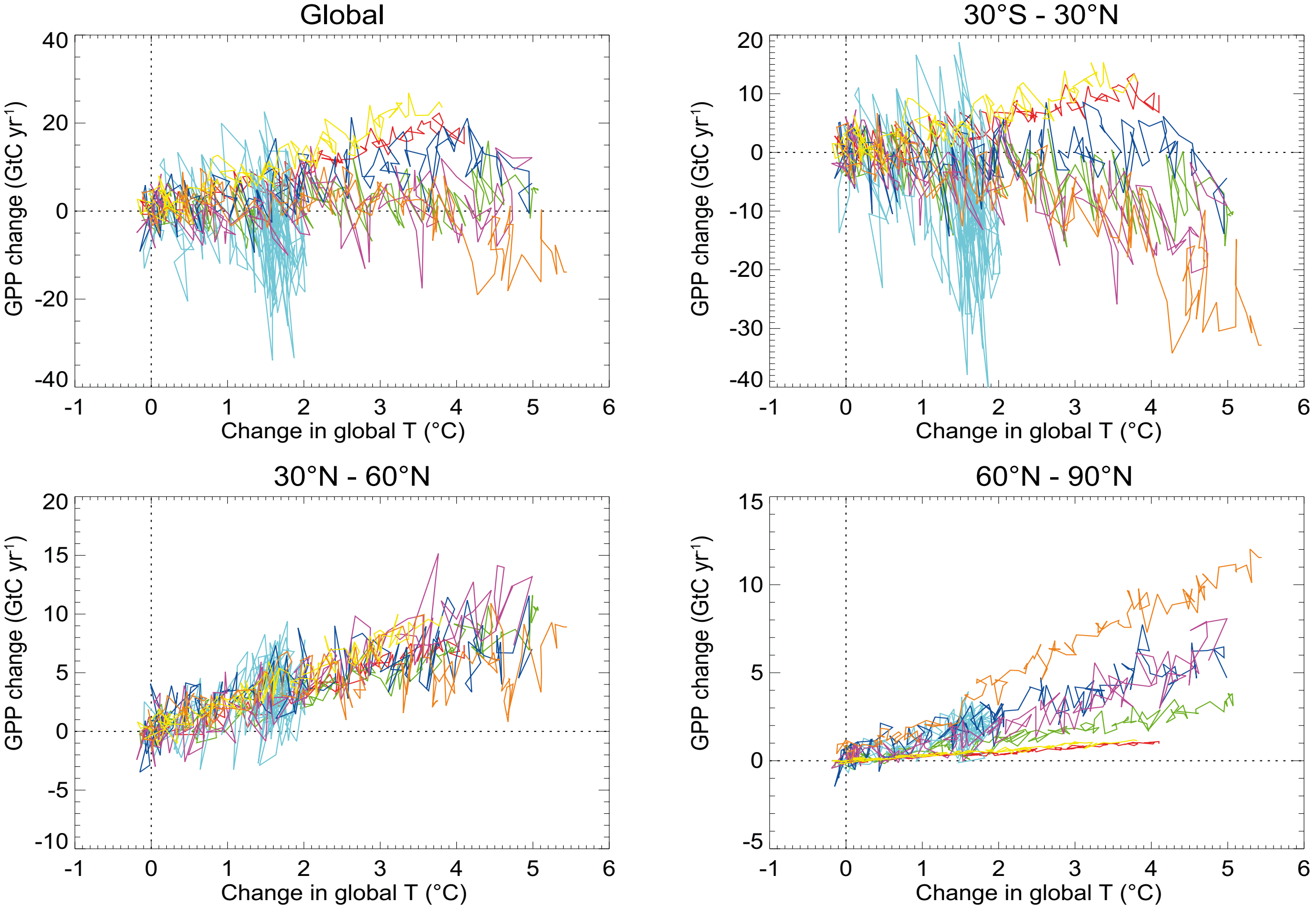


Figure 3.17 | The response of terrestrial productivity (gross primary productivity, GPP) to climate change, globally (top left) and for three latitudinal regions: 30°S–30°N; 30–60°N and 60–90°N. Data come from the Coupled Model Intercomparison Project Phase 5 (CMIP5) archive (http://cmip-pcmdi.llnl.gov/cmip5/). Seven Earth System Models were used: Norwegian Earth System Model (NorESM-ME, yellow); Community Earth System Model (CESM, red); Institute Pierre Simon Laplace (IPLS)-CM5-LR (dark blue); Geophysical Fluid Dynamics Laboratory (GFDL, pale blue); Max Plank Institute-Earth System Model (MPI-ESM, pink); Hadley Centre New Global Environmental Model 2-Earth System (HadGEM2-ES, orange); and Canadian Earth System Model 2 (CanESM2, green). Differences in GPP between model simulations with ('1pctCO$_2$') and without ('esmfixclim1') the effects of climate change are shown. Data are plotted against the global mean temperature increase above pre-industrial levels from simulations with a 1% per year increase in CO$_2$ ('1pctCO$_2$').

The High Arctic region, with tundra-dominated landscapes, has warmed more than the global average over the last century (Section 3.3; Settele et al., 2014). The Arctic tundra biome is experiencing increasing fire disturbance and permafrost degradation (Bring et al., 2016; DeBeer et al., 2016; Jiang et al., 2016; Yang et al., 2016). Both of these processes facilitate the establishment of woody species in tundra areas. Arctic terrestrial ecosystems are being disrupted by delays in winter onset and mild winters associated with global warming (*high confidence*) (Cooper, 2014). Observational constraints suggest that stabilization at 1.5°C of warming would avoid the thawing of approximately 1.5 to 2.5 million km^2 of permafrost (*medium confidence*) compared with stabilization at 2°C (Chadburn et al., 2017), but the time scale for release of thawed carbon as CO$_2$ or CH$_4$ should be many centuries (Burke et al., 2017). In northern Eurasia, the growing season length is projected to increase by about 3–12 days at 1.5°C and 6–16 days at 2°C of warming (*medium confidence*) (Zhou et al., 2018). Aalto et al. (2017) predicted a 72% reduction in cryogenic land surface processes in northern Europe for RCP2.6 in 2040–2069 (corresponding to a global warming of approximately 1.6°C), with only slightly larger losses for RCP4.5 (2°C of global warming).

Projected impacts on forests as climate change occurs include increases in the intensity of storms, wildfires and pest outbreaks (Settele et al., 2014), potentially leading to forest dieback (*medium confidence*). Warmer and drier conditions in particular facilitate fire, drought and insect disturbances, while warmer and wetter conditions increase disturbances from wind and pathogens (Seidl et al., 2017). Particularly vulnerable regions are Central and South America, Mediterranean Basin, South Africa, South Australia where the drought risk will increase (see Figure 3.12). Including disturbances in simulations may influence productivity changes in European forests in response to climate change (Reyer et al., 2017b). There is additional evidence for the attribution of increased forest fire frequency in North America to anthropogenic climate change during 1984–2015, via the mechanism of increasing fuel aridity almost doubling the western USA forest fire area compared to what would have been expected in the absence of climate change (Abatzoglou and Williams, 2016). This projection is in line with expected fire risks, which indicate that fire frequency could increase over 37.8% of the global land area during 2010–2039 (Moritz et al., 2012), corresponding to a global warming level of approximately 1.2°C, compared with over 61.9% of the global land area in 2070–2099, corresponding to a warming of approximately 3.5°C.[6] The values in Table 26-1 in a recent paper by Romero-Lankao et al. (2014) also indicate significantly lower wildfire risks in North America for near-term warming (2030–2040, considered a proxy for 1.5°C of warming) than at 2°C (*high confidence*).

The Amazon tropical forest has been shown to be close to its climatic limits (Hutyra et al., 2005), but this threshold may move under elevated CO_2 (Good et al., 2011). Future changes in rainfall, especially dry season length, will determine responses of the Amazon forest (Good et al., 2013). The forest may be especially vulnerable to combined pressure from multiple stressors, namely changes in climate and continued anthropogenic disturbance (Borma et al., 2013; Nobre et al., 2016). Modelling (Huntingford et al., 2013) and observational constraints (Cox et al., 2013) suggest that large-scale forest dieback is less likely than suggested under early coupled modelling studies (Cox et al., 2000; Jones et al., 2009). Nobre et al. (2016) estimated a climatic threshold of 4°C of warming and a deforestation threshold of 40%.

In many places around the world, the savanna boundary is moving into former grasslands. Woody encroachment, including increased tree cover and biomass, has increased over the past century, owing to changes in land management, rising CO_2 levels, and climate variability and change (often in combination) (Settele et al., 2014). For plant species in the Mediterranean region, shifts in phenology, range contraction and health decline have been observed with precipitation decreases and temperature increases (*medium confidence*) (Settele et al., 2014). Recent studies using independent complementary approaches have shown that there is a regional-scale threshold in the Mediterranean region between 1.5°C and 2°C of warming (Guiot and Cramer, 2016; Schleussner et al., 2016b). Further, Guiot and Cramer (2016) concluded that biome shifts unprecedented in the last 10,000 years can only be avoided if global warming is constrained to 1.5°C (*medium confidence*) – whilst 2°C of warming will result in a decrease of 12–15% of the Mediterranean biome area. The Fynbos biome in southwestern South Africa is vulnerable to the increasing impact of fires under increasing temperatures and drier winters. It is projected to lose about 20%, 45% and 80% of its current suitable climate area under 1°C, 2°C and 3°C of global warming, respectively, compared to 1961–1990 (*high confidence*) (Engelbrecht and Engelbrecht, 2016). In Australia, an increase in the density of trees and shrubs at the expense of grassland species is occurring across all major ecosystems and is projected to be amplified (NCCARF, 2013). Regarding Central America, Lyra et al. (2017) showed that the tropical rainforest biomass would be reduced by about 40% under global warming of 3°C, with considerable replacement by savanna and grassland. With a global warming of close to 1.5°C in 2050, a biomass decrease of 20% is projected for tropical rainforests of Central America (Lyra et al., 2017). If a linear response is assumed, this decrease may reach 30% (*medium confidence*).

Freshwater ecosystems are considered to be among the most threatened on the planet (Settele et al., 2014). Although peatlands cover only about 3% of the land surface, they hold one-third of the world's soil carbon stock (400 to 600 Pg) (Settele et al., 2014). When drained, this carbon is released to the atmosphere. At least 15% of peatlands have drained, mostly in Europe and Southeast Asia, and are responsible for 5% of human derived CO_2 emissions (Green and Page, 2017). Moreover, in the Congo basin (Dargie et al., 2017) and in the Amazonian basin (Draper et al., 2014), the peatlands store the equivalent carbon as that of a tropical forest. However, stored carbon is vulnerable to land-use change and future risk of drought, for example in northeast Brazil (*high confidence*) (Figure 3.12, Section 3.3.4.2). At the global scale, these peatlands are undergoing rapid major transformations through drainage and burning in preparation for oil palm and other crops or through unintentional burning (Magrin et al., 2014). Wetland salinization, a widespread threat to the structure and ecological functioning of inland and coastal wetlands, is occurring at a high rate and large geographic scale (Section 3.3.6; Herbert et al., 2015). Settele et al. (2014) found that rising water temperatures are projected to lead to shifts in freshwater species distributions and worsen water quality. Some of these ecosystems respond non-linearly to changes in temperature. For example, Johnson and Poiani (2016) found that the wetland function of the Prairie Pothole region in North America is projected to decline at temperatures beyond a local warming of 2°C–3°C above present-day values (1°C local warming, corresponding to 0.6°C of global warming). If the ratio of local to global warming remains similar for these small levels of warming, this would indicate a global temperature threshold of 1.2°C–1.8°C of warming. Hence, constraining global warming to approximately 1.5°C would maintain the functioning of prairie pothole ecosystems in terms of their productivity and biodiversity, although a 20% increase of precipitation could offset 2°C of global warming (*high confidence*) (Johnson and Poiani, 2016).

3.4.3.6 Summary of implications for ecosystem services

In summary, constraining global warming to 1.5°C rather than 2°C has strong benefits for terrestrial and wetland ecosystems and their services (*high confidence*). These benefits include avoidance or reduction of changes such as biome transformations, species range losses, increased extinction risks (all *high confidence*) and changes in phenology (*high confidence*), together with projected increases in extreme weather events which are not yet factored into these analyses (Section 3.3). All of these changes contribute to disruption of ecosystem functioning and loss of cultural, provisioning and regulating services provided by these ecosystems to humans. Examples of such services include soil conservation (avoidance of desertification), flood control, water and air purification, pollination, nutrient cycling, sources of food, and recreation.

3.4.4 Ocean Ecosystems

The ocean plays a central role in regulating atmospheric gas concentrations, global temperature and climate. It also provides habitat to a large number of organisms and ecosystems that provide goods and services worth trillions of USD per year (e.g., Costanza et al., 2014; Hoegh-Guldberg et al., 2015). Together with local stresses (Halpern et al., 2015), climate change poses a major threat to an increasing number of ocean ecosystems (e.g., warm water or tropical coral reefs: *virtually certain*, WGII AR5) and consequently to many

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[6] The approximate temperatures are derived from Figure 10.5a in Meehl et al. (2007), which indicates an ensemble average projection of 0.7°C or 3°C above 1980–1999 temperatures, which were already 0.5°C above pre-industrial values.

coastal communities that depend on marine resources for food, livelihoods and a safe place to live. Previous sections of this report have described changes in the ocean, including rapid increases in ocean temperature down to a depth of at least 700 m (Section 3.3.7). In addition, anthropogenic carbon dioxide has decreased ocean pH and affected the concentration of ions in seawater such as carbonate (Sections 3.3.10 and 3.4.4.5), both over a similar depth range. Increased ocean temperatures have intensified storms in some regions (Section 3.3.6), expanded the ocean volume and increased sea levels globally (Section 3.3.9), reduced the extent of polar summer sea ice (Section 3.3.8), and decreased the overall solubility of the ocean for oxygen (Section 3.3.10). Importantly, changes in the response to climate change rarely operate in isolation. Consequently, the effect of global warming of 1.5°C versus 2°C must be considered in the light of multiple factors that may accumulate and interact over time to produce complex risks, hazards and impacts on human and natural systems.

3.4.4.1 Observed impacts

Physical and chemical changes to the ocean resulting from increasing atmospheric CO_2 and other GHGs are already driving significant changes to ocean systems (*very high confidence*) and will continue to do so at 1.5°C, and more so at 2°C, of global warming above pre-industrial temperatures (Section 3.3.11). These changes have been accompanied by other changes such as ocean acidification, intensifying storms and deoxygenation (Levin and Le Bris, 2015). Risks are already significant at current greenhouse gas concentrations and temperatures, and they vary significantly among depths, locations and ecosystems, with impacts being singular, interactive and/or cumulative (Boyd et al., 2015).

3.4.4.2 Warming and stratification of the surface ocean

As atmospheric greenhouse gases have increased, the global mean surface temperature (GMST) has reached about 1°C above the pre-industrial period, and oceans have rapidly warmed from the ocean surface to the deep sea (*high confidence*) (Sections 3.3.7; Hughes and Narayanaswamy, 2013; Levin and Le Bris, 2015; Yasuhara and Danovaro, 2016; Sweetman et al., 2017). Marine organisms are already responding to these changes by shifting their biogeographical ranges to higher latitudes at rates that range from approximately 0 to 40 km yr^{-1} (Burrows et al., 2014; Chust, 2014; Bruge et al., 2016; Poloczanska et al., 2016), which has consequently affected the structure and function of the ocean, along with its biodiversity and foodwebs (*high confidence*). Movements of organisms does not necessarily equate to the movement of entire ecosystems. For example, species of reef-building corals have been observed to shift their geographic ranges, yet this has not resulted in the shift of entire coral ecosystems (*high confidence*) (Woodroffe et al., 2010; Yamano et al., 2011). In the case of 'less mobile' ecosystems (e.g., coral reefs, kelp forests and intertidal communities), shifts in biogeographical ranges may be limited, with mass mortalities and disease outbreaks increasing in frequency as the exposure to extreme temperatures increases (*very high confidence*) (Hoegh-Guldberg, 1999; Garrabou et al., 2009; Rivetti et al., 2014; Maynard et al., 2015; Krumhansl et al., 2016; Hughes et al., 2017b; see also Box 3.4). These trends are projected to become more pronounced at warming of 1.5°C, and more so at 2°C, above the pre-industrial period (Hoegh-Guldberg et al., 2007; Donner, 2009; Frieler et al., 2013; Horta E Costa et al., 2014; Vergés et al., 2014, 2016; Zarco-Perello et al., 2017) and are *likely* to result in decreases in marine biodiversity at the equator but increases in biodiversity at higher latitudes (Cheung et al., 2009; Burrows et al., 2014).

While the impacts of species shifting their ranges are mostly negative for human communities and industry, there are instances of short-term gains. Fisheries, for example, may expand temporarily at high latitudes in the Northern Hemisphere as the extent of summer sea ice recedes and NPP increases (*medium confidence*) (Cheung et al., 2010; Lam et al., 2016; Weatherdon et al., 2016). High-latitude fisheries are not only influenced by the effect of temperature on NPP but are also strongly influenced by the direct effects of changing temperatures on fish and fisheries (Section 3.4.4.9; Barange et al., 2014; Pörtner et al., 2014; Cheung et al., 2016b; Weatherdon et al., 2016). Temporary gains in the productivity of high-latitude fisheries are offset by a growing number of examples from low and mid-latitudes where increases in sea temperature are driving decreases in NPP, owing to the direct effects of elevated temperatures and/or reduced ocean mixing from reduced ocean upwelling, that is, increased stratification (*low-medium confidence*) (Cheung et al., 2010; Ainsworth et al., 2011; Lam et al., 2012, 2014, 2016; Bopp et al., 2013; Boyd et al., 2014; Chust et al., 2014; Hoegh-Guldberg et al., 2014; Poloczanska et al., 2014; Pörtner et al., 2014; Signorini et al., 2015). Reduced ocean upwelling has implications for millions of people and industries that depend on fisheries for food and livelihoods (Bakun et al., 2015; FAO, 2016; Kämpf and Chapman, 2016), although there is *low confidence* in the projection of the size of the consequences at 1.5°C. It is also important to appreciate these changes in the context of large-scale ocean processes such as the ocean carbon pump. The export of organic carbon to deeper layers of the ocean increases as NPP changes in the surface ocean, for example, with implications for foodwebs and oxygen levels (Boyd et al., 2014; Sydeman et al., 2014; Altieri and Gedan, 2015; Bakun et al., 2015; Boyd, 2015).

3.4.4.3 Storms and coastal runoff

Storms, wind, waves and inundation can have highly destructive impacts on ocean and coastal ecosystems, as well as the human communities that depend on them (IPCC, 2012; Seneviratne et al., 2012). The intensity of tropical cyclones across the world's oceans has increased, although the overall number of tropical cyclones has remained the same or decreased (*medium confidence*) (Section 3.3.6; Elsner et al., 2008; Holland and Bruyère, 2014). The direct force of wind and waves associated with larger storms, along with changes in storm direction, increases the risks of physical damage to coastal communities and to ecosystems such as mangroves (*low to medium confidence*) (Long et al., 2016; Primavera et al., 2016; Villamayor et al., 2016; Cheal et al., 2017) and tropical coral reefs (De'ath et al., 2012; Bozec et al., 2015; Cheal et al., 2017). These changes are associated with increases in maximum wind speed, wave height and the inundation, although trends in these variables vary from region to region (Section 3.3.5). In some cases, this can lead to increased exposure to related impacts, such as flooding, reduced water quality and increased sediment runoff (*medium-high confidence*) (Brodie et al., 2012; Wong et al., 2014; Anthony, 2016; AR5, Table 5.1).

Sea level rise also amplifies the impacts of storms and wave action (Section 3.3.9), with robust evidence that storm surges and damage are already penetrating farther inland than a few decades ago, changing conditions for coastal ecosystems and human communities. This is especially true for small islands (Box 3.5) and low-lying coastal communities, where issues such as storm surges can transform coastal areas (Section 3.4.5; Brown et al., 2018a). Changes in the frequency of extreme events, such as an increase in the frequency of intense storms, have the potential (along with other factors, such as disease, food web changes, invasive organisms and heat stress-related mortality; Burge et al., 2014; Maynard et al., 2015; Weatherdon et al., 2016; Clements et al., 2017) to overwhelm the capacity for natural and human systems to recover following disturbances. This has recently been seen for key ecosystems such as tropical coral reefs (Box 3.4), which have changed from coral-dominated ecosystems to assemblages dominated by other organisms such as seaweeds, with changes in associated organisms and ecosystem services (*high confidence*) (De'ath et al., 2012; Bozec et al., 2015; Cheal et al., 2017; Hoegh-Guldberg et al., 2017; Hughes et al., 2017a, b). The impacts of storms are amplified by sea level rise (Section 3.4.5), leading to substantial challenges today and in the future for cities, deltas and small island states in particular (Sections 3.4.5.2 to 3.4.5.4), as well as for coastlines and their associated ecosystems (Sections 3.4.5.5 to 3.4.5.7).

3.4.4.4 Ocean circulation

The movement of water within the ocean is essential to its biology and ecology, as well to the circulation of heat, water and nutrients around the planet (Section 3.3.7). The movement of these factors drives local and regional climates, as well as primary productivity and food production. Firmly attributing recent changes in the strength and direction of ocean currents to climate change, however, is complicated by long-term patterns and variability (e.g., Pacific decadal oscillation, PDO; Signorini et al., 2015) and a lack of records that match the long-term nature of these changes in many cases (Lluch-Cota et al., 2014). An assessment of the literature since AR5 (Sydeman et al., 2014), however, concluded that (overall) upwelling-favourable winds have intensified in the California, Benguela and Humboldt upwelling systems, but have weakened in the Iberian system and have remained neutral in the Canary upwelling system in over 60 years of records (1946–2012) (*medium confidence*). These conclusions are consistent with a growing consensus that wind-driven upwelling systems are likely to intensify under climate change in many upwelling systems (Sydeman et al., 2014; Bakun et al., 2015; Di Lorenzo, 2015), with potentially positive and negative consequences (Bakun et al., 2015).

Changes in ocean circulation can have profound impacts on marine ecosystems by connecting regions and facilitating the entry and establishment of species in areas where they were unknown before (e.g., 'tropicalization' of temperate ecosystems; Wernberg et al., 2012; Vergés et al., 2014, 2016; Zarco-Perello et al., 2017), as well as the arrival of novel disease agents (*low-medium confidence*) (Burge et al., 2014; Maynard et al., 2015; Weatherdon et al., 2016). For example, the herbivorous sea urchin *Centrostephanus rodgersii* has been reached Tasmania from the Australian mainland, where it was previously unknown, owing to a strengthening of the East Australian Current (EAC) that connects the two regions (*high confidence*) (Ling et al., 2009). As a consequence, the distribution and abundance of kelp forests has rapidly decreased, with implications for fisheries and other ecosystem services (Ling et al., 2009). These risks to marine ecosystems are projected to become greater at 1.5°C, and more so at 2°C (*medium confidence*) (Cheung et al., 2009; Pereira et al., 2010; Pinsky et al., 2013; Burrows et al., 2014).

Changes to ocean circulation can have even larger influence in terms of scale and impacts. Weakening of the Atlantic Meridional Overturning Circulation (AMOC), for example, is projected to be highly disruptive to natural and human systems as the delivery of heat to higher latitudes via this current system is reduced (Collins et al., 2013). Evidence of a slowdown of AMOC has increased since AR5 (Smeed et al., 2014; Rahmstorf et al., 2015a, b; Kelly et al., 2016), yet a strong causal connection to climate change is missing (*low confidence*) (Section 3.3.7).

3.4.4.5 Ocean acidification

Ocean chemistry encompasses a wide range of phenomena and chemical species, many of which are integral to the biology and ecology of the ocean (Section 3.3.10; Gattuso et al., 2014, 2015; Hoegh-Guldberg et al., 2014; Pörtner et al., 2014). While changes to ocean chemistry are likely to be of central importance, the literature on how climate change might influence ocean chemistry over the short and long term is limited (*medium confidence*). By contrast, numerous risks from the specific changes associated with ocean acidification have been identified (Dove et al., 2013; Kroeker et al., 2013; Pörtner et al., 2014; Gattuso et al., 2015; Albright et al., 2016), with the consensus that resulting changes to the carbonate chemistry of seawater are having, and are likely to continue to have, fundamental and substantial impacts on a wide variety of organisms (*high confidence*). Organisms with shells and skeletons made out of calcium carbonate are particularly at risk, as are the early life history stages of a large number of organisms and processes such as de-calcification, although there are some taxa that have not shown high-sensitivity to changes in CO_2, pH and carbonate concentrations (Dove et al., 2013; Fang et al., 2013; Kroeker et al., 2013; Pörtner et al., 2014; Gattuso et al., 2015). Risks of these impacts also vary with latitude and depth, with the greatest changes occurring at high latitudes as well as deeper regions. The aragonite saturation horizon (i.e., where concentrations of calcium and carbonate fall below the saturation point for aragonite, a key crystalline form of calcium carbonate) is decreasing with depth as anthropogenic CO_2 penetrates deeper into the ocean over time. Under many models and scenarios, the aragonite saturation is projected to reach the surface by 2030 onwards, with a growing list of impacts and consequences for ocean organisms, ecosystems and people (Orr et al., 2005; Hauri et al., 2016).

Further, it is difficult to reliably separate the impacts of ocean warming and acidification. As ocean waters have increased in sea surface temperature (SST) by approximately 0.9°C they have also decreased by 0.2 pH units since 1870–1899 ('pre-industrial'; Table 1 in Gattuso et al., 2015; Bopp et al., 2013). As CO_2 concentrations continue to increase along with other GHGs, pH will decrease while sea temperature will increase, reaching 1.7°C and a decrease of 0.2 pH units (by 2100 under RCP4.5) relative to the pre-industrial period. These changes are likely to continue given the negative correlation of temperature and pH. Experimental manipulation of CO_2, temperature and consequently acidification indicate that these impacts will continue to increase in size and scale as CO_2 and SST continue to increase in tandem (Dove et al., 2013; Fang et al., 2013; Kroeker et al., 2013).

While many risks have been defined through laboratory and mesocosm experiments, there is a growing list of impacts from the field (*medium confidence*) that include community-scale impacts on bacterial assemblages and processes (Endres et al., 2014), coccolithophores (K.J.S. Meier et al., 2014), pteropods and polar foodwebs (Bednaršek et al., 2012, 2014), phytoplankton (Moy et al., 2009; Riebesell et al., 2013; Richier et al., 2014), benthic ecosystems (Hall-Spencer et al., 2008; Linares et al., 2015), seagrass (Garrard et al., 2014), and macroalgae (Webster et al., 2013; Ordonez et al., 2014), as well as excavating sponges, endolithic microalgae and reef-building corals (Dove et al., 2013; Reyes-Nivia et al., 2013; Fang et al., 2014), and coral reefs (Box 3.4; Fabricius et al., 2011; Allen et al., 2017). Some ecosystems, such as those from bathyal areas (i.e., 200–3000 m below the surface), are likely to undergo very large reductions in pH by the year 2100 (0.29 to 0.37 pH units), yet evidence of how deep-water ecosystems will respond is currently limited despite the potential planetary importance of these areas (*low to medium confidence*) (Hughes and Narayanaswamy, 2013; Sweetman et al., 2017).

3.4.4.6 Deoxygenation

Oxygen levels in the ocean are maintained by a series of processes including ocean mixing, photosynthesis, respiration and solubility (Boyd et al., 2014, 2015; Pörtner et al., 2014; Breitburg et al., 2018). Concentrations of oxygen in the ocean are declining (*high confidence*) owing to three main factors related to climate change: (i) heat-related stratification of the water column (less ventilation and mixing), (ii) reduced oxygen solubility as ocean temperature increases, and (iii) impacts of warming on biological processes that produce or consume oxygen such as photosynthesis and respiration (*high confidence*) (Bopp et al., 2013; Pörtner et al., 2014; Altieri and Gedan, 2015; Deutsch et al., 2015; Schmidtko et al., 2017; Shepherd et al., 2017; Breitburg et al., 2018). Further, a range of processes (Section 3.4.11) are acting synergistically, including factors not related to climate change, such as runoff and coastal eutrophication (e.g., from coastal farming and intensive aquaculture). These changes can lead to increased phytoplankton productivity as a result of the increased concentration of dissolved nutrients. Increased supply of organic carbon molecules from coastal run-off can also increase the metabolic activity of coastal microbial communities (Altieri and Gedan, 2015; Bakun et al., 2015; Boyd, 2015). Deep sea areas are likely to experience some of the greatest challenges, as abyssal seafloor habitats in areas of deep-water formation are projected to experience decreased water column oxygen concentrations by as much as 0.03 mL L^{-1} by 2100 (Levin and Le Bris, 2015; Sweetman et al., 2017).

The number of 'dead zones' (areas where oxygenated waters have been replaced by hypoxic conditions) has been growing strongly since the 1990s (Diaz and Rosenberg, 2008; Altieri and Gedan, 2015; Schmidtko et al., 2017). While attribution can be difficult because of the complexity of the processes involved, both related and unrelated to climate change, some impacts associated to deoxygenation (*low-medium confidence*) include the expansion of oxygen minimum zones (OMZ) (Turner et al., 2008; Carstensen et al., 2014; Acharya and Panigrahi, 2016; Lachkar et al., 2018), physiological impacts (Pörtner et al., 2014), and mortality and/or displacement of oxygen dependent organisms such as fish (Hamukuaya et al., 1998; Thronson and Quigg, 2008; Jacinto, 2011) and invertebrates (Hobbs and Mcdonald, 2010; Bednaršek et al., 2016; Seibel, 2016; Altieri et al., 2017). In addition, deoxygenation interacts with ocean acidification to present substantial separate and combined challenges for fisheries and aquaculture (*medium confidence*) (Hamukuaya et al., 1998; Bakun et al., 2015; Rodrigues et al., 2015; Feely et al., 2016; S. Li et al., 2016; Asiedu et al., 2017a; Clements and Chopin, 2017; Clements et al., 2017; Breitburg et al., 2018). Deoxygenation is expected to have greater impacts as ocean warming and acidification increase (*high confidence*), with impacts being larger and more numerous than today (e.g., greater challenges for aquaculture and fisheries from hypoxia), and as the number of hypoxic areas continues to increase. Risks from deoxygenation are *virtually certain* to increase as warming continues, although our understanding of risks at 1.5°C versus 2°C is incomplete (*medium confidence*). Reducing coastal pollution, and consequently the penetration of organic carbon into deep benthic habitats, is expected to reduce the loss of oxygen in coastal waters and hypoxic areas in general (*high confidence*) (Breitburg et al., 2018).

3.4.4.7 Loss of sea ice

Sea ice is a persistent feature of the planet's polar regions (Polyak et al., 2010) and is central to marine ecosystems, people (e.g., food, culture and livelihoods) and industries (e.g., fishing, tourism, oil and gas, and shipping). Summer sea ice in the Arctic, however, has been retreating rapidly in recent decades (Section 3.3.8), with an assessment of the literature revealing that a fundamental transformation is occurring in polar organisms and ecosystems, driven by climate change (*high confidence*) (Larsen et al., 2014). These changes are strongly affecting people in the Arctic who have close relationships with sea ice and associated ecosystems, and these people are facing major adaptation challenges as a result of sea level rise, coastal erosion, the accelerated thawing of permafrost, changing ecosystems and resources, and many other issues (Ford, 2012; Ford et al., 2015).

There is considerable and compelling evidence that a further increase of 0.5°C beyond the present-day average global surface temperature will lead to multiple levels of impact on a variety of organisms, from phytoplankton to marine mammals, with some of the most dramatic changes occurring in the Arctic Ocean and western Antarctic Peninsula (Turner et al., 2014, 2017b; Steinberg et al., 2015; Piñones and Fedorov, 2016).

The impacts of climate change on sea ice are part of the focus of the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC), due to be released in 2019, and hence are not covered comprehensively here. However, there is a range of responses to the loss of sea ice that are occurring and which increase at 1.5°C and further so with 2°C of global warming. Some of these changes are described briefly here. Photosynthetic communities, such macroalgae, phytoplankton and microalgae dwelling on the underside of floating sea ice are changing, owing to increased temperatures, light and nutrient levels. As sea ice retreats, mixing of the water column increases, and phototrophs have increased access to seasonally high levels of solar radiation (*medium confidence*) (Dalpadado et al., 2014; W.N. Meier et al., 2014). These changes are expected to stimulate fisheries productivity in high-latitude regions by mid-century (*high confidence*) (Cheung et al., 2009, 2010, 2016b; Lam et al., 2014), with evidence that this is already happening for several high-latitude fisheries in the Northern Hemisphere, such as the Bering Sea, although these 'positive' impacts may be relatively short-lived (Hollowed and Sundby, 2014; Sundby et al., 2016). In addition to the impact of climate change on fisheries via impacts on net primary productivity (NPP), there are also direct effects of temperature on fish, which may in turn have a range of impacts (Pörtner et al., 2014). Sea ice in Antarctica is undergoing changes that exceed those seen in the Arctic (Maksym et al., 2011; Reid et al., 2015), with increases in sea ice coverage in the western Ross Sea being accompanied by strong decreases in the Bellingshausen and Amundsen Seas (Hobbs et al., 2016). While Antarctica is not permanently populated, the ramifications of changes to the productivity of vast regions, such as the Southern Ocean, have substantial implications for ocean foodwebs and fisheries globally.

3.4.4.8 Sea level rise

Mean sea level is increasing (Section 3.3.9), with substantial impacts already being felt by coastal ecosystems and communities (Wong et al., 2014) (*high confidence*). These changes are interacting with other factors, such as strengthening storms, which together are driving larger storm surges, infrastructure damage, erosion and habitat loss (Church et al., 2013; Stocker et al., 2013; Blankespoor et al., 2014). Coastal wetland ecosystems such as mangroves, sea grasses and salt marshes are under pressure from rising sea level (*medium confidence*) (Section 3.4.5; Di Nitto et al., 2014; Ellison, 2014; Lovelock et al., 2015; Mills et al., 2016; Nicholls et al., 2018), as well as from a wide range of other risks and impacts unrelated to climate change, with the ongoing loss of wetlands recently estimated at approximately 1% per annum across a large number of countries (Blankespoor et al., 2014; Alongi, 2015). While some ecosystems (e.g., mangroves) may be able to shift shoreward as sea levels increase, coastal development (e.g., buildings, seawalls and agriculture) often interrupts shoreward shifts, as well as reducing sediment supplies down some rivers (e.g., dams) due to coastal development (Di Nitto et al., 2014; Lovelock et al., 2015; Mills et al., 2016).

Responses to sea level rise challenges for ocean and coastal systems include reducing the impact of other stresses, such as those arising from tourism, fishing, coastal development, reduced sediment supply and unsustainable aquaculture/agriculture, in order to build ecological resilience (Hossain et al., 2015; Sutton-Grier and Moore, 2016; Asiedu et al., 2017a). The available literature largely concludes that these impacts will intensify under a 1.5°C warmer world but will be even higher at 2°C, especially when considered in the context of changes occurring beyond the end of the current century. In some cases, restoration of coastal habitats and ecosystems may be a cost-effective way of responding to changes arising from increasing levels of exposure to rising sea levels, intensifying storms, coastal inundation and salinization (Section 3.4.5 and Box 3.5; Arkema et al., 2013), although limitations of these strategies have been identified (e.g., Lovelock et al., 2015; Weatherdon et al., 2016).

3.4.4.9 Projected risks and adaptation options for oceans under global warming of 1.5°C or 2°C above pre-industrial levels

A comprehensive discussion of risk and adaptation options for all natural and human systems is not possible in the context and length of this report, and hence the intention here is to illustrate key risks and adaptation options for ocean ecosystems and sectors. This assessment builds on the recent expert consensus of Gattuso et al. (2015) by assessing new literature from 2015–2017 and adjusting the levels of risk from climate change in the light of literature since 2014. The original expert group's assessment (Supplementary Material 3.SM.3.2) was used as input for this new assessment, which focuses on the implications of global warming of 1.5°C as compared to 2°C. A discussion of potential adaptation options is also provided, the details of which will be further explored in later chapters of this special report. The section draws on the extensive analysis and literature presented in the Supplementary Material of this report (3.SM.3.2, 3.SM.3.3) and has a summary in Figures 3.18 and 3.20 which outline the added relative risks of climate change.

3.4.4.10 Framework organisms (tropical corals, mangroves and seagrass)

Marine organisms ('ecosystem engineers'), such as seagrass, kelp, oysters, salt marsh species, mangroves and corals, build physical structures or frameworks (i.e., sea grass meadows, kelp forests, oyster reefs, salt marshes, mangrove forests and coral reefs) which form the habitat for a large number of species (Gutiérrez et al., 2012). These organisms in turn provide food, livelihoods, cultural significance, and services such as coastal protection to human communities (Bell et al., 2011, 2018; Cinner et al., 2012; Arkema et al., 2013; Nurse et al., 2014; Wong et al., 2014; Barbier, 2015; Bell and Taylor, 2015; Hoegh-Guldberg et al., 2015; Mycoo, 2017; Pecl et al., 2017).

Risks of climate change impacts for seagrass and mangrove ecosystems were recently assessed by an expert group led by Short et al. (2016). Impacts of climate change were assessed to be similar across a range of submerged and emerged plants. Submerged plants such as seagrass were affected mostly by temperature extremes (Arias-Ortiz et al., 2018), and indirectly by turbidity, while emergent communities such as mangroves and salt marshes were most susceptible to sea level variability and temperature extremes, which is consistent with other evidence (Di Nitto et al., 2014; Sierra-Correa and Cantera Kintz, 2015; Osorio et al., 2016; Sasmito et al., 2016), especially in the context of human activities that reduce sediment supply (Lovelock et al., 2015) or interrupt the shoreward movement of mangroves though the construction of coastal infrastructure. This in turn leads to 'coastal squeeze' where coastal ecosystems are trapped between changing ocean conditions and coastal infrastructure (Mills et al., 2016). Projections of the future distribution of seagrasses suggest a poleward shift, which raises concerns that low-latitude seagrass communities may contract as a result of increasing stress levels (Valle et al., 2014).

Climate change (e.g., sea level rise, heat stress, storms) presents risk for coastal ecosystems such as seagrass (*high confidence*) and reef-building corals (*very high confidence*) (Figure 3.18, Supplementary Material 3.SM.3.2), with evidence of increasing concern since AR5 and the conclusion that tropical corals may be even more vulnerable to climate change than indicated in assessments made in 2014 (Hoegh-Guldberg et al., 2014; Gattuso et al., 2015). The current assessment also considered the heatwave-related loss of 50% of shallow-water corals across hundreds of kilometres of the world's largest continuous coral reef system, the Great Barrier Reef. These large-scale impacts, plus the observation of back-to-back bleaching events on the Great Barrier Reef (predicted two decades ago, Hoegh-Guldberg, 1999) and arriving sooner than predicted (Hughes et al., 2017b, 2018), suggest that the research community may have underestimated climate risks for coral reefs (Figure 3.18). The general assessment of climate risks for mangroves prior to this special report was that they face greater risks from deforestation and unsustainable coastal development than from climate change (Alongi, 2008; Hoegh-Guldberg et al., 2014; Gattuso et al., 2015). Recent large-scale die-offs (Duke et al., 2017; Lovelock et al., 2017), however, suggest that risks from climate change may have been underestimated for mangroves as well. With the events of the last past three years in mind, risks are now considered to be undetectable to moderate (i.e., moderate risks now start at 1.3°C as opposed to 1.8°C; *medium confidence*). Consequently, when average global warming reaches 1.3°C above pre-industrial levels, the risk of climate change to mangroves are projected to be moderate (Figure 3.18) while tropical coral reefs will have reached a high level of risk as examplified by increasing damage from heat stress since the early 1980s. At global warming of 1.8°C above pre-industrial levels, seagrasses are projected to reach moderate to high levels of risk (e.g., damage resulting from sea level rise, erosion, extreme temperatures, and storms), while risks to mangroves from climate change are projected to remain moderate (e.g., not keeping up with sea level rise, and more frequent heat stress mortality) although there is *low certainty* as to when or if this important ecosystem is likely to transition to higher levels of additional risk from climate change (Figure 3.18).

Warm water (tropical) coral reefs are projected to reach a very high risk of impact at 1.2°C (Figure 3.18), with most available evidence suggesting that coral-dominated ecosystems will be non-existent at this temperature or higher (*high confidence*). At this point, coral abundance will be near zero at many locations and storms will contribute to 'flattening' the three-dimensional structure of reefs without recovery, as already observed for some coral reefs (Alvarez-Filip et al., 2009). The impacts of warming, coupled with ocean acidification, are expected to undermine the ability of tropical coral reefs to provide habitat for thousand of species, which together provide a range of ecosystem services (e.g., food, livelihoods, coastal protection, cultural services) that are important for millions of people (*high confidence*) (Burke et al., 2011).

Strategies for reducing the impact of climate change on framework organisms include reducing stresses not directly related to climate change (e.g., coastal pollution, overfishing and destructive coastal development) in order to increase their ecological resilience in the face of accelerating climate change impacts (World Bank, 2013; Ellison, 2014; Anthony et al., 2015; Sierra-Correa and Cantera Kintz, 2015; Kroon et al., 2016; O'Leary et al., 2017), as well as protecting locations where organisms may be more robust (Palumbi et al., 2014) or less exposed to climate change (Bongaerts et al., 2010; van Hooidonk et al., 2013; Beyer et al., 2018). This might involve cooler areas due to upwelling, or involve deep-water locations that experience less extreme conditions and impacts. Given the potential value of such locations for promoting the survival of coral communities under climate change, efforts to prevent their loss resulting from other stresses are important (Bongaerts et al., 2010, 2017; Chollett et al., 2010, 2014; Chollett and Mumby, 2013; Fine et al., 2013; van Hooidonk et al., 2013; Cacciapaglia and van Woesik, 2015; Beyer et al., 2018). A full understanding of the role of refugia in reducing the loss of ecosystems has yet to be developed (*low to medium confidence*). There is also interest in *ex situ* conservation approaches involving the restoration of corals via aquaculture (Shafir et al., 2006; Rinkevich, 2014) or the use of 'assisted evolution' to help corals adapt to changing sea temperatures (van Oppen et al., 2015, 2017), although there are numerous challenges that must be surpassed if these approaches are to be cost-effective responses to preserving coral reefs under rapid climate change (*low confidence*) (Hoegh-Guldberg, 2012, 2014a; Bayraktarov et al., 2016).

High levels of adaptation are expected to be required to prevent impacts on food security and livelihoods in coastal populations (*medium confidence*). Integrating coastal infrastructure with changing ecosystems such as mangroves, seagrasses and salt marsh, may offer adaptation strategies as they shift shoreward as sea levels rise (*high confidence*). Maintaining the sediment supply to coastal areas would also assist mangroves in keeping pace with sea level rise (Shearman et al., 2013; Lovelock et al., 2015; Sasmito et al., 2016). For this reason, habitat for mangroves can be strongly affected by human actions such as building dams which reduce the sediment supply and hence the ability of mangroves to escape 'drowning' as sea level rises (Lovelock et al., 2015). In addition, integrated coastal zone management should recognize the importance and economic expediency of using natural ecosystems such as mangroves and tropical coral reefs to protect coastal human communities (Arkema et al., 2013; Temmerman et al., 2013; Ferrario et al., 2014; Hinkel et al., 2014; Elliff and Silva, 2017). Adaptation options include developing alternative livelihoods and food sources, ecosystem-based management/adaptation such as ecosystem restoration, and constructing coastal infrastructure that reduces the impacts of rising seas and intensifying storms (Rinkevich, 2015; Weatherdon et al., 2016; Asiedu et al., 2017a; Feller et al., 2017). Clearly, these options need to be carefully assessed in terms of feasibility, cost and scalability, as well as in the light of the coastal ecosystems involved (Bayraktarov et al., 2016).

3.4.4.11 Ocean foodwebs (pteropods, bivalves, krill and fin fish)

Ocean foodwebs are vast interconnected systems that transfer solar energy and nutrients from phytoplankton to higher trophic levels, including apex predators and commercially important species such as tuna. Here, we consider four representative groups of marine organisms which are important within foodwebs across the ocean, and which illustrate the impacts and ramifications of 1.5°C or higher levels of warming.

The first group of organisms, pteropods, are small pelagic molluscs that suspension feed and produce a calcium carbonate shell. They are highly abundant in temperate and polar waters where they are an important link in the foodweb between phytoplankton and a range of other organisms including fish, whales and birds. The second group, bivalve molluscs (e.g., clams, oysters and mussels), are filter-feeding invertebrates. These invertebrate organisms underpin important fisheries and aquaculture industries, from polar to tropical regions, and are important food sources for a range of organisms including humans. The third group of organisms considered here is a globally significant group of invertebrates known as *euphausiid crustaceans* (krill), which are a key food source for many marine organisms and hence a major link between primary producers and higher trophic levels (e.g., fish, mammals and sea birds). Antarctic krill, *Euphausia superba*, are among the most abundant species in terms of mass and are consequently an essential component of polar foodwebs (Atkinson et al., 2009). The last group, fin fishes, is vitally important components of ocean foodwebs, contribute to the income of coastal communities, industries and nations, and are important to the foodsecurity and livelihood of hundreds of millions of people globally (FAO, 2016). Further background for this section is provided in Supplementary Material 3.SM.3.2.

There is a moderate risk to ocean foodwebs under present-day conditions (*medium to high confidence*) (Figure 3.18). Changing water chemistry and temperature are already affecting the ability of pteropods to produce their shells, swim and survive (Bednaršek et al., 2016). Shell dissolution, for example, has increased by 19–26% in both nearshore and offshore populations since the pre-industrial period (Feely et al., 2016). There is considerable concern as to whether these organisms are declining further, especially given the central importance in ocean foodwebs (David et al., 2017). Reviewing the literature reveals that pteropods are projected to face high risks of impact at average global temperatures 1.5°C above pre-industrial levels and increasing risks of impacts at 2°C (*medium confidence*).

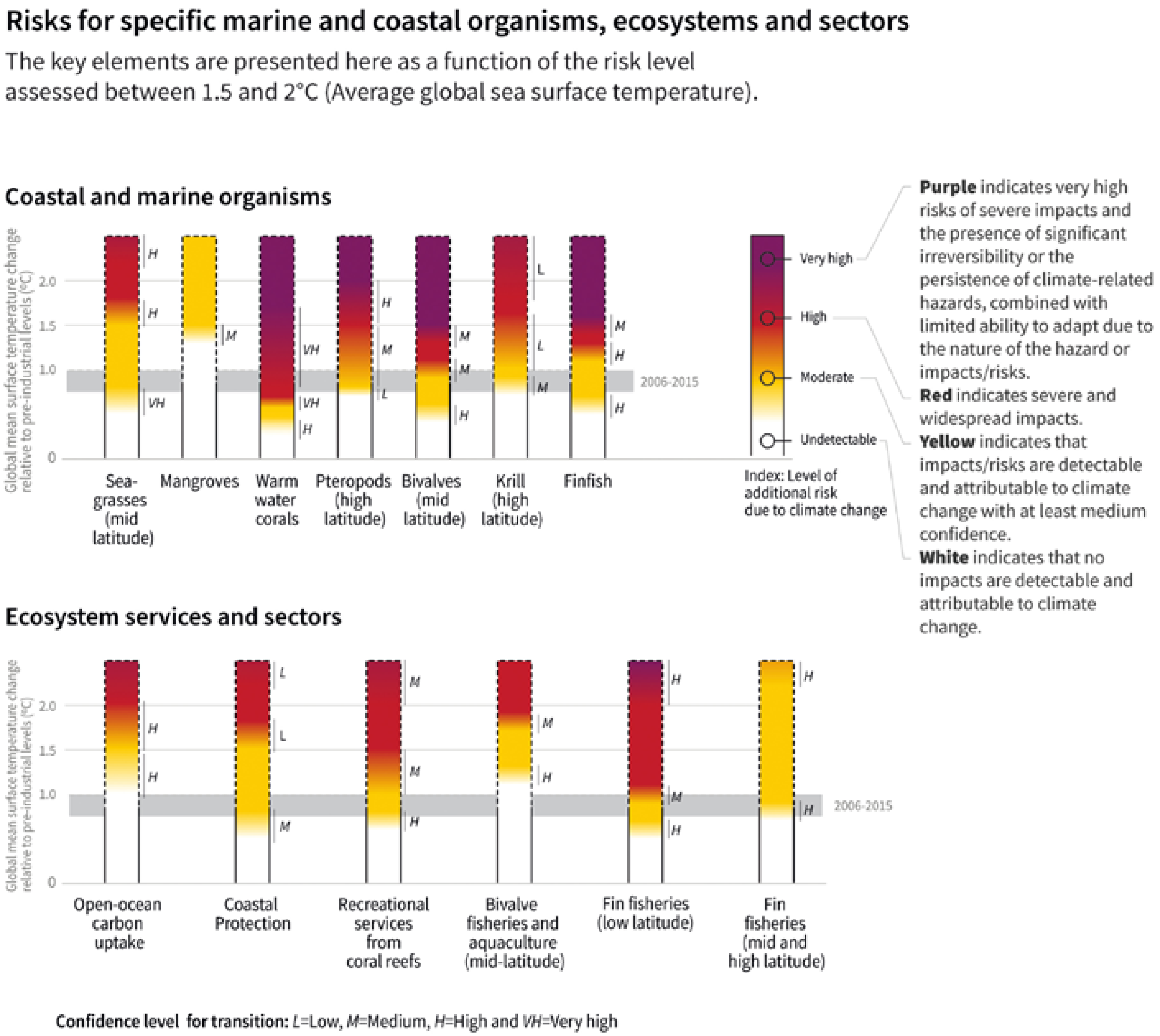
As GMST increases by 1.5°C and more, the risk of impacts from ocean warming and acidification are expected to be moderate to high, except in the case of bivalves (mid-latitudes) where the risks of impacts are projected to be high to very high (Figure 3.18). Ocean warming and acidification are already affecting the life history stages of bivalve molluscs (e.g., Asplund et al., 2014; Mackenzie et al., 2014; Waldbusser et al., 2014; Zittier et al., 2015; Shi et al., 2016; Velez et al., 2016; Q. Wang et al., 2016; Castillo et al., 2017; Lemasson et al., 2017; Ong et al., 2017; X. Zhao et al., 2017). Impacts on adult bivalves include decreased growth, increased respiration and reduced calcification, whereas larval stages tend to show greater developmental abnormalities and increased mortality after exposure to these conditions (*medium to high confidence*) (Q. Wang et al., 2016; Lemasson et al., 2017; Ong et al., 2017; X. Zhao et al., 2017). Risks are expected to accumulate at higher temperatures for bivalve molluscs, with very high risks expected at 1.8°C of warming or more. This general pattern applies to low-latitude fin fish, which are expected to experience moderate to high risks of impact at 1.3°C of global warming (*medium confidence*), and very high risks at 1.8°C at low latitudes (*medium confidence*) (Figure 3.18).

Large-scale changes to foodweb structure are occurring in all oceans. For example, record levels of sea ice loss in the Antarctic (Notz and Stroeve, 2016; Turner et al., 2017b) translate into a loss of habitat and hence reduced abundance of krill (Piñones and Fedorov, 2016), with negative ramifications for the seabirds and whales which feed on krill (Croxall, 1992; Trathan and Hill, 2016) (*low-medium confidence*). Other influences, such as high rates of ocean acidification coupled with shoaling of the aragonite saturation horizon, are likely to also play key roles (Kawaguchi et al., 2013; Piñones and Fedorov, 2016). As with many risks associated with impacts at the ecosystem scale, most adaptation options focus on the management of stresses unrelated to climate change but resulting from human activities, such as pollution and habitat destruction. Reducing these stresses will be important in efforts to maintain important foodweb components. Fisheries management at local to regional scales will be important in reducing stress on foodweb organisms, such as those discussed here, and in helping communities and industries adapt to changing foodweb structures and resources (see further discussion of fisheries *per se* below; Section 3.4.6.3). One strategy is to maintain larger population levels of fished species in order to provide more resilient stocks in the face of challenges that are increasingly driven by climate change (Green et al., 2014; Bell and Taylor, 2015).

3.4.4.12 Key ecosystem services (e.g., carbon uptake, coastal protection, and tropical coral reef recreation)

The ocean provides important services, including the regulation of atmospheric composition via gas exchange across the boundary between ocean and atmosphere, and the storage of carbon in vegetation and soils associated with ecosystems such as mangroves, salt marshes and coastal peatlands. These services involve a series of physicochemical processes which are influenced by ocean chemistry, circulation, biology, temperature and biogeochemical components, as well as by factors other than climate (Boyd, 2015). The ocean is also a net sink for CO_2 (another important service), absorbing approximately 30% of human emissions from the burning of fossil fuels and modification of land use (IPCC, 2013). Carbon uptake by the ocean is decreasing (Iida et al., 2015), and there is increasing concern from observations and models regarding associated changes to ocean circulation (Sections 3.3.7 and 3.4.4., Rahmstorf et al., 2015b);. Biological components of carbon uptake by the ocean are also changing, with observations of changing net primary productivity (NPP) in equatorial and coastal upwelling systems (*medium confidence*) (Lluch-Cota et al., 2014; Sydeman et al., 2014; Bakun et al., 2015), as well as subtropical gyre systems (*low confidence*) (Signorini et al., 2015). There is general agreement that NPP will decline as ocean warming and acidification increase (*medium confidence*) (Bopp et al., 2013; Boyd et al., 2014; Pörtner et al., 2014; Boyd, 2015).

Projected risks of impacts from reductions in carbon uptake, coastal protection and services contributing to coral reef recreation suggest a transition from moderate to high risks at 1.5°C and higher (*low confidence*). At 2°C, risks of impacts associated with changes to carbon uptake are high (*high confidence*), while the risks associated with reduced coastal protection and recreation on tropical coral reefs are high, especially given the vulnerability of this ecosystem type, and others (e.g., seagrass and mangroves), to climate change (*medium confidence*) (Figure 3.18). Coastal protection is a service provided by natural barriers such as mangroves, seagrass meadows, coral reefs, and other coastal ecosystems, and it is important for protecting human communities and infrastructure against the impacts associated with rising sea levels, larger waves and intensifying storms (*high confidence*) (Gutiérrez et al., 2012; Kennedy et al., 2013; Ferrario et al., 2014; Barbier, 2015; Cooper et al., 2016; Hauer et al., 2016; Narayan et al., 2016). Both natural and human coastal protection have the potential to reduce these impacts (Fu and Song, 2017). Tropical coral reefs, for example, provide effective protection by dissipating about 97% of wave energy, with 86% of the energy being dissipated by reef crests alone (Ferrario et al., 2014; Narayan et al., 2016). Mangroves similarly play an important role in coastal protection, as well as providing resources for coastal communities, but they are already under moderate risk of not keeping up with sea level rise due to climate change and to contributing factors, such as reduced sediment supply or obstacles to shoreward shifts (Saunders et al., 2014; Lovelock et al., 2015). This implies that coastal areas currently protected by mangroves may experience growing risks over time.



Purple indicates very high risks of severe impacts and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.
Red indicates severe and widespread impacts.
Yellow indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.
White indicates that no impacts are detectable and attributable to climate change.

Confidence level for transition: *L*=Low, *M*=Medium, *H*=High and *VH*=Very high

Figure 3.18 | Summary of additional risks of impacts from ocean warming (and associated climate change factors such ocean acidification) for a range of ocean organisms, ecosystems and sectors at 1.0°C, 1.5°C and 2.0°C of warming of the average sea surface temperature (SST) relative to the pre-industrial period. The grey bar represents the range of GMST for the most recent decade: 2006–2015. The assessment of changing risk levels and associated confidence were primarily derived from the expert judgement of Gattuso et al. (2015) and the lead authors and relevant contributing authors of Chapter 3 (SR1.5), while additional input was received from the many reviewers of the ocean systems section of SR1.5. Notes: (i) The analysis shown here is not intended to be comprehensive. The examples of organisms, ecosystems and sectors included here are intended to illustrate the scale, types and projection of risks for representative natural and human ocean systems. (ii) The evaluation of risks by experts did not consider genetic adaptation, acclimatization or human risk reduction strategies (mitigation and societal adaptation). (iii) As discussed elsewhere (Sections 3.3.10 and 3.4.4.5, Box 3.4; Gattuso et al., 2015), ocean acidification is also having impacts on organisms and ecosystems as carbon dioxide increases in the atmosphere. These changes are part of the responses reported here, although partitioning the effects of the two drivers is difficult at this point in time and hence was not attempted. (iv) Confidence levels for location of transition points between levels of risk (L = low, M = moderate, H = high and VH = very high) are assessed and presented here as in the accompanying study by Gattuso et al. (2015). Three transitions in risk were possible: W–Y (white to yellow), Y–R (yellow to red), and R–P (red to purple), with the colours corresponding to the level of additional risk posed by climate change. The confidence levels for these transitions were assessed, based on level of agreement and extent of evidence, and appear as letters associated with each transition (see key in diagram).

Tourism is one of the largest industries globally (Rosselló-Nadal, 2014; Markham et al., 2016; Spalding et al., 2017). A substantial part of the global tourist industry is associated with tropical coastal regions and islands, where tropical coral reefs and related ecosystems play important roles (Section 3.4.9.1) (*medium confidence*). Coastal tourism can be a dominant money earner in terms of foreign exchange for many countries, particularly small island developing states (SIDS) (Section 3.4.9.1, Box 3.5; Weatherdon et al., 2016; Spalding et al., 2017). The direct relationship between increasing global temperatures, intensifying storms, elevated thermal stress, and the loss of tropical coral reefs has raised concern about the risks of climate change for local economies and industries based on tropical coral reefs. Risks to coral reef recreational services from climate change are considered here, as well as in Box 3.5, Section 3.4.9 and Supplementary Material 3.SM.3.2.

Adaptations to the broad global changes in carbon uptake by the ocean are limited and are discussed later in this report with respect to changes in NPP and implications for fishing industries. These adaptation options are broad and indirect, and the only other solution at large scale is to reduce the entry of CO_2 into the ocean. Strategies for adapting to reduced coastal protection involve (a) avoidance of vulnerable areas and hazards, (b) managed retreat from threatened locations, and/or (c) accommodation of impacts and loss of services (Bell, 2012; André et al., 2016; Cooper et al., 2016; Mills et al., 2016; Raabe and Stumpf, 2016; Fu and Song, 2017). Within these broad options, there are some strategies that involve direct human intervention, such as coastal hardening and the construction of seawalls and artificial reefs (Rinkevich, 2014, 2015; André et al., 2016; Cooper et al., 2016; Narayan et al., 2016), while others exploit opportunities for increasing coastal protection by involving naturally occurring oyster banks, coral reefs, mangroves, seagrass and other ecosystems (UNEP-WCMC, 2006; Scyphers et al., 2011; Zhang et al., 2012; Ferrario et al., 2014; Cooper et al., 2016). Natural ecosystems, when healthy, also have the ability to repair themselves after being damaged, which sets them apart from coastal hardening and other human structures that require constant maintenance (Barbier, 2015; Elliff and Silva, 2017). In general, recognizing and restoring coastal ecosystems may be more cost-effective than installing human structures, in that creating and maintaining structures is typically expensive (Temmerman et al., 2013; Mycoo, 2017).

Recent studies have increasingly stressed the need for coastal protection to be considered within the context of coastal land management, including protecting and ensuring that coastal ecosystems are able to undergo shifts in their distribution and abundance as climate change occurs (Clausen and Clausen, 2014; Martínez et al., 2014; Cui et al., 2015; André et al., 2016; Mills et al., 2016). Facilitating these changes will require new tools in terms of legal and financial instruments, as well as integrated planning that involves not only human communities and infrastructure, but also associated ecosystem responses and values (Bell, 2012; Mills et al., 2016). In this regard, the interactions between climate change, sea level rise and coastal disasters are increasingly being informed by models (Bosello and De Cian, 2014) with a widening appreciation of the role of natural ecosystems as an alternative to hardened coastal structures (Cooper et al., 2016). Adaptation options for tropical coral reef recreation include: (i) protecting and improving biodiversity and ecological function by minimizing the impact of stresses unrelated to climate change (e.g., pollution and overfishing), (ii) ensuring adequate levels of coastal protection by supporting and repairing ecosystems that protect coastal regions, (iii) ensuring fair and equitable access to the economic opportunities associated with recreational activities, and (iv) seeking and protecting supplies of water for tourism, industry and agriculture alongside community needs.

Box 3.4 | Warm-Water (Tropical) Coral Reefs in a 1.5°C Warmer World

Warm-water coral reefs face very high risks (Figure 3.18) from climate change. A world in which global warming is restricted to 1.5°C above pre-industrial levels would be a better place for coral reefs than that of a 2°C warmer world, in which coral reefs would mostly disappear (Donner et al., 2005; Hoegh-Guldberg et al., 2014; Schleussner et al., 2016b; van Hooidonk et al., 2016; Frieler et al., 2017; Hughes et al., 2017a). Even with warming up until today (GMST for decade 2006–2015: 0.87°C; Chapter 1), a substantial proportion of coral reefs have experienced large-scale mortalities that have lead to much reduced coral populations (Hoegh-Guldberg et al., 2014). In the last three years alone (2016–2018), large coral reef systems such as the Great Barrier Reef (Australia) have lost as much as 50% of their shallow water corals (Hughes et al., 2017b).

Coral-dominated reefs are found along coastlines between latitudes 30°S and 30°N, where they provide habitat for over a million species (Reaka-Kudla, 1997) and food, income, coastal protection, cultural context and many other services for millions of people in tropical coastal areas (Burke et al., 2011; Cinner et al., 2012; Kennedy et al., 2013; Pendleton et al., 2016). Ultimately, coral reefs are underpinned by a mutualistic symbiosis between reef-building corals and dinoflagellates from the genus *Symbiodinium* (Hoegh-Guldberg et al., 2017). Warm-water coral reefs are found down to depths of 150 m and are dependent on light, making them distinct from the cold deep-water reef systems that extend down to depths of 2000 m or more. The difficulty in accessing deep-water reefs also means that the literature on the impacts of climate change on these systems is very limited by comparison to those on warm-water coral reefs (Hoegh-Guldberg et al., 2017). Consequently, this Box focuses on the impacts of climate change on warm-water (tropical) coral reefs, particularly with respect to their prospects under average global surface temperatures of 1.5°C and 2°C above the pre-industrial period.

Box 3.4 (continued)

The distribution and abundance of coral reefs has decreased by approximately 50% over the past 30 years (Gardner et al., 2005; Bruno and Selig, 2007; De'ath et al., 2012) as a result of pollution, storms, overfishing and unsustainable coastal development (Burke et al., 2011; Halpern et al., 2015; Cheal et al., 2017). More recently, climate change (i.e., heat stress; Hoegh-Guldberg, 1999; Baker et al., 2008; Spalding and Brown, 2015; Hughes et al., 2017b) has emerged as the greatest threat to coral reefs, with temperatures of just 1°C above the long-term summer maximum for an area (reference period 1985–1993) over 4–6 weeks being enough to cause mass coral bleaching (loss of the symbionts) and mortality (*very high confidence*) (WGII AR5, Box 18-2; Cramer et al., 2014). Ocean warming and acidification can also slow growth and calcification, making corals less competitive compared to other benthic organisms such as macroalgae or seaweeds (Dove et al., 2013; Reyes-Nivia et al., 2013, 2014). As corals disappear, so do fish and many other reef-dependent species, which directly impacts industries such as tourism and fisheries, as well as the livelihoods for many, often disadvantaged, coastal people (Wilson et al., 2006; Graham, 2014; Graham et al., 2015; Cinner et al., 2016; Pendleton et al., 2016). These impacts are exacerbated by increasingly intense storms (Section 3.3.6), which physically destroy coral communities and hence reefs (Cheal et al., 2017), and by ocean acidification (Sections 3.3.10 and 3.4.4.5), which can weaken coral skeletons, contribute to disease, and slow the recovery of coral communities after mortality events (*low to medium confidence*) (Gardner et al., 2005; Dove et al., 2013; Kennedy et al., 2013; Webster et al., 2013; Hoegh-Guldberg, 2014b; Anthony, 2016). Ocean acidification also leads to enhanced activity by decalcifying organisms such as excavating sponges (Kline et al., 2012; Dove et al., 2013; Fang et al., 2013, 2014; Reyes-Nivia et al., 2013, 2014).

The predictions of back-to-back bleaching events (Hoegh-Guldberg, 1999) have become the reality in the summers of 2016–2017 (e.g., Hughes et al., 2017b), as have projections of declining coral abundance (*high confidence*). Models have also become increasingly capable and are currently predicting the large-scale loss of coral reefs by mid-century under even low-emissions scenarios (Hoegh-Guldberg, 1999; Donner et al., 2005; Donner, 2009; van Hooidonk and Huber, 2012; Frieler et al., 2013; Hoegh-Guldberg et al., 2014; van Hooidonk et al., 2016). Even achieving emissions reduction targets consistent with the ambitious goal of 1.5°C of global warming under the Paris Agreement will result in the further loss of 70–90% of reef-building corals compared to today, with 99% of corals being lost under warming of 2°C or more above the pre-industrial period (Frieler et al., 2013; Hoegh-Guldberg, 2014b; Hoegh-Guldberg et al., 2014; Schleussner et al., 2016b; Hughes et al., 2017a).

The assumptions underpinning these assessments are considered to be highly conservative. In some cases, 'optimistic' assumptions in models include rapid thermal adaptation by corals of 0.2°C–1°C per decade (Donner et al., 2005) or 0.4°C per decade (Schleussner et al., 2016b), as well as very rapid recovery rates from impacts (e.g., five years in the case of Schleussner et al., 2016b). Adaptation to climate change at these high rates, has not been documented, and recovery from mass mortality tends to take much longer (>15 years; Baker et al., 2008). Probability analysis also indicates that the underlying increases in sea temperatures that drive coral bleaching and mortality are 25% less likely under 1.5°C when compared to 2°C (King et al., 2017). Spatial differences between the rates of heating suggest the possibility of temporary climate refugia (Caldeira, 2013; van Hooidonk et al., 2013; Cacciapaglia and van Woesik, 2015; Keppel and Kavousi, 2015), which may play an important role in terms of the regeneration of coral reefs, especially if these refuges are protected from risks unrelated to climate change. Locations at higher latitudes are reporting the arrival of reef-building corals, which may be valuable in terms of the role of limited refugia and coral reef structures but will have low biodiversity (*high confidence*) when compared to present-day tropical reefs (Kersting et al., 2017). Similarly, deep-water (30–150 m) or mesophotic coral reefs (Bongaerts et al., 2010; Holstein et al., 2016) may play an important role because they avoid shallow water extremes (i.e., heat and storms) to some extent, although the ability of these ecosystems to assist in repopulating damaged shallow water areas may be limited (Bongaerts et al., 2017).

Given the sensitivity of corals to heat stress, even short periods of overshoot (i.e., decades) are expected to be extremely damaging to coral reefs. Losing 70–90% of today's coral reefs, however, will remove resources and increase poverty levels across the world's tropical coastlines, highlighting the key issue of equity for the millions of people that depend on these valuable ecosystems (Cross-Chapter Box 6; Spalding et al., 2014; Halpern et al., 2015). Anticipating these challenges to food and livelihoods for coastal communities will become increasingly important, as will adaptation options, such as the diversification of livelihoods and the development of new sustainable industries, to reduce the dependency of coastal communities on threatened ecosystems such as coral reefs (Cinner et al., 2012, 2016; Pendleton et al., 2016). At the same time, coastal communities will need to pre-empt changes to other services provided by coral reefs such as coastal protection (Kennedy et al., 2013; Hoegh-Guldberg et al., 2014; Pörtner et al., 2014; Gattuso et al., 2015). Other threats and challenges to coastal living, such as sea level rise, will amplify challenges from declining coral reefs, specially for SIDS and low-lying tropical nations. Given the scale and cost of these interventions, implementing them earlier rather than later would be expedient.

3.4.5 Coastal and Low-Lying Areas, and Sea Level Rise

Sea level rise (SLR) is accelerating in response to climate change (Section 3.3.9; Church et al., 2013) and will produce significant impacts (*high confidence*). In this section, impacts and projections of SLR are reported at global and city scales (Sections 3.4.5.1 and 3.4.5.2) and for coastal systems (Sections 3.4.5.3 to 3.4.5.6). For some sectors, there is a lack of precise evidence of change at 1.5°C and 2°C of global warming. Adaptation to SLR is discussed in Section 3.4.5.7.

3.4.5.1 Global / sub-global scale

Sea level rise (SLR) and other oceanic climate changes are already resulting in salinization, flooding, and erosion and in the future are projected to affect human and ecological systems, including health, heritage, freshwater availability, biodiversity, agriculture, fisheries and other services, with different impacts seen worldwide (*high confidence*). Owing to the commitment to SLR, there is an overlapping uncertainty in projections at 1.5°C and 2°C (Schleussner et al., 2016b; Sanderson et al., 2017; Goodwin et al., 2018; Mengel et al., 2018; Nicholls et al., 2018; Rasmussen et al., 2018) and about 0.1 m difference in global mean sea level (GMSL) rise between 1.5°C and 2°C worlds in the year 2100 (Section 3.3.9, Table 3.3). Exposure and impacts at 1.5°C and 2°C differ at different time horizons (Schleussner et al., 2016b; Brown et al., 2018a, b; Nicholls et al., 2018; Rasmussen et al., 2018). However, these are distinct from impacts associated with higher increases in temperature (e.g., 4°C or more, as discussed in Brown et al., 2018a) over centennial scales. The benefits of climate change mitigation reinforce findings of earlier IPCC reports (e.g., Wong et al., 2014).

Table 3.3 shows the land and people exposed to SLR (assuming there is no adaptation or protection at all) using the Dynamic Interactive Vulnerability Assessment (DIVA) model (extracted from Brown et al., 2018a and Goodwin et al., 2018; see also Supplementary Material 3.SM, Table 3.SM.4). Thus, exposure increases even with temperature stabilization. The exposed land area is projected to at least double by 2300 using a RCP8.5 scenario compared with a mitigation scenario (Brown et al., 2018a). In the 21st century, land area exposed to sea level rise (assuming there is no adaptation or protection at all) is projected to be at least an order of magnitude larger than the cumulative land loss due to submergence (which takes into account defences) (Brown et al., 2016, 2018a) regardless of the SLR scenario applied. Slower rates of rise due to climate change mitigation may provide a greater opportunity for adaptation (*medium confidence*), which could substantially reduce impacts.

In agreement with the assessment in WGII AR5 Section 5.4.3.1 (Wong et al., 2014), climate change mitigation may reduce or delay coastal exposure and impacts (*very high confidence*). Adaptation has the potential to substantially reduce risk through a portfolio of available options (Sections 5.4.3.1 and 5.5 of Wong et al., 2014; Sections 6.4.2.3 and 6.6 of Nicholls et al., 2007). At 1.5°C in 2100, 31–69 million people (2010 population values) worldwide are projected to be exposed to flooding, assuming no adaptation or protection at all, compared with 32–79 million people (2010 population values) at 2°C in 2100 (Supplementary Material 3.SM, Table 3.SM.4; Rasmussen et al., 2018). As a result, up to 10.4 million more people would be exposed to sea level rise at 2°C compared with 1.5°C in 2100 (*medium confidence*). With a 1.5°C stabilization scenario in 2100, 62.7 million people per year are at risk from flooding, with this value increasing to 137.6 million people per year in 2300 (50th percentile, average across SSP1–5, no socio-economic change after 2100). These projections assume that no upgrade to current protection levels occurs (Nicholls et al., 2018). The number of people at risk increases by approximately 18% in 2030 if a 2°C scenario is used and by 266% in 2300 if an RCP8.5 scenario is considered (Nicholls et al., 2018). Through prescribed IPCC Special Report on Emissions Scenarios (SRES) SLR scenarios, Arnell et al. (2016) also found that the number of people exposed to flooding increased substantially at warming levels higher than 2°C, assuming no adaptation beyond current protection levels. Additionally, impacts increased in the second half of the 21st century.

Coastal flooding is projected to cost thousands of billions of USD annually, with damage costs under constant protection estimated at 0.3–5.0% of global gross domestic product (GDP) in 2100 under an RCP2.6 scenario (Hinkel et al., 2014). Risks are projected to be highest in South and Southeast Asia, assuming there is no upgrade to current protection levels, for all levels of climate warming (Arnell et al., 2016; Brown et al., 2016). Countries with at least 50 million people exposed to SLR (assuming no adaptation or protection at all) based on a 1,280 Pg C emissions scenario (approximately a 1.5°C temperature rise above today's level) include China, Bangladesh, Egypt, India, Indonesia, Japan, Philippines, United States and Vietnam (Clark et al., 2016). Rasmussen et al. (2018) and Brown et al. (2018a) project that similar countries would have high exposure to SLR in the 21st century using 1.5°C and 2°C scenarios. Thus, there is *high confidence* that SLR will have significant impacts worldwide in this century and beyond.

3.4.5.2 Cities

Observations of the impacts of SLR in cities are difficult to record because multiple drivers of change are involved. There are observations of ongoing and planned adaptation to SLR and extreme water levels in some cities (Araos et al., 2016; Nicholls et al., 2018), whilst other cities have yet to prepare for these impacts (*high confidence*) (see Section 3.4.8 and Cross-Chapter Box 9 in Chapter 4). There are limited observations and analyses of how cities will cope with higher and/or multi-centennial SLR, with the exception of Amsterdam, New York and London (Nicholls et al., 2018).

Coastal urban areas are projected to see more extreme water levels due to rising sea levels, which may lead to increased flooding and damage of infrastructure from extreme events (unless adaptation is undertaken), plus salinization of groundwater. These impacts may be enhanced through localized subsidence (Wong et al., 2014), which causes greater relative SLR. At least 136 megacities (port cities with a population greater than 1 million in 2005) are at risk from flooding due to SLR (with magnitudes of rise possible under 1.5°C or 2°C in the 21st century, as indicated in Section 3.3.9) unless further adaptation is undertaken (Hanson et al., 2011; Hallegatte et al., 2013). Many of these cities are located in South and Southeast Asia (Hallegatte et al., 2013; Cazenave and Cozannet, 2014; Clark et al., 2016; Jevrejeva et al., 2016). Jevrejeva et al. (2016) projected that more than 90% of global coastlines could experience SLR greater than 0.2 m with 2°C of warming by 2040 (RCP8.5). However, for scenarios where 2°C is stabilized or occurs later in time, this figure is likely to differ because of the commitment to SLR. Raising existing dikes helps protect against SLR, substantially reducing risks, although other forms of adaptation exist. By 2300, dike heights under a non-mitigation scenario (RCP8.5) could be more than 2 m higher (on average for 136 megacities) than under climate change mitigation scenarios at 1.5°C or 2°C (Nicholls et al., 2018). Thus, rising sea levels commit coastal cities to long-term adaptation (*high confidence*).

3.4.5.3 Small islands

Qualitative physical observations of SLR (and other stresses) include inundation of parts of low-lying islands, land degradation due to saltwater intrusion in Kiribati and Tuvalu (Wairiu, 2017), and shoreline change in French Polynesia (Yates et al., 2013), Tuvalu (Kench et al., 2015, 2018) and Hawaii (Romine et al., 2013). Observations, models and other evidence indicate that unconstrained Pacific atolls have kept pace with SLR, with little reduction in size or net gain in land (Kench et al., 2015, 2018; McLean and Kench, 2015; Beetham et al., 2017). Whilst islands are highly vulnerable to SLR (*high confidence*), they are also reactive to change. Small islands are impacted by multiple climatic stressors, with SLR being a more important stressor to some islands than others (Sections 3.4.10, 4.3.5.6, 5.2.1, 5.5.3.3, Boxes 3.5, 4.3 and 5.3).

Observed adaptation to multiple drivers of coastal change, including SLR, includes retreat (migration), accommodation and defence. Migration (internal and international) has always been important on small islands (Farbotko and Lazrus, 2012; Weir et al., 2017), with changing environmental and weather conditions being just one factor in the choice to migrate (Sections 3.4.10, 4.3.5.6 and 5.3.2; Campbell and Warrick, 2014). Whilst flooding may result in migration or relocation, for example in Vunidogoloa, Fiji (McNamara and Des Combes, 2015; Gharbaoui and Blocher, 2016) and the Solomon Islands (Albert et al., 2017), in situ adaptation may be tried or preferred, for example stilted housing or raised floors in Tubigon, Bohol, Philippines (Jamero et al., 2017), raised roads and floors in Batasan and Ubay, Philippines (Jamero et al., 2018), and raised platforms for faluw in Leang, Federated States of Micronesia (Nunn et al., 2017). Protective features, such as seawalls or beach nourishment, are observed to locally reduce erosion and flood risk but can have other adverse implications (Sovacool, 2012; Mycoo, 2014, 2017; Nurse et al., 2014; AR5 Section 29.6.22).

There is a lack of precise, quantitative studies of projected impacts of SLR at 1.5°C and 2°C. Small islands are projected to be at risk and very sensitive to coastal climate change and other stressors (*high confidence*) (Nurse et al., 2014; Benjamin and Thomas, 2016; Ourbak and Magnan, 2017; Brown et al., 2018a; Nicholls et al., 2018; Rasmussen et al., 2018; AR5 Sections 29.3 and 29.4), such as oceanic warming, SLR (resulting in salinization, flooding and erosion), cyclones and mass coral bleaching and mortality (Section 3.4.4, Boxes 3.4 and 3.5). These impacts can have significant socio-economic and ecological implications, such as on health, agriculture and water resources, which in turn have impacts on livelihoods (Sovacool, 2012; Mycoo, 2014, 2017; Nurse et al., 2014). Combinations of drivers causing adverse impacts are important. For example, Storlazzi et al. (2018) found that the impacts of SLR and wave-induced flooding (within a temperature horizon equivalent of 1.5°C), could affect freshwater availability on Roi-Namur, Marshall Islands, but is also dependent on other extreme weather events. Freshwater resources may also be affected by a 0.40 m rise in sea level (which may be experienced with a 1.5°C warming) in other Pacific atolls (Terry and Chui, 2012). Whilst SLR is a major hazard for atolls, islands reaching higher elevations are also threatened given that there is often a lot of infrastructure located near the coast (*high confidence*) (Kumar and Taylor, 2015; Nicholls et al., 2018). Tens of thousands of people on small islands are exposed to SLR (Rasmussen et al., 2018). Giardino et al. (2018) found that hard defence structures on the island of Ebeye in the Marshall Islands were effective in reducing damage due to SLR at 1.5°C and 2°C. Additionally, damage was also reduced under mitigation scenarios compared with non-mitigation scenarios. In Jamaica and St Lucia, SLR and extreme sea levels are projected to threaten transport system infrastructure at 1.5°C unless further adaptation is undertaken (Monioudi et al., 2018). Slower rates of SLR will provide a greater opportunity for adaptation to be successful (*medium confidence*), but this may not be substantial enough on islands with a very low mean elevation. Migration and/or relocation may be an adaptation option (Section 3.4.10). Thomas and Benjamin (2017) highlight three areas of concern in the context of loss and damage at 1.5°C: a lack of data, gaps in financial assessments, and a lack of targeted policies or mechanisms to address these issues (Cross-Chapter Box 12 in Chapter 5). Small islands are projected to remain vulnerable to SLR (*high confidence*).

3.4.5.4 Deltas and estuaries

Observations of SLR and human influence are felt through salinization, which leads to mixing in deltas and estuaries, aquifers, leading to flooding (also enhanced by precipitation and river discharge), land degradation and erosion. Salinization is projected to impact freshwater sources and pose risks to ecosystems and human systems (Section 5.4; Wong et al., 2014). For instance, in the Delaware River estuary on the east coast of the USA, upward trends of salinity (measured since the 1900s), accounting for the effects of streamflow and seasonal variations, have been detected and SLR is a potential cause (Ross et al., 2015).

Z. Yang et al. (2015) found that future climate scenarios for the USA (A1B 1.6°C and B1 2°C in the 2040s) had a greater effect on salinity intrusion than future land-use/land-cover change in the Snohomish River estuary in Washington state (USA). This resulted in a shift in the salinity both upstream and downstream in low flow conditions. Projecting impacts in deltas needs an understanding of both fluvial discharge and SLR, making projections complex because the drivers operate on different temporal and spatial scales (Zaman et al., 2017; Brown et al., 2018b). The mean annual flood depth when 1.5°C is first projected to be reached in the Ganges-Brahmaputra delta may be less than the most extreme annual flood depth seen today, taking into account SLR, surges, tides, bathymetry and local river flows (Brown et al., 2018b). Further, increased river salinity and saline intrusion in the Ganges-Brahmaputra-Meghna is likely with 2°C of warming (Zaman et al., 2017). Salinization could impact agriculture and food security (Cross-Chapter Box 6 in this chapter). For 1.5°C or 2°C stabilization conditions in 2200 or 2300 plus surges, a minimum of 44% of the

Bangladeshi Ganges-Brahmaputra, Indian Bengal, Indian Mahanadi and Ghanese Volta delta land area (without defences) would be exposed unless sedimentation occurs (Brown et al., 2018b). Other deltas are similarly vulnerable. SLR is only one factor affecting deltas, and assessment of numerous geophysical and anthropogenic drivers of geomorphic change is important (Tessler et al., 2018). For example, dike building to reduce flooding and dam building (Gupta et al., 2012) restricts sediment movement and deposition, leading to enhanced subsidence, which can occur at a greater rate than SLR (Auerbach et al., 2015; Takagi et al., 2016). Although dikes remain essential for reducing flood risk today, promoting sedimentation is an advisable strategy (Brown et al., 2018b) which may involve nature-based solutions. Transformative decisions regarding the extent of sediment restrictive infrastructure may need to be considered over centennial scales (Brown et al., 2018b). Thus, in a 1.5°C or 2°C warmer world, deltas, which are home to millions of people, are expected to be highly threatened from SLR and localized subsidence (*high confidence*).

3.4.5.5 Wetlands

Observations indicate that wetlands, such as saltmarshes and mangrove forests, are disrupted by changing conditions (Sections 3.4.4.8; Wong et al., 2014; Lovelock et al., 2015), such as total water levels and sediment availability. For example, saltmarshes in Connecticut and New York, USA, measured from 1900 to 2012, have accreted with SLR but have lost marsh surface relative to tidal datums, leading to increased marsh flooding and further accretion (Hill and Anisfeld, 2015). This change stimulated marsh carbon storage and aided climate change mitigation.

Salinization may lead to shifts in wetland communities and their ecosystem functions (Herbert et al., 2015). Some projections of wetland change, with magnitudes (but not necessarily rates or timing) of SLR analogous to 1.5°C and 2°C of global warming, indicate a net loss of wetlands in the 21st century (e.g., Blankespoor et al., 2014; Cui et al., 2015; Arnell et al., 2016; Crosby et al., 2016), whilst others report a net gain with wetland transgression (e.g., Raabe and Stumpf, 2016 in the Gulf of Mexico). However, the feedback between wetlands and sea level is complex, with parameters such as a lack of accommodation space restricting inland migration, or sediment supply and feedbacks between plant growth and geomorphology (Kirwan and Megonigal, 2013; Ellison, 2014; Martínez et al., 2014; Spencer et al., 2016) still being explored. Reducing global warming from 2°C to 1.5°C will deliver long-term benefits, with natural sedimentation rates more likely keep up with SLR. It remains unclear how wetlands will respond and under what conditions (including other climate parameters) to a global temperature rise of 1.5°C and 2°C. However, they have great potential to aid and benefit climate change mitigation and adaptation (*medium confidence*) (Sections 4.3.2.2 and 4.3.2.3).

3.4.5.6 Other coastal settings

Numerous impacts have not been quantified at 1.5°C or 2°C but remain important. This includes systems identified in WGII AR5 (AR5 – Section 5.4 of Wong et al., 2014), such as beaches, barriers, sand dunes, rocky coasts, aquifers, lagoons and coastal ecosystems (for the last system, see Section 3.4.4.12). For example, SLR potentially affects erosion and accretion, and therefore sediment movement, instigating shoreline change (Section 5.4.2.1 of Wong et al., 2014), which could affect land-based ecosystems. Global observations indicate no overall clear effect of SLR on shoreline change (Le Cozannet et al., 2014), as it is highly site specific (e.g., Romine et al., 2013). Infrastructure and geological constraints reduce shoreline movement, causing coastal squeeze. In Japan, for example, SLR is projected to cause beach losses under an RCP2.6 scenario, which will worsen under RCP8.5 (Udo and Takeda, 2017). Further, compound flooding (the combined risk of flooding from multiple sources) has increased significantly over the past century in major coastal cities (Wahl et al., 2015) and is likely to increase with further development and SLR at 1.5°C and 2°C unless adaptation is undertaken. Thus, overall SLR will have a wide range of adverse effects on coastal zones (*medium confidence*).

3.4.5.7 Adapting to coastal change

Adaptation to coastal change from SLR and other drivers is occurring today (*high confidence*) (see Cross-Chapter Box 9 in Chapter 4), including migration, ecosystem-based adaptation, raising infrastructure and defences, salt-tolerant food production, early warning systems, insurance and education (Section 5.4.2.1 of Wong et al., 2014). Climate change mitigation will reduce the rate of SLR this century, decreasing the need for extensive and, in places, immediate adaptation. Adaptation will reduce impacts in human settings (*high confidence*) (Hinkel et al., 2014; Wong et al., 2014), although there is less certainty for natural ecosystems (Sections 4.3.2 and 4.3.3.3). While some ecosystems (e.g., mangroves) may be able to move shoreward as sea levels increase, coastal development (e.g., coastal building, seawalls and agriculture) often interrupt these transitions (Saunders et al., 2014). Options for responding to these challenges include reducing the impact of other stresses such as those arising from tourism, fishing, coastal development and unsustainable aquaculture/agriculture. In some cases, restoration of coastal habitats and ecosystems can be a cost-effective way of responding to changes arising from increasing levels of exposure from rising sea levels, changes in storm conditions, coastal inundation and salinization (Arkema et al., 2013; Temmerman et al., 2013; Ferrario et al., 2014; Hinkel et al., 2014; Spalding et al., 2014; Elliff and Silva, 2017).

Since AR5, planned and autonomous adaptation and forward planning have become more widespread (Araos et al., 2016; Nicholls et al., 2018), but continued efforts are required as many localities are in the early stages of adapting or are not adapting at all (Cross-Chapter Box 9 in Chapter 4; Araos et al., 2016). This is region and sub-sector specific, and also linked to non-climatic factors (Ford et al., 2015; Araos et al., 2016; Lesnikowski et al., 2016). Adaptation pathways (e.g., Ranger et al., 2013; Barnett et al., 2014; Rosenzweig and Solecki, 2014; Buurman and Babovic, 2016) assist long-term planning but are not widespread practices despite knowledge of long-term risks (Section 4.2.2). Furthermore, human retreat and migration are increasingly being considered as an adaptation response (Hauer et al., 2016; Geisler and Currens, 2017), with a growing emphasis on green adaptation. There are few studies on the adaptation limits to SLR where transformation change may be required (AR5-Section 5.5 of Wong et al., 2014; Nicholls et al., 2015). Sea level rise poses a long-term threat (Section 3.3.9), and adaptation will remain essential at the centennial scale under 1.5°C and 2°C of warming (*high confidence*).

Table 3.3 | Land and people exposed to sea level rise (SLR), assuming no protection at all. Extracted from Brown et al. (2018a) and Goodwin et al. (2018). SSP: Shared Socio-Economic Pathway; wrt: with respect to; *:Population held constant at 2100 level.

Climate scenario	Impact factor, assuming there is no adaptation or protection at all (50th, [5th-95th percentiles])	Year			
		2050	2100	2200	2300
1.5°C	Temperature rise wrt 1850–1900 (°C)	1.71 (1.44–2.16)	1.60 (1.26–2.33)	1.41 (1.15–2.10)	1.32 (1.12–1.81)
	SLR (m) wrt 1986–2005	0.20 (0.14–0.29)	0.40 (0.26–0.62)	0.73 (0.47–1.25)	1.00 (0.59–1.55)
	Land exposed (x10^3 km^2)	574 [558–597]	620 [575–669]	666 [595–772]	702 [666–853]
	People exposed, SSP1–5 (millions)	127.9–139.0 [123.4–134.0, 134.5–146.4]	102.7–153.5 [94.8–140.7, 102.7–153.5]	--	133.8–207.1 [112.3–169.6, 165.2–263.4]*
2°C	Temperature rise wrt 1850–1900 (° C)	1.76 (1.51–2.16)	2.03 (1.72–2.64)	1.90 (1.66–2.57)	1.80 (1.60–2.20)
	SLR (m) wrt 1986-2005	0.20 (0.14–0.29)	0.46 (0.30–0.69)	0.90 (0.58–1.50)	1.26 (0.74–1.90)
	Land exposed (x10^3 km^2)	575 [558–598]	637 [585–686]	705 [618–827]	767 [642–937]
	People exposed, SSP1–5 (millions)	128.1–139.2 [123.6–134.2, 134.7–146.6]	105.5–158.1 [97.0–144.1, 118.1–179.0]	--	148.3–233.0 [120.3–183.4, 186.4–301.8]*

Box 3.5 | Small Island Developing States (SIDS)

Global warming of 1.5°C is expected to prove challenging for small island developing states (SIDS) that are already experiencing impacts associated with climate change (*high confidence*). At 1.5°C, compounding impacts from interactions between climate drivers may contribute to the loss of, or change in, critical natural and human systems (*medium to high confidence*). There are a number of reduced risks at 1.5°C versus 2°C, particularly when coupled with adaptation efforts (*medium to high confidence*).

Changing climate hazards for SIDS at 1.5°C

Mean surface temperature is projected to increase in SIDS at 1.5°C of global warming (*high confidence*). The Caribbean region will experience 0.5°C–1.5°C of warming compared to a 1971–2000 baseline, with the strongest warming occurring over larger land masses (Taylor et al., 2018). Under the Representative Concentration Pathway (RCP)2.6 scenario, the western tropical Pacific is projected to experience warming of 0.5°C–1.7°C relative to 1961–1990. Extreme temperatures will also increase, with potential for elevated impacts as a result of comparably small natural variability (Reyer et al., 2017a). Compared to the 1971–2000 baseline, up to 50% of the year is projected to be under warm spell conditions in the Caribbean at 1.5°C, with a further increase of up to 70 days at 2°C (Taylor et al., 2018).

Changes in precipitation patterns, freshwater availability and drought sensitivity differ among small island regions (*medium to high confidence*). Some western Pacific islands and those in the northern Indian Ocean may see increased freshwater availability, while islands in most other regions are projected to see a substantial decline (Holding et al., 2016; Karnauskas et al., 2016). For several SIDS, approximately 25% of the overall freshwater stress projected under 2°C at 2030 could be avoided by limiting global warming to 1.5°C (Karnauskas et al., 2018). In accordance with an overall drying trend, an increasing drought risk is projected for Caribbean SIDS (Lehner et al., 2017), and moderate to extreme drought conditions are projected to be about 9% longer on average at 2°C versus 1.5°C for islands in this region (Taylor et al., 2018).

Projected changes in the ocean system at higher warming targets (Section 3.4.4), including potential changes in circulation (Section 3.3.7) and increases in both surface temperatures (Section 3.3.7) and ocean acidification (Section 3.3.10), suggest increasing risks for SIDS associated with warming levels close to and exceeding 1.5°C.

Differences in global sea level between 1.5°C and 2°C depend on the time scale considered and are projected to fully materialize only after 2100 (Section 3.3.9). Projected changes in regional sea level are similarly time dependent, but generally found to be above the global average for tropical regions including small islands (Kopp et al., 2014; Jevrejeva et al., 2016). Threats related to sea level rise (SLR) for SIDS, for example from salinization, flooding, permanent inundation, erosion and pressure on ecosystems, will therefore persist well beyond the 21st century even under 1.5°C of warming (Section 3.4.5.3; Nicholls et al., 2018). Prolonged interannual sea level inundations may increase throughout the tropical Pacific with ongoing warming and in the advent of an

Box 3.5 (continued)

increased frequency of extreme La Niña events, exacerbating coastal impacts of projected global mean SLR (Widlansky et al., 2015). Changes to the frequency of extreme El Niño and La Niña events may also increase the frequency of droughts and floods in South Pacific islands (Box 4.2, Section 3.5.2; Cai et al., 2012).

Extreme precipitation in small island regions is often linked to tropical storms and contributes to the climate hazard (Khouakhi et al., 2017). Similarly, extreme sea levels for small islands, particularly in the Caribbean, are linked to tropical cyclone occurrence (Khouakhi and Villarini, 2017). Under a 1.5°C stabilization scenario, there is a projected decrease in the frequency of weaker tropical storms and an increase in the number of intense cyclones (Section 3.3.6; Wehner et al., 2018a). There are not enough studies to assess differences in tropical cyclone statistics for 1.5°C versus 2°C (Section 3.3.6). There are considerable differences in the adaptation responses to tropical cyclones across SIDS (Cross-Chapter Box 11 in Chapter 4).

Impacts on key natural and human systems

Projected increases in aridity and decreases in freshwater availability at 1.5°C of warming, along with additional risks from SLR and increased wave-induced run-up, might leave several atoll islands uninhabitable (Storlazzi et al., 2015; Gosling and Arnell, 2016). Changes in the availability and quality of freshwater, linked to a combination of changes to climate drivers, may adversely impact SIDS' economies (White and Falkland, 2010; Terry and Chui, 2012; Holding and Allen, 2015; Donk et al., 2018). Growth-rate projections based on temperature impacts alone indicate robust negative impacts on gross domestic product (GDP) per capita growth for SIDS (Sections 3.4.7.1, 3.4.9.1 and 3.5.4.9; Pretis et al., 2018). These impacts would be reduced considerably under 1.5°C but may be increased by escalating risks from climate-related extreme weather events and SLR (Sections 3.4.5.3, 3.4.9.4 and 3.5.3)

Marine systems and associated livelihoods in SIDS face higher risks at 2°C compared to 1.5°C (*medium to high confidence*). Mass coral bleaching and mortality are projected to increase because of interactions between rising ocean temperatures, ocean acidification, and destructive waves from intensifying storms (Section 3.4.4 and 5.2.3, Box 3.4). At 1.5°C, approximately 70–90% of global coral reefs are projected to be at risk of long-term degradation due to coral bleaching, with these values increasing to 99% at 2°C (Frieler et al., 2013; Schleussner et al., 2016b). Higher temperatures are also related to an increase in coral disease development, leading to coral degradation (Maynard et al., 2015). For marine fisheries, limiting warming to 1.5°C decreases the risk of species extinction and declines in maximum catch potential, particularly for small islands in tropical oceans (Cheung et al., 2016a).

Long-term risks of coastal flooding and impacts on populations, infrastructure and assets are projected to increase with higher levels of warming (*high confidence*). Tropical regions including small islands are expected to experience the largest increases in coastal flooding frequency, with the frequency of extreme water-level events in small islands projected to double by 2050 (Vitousek et al., 2017). Wave-driven coastal flooding risks for reef-lined islands may increase as a result of coral reef degradation and SLR (Quataert et al., 2015). Exposure to coastal hazards is particularly high for SIDS, with a significant share of population, infrastructure and assets at risk (Sections 3.4.5.3 and 3.4.9; Scott et al., 2012; Kumar and Taylor, 2015; Rhiney, 2015; Byers et al., 2018). Limiting warming to 1.5°C instead of 2°C would spare the inundation of lands currently home to 60,000 individuals in SIDS by 2150 (Rasmussen et al., 2018). However, such estimates do not consider shoreline response (Section 3.4.5) or adaptation.

Risks of impacts across sectors are projected to be higher at 1.5°C compared to the present, and will further increase at 2°C (*medium to high confidence*). Projections indicate that at 1.5°C there will be increased incidents of internal migration and displacement (Sections 3.5.5, 4.3.6 and 5.2.2; Albert et al., 2017), limited capacity to assess loss and damage (Thomas and Benjamin, 2017) and substantial increases in the risk to critical transportation infrastructure from marine inundation (Monioudi et al., 2018). The difference between 1.5°C and 2°C might exceed limits for normal thermoregulation of livestock animals and result in persistent heat stress for livestock animals in SIDS (Lallo et al., 2018).

At 1.5°C, limits to adaptation will be reached for several key impacts in SIDS, resulting in residual impacts, as well as loss and damage (Section 1.1.1, Cross-Chapter Box 12 in Chapter 5). Limiting temperature increase to 1.5°C versus 2°C is expected to reduce a number of risks, particularly when coupled with adaptation efforts that take into account sustainable development (Section 3.4.2 and 5.6.3.1, Box 4.3 and 5.3, Mycoo, 2017; Thomas and Benjamin, 2017). Region-specific pathways for SIDS exist to address climate change (Section 5.6.3.1, Boxes 4.6 and 5.3, Cross-Chapter Box 11 in Chapter 4).

3.4.6 Food, Nutrition Security and Food Production Systems (Including Fisheries and Aquaculture)

3.4.6.1 Crop production

Quantifying the observed impacts of climate change on food security and food production systems requires assumptions about the many non-climate variables that interact with climate change variables. Implementing specific strategies can partly or greatly alleviate the climate change impacts on these systems (Wei et al., 2017), whilst the degree of compensation is mainly dependent on the geographical area and crop type (Rose et al., 2016). Despite these uncertainties, recent studies confirm that observed climate change has already affected crop suitability in many areas, resulting in changes in the production levels of the main agricultural crops. These impacts are evident in many areas of the world, ranging from Asia (C. Chen et al., 2014; Sun et al., 2015; He and Zhou, 2016) to America (Cho and McCarl, 2017) and Europe (Ramirez-Cabral et al., 2016), and they particularly affect the typical local crops cultivated in specific climate conditions (e.g., Mediterranean crops like olive and grapevine, Moriondo et al., 2013a, b).

Temperature and precipitation trends have reduced crop production and yields, with the most negative impacts being on wheat and maize (Lobell et al., 2011), whilst the effects on rice and soybean yields are less clear and may be positive or negative (Kim et al., 2013; van Oort and Zwart, 2018). Warming has resulted in positive effects on crop yield in some high-latitude areas (Jaggard et al., 2007; Supit et al., 2010; Gregory and Marshall, 2012; C. Chen et al., 2014; Sun et al., 2015; He and Zhou, 2016; Daliakopoulos et al., 2017), and may make it possible to have more than one harvest per year (B. Chen et al., 2014; Sun et al., 2015). Climate variability has been found to explain more than 60% of the of maize, rice, wheat and soybean yield variations in the main global breadbaskets areas (Ray et al., 2015), with the percentage varying according to crop type and scale (Moore and Lobell, 2015; Kent et al., 2017). Climate trends also explain changes in the length of the growing season, with greater modifications found in the northern high-latitude areas (Qian et al., 2010; Mueller et al., 2015).

The rise in tropospheric ozone has already reduced yields of wheat, rice, maize and soybean by 3–16% globally (Van Dingenen et al., 2009). In some studies, increases in atmospheric CO_2 concentrations were found to increase yields by enhancing radiation and water use efficiencies (Elliott et al., 2014; Durand et al., 2018). In open-top chamber experiments with a combination of elevated CO_2 and 1.5°C of warming, maize and potato yields were observed to increase by 45.7% and 11%, respectively (Singh et al., 2013; Abebe et al., 2016). However, observations of trends in actual crop yields indicate that reductions as a result of climate change remain more common than crop yield increases, despite increased atmospheric CO_2 concentrations (Porter et al., 2014). For instance, McGrath and Lobell (2013) indicated that production stimulation at increased atmospheric CO_2 concentrations was mostly driven by differences in climate and crop species, whilst yield variability due to elevated CO_2 was only about 50–70% of the variability due to climate. Importantly, the faster growth rates induced by elevated CO_2 have been found to coincide with lower protein content in several important C3 cereal grains (Myers et al., 2014), although this may not always be the case for C4 grains, such as sorghum, under drought conditions (De Souza et al., 2015). Elevated CO_2 concentrations of 568–590 ppm (a range that corresponds approximately to RCP6 in the 2080s and hence a warming of 2.3°C–3.3°C (van Vuuren et al., 2011a, AR5 WGI Table 12.2) alone reduced the protein, micronutrient and B vitamin content of the 18 rice cultivars grown most widely in Southeast Asia, where it is a staple food source, by an amount sufficient to create nutrition-related health risks for 600 million people (Zhu et al., 2018). Overall, the effects of increased CO_2 concentrations alone during the 21st century are therefore expected to have a negative impact on global food security (*medium confidence*).

Crop yields in the future will also be affected by projected changes in temperature and precipitation. Studies of major cereals showed that maize and wheat yields begin to decline with 1°C–2°C of local warming and under nitrogen stress conditions at low latitudes (*high confidence*) (Porter et al., 2014; Rosenzweig et al., 2014). A few studies since AR5 have focused on the impacts on cropping systems for scenarios where the global mean temperature increase is within 1.5°C. Schleussner et al. (2016b) projected that constraining warming to 1.5°C rather than 2°C would avoid significant risks of declining tropical crop yield in West Africa, Southeast Asia, and Central and South America. Ricke et al. (2016) highlighted that cropland stability declines rapidly between 1°C and 3°C of warming, whilst Bassu et al. (2014) found that an increase in air temperature negatively influences the modelled maize yield response by -0.5 t ha^{-1} $°C^{-1}$ and Challinor et al. (2014) reported similar effect for tropical regions. Niang et al. (2014) projected significantly lower risks to crop productivity in Africa at 1.5°C compared to 2°C of warming. Lana et al. (2017) indicated that the impact of temperature increases on crop failure of maize hybrids would be much greater as temperatures increase by 2°C compared to 1.5°C (*high confidence*). J. Huang et al. (2017) found that limiting warming to 1.5°C compared to 2°C would reduce maize yield losses over drylands. Although Rosenzweig et al. (2017, 2018) did not find a clear distinction between yield declines or increases in some breadbasket regions between the two temperature levels, they generally did find projections of decreasing yields in breadbasket regions when the effects of CO_2 fertilization were excluded. Iizumi et al. (2017) found smaller reductions in maize and soybean yields at 1.5°C than at 2°C of projected warming, higher rice production at 2°C than at 1.5°C, and no clear differences for wheat on a global mean basis. These results are largely consistent with those of other studies (Faye et al., 2018; Ruane et al., 2018). In the western Sahel and southern Africa, moving from 1.5°C to 2°C of warming has been projected to result in a further reduction of the suitability of maize, sorghum and cocoa cropping areas and yield losses, especially for C3 crops, with rainfall change only partially compensating these impacts (Läderach et al., 2013; World Bank, 2013; Sultan and Gaetani, 2016).

A significant reduction has been projected for the global production of wheat (by 6.0 ± 2.9%), rice (by 3.2 ± 3.7%), maize (by 7.4 ± 4.5%), and soybean, (by 3.1%) for each degree Celsius increase in global mean temperature (Asseng et al., 2015; C. Zhao et al., 2017). Similarly, Li et al. (2017) indicated a significant reduction in rice yields for each degree Celsius increase, by about 10.3%, in the greater Mekong subregion (*medium confidence*; Cross-Chapter Box 6: Food Security in this chapter). Large rice and maize yield losses are to be expected in China, owing to climate extremes (*medium confidence*) (Wei et al., 2017; Zhang et al., 2017).

While not often considered, crop production is also negatively affected by the increase in both direct and indirect climate extremes. Direct extremes include changes in rainfall extremes (Rosenzweig et al., 2014), increases in hot nights (Welch et al., 2010; Okada et al., 2011), extremely high daytime temperatures (Schlenker and Roberts, 2009; Jiao et al., 2016; Lesk et al., 2016), drought (Jiao et al., 2016; Lesk et al., 2016), heat stress (Deryng et al., 2014, Betts et al., 2018), flooding (Betts et al., 2018; Byers et al., 2018), and chilling damage (Jiao et al., 2016), while indirect effects include the spread of pests and diseases (Jiao et al., 2014; van Bruggen et al., 2015), which can also have detrimental effects on cropping systems.

Taken together, the findings of studies on the effects of changes in temperature, precipitation, CO_2 concentration and extreme weather events indicate that a global warming of 2°C is projected to result in a greater reduction in global crop yields and global nutrition than global warming of 1.5°C (*high confidence*; Section 3.6).

3.4.6.2 Livestock production

Studies of climate change impacts on livestock production are few in number. Climate change is expected to directly affect yield quantity and quality (Notenbaert et al., 2017), as well as indirectly impacting the livestock sector through feed quality changes and spread of pests and diseases (Kipling et al., 2016) (*high confidence*). Increased warming and its extremes are expected to cause changes in physiological processes in livestock (i.e., thermal distress, sweating and high respiratory rates) (Mortola and Frappell, 2000) and to have detrimental effects on animal feeding, growth rates (André et al., 2011; Renaudeau et al., 2011; Collier and Gebremedhin, 2015) and reproduction (De Rensis et al., 2015). Wall et al. (2010) observed reduced milk yields and increased cow mortality as the result of heat stress on dairy cow production over some UK regions.

Further, a reduction in water supply might increase cattle water demand (Masike and Urich, 2008). Generally, heat stress can be responsible for domestic animal mortality increase and economic losses (Vitali et al., 2009), affecting a wide range of reproductive parameters (e.g., embryonic development and reproductive efficiency in pigs, Barati et al., 2008; ovarian follicle development and ovulation in horses, Mortensen et al., 2009). Much attention has also been dedicated to ruminant diseases (e.g., liver fluke, Fox et al., 2011; blue-tongue virus, Guis et al., 2012; foot-and-mouth disease (FMD), Brito et al. (2017); and zoonotic diseases, Njeru et al., 2016; Simulundu et al., 2017).

Climate change impacts on livestock are expected to increase. In temperate climates, warming is expected to lengthen the forage growing season but decrease forage quality, with important variations due to rainfall changes (Craine et al., 2010; Hatfield et al., 2011; Izaurralde et al., 2011). Similarly, a decrease in forage quality is expected for both natural grassland in France (Graux et al., 2013) and sown pastures in Australia (Perring et al., 2010). Water resource availability for livestock is expected to decrease owing to increased runoff and reduced groundwater resources. Increased temperature will likely induce changes in river discharge and the amount of water in basins, leading human and livestock populations to experience water stress, especially in the driest areas (i.e., sub-Saharan Africa and South Asia) (*medium confidence*) (Palmer et al., 2008). Elevated temperatures are also expected to increase methane production (Knapp et al., 2014; M.A. Lee et al., 2017). Globally, a decline in livestock of 7–10% is expected at about 2°C of warming, with associated economic losses between $9.7 and $12.6 billion (Boone et al., 2018).

3.4.6.3 Fisheries and aquaculture production

Global fisheries and aquaculture contribute a total of 88.6 and 59.8 million tonnes of fish and other products annually (FAO, 2016), and play important roles in the food security of a large number of countries (McClanahan et al., 2015; Pauly and Charles, 2015) as well as being essential for meeting the protein demand of a growing global population (Cinner et al., 2012, 2016; FAO, 2016; Pendleton et al., 2016). A steady increase in the risks associated with bivalve fisheries and aquaculture at mid-latitudes is coincident with increases in temperature, ocean acidification, introduced species, disease and other drivers (Lacoue-Labarthe et al., 2016; Clements and Chopin, 2017; Clements et al., 2017; Parker et al., 2017). Sea level rise and storm intensification pose a risk to hatcheries and other infrastructure (Callaway et al., 2012; Weatherdon et al., 2016), whilst others risks are associated with the invasion of parasites and pathogens (Asplund et al., 2014; Castillo et al., 2017). Specific human strategies have reduced these risks, which are expected to be moderate under RCP2.6 and very high under RCP8.5 (Gattuso et al., 2015). The risks related to climate change for fin fish (Section 3.4.4) are producing a number of challenges for small-scale fisheries (e.g., Kittinger, 2013; Pauly and Charles, 2015; Bell et al., 2018). Recent literature from 2015 to 2017 has described growing threats from rapid shifts in the biogeography of key species (Poloczanska et al., 2013, 2016; Burrows et al., 2014; García Molinos et al., 2015) and the ongoing rapid degradation of key ecosystems such as coral reefs, seagrass and mangroves (Section 3.4.4, Box 3.4). The acceleration of these changes, coupled with non-climate stresses (e.g., pollution, overfishing and unsustainable coastal development), are driving many small-scale fisheries well below the sustainable harvesting levels required to maintain these resources as a source of food (McClanahan et al., 2009, 2015; Cheung et al., 2010; Pendleton et al., 2016). As a result, future scenarios surrounding climate change and global population growth increasingly project shortages of fish protein for many regions, such as the Pacific Ocean (Bell et al., 2013, 2018) and Indian Ocean (McClanahan et al., 2015). Mitigation of these risks involves marine spatial planning, fisheries repair, sustainable aquaculture, and the development of alternative livelihoods (Kittinger, 2013; McClanahan et al., 2015; Song and Chuenpagdee, 2015; Weatherdon et al., 2016). Other threats concern the increasing incidence of alien species and diseases (Kittinger et al., 2013; Weatherdon et al., 2016).

Risks of impacts related to climate change on low-latitude small-scale fin fisheries are moderate today but are expected to reach very high levels by 1.1°C of global warming. Projections for mid- to high-latitude fisheries include increases in fishery productivity in some cases (Cheung et al., 2013; Hollowed et al., 2013; Lam et al., 2014; FAO, 2016). These projections are associated with the biogeographical shift of species towards higher latitudes (Fossheim et al., 2015), which brings benefits as well as challenges (e.g., increased production yet a greater risk of disease and invasive species; *low confidence*). Factors underpinning the expansion of fisheries production to high-latitude locations include warming, increased light levels and mixing due to retreating sea ice (Cheung et al., 2009), which result in substantial increases in primary productivity and fish harvesting in the North Pacific and North Atlantic (Hollowed and Sundby, 2014).

Present-day risks for mid-latitude bivalve fisheries and aquaculture become undetectible up to 1.1°C of global warming, moderate at 1.3°C, and moderate to high up to 1.9°C (Figure 3.18). For instance, Cheung et al. (2016a), simulating the loss in fishery productivity at 1.5°C, 2°C and 3.5°C above the pre-industrial period, found that the potential global catch for marine fisheries will *likely* decrease by more than three million metric tonnes for each degree of warming. Low-latitude fin-fish fisheries have higher risks of impacts, with risks being moderate under present-day conditions and becoming high above 0.9°C and very high at 2°C of global warming. High-latitude fisheries are undergoing major transformations, and while production is increasing, present-day risk is moderate and is projected to remain moderate at 1.5°C and 2°C (Figure 3.18).

Adaptation measures can be applied to shellfish, large pelagic fish resources and biodiversity, and they include options such as protecting reproductive stages and brood stocks from periods of high ocean acidification (OA), stock selection for high tolerance to OA (*high confidence*) (Ekstrom et al., 2015; Rodrigues et al., 2015; Handisyde et al., 2016; Lee, 2016; Weatherdon et al., 2016; Clements and Chopin, 2017), redistribution of highly migratory resources (e.g., Pacific tuna) (*high confidence*), governance instruments such as international fisheries agreements (Lehodey et al., 2015; Matear et al., 2015), protection and regeneration of reef habitats, reduction of coral reef stresses, and development of alternative livelihoods (e.g., aquaculture; Bell et al., 2013, 2018).

Cross-Chapter Box 6 | Food Security

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Climate change influences food and nutritional security through its effects on food availability, quality, access and distribution (Paterson and Lima, 2010; Thornton et al., 2014; FAO, 2016). More than 815 million people were undernourished in 2016, and 11% of the world's population has experienced recent decreases in food security, with higher percentages in Africa (20%), southern Asia (14.4%) and the Caribbean (17.7%) (FAO et al., 2017). Overall, food security is expected to be reduced at 2°C of global warming compared to 1.5°C, owing to projected impacts of climate change and extreme weather on yields, crop nutrient content, livestock, fisheries and aquaculture and land use (cover type and management) (Sections 3.4.3.6, 3.4.4.12 and 3.4.6), (*high confidence*). The effects of climate change on crop yield, cultivation area, presence of pests, food price and supplies are projected to have major implications for sustainable development, poverty eradication, inequality and the ability of the international community to meet the United Nations sustainable development goals (SDGs; Cross-Chapter Box 4 in Chapter 1).

Goal 2 of the SDGs is to end hunger, achieve food security, improve nutrition and promote sustainable agriculture by 2030. This goal builds on the first millennium development goal (MDG-1) which focused on eradicating extreme poverty and hunger, through efforts that reduced the proportion of undernourished people in low- and middle-income countries from 23.3% in 1990 to 12.9% in 2015. Climate change threatens the capacity to achieve SDG 2 and could reverse the progress made already. Food security and agriculture are also critical to other aspects of sustainable development, including poverty eradication (SDG 1), health and well-being (SDG 3), clean water (SDG 6), decent work (SDG 8), and the protection of ecosystems on land (SDG 14) and in water (SDG 15) (UN, 2015, 2017; Pérez-Escamilla, 2017).

Increasing global temperature poses large risks to food security globally and regionally, especially in low-latitude areas (*medium confidence*) (Cheung et al., 2010; Rosenzweig et al., 2013; Porter et al., 2014; Rosenzweig and Hillel, 2015; Lam et al., 2016), with warming of 2°C projected to result in a greater reduction in global crop yields and global nutrition than warming of 1.5°C (*high confidence*) (Section 3.4.6), owing to the combined effects of changes in temperature, precipitation and extreme weather events, as well as increasing CO_2 concentrations. Climate change can exacerbate malnutrition by reducing nutrient availability and the quality of food products (*medium confidence*) (Cramer et al., 2014; Zhu et al., 2018). Generally, vulnerability to decreases in water and food availability is projected to be reduced at 1.5°C versus 2°C (Cheung et al., 2016a; Betts et al., 2018), especially in regions such as the African Sahel, the Mediterranean, central Europe, the Amazon, and western and southern Africa (*medium confidence*) (Sultan and Gaetani, 2016; Lehner et al., 2017; Betts et al., 2018; Byers et al., 2018; Rosenzweig et al., 2018).

Cross-Chapter Box 6 (continued)

Rosenzweig et al. (2018) and Ruane et al. (2018) reported that the higher CO_2 concentrations associated with 2°C as compared to those at 1.5°C of global warming are projected to drive positive effects in some regions. Production can also benefit from warming in higher latitudes, with more fertile soils, favouring crops, and grassland production, in contrast to the situation at low latitudes (Section 3.4.6), and similar benefits could arise for high-latitude fisheries production (*high confidence*) (Section 3.4.6.3). Studies exploring regional climate change risks on crop production are strongly influenced by the use of different regional climate change projections and by the assumed strength of CO_2 fertilization effects (Section 3.6), which are uncertain. For C3 crops, theoretically advantageous CO_2 fertilization effects may not be realized in the field; further, they are often accompanied by losses in protein and nutrient content of crops (Section 3.6), and hence these projected benefits may not be realized. In addition, some micronutrients such as iron and zinc will accumulate less and be less available in food (Myers et al., 2014). Together, the impacts on protein availability may bring as many as 150 million people into protein deficiency by 2050 (Medek et al., 2017). However, short-term benefits could arise for high-latitude fisheries production as waters warm, sea ice contracts and primary productivity increases under climate change (*high confidence*) (Section 3.4.6.3; Cheung et al., 2010; Hollowed and Sundby, 2014; Lam et al., 2016; Sundby et al., 2016; Weatherdon et al., 2016).

Factors affecting the projections of food security include variability in regional climate projections, climate change mitigation (where land use is involved; see Section 3.6 and Cross-Chapter Box 7 in this chapter) and biological responses (*medium confidence*) (Section 3.4.6.1; McGrath and Lobell, 2013; Elliott et al., 2014; Pörtner et al., 2014; Durand et al., 2018), extreme events such as droughts and floods (*high confidence*) (Sections 3.4.6.1, 3.4.6.2; Rosenzweig et al., 2014; Wei et al., 2017), financial volatility (Kannan et al., 2000; Ghosh, 2010; Naylor and Falcon, 2010; HLPE, 2011), and the distributions of pests and disease (Jiao et al., 2014; van Bruggen et al., 2015). Changes in temperature and precipitation are projected to increase global food prices by 3–84% by 2050 (IPCC, 2013). Differences in price impacts of climate change are accompanied by differences in land-use change (Nelson et al., 2014b), energy policies and food trade (Mueller et al., 2011; Wright, 2011; Roberts and Schlenker, 2013). Fisheries and aquatic production systems (aquaculture) face similar challenges to those of crop and livestock sectors (Section 3.4.6.3; Asiedu et al., 2017a, b; Utete et al., 2018). Human influences on food security include demography, patterns of food waste, diet shifts, incomes and prices, storage, health status, trade patterns, conflict, and access to land and governmental or other assistance (Chapters 4 and 5). Across all these systems, the efficiency of adaptation strategies is uncertain because it is strongly linked with future economic and trade environments and their response to changing food availability (*medium confidence*) (Lobell et al., 2011; von Lampe et al., 2014; d'Amour et al., 2016; Wei et al., 2017).

Climate change impacts on food security can be reduced through adaptation (Hasegawa et al., 2014). While climate change is projected to decrease agricultural yield, the consequences could be reduced substantially at 1.5°C versus 2°C with appropriate investment (*high confidence*) (Neumann et al., 2010; Muller, 2011; Roudier et al., 2011), awareness-raising to help inform farmers of new technologies for maintaining yield, and strong adaptation strategies and policies that develop sustainable agricultural choices (Sections 4.3.2 and 4.5.3). In this regard, initiatives such as 'climate-smart' food production and distribution systems may assist via technologies and adaptation strategies for food systems (Lipper et al., 2014; Martinez-Baron et al., 2018; Whitfield et al., 2018), as well as helping meet mitigation goals (Harvey et al., 2014).

K.R. Smith et al. (2014) concluded that climate change will exacerbate current levels of childhood undernutrition and stunting through reduced food availability. As well, climate change can drive undernutrition-related childhood mortality, and increase disability-adjusted life years lost, with the largest risks in Asia and Africa (Supplementary Material 3.SM, Table 3.SM.12; Ishida et al., 2014; Hasegawa et al., 2016; Springmann et al., 2016). Studies comparing the health risks associated with reduced food security at 1.5°C and 2°C concluded that risks would be higher and the globally undernourished population larger at 2°C (Hales et al., 2014; Ishida et al., 2014; Hasegawa et al., 2016). Climate change impacts on dietary and weight-related risk factors are projected to increase mortality, owing to global reductions in food availability and consumption of fruit, vegetables and red meat (Springmann et al., 2016). Further, temperature increases are projected to reduce the protein and micronutrient content of major cereal crops, which is expected to further affect food and nutritional security (Myers et al., 2017; Zhu et al., 2018).

Strategies for improving food security often do so in complex settings such as the Mekong River basin in Southeast Asia. The Mekong is a major food bowl (Smajgl et al., 2015) but is also a climate change hotspot (de Sherbinin, 2014; Lebel et al., 2014). This area is also a useful illustration of the complexity of adaptation choices and actions in a 1.5°C warmer world. Climate projections include increased annual average temperatures and precipitation in the Mekong (Zhang et al., 2017), as well as increased flooding and related disaster risks (T.F. Smith et al., 2013; Ling et al., 2015; Zhang et al., 2016). Sea level rise and saline intrusion are ongoing risks to agricultural systems in this area by reducing soil fertility and limiting the crop productivity (Renaud et al., 2015). The main climate impacts in the Mekong are expected to be on ecosystem health, through salinity intrusion, biomass reduction and biodiversity losses (Le Dang et al., 2013; Smajgl et al., 2015); agricultural productivity and food security (Smajgl et al., 2015); livelihoods such as fishing and farming (D. Wu et al., 2013); and disaster risk (D. Wu et al., 2013; Hoang et al., 2016), with implications for human mortality and economic and infrastructure losses.

Cross-Chapter Box 6 (continued)

Adaptation imperatives and costs in the Mekong will be higher under higher temperatures and associated impacts on agriculture and aquaculture, hazard exposure, and infrastructure. Adaptation measures to meet food security include greater investment in crop diversification and integrated agriculture–aquaculture practices (Renaud et al., 2015), improvement of water-use technologies (e.g., irrigation, pond capacity improvement and rainwater harvesting), soil management, crop diversification, and strengthening allied sectors such as livestock rearing and aquaculture (ICEM, 2013). Ecosystem-based approaches, such as integrated water resources management, demonstrate successes in mainstreaming adaptation into existing strategies (Sebesvari et al., 2017). However, some of these adaptive strategies can have negative impacts that deepen the divide between land-wealthy and land-poor farmers (Chapman et al., 2016). Construction of high dikes, for example, has enabled triple-cropping, which benefits land-wealthy farmers but leads to increasing debt for land-poor farmers (Chapman and Darby, 2016).

Institutional innovation has happened through the Mekong River Commission (MRC), which is an intergovernmental body between Cambodia, Lao PDR, Thailand and Viet Nam that was established in 1995. The MRC has facilitated impact assessment studies, regional capacity building and local project implementation (Schipper et al., 2010), although the mainstreaming of adaptation into development policies has lagged behind needs (Gass et al., 2011). Existing adaptation interventions can be strengthened through greater flexibility of institutions dealing with land-use planning and agricultural production, improved monitoring of saline intrusion, and the installation of early warning systems that can be accessed by the local authorities or farmers (Renaud et al., 2015; Hoang et al., 2016; Tran et al., 2018). It is critical to identify and invest in synergistic strategies from an ensemble of infrastructural options (e.g., building dikes); soft adaptation measures (e.g., land-use change) (Smajgl et al., 2015; Hoang et al., 2018); combinations of top-down government-led (e.g., relocation) and bottom-up household strategies (e.g., increasing house height) (Ling et al., 2015); and community-based adaptation initiatives that merge scientific knowledge with local solutions (Gustafson et al., 2016, 2018; Tran et al., 2018). Special attention needs to be given to strengthening social safety nets and livelihood assets whilst ensuring that adaptation plans are mainstreamed into broader development goals (Sok and Yu, 2015; Kim et al., 2017). The combination of environmental, social and economic pressures on people in the Mekong River basin highlights the complexity of climate change impacts and adaptation in this region, as well as the fact that costs are projected to be much lower at 1.5°C than 2°C of global warming.

3.4.7 Human Health

Climate change adversely affects human health by increasing exposure and vulnerability to climate-related stresses, and decreasing the capacity of health systems to manage changes in the magnitude and pattern of climate-sensitive health outcomes (Cramer et al., 2014; Hales et al., 2014). Changing weather patterns are associated with shifts in the geographic range, seasonality and transmission intensity of selected climate-sensitive infectious diseases (e.g., Semenza and Menne, 2009), and increasing morbidity and mortality are associated with extreme weather and climate events (e.g., K.R. Smith et al., 2014). Health detection and attribution studies conducted since AR5 have provided evidence, using multistep attribution, that climate change is negatively affecting adverse health outcomes associated with heatwaves, Lyme disease in Canada, and *Vibrio* emergence in northern Europe (Mitchell, 2016; Mitchell et al., 2016; Ebi et al., 2017). The IPCC AR5 concluded there is *high* to *very high confidence* that climate change will lead to greater risks of injuries, disease and death, owing to more intense heatwaves and fires, increased risks of undernutrition, and consequences of reduced labour productivity in vulnerable populations (K.R. Smith et al., 2014).

3.4.7.1 Projected risk at 1.5°C and 2°C of global warming

The projected risks to human health of warming of 1.5°C and 2°C, based on studies of temperature-related morbidity and mortality, air quality and vector borne diseases assessed in and since AR5, are summarized in Supplementary Material 3.SM, Tables 3.SM.8, 3.SM.9 and 3.SM.10 (based on Ebi et al., 2018). Other climate-sensitive health outcomes, such as diarrheal diseases, mental health issues and the full range of sources of poor air quality, were not considered because of the lack of projections of how risks could change at 1.5°C and 2°C. Few projections were available for specific temperatures above pre-industrial levels; Supplementary Material 3.SM, Table 3.SM.7 provides the conversions used to translate risks projected for particular time slices to those for specific temperature changes (Ebi et al., 2018).

Temperature-related morbidity and mortality: The magnitude of projected heat-related morbidity and mortality is greater at 2°C than at 1.5°C of global warming (*very high confidence*)(Doyon et al., 2008; Jackson et al., 2010; Hanna et al., 2011; Huang et al., 2012; Petkova et al., 2013; Hajat et al., 2014; Hales et al., 2014; Honda et al., 2014; Vardoulakis et al., 2014; Garland et al., 2015; Huynen and Martens, 2015; Li et al., 2015; Schwartz et al., 2015; L. Wang et al., 2015; Guo et al., 2016; T. Li et al., 2016; Chung et al., 2017; Kendrovski et al., 2017; Mishra et al., 2017; Arnell et al., 2018; Mitchell et al., 2018b). The number of people exposed to heat events is projected to be greater at 2°C than at 1.5°C (Russo et al., 2016; Mora et al., 2017; Byers et al., 2018; Harrington and Otto, 2018; King et al., 2018). The extent to which morbidity and mortality are projected to increase varies by region, presumably because of differences in acclimatization, population vulnerability, the built environment, access to air conditioning and other factors (Russo et al., 2016; Mora et al., 2017; Byers et al., 2018; Harrington and Otto, 2018; King et al., 2018). Populations at highest risk include older adults, children, women, those with chronic diseases, and people taking certain medications (*very high confidence*). Assuming adaptation takes place reduces the projected magnitude of risks (Hales et al., 2014; Huynen and Martens, 2015; T. Li et al., 2016).

In some regions, cold-related mortality is projected to decrease with increasing temperatures, although increases in heat-related mortality generally are projected to outweigh any reductions in cold-related mortality with warmer winters, with the heat-related risks increasing with greater degrees of warming (Huang et al., 2012; Hajat et al., 2014; Vardoulakis et al., 2014; Gasparrini et al., 2015; Huynen and Martens, 2015; Schwartz et al., 2015).

Occupational health: Higher ambient temperatures and humidity levels place additional stress on individuals engaging in physical activity. Safe work activity and worker productivity during the hottest months of the year would be increasingly compromised with additional climate change (*medium confidence*) (Dunne et al., 2013; Kjellstrom et al., 2013, 2018; Sheffield et al., 2013; Habibi Mohraz et al., 2016). Patterns of change may be complex; for example, at 1.5°C, there could be about a 20% reduction in areas experiencing severe heat stress in East Asia, compared to significant increases in low latitudes at 2°C (Lee and Min, 2018). The costs of preventing workplace heat-related illnesses through worker breaks suggest that the difference in economic loss between 1.5°C and 2°C could be approximately 0.3% of global gross domestic product (GDP) in 2100 (Takakura et al., 2017). In China, taking into account population growth and employment structure, high temperature subsidies for employees working on extremely hot days are projected to increase from 38.6 billion yuan yr^{-1} in 1979–2005 to 250 billion yuan yr^{-1} in the 2030s (about 1.5°C) (Zhao et al., 2016).

Air quality: Because ozone formation is temperature dependent, projections focusing only on temperature increase generally conclude that ozone-related mortality will increase with additional warming, with the risks higher at 2°C than at 1.5°C (*high confidence*) (Supplementary Material 3.SM, Table 3.SM.9; Heal et al., 2013; Tainio et al., 2013; Likhvar et al., 2015; Silva et al., 2016; Dionisio et al., 2017; J.Y. Lee et al., 2017). Reductions in precursor emissions would reduce future ozone concentrations and associated mortality. Mortality associated with exposure to particulate matter could increase or decrease in the future, depending on climate projections and emissions assumptions (Supplementary Material 3.SM, Table 3.SM.8; Tainio et al., 2013; Likhvar et al., 2015; Silva et al., 2016).

Malaria: Recent projections of the potential impacts of climate change on malaria globally and for Asia, Africa, and South America (Supplementary Material 3.SM, Table 3.SM.10) confirm that weather and climate are among the drivers of the geographic range, intensity of transmission, and seasonality of malaria, and that the relationships are not necessarily linear, resulting in complex patterns of changes in risk with additional warming (*very high confidence*) (Ren et al., 2016; Song et al., 2016; Semakula et al., 2017). Projections suggest that the burden of malaria could increase with climate change because of a greater geographic range of the Anopheles vector, longer season, and/or increase in the number of people at risk, with larger burdens at higher levels of warming, but with regionally variable patterns *(medium to high confidence*). Vector populations are projected to shift with climate change, with expansions and reductions depending on the degree of local warming, the ecology of the mosquito vector, and other factors (Ren et al., 2016).

Aedes **(mosquito vector for dengue fever, chikungunya, yellow fever and Zika virus)**: Projections of the geographic distribution of *Aedes aegypti* and Ae. *albopictus* (principal vectors) or of the prevalence of dengue fever generally conclude that there will be an increase in the number of mosquitos and a larger geographic range at 2°C than at 1.5°C, and they suggest that more individuals will be at risk of dengue fever, with regional differences (*high confidence*) (Fischer et al., 2011, 2013; Colón-González et al., 2013, 2018; Bouzid et al., 2014; Ogden et al., 2014a; Mweya et al., 2016). The risks increase with greater warming. Projections suggest that climate change is projected to expand the geographic range of chikungunya, with greater expansions occurring at higher degrees of warming (Tjaden et al., 2017).

Other vector-borne diseases: Increased warming in North America and Europe could result in geographic expansions of regions (latitudinally and altitudinally) climatically suitable for West Nile virus transmission, particularly along the current edges of its transmission areas, and extension of the transmission season, with the magnitude and pattern of changes varying by location and level of warming (Semenza et al., 2016). Most projections conclude that climate change could expand the geographic range and seasonality of Lyme and other tick-borne diseases in parts of North America and Europe (Ogden et al., 2014b; Levi et al., 2015). The projected changes are larger with greater warming and under higher greenhouse gas emissions pathways. Projections of the impacts of climate change on leishmaniosis and Chagas disease indicate that climate change could increase or decrease future health burdens, with greater impacts occurring at higher degrees of warming (González et al., 2014; Ceccarelli and Rabinovich, 2015).

In summary, warming of 2°C poses greater risks to human health than warming of 1.5°C, often with the risks varying regionally, with a few exceptions (*high confidence*). There is *very high confidence* that each additional unit of warming could increase heat-related morbidity and mortality, and that adaptation would reduce the magnitude of impacts. There is *high confidence* that ozone-related mortality could increase if precursor emissions remain the same, and that higher temperatures could affect the transmission of some infectious diseases, with increases and decreases projected depending on the disease (e.g., malaria, dengue fever, West Nile virus and Lyme disease), region and degree of temperature change.

3.4.8 Urban Areas

There is new literature on urban climate change and its differential impacts on and risks for infrastructure sectors – energy, water, transport and buildings – and vulnerable populations, including those living in informal settlements (UCCRN, 2018). However, there is limited literature on the risks of warming of 1.5°C and 2°C in urban areas. Heat-related extreme events (Matthews et al., 2017), variability in precipitation (Yu et al., 2018) and sea level rise can directly affect urban areas (Section 3.4.5, Bader et al., 2018; Dawson et al., 2018). Indirect risks may arise from interactions between urban and natural systems.

Future warming and urban expansion could lead to more extreme heat stress (Argüeso et al., 2015; Suzuki-Parker et al., 2015). At 1.5°C of warming, twice as many megacities (such as Lagos, Nigeria and Shanghai, China) could become heat stressed, exposing more than 350 million more people to deadly heat by 2050 under midrange population growth. Without considering adaptation options, such as cooling from more reflective roofs, and overall characteristics of urban agglomerations in terms of land use, zoning and building codes (UCCRN, 2018), Karachi (Pakistan) and Kolkata (India) could experience conditions equivalent to the deadly 2015 heatwaves on an annual basis under 2°C of warming (Akbari et al., 2009; Oleson et al., 2010; Matthews et al., 2017). Warming of 2°C is expected to increase the risks of heatwaves in China's urban agglomerations (Yu et al., 2018). Stabilizing at 1.5°C of warming instead of 2°C could decrease mortality related to extreme temperatures in key European cities, assuming no adaptation and constant vulnerability (Jacob et al., 2018; Mitchell et al., 2018a). Holding temperature change to below 2°C but taking urban heat islands (UHI) into consideration, projections indicate that there could be a substantial increase in the occurrence of deadly heatwaves in cities. The urban impacts of these heatwaves are expected to be similar at 1.5°C and 2°C and substantially larger than under the present climate (Matthews et al., 2017; Yu et al., 2018). Increases in the intensity of UHI could exacerbate warming of urban areas, with projections ranging from a 6% decrease to a 30% increase for a doubling of CO_2 (McCarthy et al., 2010). Increases in population and city size, in the context of a warmer climate, are projected to increase UHI (Georgescu et al., 2012; Argüeso et al., 2014; Conlon et al., 2016; Kusaka et al., 2016; Grossman-Clarke et al., 2017).

For extreme heat events, an additional 0.5°C of warming implies a shift from the upper bounds of observed natural variability to a new global climate regime (Schleussner et al., 2016b), with distinct implications for the urban poor (Revi et al., 2014; Jean-Baptiste et al., 2018; UCCRN, 2018). Adverse impacts of extreme events could arise in tropical coastal areas of Africa, South America and Southeast Asia (Schleussner et al., 2016b). These urban coastal areas in the tropics are particularly at risk given their large informal settlements and other vulnerable urban populations, as well as vulnerable assets, including businesses and critical urban infrastructure (energy, water, transport and buildings) (McGranahan et al., 2007; Hallegatte et al., 2013; Revi et al., 2014; UCCRN, 2018). Mediterranean water stress is projected to increase from 9% at 1.5°C to 17% at 2°C compared to values in 1986–2005 period. Regional dry spells are projected to expand from 7% at 1.5°C to 11% at 2°C for the same reference period. Sea level rise is expected to be lower at 1.5°C than 2°C, lowering risks for coastal metropolitan agglomerations (Schleussner et al., 2016b).

Climate models are better at projecting implications of greenhouse gas forcing on physical systems than at assessing differential risks associated with achieving a specific temperature target (James et al., 2017). These challenges in managing risks are amplified when combined with the scale of urban areas and assumptions about socio-economic pathways (Krey et al., 2012; Kamei et al., 2016; Yu et al., 2016; Jiang and Neill, 2017).

In summary, in the absence of adaptation, in most cases, warming of 2°C poses greater risks to urban areas than warming of 1.5°C, depending on the vulnerability of the location (coastal or non-coastal) (*high confidence*), businesses, infrastructure sectors (energy, water and transport), levels of poverty, and the mix of formal and informal settlements.

3.4.9 Key Economic Sectors and Services

Climate change could affect tourism, energy systems and transportation through direct impacts on operations (e.g., sea level rise) and through impacts on supply and demand, with the risks varying significantly with geographic region, season and time. Projected risks also depend on assumptions with respect to population growth, the rate and pattern of urbanization, and investments in infrastructure. Table 3.SM.11 in Supplementary Material 3.SM summarizes the cited publications.

3.4.9.1 Tourism

The implications of climate change for the global tourism sector are far-reaching and are impacting sector investments, destination assets (environment and cultural), operational and transportation costs, and tourist demand patterns (Scott et al., 2016a; Scott and Gössling, 2018). Since AR5, observed impacts on tourism markets and destination communities continue to be not well analysed, despite the many analogue conditions (e.g., heatwaves, major hurricanes, wild fires, reduced snow pack, coastal erosion and coral reef bleaching) that are anticipated to occur more frequently with climate change. There is some evidence that observed impacts on tourism assets, such as environmental and cultural heritage, are leading to the development of 'last chance to see' tourism markets, where travellers visit destinations before they are substantially degraded by climate change impacts or to view the impacts of climate change on landscapes (Lemelin et al., 2012; Stewart et al., 2016; Piggott-McKellar and McNamara, 2017).

There is limited research on the differential risks of a 1.5° versus 2°C temperature increase and resultant environmental and socio-economic impacts in the tourism sector. The translation of these changes in climate resources for tourism into projections of tourism demand remains geographically limited to Europe. Based on analyses of tourist comfort, summer and spring/autumn tourism in much of western Europe may be favoured by 1.5°C of warming, but with negative effects projected for Spain and Cyprus (decreases of 8% and 2%, respectively, in overnight stays) and most coastal regions of the Mediterranean (Jacob et al., 2018). Similar geographic patterns of potential tourism gains (central and northern Europe) and reduced summer favourability (Mediterranean countries) are projected under 2°C (Grillakis et al., 2016). Considering potential changes in natural snow only, winter overnight stays at 1.5°C are projected to decline by 1–2% in Austria, Italy and Slovakia, with an additional 1.9 million overnight stays lost under 2°C of warming (Jacob et al., 2018). Using an econometric analysis of the relationship between regional tourism demand and climate conditions, Ciscar et al. (2014) projected that a 2°C warmer world would reduce European tourism by 5% (€15 billion yr^{-1}), with losses of up to 11% (€6 billion yr^{-1}) for southern Europe and a potential gain of €0.5 billion yr^{-1} in the UK.

There is growing evidence that the magnitude of projected impacts is temperature dependent and that sector risks could be much greater with higher temperature increases and resultant environmental and socio-economic impacts (Markham et al., 2016; Scott et al., 2016a; Jones, 2017; Steiger et al., 2017). Studies from 27 countries consistently project substantially decreased reliability of ski areas that are dependent on natural snow, increased snowmaking requirements and investment in snowmaking systems, shortened and more variable ski seasons, a contraction in the number of operating ski areas, altered competitiveness among and within regional ski markets, and subsequent impacts on employment and the value of vacation properties (Steiger et al., 2017). Studies that omit snowmaking do not reflect the operating realities of most ski areas and overestimate impacts at 1.5°C–2°C. In all regional markets, the extent and timing of these impacts depend on the magnitude of climate change and the types of adaptive responses by the ski industry, skiers and destination communities. The decline in the number of former Olympic Winter Games host locations that could remain climatically reliable for future Olympic and Paralympic Winter Games has been projected to be much greater under scenarios warmer than 2°C (Scott et al., 2015; Jacob et al., 2018).

The tourism sector is also affected by climate-induced changes in environmental assets critical for tourism, including biodiversity, beaches, glaciers and other features important for environmental and cultural heritage. Limited analyses of projected risks associated with 1.5°C versus 2°C are available (Section 3.4.4.12). A global analysis of sea level rise (SLR) risk to 720 UNESCO Cultural World Heritage sites projected that about 47 sites might be affected under 1°C of warming, with this number increasing to 110 and 136 sites under 2°C and 3°C, respectively (Marzeion and Levermann, 2014). Similar risks to vast worldwide coastal tourism infrastructure and beach assets remain unquantified for most major tourism destinations and small island developing states (SIDS) that economically depend on coastal tourism. One exception is the projection that an eventual 1 m SLR could partially or fully inundate 29% of 900 coastal resorts in 19 Caribbean countries, with a substantially higher proportion (49–60%) vulnerable to associated coastal erosion (Scott and Verkoeyen, 2017).

A major barrier to understanding the risks of climate change for tourism, from the destination community scale to the global scale, has been the lack of integrated sectoral assessments that analyse the full range of potential compounding impacts and their interactions with other major drivers of tourism (Rosselló-Nadal, 2014; Scott et al., 2016b). When applied to 181 countries, a global vulnerability index including 27 indicators found that countries with the lowest risk are located in western and northern Europe, central Asia, Canada and New Zealand, while the highest sector risks are projected for Africa, the Middle East, South Asia and SIDS in the Caribbean, Indian and Pacific Oceans (Scott and Gössling, 2018). Countries with the highest risks and where tourism represents a significant proportion of the national economy (i.e., more than 15% of GDP) include many SIDS and least developed countries. Sectoral climate change risk also aligns strongly with regions where tourism growth is projected to be the strongest over the coming decades, including sub-Saharan Africa and South Asia, pointing to an important potential barrier to tourism development. The transnational implications of these impacts on the highly interconnected global tourism sector and the contribution of tourism to achieving the 2030 sustainable development goals (SDGs) remain important uncertainties.

In summary, climate is an important factor influencing the geography and seasonality of tourism demand and spending globally (*very high confidence*). Increasing temperatures are projected to directly impact climate-dependent tourism markets, including sun, beach and snow sports tourism, with lesser risks for other tourism markets that are less climate sensitive (*high confidence*). The degradation or loss of beach and coral reef assets is expected to increase risks for coastal tourism, particularly in subtropical and tropical regions (*high confidence*).

3.4.9.2 Energy systems

Climate change is projected to lead to an increased demand for air conditioning in most tropical and subtropical regions (Arent et al., 2014; Hong and Kim, 2015) (*high confidence*). Increasing temperatures will decrease the thermal efficiency of fossil, nuclear, biomass and solar power generation technologies, as well as buildings and other infrastructure (Arent et al., 2014). For example, in Ethiopia, capital expenditures through 2050 might either decrease by approximately 3% under extreme wet scenarios or increase by up to 4% under a severe dry scenario (Block and Strzepek, 2012).

Impacts on energy systems can affect gross domestic product (GDP). The economic damage in the United States from climate change is estimated to be, on average, roughly 1.2% cost of GDP per year per 1°C increase under RCP8.5 (Hsiang et al., 2017). Projections of GDP indicate that negative impacts of energy demand associated with space heating and cooling in 2100 will be greatest (median: –0.94% change in GDP) under 4°C (RCP8.5) compared with under 1.5°C (median: –0.05%), depending on the socio-economic conditions (Park et al., 2018). Additionally, projected total energy demands for heating and cooling at the global scale do not change much with increases in global mean surface temperature (GMST) of up to 2°C. A high degree of variability is projected between regions (Arnell et al., 2018).

Evidence for the impact of climate change on energy systems since AR5 is limited. Globally, gross hydropower potential is projected to increase (by 2.4% under RCP2.6 and by 6.3% under RCP8.5 for the 2080s), with the most growth expected in Central Africa, Asia, India and northern high latitudes (van Vliet et al., 2016). Byers et al. (2018) found that energy impacts at 2°C increase, including more cooling degree days, especially in tropical regions, as well as increased hydro-climatic risk to thermal and hydropower plants predominantly in Europe, North America, South and Southeast Asia and southeast Brazil. Donk et al. (2018) assessed future climate impacts on hydropower in Suriname and projected a decrease of approximately 40% in power capacity for a global temperature increase in the range of 1.5°C. At minimum and maximum increases in global mean temperature of 1.35°C and 2°C, the overall stream flow in Florida, USA is projected to increase by an average of 21%, with pronounced seasonal variations, resulting in increases in power generation in winter (+72%) and autumn (+15%) and decreases in summer (–14%; Chilkoti et al., 2017). Greater changes are projected at higher temperature increases. In a reference scenario with global mean temperatures rising by 1.7°C from 2005 to 2050, U.S. electricity demand in 2050 was 1.6–6.5% higher than in a control scenario with constant temperatures (McFarland et al., 2015). Decreased electricity generation of –15% is projected for Brazil starting in 2040, with values expected to decline to –28% later in the century (de Queiroz et al., 2016). In large parts of Europe, electricity demand is projected to decrease, mainly owing to reduced heating demand (Jacob et al., 2018).

In Europe, no major differences in large-scale wind energy resources or in inter- or intra-annual variability are projected for 2016–2035 under RCP8.5 and RCP4.5 (Carvalho et al., 2017). However, in 2046–2100, wind energy density is projected to decrease in eastern Europe (–30%) and increase in Baltic regions (+30%). Intra-annual variability is expected to increase in northern Europe and decrease in southern Europe. Under RCP4.5 and RCP8.5, the annual energy yield of European wind farms as a whole, as projected to be installed by 2050, will remain stable (±5 yield for all climate models). However, wind farm yields are projected to undergo changes of up to 15% in magnitude at country and local scales and of 5% at the regional scale (Tobin et al., 2015, 2016). Hosking et al. (2018) assessed wind power generation over Europe for 1.5°C of warming and found the potential for wind energy to be greater than previously assumed in northern Europe. Additionally, Tobin et al. (2018) assessed impacts under 1.5°C and 2°C of warming on wind, solar photovoltaic and thermoelectric power generation across Europe. These authors found that photovoltaic and wind power might be reduced by up to 10%, and hydropower and thermoelectric generation might decrease by up to 20%, with impacts being limited at 1.5°C of warming but increasing as temperature increases (Tobin et al., 2018).

3.4.9.3 Transportation

Road, air, rail, shipping and pipeline transportation can be impacted directly or indirectly by weather and climate, including increases in precipitation and temperature; extreme weather events (flooding and storms); SLR; and incidence of freeze–thaw cycles (Arent et al., 2014). Much of the published research on the risks of climate change for the transportation sector has been qualitative.

The limited new research since AR5 supports the notion that increases in global temperatures will impact the transportation sector. Warming is projected to result in increased numbers of days of ice-free navigation and a longer shipping season in cold regions, thus affecting shipping and reducing transportation costs (Arent et al., 2014). In the North Sea Route, large-scale commercial shipping might not be possible until 2030 for bulk shipping and until 2050 for container shipping under RCP8.5. A 0.05% increase in mean temperature is projected from an increase in short-lived pollutants, as well as elevated CO_2 and non-CO_2 emissions, associated with additional economic growth enabled by the North Sea Route. (Yumashev et al., 2017). Open water vessel transit has the potential to double by mid-century, with a two to four month longer season (Melia et al., 2016).

3.4.10 Livelihoods and Poverty, and the Changing Structure of Communities

Multiple drivers and embedded social processes influence the magnitude and pattern of livelihoods and poverty, as well as the changing structure of communities related to migration, displacement and conflict (Adger et al., 2014). In AR5, evidence of a climate change signal was limited, with more evidence of impacts of climate change on the places where indigenous people live and use traditional ecological knowledge (Olsson et al., 2014).

3.4.10.1 Livelihoods and poverty

At approximately 1.5°C of global warming (2030), climate change is expected to be a poverty multiplier that makes poor people poorer and increases the poverty head count (Hallegatte et al., 2016; Hallegatte and Rozenberg, 2017). Poor people might be heavily affected by climate change even when impacts on the rest of population are limited. Climate change alone could force more than 3 million to 16 million people into extreme poverty, mostly through impacts on agriculture and food prices (Hallegatte et al., 2016; Hallegatte and Rozenberg, 2017). Unmitigated warming could reshape the global economy later in the century by reducing average global incomes and widening global income inequality (Burke et al., 2015b). The most severe impacts are projected for urban areas and some rural regions in sub-Saharan Africa and Southeast Asia.

3.4.10.2 The changing structure of communities: migration, displacement and conflict

Migration: In AR5, the potential impacts of climate change on migration and displacement were identified as an emerging risk (Oppenheimer et al., 2014). The social, economic and environmental factors underlying migration are complex and varied; therefore, detecting the effect of observed climate change or assessing its possible magnitude with any degree of confidence is challenging (Cramer et al., 2014).

No studies have specifically explored the difference in risks between 1.5°C and 2°C of warming on human migration. The literature consistently highlights the complexity of migration decisions and the difficulties in attributing causation (e.g., Nicholson, 2014; Baldwin and Fornalé, 2017; Bettini, 2017; Constable, 2017; Islam and Shamsuddoha, 2017; Suckall et al., 2017). The studies on migration that have most closely explored the probable impacts of 1.5°C and 2°C have mainly focused on the direct effects of temperature and precipitation anomalies on migration or the indirect effects of these climatic changes through changing agriculture yield and livelihood sources (Mueller et al., 2014; Piguet and Laczko, 2014; Mastrorillo et al., 2016; Sudmeier-Rieux et al., 2017).

Temperature has had a positive and statistically significant effect on outmigration over recent decades in 163 countries, but only for agriculture-dependent countries (R. Cai et al., 2016). A 1°C increase in average temperature in the International Migration Database of the Organisation for Economic Co-operation and Development (OECD) was associated with a 1.9% increase in bilateral migration flows from 142 sending countries and 19 receiving countries, and an additional millimetre of average annual precipitation was associated with an increase in migration by 0.5% (Backhaus et al., 2015). In another study, an increase in precipitation anomalies from the long-term mean, was strongly associated with an increase in outmigration, whereas no significant effects of temperature anomalies were reported (Coniglio and Pesce, 2015).

Internal and international migration have always been important for small islands (Farbotko and Lazrus, 2012; Weir et al., 2017). There is rarely a single cause for migration (Constable, 2017). Numerous factors are important, including work, education, quality of life, family ties, access to resources, and development (Bedarff and Jakobeit, 2017; Speelman et al., 2017; Nicholls et al., 2018). Depending on the situation, changing weather, climate or environmental conditions might each be a factor in the choice to migrate (Campbell and Warrick, 2014).

Displacement: At 2°C of warming, there is a potential for significant population displacement concentrated in the tropics (Hsiang and Sobel, 2016). Tropical populations may have to move distances greater than 1000 km if global mean temperature rises by 2°C from 2011–2030 to the end of the century. A disproportionately rapid evacuation from the tropics could lead to a concentration of population in tropical margins and the subtropics, where population densities could increase by 300% or more (Hsiang and Sobel, 2016).

Conflict: A recent study has called for caution in relating conflict to climate change, owing to sampling bias (Adams et al., 2018). Insufficient consideration of the multiple drivers of conflict often leads to inconsistent associations being reported between climate change and conflict (e.g., Hsiang et al., 2013; Hsiang and Burke, 2014; Buhaug, 2015, 2016; Carleton and Hsiang, 2016; Carleton et al., 2016). There also are inconsistent relationships between climate change, migration and conflict (e.g., Theisen et al., 2013; Buhaug et al., 2014; Selby, 2014; Christiansen, 2016; Brzoska and Fröhlich, 2016; Burrows and Kinney, 2016; Reyer et al., 2017c; Waha et al., 2017). Across world regions and from the international to micro level, the relationship between drought and conflict is weak under most circumstances (Buhaug, 2016; von Uexkull et al., 2016). However, drought significantly increases the likelihood of sustained conflict for particularly vulnerable nations or groups, owing to the dependence of their livelihood on agriculture. This is particularly relevant for groups in the least developed countries (von Uexkull et al., 2016), in sub-Saharan Africa (Serdeczny et al., 2016; Almer et al., 2017) and in the Middle East (Waha et al., 2017). Hsiang et al. (2013) reported causal evidence and convergence across studies that climate change is linked to human conflicts across all major regions of the world, and across a range of spatial and temporal scales. A 1°C increase in temperature or more extreme rainfall increases the frequency of intergroup conflicts by 14% (Hsiang et al., 2013). If the world warms by 2°C–4°C by 2050, rates of human conflict could increase. Some causal associations between violent conflict and socio-political instability were reported from local to global scales and from hour to millennium time frames (Hsiang and Burke, 2014). A temperature increase of one standard deviation increased the risk of interpersonal conflict by 2.4% and intergroup conflict by 11.3% (Burke et al., 2015a). Armed-conflict risks and climate-related disasters are both relatively common in ethnically fractionalized countries, indicating that there is no clear signal that environmental disasters directly trigger armed conflicts (Schleussner et al., 2016a).

In summary, average global temperatures that extend beyond 1.5°C are projected to increase poverty and disadvantage in many populations globally (*medium confidence*). By the mid- to late 21st century, climate change is projected to be a poverty multiplier that makes poor people poorer and increases poverty head count, and the association between temperature and economic productivity is not linear (*high confidence*). Temperature has a positive and statistically significant effect on outmigration for agriculture-dependent communities (*medium confidence*).

3.4.11 Interacting and Cascading Risks

The literature on compound as well as interacting and cascading risks at warming of 1.5°C and 2°C is limited. Spatially compound risks, often referred to as hotspots, involve multiple hazards from different sectors overlapping in location (Piontek et al., 2014). Global exposures were assessed for 14 impact indicators, covering water, energy and land sectors, from changes including drought intensity and water stress index, cooling demand change and heatwave exposure, habitat degradation, and crop yields using an ensemble of climate and impact models (Byers et al., 2018). Exposures are projected to approximately double between 1.5°C and 2°C, and the land area affected by climate risks is expected to increase as warming progresses. For populations vulnerable to poverty, the exposure to climate risks in multiple sectors could be an order of magnitude greater (8–32 fold) in the high poverty and inequality scenarios (SSP3; 765–1,220 million) compared to under sustainable socio-economic development (SSP1; 23–85 million). Asian and African regions are projected to experience 85–95% of global exposure, with 91–98% of the exposed and vulnerable population (depending on SSP/GMT combination), approximately half of which are in South Asia. Figure 3.19 shows that moderate and large multi-sector impacts are prevalent at 1.5°C where vulnerable people live, predominantly in South Asia (mostly Pakistan, India and China), but that impacts spread to sub-Saharan Africa, the Middle East and East Asia at higher levels of warming. Beyond 2°C and at higher risk thresholds, the world's poorest populations are expected to be disproportionately impacted, particularly in cases (SSP3) of great inequality in Africa and southern Asia. Table 3.4 shows the number of exposed and vulnerable people at 1.5°C and 2°C of warming, with 3°C shown for context, for selected multi-sector risks.

3.4.12 Summary of Projected Risks at 1.5°C and 2°C of Global Warming

The information presented in Section 3.4 is summarized below in Table 3.5, which illustrates the growing evidence of increasing risks across a broad range of natural and human systems at 1.5°C and 2°C of global warming.

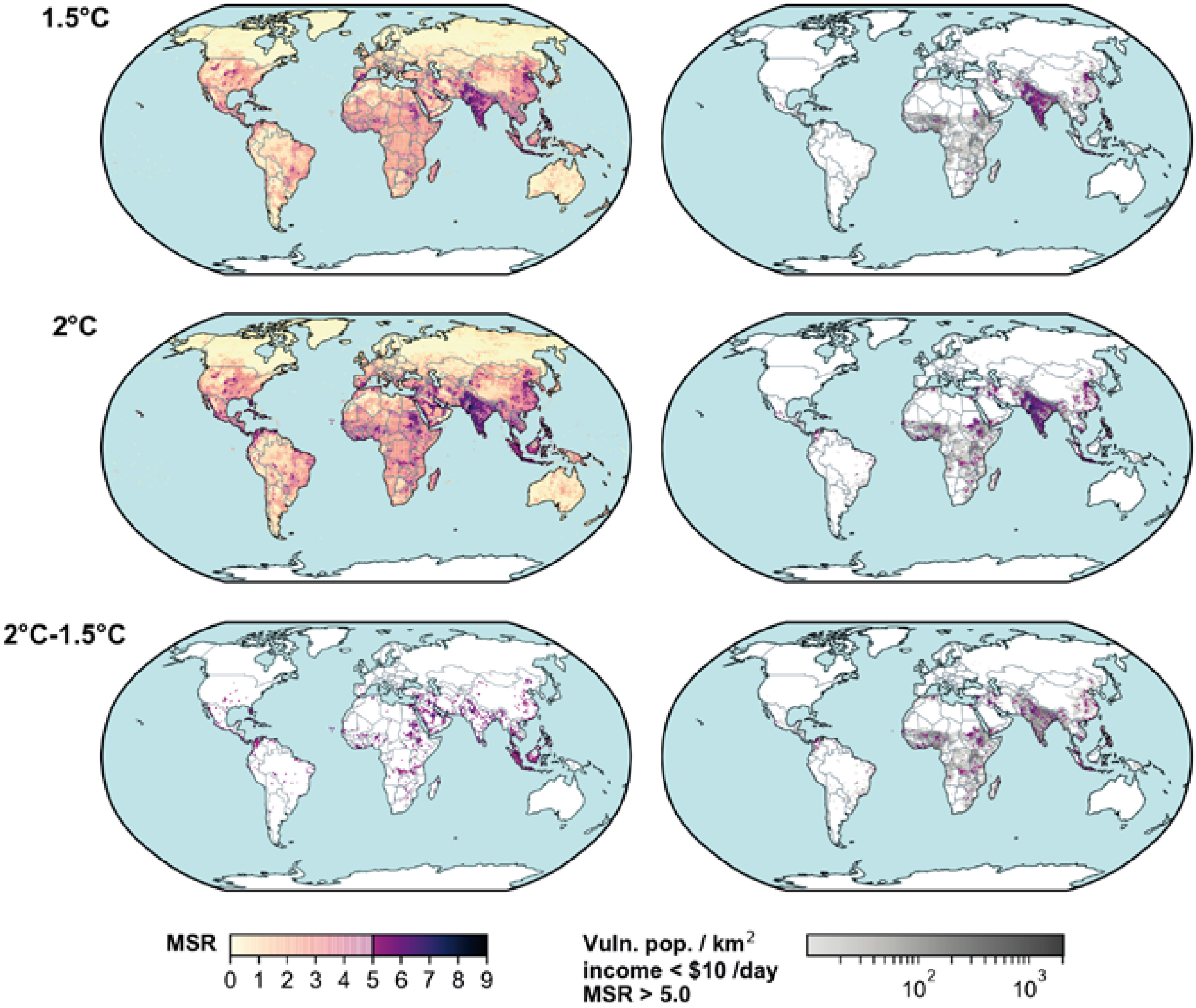


Figure 3.19 | Multi-sector risk maps for 1.5°C (top), 2°C (middle), and locations where 2°C brings impacts not experienced at 1.5°C (2°C–1.5°C; bottom). The maps in the left column show the full range of the multi-sector risk (MSR) score (0–9), with scores ≤5.0 shown with a transparency gradient and scores >5.0 shown with a colour gradient. Score must be >4.0 to be considered 'multi-sector'. The maps in the right column overlay the 2050 vulnerable populations (low income) under Shared Socio-Economic Pathway (SSP)2 (greyscale) with the multi-sector risk score >5.0 (colour gradient), thus indicating the concentrations of exposed and vulnerable populations to risks in multiple sectors. Source: Byers et al. (2018).

Table 3.4 | Number of exposed and vulnerable people at 1.5°C, 2°C, and 3°C for selected multi-sector risks under shared socioeconomic pathways (SSPs). Source: Byers et al., 2018

SSP2 (SSP1 to SSP3 range), millions	1.5°C		2°C		3°C	
Indicator	Exposed	Exposed and vulnerable	Exposed	Exposed and vulnerable	Exposed	Exposed and vulnerable
Water stress index	3340 (3032–3584)	496 (103–1159)	3658 (3080–3969)	586 (115–1347)	3920 (3202–4271)	662 (146–1480)
Heatwave event exposure	3960 (3546–4508)	1187 (410–2372)	5986 (5417–6710)	1581 (506–3218)	7909 (7286–8640)	1707 (537–3575)
Hydroclimate risk to power production	334 (326–337)	30 (6–76)	385 (374–389)	38 (9–94)	742 (725–739)	72 (16–177)
Crop yield change	35 (32–36)	8 (2–20)	362 (330–396)	81 (24–178)	1817 (1666–1992)	406 (118–854)
Habitat degradation	91 (92–112)	10 (4–31)	680 (314–706)	102 (23–234)	1357 (809–1501)	248 (75–572)
Multi-sector exposure						
Two indicators	1129 (1019–1250)	203 (42–487)	2726 (2132–2945)	562 (117–1220)	3500 (3212–3864)	707 (212–1545)
Three indicators	66 (66–68)	7 (0.9–19)	422 (297–447)	54 (8–138)	1472 (1177–1574)	237 (48–538)
Four indicators	5 (0.3–5.7)	0.3 (0–1.2)	11 (5–14)	0.5 (0–2)	258 (104–280)	33 (4–86)

Table 3.5 | Summary of projected risks to natural and human systems at 1.5°C and 2°C of global warming, and of the potential to adapt to these risks. Table summarizes the chapter text and with references supporting table entries found in the main chapter text. Risk magnitude is provided either as assessed levels of risk (very high: vh, high: h, medium: m, or low: l) or as quantitative examples of risk levels taken from the literature. Further compilations of quantified levels of risk taken from the literature may be found Tables 3.SM1-5 in the Supplementary Material. Similarly, potential to adapt is assessed from the literature by expert judgement as either high (h), medium (m), or low (l). Confidence in each assessed level/quantification of risk, or in each assessed adaptation potential, is indicated as very high (VH), high (H), medium (M), or low (L). Note that the use of l, m, h and vh here is distinct from the use of L, M, H and VH in Figures 3.18, 3.20 and 3.21.

Sector	Physical climate change drivers	Nature of risk	Global risks at 1.5°C of global warming above pre-industrial	Global risks at 2°C of global warming above pre-industrial	Change in risk when moving from 1.5°C to 2°C of warming	Confidence in risk statements	Regions where risks are particularly high with 2°C of global warming	Regions where the change in risk when moving from 1.5°C to 2°C are particularly high	Regions with little or no information	RFC*	Adaptation potential at 1.5°C	Adaptation potential at 2°C	Confidence in assigning adaptation potential
Freshwater	Precipitation, temperature, snowmelt	Water Stress	Around half compared to the risks at 2°C[1]	Additional 8% of the world population in 2000 exposed to new or aggravated water scarcity[1]	Up to 100% increase	M		Europe, Australia, southern Africa		3	l	l	M
		Fluvial flood	100% increase in the population affected compared to the impact simulated over the baseline period 1976–2005[2]	170% increase in the population affected compared to the impact simulated over the baseline period 1976–2005[2]	70% increase	M	USA, Asia, Europe		Africa, Oceania	2	l/m	l/m	M
		Drought	350.2 ± 158.8 million, changes in urban population exposure to severe drought at the globe scale[3]	410.7 ± 213.5 million, changes in urban population exposure to severe drought at the globe scale[3]	60.5 ± 84.1 million (±84.1 based on the SSP1 scenario) (based on PDSI estimate)	M	Central Europe, southern Europe, Mediterranean, West Africa, East and West Asia, Southeast Asia (based on PDSI estimate[#])			2	l/m	l/m	L
Terrestrial ecosystems	Temperature, precipitation	Species range loss	6% insects, 4% vertebrates, 8% plants, lose >50% range[4]	18% insects, 8% vertebrates, 16% plants lose >50% range[4]	Double or triple	M		Amazon, Europe, southern Africa		1,4	m	l	H
		Loss of ecosystem functioning and services	m	h		M				4			
		Shifts of biomes (major ecosystem types)	About 7% transformed[5]	13% (range 8–20%) transformed[5]	About double	M		Arctic, Tibet, Himalayas, South Africa, Australia		4			
	Heat and cold stress, warming, precipitation drought	Wildfire	h	h	Increased risk	M	Canada, USA and Mediterranean	Mediterranean	Central and South America, Australia, Russia, China, Africa	1, 2, 4, 5	l	l	M

Table 3.5 (continued)

Sector	Physical climate change drivers	Nature of risk	Global risks at 1.5°C of global warming above pre-industrial	Global risks at 2°C of global warming above pre-industrial	Change in risk when moving from 1.5°C to 2°C of warming	Confidence in risk statements	Regions where risks are particularly high with 2°C of global warming	Regions where the change in risk when moving from 1.5°C to2°C are particularly high	Regions with little or no information	RFC*	Adaptation potential at 1.5°C	Adaptation potential at 2°C	Confidence in assigning adaptation potential
Ocean	Warming and stratification of the surface ocean	Loss of framework species (coral reefs)	vh	vh	Greater rate of loss: from 70–90% loss at 1.5°C to 99% loss at 2°C and above	H/very H	Tropical/ subtropical countries	Tropical/ subtropical countries	Southern Red Sea, Somalia, Yemen, deep water coral reefs	1,2	h	l	H
		Loss of framework species (seagrass)	m	h	Increase in risk	M	Tropical/ subtropical countries	Tropical/ subtropical countries	Southern Red Sea, Somalia, Yemen, Myanmar	1,2	m	l	M/H
		Loss of framework species (mangroves)	m	m	Uncertain and depends on other human activities	M/H	Tropical/ subtropical countries	Tropical/ subtropical countries	Southern Red Sea, Somalia, Yemen, Myanmar	1,3	m	l	L/M
		Disruption of marine foodwebs	h	vh	Large increase in risk	M	Global	Global	Deep sea	4	m	l	M/H
		Range migration of marine species and ecosystems	m	h	Large increase in risk	H	Global	Global	Deep sea	1	m	l	H
		Loss of fin fish and fisheries	h	h/vh	Large increase in risk	H	Global	Global	Deep sea, up-welling systems	4	m	m/l	M/H
	Ocean acidification and elevated sea temperatures	Loss of coastal ecosystems and protection	m	h	Increase in risk	M	Low-latitude tropical/ subtropical countries	Low-latitude tropical/subtropical countries	Most regions – risks not well defined	1	m	m/l	M
		Loss of bivalves and bivalve fisheries	m/h	h/vh	Large increase in risk	H	Temperate countries with upwelling	Temperate countries with upwelling	Most regions – risks not well defined	4	m/h	l/m	M/H
		Changes to physiology and ecology of marine species	l/m	m	Increase in risk	H	Global	Global	Most regions – risks not well defined	4	l	l	M/H
	Reduced bulk ocean circulation and de-oxygenation	Increased hypoxic dead zones	l	l/m	Large increase in risk	L/M	Temperate countries with upwelling	Temperate countries with upwelling	Deep sea	4	m	l	M
		Changes to upwelling productivity	l	m	Increase in risk	L/M	Most upwelling regions	Most upwelling regions	Some upwelling systems	4	l	l	M

Table 3.5 (continued)

Sector	Physical climate change drivers	Nature of risk	Global risks at 1.5°C of global warming above pre-industrial	Global risks at 2°C of global warming above pre-industrial	Change in risk when moving from 1.5°C to 2°C of warming	Confidence in risk statements	Regions where risks are particularly high with 2°C of global warming	Regions where the change in risk when moving from 1.5°C to2°C are particularly high	Regions with little or no information	RFC*	Adaptation potential at 1.5°C	Adaptation potential at 2°C	Confidence in assigning adaptation potential
Ocean	Intensified storms, precipitation plus sea level rise	Loss of coastal ecosystems	h	h/vh	Large increase in risk	H	Tropical/ subtropical countries	Tropical/ subtropical countries		1, 4	m	l	M
		Inundation and destruction of human/coastal infrastructure and livelihoods	h	h/vh	Large increase in risk	H	Global	Global		1, 5	m/h	m	M/L
	Loss of sea ice	Loss of habitat	h	vh	Large increase in risk	H	Polar regions	Polar regions		1	l	very l	H
		Increased productivity but changing fisheries	l/m	m/h	Large increase in risk	very H	Polar regions	Polar regions		1, 4	l	m/l	H
Coastal	Sea level rise, increased storminess	Area exposed (assuming no defences)	562–575th km^2 when 1.5°C first reached[6,7,8]	590–613th km^2 when 2°C first reached[6,7,8]	Increasing; 25–38th km^2 when temperatures are first reached, 10–17th km^2 in 2100 increasing to 16–230th km^2 in 2300[6,7,8]	M/H (dependent on population datasets)	Asia, small islands	Asia, small islands	Small islands	2, 3	m	m	M
		Population exposed (assuming no defences)	128–143 million when 1.5°C first reached	141–151 million when 2°C first reached	Increasing; 13–8 million when temperatures are first reached, 0–6 million people in 2100, increasing to 35–95 million people in 2300[6]	M/H (dependent on population datasets)	Asia, small islands	Asia, small islands	Small islands	2, 3	m	m	M
		People at risk accounting for defences (modelled in 1995)	2–28 million people yr^{-1} if defences are not upgraded from the modelled 1995 baseline[9]	15–53 million people yr^{-1} if defences are not upgraded from the modelled 1995 baseline[9]	Increasing with time, but highly dependent on adaptation[9]	M/H (dependent on adaptation)	Asia, small islands, potentially African nations	Asia, small islands	Small islands	2, 3, 4	m	m	M

Table 3.5 (continued)

Sector	Physical climate change drivers	Nature of risk	Global risks at 1.5°C of global warming above pre-industrial	Global risks at 2°C of global warming above pre-industrial	Change in risk when moving from 1.5°C to 2°C of warming	Confidence in risk statements	Regions where risks are particularly high with 2°C of global warming	Regions where the change in risk when moving from 1.5°C to2°C are particularly high	Regions with little or no information	RFC*	Adaptation potential at 1.5°C	Adaptation potential at 2°C	Confidence in assigning adaptation potential
Food security and food production systems	Heat and cold stress, warming, precipitation, drought	Changes in ecosystem production	m/h	h	Large increase	M/H	Global	North America, Central and South America, Mediterranean basin, South Africa, Australia, Asia		2, 4, 5	h	m/h	M/H
	Heat and cold stress, warming, precipitation drought	Shift and composition change of biomes (major ecosystem types)	m/h	h	Moderate increase	L/M	Global	Global, tropical areas, Mediterranean	Africa, Asia	1, 2, 3, 4	l/m	l	L/M
Human health	Temperature	Heat-related morbidity and mortality	m	m/h	Risk increased	VH	All regions at risk	All regions	Africa	2, 3, 4	h	h	H
		Occupational heat stress	m	m/h	Risk increased	M	Tropical regions	Tropical regions	Africa	2, 3, 4	h	m	M
	Air quality	Ozone-related mortality	m (if precursor emissions remain the same)	m/h (if precursor emissions remain the same)	Risk increased	H	High income and emerging economies	High income and emerging economies	Africa, parts of Asia	2, 3, 4	l	l	M
	Temperature, precipitation	Undernutrition	m	m/h	Risk increased	H	Low-income countries in Africa and Asia	Low-income countries in Africa and Asia	Small islands	2, 3, 4	m	l	M
Key economic sectors	Temperature	Tourism (sun, beach, and snow sports)	m/h	h	Risk increased	VH	Coastal tourism, particularly in subtropical and tropical regions	Coastal tourism, particularly in subtropical and tropical regions	Africa	1, 2, 3	m	l	H

*RFC: 1 = unique and threatened systems, 2 = extreme events, 3 = unequal distribution of impacts, 4 = global aggregate impacts (economic + biodiversity), 5 = large-scale singular events.

PDSI-based drought estimates tend to overestimate drought impacts (see Section 3.3.4); hence projections with other drought indices may differ. Further quantifications may be found in Table 3.SM.1

[1] Gerten et al., 2013; [2] Alfieri et al., 2017; [3] Liu et al., 2018; [4] Warren et al., 2018a; [5] Warzawski et al., 2013; [6] Brown et al., 2018a; [7] Rasmussen et al., 2018; [8] Yokoki et al., 2018; [9] Nicholls et al., 2018.

3.4.13 Synthesis of Key Elements of Risk

Some elements of the assessment in Section 3.4 were synthesized into Figure 3.18 and 3.20, indicating the overall risk for a representative set of natural and human systems from increases in global mean surface temperature (GMST) and anthropogenic climate change. The elements included are supported by a substantive enough body of literature providing at least *medium confidence* in the assessment. The format for Figures 3.18 and 3.20 match that of Figure 19.4 of WGII AR5 Chapter 19 (Oppenheimer et al., 2014) indicating the levels of additional risk as colours: undetectable (white) to moderate (detected and attributed; yellow), from moderate to high (severe and widespread; red), and from high to very high (purple), the last of which indicates significant irreversibility or persistence of climate-related hazards combined with a much reduced capacity to adapt. Regarding the transition from undetectable to moderate, the impact literature assessed in AR5 focused on describing and quantifying linkages between weather and climate patterns and impact outcomes, with limited detection and attribution to anthropogenic climate change (Cramer et al., 2014). A more recent analysis of attribution to greenhouse gas forcing at the global scale (Hansen and Stone, 2016) confirmed that the impacts related to changes in regional atmospheric and ocean temperature can be confidently attributed to anthropogenic forcing, while attribution to anthropogenic forcing of those impacts related to precipitation is only weakly evident or absent. Moreover, there is no strong direct relationship between the robustness of climate attribution and that of impact attribution (Hansen and Stone, 2016).

The current synthesis is complementary to the synthesis in Section 3.5.2 that categorizes risks into 'Reasons for Concern' (RFCs), as described in Oppenheimer et al. (2014). Each element, or burning ember, presented here (Figures 3.18, 3.20) maps to one or more RFCs (Figure 3.21). It should be emphasized that risks to the elements assessed here are only a subset of the full range of risks that contribute to the RFCs. Figures 3.18 and 3.20 are not intended to replace the RFCs but rather to indicate how risks to particular elements of the Earth system accrue with global warming, through the visual burning embers format, with a focus on levels of warming of 1.5°C and 2°C. Key evidence assessed in earlier parts of this chapter is summarized to indicate the transition points between the levels of risk. In this regard, the assessed confidence in assigning the transitions between risk levels are as follows: L=Low, M=Medium, H=High, and VH=Very high levels of confidence. A detailed account of the procedures involved is provided in the Supplementary Material (3.SM.3.2 and 3.SM.3.3).

In terrestrial ecosystems (feeding into RFC1 and RFC4), detection and attribution studies show that impacts of climate change on terrestrial ecosystems began to take place over the past few decades, indicating a transition from no risk (white areas in Figure 3.20) to moderate risk below recent temperatures (*high confidence*) (Section 3.4.3). Risks to unique and threatened terrestrial ecosystems are generally projected to be higher under warming of 2°C compared to 1.5°C (Section 3.5.2.1), while at the global scale severe and widespread risks are projected to occur by 2°C of warming. These risks are associated with biome shifts and species range losses (Sections 3.4.3 and 3.5.2.4); however, because many systems and species are projected to be unable to adapt to levels of warming below 2°C, the transition to high risk (red areas in Figure 3.20) is located below 2°C (*high confidence*). With 3°C of warming, however, biome shifts and species range losses are expected to escalate to very high levels, and the systems are projected to have very little capacity to adapt (Figure 3.20) (*high confidence*) (Section 3.4.3).

In the Arctic (related to RFC1), the increased rate of summer sea ice melt was detected and attributed to climate change by the year 2000 (corresponding to warming of 0.7°C), indicating moderate risk. At 1.5°C of warming an ice-free Arctic Ocean is considered *unlikely*, whilst by 2°C of warming it is considered *likely* and this unique ecosystem is projected to be unable to adapt. Hence, a transition from high to very high risk is expected between 1.5°C and 2°C of warming.

For warm-water coral reefs, there is *high confidence* in the transitions between risk levels, especially in the growing impacts in the transition of warming from non-detectable (0.2°C to 0.4°C), and then successively higher levels risk until high and very high levels of risks by 1.2°C (Section 3.4.4 and Box 3.4). This assessment considered the heatwave-related loss of 50% of shallow water corals across hundreds of kilometres of the world's largest continuous coral reef system, the Great Barrier Reef, as well as losses at other sites globally. The major increase in the size and loss of coral reefs over the past three years, plus sequential mass coral bleaching and mortality events on the Great Barrier Reef, (Hoegh-Guldberg, 1999; Hughes et al., 2017b, 2018), have reinforced the scale of climate-change related risks to coral reefs. General assessments of climate-related risks for mangroves prior to this special report concluded that they face greater risks from deforestation and unsustainable coastal development than from climate change (Alongi, 2008; Hoegh-Guldberg et al., 2014; Gattuso et al., 2015). Recent climate-related die-offs (Duke et al., 2017; Lovelock et al., 2017), however, suggest that climate change risks may have been underestimated for mangroves as well, and risks have thus been assessed as undetectable to moderate, with the transition now starting at 1.3°C as opposed to 1.8°C as assessed in 2015 (Gattuso et al., 2015). Risks of impacts related to climate change on small-scale fisheries at low latitudes, many of which are dependent on ecosystems such as coral reefs and mangroves, are moderate today but are expected to reach high levels of risk around 0.9°C–1.1°C (*high confidence*) (Section 3.4.4.10).

The transition from undetectable to moderate risk (related to RFCs 3 and 4), shown as white to yellow in Figure 3.20, is based on AR5 WGII Chapter 7, which indicated with *high confidence* that climate change impacts on crop yields have been detected and attributed to climate change, and the current assessment has provided further evidence to confirm this (Section 3.4.6). Impacts have been detected in the tropics (AR5 WGII Chapters 7 and 18), and regional risks are projected to become high in some regions by 1.5°C of warming, and in many regions by 2.5°C, indicating a transition from moderate to high risk between 1.5°C and 2.5°C of warming (*medium confidence*).

Impacts from fluvial flooding (related to RFCs 2, 3 and 4) depend on the frequency and intensity of the events, as well as the extent of exposure and vulnerability of society (i.e., socio-economic conditions and the effect of non-climate stressors). Moderate risks posed by 1.5°C of warming are expected to continue to increase with higher levels of warming (Sections 3.3.5 and 3.4.2), with projected risks being threefold the current risk in economic damages due to flooding in 19 countries for warming of 2°C, indicating a transition to high risk at this level (*medium confidence*). Because few studies have assessed the potential to adapt to these risks, there was insufficient evidence to locate a transition to very high risk (purple).

Climate-change induced sea level rise (SLR) and associated coastal flooding (related to RFCs 2, 3 and 4) have been detectable and attributable since approximately 1970 (Slangen et al., 2016), during which time temperatures have risen by 0.3°C (*medium confidence*) (Section 3.3.9). Analysis suggests that impacts could be more widespread in sensitive systems such as small islands (*high confidence*) (Section 3.4.5.3) and increasingly widespread by the 2070s (Brown et al., 2018a) as temperatures rise from 1.5°C to 2°C, even when adaptation measures are considered, suggesting a transition to high risk (Section 3.4.5). With 2.5°C of warming, adaptation limits are expected to be exceeded in sensitive areas, and hence a transition to very high risk is projected. Additionally, at this temperature, sea level rise could have adverse effects for centuries, posing significant risk to low-lying areas (*high confidence*) (Sections 3.4.5.7 and 3.5.2.5).

For heat-related morbidity and mortality (related to RFCs 2, 3 and 4), detection and attribution studies show heat-related mortality in some locations increasing with climate change (*high confidence*) (Section 3.4.7; Ebi et al., 2017). The projected risks of heat-related morbidity and mortality are generally higher under warming of 2°C than 1.5°C (*high confidence*), with projections of greater exposure to high ambient temperatures and increased morbidity and mortality (Section 3.4.7). Risk levels will depend on the rate of warming and the (related) level of adaptation, so a transition in risk from moderate (yellow) to high (red) is located between 1°C and 3°C (*medium confidence*).

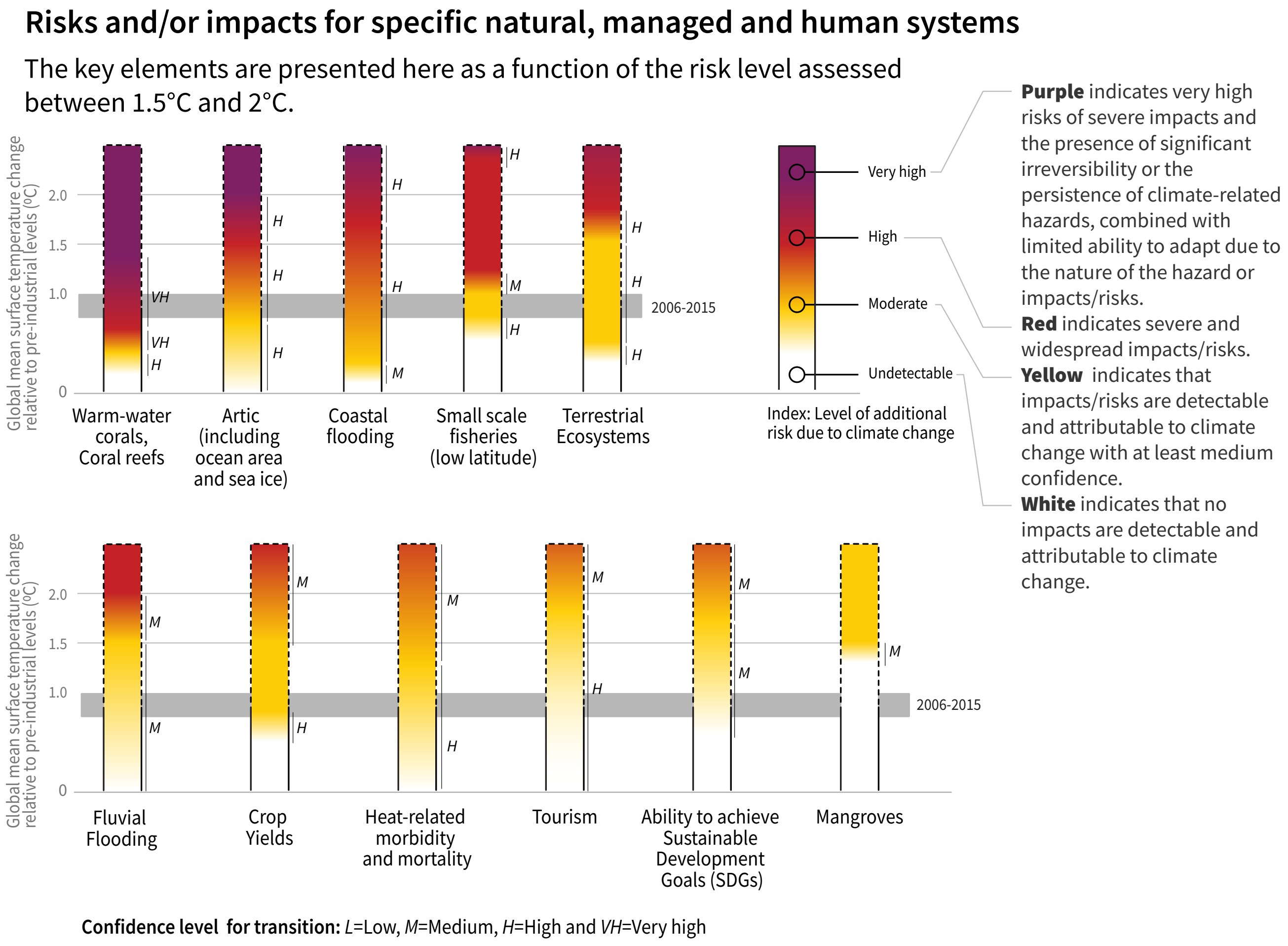


Figure 3.20 | The dependence of risks and/or impacts associated with selected elements of human and natural systems on the level of climate change, adapted from Figure 3.21 and from AR5 WGII Chapter 19, Figure 19.4, and highlighting the nature of this dependence between 0°C and 2°C warming above pre-industrial levels. The selection of impacts and risks to natural, managed and human systems is illustrative and is not intended to be fully comprehensive. Following the approach used in AR5, literature was used to make expert judgements to assess the levels of global warming at which levels of impact and/or risk are undetectable (white), moderate (yellow), high (red) or very high (purple). The colour scheme thus indicates the additional risks due to climate change. The transition from red to purple, introduced for the first time in AR4, is defined by a very high risk of severe impacts and the presence of significant irreversibility or persistence of climate-related hazards combined with limited ability to adapt due to the nature of the hazard or impact. Comparison of the increase of risk across RFCs indicates the relative sensitivity of RFCs to increases in GMST. As was done previously, this assessment takes autonomous adaptation into account, as well as limits to adaptation independently of development pathway. The levels of risk illustrated reflect the judgements of the authors of Chapter 3 and Gattuso et al. (2015; for three marine elements). The grey bar represents the range of GMST for the most recent decade: 2006–2015.

For tourism (related to RFCs 3 and 4), changing weather patterns, extreme weather and climate events, and sea level rise are affecting many – but not all – global tourism investments, as well as environmental and cultural destination assets (Section 3.4.4.12), with 'last chance to see' tourism markets developing based on observed impacts on environmental and cultural heritage (Section 3.4.9.1), indicating a transition from undetectable to moderate risk between 0°C and 1.5°C of warming (*high confidence*). Based on limited analyses, risks to the tourism sector are projected to be larger at 2°C than at 1.5°C, with impacts on climate-sensitive sun, beach and snow sports tourism markets being greatest. The degradation or loss of coral reef systems is expected to increase the risks to coastal tourism in subtropical and tropical regions. A transition in risk from moderate to high levels of added risk from climate change is projcted to occur between 1.5°C and 3°C (*medium confidence*).

Climate change is already having large scale impacts on ecosystems, human health and agriculture, which is making it much more difficult to reach goals to eradicate poverty and hunger, and to protect health and life on land (Sections 5.1 and 5.2.1 in Chapter 5), suggesting a transition from undetectable to moderate risk for recent temperatures at 0.5°C of warming (*medium confidence*). Based on the limited analyses available, there is evidence and agreement that the risks to sustainable development are considerably less at 1.5°C than 2°C (Section 5.2.2), including impacts on poverty and food security. It is easier to achieve many of the sustainable development goals (SDGs) at 1.5°C, suggesting that a transition to higher risk will not begin yet at this level. At 2°C and higher levels of warming (e.g., RCP8.5), however, there are high risks of failure to meet SDGs such as eradicating poverty and hunger, providing safe water, reducing inequality and protecting ecosystems, and these risks are projected to become severe and widespread if warming increases further to about 3°C (*medium confidence*) (Section 5.2.3).

Disclosure statement: The selection of elements depicted in Figures 3.18 and 3.20 is not intended to be fully comprehensive and does not necessarily include all elements for which there is a substantive body of literature, nor does it necessarily include all elements which are of particular interest to decision-makers.

3.5 Avoided Impacts and Reduced Risks at 1.5°C Compared with 2°C of Global Warming

3.5.1 Introduction

Oppenheimer et al. (2014, AR5 WGII Chapter 19) provided a framework that aggregates projected risks from global mean temperature change into five categories identified as 'Reasons for Concern'. Risks are classified as moderate, high or very high and coloured yellow, red or purple, respectively, in Figure 19.4 of that chapter (AR5 WGII Chapter 19 for details and findings). The framework's conceptual basis and the risk judgements made by Oppenheimer et al. (2014) were recently reviewed, and most judgements were confirmed in the light of more recent literature (O'Neill et al., 2017). The approach of Oppenheimer et al. (2014) was adopted, with updates to the aggregation of risk informed by the most recent literature, for the analysis of avoided impacts at 1.5°C compared to 2°C of global warming presented in this section.

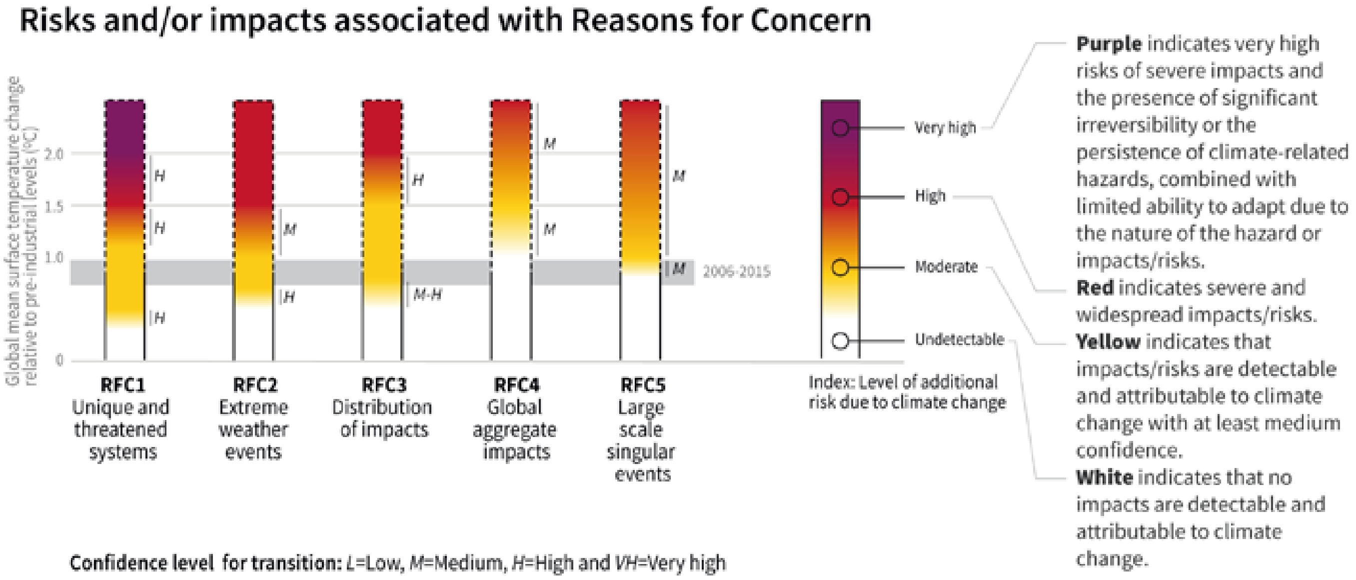
The regional economic benefits that could be obtained by limiting the global temperature increase to 1.5°C of warming, rather than 2°C or higher levels, are discussed in Section 3.5.3 in the light of the five RFCs explored in Section 3.5.2. Climate change hotspots that could be avoided or reduced by achieving the 1.5°C target are summarized in Section 3.5.4. The section concludes with a discussion of regional tipping points that could be avoided at 1.5°C compared to higher degrees of global warming (Section 3.5.5).

3.5.2 Aggregated Avoided Impacts and Reduced Risks at 1.5°C versus 2°C of Global Warming

A brief summary of the accrual of RFCs with global warming, as assessed in WGII AR5, is provided in the following sections, which leads into an update of relevant literature published since AR5. The new literature is used to confirm the levels of global warming at which risks are considered to increase from undetectable to moderate, from moderate to high, and from high to very high. Figure 3.21 modifies Figure 19.4 from AR5 WGII, and the following text in this subsection provides justification for the modifications. O'Neill et al. (2017) presented a very similar assessment to that of WGII AR5, but with further discussion of the potential to create 'embers' specific to socio-economic scenarios in the future. There is insufficient literature to do this at present, so the original, simple approach has been used here. As the focus of the present assessment is on the consequences of global warming of 1.5°C–2°C above the pre-industrial period, no assessment for global warming of 3°C or more is included in the figure (i.e., analysis is discontinued at 2.5°C).

3.5.2.1 RFC 1 – Unique and threatened systems

WGII AR5 Chapter 19 found that some unique and threatened systems are at risk from climate change at current temperatures, with increasing numbers of systems at potential risk of severe consequences at global warming of 1.6°C above pre-industrial levels. It was also observed that many species and ecosystems have a limited ability to adapt to the very large risks associated with warming of 2.6°C or more, particularly Arctic sea ice and coral reef systems (*high confidence*). In the AR5 analysis, a transition from white to yellow indicated that the onset of moderate risk was located below present-day global temperatures (*medium confidence*); a transition from yellow to red indicated that the onset of high risk was located at 1.6°C, and a transition from red to purple indicated that the onset of very high risk was located at about 2.6°C. This WGII AR5 analysis already implied that there would be a significant reduction in risks to unique and threatened systems if warming were limited to 1.5°C compared with 2°C. Since AR5, evidence of present-day impacts in these systems has continued to grow (Sections 3.4.2, 3.4.4 and 3.4. 5), whilst new evidence has also accumulated for reduced risks at 1.5°C compared to 2°C of warming in Arctic ecosystems (Section 3.3.9), coral reefs (Section 3.4.4) and some other unique ecosystems (Section 3.4.3), as well as for biodiversity.



Risks and/or impacts associated with Reasons for Concern

Purple indicates very high risks of severe impacts and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.

Red indicates severe and widespread impacts/risks.

Yellow indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.

White indicates that no impacts are detectable and attributable to climate change.

Confidence level for transition: *L*=Low, *M*=Medium, *H*=High and *VH*=Very high

Figure 3.21 | The dependence of risks and/or impacts associated with the Reasons for Concern (RFCs) on the level of climate change, updated and adapted from WGII AR5 Ch 19, Figure 19.4 and highlighting the nature of this dependence between 0°C and 2°C warming above pre-industrial levels. As in the AR5, literature was used to make expert judgements to assess the levels of global warming at which levels of impact and/or risk are undetectable (white), moderate (yellow), high (red) or very high (purple). The colour scheme thus indicates the additional risks due to climate change. The transition from red to purple, introduced for the first time in AR4, is defined by very high risk of severe impacts and the presence of significant irreversibility, or persistence of climate-related hazards combined with a limited ability to adapt due to the nature of the hazard or impact. Comparison of the increase of risk across RFCs indicates the relative sensitivity of RFCs to increases in GMST. As was done previously, this assessment takes autonomous adaptation into account, as well as limits to adaptation (RFC 1, 3, 5) independently of development pathway. The rate and timing of impacts were taken into account in assessing RFC 1 and 5. The levels of risk illustrated reflect the judgements of the Ch 3 authors. **RFC1 Unique and threatened systems:** ecological and human systems that have restricted geographic ranges constrained by climate related conditions and have high endemism or other distinctive properties. Examples include coral reefs, the Arctic and its indigenous people, mountain glaciers and biodiversity hotspots. **RFC2 Extreme weather events:** risks/impacts to human health, livelihoods, assets and ecosystems from extreme weather events such as heatwaves, heavy rain, drought and associated wildfires, and coastal flooding. **RFC3 Distribution of impacts:** risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability. **RFC4 Global aggregate impacts:** global monetary damage, global scale degradation and loss of ecosystems and biodiversity. **RFC5 Large-scale singular events:** are relatively large, abrupt and sometimes irreversible changes in systems that are caused by global warming. Examples include disintegration of the Greenland and Antarctic ice sheets. The grey bar represents the range of GMST for the most recent decade: 2006–2015.

New literature since AR5 has provided a closer focus on the comparative levels of risk to coral reefs at 1.5°C versus 2°C of global warming. As assessed in Section 3.4.4 and Box 3.4, reaching 2°C will increase the frequency of mass coral bleaching and mortality to a point at which it will result in the total loss of coral reefs from the world's tropical and subtropical regions. Restricting overall warming to 1.5°C will still see a downward trend in average coral cover (70–90% decline by mid-century) but will prevent the total loss of coral reefs projected with warming of 2°C (Frieler et al., 2013). The remaining reefs at 1.5°C will also benefit from increasingly stable ocean conditions by the mid-to-late 21st century. Limiting global warming to 1.5°C during the course of the century may, therefore, open the window for many ecosystems to adapt or reassort geographically. This indicates a transition in risk in this system from high to very high (*high confidence*) at 1.5°C of warming and contributes to a lowering of the transition from high to very high (Figure 3.21) in this RFC1 compared to in AR5. Further details of risk transitions for ocean systems are described in Figure 3.18.

Substantial losses of Arctic Ocean summer ice were projected in WGI AR5 for global warming of 1.6°C, with a nearly ice-free Arctic Ocean being projected for global warming of more than 2.6°C. Since AR5, the importance of a threshold between 1°C and 2°C has been further emphasized in the literature, with sea ice projected to persist throughout the year for a global warming of less than 1.5°C, yet chances of an ice-free Arctic during summer being high at 2°C of warming (Section 3.3.8). Less of the permafrost in the Arctic is projected to thaw under 1.5°C of warming (17–44%) compared with under 2°C (28–53%) (Section 3.3.5.2; Chadburn et al., 2017), which is expected to reduce risks to both social and ecological systems in the Arctic. This indicates a transition in the risk in this system from high to very high between 1.5°C and 2°C of warming and contributes to a lowering of the transition from high to very high in this RFC1 compared to in AR5.

AR5 identified a large number of threatened systems, including mountain ecosystems, highly biodiverse tropical wet and dry forests, deserts, freshwater systems and dune systems. These include Mediterranean areas in Europe, Siberian, tropical and desert ecosystems in Asia, Australian rainforests, the Fynbos and succulent Karoo areas of South Africa, and wetlands in Ethiopia, Malawi, Zambia and Zimbabwe. In all these systems, impacts accrue with greater warming and impacts at 2°C are expected to be greater than those at 1.5°C (*medium confidence*). One study since AR5 has shown that constraining global warming to 1.5°C would maintain the functioning of prairie pothole ecosystems in North America in terms of their productivity and biodiversity, whilst warming of 2°C would not do so (Johnson et al., 2016). The large proportion of insects projected to lose over half their range at 2°C of warming (25%) compared to at 1.5°C (9%) also suggests a significant loss of functionality in these threatened systems at 2°C of warming, owing to the critical role of insects in nutrient cycling, pollination, detritivory and other important ecosystem processes (Section 3.4.3).

Unique and threatened systems in small island states and in systems fed by glacier meltwater were also considered to contribute to this RFC in AR5, but there is little new information about these systems that pertains to 1.5°C or 2°C of global warming. Taken together, the evidence suggests that the transition from high to very high risk in unique and threatened systems occurs at a lower level of warming, between 1.5°C and 2°C (*high confidence*), than in AR5, where this transition was located at 2.6°C. The transition from moderate to high risk relocates very slightly from 1.6°C to 1.5°C (*high confidence*). There is also *high confidence* in the location of the transition from low to moderate risk below present-day global temperatures.

3.5.2.2 RFC 2 – Extreme weather events

Reduced risks in terms of the likelihood of occurrence of extreme weather events are discussed in this sub-subsection for 1.5°C as compared to 2°C of global warming, for those extreme events where evidence is currently available based on the assessments of Section 3.3. AR5 assigned a moderate level of risk from extreme weather events at recent temperatures (1986–2005) owing to the attribution of heat and precipitation extremes to climate change, and a transition to high risk beginning below 1.6°C of global warming based on the magnitude, likelihood and timing of projected changes in risk associated with extreme events, indicating more severe and widespread impacts. The AR5 analysis already suggested a significant benefit of limiting warming to 1.5°C, as doing so might keep risks closer to the moderate level. New literature since AR5 has provided greater confidence in a reduced level of risks due to extreme weather events at 1.5°C versus 2°C of warming for some types of extremes (Section 3.3 and below; Figure 3.21).

Temperature: It is expected that further increases in the number of warm days/nights and decreases in the number of cold days/nights, and an increase in the overall temperature of hot and cold extremes would occur under 1.5°C of global warming relative to pre-industrial levels (*high confidence*) compared to under the present-day climate (1°C of warming), with further changes occurring towards 2°C of global warming (Section 3.3). As assessed in Sections 3.3.1 and 3.3.2, impacts of 0.5°C of global warming can be identified for temperature extremes at global scales, based on observations and the analysis of climate models. At 2°C of global warming, it is *likely* that temperature increases of more than 2°C would occur over most land regions in terms of extreme temperatures (up to 4°C–6°C depending on region and considered extreme index) (Section 3.3.2, Table 3.2). Regional increases in temperature extremes can be robustly limited if global warming is constrained to 1.5°C, with regional warmings of up to 3°C–4.5°C (Section 3.3.2, Table 3.2). Benefits obtained from this general reduction in extremes depend to a large extent on whether the lower range of increases in extremes at 1.5°C is sufficient for critical thresholds to be exceeded, within the context of wide-ranging aspects such as crop yields, human health and the sustainability of ecosystems.

Heavy precipitation: AR5 assessed trends in heavy precipitation for land regions where observational coverage was sufficient for assessment. It concluded with *medium confidence* that anthropogenic forcing has contributed to a global-scale intensification of heavy precipitation over the second half of the 20th century, for a global warming of approximately 0.5°C (Section 3.3.3). A recent observation-based study likewise showed that a 0.5°C increase in global mean temperature has had a detectable effect on changes in precipitation extremes at the global scale (Schleussner et al., 2017), thus suggesting that there would be detectable differences in heavy precipitation at 1.5°C and 2°C of global warming. These results are consistent with analyses of climate projections, although they also highlight a large amount of regional variation in the sensitivity of changes in heavy precipitation (Section 3.3.3).

Droughts: When considering the difference between precipitation and evaporation (P–E) as a function of global temperature changes, the subtropics generally display an overall trend towards drying, whilst the northern high latitudes display a robust response towards increased wetting (Section 3.3.4, Figure 3.12). Limiting global mean temperature increase to 1.5°C as opposed to 2°C could substantially reduce the risk of reduced regional water availability in some regions (Section 3.3.4). Regions that are projected to benefit most robustly from restricted warming include the Mediterranean and southern Africa (Section 3.3.4).

Fire: Increasing evidence that anthropogenic climate change has already caused significant increases in fire area globally (Section 3.4.3) is in line with projected fire risks. These risks are projected to increase further under 1.5°C of global warming relative to the present day (Section 3.4.3). Under 1.2°C of global warming, fire frequency has been estimated to increase by over 37.8% of global land areas, compared to 61.9% of global land areas under 3.5°C of warming. For in-depth discussion and uncertainty estimates, see Meehl et al. (2007), Moritz et al. (2012) and Romero-Lankao et al. (2014).

Regarding extreme weather events (RFC2), the transition from moderate to high risk is located between 1°C and 1.5°C of global warming (Figure 3.21), which is very similar to the AR5 assessment but is assessed with greater confidence (*medium confidence*). The impact literature contains little information about the potential for human society to adapt to extreme weather events, and hence it has not been possible to locate the transition from high to very high risk within the context of assessing impacts at 1.5°C and 2°C of global warming. There is thus *low confidence* in the level at which global warming could lead to very high risks associated with extreme weather events in the context of this report.

3.5.2.3 RFC 3 – Distribution of impacts

Risks due to climatic change are unevenly distributed and are generally greater at lower latitudes and for disadvantaged people and communities in countries at all levels of development. AR5 located the transition from undetectable to moderate risk below recent temperatures, owing to the detection and attribution of regionally differentiated changes in crop yields (*medium to high confidence*; Figure 3.20), and new literature has continued to confirm this finding. Based on the assessment of risks to regional crop production and water resources, AR5 located the transition from moderate to high risk between 1.6°C and 2.6°C above pre-industrial levels. Cross-Chapter Box 6 in this chapter highlights that at 2°C of warming, new literature shows that risks of food shortage are projected to emerge in the African Sahel, the Mediterranean, central Europe, the Amazon, and western and southern Africa, and that these are much larger than the corresponding risks at 1.5°C. This suggests a transition from moderate to high risk of regionally differentiated impacts between 1.5°C and 2°C above pre-industrial levels for food security (*medium confidence*) (Figure 3.20). Reduction in the availability of water resources at 2°C is projected to be greater than 1.5°C of global warming, although changes in socio-economics could have a greater influence (Section 3.4.2), with larger risks in the Mediterranean (Box 3.2); estimates of the magnitude of the risks remain similar to those cited in AR5. Globally, millions of people may be at risk from sea level rise (SLR) during the 21st century (Hinkel et al., 2014; Hauer et al., 2016), particularly if adaptation is limited. At 2°C of warming, more than 90% of global coastlines are projected to experience SLR greater than 0.2 m, suggesting regional differences in the risks of coastal flooding. Regionally differentiated multi-sector risks are already apparent at 1.5°C of warming, being more prevalent where vulnerable people live, predominantly in South Asia (mostly Pakistan, India and China), but these risks are projected to spread to sub-Saharan Africa, the Middle East and East Asia as temperature rises, with the world's poorest people disproportionately impacted at 2°C of warming (Byers et al., 2018). The hydrological impacts of climate change in Europe are projected to increase in spatial extent and intensity across increasing global warming levels of 1.5°C, 2°C and 3°C (Donnelly et al., 2017). Taken together, a transition from moderate to high risk is now located between 1.5°C and 2°C above pre-industrial levels, based on the assessment of risks to food security, water resources, drought, heat exposure and coastal submergence (*high confidence*; Figure 3.21).

3.5.2.4 RFC 4 – Global aggregate impacts

Oppenheimer et al. (2014) explained the inclusion of non-economic metrics related to impacts on ecosystems and species at the global level, in addition to economic metrics in global aggregate impacts. The degradation of ecosystem services by climate change and ocean acidification have generally been excluded from previous global aggregate economic analyses.

Global economic impacts: WGII AR5 found that overall global aggregate impacts become moderate at 1°C–2°C of warming, and the transition to moderate risk levels was therefore located at 1.6°C above pre-industrial levels. This was based on the assessment of literature using model simulations which indicated that the global aggregate economic impact will become significantly negative between 1°C and 2°C of warming (*medium confidence*), whilst there will be a further increase in the magnitude and likelihood of aggregate economic risks at 3°C of warming (*low confidence*).

Since AR5, three studies have emerged using two entirely different approaches which indicate that economic damages are projected to be higher by 2100 if warming reaches 2°C than if it is constrained to 1.5°C. The study by Warren et al. (2018c) used the integrated assessment model PAGE09 to estimate that avoided global economic damages of 22% (10–26%) accrue from constraining warming to 1.5°C rather than 2°C, 90% (77–93%) from 1.5°C rather than 3.66°C, and 87% (74–91%) from 2°C rather than 3.66°C. In the second study, Pretis et al. (2018) identified several regions where economic damages are projected to be greater at 2°C compared to 1.5°C of warming, further estimating that projected damages at 1.5°C remain similar to today's levels of economic damage. The third study, by M. Burke et al. (2018) used an empirical, statistical approach and found that limiting warming to 1.5°C instead of 2°C would save 1.5–2.0% of the gross world product (GWP) by mid-century and 3.5% of the GWP by end-of-century (see Figure 2A in M. Burke et al., 2018). Based on a 3% discount rate, this corresponds to 8.1–11.6 trillion USD and 38.5 trillion USD in avoided damages by mid- and end-of-century, respectively, agreeing closely with the estimate by Warren et al. (2018c) of 15 trillion USD. Under the no-policy baseline scenario, temperature rises by 3.66°C by 2100, resulting in a global gross domestic product (GDP) loss of 2.6% (5–95% percentile range 0.5–8.2%), compared with 0.3% (0.1–0.5%) by 2100 under the 1.5°C scenario and 0.5% (0.1–1.0%) in the 2°C scenario. Limiting warming to 1.5°C rather than 2°C by 2060 has also been estimated to result in co-benefits of 0.5–0.6% of the world GDP, owing to reductions in air pollution (Shindell et al., 2018), which is similar to the avoided damages identified for the USA (Box 3.6).

Two studies focusing only on the USA found that economic damages are projected to be higher by 2100 if warming reaches 2°C than if it is constrained to 1.5°C. Hsiang et al. (2017) found a mean difference of 0.35% GDP (range 0.2–0.65%), while Yohe (2017) identified a GDP loss of 1.2% per degree of warming, hence approximately 0.6% for half a degree. Further, the avoided risks compared to a no-policy baseline are greater in the 1.5°C case (4%, range 2–7%) compared to the 2°C case (3.5%, range 1.8–6.5%). These analyses suggest that the point at which global aggregates of economic impacts become negative is below 2°C (*medium confidence*), and that there is a possibility that it is below 1.5°C of warming.

Oppenheimer et al. (2014) noted that the global aggregated damages associated with large-scale singular events has not been explored, and reviews of integrated modelling exercises have indicated a potential underestimation of global aggregate damages due to the lack of consideration of the potential for these events in many studies. Since AR5, further analyses of the potential economic consequences of triggering these large-scale singular events have indicated a two to eight fold larger economic impact associated with warming of 3°C than estimated in most previous analyses, with the extent of increase depending on the number of events incorporated. Lemoine and Traeger (2016) included only three known singular events whereas Y. Cai et al. (2016) included five.

Biome shifts, species range loss, increased risks of species extinction and risks of loss of ecosystem functioning and services: 13% (range 8–20%) of Earth's land area is projected to undergo biome shifts at 2°C of warming compared to approximately 7% at 1.5°C (*medium confidence*) (Section 3.4.3; Warszawski et al., 2013), implying a halving of biome transformations. Overall levels of species loss at 2°C of warming are similar to values found in previous studies for plants and vertebrates (Warren et al., 2013, 2018a), but insects have been found to be more sensitive to climate change, with 18% (6–35%) projected to lose over half their range at 2°C of warming compared to 6% (1–18%) under 1.5°C of warming, corresponding to a difference of 66% (Section 3.4.3). The critical role of insects in ecosystem functioning therefore suggests that there will be impacts on global ecosystem functioning already at 2°C of warming, whilst species that lose large proportions of their range are considered to be at increased risk of extinction (Section 3.4.3.3). Since AR5, new literature has indicated that impacts on marine fish stocks and fisheries are lower under 1.5°C–2°C of global warming relative to pre-industrial levels compared to under higher warming scenarios (Section 3.4.6), especially in tropical and polar systems.

In AR5, the transition from undetectable to moderate impacts was considered to occur between 1.6°C and 2.6°C of global warming reflecting impacts on the economy and on biodiversity globally, whereas high risks were associated with 3.6°C of warming to reflect the high risks to biodiversity and accelerated effects on the global economy. New evidence suggests moderate impacts on the global aggregate economy and global biodiversity by 1.5°C of warming, suggesting a lowering of the temperature level for the transition to moderate risk to 1.5°C (Figure 3.21). Further, recent literature points to higher risks than previously assessed for the global aggregate economy and global biodiversity by 2°C of global warming, suggesting that the transition to a high risk level is located between 1.5°C and 2.5°C of warming (Figure 3.21), as opposed to at 3.6°C as previously assessed (*medium confidence*).

3.5.2.5 RFC 5 – Large-scale singular events

Large-scale singular events are components of the global Earth system that are thought to hold the risk of reaching critical tipping points under climate change, and that can result in or be associated with major shifts in the climate system. These components include:

- the cryosphere: West Antarctic ice sheet, Greenland ice sheet
- the thermohaline circulation: slowdown of the Atlantic Meridional Overturning Circulation (AMOC)
- the El Niño–Southern Oscillation (ENSO) as a global mode of climate variability
- role of the Southern Ocean in the global carbon cycle

AR5 assessed that the risks associated with these events become moderate between 0.6°C and 1.6°C above pre-industrial levels, based on early warning signs, and that risk was expected to become high between 1.6°C and 4.6°C based on the potential for commitment to large irreversible sea level rise from the melting of land-based ice sheets (*low to medium confidence*). The increase in risk between 1.6°C and 2.6°C above pre-industrial levels was assessed to be disproportionately large. New findings since AR5 are described in detail below.

Greenland and West Antarctic ice sheets and marine ice sheet instability (MISI): Various feedbacks between the Greenland ice sheet and the wider climate system, most notably those related to the dependence of ice melt on albedo and surface elevation, make irreversible loss of the ice sheet a possibility. Church et al. (2013) assessed this threshold to be at 2°C of warming or higher levels relative to pre-industrial temperature. Robinson et al. (2012) found a range for this threshold of 0.8°C–3.2°C (95% confidence). The threshold of global temperature increase that may initiate irreversible loss of the West Antarctic ice sheet and marine ice sheet instability (MISI) is estimated to lie be between 1.5°C and 2°C. The time scale for eventual loss of the ice sheets varies between millennia and tens of millennia and assumes constant surface temperature forcing during this period. If temperature were to decline subsequently the ice sheets might regrow, although the amount of cooling required is likely to be highly dependent on the duration and rate of the previous retreat. The magnitude of global sea level rise that could occur over the next two centuries under 1.5°C–2°C of global warming is estimated to be in the order of several tenths of a metre according to most studies (*low confidence*) (Schewe et al., 2011; Church et al., 2013; Levermann et al., 2014; Marzeion and Levermann, 2014; Fürst et al., 2015; Golledge et al., 2015), although a smaller number of investigations (Joughin et al., 2014; Golledge et al., 2015; DeConto and Pollard, 2016) project increases of 1–2 m. This body of evidence suggests that the temperature range of 1.5°C–2°C may be regarded as representing moderate risk, in that it may trigger MISI in Antarctica or irreversible loss of the Greenland ice sheet and it may be associated with sea level rise by as much as 1–2 m over a period of two centuries.

Thermohaline circulation (slowdown of AMOC): It is *more likely than not* that the AMOC has been weakening in recent decades, given the detection of cooling of surface waters in the North Atlantic and evidence that the Gulf Stream has slowed since the late 1950s (Rahmstorf et al., 2015b; Srokosz and Bryden, 2015; Caesar et al., 2018). There is limited evidence linking the recent weakening of the AMOC to anthropogenic warming (Caesar et al., 2018). It is *very likely* that the AMOC will weaken over the 21st century. Best estimates and ranges for the reduction based on CMIP5 simulations are 11% (1–24%) in RCP2.6 and 34% (12–54%) in RCP8.5 (AR5). There is no evidence indicating significantly different amplitudes of AMOC weakening for 1.5°C versus 2°C of global warming, or of a shutdown of the AMOC at these global temperature thresholds. Associated risks are classified as low to moderate.

El Niño–Southern Oscillation (ENSO): Extreme El Niño events are associated with significant warming of the usually cold eastern Pacific Ocean, and they occur about once every 20 years (Cai et al., 2015). Such events reorganize the distribution of regions of organized convection and affect weather patterns across the globe. Recent research indicates that the frequency of extreme El Niño events increases linearly with the global mean temperature, and that the number of such events might double (one event every ten years) under 1.5°C of global warming (G. Wang et al., 2017). This pattern is projected to persist for a century after stabilization at 1.5°C, thereby challenging the limits to adaptation, and thus indicates high risk even at the 1.5°C threshold. La Niña event (the opposite or balancing event to El Niño) frequency is projected to remain similar to that of the present day under 1.5°C–2°C of global warming.

Role of the Southern Ocean in the global carbon cycle: The critical role of the Southern Ocean as a net sink of carbon might decline under global warming, and assessing this effect under 1.5°C compared to 2°C of global warming is a priority. Changes in ocean chemistry (e.g., oxygen content and ocean acidification), especially those associated with the deep sea, are associated concerns (Section 3.3.10).

For large-scale singular events (RFC5), moderate risk is now located at 1°C of warming and high risk is located at 2.5°C (Figure 3.21), as opposed to at 1.6°C (moderate risk) and around 4°C (high risk) in AR5, because of new observations and models of the West Antarctic ice sheet (*medium confidence*), which suggests that the ice sheet may be in the early stages of marine ice sheet instability (MISI). Very high risk is assessed as lying above 5°C because the growing literature on process-based projections of the West Antarctic ice sheet predominantly supports the AR5 assessment of an MISI contribution of several additional tenths of a metre by 2100.

3.5.3 Regional Economic Benefit Analysis for the 1.5°C versus 2°C Global Goals

This section reviews recent literature that has estimated the economic benefits of constraining global warming to 1.5°C compared to 2°C. The focus here is on evidence pertaining to specific regions, rather than on global aggregated benefits (Section 3.5.2.4). At 2°C of global warming, lower economic growth is projected for many countries than at 1.5°C of global warming, with low-income countries projected to experience the greatest losses (*low to medium confidence*) (M. Burke et al., 2018; Pretis et al., 2018). A critical issue for developing countries in particular is that advantages in some sectors are projected to be offset by increasing mitigation costs (Rogelj et al., 2013; M. Burke et al., 2018), with food production being a key factor. That is, although restraining the global temperature increase to 2°C is projected to reduce crop losses under climate change relative to higher levels of warming, the associated mitigation costs may increase the risk of hunger in low-income countries (*low confidence*) (Hasegawa et al., 2016). It is *likely* that the even more stringent mitigation measures required to restrict global warming to 1.5°C (Rogelj et al., 2013) will further increase these mitigation costs and impacts. International trade in food might be a key response measure for alleviating hunger in developing countries under 1.5°C and 2°C stabilization scenarios (IFPRI, 2018).

Although warming is projected to be the highest in the Northern Hemisphere under 1.5°C or 2°C of global warming, regions in the tropics and Southern Hemisphere subtropics are projected to experience the largest impacts on economic growth (*low to medium confidence*) (Gallup et al., 1999; M. Burke et al., 2018; Pretis et al., 2018). Despite the uncertainties associated with climate change projections and econometrics (e.g., M. Burke et al., 2018), it is *more likely than not* that there will be large differences in economic growth under 1.5°C and 2°C of global warming for developing versus developed countries (M. Burke et al., 2018; Pretis et al., 2018). Statistically significant reductions in gross domestic product (GDP) per capita growth are projected across much of the African continent, Southeast Asia, India, Brazil and Mexico (*low to medium confidence*). Countries in the western parts of tropical Africa are projected to benefit most from restricting global warming to 1.5°C, as opposed to 2°C, in terms of future economic growth (Pretis et al., 2018). An important reason why developed countries in the tropics and subtropics are projected to benefit substantially from restricting global warming to 1.5°C is that present-day temperatures in these regions are above the threshold thought to be optimal for economic production (M. Burke et al., 2015b, 2018).

The world's largest economies are also projected to benefit from restricting warming to 1.5°C as opposed to 2°C (*medium confidence*), with the likelihood of such benefits being realized estimated at 76%, 85% and 81% for the USA, China and Japan, respectively (M. Burke et al., 2018). Two studies focusing only on the USA found that economic damages are projected to be higher by 2100 if warming reaches 2°C than if it is constrained to 1.5°C. Yohe (2017) found a mean difference of 0.35% GDP (range 0.2–0.65%), while Hsiang et al. (2017) identified a GDP loss of 1.2% per degree of warming, hence approximately 0.6% for half a degree. Overall, no statistically significant changes in GDP are projected to occur over most of the developed world under 1.5°C of global warming in comparison to present-day conditions, but under 2°C of global warming impacts on GDP are projected to be generally negative (*low confidence*) (Pretis et al., 2018).

A caveat to the analyses of Pretis et al. (2018) and M. Burke et al. (2018) is that the effects of sea level rise were not included in the estimations of damages or future economic growth, implying a potential underestimation of the benefits of limiting warming to 1.5°C for the case where significant sea level rise is avoided at 1.5°C but not at 2°C.

3.5.4 Reducing Hotspots of Change for 1.5°C and 2°C of Global Warming

This subsection integrates Sections 3.3 and 3.4 in terms of climate-change-induced hotspots that occur through interactions across the physical climate system, ecosystems and socio-economic human systems, with a focus on the extent to which risks can be avoided or reduced by achieving the 1.5°C global warming goal (as opposed to the 2°C goal). Findings are summarized in Table 3.6.

3.5.4.1 Arctic sea ice

Ice-free Arctic Ocean summers are *very likely* at levels of global warming higher than 2°C (Notz and Stroeve, 2016; Rosenblum and Eisenman, 2016; Screen and Williamson, 2017; Niederdrenk and Notz, 2018). Some studies even indicate that the entire Arctic Ocean summer period will become ice free under 2°C of global warming, whilst others more conservatively estimate this probability to be in the order of 50% (Section 3.3.8; Sanderson et al., 2017). The probability of an ice-free Arctic in September at 1.5°C of global warming is low and substantially lower than for the case of 2°C of global warming (*high confidence*) (Section 3.3.8; Screen and Williamson, 2017; Jahn, 2018; Niederdrenk and Notz, 2018). There is, however, a single study that questions the validity of the 1.5°C threshold in terms of maintaining summer Arctic Ocean sea ice (Niederdrenk and Notz, 2018). In contrast to summer, little ice is projected to be lost during winter for either 1.5°C or 2°C of global warming (*medium confidence*) (Niederdrenk and Notz, 2018). The losses in sea ice at 1.5°C and 2°C of warming will result in habitat losses for organisms such as seals, polar bears, whales and sea birds (e.g., Larsen et al., 2014). There is *high agreement and robust evidence* that photosynthetic species will change because of sea ice retreat and related changes in temperature and radiation (Section 3.4.4.7), and this is *very likely* to benefit fisheries productivity in the Northern Hemisphere spring bloom system (Section 3.4.4.7).

3.5.4.2 Arctic land regions

In some Arctic land regions, the warming of cold extremes and the increase in annual minimum temperature at 1.5°C are stronger than the global mean temperature increase by a factor of two to three, meaning 3°C–4.5°C of regional warming at 1.5°C of global warming (e.g., northern Europe in Supplementary Material 3.SM, Figure 3.SM.5 see also Section 3.3.2.2 and Seneviratne et al., 2016). Moreover, over much of the Arctic, a further increase of 0.5°C in the global surface temperature, from 1.5°C to 2°C, may lead to further temperature increases of 2°C–2.5°C (Figure 3.3). As a consequence, biome (major ecosystem type) shifts are *likely* in the Arctic, with increases in fire frequency, degradation of permafrost, and tree cover *likely* to occur at 1.5°C of warming and further amplification of these changes expected under 2°C of global warming (e.g., Gerten et al., 2013; Bring et al., 2016). Rising temperatures, thawing permafrost and changing weather patterns are projected to increasingly impact people, infrastructure and industries in the Arctic (W.N. Meier et al., 2014) with these impacts larger at 2°C than at 1.5°C of warming (*medium confidence*).

3.5.4.3 Alpine regions

Alpine regions are generally regarded as climate change hotspots given that rich biodiversity has evolved in their cold and harsh climate, but with many species consequently being vulnerable to increases in temperature. Under regional warming, alpine species have been found to migrate upwards on mountain slopes (Reasoner and Tinner, 2009), an adaptation response that is obviously limited by mountain height and habitability. Moreover, many of the world's alpine regions are important from a water security perspective through associated glacier melt, snow melt and river flow (see Section 3.3.5.2 for a discussion of these aspects). Projected biome shifts are *likely* to be severe in alpine regions already at 1.5°C of warming and to increase further at 2°C (Gerten et al., 2013, Figure 1b; B. Chen et al., 2014).

3.5.4.4 Southeast Asia

Southeast Asia is a region highly vulnerable to increased flooding in the context of sea level rise (Arnell et al., 2016; Brown et al., 2016, 2018a). Risks from increased flooding are projected to rise from 1.5°C to 2°C of warming (*medium confidence*), with substantial increases projected beyond 2°C (Arnell et al., 2016). Southeast Asia displays statistically significant differences in projected changes in heavy precipitation, runoff and high flows at 1.5°C versus 2°C of warming, with stronger increases occurring at 2°C (Section 3.3.3; Wartenburger et al., 2017; Döll et al., 2018; Seneviratne et al., 2018c); thus, this region is considered a hotspot in terms of increases in heavy precipitation between these two global temperature levels (*medium confidence*) (Schleussner et al., 2016b; Seneviratne et al., 2016). For Southeast Asia, 2°C of warming by 2040 could lead to a decline by one-third in per capita crop production associated with general decreases in crop yields (Nelson et al., 2010). However, under 1.5°C of warming, significant risks for crop yield reduction in the region are avoided (Schleussner et al., 2016b). These changes pose significant risks for poor people in both rural regions and urban areas of Southeast Asia (Section 3.4.10.1), with these risks being larger at 2°C of global warming compared to 1.5°C (*medium confidence*).

3.5.4.5 Southern Europe and the Mediterranean

The Mediterranean is regarded as a climate change hotspot, both in terms of projected stronger warming of the regional land-based hot extremes compared to the mean global temperature increase (e.g., Seneviratne et al., 2016) and in terms of of robust increases in the probability of occurrence of extreme droughts at 2°C vs 1.5°C global warming (Section 3.3.4). Low river flows are projected to decrease in the Mediterranean under 1.5°C of global warming (Marx et al., 2018), with associated significant decreases in high flows and floods (Thober et al., 2018), largely in response to reduced precipitation. The median reduction in annual runoff is projected to almost double from about 9% (*likely* range 4.5–15.5%) at 1.5°C to 17% (*likely* range 8–25%) at 2°C (Schleussner et al., 2016b). Similar results were found by Döll et al. (2018). Overall, there is *high confidence* that strong increases in dryness and decreases in water availability in the Mediterranean and southern Europe would occur from 1.5°C to 2°C of global warming. Sea level rise is expected to be lower for 1.5°C versus 2°C, lowering risks for coastal metropolitan agglomerations. The risks (assuming current adaptation) related to water deficit in the Mediterranean are high for global warming of 2°C but could be substantially reduced if global warming were limited to 1.5°C (Section 3.3.4; Guiot and Cramer, 2016; Schleussner et al., 2016b; Donnelly et al., 2017).

3.5.4.6 West Africa and the Sahel

West Africa and the Sahel are *likely* to experience increases in the number of hot nights and longer and more frequent heatwaves even if the global temperature increase is constrained to 1.5°C, with further increases expected at 2°C of global warming and beyond (e.g., Weber et al., 2018). Moreover, daily rainfall intensity and runoff is expected to increase (*low confidence*) towards 2°C and higher levels of global warming (Schleussner et al., 2016b; Weber et al., 2018), with these changes also being relatively large compared to the projected changes at 1.5°C of warming. Moreover, increased risks are projected in terms of drought, particularly for the pre-monsoon season (Sylla et al., 2015), with both rural and urban populations affected, and more so at 2°C of global warming as opposed to 1.5°C (Liu et al., 2018). Based on a World Bank (2013) study for sub-Saharan Africa, a 1.5°C warming by 2030 might reduce the present maize cropping areas by 40%, rendering these areas no longer suitable for current cultivars. Substantial negative impacts are also projected for sorghum suitability in the western Sahel (Läderach et al., 2013; Sultan and Gaetani, 2016). An increase in warming to 2°C by 2040 would result in further yield losses and damages to crops (i.e., maize, sorghum, wheat, millet, groundnut and cassava). Schleussner et al. (2016b) found consistently reduced impacts on crop yield for West Africa under 2°C compared to 1.5°C of global warming. There is *medium confidence* that vulnerabilities to water and food security in the African Sahel will be higher at 2°C compared to 1.5°C of global warming (Cheung et al., 2016a; Betts et al., 2018), and at 2°C these vulnerabilities are expected to be worse (*high evidence*) (Sultan and Gaetani, 2016; Lehner et al., 2017; Betts et al., 2018; Byers et al., 2018; Rosenzweig et al., 2018). Under global warming of more than 2°C, the western Sahel might experience the strongest drying and experience serious food security issues (Ahmed et al., 2015; Parkes et al., 2018).

3.5.4.7 Southern Africa

The southern African region is projected to be a climate change hotspot in terms of both hot extremes (Figures 3.5 and 3.6) and drying (Figure 3.12). Indeed, temperatures have been rising in the subtropical regions of southern Africa at approximately twice the global rate over the last five decades (Engelbrecht et al., 2015). Associated elevated warming of the regional land-based hot extremes has occurred (Section 3.3; Seneviratne et al., 2016). Increases in the number of hot nights, as well as longer and more frequent heatwaves, are projected even if the global temperature increase is constrained to 1.5°C (*high confidence*), with further increases expected at 2°C of global warming and beyond (*high confidence*) (Weber et al., 2018).

Moreover, southern Africa is *likely* to generally become drier with reduced water availability under low mitigation (Niang et al., 2014; Engelbrecht et al., 2015; Karl et al., 2015; James et al., 2017), with this particular risk being prominent under 2°C of global warming and even under 1.5°C (Gerten et al., 2013). Risks are significantly reduced, however, under 1.5°C of global warming compared to under higher levels (Schleussner et al., 2016b). There are consistent and statistically significant increases in projected risks of increased meteorological drought in southern Africa at 2°C versus 1.5°C of warming (*medium confidence*). Despite the general rainfall reductions projected for southern Africa, daily rainfall intensities are expected to increase over much of the region (*medium confidence*), and increasingly so with higher levels of global warming. There is *medium confidence* that livestock in southern Africa will experience increased water stress under both 1.5°C and 2°C of global warming, with negative economic consequences (e.g., Boone et al., 2018). The region is also projected to experience reduced maize, sorghum and cocoa cropping area suitability, as well as yield losses under 1.5°C of warming, with further decreases occurring towards 2°C of warming (World Bank, 2013). Generally, there is *high confidence* that vulnerability to decreases in water and food availability is reduced at 1.5°C versus 2°C for southern Africa (Betts et al., 2018), whilst at 2°C these are expected to be higher (*high confidence*) (Lehner et al., 2017; Betts et al., 2018; Byers et al., 2018; Rosenzweig et al., 2018).

3.5.4.8 Tropics

Worldwide, the largest increases in the number of hot days are projected to occur in the tropics (Figure 3.7). Moreover, the largest differences in the number of hot days for 1.5°C versus 2°C of global warming are projected to occur in the tropics (Mahlstein et al., 2011). In tropical Africa, increases in the number of hot nights, as well as longer and more frequent heatwaves, are projected under 1.5°C of global warming, with further increases expected under 2°C of global warming (Weber et al., 2018). Impact studies for major tropical cereals reveal that yields of maize and wheat begin to decline with 1°C to 2°C of local warming in the tropics. Schleussner et al. (2016b) project that constraining warming to 1.5°C rather than 2°C would avoid significant risks of tropical crop yield declines in West Africa, Southeast Asia, and Central and South America. There is *limited evidence* and thus *low confidence* that these changes may result in significant population displacement from the tropics to the subtropics (e.g., Hsiang and Sobel, 2016).

3.5.4.9 Small islands

It is widely recognized that small islands are very sensitive to climate change impacts such as sea level rise, oceanic warming, heavy precipitation, cyclones and coral bleaching *(high confidence)* (Nurse et al., 2014; Ourbak and Magnan, 2017). Even at 1.5°C of global warming, the compounding impacts of changes in rainfall, temperature, tropical cyclones and sea level are likely to be significant across multiple natural and human systems. There are potential benefits to small island developing states (SIDS) from avoided risks at 1.5°C versus 2°C, especially when coupled with adaptation efforts. In terms of sea level rise, by 2150, roughly 60,000 fewer people living in SIDS will be exposed in a 1.5°C world than in a 2°C world (Rasmussen et al., 2018). Constraining global warming to 1.5°C may significantly reduce water stress (by about 25%) compared to the projected water stress at 2°C, for example in the Caribbean region (Karnauskas et al., 2018), and may enhance the ability of SIDS to adapt (Benjamin and Thomas, 2016). Up to 50% of the year is projected to be very warm in the Caribbean at 1.5°C, with a further increase by up to 70 days at 2°C versus 1.5°C (Taylor et al., 2018). By limiting warming to 1.5°C instead of 2°C in 2050, risks of coastal flooding (measured as the flood amplification factors for 100-year flood events) are reduced by 20–80% for SIDS (Rasmussen et al., 2018). A case study of Jamaica with lessons for other Caribbean SIDS demonstrated that the difference between 1.5°C and 2°C is *likely* to challenge livestock thermoregulation, resulting in persistent heat stress for livestock (Lallo et al., 2018).

3.5.4.10 Fynbos and shrub biomes

The Fynbos and succulent Karoo biomes of South Africa are threatened systems that were assessed in AR5. Similar shrublands exist in the semi-arid regions of other continents, with the Sonora-Mojave creosotebush-white bursage desert scrub ecosystem in the USA being a prime example. Impacts accrue across these systems with greater warming, with impacts at 2°C likely to be greater than those at 1.5°C (*medium confidence*). Under 2°C of global warming, regional warming in drylands is projected to be 3.2°C–4°C, and under 1.5°C of global warming, mean warming in drylands is projected to still be about 3°C. The Fynbos biome in southwestern South Africa is vulnerable to the increasing impact of fires under increasing temperatures and drier winters (*high confidence*). The Fynbos biome is projected to lose about 20%, 45% and 80% of its current suitable climate area relative to its present-day area under 1°C, 2°C and 3°C of warming, respectively (Engelbrecht and Engelbrecht, 2016), demonstrating the value of climate change mitigation in protecting this rich centre of biodiversity.

Table 3.6 | Emergence and intensity of climate change hotspots under different degrees of global warming.

Region and/or Phenomenon	Warming of 1.5°C or less	Warming of 1.5°C–2°C	Warming of 2°C–3°C
Arctic sea ice	Arctic summer sea ice is *likely* to be maintained Habitat losses for organisms such as polar bears, whales, seals and sea birds Benefits for Arctic fisheries	The risk of an ice-free Arctic in summer is about 50% or higher Habitat losses for organisms such as polar bears, whales,seals and sea birds may be critical if summers are ice free Benefits for Arctic fisheries	The Arctic is *very likely* to be ice free in summer Critical habitat losses for organisms such as polar bears, whales, seals and sea birds Benefits for Arctic fisheries
Arctic land regions	Cold extremes warm by a factor of 2–3, reaching up to 4.5°C (*high confidence*) Biome shifts in the tundra and permafrost deterioration are *likely*	Cold extremes warm by as much as 8°C (*high confidence*) Larger intrusions of trees and shrubs in the tundra than under 1.5°C of warming are *likely*; larger but constrained losses in permafrost are *likely*	Drastic regional warming is *very likely* A collapse in permafrost may occur (*low confidence*); a drastic biome shift from tundra to boreal forest is possible (*low confidence*)
Alpine regions	Severe shifts in biomes are *likely*	Even more severe shifts are *likely*	Critical losses in alpine habitats are *likely*
Southeast Asia	Risks for increased flooding related to sea level rise Increases in heavy precipitation events Significant risks of crop yield reductions are avoided	Higher risks of increased flooding related to sea level rise (*medium confidence*) Stronger increases in heavy precipitation events (*medium confidence*) One-third decline in per capita crop production (*medium confidence*)	Substantial increases in risks related to flooding from sea level rise Substantial increase in heavy precipitation and high-flow events Substantial reductions in crop yield
Mediterranean	Increase in probability of extreme drought (*medium confidence*) *Medium confidence* in reduction in runoff of about 9% (*likely* range 4.5–15.5%) Risk of water deficit (*medium confidence*)	Robust increase in probability of extreme drought (*medium confidence*) *Medium confidence* in further reductions (about 17%) in runoff (*likely* range 8–28%) Higher risks of water deficit (*medium confidence*)	Robust and large increases in extreme drought. Substantial reductions in precipitation and in runoff (*medium confidence*) Very high risks of water deficit (*medium confidence*)
West Africa and the Sahel	Increases in the number of hot nights and longer and more frequent heatwaves are *likely* Reduced maize and sorghum production is *likely*, with area suitable for maize production reduced by as much as 40% Increased risks of undernutrition	Further increases in number of hot nights and longer and more frequent heatwaves are *likely* Negative impacts on maize and sorghum production *likely* larger than at 1.5°C; *medium confidence* that vulnerabilities to food security in the African Sahel will be higher at 2°C compared to 1.5°C Higher risks of undernutrition	Substantial increases in the number of hot nights and heatwave duration and frequency (*very likely*) Negative impacts on crop yield may result in major regional food insecurities (*medium confidence*) High risks of undernutrition
Southern Africa	Reductions in water availability (*medium confidence*) Increases in number of hot nights and longer and more frequent heatwaves (*high confidence*) High risks of increased mortality from heatwaves High risk of undernutrition in communities dependent on dryland agriculture and livestock	Larger reductions in rainfall and water availability (*medium confidence*) Further increases in number of hot nights and longer and more frequent heatwaves (*high confidence*), associated increases in risks of increased mortality from heatwaves compared to 1.5°C warming (*high confidence*) Higher risks of undernutrition in communities dependent on dryland agriculture and livestock	Large reductions in rainfall and water availability (*medium confidence)* Drastic increases in the number of hot nights, hot days and heatwave duration and frequency to impact substantially on agriculture, livestock and human health and mortality (*high confidence*) Very high risks of undernutrition in communities dependent on dryland agriculture and livestock
Tropics	Increases in the number of hot days and hot nights as well as longer and more frequent heatwaves (*high confidence*) Risks to tropical crop yields in West Africa, Southeast Asia and Central and South America are significantly less than under 2°C of warming	The largest increase in hot days under 2°C compared to 1.5°C is projected for the tropics. Risks to tropical crop yields in West Africa, Southeast Asia and Central and South America could be extensive	Oppressive temperatures and accumulated heatwave duration *very likely* to directly impact human health, mortality and productivity Substantial reductions in crop yield *very likely*
Small islands	Land of 60,000 less people exposed by 2150 on SIDS compared to impacts under 2°C of global warming Risks for coastal flooding reduced by 20–80% for SIDS compared to 2°C of global warming Freshwater stress reduced by 25% Increase in the number of warm days for SIDS in the tropics Persistent heat stress in cattle avoided Loss of 70–90% of coral reefs	Tens of thousands of people displaced owing to inundation of SIDS High risks for coastal flooding Freshwater stress reduced by 25% compared to 2°C of global warming Freshwater stress from projected aridity Further increase of about 70 warm days per year Persistent heat stress in cattle in SIDS Loss of most coral reefs and weaker remaining structures owing to ocean acidification	Substantial and widespread impacts through inundation of SIDS, coastal flooding, freshwater stress, persistent heat stress and loss of most coral reefs (*very likely*)
Fynbos biome	About 30% of suitable climate area lost (*medium confidence*)	Increased losses (about 45%) of suitable climate area (*medium confidence*)	Up to 80% of suitable climate area lost (*medium confidence*)

3.5.5 Avoiding Regional Tipping Points by Achieving More Ambitious Global Temperature Goals

Tipping points refer to critical thresholds in a system that, when exceeded, can lead to a significant change in the state of the system, often with an understanding that the change is irreversible. An understanding of the sensitivities of tipping points in the physical climate system, as well as in ecosystems and human systems, is essential for understanding the risks associated with different degrees of global warming. This subsection reviews tipping points across these three areas within the context of the different sensitivities to 1.5°C versus 2°C of global warming. Sensitivities to less ambitious global temperature goals are also briefly reviewed. Moreover, an analysis is provided of how integrated risks across physical, natural and human systems may accumulate to lead to the exceedance of thresholds for particular systems. The emphasis in this section is on the identification of regional tipping points and their sensitivity to 1.5°C and 2°C of global warming, whereas tipping points in the global climate system, referred to as large-scale singular events, were already discussed in Section 3.5.2. A summary of regional tipping points is provided in Table 3.7.

3.5.5.1 Arctic sea ice

Collins et al. (2013) discussed the loss of Arctic sea ice in the context of potential tipping points. Climate models have been used to assess whether a bifurcation exists that would lead to the irreversible loss of Arctic sea ice (Armour et al., 2011; Boucher et al., 2012; Ridley et al., 2012) and to test whether the summer sea ice extent can recover after it has been lost (Schröder and Connolley, 2007; Sedláček et al., 2011; Tietsche et al., 2011). These studies did not find evidence of bifurcation or indicate that sea ice returns within a few years of its loss, leading Collins et al. (2013) to conclude that there is little evidence for a tipping point in the transition from perennial to seasonal ice cover. No evidence has been found for irreversibility or tipping points, suggesting that year-round sea ice will return given a suitable climate (*medium confidence*) (Schröder and Connolley, 2007; Sedláček et al., 2011; Tietsche et al., 2011).

3.5.5.2 Tundra

Tree growth in tundra-dominated landscapes is strongly constrained by the number of days with mean air temperature above 0°C. A potential tipping point exists where the number of days below 0°C decreases to the extent that the tree fraction increases significantly. Tundra-dominated landscapes have warmed more than the global average over the last century (Settele et al., 2014), with associated increases in fires and permafrost degradation (Bring et al., 2016; DeBeer et al., 2016; Jiang et al., 2016; Yang et al., 2016). These processes facilitate conditions for woody species establishment in tundra areas, and for the eventual transition of the tundra to boreal forest. The number of investigations into how the tree fraction may respond in the Arctic to different degrees of global warming is limited, and studies generally indicate that substantial increases will *likely* occur gradually (e.g., Lenton et al., 2008). Abrupt changes are only plausible at levels of warming significantly higher than 2°C (*low confidence*) and would occur in conjunction with a collapse in permafrost (Drijfhout et al., 2015).

3.5.5.3 Permafrost

Widespread thawing of permafrost potentially makes a large carbon store (estimated to be twice the size of the atmospheric store; Dolman et al., 2010) vulnerable to decomposition, which could lead to further increases in atmospheric carbon dioxide and methane and hence to further global warming. This feedback loop between warming and the release of greenhouse gas from thawing tundra represents a potential tipping point. However, the carbon released to the atmosphere from thawing permafrost is projected to be restricted to 0.09–0.19 Gt C yr^{-1} at 2°C of global warming and to 0.08–0.16 Gt C yr^{-1} at 1.5°C (E.J. Burke et al., 2018), which does not indicate a tipping point (*medium confidence*). At higher degrees of global warming, in the order of 3°C, a different type of tipping point in permafrost may be reached. A single model projection (Drijfhout et al., 2015) suggested that higher temperatures may induce a smaller ice fraction in soils in the tundra, leading to more rapidly warming soils and a positive feedback mechanism that results in permafrost collapse (*low confidence*). The disparity between the multi-millennial time scales of soil carbon accumulation and potentially rapid decomposition in a warming climate implies that the loss of this carbon to the atmosphere would be essentially irreversible (Collins et al., 2013).

3.5.5.4 Asian monsoon

At a fundamental level, the pressure gradient between the Indian Ocean and Asian continent determines the strength of the Asian monsoon. As land masses warm faster than the oceans, a general strengthening of this gradient, and hence of monsoons, may be expected under global warming (e.g., Lenton et al., 2008). Additional factors such as changes in albedo induced by aerosols and snow-cover change may also affect temperature gradients and consequently pressure gradients and the strength of the monsoon. In fact, it has been estimated that an increase of the regional land mass albedo to 0.5 over India would represent a tipping point resulting in the collapse of the monsoon system (Lenton et al., 2008). The overall impacts of the various types of radiative forcing under different emissions scenarios are more subtle, with a weakening of the monsoon north of about 25°N in East Asia but a strengthening south of this latitude projected by Jiang and Tian (2013) under high and modest emissions scenarios. Increases in the intensity of monsoon precipitation are *likely* under low mitigation (AR5). Given that scenarios of 1.5°C or 2°C of global warming would include a substantially smaller radiative forcing than those assessed in the study by Jiang and Tian (2013), there is *low confidence* regarding changes in monsoons at these low global warming levels, as well as regarding the differences between responses at 1.5°C versus 2°C of warming.

3.5.5.5 West African monsoon and the Sahel

Earlier work has identified 3°C of global warming as the tipping point leading to a significant strengthening of the West African monsoon and subsequent wettening (and greening) of the Sahel and Sahara (Lenton et al., 2008). AR5 (Niang et al., 2014), as well as more recent research through the Coordinated Regional Downscaling Experiment for Africa (CORDEX–AFRICA), provides a more uncertain view, however, in terms of the rainfall futures of the Sahel under low mitigation futures. Even if a wetter Sahel should materialize under 3°C of global warming (*low* *confidence*), it should be noted that there would be significant offsets in the form of strong regional warming and related adverse impacts on crop yield, livestock mortality and human health under such low mitigation futures (Engelbrecht et al., 2015; Sylla et al., 2016; Weber et al., 2018).

3.5.5.6 Rainforests

A large portion of rainfall over the world's largest rainforests is recirculated (e.g., Lenton et al., 2008), which raises the concern that deforestation may trigger a threshold in reduced forest cover, leading to pronounced forest dieback. For the Amazon, this deforestation threshold has been estimated to be 40% (Nobre et al., 2016). Global warming of 3°C–4°C may also, independent of deforestation, represent a tipping point that results in a significant dieback of the Amazon forest, with a key forcing mechanism being stronger El Niño events bringing more frequent droughts to the region (Nobre et al., 2016). Increased fire frequencies under global warming may interact with and accelerate deforestation, particularly during periods of El Niño-induced droughts (Lenton et al., 2008; Nobre et al., 2016). Global warming of 3°C is projected to reduce the extent of tropical rainforest in Central America, with biomass being reduced by about 40%, which can lead to a large replacement of rainforest by savanna and grassland (Lyra et al., 2017). Overall, modelling studies (Huntingford et al., 2013; Nobre et al., 2016) and observational constraints (Cox et al., 2013) suggest that pronounced rainforest dieback may only be triggered at 3°C–4°C (*medium confidence*), although pronounced biomass losses may occur at 1.5°C– 2°C of global warming.

3.5.5.7 Boreal forests

Boreal forests are likely to experience stronger local warming than the global average (WGII AR5; Collins et al., 2013). Increased disturbance from fire, pests and heat-related mortality may affect, in particular, the southern boundary of boreal forests (*medium confidence*) (Gauthier et al., 2015), with these impacts accruing with greater warming and thus impacts at 2°C would be expected to be greater than those at 1.5°C (*medium confidence*). A tipping point for significant dieback of the boreal forests is thought to exist, where increased tree mortality would result in the creation of large regions of open woodlands and grasslands, which would favour further regional warming and increased fire frequencies, thus inducing a powerful positive feedback mechanism (Lenton et al., 2008; Lenton, 2012). This tipping point has been estimated to exist between 3°C and 4°C of global warming (*low confidence*) (Lucht et al., 2006; Kriegler et al., 2009), but given the complexities of the various forcing mechanisms and feedback processes involved, this is thought to be an uncertain estimate.

3.5.5.8 Heatwaves, unprecedented heat and human health

Increases in ambient temperature are linearly related to hospitalizations and deaths once specific thresholds are exceeded (so there is not a tipping point per se). It is plausible that coping strategies will not be in place for many regions, with potentially significant impacts on communities with low adaptive capacity, effectively representing the occurrence of a local/regional tipping point. In fact, even if global warming is restricted to below 2°C, there could be a substantial increase in the occurrence of deadly heatwaves in cities if urban heat island effects are considered, with impacts being similar at 1.5°C and 2°C but substantially larger than under the present climate (Matthews et al., 2017). At 1.5°C of warming, twice as many megacities (such as Lagos, Nigeria, and Shanghai, China) than at present are *likely* to become heat stressed, potentially exposing more than 350 million more people to deadly heat stress by 2050. At 2°C of warming, Karachi (Pakistan) and Kolkata (India) could experience conditions equivalent to their deadly 2015 heatwaves on an annual basis (*medium confidence*). These statistics imply a tipping point in the extent and scale of heatwave impacts. However, these projections do not integrate adaptation to projected warming, for instance cooling that could be achieved with more reflective roofs and urban surfaces in general (Akbari et al., 2009; Oleson et al., 2010).

3.5.5.9 Agricultural systems: key staple crops

A large number of studies have consistently indicated that maize crop yield will be negatively affected under increased global warming, with negative impacts being higher at 2°C of warming than at 1.5°C (e.g., Niang et al., 2014; Schleussner et al., 2016b; J. Huang et al., 2017; Iizumi et al., 2017). Under 2°C of global warming, losses of 8–14% are projected in global maize production (Bassu et al., 2014). Under global warming of more than 2°C, regional losses are projected to be about 20% if they co-occur with reductions in rainfall (Lana et al., 2017). These changes may be classified as incremental rather than representing a tipping point. Large-scale reductions in maize crop yield, including the potential collapse of this crop in some regions, may exist under 3°C or more of global warming (*low confidence*) (e.g., Thornton et al., 2011).

3.5.5.10 Agricultural systems: livestock in the tropics and subtropics

The potential impacts of climate change on livestock (Section 3.4.6), in particular the direct impacts through increased heat stress, have been less well studied than impacts on crop yield, especially from the perspective of critical thresholds being exceeded. A case study from Jamaica revealed that the difference in heat stress for livestock between 1.5°C and 2°C of warming is likely to exceed the limits for normal thermoregulation and result in persistent heat stress for these animals (Lallo et al., 2018). It is plausible that this finding holds for livestock production in both tropical and subtropical regions more generally (*medium confidence*) (Section 3.4.6). Under 3°C of global warming, significant reductions in the areas suitable for livestock production could occur (*low confidence*), owing to strong increases in regional temperatures in the tropics and subtropics (*high confidence*). Thus, regional tipping points in the viability of livestock production may well exist, but little evidence quantifying such changes exists.

Table 3.7 | Summary of enhanced risks in the exceedance of regional tipping points under different global temperature goals.

Tipping point	Warming of 1.5°C or less	Warming of 1.5°C–2°C	Warming of up to 3°C
Arctic sea ice	Arctic summer sea ice is *likely* to be maintained Sea ice changes reversible under suitable climate restoration	The risk of an ice-free Arctic in summer is about 50% or higher Sea ice changes reversible under suitable climate restoration	Arctic is *very likely* to be ice free in summer Sea ice changes reversible under suitable climate restoration
Tundra	Decrease in number of growing degree days below 0°C Abrupt increases in tree cover are *unlikely*	Further decreases in number of growing degree days below 0°C Abrupt increased in tree cover are *unlikely*	Potential for an abrupt increase in tree fraction (*low confidence*)
Permafrost	17–44% reduction in permafrost Approximately 2 million km^2 more permafrost maintained than under 2°C of global warming (*medium confidence*) Irreversible loss of stored carbon	28–53% reduction in permafrost Irreversible loss of stored carbon	Potential for permafrost collapse (*low confidence*)
Asian monsoon	*Low confidence* in projected changes	*Low confidence* in projected changes	Increases in the intensity of monsoon precipitation *likely*
West African monsoon and the Sahel	Uncertain changes; *unlikely* that a tipping point is reached	Uncertain changes; *unlikely* that tipping point is reached	Strengthening of monsoon with wettening and greening of the Sahel and Sahara (*low confidence*) Negative associated impacts through increases in extreme temperature events
Rainforests	Reduced biomass, deforestation and fire increases pose uncertain risks to forest dieback	Larger biomass reductions than under 1.5°C of warming; deforestation and fire increases pose uncertain risk to forest dieback	Reduced extent of tropical rainforest in Central America and large replacement of rainforest by savanna and grassland Potential tipping point leading to pronounced forest dieback (*medium confidence*)
Boreal forests	Increased tree mortality at southern boundary of boreal forest (*medium confidence*)	Further increases in tree mortality at southern boundary of boreal forest (*medium confidence*)	Potential tipping point at 3°C–4°C for significant dieback of boreal forest (*low confidence*)
Heatwaves, unprecedented heat and human health	Substantial increase in occurrence of potentially deadly heatwaves (*likely*) More than 350 million more people exposed to deadly heat by 2050 under a midrange population growth scenario (*likely*)	Substantial increase in potentially deadly heatwaves (*likely*) Annual occurrence of heatwaves similar to the deadly 2015 heatwaves in India and Pakistan (*medium confidence*)	Substantial increase in potentially deadly heatwaves *very likely*
Agricultural systems: key staple crops	Global maize crop reductions of about 10%	Larger reductions in maize crop production than under 1.5°C of about 15%	Drastic reductions in maize crop globally and in Africa (*high confidence*) Potential tipping point for collapse of maize crop in some regions (*low confidence*)
Livestock in the tropics and subtropics	Increased heat stress	Onset of persistent heat stress (*medium confidence*)	Persistent heat stress *likely*

Box 3.6 | Economic Damages from Climate Change

Balancing the costs and benefits of mitigation is challenging because estimating the value of climate change damages depends on multiple parameters whose appropriate values have been debated for decades (for example, the appropriate value of the discount rate) or that are very difficult to quantify (for example, the value of non-market impacts; the economic effects of losses in ecosystem services; and the potential for adaptation, which is dependent on the rate and timing of climate change and on the socio-economic content). See Cross-Chapter Box 5 in Chapter 2 for the definition of the social cost of carbon and for a discussion of the economics of 1.5°C-consistent pathways and the social cost of carbon, including the impacts of inequality on the social cost of carbon.

Global economic damages of climate change are projected to be smaller under warming of 1.5°C than 2°C in 2100 (Warren et al., 2018c). The mean net present value of the costs of damages from warming in 2100 for 1.5°C and. 2°C (including costs associated with climate change-induced market and non-market impacts, impacts due to sea level rise, and impacts associated with large-scale discontinuities) are $54 and $69 trillion, respectively, relative to 1961–1990.

Box 3.6 (continued)

Values of the social cost of carbon vary when tipping points are included. The social cost of carbon in the default setting of the Dynamic Integrated Climate-Economy (DICE) model increases from \$15 tCO_2^{-1} to \$116 (range 50–166) tCO_2^{-1} when large-scale singularities or 'tipping elements' are incorporated (Y. Cai et al., 2016; Lemoine and Traeger, 2016). Lemoine and Traeger (2016) included optimization calculations that minimize welfare impacts resulting from the combination of climate change risks and climate change mitigation costs, showing that welfare is minimized if warming is limited to 1.5°C. These calculations excluded the large health co-benefits that accrue when greenhouse gas emissions are reduced (Section 3.4.7.1; Shindell et al., 2018).

The economic damages of climate change in the USA are projected to be large (Hsiang et al., 2017; Yohe, 2017). Hsiang et al. (2017) shows that the USA stand to lose -0.1 to 1.7% of the Gross Domestic Product (GDP) at 1.5°C warming. Yohe (2017) calculated transient temperature trajectories from a linear relationship with contemporaneous cumulative emissions under a median no-policy baseline trajectory that brings global emissions to roughly 93 $GtCO_2$ yr^{-1} by the end of the century (Fawcett et al., 2015), with 1.75°C per 1000 $GtCO_2$ as the median estimate. Associated aggregate economic damages in decadal increments through the year 2100 are estimated in terms of the percentage loss of GDP at the median, 5th percentile and 95th percentile transient temperature (Hsiang et al., 2017). The results for the baseline no-policy case indicate that economic damages along median temperature change and median damages (median-median) reach 4.5% of GDP by 2100, with an uncertainty range of 2.5% and 8.5% resulting from different combinations of temperature change and damages. Avoided damages from achieving a 1.5°C temperature limit along the median-median case are nearly 4% (range 2–7%) by 2100. Avoided damages from achieving a 2°C temperature limit are only 3.5% (range 1.8–6.5%). Avoided damages from achieving 1.5°C versus 2°C are modest at about 0.35% (range 0.20–0.65%) by 2100. The values of achieving the two temperature limits do not diverge significantly until 2040, when their difference tracks between 0.05 and 0.13%; the differences between the two temperature targets begin to diverge substantially in the second half of the century.

3.6 Implications of Different 1.5°C and 2°C Pathways

This section provides an overview on specific aspects of the mitigation pathways considered compatible with 1.5°C of global warming. Some of these aspects are also addressed in more detail in Cross-Chapter Boxes 7 and 8 in this chapter.

3.6.1 Gradual versus Overshoot in 1.5°C Scenarios

All 1.5°C scenarios from Chapter 2 include some overshoot above 1.5°C of global warming during the 21st century (Chapter 2 and Cross-Chapter Box 8 in this chapter). The level of overshoot may also depend on natural climate variability. An overview of possible outcomes of 1.5°C-consistent mitigation scenarios for changes in the physical climate at the time of overshoot and by 2100 is provided in Cross-Chapter Box 8 on '1.5°C warmer worlds'. Cross-Chapter Box 8 also highlights the implications of overshoots.

3.6.2 Non-CO_2 Implications and Projected Risks of Mitigation Pathways

3.6.2.1 Risks arising from land-use changes in mitigation pathways

In mitigation pathways, land-use change is affected by many different mitigation options. First, mitigation of non-CO_2 emissions from agricultural production can shift agricultural production between regions via trade of agricultural commodities. Second, protection of carbon-rich ecosystems such as tropical forests constrains the area for agricultural expansion. Third, demand-side mitigation measures, such as less consumption of resource-intensive commodities (animal products) or reductions in food waste, reduce pressure on land (Popp et al., 2017; Rogelj et al., 2018). Finally, carbon dioxide removal (CDR) is a key component of most, but not all, mitigation pathways presented in the literature to date which constrain warming to 1.5°C or 2°C. Carbon dioxide removal measures that require land include bioenergy with carbon capture and storage (BECCS), afforestation and reforestation (AR), soil carbon sequestration, direct air capture, biochar and enhanced weathering (see Cross-Chapter Box 7 in this chapter). These potential methods are assessed in Section 4.3.7.

In cost-effective integrated assessment modelling (IAM) pathways recently developed to be consistent with limiting warming to 1.5°C, use of CDR in the form of BECCS and AR are fundamental elements (Chapter 2; Popp et al., 2017; Hirsch et al., 2018; Rogelj et al., 2018; Seneviratne et al., 2018c). The land-use footprint of CDR deployment in 1.5°C-consistent pathways can be substantial (Section 2.3.4, Figure 2.11), even though IAMs predominantly rely on second-generation biomass and assume future productivity increases in agriculture.

A body of literature has explored potential consequences of large-scale use of CDR. In this case, the corresponding land footprint by the end of the century could be extremely large, with estimates including: up to 18% of the land surface being used (Wiltshire and Davies-Barnard, 2015); vast acceleration of the loss of primary forest and natural grassland (Williamson, 2016) leading to increased greenhouse gas emissions (P. Smith et al., 2013, 2015); and potential loss of up to 10% of the current forested lands to biofuels (Yamagata et al., 2018). Other estimates reach 380–700 Mha or 21–64% of current arable cropland (Section 4.3.7). Boysen et al. (2017) found that in a scenario in which emissions reductions were sufficient only to limit warming to 2.5°C, use of CDR to further limit warming to 1.7°C would result in the conversion of 1.1–1.5 Gha of land – implying enormous losses of both cropland and natural ecosystems. Newbold et al. (2015) found that biodiversity loss in the Representative Concentration Pathway (RCP)2.6 scenario could be greater than that in RCP4.5 and RCP6, in which there is more climate change but less land-use change. Risks to biodiversity conservation and agricultural production are therefore projected to result from large-scale bioenergy deployment pathways (P. Smith et al., 2013; Tavoni and Socolow, 2013). One study explored an extreme mitigation strategy encouraging biofuel expansion sufficient to limit warming to 1.5°C and found that this would be more disruptive to land use and crop prices than the impacts of a 2°C warmer world which has a larger climate signal and lower mitigation requirement (Ruane et al., 2018). However, it should again be emphasized that many of the pathways explored in Chapter 2 of this report follow strategies that explore how to reduce these issues. Chapter 4 provides an assessment of the land footprint of various CDR technologies (Section 4.3.7).

The degree to which BECCS has these large land-use footprints depends on the source of the bioenergy used and the scale at which BECCS is deployed. Whether there is competition with food production and biodiversity depends on the governance of land use, agricultural intensification, trade, demand for food (in particular meat), feed and timber, and the context of the whole supply chain (Section 4.3.7, Fajardy and Mac Dowell, 2017; Booth, 2018; Sterman et al., 2018).

The more recent literature reviewed in Chapter 2 explores pathways which limit warming to 2°C or below and achieve a balance between sources and sinks of CO_2 by using BECCS that relies on second-generation (or even third-generation) biofuels, changes in diet or more generally, management of food demand, or CDR options such as forest restoration (Chapter 2; Bajželj et al., 2014). Overall, this literature explores how to reduce the issues of competition for land with food production and with natural ecosystems (in particular forests) (Cross-Chapter Box 1 in Chapter 1; van Vuuren et al., 2009; Haberl et al., 2010, 2013; Bajželj et al., 2014; Daioglou et al., 2016; Fajardy and Mac Dowell, 2017).

Some IAMs manage this transition by effectively protecting carbon stored on land and focusing on the conversion of pasture area into both forest area and bioenergy cropland. Some IAMs explore 1.5°C-consistent pathways with demand-side measures such as dietary changes and efficiency gains such as agricultural changes (Sections 2.3.4 and 2.4.4), which lead to a greatly reduced CDR deployment and consequently land-use impacts (van Vuuren et al., 2018). In reality, however, whether this CDR (and bioenergy in general) has large adverse impacts on environmental and societal goals depends in large part on the governance of land use (Section 2.3.4; Obersteiner et al., 2016; Bertram et al., 2018; Humpenöder et al., 2018).

Rates of sequestration of 3.3 GtC ha^{-1} require 970 Mha of afforestation and reforestation (Smith et al., 2015). Humpenöder et al. (2014) estimated that in least-cost pathways afforestation would cover 2800 Mha by the end of the century to constrain warming to 2°C. Hence, the amount of land considered if least-cost mitigation is implemented by afforestation and reforestation could be up to three to five times greater than that required by BECCS, depending on the forest management used. However, not all of the land footprint of CDR is necessarily to be in competition with biodiversity protection. Where reforestation is the restoration of natural ecosystems, it benefits both carbon sequestration and conservation of biodiversity and ecosystem services (Section 4.3.7) and can contribute to the achievement of the Aichi targets under the Convention on Biological Diversity (CBD) (Leadley et al., 2016). However, reforestation is often not defined in this way (Section 4.3.8; Stanturf et al., 2014) and the ability to deliver biodiversity benefits is strongly dependent on the precise nature of the reforestation, which has different interpretations in different contexts and can often include agroforestry rather than restoration of pristine ecosystems (Pistorious and Kiff, 2017). However, 'natural climate solutions', defined as conservation, restoration, and improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions across global forests, wetlands, grasslands and agricultural lands, are estimated to have the potential to provide 37% of the cost-effective CO_2 mitigation needed by southern Europe and the Mediterranean by 2030 – in order to have a >66% chance of holding warming to below 2°C (Griscom et al., 2017).

Any reductions in agricultural production driven by climate change and/or land management decisions related to CDR may (e.g., Nelson et al., 2014a; Dalin and Rodríguez-Iturbe, 2016) or may not (Muratori et al., 2016) affect food prices. However, these studies did not consider the deployment of second-generation (instead of first-generation) bioenergy crops, for which the land footprint can be much smaller.

Irrespective of any mitigation-related issues, in order for ecosystems to adapt to climate change, land use would also need to be carefully managed to allow biodiversity to disperse to areas that become newly climatically suitable for it (Section 3.4.1) and to protect the areas where the future climate will still remain suitable. This implies a need for considerable expansion of the protected area network (Warren et al., 2018b), either to protect existing natural habitat or to restore it (perhaps through reforestation, see above). At the same time, adaptation to climate change in the agricultural sector (Rippke et al., 2016) can require transformational as well as new approaches to land-use management; in order to meet the rising food demand of a growing human population, it is projected that additional land will need to be brought into production unless there are large increases in agricultural productivity (Tilman et al., 2011). However, future rates of deforestation may be underestimated in the existing literature (Mahowald et al., 2017a), and reforestation may therefore be associated with significant co-benefits if implemented to restore natural ecosystems (*high confidence*).

3.6.2.2 Biophysical feedbacks on regional climate associated with land-use changes

Changes in the biophysical characteristics of the land surface are known to have an impact on local and regional climates through changes in albedo, roughness, evapotranspiration and phenology, which can lead to a change in temperature and precipitation. This includes changes in land use through agricultural expansion/intensification (e.g., Mueller et al., 2016), reforestation/revegetation endeavours (e.g., Feng et al., 2016; Sonntag et al., 2016; Bright et al., 2017) and changes in land management (e.g., Luyssaert et al., 2014; Hirsch et al., 2017) that can

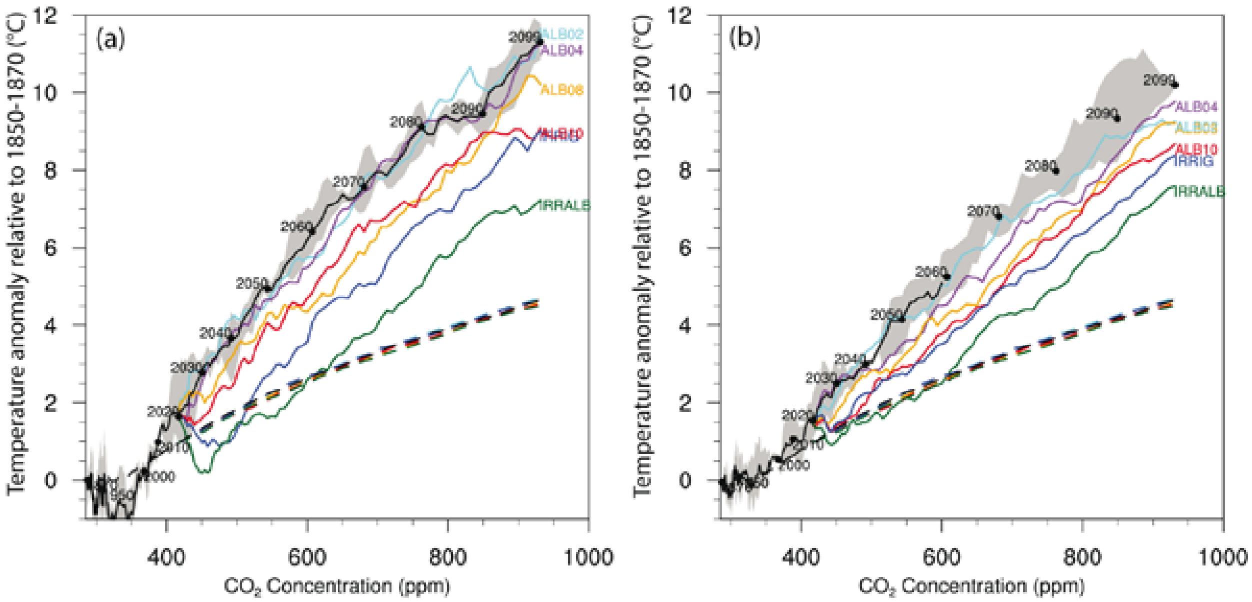


Figure 3.22 | Regional temperature scaling with carbon dioxide (CO_2) concentration (ppm) from 1850 to 2099 for two different regions defined in the Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) for central Europe (CEU) (a) and central North America (CNA) (b). Solid lines correspond to the regional average annual maximum daytime temperature (TXx) anomaly, and dashed lines correspond to the global mean temperature anomaly, where all temperature anomalies are relative to 1850–1870 and units are degrees Celsius. The black line in all panels denotes the three-member control ensemble mean, with the grey shaded regions corresponding to the ensemble range. The coloured lines represent the three-member ensemble means of the experiments corresponding to albedo +0.02 (cyan), albedo +0.04 (purple), albedo + 0.08 (orange), albedo +0.10 (red), irrigation (blue), and irrigation with albedo +0.10 (green). Adapted from Hirsch et al. (2017).

involve double cropping (e.g., Jeong et al., 2014; Mueller et al., 2015; Seifert and Lobell, 2015), irrigation (e.g., Lobell et al., 2009; Sacks et al., 2009; Cook et al., 2011; Qian et al., 2013; de Vrese et al., 2016; Pryor et al., 2016; Thiery et al., 2017), no-till farming and conservation agriculture (e.g., Lobell et al., 2006; Davin et al., 2014), and wood harvesting (e.g., Lawrence et al., 2012). Hence, the biophysical impacts of land-use changes are an important topic to assess in the context of low-emissions scenarios (e.g., van Vuuren et al., 2011b), in particular for 1.5°C warming levels (see also Cross-Chapter Box 7 in this chapter).

The magnitude of the biophysical impacts is potentially large for temperature extremes. Indeed, changes induced both by modifications in moisture availability and irrigation and by changes in surface albedo tend to be larger (i.e., stronger cooling) for hot extremes than for mean temperatures (e.g., Seneviratne et al., 2013; Davin et al., 2014; Wilhelm et al., 2015; Hirsch et al., 2017; Thiery et al., 2017). The reasons for reduced moisture availability are related to a strong contribution of moisture deficits to the occurrence of hot extremes in mid-latitude regions (Mueller and Seneviratne, 2012; Seneviratne et al., 2013). In the case of surface albedo, cooling associated with higher albedo (e.g., in the case of no-till farming) is more effective at cooling hot days because of the higher incoming solar radiation for these days (Davin et al., 2014). The overall effect of either irrigation or albedo has been found to be at the most in the order of about 1°C–2°C regionally for temperature extremes. This can be particularly important in the context of low-emissions scenarios because the overall effect is in this case of similar magnitude to the response to the greenhouse gas forcing (Figure 3.22; Hirsch et al., 2017; Seneviratne et al., 2018a,c).

In addition to the biophysical feedbacks from land-use change and land management on climate, there are potential consequences for particular ecosystem services. This includes climate change-induced changes in crop yield (e.g., Schlenker and Roberts, 2009; van der Velde et al., 2012; Asseng et al., 2013, 2015; Butler and Huybers, 2013; Lobell et al., 2014) which may be further exacerbated by competing demands for arable land between reforestation mitigation activities, crop growth for BECCS (Chapter 2), increasing food production to support larger populations, and urban expansion (see review by Smith et al., 2010). In particular, some land management practices may have further implications for food security, for instance throughincreases or decreases in yield when tillage is ceased in some regions (Pittelkow et al., 2014).

We note that the biophysical impacts of land use in the context of mitigation pathways constitute an emerging research topic. This topic, as well as the overall role of land-use change in climate change projections and socio-economic pathways, will be addressed in depth in the upcoming IPCC Special Report on Climate Change and Land Use due in 2019.

3.6.2.3 Atmospheric compounds (aerosols and methane)

There are multiple pathways that could be used to limit anthropogenic climate change, and the details of the pathways will influence the impacts of climate change on humans and ecosystems. Anthropogenic-driven changes in aerosols cause important modifications to the global climate (Bindoff et al., 2013a; Boucher et al., 2013b; P. Wu et al., 2013; Sarojini et al., 2016; H. Wang et al., 2016). Enforcement of strict air quality policies may lead to a large decrease in cooling aerosol emissions in the next few decades. These aerosol emission reductions may cause a warming comparable to that resulting from the increase in greenhouse gases by mid-21st century under low CO_2 pathways (Kloster et al., 2009; Acosta Navarro et al., 2017). Further background is provided in Sections 2.2.2 and 2.3.1; Cross Chapter Box 1 in Chapter 1). Because aerosol effects on the energy budget are regional, strong regional changes in precipitation from aerosols may occur if aerosol emissions are reduced for air quality reasons or as a co-benefit from switches to sustainable energy sources (H. Wang et al., 2016). Thus, regional impacts, especially on precipitation, are very sensitive to 1.5°C-consistent pathways (Z. Wang et al., 2017).

Pathways which rely heavily on reductions in methane (CH_4) instead of CO_2 will reduce warming in the short term because CH_4 is such a stronger and shorter-lived greenhouse gas than CO_2, but will lead to stronger warming in the long term because of the much longer residence time of CO_2 (Myhre et al., 2013; Pierrehumbert, 2014). In addition, the dominant loss mechanism for CH_4 is atmospheric photo-oxidation. This conversion modifies ozone formation and destruction in the troposphere and stratosphere, therefore modifying the contribution of ozone to radiative forcing, as well as feedbacks on the oxidation rate of methane itself (Myhre et al., 2013). Focusing on pathways and policies which both improve air quality and reduce impacts of climate change can provide multiple co-benefits (Shindell et al., 2017). These pathways are discussed in detail in Sections 4.3.7 and 5.4.1 and in Cross-Chapter Box 12 in Chapter 5.

Atmospheric aerosols and gases can also modify the land and ocean uptake of anthropogenic CO_2; some compounds enhance uptake while others reduce it (Section 2.6.2; Ciais et al., 2013). While CO_2 emissions tend to encourage greater uptake of carbon by the land and the ocean (Ciais et al., 2013), CH_4 emissions can enhance ozone pollution, depending on nitrogen oxides, volatile organic compounds and other organic species concentrations, and ozone pollution tends to reduce land productivity (Myhre et al., 2013; B. Wang et al., 2017). Aside from inhibiting land vegetation productivity, ozone may also alter the CO_2, CH_4 and nitrogen (N_2O) exchange at the land–atmosphere interface and transform the global soil system from a sink to a source of carbon (B. Wang et al., 2017). Aerosols and associated nitrogen-based compounds tend to enhance the uptake of CO_2 in land and ocean systems through deposition of nutrients and modification of climate (Ciais et al., 2013; Mahowald et al., 2017b).

Cross-Chapter Box 7 | Land-Based Carbon Dioxide Removal in Relation to 1.5°C of Global Warming

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Climate and land form a complex system characterized by multiple feedback processes and the potential for non-linear responses to perturbation. Climate determines land cover and the distribution of vegetation, affecting above- and below-ground carbon stocks. At the same time, land cover influences global climate through altered biogeochemical processes (e.g., atmospheric composition and nutrient flow into oceans), and regional climate through changing biogeophysical processes including albedo, hydrology, transpiration and vegetation structure (Forseth, 2010).

Greenhouse gas (GHG) fluxes related to land use are reported in the 'agriculture, forestry and other land use' sector (AFOLU) and comprise about 25% (about 10–12 $GtCO_2eq\ yr^{-1}$) of anthropogenic GHG emissions (P. Smith et al., 2014). Reducing emissions from land use, as well as land-use change, are thus an important component of low-emissions mitigation pathways (Clarke et al., 2014), particularly as land-use emissions can be influenced by human actions such as deforestation, afforestation, fertilization, irrigation, harvesting, and other aspects of cropland, grazing land and livestock management (Paustian et al., 2006; Griscom et al., 2017; Houghton and Nassikas, 2018).

In the IPCC Fifth Assessment Report, the vast majority of scenarios assessed with a 66% or better chance of limiting global warming to 2°C by 2100 included carbon dioxide removal (CDR) – typically about 10 $GtCO_2\ yr^{-1}$ in 2100 or about 200–400 $GtCO_2$ over the course of the century (Smith et al., 2015; van Vuuren et al., 2016). These integrated assessment model (IAM) results were predominately achieved by using bioenergy with carbon capture and storage (BECCS) and/or afforestation and reforestation (AR). Virtually all scenarios that limit either peak or end-of-century warming to 1.5°C also use land-intensive CDR technologies (Rogelj et al., 2015; Holz et al., 2017; Kriegler et al., 2017; Fuss et al., 2018; van Vuuren et al., 2018). Again, AR (Sections 2.3 and 4.3.7) and BECCS (Sections 4.3.2. and 4.3.7) predominate. Other CDR options, such as the application of biochar to soil, soil carbon sequestration, and enhanced weathering (Section 4.3.7) are not yet widely incorporated into IAMs, but their deployment would also necessitate the use of land and/or changes in land management.

Integrated assessment models provide a simplified representation of land use and, with only a few exceptions, do not include biophysical feedback processes (e.g., albedo and evapotranspiration effects) (Kreidenweis et al., 2016) despite the importance of these processes for regional climate, in particular hot extremes (Section 3.6.2.2; Seneviratne et al., 2018c). The extent, location and impacts of large-scale land-use change described by existing IAMs can also be widely divergent, depending on model structure, scenario parameters, modelling objectives and assumptions (including regarding land availability and productivity) (Prestele et

Cross-Chapter Box 7 (continued)

al., 2016; Alexander et al., 2017; Popp et al., 2017; Seneviratne et al., 2018c). Despite these limitations, IAM scenarios effectively highlight the extent and nature of potential land-use transitions implicit in limiting warming to 1.5°C.

Cross-Chapter Box 7 Table 1 presents a comparison of the five CDR options assessed in this report. This illustrates that if BECCS and AR were to be deployed at a scale of 12 $GtCO_2$ yr^{-1} in 2100, for example, they would have a substantial land and water footprint. Whether this footprint would result in adverse impacts, for example on biodiversity or food production, depends on the existence and effectiveness of measures to conserve land carbon stocks, limit the expansion of agriculture at the expense of natural ecosystems, and increase agriculture productivity (Bonsch et al., 2016; Obersteiner et al., 2016; Bertram et al., 2018; Humpenöder et al., 2018). In comparison, the land and water footprints of enhanced weathering, soil carbon sequestration and biochar application are expected to be far less per $GtCO_2$ sequestered. These options may offer potential co-benefits by providing an additional source of nutrients or by reducing N_2O emissions, but they are also associated with potential side effects. Enhanced weathering would require massive mining activity, and providing feedstock for biochar would require additional land, even though a proportion of the required biomass is expected to come from residues (Woolf et al., 2010; Smith, 2016). For the terrestrial CDR options, permanence and saturation are important considerations, making their viability and long-term contributions to carbon reduction targets uncertain.

The technical, political and social feasibility of scaling up and implementing land-intensive CDR technologies (Cross-Chapter Box 3 in Chapter 1) is recognized to present considerable potential barriers to future deployment (Boucher et al., 2013a; Fuss et al., 2014, 2018; Anderson and Peters, 2016; Vaughan and Gough, 2016; Williamson, 2016; Minx et al., 2017, 2018; Nemet et al., 2018; Strefler et al., 2018; Vaughan et al., 2018). To investigate the implications of restricting CDR options should these barriers prove difficult to overcome, IAM studies (Section 2.3.4) have developed scenarios that limit – either implicitly or explicitly – the use of BECCS and bioenergy (Krey et al., 2014; Bauer et al., 2018; Rogelj et al., 2018) or the use of BECCS and afforestation (Strefler et al., 2018). Alternative strategies to limit future reliance on CDR have also been examined, including increased electrification, agricultural intensification, behavioural change, and dramatic improvements in energy and material efficiency (Bauer et al., 2018; Grubler et al., 2018; van Vuuren et al., 2018). Somewhat counterintuitively, scenarios that seek to limit the deployment of BECCs may result in increased land use, through greater deployment of bioenergy, and afforestation (Chapter 2, Box 2.1; Krey et al., 2014; Krause et al., 2017; Bauer et al., 2018; Rogelj et al., 2018). Scenarios aiming to minimize the total human land footprint (including land for food, energy and climate mitigation) also result in land-use change, for example by increasing agricultural efficiency and dietary change (Grubler et al., 2018).

The impacts of changing land use are highly context, location and scale dependent (Robledo-Abad et al., 2017). The supply of biomass for CDR (e.g., energy crops) has received particular attention. The literature identifies regional examples of where the use of land to produce biofuels might be sustainably increased (Jaiswal et al., 2017), where biomass markets could contribute to the provision of ecosystem services (Dale et al., 2017), and where bioenergy could increase the resilience of production systems and contribute to rural development (Kline et al., 2017). However, studies of global biomass potential provide only limited insight into the local feasibility of supplying large quantities of biomass on a global scale (Slade et al., 2014). Concerns about large-scale use of biomass for CDR include a range of potential consequences including greatly increased demand for freshwater use, increased competition for land, loss of biodiversity and/or impacts on food security (Section 3.6.2.1; Heck et al., 2018). The short- versus long-term carbon impacts of substituting biomass for fossil fuels, which are largely determined by feedstock choice, also remain a source of contention (Schulze et al., 2012; Jonker et al., 2014; Booth, 2018; Sterman et al., 2018).

Afforestation and reforestation can also present trade-offs between biodiversity, carbon sequestration and water use, and these strategies have a higher land footprint per tonne of CO_2 removed (Cunningham, 2015; Naudts et al., 2016; Smith et al., 2018). For example, changing forest management to strategies favouring faster growing species, greater residue extraction and shorter rotations may have a negative impact on biodiversity (de Jong et al., 2014). In contrast, reforestation of degraded land with native trees can have substantial benefits for biodiversity (Section 3.6). Despite these constraints, the potential for increased carbon sequestration through improved land stewardship measures is considered to be substantial (Griscom et al., 2017).

Evaluating the synergies and trade-offs between mitigation and adaptation actions, resulting land and climate impacts, and the myriad issues related to land-use governance will be essential to better understand the future role of CDR technologies. This topic will be addressed further in the IPCC Special Report on Climate Change and Land (SRCCL) due to be published in 2019.

Cross-Chapter Box 7 (continued next page)

Cross-Chapter Box 7 (continued)

Key messages:

Cost-effective strategies to limit peak or end-of-century warming to 1.5°C all include enhanced GHG removals in the AFOLU sector as part of their portfolio of measures (*high confidence*).

Large-scale deployment of land-based CDR would have far-reaching implications for land and water availability (*high confidence*). This may impact food production, biodiversity and the provision of other ecosystem services (*high confidence*).

The impacts of deploying land-based CDR at large scales can be reduced if a wider portfolio of CDR options is deployed, and if increased mitigation effort focuses on strongly limiting demand for land, energy and material resources, including through lifestyle and dietary changes (*medium confidence*).

Afforestation and reforestation may be associated with significant co-benefits if implemented appropriately, but they feature large land and water footprints if deployed at large scales (*medium confidence*).

Cross-Chapter Box 7, Table 1 | Comparison of land-based carbon removal options.

Sources: [a] assessed ranges by Fuss et al. (2018), see Figures in Section 4.3.7 for full literature range; [b] based on the 2100 estimate for mean potentials by Smith et al. (2015). Note that biophysical impacts of land-based CDR options besides albedo changes (e.g., through changes in evapotranspiration related to irrigation or land cover/use type) are not displayed.

Option	Potentials [a]	Cost [a]	Required land [b]	Required water [b]	Impact on nutrients [b]	Impact on albedo [b]	Saturation and permanence [a]
	$GtCO_2\ y^{-1}$	*$\$\ tCO_2^{-1}$*	*$Mha\ GtCO_2^{-1}$*	*$km^3\ GtCO_2^{-1}$*	*$Mt\ N, P, K\ y^{-1}$*	*No units*	*No units*
BECCS	0.5–5	100–200	31–58	60	Variable	Variable; depends on source of biofuel (higher albedo for crops than for forests) and on land management (e.g., no-till farming for crops)	Long-term governance of storage; limits on rates of bioenergy production and carbon sequestration
Afforestation & reforestation	0.5–3.6	5–50	80	92	0.5	Negative, or reduced GHG benefit where not negative	Saturation of forests; vulnerable to disturbance; post-AR forest management essential
Enhanced weathering	2–4	50–200	3	0.4	0	0	Saturation of soil; residence time from months to geological timescale
Biochar	0.3–2	30–120	16–100	0	N: 8.2, P: 2.7, K: 19.1	0.08–0.12	Mean residence times between decades to centuries, depending on soil type, management and environmental conditions
Soil carbon sequestration	2.3–5	0–100	0	0	N: 21.8, P: 5.5, K: 4.1	0	Soil sinks saturate and can reverse if poor management practices resume

3.6.3 Implications Beyond the End of the Century

3.6.3.1 Sea ice

Sea ice is often cited as a tipping point in the climate system (Lenton, 2012). Detailed modelling of sea ice (Schröder and Connolley, 2007; Sedláček et al., 2011; Tietsche et al., 2011), however, suggests that summer sea ice can return within a few years after its artificial removal for climates in the late 20th and early 21st centuries. Further studies (Armour et al., 2011; Boucher et al., 2012; Ridley et al., 2012) modelled the removal of sea ice by raising CO_2 concentrations and studied subsequent regrowth by lowering CO_2. These studies suggest that changes in Arctic sea ice are neither irreversible nor exhibit bifurcation behaviour. It is therefore plausible that the extent of Arctic sea ice may quickly re-equilibrate to the end-of-century climate under an overshoot scenario.

3.6.3.2 Sea level

Policy decisions related to anthropogenic climate change will have a profound impact on sea level, not only for the remainder of this century but for many millennia to come (Clark et al., 2016). On these long time scales, 50 m of sea level rise (SLR) is possible (Clark et al., 2016). While it is *virtually certain* that sea level will continue to rise well beyond 2100, the amount of rise depends on future cumulative emissions (Church et al., 2013) as well as their profile over time (Bouttes et al., 2013; Mengel et al., 2018). Marzeion et al. (2018) found that 28–44% of present-day glacier volume is unsustainable in the present-day climate and that it would eventually melt over the course of a few centuries, even if there were no further climate change. Some components of SLR, such as thermal expansion, are only considered reversible on centennial time scales (Bouttes et al., 2013; Zickfeld et al., 2013), while the contribution from ice sheets may not be reversible under any plausible future scenario (see below).

Based on the sensitivities summarized by Levermann et al. (2013), the contributions of thermal expansion (0.20–0.63 m °C^{-1}) and glaciers (0.21 m °C^{-1} but falling at higher degrees of warming mostly because of the depletion of glacier mass, with a possible total loss of about 0.6 m) amount to 0.5–1.2 m and 0.6–1.7 m in 1.5°C and 2°C warmer worlds, respectively. The bulk of SLR on greater than centennial time scales will therefore be caused by contributions from the continental ice sheets of Greenland and Antarctica, whose existence is threatened on multi-millennial time scales.

For Greenland, where melting from the ice sheet's surface is important, a well-documented instability exists where the surface of a thinning ice sheet encounters progressively warmer air temperatures that further promote melting and thinning. A useful indicator associated with this instability is the threshold at which annual mass loss from the ice sheet by surface melt exceeds mass gain by snowfall. Previous estimates put this threshold at about 1.9°C to 5.1°C above pre-industrial temperatures (Gregory and Huybrechts, 2006). More recent analyses, however, suggest that this threshold sits between 0.8°C and 3.2°C, with a best estimate at 1.6°C (Robinson et al., 2012). The continued decline of the ice sheet after this threshold has been passed is highly dependent on the future climate and varies between about 80% loss after 10,000 years to complete loss after as little as 2000 years (contributing about 6 m to SLR). Church et al. (2013) were unable to quantify a *likely* range for this threshold. They assigned *medium confidence* to a range greater than 2°C but less than 4°C, and had *low confidence* in a threshold of about 1°C. There is insufficient new literature to change this assessment.

The Antarctic ice sheet, in contrast, loses the mass gained by snowfall as outflow and subsequent melt to the ocean, either directly from the underside of floating ice shelves or indirectly by the melting of calved icebergs. The long-term existence of this ice sheet will also be affected by a potential instability (the marine ice sheet instability, MISI), which links outflow (or mass loss) from the ice sheet to water depth at the grounding line (i.e., the point at which grounded ice starts to float and becomes an ice shelf) so that retreat into deeper water (the bedrock underlying much of Antarctica slopes downwards towards the centre of the ice sheet) leads to further increases in outflow and promotes yet further retreat (Schoof, 2007). More recently, a variant on this mechanism was postulated in which an ice cliff forms at the grounding line and retreats rapidly though fracture and iceberg calving (DeConto and Pollard, 2016). There is a growing body of evidence (Golledge et al., 2015; DeConto and Pollard, 2016) that large-scale retreat may be avoided in emissions scenarios such as Representative Concentration Pathway (RCP)2.6 but that higher-emissions RCP scenarios could lead to the loss of the West Antarctic ice sheet and sectors in East Antarctica, although the duration (centuries or millennia) and amount of mass loss during such a collapse is highly dependent on model details and no consensus exists yet. Schoof (2007) suggested that retreat may be irreversible, although a rigorous test has yet to be made. In this context, overshoot scenarios, especially of higher magnitude or longer duration, could increase the risk of such irreversible retreat.

Church et al. (2013) noted that the collapse of marine sectors of the Antarctic ice sheet could lead to a global mean sea level (GMSL) rise above the likely range, and that there was *medium confidence* that this additional contribution 'would not exceed several tenths of a metre during the 21st century'.

The multi-centennial evolution of the Antarctic ice sheet has been considered in papers by DeConto and Pollard (2016) and Golledge et al. (2015). Both suggest that RCP2.6 is the only RCP scenario leading to long-term contributions to GMSL of less than 1.0 m. The long-term committed future of Antarctica and the GMSL contribution at 2100 are complex and require further detailed process-based modelling; however, a threshold in this contribution may be located close to 1.5°C to 2°C of global warming.

In summary, there is *medium confidence* that a threshold in the long-term GMSL contribution of both the Greenland and Antarctic ice sheets lies around 1.5°C to 2°C of global warming relative to pre-industrial; however, the GMSL associated with these two levels of global warming cannot be differentiated on the basis of the existing literature.

3.6.3.3 Permafrost

The slow rate of permafrost thaw introduces a lag between the transient degradation of near-surface permafrost and contemporary climate, so that the equilibrium response is expected to be 25–38% greater than the transient response simulated in climate models (Slater and Lawrence, 2013). The long-term, equilibrium Arctic permafrost loss to global warming was analysed by Chadburn et al. (2017). They used an empirical relation between recent mean annual air temperatures and the area underlain by permafrost coupled to Coupled Model Intercomparison Project Phase 5 (CMIP5) stabilization projections to 2300 for RCP2.6 and RCP4.5. Their estimate of the sensitivity of permafrost to warming is 2.9–5.0 million km^2 °C^{-1} (1 standard deviation confidence interval), which suggests that stabilizing climate at 1.5°C as opposed to 2°C would reduce the area of eventual permafrost loss by 1.5 to 2.5 million km^2 (stabilizing at 56–83% as opposed to 43–72% of 1960–1990 levels). This work, combined with the assessment of Collins et al. (2013) on the link between global warming and permafrost loss, leads to the assessment that permafrost extent would be appreciably greater in a 1.5°C warmer world compared to in a 2°C warmer world (*low to medium confidence*).

3.7 Knowledge Gaps

Most scientific literature specific to global warming of 1.5°C is only just emerging. This has led to differences in the amount of information available and gaps across the various sections of this chapter. In general, the number of impact studies that specifically focused on 1.5°C lags behind climate-change projections in general, due in part to the dependence of the former on the latter. There are also insufficient studies focusing on regional changes, impacts and consequences at 1.5°C and 2°C of global warming.

The following gaps have been identified with respect to tools, methodologies and understanding in the current scientific literature specific to Chapter 3. The gaps identified here are not comprehensive but highlight general areas for improved understanding, especially regarding global warming at 1.5°C compared to 2°C and higher levels.

3.7.1 Gaps in Methods and Tools

- Regional and global climate model simulations for low-emissions scenarios such as a 1.5°C warmer world.

- Robust probabilistic models which separate the relatively small signal between 1.5°C versus 2°C from background noise, and which handle the many uncertainties associated with non-linearities, innovations, overshoot, local scales, and latent or lagging responses in climate.

- Projections of risks under a range of climate and development pathways required to understand how development choices affect the magnitude and pattern of risks, and to provide better estimates of the range of uncertainties.

- More complex and integrated socio-ecological models for predicting the response of terrestrial as well as coastal and oceanic ecosystems to climate and models which are more capable of separating climate effects from those associated with human activities.

- Tools for informing local and regional decision-making, especially when the signal is ambiguous at 1.5°C and/or reverses sign at higher levels of global warming.

3.7.2 Gaps in Understanding

3.7.2.1 Earth systems and 1.5°C of global warming

- The cumulative effects of multiple stresses and risks (e.g., increased storm intensity interacting with sea level rise and the effect on coastal people; feedbacks on wetlands due to climate change and human activities).

- Feedbacks associated with changes in land use/cover for low-emissions scenarios, for example feedback from changes in forest cover, food production, biofuel production, bio-energy with carbon capture and storage (BECCS), and associated unquantified biophysical impacts.

- The distinct impacts of different overshoot scenarios, depending on (i) the peak temperature of the overshoot, (ii) the length of the overshoot period, and (iii) the associated rate of change in global temperature over the time period of the overshoot.

3.7.2.2 Physical and chemical characteristics of a 1.5°C warmer world

- Critical thresholds for extreme events (e.g., drought and inundation) between 1.5°C and 2°C of warming for different climate models and projections. All aspects of storm intensity and frequency as a function of climate change, especially for 1.5°C and 2°C warmer worlds, and the impact of changing storminess on storm surges, damage, and coastal flooding at regional and local scales.

- The timing and implications of the release of stored carbon in Arctic permafrost in a 1.5°C warmer world and for climate stabilization by the end of the century.

- Antarctic ice sheet dynamics, global sea level, and links between seasonal and year-long sea ice in both polar regions.

3.7.2.3 Terrestrial and freshwater systems

- The dynamics between climate change, freshwater resources and socio-economic impacts for lower levels of warming.

- How the health of vegetation is likely to change, carbon storage in plant communities and landscapes, and phenomena such as the fertilization effect.

- The risks associated with species' maladaptation in response to climatic changes (e.g., effects of late frosts). Questions associated with issues such as the consequences of species advancing their spring phenology in response to warming, as well as the interaction between climate change, range shifts and local adaptation in a 1.5°C warmer world.

- The biophysical impacts of land use in the context of mitigation pathways.

3.7.2.4 Ocean Systems

- Deep sea processes and risks to deep sea habitats and ecosystems.

- How changes in ocean chemistry in a 1.5°C warmer world, including decreasing ocean oxygen content, ocean acidification and changes in the activity of multiple ion species, will affect natural and human systems.

- How ocean circulation is changing towards 1.5°C and 2°C warmer worlds, including vertical mixing, deep ocean processes, currents, and their impacts on weather patterns at regional to local scales.

- The impacts of changing ocean conditions at 1.5°C and 2°C of warming on foodwebs, disease, invading species, coastal protection, fisheries and human well-being, especially as organisms modify their biogeographical ranges within a changing ocean.

- Specific linkages between food security and changing coastal and ocean resources.

3.7.2.5 Human systems

- The impacts of global and regional climate change at 1.5°C on food distribution, nutrition, poverty, tourism, coastal infrastructure and public health, particularly for developing nations.
- Health and well-being risks in the context of socio-economic and climate change at 1.5°C, especially in key areas such as occupational health, air quality and infectious disease.
- Micro-climates at urban/city scales and their associated risks for natural and human systems, within cities and in interaction with surrounding areas. For example, current projections do not integrate adaptation to projected warming by considering cooling that could be achieved through a combination of revised building codes, zoning and land use to build more reflective roofs and urban surfaces that reduce urban heat island effects.
- Implications of climate change at 1.5°C on livelihoods and poverty, as well as on rural communities, indigenous groups and marginalized people.
- The changing levels of risk in terms of extreme events, including storms and heatwaves, especially with respect to people being displaced or having to migrate away from sensitive and exposed systems such as small islands, low-lying coasts and deltas.

Cross-Chapter Box 8 | 1.5°C Warmer Worlds

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Introduction

The Paris Agreement includes goals of stabilizing global mean surface temperature (GMST) well below 2°C and 1.5°C above pre-industrial levels in the longer term. There are several aspects, however, that remain open regarding what a '1.5°C warmer world' could be like, in terms of mitigation (Chapter 2) and adaptation (Chapter 4), as well as in terms of projected warming and associated regional climate change (Chapter 3), which are overlaid on anticipated and differential vulnerabilities (Chapter 5). **Alternative '1.5°C warmer worlds' resulting from mitigation and adaptation choices, as well as from climate variability (climate 'noise'), can be vastly different,** as highlighted in this Cross-Chapter Box. In addition, the range of models underlying 1.5°C projections can be substantial and needs to be considered.

Key questions[7]:

- **What is a 1.5°C global mean warming, how is it measured, and what temperature increase does it imply for single locations and at specific times?** Global mean surface temperature (GMST) corresponds to the globally averaged temperature of Earth derived from point-scale ground observations or computed in climate models (Chapters 1 and 3). Global mean surface temperature is additionally defined over a given time frame, for example averaged over a month, a year, or multiple decades. Because of climate variability, a climate-based GMST typically needs to be defined over several decades (typically 20 or 30 years; Chapter 3, Section 3.2). Hence, whether or when global warming reaches 1.5°C depends to some extent on the choice of pre-industrial reference period, whether 1.5°C refers to total or human-induced warming, and which variables and coverage are used to define GMST change (Chapter 1). By definition, because GMST is an average in time and space, there will be locations and time periods in which 1.5°C of warming is exceeded, even if the global mean warming is at 1.5°C. In some locations, these differences can be particularly large (Cross-Chapter Box 8, Figure 1).

- **What is the impact of different climate models for projected changes in climate at 1.5°C of global warming?** The range between single model simulations of projected regional changes at 1.5°C GMST increase can be substantial for regional responses (Chapter 3, Section 3.3). For instance, for the warming of cold extremes in a 1.5°C warmer world, some model simulations project a 3°C warming while others project more than 6°C of warming in the Arctic land areas (Cross-Chapter Box 8, Figure 2). For hot temperature extremes in the contiguous United States, the range of model simulations includes temperatures lower than pre-industrial values (–0.3°C) and a warming of 3.5°C (Cross-Chapter Box 8, Figure 2). Some regions display an even larger range (e.g., 1°C–6°C regional warming in hot extremes in central Europe at 1.5°C of warming; Chapter 3, Sections 3.3.1 and 3.3.2). This large spread is due to both modelling uncertainty and internal climate variability. While the range is large, it also highlights risks that can be avoided with near certainty in a 1.5°C warmer world compared to worlds at higher levels of warming (e.g., an 8°C warming of cold extremes in the Arctic is not reached at 1.5°C of global warming in the multimodel ensemble but could happen at 2°C of global warming; Cross-Chapter Box 8, Figure 2). Inferred projected ranges of regional responses (mean value, minimum and maximum) for different mitigation scenarios from Chapter 2 are displayed in Cross-Chapter Box 8, Table 1.

- **What is the impact of emissions pathways with, versus without, an overshoot?** All mitigation pathways projecting less than 1.5°C of global warming over or at the end of the 21st century include some probability of overshooting 1.5°C. These pathways include some periods with warming stronger than 1.5°C in the course of the coming decades and/or some probability of not reaching 1.5°C (Chapter 2, Section 2.2). This is inherent to the difficulty of limiting global warming to 1.5°C, given that we are already very close to this warming level. The implications of overshooting are large for risks to natural and human

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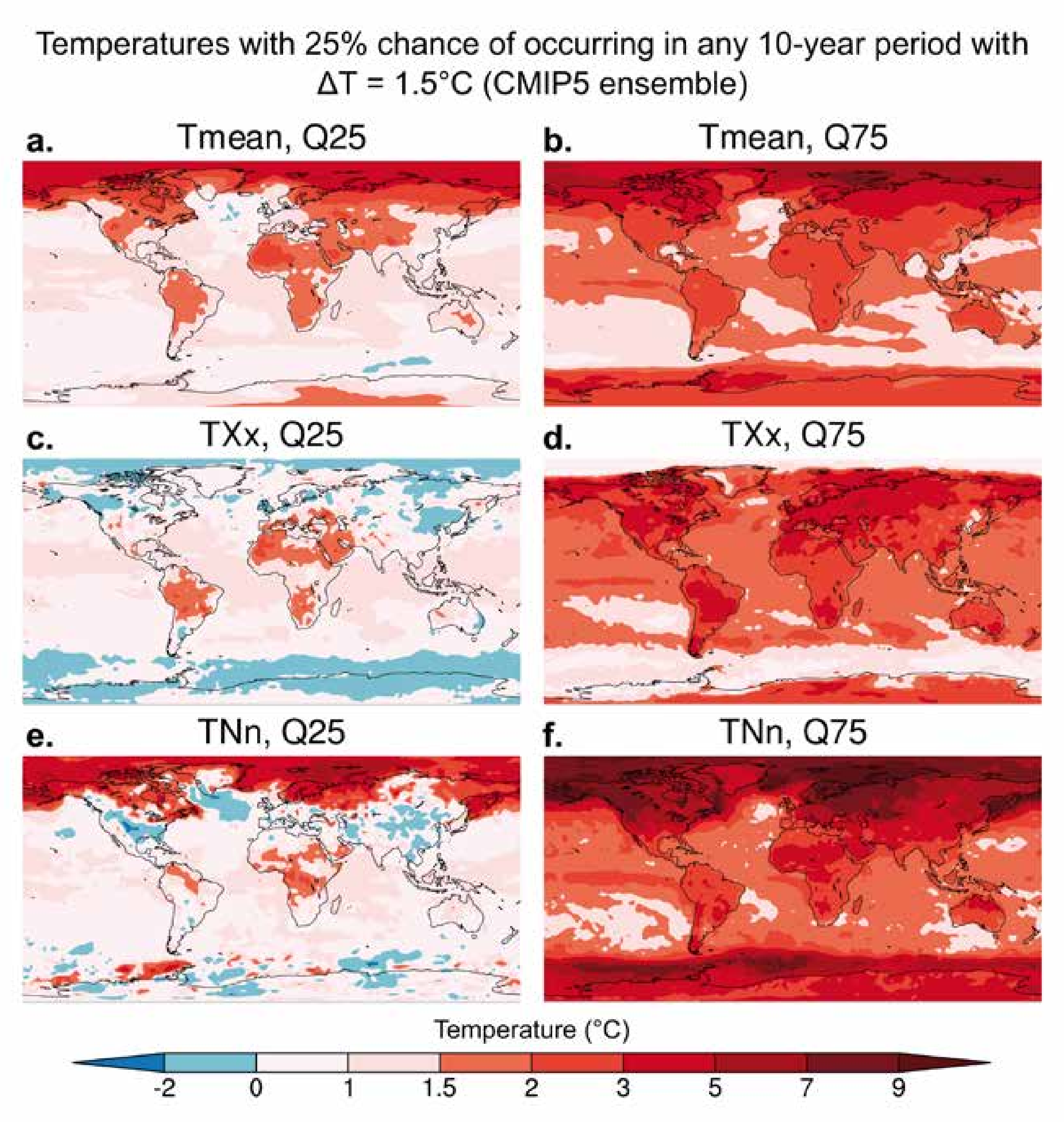
[7] Part of this discussion is based on Seneviratne et al. (2018b).

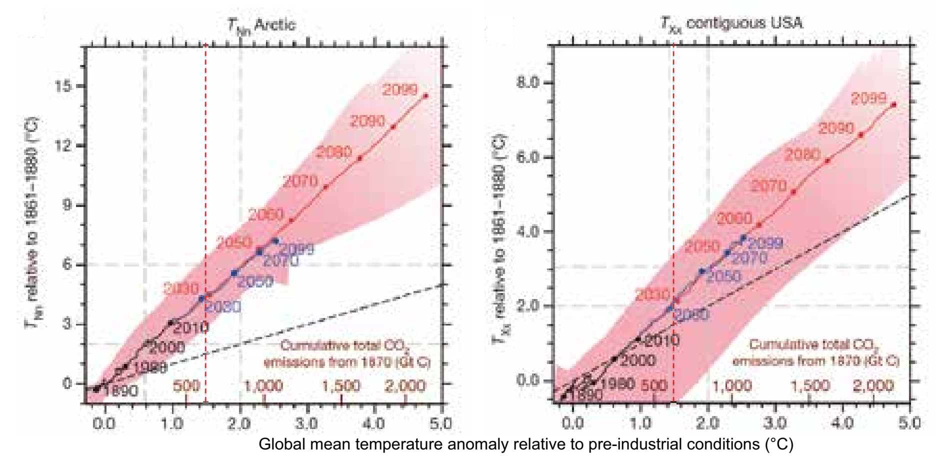
Cross-Chapter Box 8 (continued)



Cross-Chapter Box 8, Figure 1 | Range of projected realized temperatures at 1.5°C of global warming (due to stochastic noise and model-based spread). Temperatures with a 25% chance of occurrence at any location within a 10-year time frame are shown, corresponding to GMST anomalies of 1.5°C (Coupled Model Intercomparison Project Phase 5 (CMIP5) multimodel ensemble). The plots display the 25th percentile (Q25, left) and 75th percentile (Q75, right) values of mean temperature (Tmean), yearly maximum daytime temperature (TXx) and yearly minimum night-time temperature (TNn), sampled from all time frames with GMST anomalies of 1.5°C in Representative Concentration Pathway (RCP)8.5 model simulations of the CMIP5 ensemble. From Seneviratne et al. (2018b).

Cross-Chapter Box 8 (continued next page)

Cross-Chapter Box 8 (continued)



Cross-Chapter Box 8, Figure 2 | Spread of projected multimodel changes in minimum annual night-time temperature (TNn) in Arctic land (left) and in maximum annual daytime temperature (TXx) in the contiguous United States as a function of mean global warming in climate simulations. The multimodel range (due to model spread and internal climate variability) is indicated in red shading (minimum and maximum value based on climate model simulations). The multimodel mean value is displayed with solid red and blue lines for two emissions pathways (blue: Representative Concentration Pathway (RCP)4.5; red: RCP8.5). The dashed red line indicates projections for a 1.5°C warmer world. The dashed black line displays the 1:1 line. The figure is based on Figure 3 of Seneviratne et al. (2016).

systems, especially if the temperature at peak warming is high, because some risks may be long lasting and irreversible, such as the loss of some ecosystems (Chapter 3, Box 3.4). The chronology of emissions pathways and their implied warming is also important for the more slowly evolving parts of the Earth system, such as those associated with sea level rise. In addition, for several types of risks the rate of change may be most relevant (Loarie et al., 2009; LoPresti et al., 2015), with potentially large risks occurring in the case of a rapid rise to overshooting temperatures, even if a decrease to 1.5°C may be achieved at the end of the 21st century or later. On the other hand, if overshoot is to be minimized, the remaining equivalent CO_2 budget available for emissions has to be very small, which implies that large, immediate and unprecedented global efforts to mitigate GHGs are required (Cross-Chapter Box 8, Table 1; Chapter 4).

- **What is the probability of reaching 1.5°C of global warming if emissions compatible with 1.5°C pathways are followed?** Emissions pathways in a 'prospective scenario' (see Chapter 1, Section 1.2.3, and Cross-Chapter Box 1 in Chapter 1 on 'Scenarios and pathways') compatible with 1.5°C of global warming are determined based on their probability of reaching 1.5°C by 2100 (Chapter 2, Section 2.1), given current knowledge of the climate system response. These probabilities cannot be quantified precisely but are typically 50–66% in 1.5°C-consistent pathways (Section 1.2.3). This implies a one-in-two to one-in-three probability that global warming would exceed 1.5°C even under a 1.5°C-consistent pathway, including some possibility that global warming would be substantially over this value (generally about 5–10% probability; see Cross-Chapter Box 8, Table 1 and Seneviratne et al., 2018b). These alternative outcomes need to be factored into the decision-making process. To address this issue, 'adaptive' mitigation scenarios have been proposed in which emissions are continually adjusted to achieve a temperature goal (Millar et al., 2017). The set of dimensions involved in mitigation options (Chapter 4) is complex and need system-wide approaches to be successful. Adaptive scenarios could be facilitated by the global stocktake mechanism established in the Paris Agreement, and thereby transfer the risk of higher-than-expected warming to a risk of faster-than-expected mitigation efforts. However, there are some limits to the feasibility of such approaches because some investments, for example in infrastructure, are long term and also because the actual departure from an aimed pathway will need to be detected against the backdrop of internal climate variability, typically over several decades (Haustein et al., 2017; Seneviratne et al., 2018b). Avoiding impacts that depend on atmospheric composition as well as GMST (Baker et al., 2018) would also require limits on atmospheric CO_2 concentrations in the event of a lower-than-expected GMST response.

- **How can the transformation towards a 1.5°C warmer world be implemented?** This can be achieved in a variety of ways, such as decarbonizing the economy with an emphasis on demand reductions and sustainable lifestyles, or, alternatively, with an emphasis on large-scale technological solutions, amongst many other options (Chapter 2, Sections 2.3 and 2.4; Chapter 4, Sections 4.1 and 4.4.4). Different portfolios of mitigation measures come with distinct synergies and trade-offs with respect to other societal objectives. Integrated solutions and approaches are required to achieve multiple societal objectives simultaneously (see Chapter 4, Section 4.5.4 for a set of synergies and trade-offs).

Cross-Chapter Box 8 (continued)

- **What determines risks and opportunities in a 1.5°C warmer world?** The risks to natural, managed and human systems in a 1.5°C warmer world will depend not only on uncertainties in the regional climate that results from this level of warming, but also very strongly on the methods that humanity uses to limit global warming to 1.5°C. This is particularly the case for natural ecosystems and agriculture (see Cross-Chapter Box 7 in this chapter and Chapter 4, Section 4.3.2). The risks to human systems will also depend on the magnitude and effectiveness of policies and measures implemented to increase resilience to the risks of climate change and on development choices over coming decades, which will influence the underlying vulnerabilities and capacities of communities and institutions for responding and adapting.

- **Which aspects are not considered, or only partly considered, in the mitigation scenarios from Chapter 2?** These include biophysical impacts of land use, water constraints on energy infrastructure, and regional implications of choices of specific scenarios for tropospheric aerosol concentrations or the modulation of concentrations of short-lived climate forcers, that is, greenhouse gases (Chapter 3, Section 3.6.3). Such aspects of development pathways need to be factored into comprehensive assessments of the regional implications of mitigation and adaptation measures. On the other hand, some of these aspects are assessed in Chapter 4 as possible options for mitigation and adaptation to a 1.5°C warmer world.

- **Are there commonalities to all alternative 1.5°C warmer worlds?** Human-driven warming linked to CO_2 emissions is nearly irreversible over time frames of 1000 years or more (Matthews and Caldeira, 2008; Solomon et al., 2009). The GSMT of the Earth responds to the cumulative amount of CO_2 emissions. Hence, all 1.5°C stabilization scenarios require both net CO_2 emissions and multi-gas CO_2-forcing-equivalent emissions to be zero at some point (Chapter 2, Section 2.2). This is also the case for stabilization scenarios at higher levels of warming (e.g., at 2°C); the only difference is the projected time at which the net CO_2 budget is zero.

  Hence, a transition to decarbonization of energy use is necessary in all scenarios. It should be noted that **all scenarios of Chapter 2 include approaches for carbon dioxide removal (CDR)** in order to achieve the net zero CO_2 emissions budget. **Most of these use carbon capture and storage (CCS)** in addition to reforestation, although to varying degrees (Chapter 4, Section 4.3.7). Some potential pathways to 1.5°C of warming in 2100 would minimize the need for CDR (Obersteiner et al., 2018; van Vuuren et al., 2018). Taking into account the implementation of CDR, the CO_2-induced warming by 2100 is determined by the difference between the total amount of CO_2 generated (that can be reduced by early decarbonization) and the total amount permanently stored out of the atmosphere, for example by geological sequestration (Chapter 4, Section 4.3.7).

- **What are possible storylines of 'warmer worlds' at 1.5°C versus higher levels of global warming?** Cross-Chapter Box 8, Table 2 features possible storylines based on the scenarios of Chapter 2, the impacts of Chapters 3 and 5, and the options of Chapter 4. These storylines are not intended to be comprehensive of all possible future outcomes. Rather, they are intended as plausible scenarios of alternative warmer worlds, with two storylines that include stabilization at 1.5°C (Scenario 1) or close to 1.5°C (Scenario 2), and one storyline missing this goal and consequently only including reductions of CO_2 emissions and efforts towards stabilization at higher temperatures (Scenario 3).

Summary:

There is no single '1.5°C warmer world'. Impacts can vary strongly for different worlds characterized by a 1.5°C global warming. Important aspects to consider (besides the changes in global temperature) are the possible occurrence of an overshoot and its associated peak warming and duration, how stabilization of the increase in global surface temperature at 1.5°C could be achieved, how policies might be able to influence the resilience of human and natural systems, and the nature of regional and subregional risks.

The implications of overshooting are large for risks to natural and human systems, especially if the temperature at peak warming is high, because some risks may be long lasting and irreversible, such as the loss of some ecosystems. In addition, for several types of risks, the rate of change may be most relevant, with potentially large risks occurring in the case of a rapid rise to overshooting temperatures, even if a decrease to 1.5°C may be achieved at the end of the 21st century or later. If overshoot is to be minimized, the remaining equivalent CO_2 budget available for emissions has to be very small, which implies that large, immediate and unprecedented global efforts to mitigate GHGs are required.

The time frame for initiating major mitigation measures is essential in order to reach a 1.5°C (or even a 2°C) global stabilization of climate warming (see consistent cumulative CO_2 emissions up to peak warming in Cross-Chapter Box 8, Table 1). If mitigation pathways are not rapidly activated, much more expensive and complex adaptation measures will have to be taken to avoid the impacts of higher levels of global warming on the Earth system.

Cross-Chapter Box 8 (continued next page)

Cross-Chapter Box 8 (continued)

Cross-Chapter Box 8, Table 1 | Different worlds resulting from 1.5°C and 2°C mitigation (prospective) pathways, including 66% (probable) best-case outcome, and 5% worst-case outcome, based on Chapter 2 scenarios and Chapter 3 assessments of changes in regional climate. Note that the pathway characteristics estimates are based on computations with the MAGICC model (Meinshausen et al., 2011) consistent with the set-up used in AR5 WGIII (Clarke et al., 2014), but are uncertain and will be subject to updates and adjust-ments (see Chapter 2 for details). Updated from Seneviratne et al. (2018b).

		B1.5_LOS (below 1.5°C with low overshoot) with 2/3 ´probable best-case outcome´[a]	**B1.5_LOS (below 1.5°C with low overshoot) with 1/20 ´worst-case outcome´[b]**	**L20 (lower than 2°C) with 2/3 ´probable best-case outcome´[a]**	**L20 (lower than 2°C) with 1/20 ´worst-case outcome´[b]**
General characteristics of pathway	**Overshoot > 1.5°C in 21st century[c]**	**Yes (51/51)**	**Yes (51/51)**	**Yes (72/72)**	**Yes (72/72)**
	Overshoot > 2°C in 21st century	**No (0/51)**	**Yes (37/51)**	**No (72/72)**	**Yes (72/72)**
	Cumulative CO_2 emissions up to peak warming (relative to 2016)[d] [$GtCO_2$]	610–760	590–750	1150–1460	1130–1470
	Cumulative CO_2 emissions up to 2100 (relative to 2016)[d] [$GtCO_2$]	170–560		1030–1440	
	Global GHG emissions in 2030[d] [$GtCO_2$ y-1]	19–23		31–38	
	Years of global net zero CO_2 emissions[d]	2055–2066		2082–2090	
Possible climate range at peak warming (regional+global)	**Global mean temperature anomaly at peak warming**	**1.7°C (1.66°C–1.72°C)**	**2.05°C (2.00°C–2.09°C)**	**2.11°C (2.05°C–2.17°C)**	**2.67°C (2.59°C–2.76°C)**
	Warming in the Arctic[e] (TNn[f])	4.93°C (4.36, 5.52)	6.02°C (5.12, 6.89)	6.24°C (5.39, 7.21)	7.69°C (6.69, 8.93)
	Warming in Central North America[e] (TXx[g])	2.65°C (1.92, 3.15)	3.11°C (2.37, 3.63)	3.18°C (2.50, 3.71)	4.06°C (3.35, 4.63)
	Warming in Amazon region[e] (TXx)	2.55°C (2.23, 2.83)	3.07°C (2.74, 3.46)	3.16°C (2.84, 3.57)	4.05°C (3.62, 4.46)
	Drying in the Mediterranean region[e,h]	–1.11 (–2.24, –0.41)	–1.28 (–2.44, –0.51)	–1.38 (–2.58, –0.53)	–1.56 (–3.19, –0.67)
	Increase in heavy precipitation events[e] in Southern Asia[i]	9.94% (6.76, 14.00)	11.94% (7.52, 18.86)	12.68% (7.71, 22.39)	19.67% (11.56, 27.24)
Possible climate range in 2100 (regional+global)	**Global mean temperature warming in 2100**	**1.46°C (1.41°C–1.51°C)**	**1.87°C (1.81°C–1.94°C)**	**2.06°C (1.99°C–2.15°C)**	**2.66°C (2.56°C–2.76°C)**
	Warming in the Arctic[j] (TNn)	4.28°C (3.71, 4.77)	5.50°C (4.74, 6.21)	6.08°C (5.20, 6.94)	7.63°C (6.66, 8.90)
	Warming in Central North America[j] (TXx)	2.31°C (1.56, 2.66)	2.83°C (2.03, 3.49)	3.12°C (2.38, 3.67)	4.06°C (3.33, 4.59)
	Warming in Amazon region[j] (TXx)	2.22°C (2.00, 2.45)	2.76°C (2.50, 3.07)	3.10°C (2.75, 3.49)	4.03°C (3.62, 4.45)
	Drying in the Mediterranean region[j]	–0.95 (–1.98, –0.30)	–1.10 (–2.17, –0.51)	–1.26 (–2.43, –0.52)	–1.55 (–3.17, –0.67)
	Increase in heavy precipitation events in Southern Asia[j]	8.38% (4.63, 12.68)	10.34% (6.64, 16.07)	12.02% (7.41, 19.62)	19.72% (11.34, 26.95)

Notes:

a) 66th percentile for global temperature (that is, 66% likelihood of being at or below values)

b) 95th percentile for global temperature (that is, 5% likelihood of being at or above values)

c) All 1.5°C scenarios include a substantial probability of overshooting above 1.5°C global warming before returning to 1.5°C.

d) Interquartile range (25th percentile, q25, and 75th percentile, q75)

e) The regional projections in these rows provide the median and the range [q25, q75] associated with the median global temperature outcomes of the considered mitigation scenarios at peak warming.

f) TNn: Annual minimum night-time temperature

g) TXx: Annual maximum day-time temperature

h) Indicates drying of soil moisture expressed in units of standard deviations of pre-industrial climate (1861–1880) variability (where –1 is dry; –2 is severely dry; and –3 is very severely dry);

i) Rx5day: the annual maximum consecutive 5-day precipitation.

j) As for footnote e, but for the regional responses associated with the median global temperature outcomes of the considered mitigation scenarios in 2100

Cross-Chapter Box 8 (continued)

Cross-Chapter Box 8, Table 2 | Storylines of possible worlds resulting from different mitigation options. The storylines build upon Cross-Chapter Box 8, Table 1 and the assessments of Chapters 1–5. Only a few of the many possible storylines were chosen and they are presented for illustrative purposes.

Scenario 1 [one possible storyline among best-case scenarios]: **Mitigation:** early move to decarbonization, decarbonization designed to minimize land footprint, coordination and rapid action of the world's nations towards 1.5°C goal by 2100 **Internal climate variability:** probable (66%) best-case outcome for global and regional climate responses	**In 2020, strong participation and support for the Paris Agreement and its ambitious goals for reducing CO_2 emissions by an almost unanimous international community led to a time frame for net zero emissions that is compatible with halting global warming at 1.5°C by 2100.** There is strong participation in all major world regions at the national, state and/or city levels. Transport is strongly decarbonized through a shift to electric vehicles, with more cars with electric than combustion engines being sold by 2025 (Chapter 2, Section 2.4.3; Chapter 4, Section 4.3.3). Several industry-sized plants for carbon capture and storage are installed and tested in the 2020s (Chapter 2, Section 2.4.2; Chapter 4, Sections 4.3.4 and 4.3.7). Competition for land between bioenergy cropping, food production, and biodiversity conservation is minimized by sourcing bioenergy for carbon capture and storage from agricultural wastes, algae and kelp farms (Cross-Chapter Box 7 in Chapter 3; Chapter 4, Section 4.3.2). Agriculture is intensified in countries with coordinated planning associated with a drastic decrease in food waste (Chapter 2, Section 2.4.4; Chapter 4, Section 4.3.2). This leaves many natural ecosystems relatively intact, supporting continued provision of most ecosystem services, although relocation of species towards higher latitudes and elevations still results in changes in local biodiversity in many regions, particularly in mountain, tropical, coastal and Arctic ecosystems (Chapter 3, Section 3.4.3). Adaptive measures such as the establishment of corridors for the movement of species and parts of ecosystems become a central practice within conservation management (Chapter 3, Section 3.4.3; Chapter 4, Section 4.3.2). The movement of species presents new challenges for resource management as novel ecosystems, as well as pests and disease, increase (Cross-Chapter Box 6 in Chapter 3). Crops are grown on marginal land, no-till agriculture is deployed, and large areas are reforested with native trees (Chapter 2, Section 2.4.4; Chapter 3, Section 3.6.2; Cross-Chapter Box 7 in Chapter 3; Chapter 4, Section 4.3.2). Societal preference for healthy diets reduces meat consumption and associated GHG emissions (Chapter 2, Section 2.4.4; Chapter 4, Section 4.3.2; Cross-Chapter Box 6 in Chapter 3). By 2100, global mean temperature is on average 0.5°C warmer than it was in 2018 (Chapter 1, Section 1.2.1). Only a minor temperature overshoot occurs during the century (Chapter 2, Section 2.2). In mid-latitudes, frequent hot summers and precipitation events tend to be more intense (Chapter 3, Section 3.3). Coastal communities struggle with increased inundation associated with rising sea levels and more frequent and intense heavy rainfall (Chapter 3, Sections 3.3.2 and 3.3.9; Chapter 4, Section 4.3.2; Chapter 5, Box 5.3 and Section 5.3.2; Cross-Chapter Box 12 in Chapter 5), and some respond by moving, in many cases with consequences for urban areas. In the tropics, in particular in megacities, there are frequent deadly heatwaves whose risks are reduced by proactive adaptation (Chapter 3, Sections 3.3.1 and 3.4.8; Chapter 4, Section 4.3.8), overlaid on a suite of development challenges and limits in disaster risk management (Chapter 4, Section 4.3.3; Chapter 5, Sections 5.2.1 and 5.2.2; Cross-Chapter Box 12 in Chapter 5). Glaciers extent decreases in most mountainous areas (Chapter 3, Sections 3.3.5 and 3.5.4). Reduced Arctic sea ice opens up new shipping lanes and commercial corridors (Chapter 3, Section 3.3.8; Chapter 4, Box 4.3). Small island developing states (SIDS), as well as coastal and low-lying areas, have faced significant changes but have largely persisted in most regions (Chapter 3, Sections 3.3.9 and 3.5.4, Box 3.5). The Mediterranean area becomes drier (Chapter 3, Section 3.3.4 and Box 3.2) and irrigation of crops expands, drawing the water table down in many areas (Chapter 3, Section 3.4.6). The Amazon is reasonably well preserved, through avoided risk of droughts (Chapter 3, Sections 3.3.4 and 3.4.3; Chapter 4, Box 4.3) and reduced deforestation (Chapter 2, Section 2.4.4; Cross-Chapter Box 7 in Chapter 3; Chapter 4, Section 4.3.2), and the forest services are working with the pattern observed at the beginning of the 21st century (Chapter 4, Box 4.3). While some climate hazards become more frequent (Chapter 3, Section 3.3), timely adaptation measures help reduce the associated risks for most, although poor and disadvantaged groups continue to experience high climate risks to their livelihoods and well-being (Chapter 5, Section 5.3.1; Cross-Chapter Box 12 in Chapter 5; Chapter 3, Boxes 3.4 and 3.5; Cross-Chapter Box 6 in Chapter 3). Summer sea ice has not completely disappeared from the Arctic (Chapter 3, Section 3.4.4.7) and coral reefs, having been driven to a low level (10–30% of levels in 2018), have partially recovered by 2100 after extensive dieback (Chapter 3, Section 3.4.4.10 and Box 3.4). The Earth system, while warmer, is still recognizable compared to the 2000s, and no major tipping points are reached (Chapter 3, Section 3.5.2.5). Crop yields remain relatively stable (Chapter 3, Section 3.4). Aggregate economic damage of climate change impacts is relatively small, although there are some local losses associated with extreme weather events (Chapter 3, Section 3.5; Chapter 4). Human well-being remains overall similar to that in 2020 (Chapter 5, Section 5.2.2).
Scenario 2 [one possible storyline among mid-case scenarios]: **Mitigation:** delayed action (ambitious targets reached only after warmer decade in the 2020s due to internal climate variability), overshoot at 2°C, decrease towards 1.5°C afterward, no efforts to minimize the land and water footprints of bioenergy **Internal climate variability:** 10% worst-case outcome (2020s) followed by normal internal climate variability	**The international community continues to largely support the Paris Agreement and agrees in 2020 on reduction targets for CO_2 emissions and time frames for net zero emissions. However, these targets are not ambitious enough to reach stabilization at 2°C of warming, let alone 1.5°C.** In the 2020s, internal climate variability leads to higher warming than projected, in a reverse development to what happened in the so-called 'hiatus' period of the 2000s. Temperatures are regularly above 1.5°C of warming, although radiative forcing is consistent with a warming of 1.2°C or 1.3°C. Deadly heatwaves in major cities (Chicago, Kolkata, Beijing, Karachi, São Paulo), droughts in southern Europe, southern Africa and the Amazon region, and major flooding in Asia, all intensified by the global and regional warming (Chapter 3, Sections 3.3.1, 3.3.2, 3.3.3, 3.3.4 and 3.4.8; Cross-Chapter Box 11 in Chapter 4), lead to increasing levels of public unrest and political destabilization (Chapter 5, Section 5.2.1). An emergency global summit in 2025 moves to much more ambitious climate targets. Costs for rapidly phasing out fossil fuel use and infrastructure, while rapidly expanding renewables to reduce emissions, are much higher than in Scenario 1, owing to a failure to support economic measures to drive the transition (Chapter 4). Disruptive technologies become crucial to face up to the adaptation measures needed (Chapter 4, Section 4.4.4).

Cross-Chapter Box 8 (continued)

Cross-Chapter Box 8, Table 2 *(continued)*

Scenario 2 [one possible storyline among mid-case scenarios]: **Mitigation:** delayed action (ambitious targets reached only after warmer decade in the 2020s due to internal climate variability), overshoot at 2°C, decrease towards 1.5°C afterward, no efforts to minimize the land and water footprints of bioenergy **Internal climate variability:** 10% worst-case outcome (2020s) followed by normal internal climate variability	Temperature peaks at 2°C of warming by the middle of the century before decreasing again owing to intensive implementation of bioenergy plants with carbon capture and storage (Chapter 2), without efforts to minimize the land and water footprint of bioenergy production (Cross-Chapter Box 7 in Chapter 3). Reaching 2°C of warming for several decades eliminates or severely damages key ecosystems such as coral reefs and tropical forests (Chapter 3, Section 3.4). The elimination of coral reef ecosystems and the deterioration of their calcified frameworks, as well as serious losses of coastal ecosystems such as mangrove forests and seagrass beds (Chapter 3, Boxes 3.4 and 3.5, Sections 3.4.4.10 and 3.4.5), leads to much reduced levels of coastal defence from storms, winds and waves. These changes increase the vulnerability and risks facing communities in tropical and subtropical regions, with consequences for many coastal communities (Cross-Chapter Box 12 in Chapter 5). These impacts are being amplified by steadily rising sea levels (Chapter 3, Section 3.3.9) and intensifying storms (Chapter 3, Section 3.4.4.3). The intensive area required for the production of bioenergy, combined with increasing water stress, puts pressure on food prices (Cross-Chapter Box 6 in Chapter 3), driving elevated rates of food insecurity, hunger and poverty (Chapter 4, Section 4.3.2; Cross-Chapter Box 6 in Chapter 3; Cross-Chapter Box 11 in Chapter 4). Crop yields decline significantly in the tropics, leading to prolonged famines in some African countries (Chapter 3, Section 3.4; Chapter 4, Section 4.3.2). Food trumps environment in terms of importance in most countries, with the result that natural ecosystems decrease in abundance, owing to climate change and land-use change (Cross-Chapter Box 7 in Chapter 3). The ability to implement adaptive action to prevent the loss of ecosystems is hindered under the circumstances and is consequently minimal (Chapter 3, Sections 3.3.6 and 3.4.4.10). Many natural ecosystems, in particular in the Mediterranean, are lost because of the combined effects of climate change and land-use change, and extinction rates increase greatly (Chapter 3, Section 3.4 and Box 3.2). By 2100, warming has decreased but is still stronger than 1.5°C, and the yields of some tropical crops are recovering (Chapter 3, Section 3.4.3). Several of the remaining natural ecosystems experience irreversible climate change-related damages whilst others have been lost to land-use change, with very rapid increases in the rate of species extinctions (Chapter 3, Section 3.4; Cross-Chapter Box 7 in Chapter 3; Cross-Chapter Box 11 in Chapter 4). Migration, forced displacement, and loss of identity are extensive in some countries, reversing some achievements in sustainable development and human security (Chapter 5, Section 5.3.2). Aggregate economic impacts of climate change damage are small, but the loss in ecosystem services creates large economic losses (Chapter 4, Sections 4.3.2 and 4.3.3). The health and well-being of people generally decrease from 2020, while the levels of poverty and disadvantage increase considerably (Chapter 5, Section 5.2.1).
Scenario 3 [one possible storyline among worst-case scenarios]: **Mitigation:** uncoordinated action, major actions late in the 21st century, 3°C of warming in 2100 **Internal climate variability:** unusual (ca. 10%) best-case scenario for one decade, followed by normal internal climate variability	**In 2020, despite past pledges, the international support for the Paris Agreement starts to wane. In the years that follow, CO_2 emissions are reduced at the local and national level but efforts are limited and not always successful.** Radiative forcing increases and, due to chance, the most extreme events tend to happen in less populated regions and thus do not increase global concerns. Nonetheless, there are more frequent heatwaves in several cities and less snow in mountain resorts in the Alps, Rockies and Andes (Chapter 3, Section 3.3). Global warming of 1.5°C is reached by 2030 but no major changes in policies occur. Starting with an intense El Niño–La Niña phase in the 2030s, several catastrophic years occur while global warming starts to approach 2°C. There are major heatwaves on all continents, with deadly consequences in tropical regions and Asian megacities, especially for those ill-equipped for protecting themselves and their communities from the effects of extreme temperatures (Chapter 3, Sections 3.3.1, 3.3.2 and 3.4.8). Droughts occur in regions bordering the Mediterranean Sea, central North America, the Amazon region and southern Australia, some of which are due to natural variability and others to enhanced greenhouse gas forcing (Chapter 3, Section 3.3.4; Chapter 4, Section 4.3.2; Cross-Chapter Box 11 in Chapter 4). Intense flooding occurs in high-latitude and tropical regions, in particular in Asia, following increases in heavy precipitation events (Chapter 3, Section 3.3.3). Major ecosystems (coral reefs, wetlands, forests) are destroyed over that period (Chapter 3, Section 3.4), with massive disruption to local livelihoods (Chapter 5, Section 5.2.2 and Box 5.3; Cross-Chapter Box 12 in Chapter 5). An unprecedented drought leads to large impacts on the Amazon rainforest (Chapter 3, Sections 3.3.4 and 3.4), which is also affected by deforestation (Chapter 2). A hurricane with intense rainfall and associated with high storm surges (Chapter 3, Section 3.3.6) destroys a large part of Miami. A two-year drought in the Great Plains in the USA and a concomitant drought in eastern Europe and Russia decrease global crop production (Chapter 3, Section 3.3.4), resulting in major increases in food prices and eroding food security. Poverty levels increase to a very large scale, and the risk and incidence of starvation increase considerably as food stores dwindle in most countries; human health suffers (Chapter 3, Section 3.4.6.1; Chapter 4, Sections 4.3.2 and 4.4.3; Chapter 5, Section 5.2.1). There are high levels of public unrest and political destabilization due to the increasing climatic pressures, resulting in some countries becoming dysfunctional (Chapter 4, Sections 4.4.1 and 4.4.2). The main countries responsible for the CO_2 emissions design rapidly conceived mitigation plans and try to install plants for carbon capture and storage, in some cases without sufficient prior testing (Chapter 4, Section 4.3.6). Massive investments in renewable energy often happen too late and are uncoordinated; energy prices soar as a result of the high demand and lack of infrastructure. In some cases, demand cannot be met, leading to further delays. Some countries propose to consider sulphate-aerosol based Solar Radiation Modification (SRM) (Chapter 4, Section 4.3.8); however, intensive international negotiations on the topic take substantial time and are inconclusive because of overwhelming concerns about potential impacts on monsoon rainfall and risks in case of termination (Cross-Chapter Box 10 in Chapter 5). Global and regional temperatures continue to increase strongly while mitigation solutions are being developed and implemented.

Cross-Chapter Box 8 (continued)

Cross-Chapter Box 8, Table 2 *(continued)*

Scenario 3 [one possible storyline among worst-case scenarios]: **Mitigation:** uncoordinated action, major actions late in the 21st century, 3°C of warming in 2100 **Internal climate variability:** unusual (ca. 10%) best-case scenario for one decade, followed by normal internal climate variability	Global mean warming reaches 3°C by 2100 but is not yet stabilized despite major decreases in yearly CO_2 emissions, as a net zero CO_2 emissions budget could not yet be achieved and because of the long lifetime of CO_2 concentrations (Chapters 1, 2 and 3). The world as it was in 2020 is no longer recognizable, with decreasing life expectancy, reduced outdoor labour productivity, and lower quality of life in many regions because of too frequent heatwaves and other climate extremes (Chapter 4, Section 4.3.3). Droughts and stress on water resources renders agriculture economically unviable in some regions (Chapter 3, Section 3.4; Chapter 4, Section 4.3.2) and contributes to increases in poverty (Chapter 5, Section 5.2.1; Cross-Chapter Box 12 in Chapter 5). Progress on the sustainable development goals is largely undone and poverty rates reach new highs (Chapter 5, Section 5.2.3). Major conflicts take place (Chapter 3, Section 3.4.9.6; Chapter 5, Section 5.2.1). Almost all ecosystems experience irreversible impacts, species extinction rates are high in all regions, forest fires escalate, and biodiversity strongly decreases, resulting in extensive losses to ecosystem services. These losses exacerbate poverty and reduce quality of life (Chapter 3, Section 3.4; Chapter 4, Section 4.3.2). Life for many indigenous and rural groups becomes untenable in their ancestral lands (Chapter 4, Box 4.3; Cross-Chapter Box 12 in Chapter 5). The retreat of the West Antarctic ice sheet accelerates (Chapter 3, Sections 3.3 and 3.6), leading to more rapid sea level rise (Chapter 3, Section 3.3.9; Chapter 4, Section 4.3.2). Several small island states give up hope of survival in their locations and look to an increasingly fragmented global community for refuge (Chapter 3, Box 3.5; Cross-Chapter Box 12 in Chapter 5). Aggregate economic damages are substantial, owing to the combined effects of climate changes, political instability, and losses of ecosystem services (Chapter 4, Sections 4.4.1 and 4.4.2; Chapter 3, Box 3.6 and Section 3.5.2.4). The general health and well-being of people is substantially reduced compared to the conditions in 2020 and continues to worsen over the following decades (Chapter 5, Section 5.2.3).

Frequently Asked Questions

FAQ 3.1 | What are the Impacts of 1.5°C and 2°C of Warming?

Summary: *The impacts of climate change are being felt in every inhabited continent and in the oceans. However, they are not spread uniformly across the globe, and different parts of the world experience impacts differently. An average warming of 1.5°C across the whole globe raises the risk of heatwaves and heavy rainfall events, amongst many other potential impacts. Limiting warming to 1.5°C rather than 2°C can help reduce these risks, but the impacts the world experiences will depend on the specific greenhouse gas emissions 'pathway' taken. The consequences of temporarily overshooting 1.5°C of warming and returning to this level later in the century, for example, could be larger than if temperature stabilizes below 1.5°C. The size and duration of an overshoot will also affect future impacts.*

Human activity has warmed the world by about 1°C since pre-industrial times, and the impacts of this warming have already been felt in many parts of the world. This estimate of the increase in global temperature is the average of many thousands of temperature measurements taken over the world's land and oceans. Temperatures are not changing at the same speed everywhere, however: warming is strongest on continents and is particularly strong in the Arctic in the cold season and in mid-latitude regions in the warm season. This is due to self-amplifying mechanisms, for instance due to snow and ice melt reducing the reflectivity of solar radiation at the surface, or soil drying leading to less evaporative cooling in the interior of continents. This means that some parts of the world have already experienced temperatures greater than 1.5°C above pre-industrial levels.

Extra warming on top of the approximately 1°C we have seen so far would amplify the risks and associated impacts, with implications for the world and its inhabitants. This would be the case even if the global warming is held at 1.5°C, just half a degree above where we are now, and would be further amplified at 2°C of global warming. Reaching 2°C instead of 1.5°C of global warming would lead to substantial warming of extreme hot days in all land regions. It would also lead to an increase in heavy rainfall events in some regions, particularly in the high latitudes of the Northern Hemisphere, potentially raising the risk of flooding. In addition, some regions, such as the Mediterranean, are projected to become drier at 2°C versus 1.5°C of global warming. The impacts of any additional warming would also include stronger melting of ice sheets and glaciers, as well as increased sea level rise, which would continue long after the stabilization of atmospheric CO_2 concentrations.

Change in climate means and extremes have knock-on effects for the societies and ecosystems living on the planet. Climate change is projected to be a poverty multiplier, which means that its impacts are expected to make the poor poorer and the total number of people living in poverty greater. The 0.5°C rise in global temperatures that we have experienced in the past 50 years has contributed to shifts in the distribution of plant and animal species, decreases in crop yields and more frequent wildfires. Similar changes can be expected with further rises in global temperature.

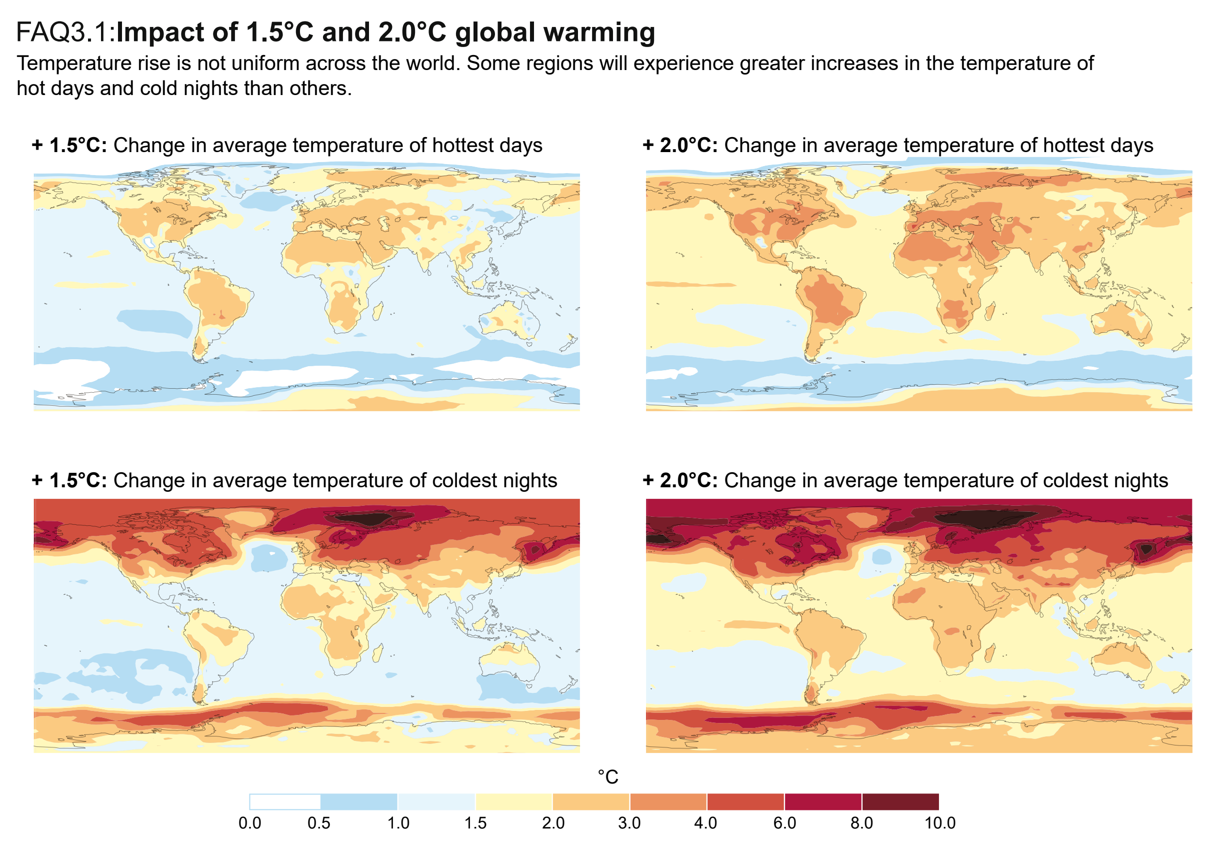
Essentially, the lower the rise in global temperature above pre-industrial levels, the lower the risks to human societies and natural ecosystems. Put another way, limiting warming to 1.5°C can be understood in terms of 'avoided impacts' compared to higher levels of warming. Many of the impacts of climate change assessed in this report have lower associated risks at 1.5°C compared to 2°C.

Thermal expansion of the ocean means sea level will continue to rise even if the increase in global temperature is limited to 1.5°C, but this rise would be lower than in a 2°C warmer world. Ocean acidification, the process by which excess CO_2 is dissolving into the ocean and increasing its acidity, is expected to be less damaging in a world where CO_2 emissions are reduced and warming is stabilized at 1.5°C compared to 2°C. The persistence of coral reefs is greater in a 1.5°C world than that of a 2°C world, too.

The impacts of climate change that we experience in future will be affected by factors other than the change in temperature. The consequences of 1.5°C of warming will additionally depend on the specific greenhouse gas emissions 'pathway' that is followed and the extent to which adaptation can reduce vulnerability. This IPCC Special Report uses a number of 'pathways' to explore different possibilities for limiting global warming to 1.5°C above pre-industrial levels. One type of pathway sees global temperature stabilize at, or just below, 1.5°C. Another sees global temperature temporarily exceed 1.5°C before declining later in the century (known as an 'overshoot' pathway).

(continued on next page)

Such pathways would have different associated impacts, so it is important to distinguish between them for planning adaptation and mitigation strategies. For example, impacts from an overshoot pathway could be larger than impacts from a stabilization pathway. The size and duration of an overshoot would also have consequences for the impacts the world experiences. For instance, pathways that overshoot 1.5°C run a greater risk of passing through 'tipping points', thresholds beyond which certain impacts can no longer be avoided even if temperatures are brought back down later on. The collapse of the Greenland and Antarctic ice sheets on the time scale of centuries and millennia is one example of a tipping point.



FAQ 3.1, Figure 1 | Temperature change is not uniform across the globe. Projected changes are shown for the average temperature of the annual hottest day (top) and the annual coldest night (bottom) with 1.5°C of global warming (left) and 2°C of global warming (right) compared to pre-industrial levels.

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EWG DRINKING WATER STANDARDS

No-Compromise Benchmarks to Fully Protect Public Health

Health guidelines listed in the EWG Tap Water Database represent the maximum concentration of a contaminant in water that scientists consider safe. This value is based only on protecting health and does not consider technical feasibility or the cost of water treatment. This table includes health guidelines published by federal or state health and environmental agencies, or developed by EWG scientists based on the best and most recent research.

More details on health guideline selections are available in the Data Sources and **Methodology sections.**

Units used in the table: *parts per million (ppm); parts per billion (ppb); picocuries per liter (pCi/L)*

Updated April 2020

CONTAMINANT *(IN ALPHABETICAL ORDER)*	**FEDERAL LEGAL LIMIT**	**EWG STANDARD**	**SOURCE OF STANDARD**	**HEALTH EFFECTS**
1,1-Dichloroethane	Nonexistent	3 ppb	California public health goal	Cancer; change to the heart and blood vessels
1,1,2-Trichloroethane	5 ppb	0.3 ppb	California public health goal	Liver cancer; harm to the kidney; change to the central nervous system
1,2-Dibromo-3-chloropropane	0.2 ppb	0.0017 ppb	California public health goal	Testicular cancer; harm to the male reproductive system; infertility
1,2-Dichloroethane	5 ppb	0.4 ppb	California public health goal	Cancer; harm to the immune system; harm to the stomach and intestines; harm to the liver; harm to the kidney; harm to the brain and nervous system
1,2-Dichloropropane	5 ppb	0.5 ppb	California public health goal	Liver cancer; harm to the liver; harm to the kidney; change to blood cells
1,2,3-Trichloropropane	Nonexistent	0.0007 ppb	California public health goal	Cancer
1,2,4-Trichlorobenzene	70 ppb	5 ppb	California public health goal	Harm to the adrenal gland; cancer
1,3-Butadiene	Nonexistent	0.0103 ppb	Contaminant concentration corresponding to a one-in-a-million lifetime risk of cancer, as defined by the Environmental Protection Agency	Cancer; harm to the brain and nervous system; harm to reproduction and child development; change to blood cells; change to the kidney

CONTAMINANT *(IN ALPHABETICAL ORDER)*	**FEDERAL LEGAL LIMIT**	**EWG STANDARD**	**SOURCE OF STANDARD**	**HEALTH EFFECTS**
1,4-Dioxane	Nonexistent	0.35 ppb	Contaminant concentration corresponding to a one-in-a-million lifetime risk of cancer, as defined by the Environmental Protection Agency	Cancer; irritation of the lungs; harm to the kidney
p-Dichlorobenzene	75 ppb	6 ppb	California public health goal	Cancer; harm to the liver; harm to the kidney; harm to the thyroid
2,4-D (2,4-dichlorophenoxyacetic acid)	70 ppb	20 ppb	California public health goal	Hormone disruption; harm to the liver; harm to the kidney; harm to the thyroid; harm to the brain and nervous system; change to immune system function
Aluminum	Nonexistent	600 ppb	California public health goal	Harm to the brain and nervous system
Antimony	6 ppb	1 ppb	California public health goal	Harm to the liver; change to the stomach and intestines
Arsenic	10 ppb	0.004 ppb	California public health goal	Cancer; harm to the central nervous system; harm to the brain and nervous system; skin damage; change to the heart and blood vessels; increase the risk of heart disease, stroke and diabetes
Atrazine	3 ppb	0.1 ppb	EWG-recommended health guideline	Harm to the developing fetus; hormone disruption; harm to the reproductive system; changes in the nervous system; changes in brain and behavior; cancer
Barium	2 ppm	0.7 ppm	Children's health-based limit for 10-day exposure, as defined by the Environmental Protection Agency	Harm to the kidney; high blood pressure; harm to the heart and blood vessels
Benzene	5 ppb	0.15 ppb	California public health goal	Cancer; harm to blood cells; harm to the central nervous system; harm to child development; harm to the immune system

CONTAMINANT *(IN ALPHABETICAL ORDER)*	**FEDERAL LEGAL LIMIT**	**EWG STANDARD**	**SOURCE OF STANDARD**	**HEALTH EFFECTS**
Benzo[a]pyrene	0.2 ppb	0.007 ppb	California public health goal	Cancer; harm to the immune system; harm to reproduction and child development; change to the central nervous system
Beryllium	4 ppb	1 ppb	California public health goal	Harm to the stomach and intestines; harm to the lungs; harm to bones
Bromate	10 ppb	0.1 ppb	California public health goal	Cancer
Bromochloroacetic acid	Nonexistent	0.02 ppb	EWG-recommended health guideline	Cancer; harm to fetal growth and development.
Bromodichloroacetic acid	Nonexistent	0.04 ppb	EWG-recommended health guideline	Cancer; harm to fetal growth and development.
Bromodichloromethane	Nonexistent	0.4 ppb	Contaminant concentration corresponding to a one-in-a-million lifetime risk of cancer, as defined by the California Office of Environmental Health Hazard Assessment	Cancer; harm to reproduction and child development; change to fetal growth and development
Bromoform	Nonexistent	5 ppb	Contaminant concentration corresponding to a one-in-a-million lifetime risk of cancer, as defined by the California Office of Environmental Health Hazard Assessment	Cancer; harm to reproduction and child development; change to fetal growth and development
Cadmium	5 ppb	0.04 ppb	California public health goal	Cancer; harm to the kidney; change in behavior
Carbofuran	40 ppb	0.7 ppb	California public health goal	Harm to the brain and nervous system; harm to the reproductive system
Carbon tetrachloride	5 ppb	0.1 ppb	California public health goal	Cancer; harm to the liver; harm to the central nervous system; harm to the kidney; decrease in fertility

CONTAMINANT *(IN ALPHABETICAL ORDER)*	**FEDERAL LEGAL LIMIT**	**EWG STANDARD**	**SOURCE OF STANDARD**	**HEALTH EFFECTS**
Chlorate	Nonexistent	210 ppb	Health benchmark defined by the Environmental Protection Agency for testing under the Unregulated Contaminant Monitoring Rule program	Hormone disruption
Chlordane	2 ppb	0.03 ppb	California public health goal	Cancer; hormone disruption; harm to reproduction and child development
Chlorodibromoacetic acid	Nonexistent	0.02 ppb	EWG-recommended health guideline	Cancer; harm to fetal growth and development
Chlorite	1 ppm	0.050 ppm	California public health goal	Change to blood cells; change to the thyroid; hormone disruption; harm to reproduction and child development
Chloroform	Nonexistent	1 ppb	Contaminant concentration corresponding to a one-in-a-million lifetime risk of cancer, as defined by the California Office of Environmental Health Hazard Assessment	Cancer; harm to fetal growth and development
Chloromethane	Nonexistent	2.69 ppb	Health benchmark defined by the Environmental Protection Agency for testing under the Unregulated Contaminant Monitoring Rule program	Cancer
Chromium (hexavalent)	Nonexistent	0.02 ppb	California public health goal	Cancer; harm to the liver; harm to the reproductive system
Cobalt	Nonexistent	70 ppb	Health benchmark defined by the Environmental Protection Agency for testing under the Unregulated Contaminant Monitoring Rule program	Harm to the heart; change in blood chemistry; harm to the stomach and intestines

CONTAMINANT *(IN ALPHABETICAL ORDER)*	FEDERAL LEGAL LIMIT	EWG STANDARD	SOURCE OF STANDARD	HEALTH EFFECTS
Copper	Nonexistent	300 ppb	California public health goal	Diarrhea; weight loss; vomiting
Cyanide	200 ppb	150 ppb	California public health goal	Harm to the brain and nervous system; harm to the thyroid; harm to the central nervous system
Di(2-ethylhexyl) adipate	400 ppb	200 ppb	California public health goal	Change to fetal growth and development; harm to the liver
Di(2-ethylhexyl) phthalate	6 ppb	3 ppb	Contaminant concentration corresponding to a one-in-a-million lifetime risk of cancer, as defined by the Environmental Protection Agency	Harm to the male reproductive system; harm to the immune system; change to fetal growth and development; hormone disruption
Dibromoacetic acid	Nonexistent	0.04 ppb	EWG-recommended health guideline	Cancer; harm to fetal growth and development
Dibromochloromethane	Nonexistent	0.7 ppb	Contaminant concentration corresponding to a one-in-a-million lifetime risk of cancer, as defined by the California Office of Environmental Health Hazard Assessment	Cancer; harm to fetal growth and development
Dichloroacetic acid	Nonexistent	0.2 ppb	EWG-recommended health guideline	Cancer; harm to reproduction and child development
p-Dichlorobenzene	75 ppb	6 ppb	California public health goal	Cancer; harm to the liver; harm to the kidney; harm to the thyroid
Dichloromethane (methylene chloride)	5 ppb	4 ppb	California public health goal	Cancer; harm to reproduction and child development; harm to the liver
Diquat	20 ppb	6 ppb	California public health goal	Change to fetal growth and development; change in body weight; harm to the kidney; cataracts
Endothall	100 ppb	94 ppb	California public health goal	Change to the stomach and intestines; eye damage; skin irritation

CONTAMINANT *(IN ALPHABETICAL ORDER)*	FEDERAL LEGAL LIMIT	EWG STANDARD	SOURCE OF STANDARD	HEALTH EFFECTS
Endrin	2 ppb	0.3 ppb	California public health goal	Cancer; change to the central nervous system; harm to the immune system; harm to the reproductive system
Ethylbenzene	700 ppb	300 ppb	California public health goal	Cancer; harm to the lungs; harm to the liver; harm to the kidney; change to the central nervous system
Ethylene dibromide	0.05 ppb	0.01 ppb	California public health goal	Cancer; harm to the reproductive system; harm to the central nervous system; change to fetal growth and development
Glyphosate	700 ppb	5 ppb	EWG-recommended health guideline	Cancer; harm to fetal growth; harm to the kidney
Haloacetic acids (HAA5)	60 ppb	0.1 ppb	EWG-recommended health guideline	Cancer; harm to fetal growth and development
Heptachlor	0.4 ppb	0.008 ppb	California public health goal	Cancer; hormone disruption; harm to the brain and nervous system
Heptachlor epoxide	0.2 ppb	0.006 ppb	California public health goal	Cancer; hormone disruption; harm to the liver
Hexachlorobenzene	1 ppb	0.03 ppb	California public health goal	Cancer; harm to the brain and nervous system; hormone disruption
Hexachlorocyclopentadiene	50 ppb	2 ppb	California public health goal	Harm to the stomach and intestines; change to the liver; change to the kidney; irritation of the lungs
Lead	15 ppb (federal action level for lead in drinking water)	0.2 ppb	California public health goal	Harm to the brain and nervous system
Lindane	0.2 ppb	0.032 ppb	California public health goal	Cancer; harm to the brain and nervous system; harm to the immune system
Manganese	Nonexistent	100 ppb	A risk assessment advisory level defined by the Minnesota Department of Health	Harm to the brain and nervous system; change in behavior

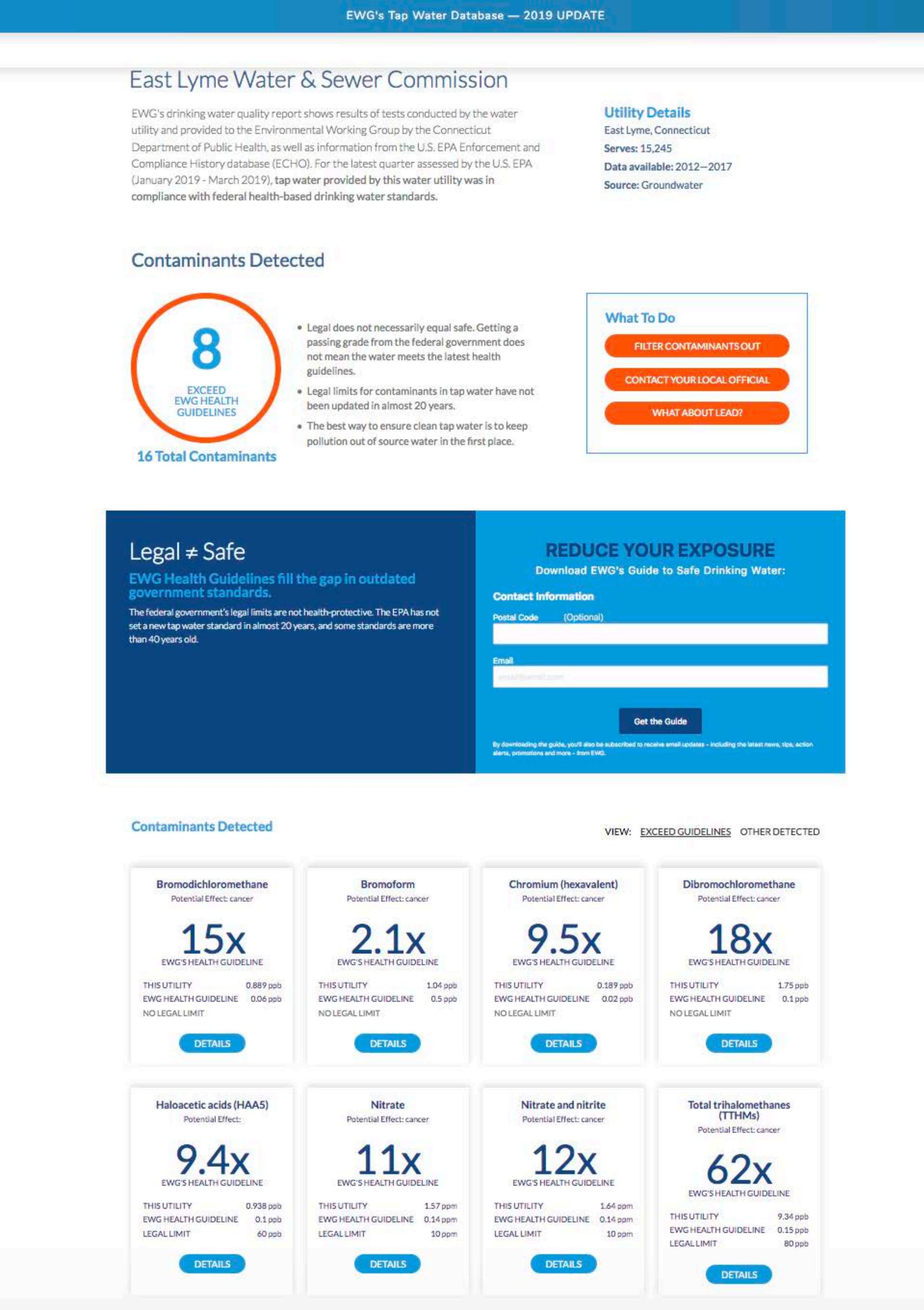
CONTAMINANT *(IN ALPHABETICAL ORDER)*	**FEDERAL LEGAL LIMIT**	**EWG STANDARD**	**SOURCE OF STANDARD**	**HEALTH EFFECTS**
Mercury (inorganic)	2 ppb	1.2 ppb	California public health goal	Harm to the brain and nervous system; harm to fetal growth and child development; harm to the kidney; harm to the immune system
Methoxychlor	40 ppb	0.09 ppb	California public health goal	Hormone disruption; harm to the reproductive system; harm to the kidney; harm to the liver; harm to the immune system; harm to the brain and nervous system
Molybdenum	Nonexistent	40 ppb	The Environmental Protection Agency health advisory for lifetime exposure	Change in blood chemistry; gout
Monobromoacetic acid	Nonexistent	25 ppb	EWG-recommended health guideline	Change to fetal growth and development
Monochloroacetic acid	Nonexistent	53 ppb	EWG-recommended health guideline	Change to fetal growth and development
Monochlorobenzene (chlorobenzene)	100 ppb	70 ppb	California public health goal	Harm to the liver; harm to the kidney
MTBE	Nonexistent	13 ppb	California public health goal	Cancer
N-Nitrosodimethylamine (NDMA)	Nonexistent	0.003 ppb	California public health goal	Cancer
Nitrate (measured as Nitrogen)	10 ppm	0.14 ppm	EWG-recommended health guideline	Cancer; harm to fetal growth and child development
Oxamyl	200 ppb	26 ppb	California public health goal	Harm to the central nervous system; harm to the brain and nervous system; harm to child development
Pentachlorophenol	1 ppb	0.3 ppb	California public health goal	Cancer; harm to child development; harm to the immune system; hormone disruption
Perchlorate	Nonexistent	1 ppb	California public health goal	Hormone disruption; harm to fetal growth and child development
Perfluorobutane sulfonate (PFBS)	Nonexistent	0.001 ppb	EWG-recommended health guideline	Cancer; harm to the immune system; hormone disruption; harm to fetal growth and child development; harm to the liver

CONTAMINANT *(IN ALPHABETICAL ORDER)*	FEDERAL LEGAL LIMIT	EWG STANDARD	SOURCE OF STANDARD	HEALTH EFFECTS
Perfluoroheptanoic acid (PFHPA)	Nonexistent	0.001 ppb	EWG-recommended health guideline	Cancer; harm to the immune system; hormone disruption; harm to fetal growth and child development; harm to the liver
Perfluorohexane sulfonate (PFHXS)	Nonexistent	0.001 ppb	EWG-recommended health guideline	Cancer; harm to the immune system; hormone disruption; harm to fetal growth and child development; harm to the liver
Perfluorononanoic acid (PFNA)	Nonexistent	0.001 ppb	EWG-recommended health guideline	Cancer; harm to the immune system; hormone disruption; harm to fetal growth and child development; harm to the liver
Perfluorooctane sulfonate (PFOS)	Nonexistent	0.001 ppb	EWG-recommended health guideline	Cancer; harm to the immune system; hormone disruption; harm to fetal growth and child development; harm to the liver
Perfluorooctanoic acid (PFOA)	Nonexistent	0.001 ppb	EWG-recommended health guideline	Cancer; harm to the immune system; hormone disruption; harm to fetal growth and child development; harm to the liver
Picloram	500 ppb	166 ppb	California public health goal	Harm to the liver; harm to the kidney; change to the reproductive system
Polychlorinated biphenyls (PCBs)	0.5 ppb	0.09 ppb	California public health goal	Breast cancer; prostate cancer; harm to the brain and nervous system; hormone disruption; harm to the immune system
Radium-226	5 pCi/L for combined radium-226 and radium-228	0.05 pCi/L	California public health goal	Cancer
Radium-228	5 pCi/L for combined radium-226 and radium-228	0.019 pCi/L	California public health goal	Cancer

CONTAMINANT *(IN ALPHABETICAL ORDER)*	FEDERAL LEGAL LIMIT	EWG STANDARD	SOURCE OF STANDARD	HEALTH EFFECTS
Selenium	50 ppb	30 ppb	California public health goal	Hormone disruption; harm to child development; harm to the brain and nervous system; skin damage
Simazine	4 ppb	0.1 ppb	EWG-recommended health guideline	Harm to the developing fetus; hormone disruption; harm to the reproductive system; changes in the nervous system; changes in brain and behavior; cancer
Strontium	Nonexistent	1.5 ppm	Health benchmark defined by the Environmental Protection Agency for testing under the Unregulated Contaminant Monitoring Rule program	Harm to bones
Strontium-90	Nonexistent	0.35 pCi/L	California public health goal	Cancer; harm to bones
Styrene	100 ppb	0.5 ppb	California public health goal	Cancer; harm to the liver; harm to the brain and nervous system
Tetrachloroethylene (perchloroethylene)	5 ppb	0.06 ppb	California public health goal	Lung cancer; breast cancer; colon cancer; harm to the kidney; harm to the liver; harm to the central nervous system
Thallium	2 ppb	0.1 ppb	California public health goal	Hair loss; harm to the liver; harm to the central nervous system; harm to the brain and nervous system; harm to the male reproductive system
Toluene	1 ppm	0.15 ppm	California public health goal	Harm to the brain and nervous system; harm to the liver; harm to the immune system; harm to the reproductive system; harm to fetal growth and development
Total trihalomethanes (TTHMs)	80 ppb	0.15 ppb	EWG-recommended health guideline	Bladder cancer; skin cancer; harm to fetal growth and development

CONTAMINANT *(IN ALPHABETICAL ORDER)*	FEDERAL LEGAL LIMIT	EWG STANDARD	SOURCE OF STANDARD	HEALTH EFFECTS
Toxaphene	3 ppb	0.03 ppb	California public health goal	Cancer; harm to the brain and nervous system; harm to the liver; harm to the kidney; hormone disruption
Tribromoacetic acid	Nonexistent	0.04 ppb	EWG-recommended health guideline	Change to fetal growth and development
Trichloroacetic acid	Nonexistent	0.1 ppb	EWG-recommended health guideline	Cancer; harm to reproduction and child development
Trichloroethylene	5 ppb	0.4 ppb	A risk assessment advisory level defined by the Minnesota Department of Health	Cancer; change to fetal growth and development; harm to the liver; harm to the kidney
Trichlorofluoromethane	Nonexistent	1.3 ppm	California public health goal	Harm to the liver; change to the central nervous system; harm to the heart and blood vessels
Trichlorotrifluoroethane	Nonexistent	4 ppm	California public health goal	Harm to the liver; change to the central nervous system; harm to the heart and blood vessels
Tritium	Nonexistent	400 pCi/L	California public health goal	Cancer
Uranium	30 ppb*	0.43 pCi/L	California public health goal	Cancer; harm to the kidney
Vanadium	Nonexistent	21 ppb	Health benchmark defined by the Environmental Protection Agency for testing under the Unregulated Contaminant Monitoring Rule program	Change in blood chemistry; harm to reproduction and child development
Vinyl chloride	2 ppb	0.05 ppb	California public health goal	Liver cancer; harm to the liver; change to the central nervous system
Xylenes (total)	10 ppm	1.8 ppm	California public health goal	Harm to the brain and nervous system; change to the central nervous system; change to fetal growth and development

** The legal limit for uranium is 30 micrograms per liter (corresponding to parts per billion or ppb), but the human health guideline for uranium is based on the overall radioactivity of the substance. Using an EPA conversion factor described in the 2002 EPA Implementation Guidance for Radionuclides, uranium test results can be converted from parts per billion to picocuries per liter. A measurement of 30 ppb is calculated to have a radioactivity level of 20 pCi/L.*



EWG's Tap Water Database — 2019 UPDATE

East Lyme Water & Sewer Commission

EWG's drinking water quality report shows results of tests conducted by the water utility and provided to the Environmental Working Group by the Connecticut Department of Public Health, as well as information from the U.S. EPA Enforcement and Compliance History database (ECHO). For the latest quarter assessed by the U.S. EPA (January 2019 - March 2019), **tap water provided by this water utility was in compliance with federal health-based drinking water standards.**

Utility Details

East Lyme, Connecticut

Serves: 15,245

Data available: 2012—2017

Source: Groundwater

Contaminants Detected

8
EXCEED
EWG HEALTH
GUIDELINES

16 Total Contaminants

- Legal does not necessarily equal safe. Getting a passing grade from the federal government does not mean the water meets the latest health guidelines.
- Legal limits for contaminants in tap water have not been updated in almost 20 years.
- The best way to ensure clean tap water is to keep pollution out of source water in the first place.

What To Do

Legal ≠ Safe

EWG Health Guidelines fill the gap in outdated government standards.

The federal government's legal limits are not health-protective. The EPA has not set a new tap water standard in almost 20 years, and some standards are more than 40 years old.

REDUCE YOUR EXPOSURE

Download EWG's Guide to Safe Drinking Water:

Contact Information

Postal Code (Optional)

Email

By downloading the guide, you'll also be subscribed to receive email updates – including the latest news, tips, action alerts, promotions and more – from EWG.

Contaminants Detected

VIEW: EXCEED GUIDELINES OTHER DETECTED

Bromodichloromethane

Potential Effect: cancer

15x
EWG'S HEALTH GUIDELINE

THIS UTILITY	0.889 ppb
EWG HEALTH GUIDELINE	0.06 ppb
NO LEGAL LIMIT	

Bromoform

Potential Effect: cancer

2.1x
EWG'S HEALTH GUIDELINE

THIS UTILITY	1.04 ppb
EWG HEALTH GUIDELINE	0.5 ppb
NO LEGAL LIMIT	

Chromium (hexavalent)

Potential Effect: cancer

9.5x
EWG'S HEALTH GUIDELINE

THIS UTILITY	0.189 ppb
EWG HEALTH GUIDELINE	0.02 ppb
NO LEGAL LIMIT	

Dibromochloromethane

Potential Effect: cancer

18x
EWG'S HEALTH GUIDELINE

THIS UTILITY	1.75 ppb
EWG HEALTH GUIDELINE	0.1 ppb
NO LEGAL LIMIT	

Haloacetic acids (HAA5)

Potential Effect:

9.4x
EWG'S HEALTH GUIDELINE

THIS UTILITY	0.938 ppb
EWG HEALTH GUIDELINE	0.1 ppb
LEGAL LIMIT	60 ppb

Nitrate

Potential Effect: cancer

11x
EWG'S HEALTH GUIDELINE

THIS UTILITY	1.57 ppm
EWG HEALTH GUIDELINE	0.14 ppm
LEGAL LIMIT	10 ppm

Nitrate and nitrite

Potential Effect: cancer

12x
EWG'S HEALTH GUIDELINE

THIS UTILITY	1.64 ppm
EWG HEALTH GUIDELINE	0.14 ppm
LEGAL LIMIT	10 ppm

Total trihalomethanes (TTHMs)

Potential Effect: cancer

62x
EWG'S HEALTH GUIDELINE

THIS UTILITY	9.34 ppb
EWG HEALTH GUIDELINE	0.15 ppb
LEGAL LIMIT	80 ppb

STATE OF CONNECTICUT
OFFICE OF POLICY AND MANAGEMENT
Intergovernmental Policy and Planning Division

June 19, 2020

To:
Governor Ned Lamont
OPM Secretary Melissa McCaw
OPM Deputy Secretary Konstantinos Diamantis
Jonathan Harris, Senior Advisor Office of the Governor
Paul Mounds, Chief of Staff, Office of the Governor
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From: OPM Acting Undersecretary Martin Heft

RE: **CT Water Planning Council Interagency Drought Work Group**
STAGE 1 – BELOW NORMAL CONDITIONS

The Connecticut Water Planning Council's Interagency Drought Work (IDW) Group met today to review the existing conditions under the Connecticut Drought Preparedness and Response Plan. We wanted to advise you of current conditions and potential for upcoming actions.

The State of Connecticut is currently at Stage 1 – Below Normal Conditions. Stage 1 is a preliminary preparedness stage that serves to alert the parties who should be prepared to respond to potentially worsening drought conditions. Typically, this stage is activated in response to early signals of abnormally dry conditions and serves as a "heads up" for the possibility of a developing drought. There is no expectation for a broad public notice of a Stage 1 declaration.

Please be advised that this is an unusual situation in that it is a rapidly developing "flash drought," so while things are not bad right now, in the coming weeks the Office of the Governor should be on standby and prepared to react quickly, with potentially little lead time.

The IDW will continue to monitor these conditions on a weekly basis and provide recommended actions.

Additionally, we have been advised that local media has already picked up on the situation. NBC-30 will air a segment this evening during their 5:30 PM broadcast.

The following criteria is routinely monitored by the IDW for the purposes of analyzing conditions leading up to and during a drought and used to recommend appropriate mitigation actions:

- Cumulative precipitation
- Groundwater levels
- Streamflow
- Drinking water reservoir levels
- Palmer Drought Severity Index
- Crop Moisture Index
- Vegetation Drought Response Index (only available during growing season)
- Fire danger
- U.S. Drought Monitor

Attached is the *Stage 1 Below Normal Conditions Defining Criteria and Recommended Mitigation Actions* excerpt for your reference.

Stage 1: Below Normal Conditions

Defining Criteria:

Stage 1 is a preliminary preparedness stage that serves to alert the parties who should be prepared to respond to potentially worsening drought conditions. The primary target audience includes state, regional, and local officials and public water suppliers. Typically, this stage is activated upon the first signals of impacts from abnormally dry conditions. There is no expectation for a broad public notice of a Stage 1 declaration.

Specific criteria thresholds are not defined for Stage 1 as the decision to begin focusing on a possible developing drought is based on the IDW's professional judgment.

Stage 1 Recommended Mitigation Actions		
Coordination & Management	*State Agencies coordinated through the IDW*	Pay attention to all aspects of agency operations that could indicate impending drought conditions; communicate and meet as needed.
		Delegate duties and responsibilities as necessary to assure information flow among state agencies.
		Designate agency spokesperson(s) to coordinate interaction with the public and expedite information referrals.
		Submit drought assessment reports as necessary to agency heads.
		Designate an individual to be the contact person for receiving and compiling drought-related information.
	Municipalities / Local Officials	Municipal water coordinators provide DPH with up-to-date municipal water coordinator contact information. If no municipal water coordinator exists, designate a local official competent in water supply issues as the municipal water coordinator and provide contact information. Municipal water coordinator maintains regular communications flow with local emergency management director.
	Water Suppliers	Designate a point contact person for communication with municipalities and the state. Provide up-to-date contact information to DPH to ensure the communication of vital information and assess needed technical and financial assistance in an emergency.
Public Outreach & Education		The Below Normal Conditions stage is intended to initiate internal communication and awareness among the IDW and other decision makers, in response to observations or reports that warrant heightened awareness of conditions. Communication with the public is not planned at this time.
Data collection, monitoring, & preparedness	*State Agencies coordinated through the IDW*	Continue to regularly monitor the primary indicators of drought; systematically collect, analyze, and disseminate real-time drought-related information.
		Identify geographic extent of dry conditions and determine affected regions.
		Plan what staff and/or funding could be made available, if necessary, to support increased monitoring activities.
		Verify that all monitoring networks and drought information websites are functioning and include relevant, up-to-date information.
		Review database of contact information for public water suppliers and municipal water coordinators and update as needed.
		Update database/map of public water suppliers that that have requested voluntary conservation and/or have placed mandatory water restrictions.