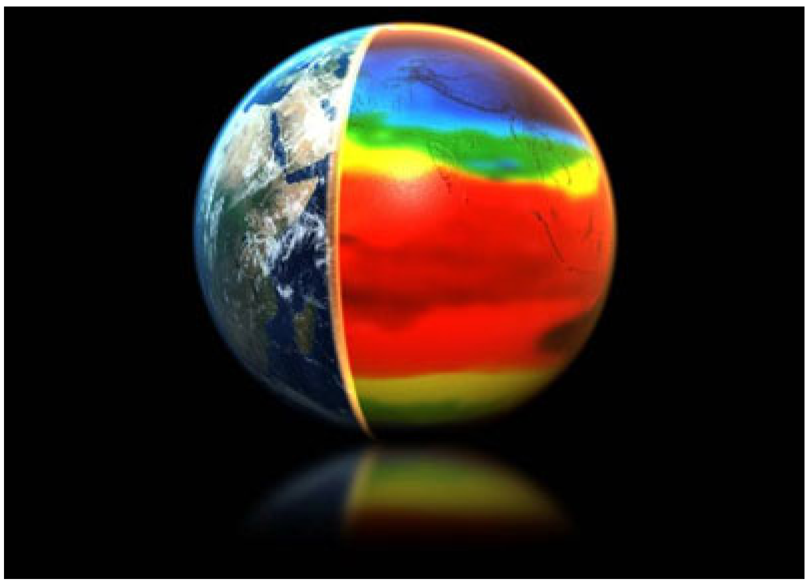
U.S. Environmental Protection Agency

Watershed Academy Web

Distance Learning Modules on Watershed Management

http://www.epa.gov/watertrain

The Effect of Climate Change on Water Resources and Programs



NOTICE: This PDF file was adapted from an on-line training module of the EPA's ***Watershed Academy Web,*** found at http://www.epa.gov/watertrain. To the extent possible, it contains the same material as the on-line version. Some interactive parts of the module had to be reformatted for this noninteractive text presentation. A self-test is included at the end of the file.

This document does not constitute EPA policy. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Links to non-EPA web sites do not imply any official EPA endorsement of or responsibility for the opinions, ideas, data, or products presented at those locations or guarantee the validity of the information provided. Links to non-EPA servers are provided solely as a pointer to information that might be useful to EPA staff and the public.

The Effect of Climate Change on Water Resources and Programs

Introduction

The goal of this module is to educate water program managers, as well as the general public, on the expected effects of climate change on water resources and water programs. This knowledge will help us to prepare for and adapt to the effects of climate change. The information in this module is organized by the following questions:

1. Climate Change 101: How is the global climate changing and what are the causes?
    - Why does climate change matter to U.S. water program managers?
    - What are the water-related effects of climate change in the United States?
2. How do actions taken to reduce the release of greenhouse gases affect water resources and water programs?
3. What is EPA's National Water Program doing to address the effects of climate change on water resources?

After completing the module, you may take the Self Test.

The following information is covered in the Climate Change 101 section:

1. What is climate?
2. What is the greenhouse effect?
3. What is causing climate change?
4. What are greenhouse gases?
5. How is the global climate changing?
    - Temperature changes
    - Other environmental changes
6. How are changes in climate evaluated and predicted?

Climate Change 101:

What Is Climate?

Climate is weather averaged over an extended period of time (30-year intervals are typically used in establishing baseline climatology) (Figure 1).

During the Earth's history, the climate has changed many times and has included ice ages and periods of warmth. Before the Industrial Revolution, natural factors such as volcanic eruptions, changes in the Earth's orbit, and the amount of energy released from the sun were the primary factors affecting the Earth's climate.

However, beginning late in the 18th century, human activities associated with the Industrial Revolution and burning fossil fuels began changing the composition of the atmosphere.

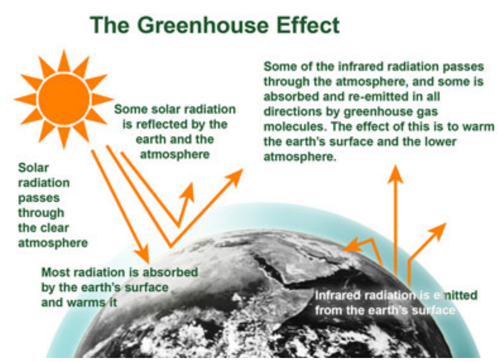
Climate: Weather, such as temperature, precipitation and wind, averaged over an extended period of time.

Figure 1

What Is the Greenhouse Effect?

Sunlight passes through the atmosphere and warms the Earth's surface. Some of this solar radiation is reflected by the Earth and the atmosphere. Greenhouse gases in the atmosphere, such as carbon dioxide (CO_2), absorb heat and further warm the surface of the Earth. This is called the greenhouse effect (Figure 2).

As more greenhouse gases are emitted into the atmosphere, heat that would normally be radiated into space is trapped within the Earth's atmosphere, causing the Earth's temperature to increase.



Greenhouse Gas: Any gas that absorbs heat in the atmosphere (e.g., CO_2)

Greenhouse Effect: Trapping and buildup of heat in the atmosphere near the Earth's surface caused in part by increased levels of greenhouse gases

Figure 2

What Is Causing Climate Change?

The global carbon cycle involves billions of tons of carbon in the form of CO_2 (Figure 3). Carbon dioxide is absorbed by oceans and living biomass and is emitted to the atmosphere annually through natural processes. When in equilibrium, carbon movement among these various reservoirs is roughly balanced.

The concentration of CO_2in the atmosphere has increased from a preindustrial value of about 280 parts per million (ppm) to 379 ppm in 2005 (IPCC, 2007d). Most scenarios of future emissions of CO_2 involve increases of CO_2. In 2004, 26.9 billion metric tons of CO_2 were emitted, and 33.9 billion metric tons are projected to be emitted in 2015. By 2030, 42.9 metric tons of CO_2 are projected to be emitted (EIA, 2007). See Figure 4.

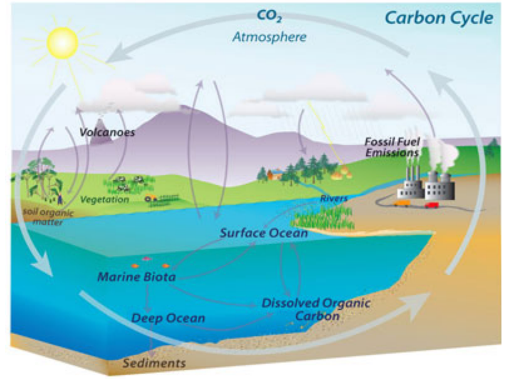


Figure 3

What Are Greenhouse Gases?

Gases that trap heat in the atmosphere are called greenhouse gases. CO_2 is the principal greenhouse gas, but other gases can have the same heat-trapping effect (Figure 5). Some of these other greenhouse gases, however, have a much stronger greenhouse, or heat-trapping, effect than CO_2. For example, methane is 21 times more potent a greenhouse gas than CO_2. Different GHGs have different atmospheric life times, and therefore actions to reduce emissions will take time to effect reductions of gases in the atmosphere. The principal, human-generated greenhouse gases that enter the atmosphere are Carbon Dioxide (CO_2): Carbon dioxide enters the atmosphere through the burning of fossil fuels (oil, natural gas and coal).

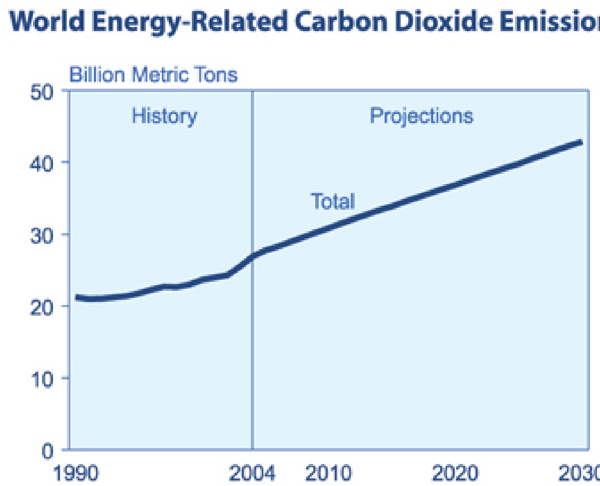


Figure 4

Methane (CH_4): Methane is emitted during the production and transport of coal, natural gas and oil. Methane emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills and anaerobic wastewater treatment plants. CH_4 is a greenhouse gas approximately 21 times more potent than CO_2 and has an atmospheric lifespan of roughly 12 years (EPA, 2009c).

Nitrous Oxide (N_2O): Nitrous oxide is emitted during agricultural and industrial activities, as well as during the combustion of fossil fuels and solid waste. Nitrous oxide is also emitted from wastewater treatment plants during nitrification and

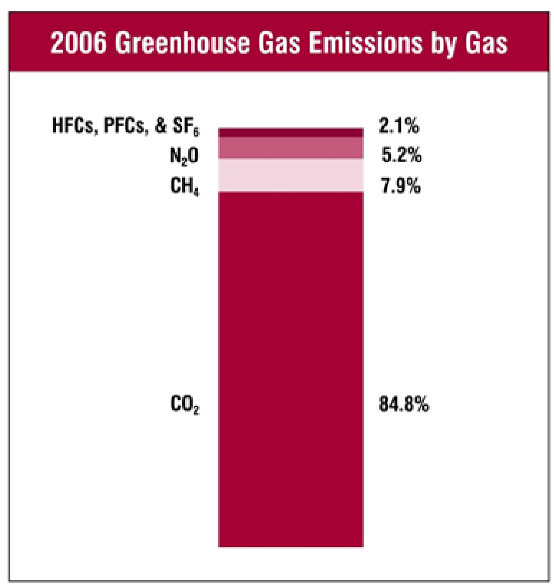


Figure 5

denitrification processes. N_2O is 310 times more potent as a greenhouse gas than CO_2 and has an atmospheric lifespan of 120 years (EPA, 2009b).

Fluorinated Gases: Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. Fluorinated gases are sometimes used as substitutes for ozone-depleting substances (i.e., CFCs, HCFCs and halons). These gases are typically emitted in smaller quantities, but because they are potent greenhouse gases, they are sometimes referred to as High Global Warming Potential gases (High GWP gases). HFCs are 140 to 11,700 times more potent than CO_2 and have atmospheric lifespans of 1–260 years. Most commercially used HFCs remain in the atmosphere less than 15 years. PFCs are 6,500 to 9,200 times more potent than CO_2 and have an atmospheric lifespan of several thousand years. Sulfur hexafluoride is 23,900 times a more potent greenhouse gas than CO_2 and is extremely long lived with very few sinks (EPA, 2009c).

How Is the Global Climate Changing?

Recorded Global Temperature Changes

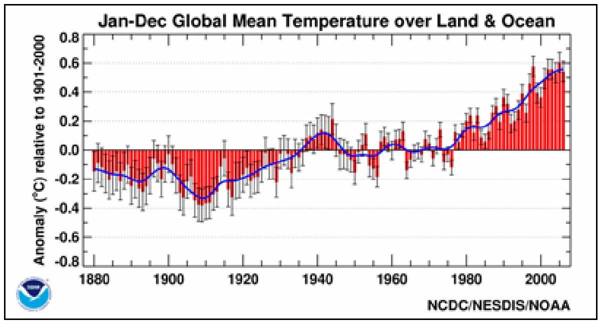


Figure 6. Annual Average Global Surface Temperature Anomalies, 1880-2006. Including 2007, seven of the eight warmest years on record globally have occurred since 2001, and the 10 warmest years have all occurred since 1995.

Global mean temperatures over land and ocean have increased over the past three decades as illustrated by Figure 6.

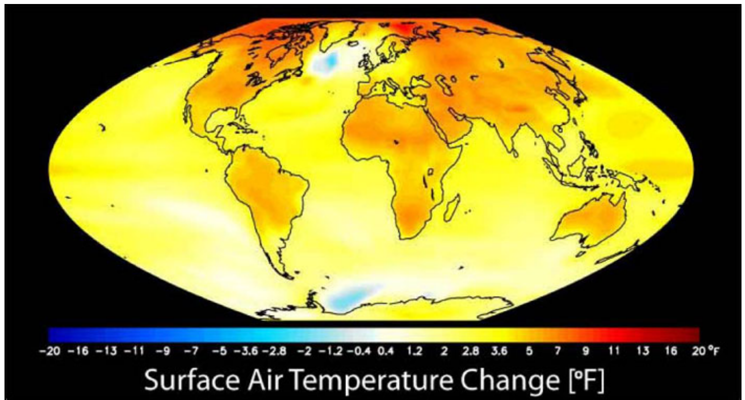
- The global average surface temperature has risen between 1.08 °F and 1.26 °F since the start of the 20th century (NOAA, 2006).
- The rate of increase since 1976 has been approximately three times faster than the century-scale trend (NCDC, 2008).
- Mean temperatures for the contiguous United States have risen at a rate near 0.6 °F per decade (NCDC, 2008).
- Six of the ten warmest years on record for the contiguous United States have occurred since 1998 (NCDC, 2008).
- Including 2007, seven of the eight warmest years on record globally have occurred since 2001 (NCDC, 2008).
- The 10 warmest years globally have all occurred since 1995 (NCDC, 2008).

Projected Global Temperature Changes

The Intergovernmental Panel on Climate Change (IPCC) projects that the average surface temperature of the Earth is likely to increase by 3.2 °F to 7.2 °F (1.8 °C to 4.0 °C) by the end of the 21st century, relative to 1980-1990 (IPCC, 2007c).

- As seen in Figure 7 warming is not predicted to be evenly distributed around the globe.

- Land areas will warm more than oceans in part because of the ocean's greater ability to store heat.
- High latitudes will warm more than low latitudes in part because of positive feedback effects from melting ice.
- Most of North America, all of Africa, Europe, northern and central Asia, and most of Central and South America are likely to warm more than the global average.
- Projections suggest that the warming will be close to the global average in south Asia, Australia and New Zealand, and southern South America.
- Warming will differ by season, with winters warming more than summers in most areas.



Projected change in annual mean surface air temperature from the late 20th century (1971-2000 average) to the middle 21st century (2051-2060 average). The change is in response to increasing greenhouse gases and aerosols based on a *middle of the road* estimate of future emissions. Warming is larger over continents than oceans, and is largest at high latitudes of the Northern Hemisphere. These results are from the GFDL CM2.1 model but are consistent with a broad consensus of modeling results.

Figure 7

Global Temperature Change Scenarios

Over the next 100 years, temperature changes are expected to be in the range of 3 °F to 7 °F, but where in this range temperatures actually occur will depend on the actual changes in CO_2 concentrations in the atmosphere, and these concentrations will depend on human activities and the success in efforts to control releases of CO_2 and other greenhouse gases.

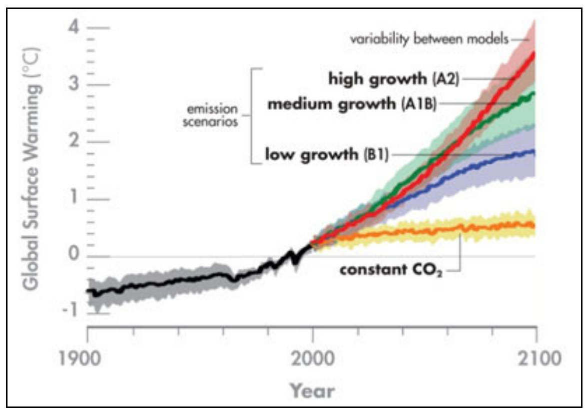


Figure 8

Figure 8 provides temperature projections to the year 2100, based on a range of emission scenarios and global climate models. Several factors, such as population growth and the implementation of new, cleaner technology, will influence whether temperature increases follow the blue, green or red lines in the graph (Figure 8). Scenarios that assume the highest emission rates of greenhouse gases provide the estimates in the top end of the temperature range. The orange line (constant CO_2) projects global temperatures with greenhouse gas concentrations stabilized at year 2000 levels (IPCC, 2007c).

> *"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."*
> – Intergovernmental Panel on Climate Change (IPCC, 2007b).

Temperature Increases Drive Other Environmental Changes

According to the IPCC, an increase in the average global temperature is very likely to lead to changes in precipitation and atmospheric moisture. Increased temperatures cause changes in atmospheric circulation and increase evaporation and water vapor, resulting in precipitation increases, more intense precipitation, more storms and sea level rise.

Climate models suggest an increase in global average annual precipitation during the 21st century (IPCC, 2007c and 2001), although changes in precipitation will vary from region to region (Figure 9). An increase in the intensity of precipitation events, particularly in tropical and high-latitude regions that experience overall increases in precipitation is also predicted. Regional precipitation projections from climate models must be considered with caution because they demonstrate limited skill at small spatial scales.

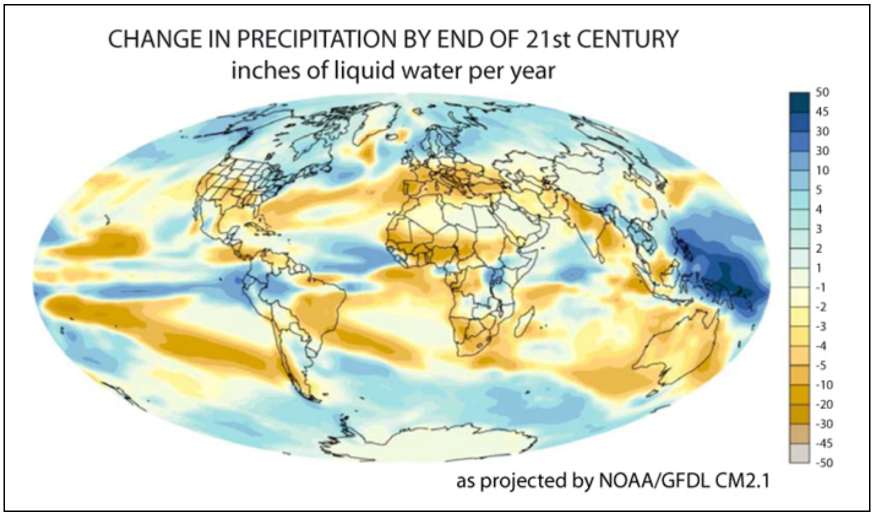


Figure 9

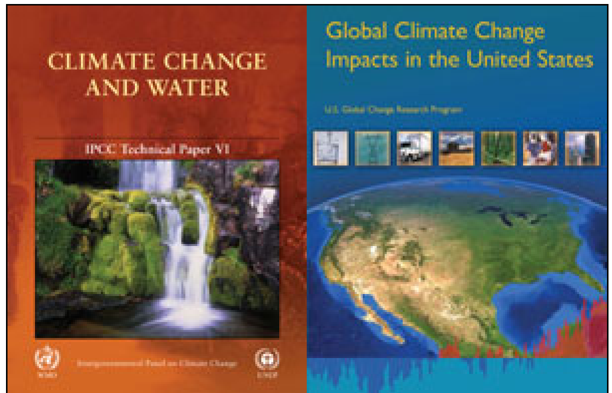
The frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapor (IPCC, 2007d). Mid-latitude storm tracks are projected to shift toward the poles, with increased intensity in some areas but at reduced frequency (EPA 2008t).

Tropical storms and hurricanes are likely to become more intense, produce stronger peak winds, and produce increased rainfall over some areas due to warming sea surface temperatures (which can energize these storms) (IPCC, 2007c).

The IPCC estimates that the global average sea level will rise by 7.2 to 23.6 inches (18-59 cm or 0.18-0.59m) by 2100 relative to 1980 to 1999 under a range of scenarios (IPCC, 2007c). These estimates assume that ice flow from Greenland and Antarctica will continue at the same rates as observed from 1993 to 2003, but these rates could increase or decrease in the future. Current model projections indicate substantial variability in future sea level rise between different locations.

How Are Changes in Climate Evaluated and Predicted?

The IPCC is a scientific intergovernmental body set up by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP) in 1988 (Figure 10). The IPCC was established to provide decision makers and others interested in climate change with an objective source of information about climate change. The IPCC does not conduct any research, nor does it monitor climate-related data or parameters. Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socioeconomic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts, and options for adaptation and mitigation.



The Intergovernmental Panel on Climate Change is a scientific intergovernmental body set up by the World Meteorological Organization and by the United Nations Environment Programme.

The U.S. Global Change Research Program (USGCRP) is a coordinated effort of many U.S. federal agencies focused on improving our understanding of the science of climate change and its potential impacts in the United States as well as global impacts.

Figure 10

The U.S. Global Change Research Program (USGCRP) was established by Congress under the Global Change Research Act of 1990. It is a multiagency program that coordinates U.S. federal support for scientific research and observing systems on climate and environmental change in the United States as well as globally. The U.S. Environmental Protection Agency is one of the 13 participating agencies in the program. The planning and implementation of EPA's climate research and assessment activities are closely coordinated with the overall USGRCP.

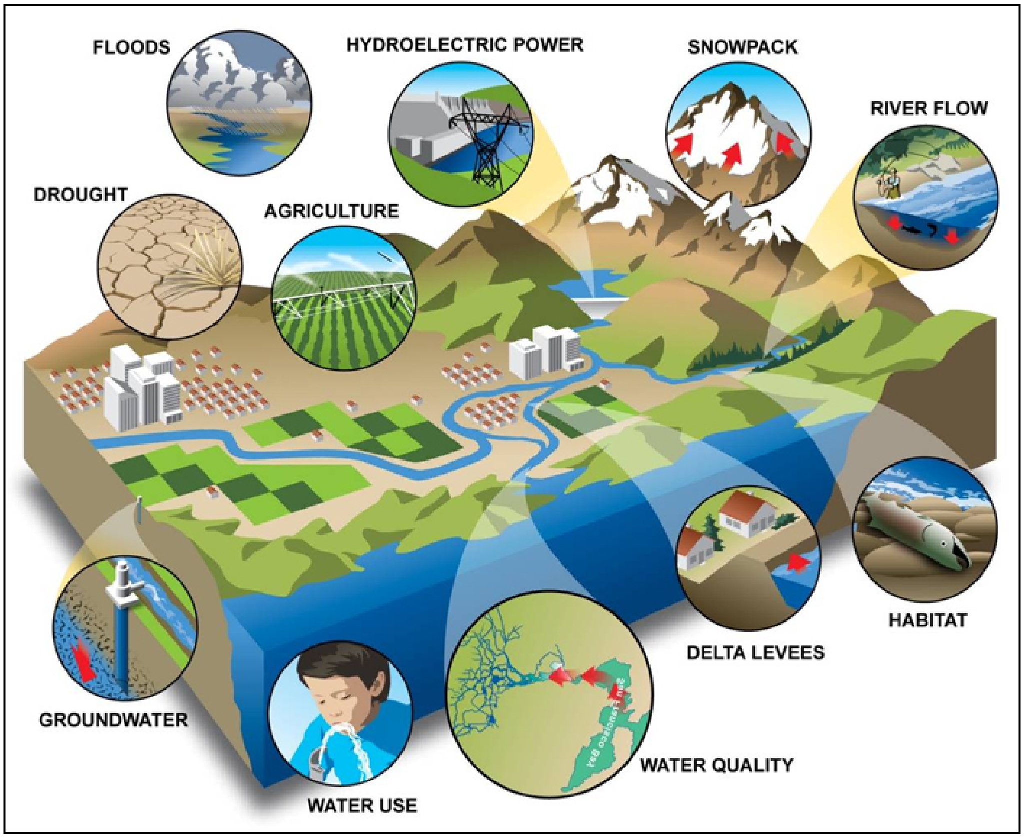
Why Does Climate Change Matter to U.S. Water Program Managers?

Climate change is expected to have dramatic effects on water resources in the United States and on the work of water program managers (Figure 11).

In addition, steps taken to reduce the release of greenhouse gases could have consequences—positive as well as negative—for water resources and programs.

Figure 11. Temperature change affects many natural processes that in turn affect the quality and quantity of our water resources.

(Source: California – Department of Water Resources. Climate Change in California Fact Sheet)



What Are the Water-Related Effects of Climate Change in the United States?

Warmer air temperature is anticipated to have the following water-related effects in the United States:

- Increases in water temperature
- Changes in the location, timing, form and amount of precipitation
- Increases in tropical storm intensity
- Rising sea levels (Figure 12 shows rising sea levels on the east coast of the United States)
- Changes in oceans and coastal regions—chemical and physical

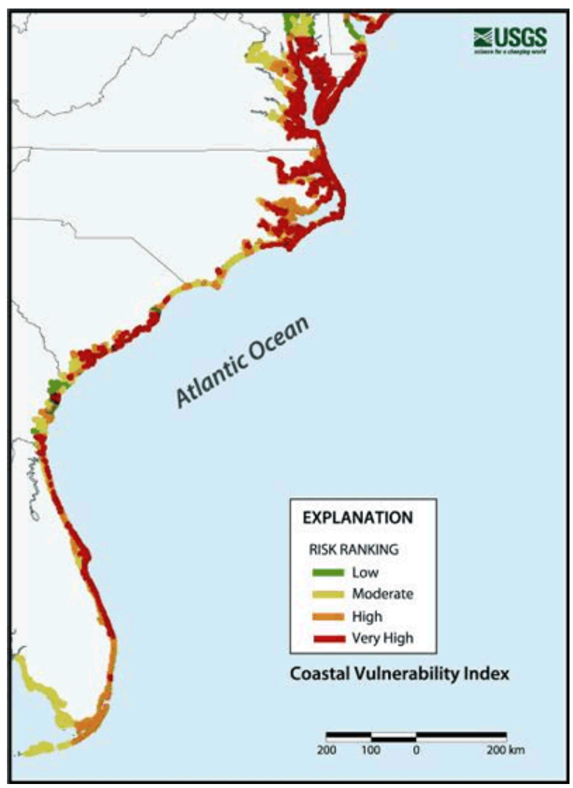


Figure 12

Air and Water Temperature Increases

Observations compiled by the National Climatic Data Center (NCDC) indicate that over the past century, temperatures rose across the contiguous United States at an average rate of 0.11 °F per decade (1.1 °F per century). Average temperatures rose at an increased rate of 0.56 °F per decade from 1979 to 2005. As indicated by the red and pink colors in Figure 13, warming occurred throughout most of the United States, with all but 3 of the 11 climate regions showing an increase of more than 1 °F since 1901. The greatest temperature increase occurred in Alaska (3.3 °F per century). The Southeast experienced a very slight cooling trend over the entire period (-0.04 °F per century) indicated by the light blue color, but warming within this region has occurred since 1979.

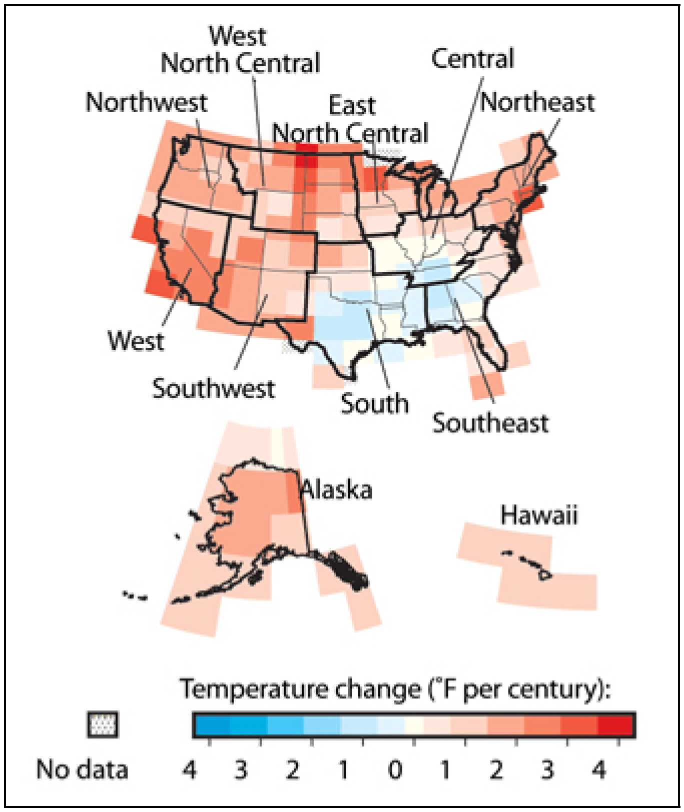


Figure 13

According to the IPCC, all of North America is very likely to warm during this century, and the annual mean warming is likely to exceed the global mean warming in most areas…warming in the United States is expected to exceed two degrees Celsius (3.6 °F) by nearly all models (IPCC, 2007c).

The Effect on Water Resources

An increase in the air temperature will cause water temperatures to increase as well. As water temperatures increase, water pollution problems will increase, and many aquatic habitats will be negatively affected (Figure 14).

For example, increases in water temperatures are expected to result in the following:

- Lower levels of dissolved oxygen due to the inverse relationship that exists between dissolved oxygen and temperature (Figure 15). As the temperature of the water increases, dissolved oxygen levels decrease.

Figure 14. Air and water temperature increases are expected to result in changes in marine species abundance and distribution.

- Increases in pathogens, nutrients and invasive species.
- Increases in concentrations of some pollutants such as ammonia and pentachlorophenol due to their chemical response to warmer temperatures.
- Increase in algal blooms (Figure 16).
- Loss of aquatic species whose survival and breeding are temperature dependent.
- Change in the abundance and spatial distribution of coastal and marine species and decline in populations of some species.
- Increased rates of evapotranspiration from waterbodies, resulting in shrinking of some waterbodies such as the Great Lakes.

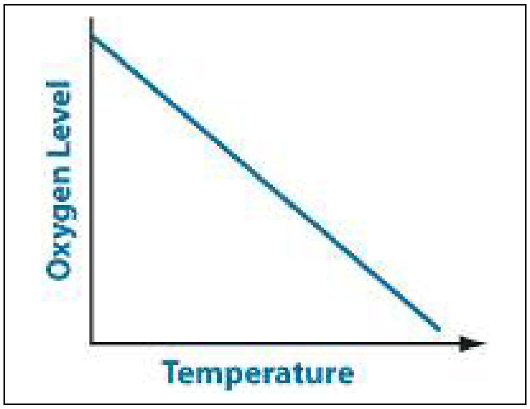


Figure 15

Figure 16

The Effect on EPA Water Programs

Increases in air and water temperatures will affect the chemistry and biology of water resources. As a result, water programs need to be prepared to handle the following effects:

- Increased number of impaired waters
- Difficulty meeting water quality and drinking water standards
- Difficulty meeting National Pollutant Discharge Elimination System (NPDES) permit limits because of more complex environmental conditions
- Reductions in availability and quality of drinking water supplies

The drinking water, surface water, discharge permits and TMDL programs have been identified as programs that face some of the greatest potential effects from air and water temperature increases (Figure 17).

Air and Water Temperature Variations: Effects on Water Programs
(Areas shaded orange reflect programs most affected by air and water temperature variations)

Drinking Water Standards	**Surface Water Standards**	Technology Based Standards	Emergency Planning
Drinking Water Planning	**Clean Water Planning**	Water Monitoring	**Water Restoration/ TMDLs**
Underground Injection Control Permits	**Discharge Permits**	Stormwater Permits	**Wetlands Permits**
Source Water Protection	**Nonpoint Pollution Control**	Coastal Zone	National Estuary Program
Drinking Water SRF	**Clean Water SRF**	Ocean Protection	Combined Sewer Overflow Plans

Figure 17

Precipitation Changes

Figure 18

As the air temperature warms, the rate at which water evaporates from soils and waterbodies increases, and that increases the amount of water being held in the atmosphere. Because there is more atmospheric moisture, there are heavier downpours when it rains. While moderate increases in annual average precipitation are expected, there is likely to be a wider variation in the pattern of rainfall, specifically, drier dry periods punctuated by more intense rainfall (Figure 18).

Observations compiled by NOAA's National Climatic Data Center (NCDC) show that total annual, average precipitation over the contiguous United States has increased at an average rate of 6.1 percent per century since 1900, although there was considerable regional variability (Figure 19).

The greatest increases were in the East North Central climate region (11.6 percent per century) and the South (11.1 percent).

Future projections suggest (IPCC, 2008a, 2007a and 2001) the following:

- Annual average precipitation increases in the northeastern United States and decreases in the southwest.
- In the Midwest and Great Lakes, lake and river levels will be lower.

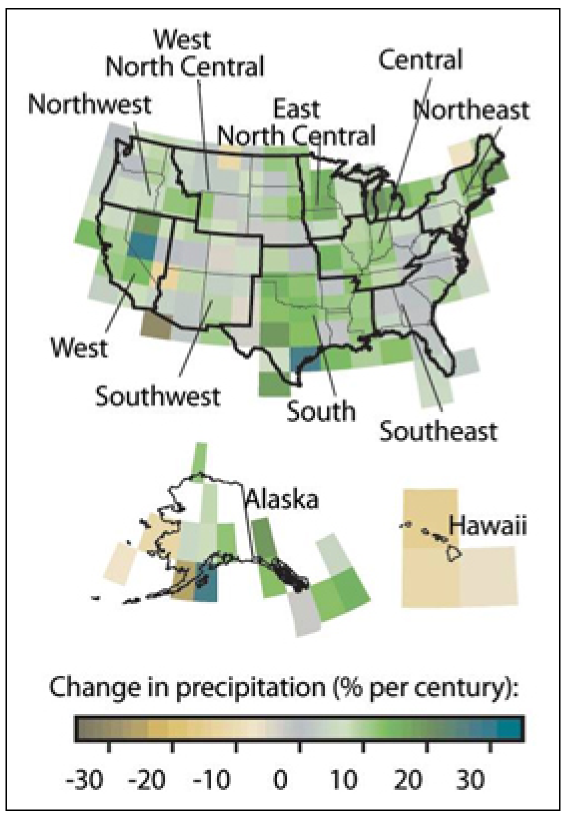


Figure 19

- In the Great Plains, there will be intensified springtime floods and summertime droughts, and agricultural productivity will likely shift northward as the droughts increase.
- Projected warming in the western mountains by the mid-21st century is very likely to cause large decreases in snowpack, earlier snowmelt, more winter rain events, increased peak winter flows and flooding, and reduced summer flows.

Note: Regional precipitation projections from climate models must be considered with caution because they demonstrate limited skill at small spatial scales.

The Effect on Water Resources

Changes in the location and amount of precipitation will affect water availability and water quality (Figure 20).

Water availability: The net impact on water availability will depend on changes in precipitation (including changes in the total amount, form and seasonal timing of precipitation). In areas where precipitation increases sufficiently, net water supplies might not be affected or they might even increase. If the precipitation remains the same or decreases though, net water supplies would decrease. This is in part due to the predicted temperature rise in most areas, which will cause evaporation rates to increase. Where water supplies decrease, there is also likely to be an increase in demand as a result of higher temperatures, which could be particularly significant for agriculture and energy production (the largest consumers of water) and also for municipal, industrial and other uses.

Water availability
- Reduced ground water and surface water supply in some areas
- Increased water demand due to higher temperatures

Water quality
- Increased runoff resulting in erosion and sedimentation
- Overwhelmed water infrastructure due to flooding

Figure 20

Water quality: Changes in the timing, intensity and duration of precipitation can negatively affect water quality. Flooding, a result of increased precipitation and intense rain storms, transports large volumes of water and contaminants into waterbodies. Flooding also can overload storm, combined sewer and wastewater systems, resulting in untreated pollutants directly entering waterways. In regions with increased rainfall frequency and intensity, more pollution and sedimentation might be produced because of runoff. Reduced rainfall can also result in more frequent wildfires, and land areas where wildfires have occurred are more vulnerable to soil erosion.

The Effect on EPA Water Programs

Changes in the location, timing, form and amount of precipitation could have similar implications for water programs as do increases in air and water temperatures. In addition, in areas with increased precipitation, pollutant runoff might increase and stress stormwater conveyance systems and negatively affect water quality and drinking water quality. For example, decreases in precipitation might stress drinking water supplies and require water programs to reevaluate the location of their drinking water intake and implement water conservation planning.

In addition to several of the programs that were affected by increases in air and water temperature, stormwater, combined sewer overflows and underground injection control permits are anticipated to be affected by changes in the location, amount and intensity of precipitation (Figure 21).

Rainfall and Snowfall Levels/Distribution: Effects on Water Programs
(Areas shaded orange reflect programs most affected by rainfall and snowfall levels)

Drinking Water Standards	Surface Water Standards	Technology Based Standards	Emergency Planning
Drinking Water Planning	Clean Water Planning	Water Monitoring	**Water Restoration/ TMDLs**
Underground Injection Control Permits	**Discharge Permits**	**Stormwater Permits**	Wetlands Permits
Source Water Protection	**Nonpoint Pollution Control**	Coastal Zone	National Estuary Program
Drinking Water SRF	**Clean Water SRF**	Ocean Protection	**Combined Sewer Overflow Plans**

Figure 21

Stormwater management systems might need to be designed to avoid being overwhelmed during intense rain storm events.

- Combined storm and sanitary sewer systems might need to be designed to avoid an increase of overflows and subsequent increased pollutant and pathogen loading resulting from untreated waste directly entering waterways.
- Increased monitoring efforts need to include biological monitoring and assessment techniques to assess the impact of higher water flow velocities.
- Watershed management techniques need to incorporate green techniques (e.g., green roofs) and smart growth to manage stormwater to reduce its velocity and to infiltrate water to replenish ground water instead of directly running off into storm drains and waterbodies.
- The importance of wetland management and buffers will increase as a method to control stormwater runoff.

Increases in Storm Intensity

Tropical storms and hurricanes are likely to become more intense, produce stronger peak winds, produce increased rainfall, and cause larger storm surges because of warming sea surface temperatures (which can energize these storms) (IPCC, 2007c). See Figure 22.

The relationship between sea surface temperatures and the frequency of tropical storms is less clear. There is currently no scientific consensus on how future climate change is likely to affect the frequency of tropical storms in any part of the world where they occur (WMO, 2006).

Figure 22. Warming air and sea surface temperatures are expected to result in greater intensity of tropical storms, accompanied by stronger peak winds, increased rainfall, and larger storm surges.

The Effect on Water Resources

Increased tropical storm intensities will have negative effects on water resources (Figure 23). More intense tropical storms can damage infrastructure, cause increased flooding, which can overwhelm water infrastructure, and cause pollutants to directly enter waterways and contaminate water supplies. Coastal erosion is also often a result of storms.

Figure 23. The effects of increased tropical storms include contaminated waters, damaged wetlands, flooded wastewater treatment plants, and damage from high wind.

In the Northeast, models predict coastal erosion, loss of wetland habitat, and increased risk of storm surges from sea level rise. In the Southeast, intense development within the coastal zone places coastal floodplains at risk for flooding from sea level rise, storm surges and extreme precipitation events. The Pacific Northwest could experience an increase in wave heights.

The Effect on EPA Water Programs

In light of the effect that increased tropical storm intensity will have on water resources, water program managers will need to adjust their priorities and planning processes to be prepared. In addition to several of the programs that have already been mentioned, coastal and ocean programs (including the National Estuary Programs), water monitoring, and emergency planning are among the programs that will be most affected by increased storm intensity (Figure 24).

Emergency plans for drinking and wastewater infrastructure need to address potential impacts from tropical storms, storm surge, flooding and high winds. The importance of wetland management and buffers will increase because they act as a buffer for storm surge and protect coastal wetlands in their own right.

Storm Intensity: Effects on Water Programs

(Areas shaded orange reflect programs most affected by storm intensity)

Drinking Water Standards	Surface Water Standards	Technology Based Standards	Emergency Planning
Drinking Water Planning	Clean Water Planning	Water Monitoring	Water Restoration/ TMDLs
Underground Injection Control Permits	Discharge Permits	Stormwater Permits	Wetlands Permits
Source Water Protection	Nonpoint Pollution Control	Coastal Zone	National Estuary Program
Drinking Water SRF	Clean Water SRF	Ocean Protection	Combined Sewer Overflow Plans

Figure 24

Sea Level Rise

Sea levels are rising worldwide and along much of the U.S. coast (IPCC, 2007c). In the United States, sea level has been rising 0.08 to 0.12 inches (2.0 to 3.0 mm) per year along most of the U.S. Atlantic and Gulf coasts (Figure 25). The rate of sea level rise varies from about 0.36 inches per year (10 mm per year) along the Louisiana coast (due to land sinking), to a drop in sea level of a few inches per decade in parts of Alaska (because the land is rising) (EPA 2008u).

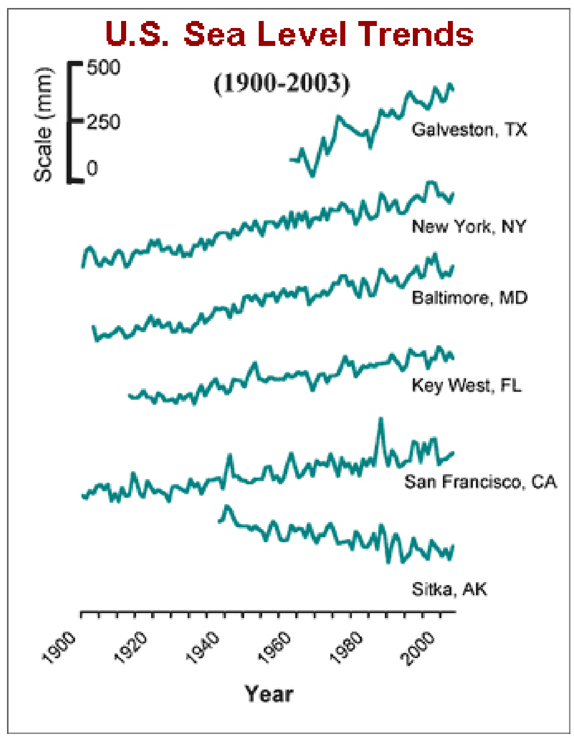


Figure 25. "Sea levels are rising worldwide and along much of the U.S. coast." – IPCC, 2007c

The factors driving sea level rise include the following:

- Ocean water expansion caused by warmer ocean temperatures
- Mountain glaciers and ice caps melting
- Greenland Ice Sheet and the West Antarctic Ice Sheet melting

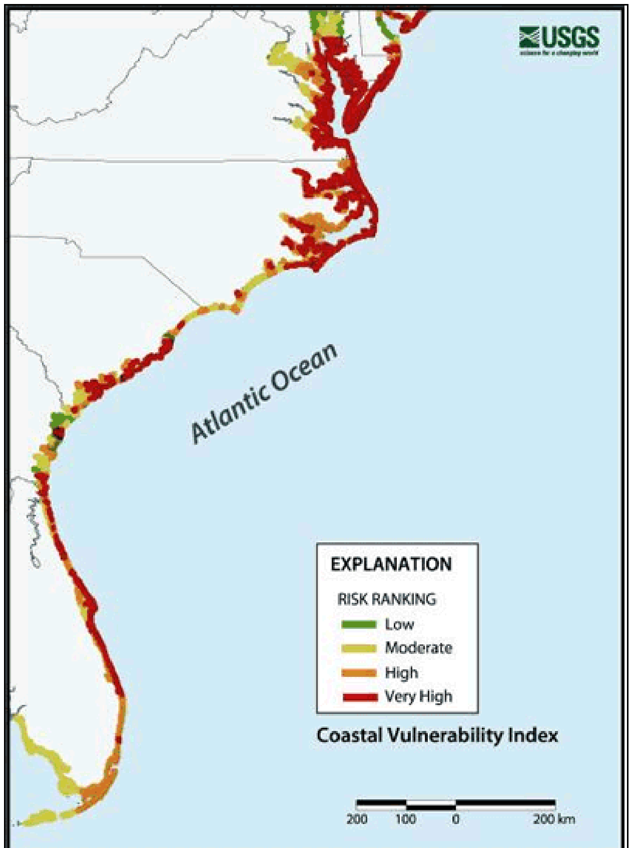
Future sea level rise estimates could be higher as new scientific studies are conducted, such as with respect to the melting of the Greenland Ice Sheet.

The Effect on Water Resources

Rising sea levels will increase erosion rates and cause the displacement of coastal wetlands, alter shorelines and cause high-value habitat to be lost. Low-lying coastal areas, such as wetlands, deltas, coastal plains, salt marshes, mangrove forests and coral reefs will be affected by sea level rise (Burkett et al. 2001, p. 345).

Major sewage treatment facilities are on low-lying coastal lands, and these facilities might need to relocate or build protective structures as sea levels rise and storm surges increase.

Rising sea level increases the salinity of both surface water and ground water through salt water intrusion. New York City, Philadelphia and much of California's Central Valley obtain some of their water from portions of rivers that are slightly upstream from the point where water is salty during droughts. If sea level rise pushes salty water upstream, the existing water intakes might draw on salty water during dry periods. Shallow coastal aquifers are also at risk (IPCC, 2007c). The freshwater Everglades recharge Florida's Biscayne aquifer, the primary water supply to the Florida Keys. As rising water levels submerge low-lying portions of the Everglades, portions of the aquifer would become saline (Figure 26).



Lands vulnerable to sea level rise. The effects of sea level rise on water resources include:

- Displacement of coastal wetlands and habitat
- Increased coastal erosion
- Inundation of wastewater treatment infrastructure
- Salt water intrusion threat to drinking water supplies

Figure 26

The Effect on EPA Water Programs

Water program managers that might be affected by sea level rise will need to do the following:

- Consider long-term projections for rising sea levels and create emergency plans for drinking water and wastewater infrastructure as necessary
- Consider relocating drinking water systems or intakes in response to salt water intrusion into freshwater supplies
- Consider relocating sewage treatment plant facilities and discharge outfalls
- Consider measures to protect existing water infrastructure facilities, such as sea walls and elevating electrical equipment
- Assess the effects of salinity changes on living resources in estuaries

- Evaluate effects of expected coastal wetland losses on health of aquatic ecosystems
- Use land use planning, building codes, land acquisition, and easements to protect land areas expected to be inundated by sea level rise (Figure 27).

Coastal and ocean programs (including the National Estuary Programs), drinking water, the Clean Water State Revolving Fund and emergency planning are among the programs that will be most affected by sea level rise.

Sea Level Rise: Effects on Water Programs
(Areas shaded orange reflect programs most affected by sea level rise)

Drinking Water Standards	Surface Water Standards	Technology Based Standards	**Emergency Planning**
Drinking Water Planning	**Clean Water Planning**	Water Monitoring	Water Restoration/ TMDLs
Underground Injection Control Permits	Discharge Permits	Stormwater Permits	**Wetlands Permits**
Source Water Protection	Nonpoint Pollution Control	**Coastal Zone**	**National Estuary Program**
Drinking Water SRF	**Clean Water SRF**	**Ocean Protection**	Combined Sewer Overflow Plans

Figure 27

Ocean and Coastal Changes

In addition to rising sea levels, the characteristics of the ocean are expected to change as the planet warms. Corals are believed to be surviving at or close to their temperature tolerance levels. If air and water temperatures continue to increase, corals might not be able to survive.

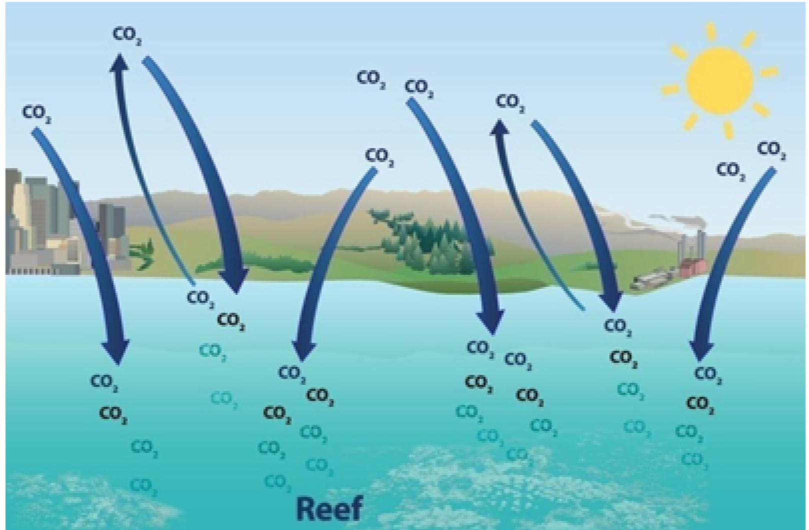
Biological habitat changes (other than sea level rise) are expected in the oceans as the air temperatures increase.

- Estuarine waters become more saline as sea levels rise.
- Ocean temperatures increase posing a threat to ocean life, e.g., corals.
- Oceans become more acidic.

The abundance and spatial distribution of saltwater species might change with the changes in water temperature and salinity levels in estuarine systems. Also, oceans are expected to become more acidic.

Ocean Acidification

Oceans naturally absorb carbon dioxide from the atmosphere. When there are increased levels of carbon dioxide in the atmosphere, oceans increase the absorption of carbon dioxide in a process called ocean acidification (Figure 28). The mixture of ocean water and the carbon dioxide forms carbonic acid. Carbonic acid reacts with carbonate ions that are also found in seawater, which are a vital component to the structure of corals and the shells of marine organisms, such as calcifying phytoplankton that form the first tier of the ocean food web. In other words, elevated levels of carbon dioxide in the atmosphere leads to less of the building blocks that are needed to form the calcium carbonate skeletons of corals and other organisms that require calcium carbonate to make their shells.



- Increased atmospheric carbon dioxide levels result in increased ocean absorption of carbon dioxide
- Increased ocean carbon dioxide absorption causes a deficit of the carbonate ions that coral and other marine organisms need to build their skeletons

Figure 28

The response of marine biota to ocean acidification is not yet clear, both for the physiology of individual organisms and for the ecosystem functioning as a whole. Extinction thresholds will likely be crossed for some organisms in the coming century (Denman et al., 2007, p. 533). Ocean acidification is not a direct consequence of warming temperatures, but, like warmer temperatures, it is caused by increased levels of carbon dioxide in the atmosphere.

The Effect on Water Resources

Ocean acidification, warmer ocean water and more saline estuaries are expected to have several impacts on coastal and ocean resources.

- Potential marine food web breakdowns from ocean acidification (Denman et al., 2007, p. 529)
- Coral, calcifying phytoplankton and zooplankton growth will be inhibited or slowed because of ocean acidification (Denman et al., 2007, p. 529)
- Habitat loss with the loss of coral reefs because of coral bleaching (Figure 29)
- Aquatic plants and animals that cannot tolerate increased salinity levels are lost

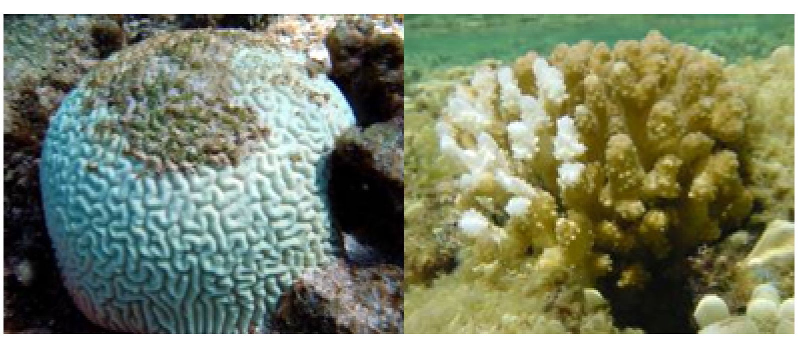


Figure 29. Air and water temperature increases are a threat to corals and cause bleaching of corals.

The Effect on EPA Water Programs

Water program managers who oversee coastal and ocean regions should be prepared to do the following:

- Reassess and increase coral reef protection efforts
- Adjust wetland programs and planning to account for changing salinity levels
- Revise estuary and watershed level protection programs to account for changes in natural systems such as increased salinity, ocean temperature and acidity
- Adjust water monitoring strategies to better track changes in salinity, temperature and acidity

Water monitoring, wetland, estuary and coastal and ocean protection programs will be most affected by changing ocean and coastal characteristics (Figure 30).

Changing Ocean Characteristics: Effects on Water Programs
(Areas shaded orange reflect programs most affected by changing ocean characteristics)

Drinking Water Standards	Surface Water Standards	Technology Based Standards	Emergency Planning
Drinking Water Planning	Clean Water Planning	**Water Monitoring**	Water Restoration/ TMDLs
Underground Injection Control Permits	Discharge Permits	Stormwater Permits	**Wetlands Permits**
Source Water Protection	Nonpoint Pollution Control	**Coastal Zone**	**National Estuary Program**
Drinking Water SRF	Clean Water SRF	**Ocean Protection**	Combined Sewer Overflow Plans

Figure 30

What Is the Relationship Between Energy, Water Resources and Climate Change?

Energy production and usage, water resources and climate change are interrelated.

- Reduced precipitation and stream flow could limit hydropower and power plant cooling (Figure 31).
- Geological sequestration of CO_2 from coal-fired power plants might pose a risk to underground sources of drinking water.
- Expanded demand for biofuels could lead to increased nutrient runoff from agriculture.

Figure 31. Coal-fired electric power plant.

Power Plants

Hydropower plants could have reduced production capacity as a result of reduced precipitation or change in snowmelt. Hydropower needs might increasingly conflict with other priorities, such as salmon restoration goals in the Pacific Northwest (IPCC, 2007a).

Figure 32. Coal plant in Alma, Wisconsin, along the Mississippi River. Climate change's effect on water resources could cause power plants to have reduced power production at hydropower plants, have limited availability of water for plant cooling, and impact cooling water withdrawals on aquatic systems.

Steam-electric plants rely on water resources. The average 500-megawatt coal-fired plant uses more than 12 million gallons of water an hour. Acoal-fired plant that implements carbon-capture technology will use almost 23 million gallons of water (Greenwire, 2008). A lack of water resources due to changes in precipitation patterns might result in a plant's diminished ability to function. In addition, cooling water withdrawals can have an impact on aquatic systems (Figure 32).

Carbon Sequestration

Carbon sequestration is one method that will decrease the greenhouse gas emissions of conventional energy sources. Carbon sequestration is the process of removing carbon dioxide from the atmosphere or capturing it at the source and storing it (Figure 33).

Geologic sequestration is the process of injecting carbon dioxide (CO_2) from a source, such as a coal-fired electric generating power plant, through a well into the deep subsurface. With proper site selection and management, geologic sequestration could play a major role in reducing the net emissions of CO_2.

While carbon sequestering practices could lessen the release of greenhouse gases, the effect of carbon sequestration on water resources is not clear. The geologic injection process might pollute ground water with carbon dioxide and brines (IPCC, 2005, p. 31).

Carbon sequestration:

- Process removes carbon dioxide from the atmosphere and stores it.
- Carbon can be stored in geologic formations.
- Geologic carbon sequestration can pose a risk to underground sources of drinking water.

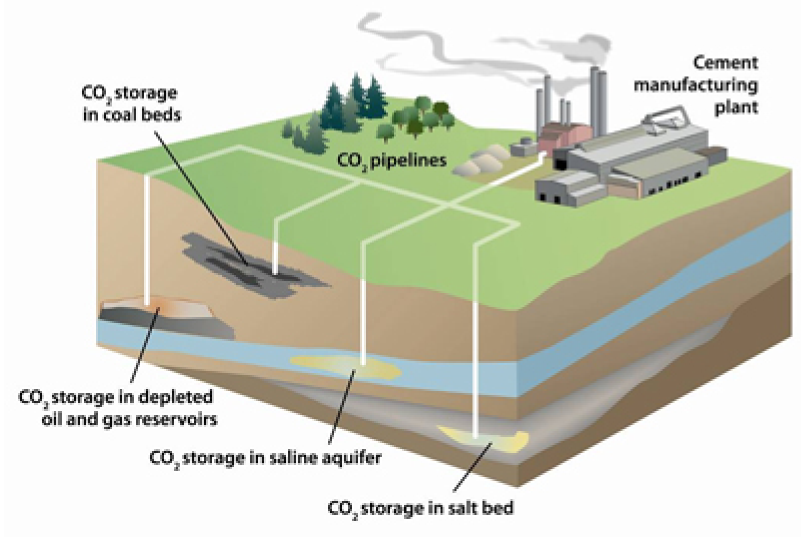


Figure 33

Biofuel Production

Almost all ethanol in the United States is made from corn kernels. Soybeans are the predominant feedstock for biodiesel. Research is underway to develop other feedstocks to make cellulosic ethanol, i.e., corn stover (stalks, leaves, cobs), switchgrass, wood waste, algae. Brazil uses sugarcane to make all its ethanol.

The goal of the 2007 Energy Independence and Security Act is to reduce the U.S. dependence on imported petroleum by requiring large increases in the amount of biofuels blended into gasoline. By 2022, 20 percent of U.S. gasoline demand could be supplied by the 36 billion gallons of biofuel required under this law. Corn kernels will supply about 15 billion gallons of that total. The resulting increase in corn production could increase water pollution from the additional use of nutrients and pesticides on corn (Figure 34). The process of growing and producing biofuels requires large amounts of water.

- Increased production of corn for biofuels is expected to result in increased loadings of nutrients to water.
- Nutrients are a major cause of water quality problems nationwide.
- Biofuel production facilities use large amounts of water.

Figure 34

The Effect on EPA Water Programs

Nonpoint source controls, technology-based standards, underground injection control permits, ocean and source water protection, drinking water planning, and surface water standards will be most affected by changes in energy generation and carbon storage (Figure 35).

Energy Generation and Carbon Storage: Effects on Water Programs

(Areas shaded orange reflect programs most affected by energy generation and carbon sequestration)

Drinking Water Standards	**Surface Water Standards**	**Technology Based Standards**	Emergency Planning
Drinking Water Planning	Clean Water Planning	Water Monitoring	Water Restoration/ TMDLs
Underground Injection Control Permits	Discharge Permits	Stormwater Permits	Wetlands Permits
Source Water Protection	**Nonpoint Pollution Control**	Coastal Zone	National Estuary Program
Drinking Water SRF	Clean Water SRF	**Ocean Protection**	Combined Sewer Overflow Plans

Figure 35

What Are the Nonwater-Related Effects of Climate Change?

The effects of climate change will extend beyond water resources and affect many other aspects of our lives, some of which are listed below (Figure 36).

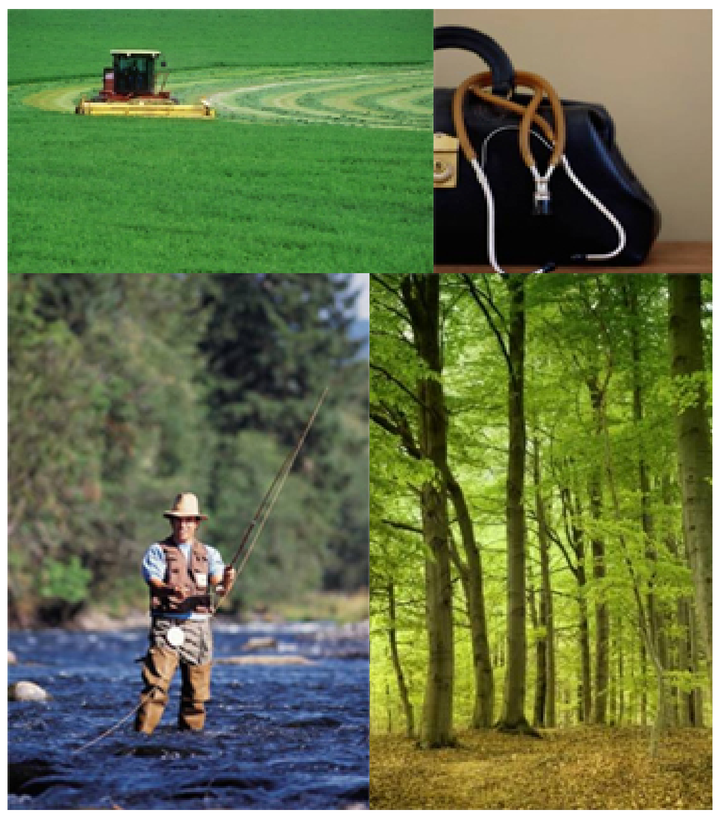


Figure 36

Agriculture depends on the length of growing seasons and precipitation, both of which EPA expects climate change will affect.

Forests also depend on precipitation, and increased temperatures might extend the forest fire season in parts of the United States. Increased temperatures and precipitation might cause increases in some insect populations and increase the spread of some diseases such as Lyme disease.

Outdoor-based recreational opportunities that involve wildlife viewing and cold weather experiences are also likely to be affected by climate change.

Throughout the world, the prevalence of some diseases and other threats to human health depend largely on local climate.

Other nonwater-related effects of climate change include effects on ecosystems, habitat and biodiversity, native people's ways of life and cultural values.

National Water Program Strategy: Response to Climate Change

In September 2008, EPA released the National Water Program Strategy: Response to Climate Chang (Figure 37). The Strategy provides an overview of the likely effects of climate change on water resources and the nation's clean water and safe drinking water programs. It also describes initial specific actions the National Water Program will take in 2008–2010 to adapt program implementation in light of climate change. The Strategy has five major goals:

Goal 1—Water Program Mitigation of Greenhouse Gases: use water programs to contribute to greenhouse gas mitigation.

Goal 2—Water Program Adaptation to Climate Change: adapt implementation of core water programs to maintain and improve program effectiveness in the context of a changing climate.

Goal 3—Climate Change Research Related to Water: strengthen the link between EPA water programs and climate change research.

Goal 4—Water Program Education on Climate Change: educate water program professionals and stakeholders on climate change impacts on water resources and programs.

Goal 5—Water Program Management of Climate Change: establish the management capability within the National Water Program to engage climate change challenges on a sustained basis.

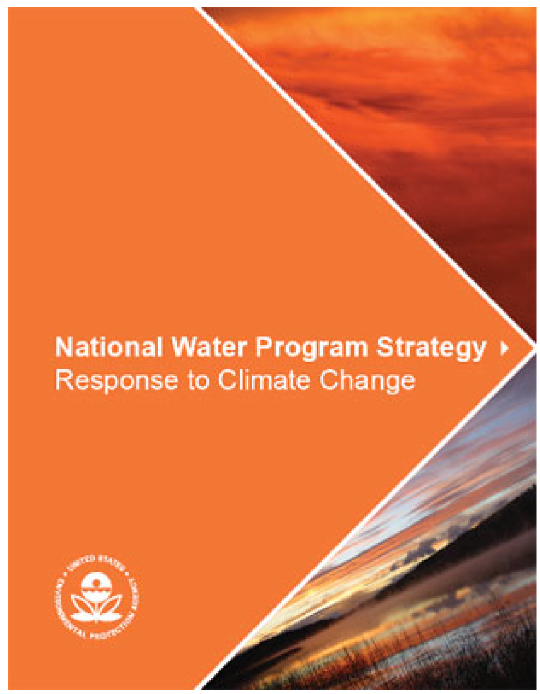


Figure 37

EPA will regularly update the strategy.

Key Actions in the National Water Program Strategy

The Strategy's major goals are supported by more specific objectives and key actions to be implemented by the National Water Program. Some key actions expand existing efforts to better address climate change, while others are new actions specifically focused on climate change issues. Appendix 2 of the Strategy provides a summary of the 44 key actions.

Half of the 44 key actions involve tasks related to adapting water program implementation to a changing climate (Figure 38). Eleven key actions relate to opportunities to mitigate greenhouse gases through water program activities. The remaining actions relate to water-related research on climate change, education of water program managers on climate change issues, and integrating climate change within the management structure of the National Water Program. Implementation of these new key actions was planned with an assumption of current funding levels.

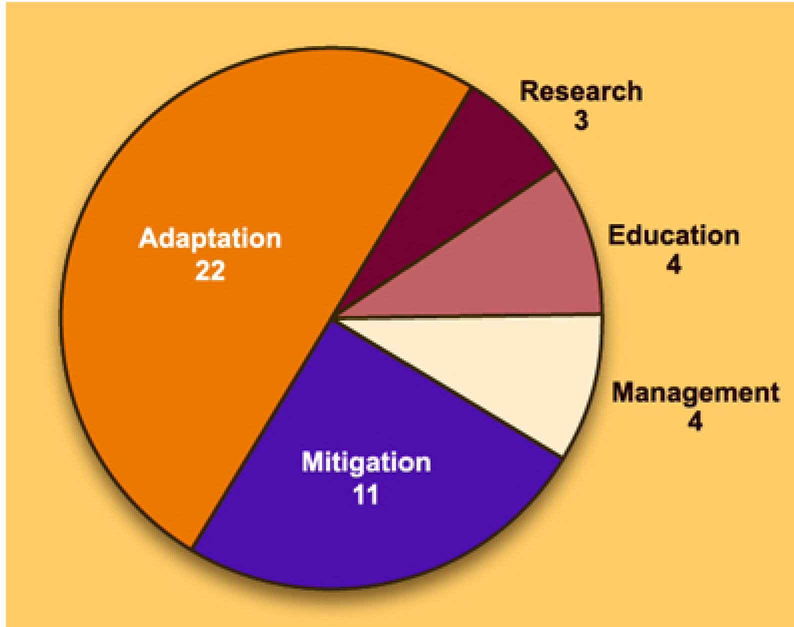


Figure 38. 44 Key Actions Support the five major goals of the National Water Program Strategy.

Goal 1: Greenhouse Gas Mitigation Strategies for Water Programs

Many of the actions that can help reduce greenhouse gas releases also help conserve scarce water supplies and help improve water quality. Some key actions related to mitigation identified in the strategy:

Water Conservation: Water conservation is a win-win-win situation—in many cases, a single program investment will have greenhouse gas, water supply and water quality benefits and will lead to economic savings and greater sustainability of water infrastructure.

By choosing energy- and water-efficient options, businesses and individuals can conserve water resources and reduce the amount of greenhouse gases that are emitted. Information on energy-efficient options is available from the ENERGY STAR Program (www.energystar.gov). Designed to save money and protect the environment through energy-efficient products and practices, the ENERGY STAR Program is a joint program between EPA and the U.S. Department of Energy. The WaterSense program (www.epa.gov/watersense), a partnership sponsored by EPA, promotes water-efficient products (Figure 39).

Figure 39. Energy Star Program (www.energystar.gov), WaterSense Program (www.epa.gov/watersense)

Energy Conservation at Water Facilities: Energy use by drinking water and wastewater facilities accounts for approximately 3 percent of U.S. energy consumption (EPRI, 1994), and these facilities are often the largest energy users in a municipality's budget. Drinking water and wastewater treatment facilities have the potential to achieve 15–30 percent energy savings (CEE, 2007, p.1) by implementing energy conservation measures alone, and even more with on-site energy generation.

Mitigation strategies:

- Water conservation
- Energy conservation at water facilities
- Energy generation at water facilities

Energy Generation at Water Facilities: Wastewater treatment facilities have opportunities to generate energy. For example, some facilities can capture methane and burn it to generate electricity.

Protect Underground Sources of Drinking Water from Geologic Carbon Sequestration: Geologic sequestration is one technology in a portfolio of options that could be effective in reducing CO_2 emissions to the atmosphere and stabilizing atmospheric concentrations of CO_2. The Underground Injection Control (UIC) Program under the Safe Drinking Water Act regulates injection of fluids, including solids, semi-solids, liquids and gases (such as CO_2) to protect underground sources of drinking water. UIC regulations address the siting, construction, operation and closure of wells that inject a wide variety of fluids, including those that are considered commodities or wastes. Proper operation of injection wells for sequestration projects is required under the Safe Drinking Water Act to safeguard underground sources of drinking water and protect public health.

Increase Green Infrastructure and Low Impact Development: Green infrastructure (Figure 40) describes an array of products, technologies and practices that use natural systems—or engineered systems that mimic natural processes—to enhance overall environmental quality and provide utility services. As a general principal, green infrastructure techniques use soils and vegetation to infiltrate, evapotranspirate or recycle stormwater runoff (Figure 40). To learn more about green infrastructure, visit www.epa.gov/ greeninfrastructure. Reducing stormwater runoff through the use of green infrastructure promotes the following:

Figure 40. Examples of green building and landscaping design: Green Infrastructure (www.epa.gov/greeninfrastructure) and Low Impact Development (www.epa.gov/owow/nps/lid).

- Ground water is naturally recharged

- Combined sewer overflow events are reduced
- Vegetation does not need to be watered as often
- Excessive stormwater is reduced and kept out of local waterways

Additional EPA Greenhouse Gas Mitigation Programs

Office of Air and Radiation

The Office of Air and Radiation (OAR) is leading EPA's greenhouse gas mitigation programs. OAR develops national programs, technical policies and regulations for controlling air pollution and radiation exposure.

In addition to various policy and regulatory efforts, OAR is taking steps to mitigate greenhouse gases through its voluntary programs:

- **ENERGY STAR Program:** certifies a range of products that meet energy efficiency standards that will reduce electricity use. www.energystar.gov
- **Methane:** capture and use methane from a range of sources including agriculture, landfills, natural gas production and distribution, and coal beds. www.epa.gov/methane
- **High Greenhouse Gas Potential:** partnerships between EPA and industries (such as primary aluminum smelters, electric power companies and magnesium smelters) to reduce the emission of high global warming potential gases including perfluorocarbons, hydrofluorocarbons and sulfur hexafluoride. www.epa.gov/highgwp
- Transportation Partnerships:
  – National Clean Diesel Campaign: provides grants to reduce diesel fuel emissions. www.epa.gov/otaq/diesel
  – SmartWay Transport Partnership: partnership with the freight industry to increase energy efficiency and security while reducing air pollution and greenhouse gases. www.epa.gov/smartway
  – Clean School Bus USA: retrofits and replaces older school buses to reduce bus idling. www.epa.gov/cleanschoolbus
  – Best Workplaces for Commuters: innovative solutions to commuting challenged. www.epa.gov/oms/bwc.htm
  – Climate Leaders: this EPA industry-government partnership works with companies to develop comprehensive climate change strategies. Partner companies commit to a corporate-wide inventory of their greenhouse gas emissions, set aggressive reduction goals and report their annual progress to EPA. Companies create a credible record of

EPA's Office of Air and Radiation
www.epa.gov/air
- Domestic and International Climate Change Policy
- Clean Air Act and Greenhouse Gases
- National Greenhouse Gas Inventory and Mandatory Reporting Rule
- Voluntary Programs

their accomplishments and receive EPA recognition as corporate environmental leaders. www.epa.gov/climateleaders

Goal 2: Adaptation Strategies for Water Programs

Adaptation of water programs to climate change will be a long process. The understanding of the impacts of climate change on water that is now emerging from scientific studies, however, provides a sufficient basis for defining an initial set of preliminary steps to adapt water programs to climate change. Key actions related to adaptation that EPA identified in the Strategy include 22 actions in the following areas:

- Drinking Water and Water Quality Standards
- Watershed Approach
- National Pollutant Discharge Elimination System (NPDES) Program
- Water Infrastructure
- Wetlands Protection

Office of Research and Development

The mission of EPA's Office of Research and Development's Global Change Research Program is to assess the impacts of global change—particularly climate variability and change—on air and water quality, ecosystems, human health, and socioeconomic systems in the United States and provide timely and useful information and decision-support tools to policy makers and resource managers to help them adapt to a changing climate (Figure 41).

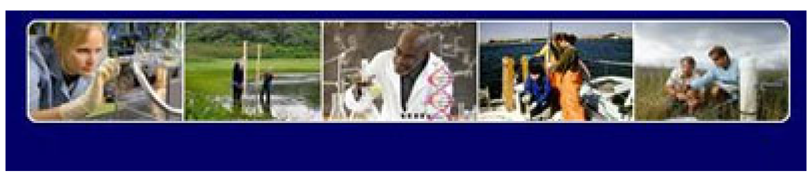


Figure 41. EPA's Office of Research and Development Global Change Research Program
www.epa.gov/ord/npd/globalresearch-intro.htm

The Global Change Research Program has two major areas of emphasis: air quality and water quality/aquatic ecosystems. The water quality/aquatic ecosystems emphasis area is working to assess the effects of global change on water quality and aquatic ecosystems in the United States. A major focus is on studying the sensitivity to climate change of goals articulated in the Clean Water Act and the Safe Drinking Water Act, and the opportunities available within the provisions of these acts to address the anticipated effects.

Specific research contributions addressing water resources include preventing combined sewer system overflows, assessing effects on water quality standards, and protecting drinking water systems from sea level rise. Research also is planned to evaluate the effects of global change on aquatic ecosystems, invasive nonindigenous species and ecosystem services.

Some examples of key actions in the Strategy related to adaptation include the following:

Develop Climate Ready Estuaries: The Climate Ready Estuaries program is a partnership between EPA and the National Estuary Programs to address climate change in coastal areas

(Figure 42). This effort is building additional capacity in coastal communities as they prepare to adapt to the effects of climate change (key action 22).

Develop Watershed Climate Change Policy: The Office of Water will develop a Climate Change Policy that promotes the incorporation of responses to climate change into watershed plans (key action 18).

Figure 42. Climate Ready Estuaries: www.epa.gov/cre

Evaluate Climate Impacts on Wet Weather Programs: EPA will work with states to assess how to address increases in precipitation due to climate change, including identifying best practices for characterizing future storms and promoting green infrastructure (key action 26).

Clarify Use of State Revolving Funds for Climate Change Projects: EPA will work with stakeholders to develop fact sheets describing how clean water and drinking water state revolving funds can be used for climate change related projects (key action 30).

Develop biological indicators and methods: EPA will work to improve the biological information base to better manage water resources in a changing climate, including developing guidance on coral reef bioassessments and biological criteria (key action 15).

Goal 3: Research Strategies for Water Programs

Research on climate change issues related to water is occurring both internationally and in the United States. Much of this research is being managed by federal agencies, including EPA. The National Water Program will benefit from much of the research now underway, and EPA will periodically revise this strategy to reflect emerging research. At the same time, the National Water Program will begin to play a larger role in defining research priorities and working with the research community to make research results as useful as possible and to communicate these findings to water program decisionmakers.

Four key research programs have been identified:

- Research projects (Figure 43) related to water now underway as part of the federal government interagency U.S. Global Change Research Program (USGCRP)
- Elements of EPA's Office of Research and Development Global Change Research Program that relate to water (all of which are consistent with the USGCRP Strategic Plan)
- Research projects underway in EPA's Office of Research and Development related to water quality, drinking water and ecosystems that relate to climate change

Figure 43. Carbon sequestration experiment with wetland grasses in Maryland.

- Research projects undertaken through industry partner associations, such as the Water Environment Research Foundation and the Water Research Foundation, to answer critical questions of utility managers

Research strategies:

- Monitor USGCRP reports
- Add climate change issues to water and drinking water research plans
- Add water-related issues in EPA climate change research plan development
- Communicate research results to water program decision makers

Goal 4: Education Strategies for Water Programs

EPA's fourth goal is to educate water program professionals and stakeholders on climate change impacts on water resources and programs. The following are among EPA's key actions to implement this goal:

Publish annual progress reports regarding the strategy implementation: Partners and stakeholders want to be informed of the progress in implementing the key actions identified in the strategy, as well as new actions as they develop. The annual reports will identify progress toward key goals identified in the strategy and identify best practices for addressing the water impacts of climate change. The final progress report for 2008 is available on the Office of Water Climate Change Web site (www.epa.gov/water/climatechange).

Visit EPA's Climate Change and Water Web sites: The Office of Water's water and climate change Web site (www.epa.gov/water/climatechange) is an important communication tool that provides basic information about the effects of climate change on water programs as well as copies of related materials and links to the EPA Climate Change Web site and other related sites (Figure 44). A LISTSERV provides periodic e-mail updates on climate change and water–related issues to subscribers. The Office of Air and Radiation's Climate Change Web site (www.epa.gov/climatechange) also includes information and suggestions of what individuals can do to decrease their greenhouse gas emissions.

Expand training programs: The National Water Program is now making an investment in training for water program professionals in the management, policy and technical challenges arising from the management of core clean water and safe drinking water programs. This training module is a product of this effort.

Goal 5: Management Strategies for Water Programs

EPA is also working to establish the management capability within the National Water Program to address climate change challenges on a sustained basis. The following are among EPA's key actions to implement the management goal:

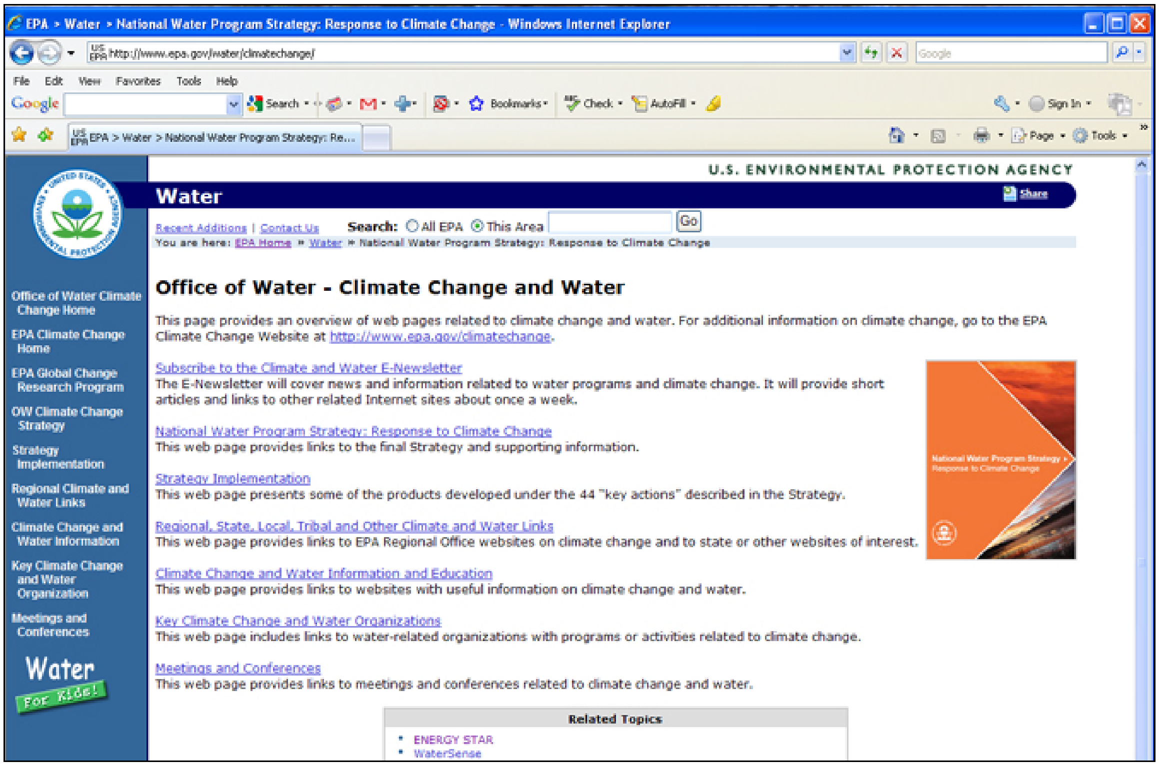


Figure 44. Office of Water—Climate Change and Water Web site www.epa.gov/water/climatechange

Integrate climate change into the EPA Strategic Plan and Annual National Water Program Guidance: As the National Water Program implements the Strategy, it is likely that issues with respect to coordinating this work with other program implementation work will arise. To address these issues, the National Water Program will integrate climate-related key actions with the established water program management tools, including EPA's Strategy and the Annual Water Program Guidance.

Support EPA Regions in water/climate change issues: EPA regional water program managers played a major role in developing the Strategy. In addition to supporting implementation of the Strategy's key actions, regions have initiated a variety of other projects addressing water and climate issues, giving special attention to water infrastructure issues.

Increase interagency coordination: The Office of Water has worked with other federal agencies to establish a Water/Climate Change Coordination Team including representatives from the U.S. Department of Agriculture, the

Figure 45. Water/Climate Change Coordination Team Members

National Oceanic and Atmospheric Administration, the U.S. Department of Interior, and the U.S. Army Corps of Engineers (Figure 45).

Where You Can Learn More About Addressing Water-Related Effects of Climate Change

- EPA's Climate Change Web site: www.epa.gov/climatechange
- Office of Water Climate Change Web site: www.epa.gov/water/climatechange
- ENERGY STAR: www.energystar.gov
- WaterSense: www.epa.gov/watersense
- Intergovernmental Panel on Climate Change (IPCC): www.ipcc.ch
- U.S. Global Change Research Program (USGCRP): www.globalchange.gov
- American Water Works Association—Climate Change and Water Resources, A Primer for Municipal Water Providers: http://apps.awwa.org/ebusmain/OnlineStore.aspx
- Water Environment Research Federation (WERF): www.werf.org/AM/Template.cfm?Section=Climate_Change
- Water Research Foundation (WRF): www.waterresearchfoundation.org/theFoundation/ourPrograms/ResearchProgramSIClimateChange.aspx
- National Academy of Sciences (NAS): http://americasclimatechoices.org/index.shtml

Case Studies

Many others are working on climate change issues in addition to EPA.

If you want to learn more about climate change and the steps that are being taken to protect water resources, visit these Web sites:

- Los Angeles, California (www.lacity.org/ead/environmental/ead_climate change.htm)
- Chicago Climate Action Plan (www.chicagoclimateaction.org)
- Seattle Green Factor (www.seattle.gov/dpd/Permits/GreenFactor/Overview)
- Water Utility Climate Alliance (www.wucaonline.org/html)
- Massachusetts Water Resources Authority (http://www.publicpolicy.umd.edu/faculty/ruth/CLIMB_exec_summ.pdf)
- King County, Washington (www.kingcounty.gov/exec/globalwarming.aspx)
- New York City, New York (www.nyc.gov/html/planyc2030/html/plan/climate.shtml)
- Keene, New Hampshire (www.ci.keene.nh.us/sustainability)

Self-Test

Click on the appropriate response to each question below. After you've completed the quiz, learn your score and compare your answers to the correct answers by clicking on the "Calculate Results" button at the end of the quiz.

1. What is the definition of climate?

☐ **A.** Climate is the average precipitation in an area.

☐ **B.** Climate is the average temperature of an area.

☐ **C.** Climate is the weather in an area averaged over an extended period of time.

☐ **D.** A and B

2. Temperature increases will not drive which of the following environmental changes?

☐ **A.** Average annual precipitation

☐ **B.** Ocean acidification

☐ **C.** Sea level rise

☐ **D.** Intensity of tropical storms and hurricanes

3. What are the principle human-generated greenhouse gasses?

☐ **A.** Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O).

☐ **B.** Fluorinated Gasses.

☐ **C.** Carbon Dioxide (CO_2) and Methane (CH_4) and Fluorinated Gasses.

☐ **D.** A and B

4. Warming in the United States is expected to exceed 2°C/3.6°F during this century.

☐ **T.** True

☐ **F.** False

5. Factors driving sea level rise include which of the following?

☐ **A.** Increasing storm intensity over the ocean.

☐ **B.** Destruction of wetlands, estuaries and other water-holding land types.

☐ **C.** Ocean water expansion caused by warmer ocean temperatures.

☐ **D.** Increasing rate of stormwater runoff in coastal areas.

6. Which of the following compounds needed by marine animals for shell building is depleted by ocean acidification?

- [ ] **A.** Carbon dioxide
- [ ] **B.** Calcium carbonate
- [ ] **C.** Carbonate ions
- [ ] **D.** Carbonic acid

7. What percentage of average U.S. energy consumption is used by drinking water and wastewater facilities?

- [ ] **A.** 0.65%
- [ ] **B.** 3%
- [ ] **C.** 10%
- [ ] **D.** 36%

8. Increased biofuel production is expected to affect the quality and quantity of water resources.

- [ ] **T.** True
- [ ] **F.** False

9. Which of the following is an EPA adaptation strategy for water programs?

- [ ] **A.** Provide climate change outreach to estuaries and recognize efforts of coastal watersheds to adapt to climate change.
- [ ] **B.** Develop biological indicators.
- [ ] **C.** Work with states to clarify the types of climate change-related infrastructure expenses that are eligible for State Revolving Fund assistance.
- [ ] **D.** Evaluate climate impacts on wet weather programs.
- [ ] **E.** All of the above.

10. Which of the following is not a greenhouse gas mitigation strategy for water programs?

- [ ] **A.** Energy generation at wastewater treatment facilities.
- [ ] **B.** Develop local watershed approaches for expected changes in water quantity and quality.
- [ ] **C.** Support and encouragement of green infrastructure and low impact development.
- [ ] **D.** Water conservation efforts supported by government programs.

Correct Answers to Self-Test

Q 1: C
Q 2: B
Q 3: D
Q 4: A
Q 5: C
Q 6: C
Q 7: B
Q 8: A
Q 9: B
Q 10: B

References Cited

1. EIA (Energy Information Administration). 2007. International Energy Outlook 2007 (May 2007). DOE/EIA-0484(2007). accessed August 31, 2009.

2. Burkett, V., J.O. Codignotto, D.L. Forbes, N. Mimura, R.J. Beamish, and V. Ittekkot. 2001. Coastal Zones and Marine Ecosystems. In IPCC. 2001. Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.)], accessed August 31, 2009.

3. CEE (Consortium for Energy Efficiency). 2007. Initiative Description: CEE National Municipal Water and Wastewater Facility Initiative, accessed August 31, 2009.

4. Denman, K.L., G. Brasseur, A. Chidthaisong, P. Ciais, P.M. Cox, R.E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S. Ramachandran, P. Leite da Silva Dias, S.C. Wofsy, and X. Zhang. 2007. Couplings Between Changes in the Climate System and Biogeochemistry (PDF). In IPCC. 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, accessed August 31, 2009.

5. EPA. 2008t. Climate Change Web Site. Climate Change – Science: Precipitation and Storm Changes, accessed August 31, 2009.

6. EPA. 2008u. Climate Change Web site. Climate Change—Science: Sea Level Changes, accessed August 31, 2009.

7. EPA. 2009b. High Global Warming Potential (GWP) Gases Web site. High Global Warming Potential (GWP) Gases – Science, accessed August 31, 2009.

8. EPA. 2009c. Methane Web site. Methane – Science. www.epa.gov/methane/scientific.html, accessed August 31, 2009.

9. EPRI (Electric Power Research Institute). 1994. Energy Audit Manual for Water/Wastewater Facilities: A Guide for Electric Utilities to Understanding Specific Unit Processes and Their Energy/Demand Relationships at Water and Wastewater Plants. CEC Report CR-104300. Electric Power Research Institute (EPRI), St. Louis, MO accessed August 31, 2009.

10. Greenwire—Land Letter. Friday, November 21, 2008. Water woes create hurdle for Western carbon-capture projects. Washington, DC, accessed August 31, 2009.

11. IPCC. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability.

12. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1032pp, accessed August 31, 2009.

13. IPCC. 2005. IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change. [Metz, B., O. Davidson, H. de Coninck, M. Loos, and L. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, accessed August 31, 2009.

14. IPCC. 2007a. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, Martin L., Canziani, Osvaldo F., Palutikof, Jean P., van der Linden, Paul J., and Hanson, Clair E. (eds.)]. Cambridge University Press, Cambridge, United Kingdom, 1000 pp, accessed August 31, 2009.

15. IPCC. 2007b. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core writing team: Pachauri, R.K, and A. Reisinger (eds.)]. IPCC, Geneva, Switzerland, p. 30, accessed August 31, 2009.

16. IPCC. 2007c. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, and M. Manning (eds.)], accessed August 31, 2009.

17. IPCC. 2007d. Summary for Policymakers. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, accessed August 31, 2009.

18. IPCC. 2008a. Climate Change and Water. IPCC Technical Paper IV, accessed August 31, 2009.

19. NASA Earth Observatory, based on IPCC Fourth Assessment Report (2007), accessed August 31, 2009.

20. NCDC (National Climatic Data Center). 2008. Climate of 2007 – in Historical Perspective Annual Report, accessed August 31, 2009.

21. NOAA. 2006. NOAA Magazine. NOAA Reports 2006 Marked by Severe Heat Waves, Widespread Drought, Wildfires. December 14, 2006. www.noaanews.noaa.gov/stories2006 / s2759.htm, accessed August 31, 2009.

22. WMO. 2006. Statement on Tropical Cyclones and Climate Change, accessed August 31, 2009.

Photo Credits:

Appreciation is expressed for the use of figures and photos from the following sources:

Figure 2: EPA. 2008q. Climate Change Web site. Climate Change—Science. accessed August 31, 2009.

Figure 3: NOAA. 2008. NOAA Earth System Research Laboratory Web site, accessed August 30, 2009.

Figure 4: EIA (Energy Information Administration). 2007. International Energy Outlook 2007 (May 2007). DOE/EIA-0484(2007). accessed August 31, 2009.

Figure 5: EPA. 2009e. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007 (April 2009) USEPA #430-R-09-004, accessed August 31, 2009.

Figure 6: NOAA - National Climatic Data Center - NOAA Environmental Satellite, Data, and Information Service. 2009. Climate of 2008 Annual Report - January 14, 2009, accessed August 31, 2009.

Figure 7: NOAA. 2007. Geophysical Fluid Dynamics Laboratory Climate Modeling Research Highlights. www.gfdl.noaa.gov/research/climate/highlights/PDF/GFDLhighlight_Vol1N6.pdf, accessed August 31, 2009.

Figure 8: NASA Earth Observatory, based on IPCC Fourth Assessment Report (2007), accessed August 31, 2009.

Figure 9: NOAA. 2007. Geophysical Fluid Dynamics Laboratory Climate Modeling Research Highlights, accessed August 31, 2009.

Figure 11: California Department of Water Resources. June 2007. Climate Change in California Fact Sheet, accessed August 31, 2009.

Figure 12: NASA Earth Observatory, based on IPCC Fourth Assessment Report (2007), accessed August 31, 2009.

Figure 13: NOAA/NESDIS/NCDC, as found in EPA. 2008v. Climate Change Web site. Climate Change—Science: Temperature Changes, accessed August 31, 2009.

Figure 17: EPA. 2008cc. National Water Program Strategy: Response to Climate Change. EPA 800-R-08-001, accessed August 31, 2009.

Figure 19: NOAA/NESDIS/NCDC, as found in EPA. 2008t. Climate Change Web Site. Climate Change—Science: Precipitation and Storm Changes, accessed August 31, 2009.

Figure 21: EPA. 2008cc. National Water Program Strategy: Response to Climate Change. EPA 800-R-08-001, accessed August 31, 2009.

Figure 23: Louisiana Department of Environmental Quality.

Figure 24: EPA. 2008cc. National Water Program Strategy: Response to Climate Change. EPA 800-R-08-001, accessed August 31, 2009.

Figure 25: Monthly and Annual Mean Sea Level Station Files from the Permanent Service for Mean Sea Level (PSMSL) at the Proudman Oceanographic Laboratory as found in EPA. 2008u. Climate Change Web site. Climate Change—Science: Sea Level Changes, accessed August 31, 2009.

Figure 26: Titus, J.G. and C. Richman. 2000. Maps of Lands Vulnerable to Sea Level Rise as found in EPA. 2008u. Climate Change Web site. Climate Change—Science: Sea Level Changes, accessed August 31, 2009.

Figure 27: EPA. 2008cc. National Water Program Strategy: Response to Climate Change. EPA 800-R-08-001, accessed August 31, 2009.

Figure 30: EPA. 2008cc. National Water Program Strategy: Response to Climate Change. EPA 800-R-08-001, accessed August 31, 2009.

Figure 35: EPA. 2008cc. National Water Program Strategy: Response to Climate Change. EPA 800-R-08-001, accessed August 31, 2009.