

Water Resources

Key Messages:

- Climate change has already altered, and will continue to alter, the water cycle, affecting where, when, and how much water is available for all uses.
- Floods and droughts are likely to become more common and more intense as regional and seasonal precipitation patterns change, and rainfall becomes more concentrated into heavy events (with longer, hotter dry periods in between).
- Precipitation and runoff are likely to increase in the Northeast and Midwest in winter and spring, and decrease in the West, especially the Southwest, in spring and summer.
- In areas where snowpack dominates, the timing of runoff will continue to shift to earlier in the spring and flows will be lower in late summer.
- Surface water quality and groundwater quantity will be affected by a changing climate.
- Climate change will place additional burdens on already stressed water systems.
- The past century is no longer a reasonable guide to the future for water management.

Key Sources

CCSP 3.3	CCSP 3.4	CCSP 4.3	CCSP 4.5	CCSP 4.6	CCSP 4.7
Extremes	Abrupt Climate Change	Impacts	Energy	Health	Transportation
CCSP 5.1	CCSP 5.2	IPCC WG-1	IPCC WG-2	IPCC Water	
Data Uses & Limitations	Uncertainty				

Changes in the water cycle, which are consistent with the warming observed over the past several decades, include:

- changes in precipitation patterns and intensity
- changes in the incidence of drought
- widespread melting of snow and ice
- increasing atmospheric water vapor
- increasing evaporation
- increasing water temperatures
- reductions in lake and river ice
- changes in soil moisture and runoff

For the future, marked regional differences are projected, with increases in annual precipitation, runoff, and soil moisture in much of the Midwest and Northeast, and declines in much of the West, especially the Southwest.



Skagit River and surrounding mountains in the Northwest

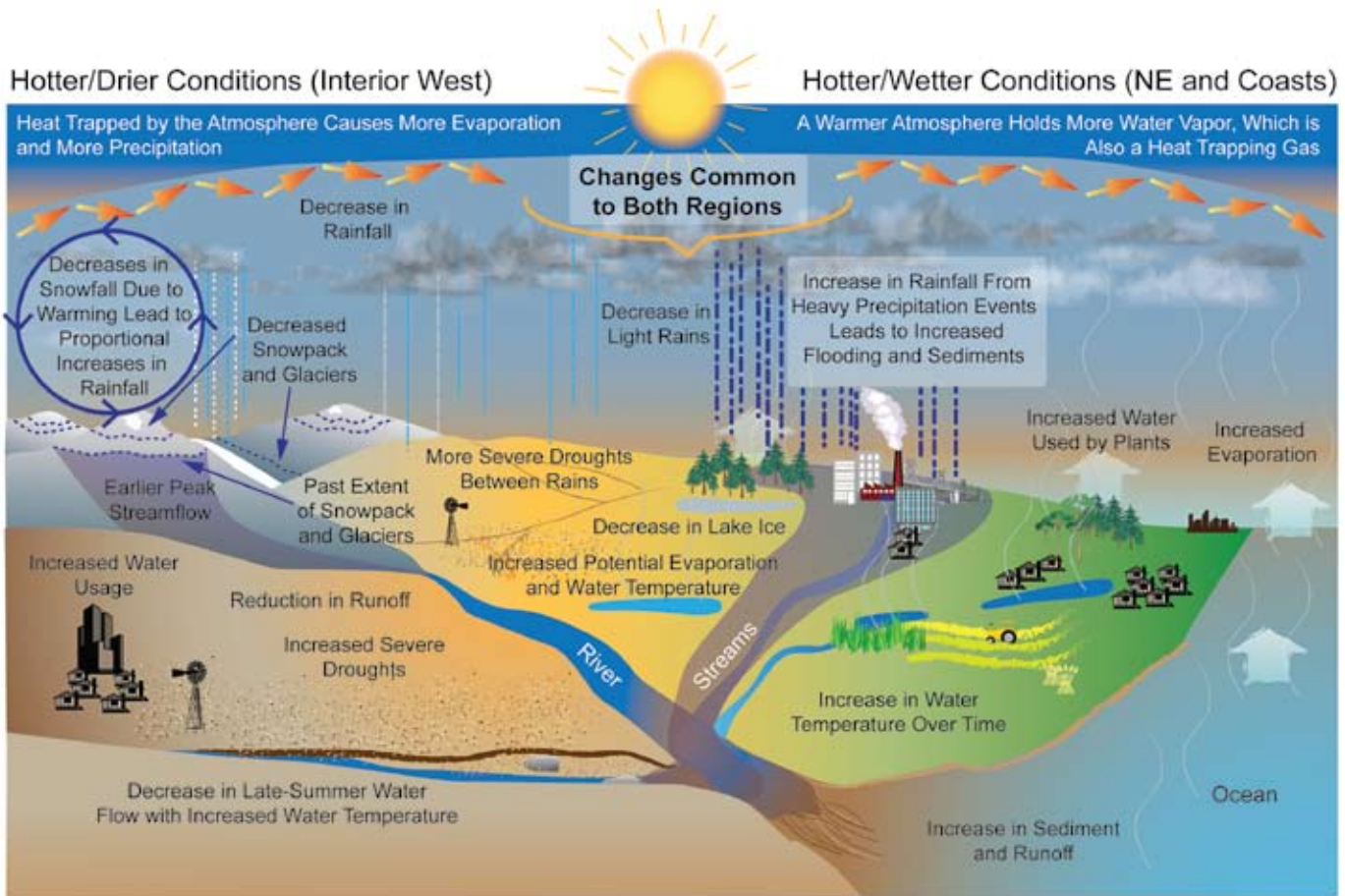
The impacts of climate change include too little water in some places, too much water in other places, and degraded water quality. Some locations are expected to be subject to all of these conditions during different times of the year. Water cycle changes are expected to continue and to adversely affect energy production and use, human health, transportation, agriculture, and ecosystems (see table on page 50).¹⁴²

Climate change has already altered, and will continue to alter, the water cycle, affecting where, when, and how much water is available for all uses.

Substantial changes to the water cycle are expected as the planet warms because the movement of water in the atmosphere and oceans is one of the primary mechanisms for the redistribution of heat around the world. Evidence is mounting that human-induced climate change is already altering many of the existing patterns of precipitation in the United States, including when, where, how much, and what kind of precipitation falls.^{68,142} A warmer climate increases evaporation of water from land and sea, and allows more moisture to be held in the atmosphere. For every 1°F rise in temperature, the water holding capacity of the atmosphere increases by about 4 percent.⁴⁹



Projected Changes in the Water Cycle

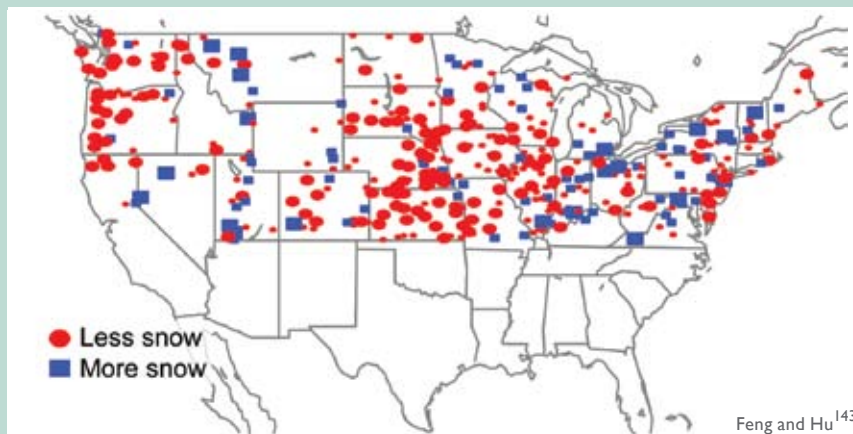


NOAA/NCDC

The water cycle exhibits many changes as the Earth warms. Wet and dry areas respond differently.

In addition, changes in atmospheric circulation will tend to move storm tracks northward with the result that dry areas will become drier and wet areas wetter. Hence, the arid Southwest is projected to experience longer and more severe droughts from the combination of increased evaporation and reductions in precipitation.¹⁰⁸

Changes in Snowfall Contributions to Wintertime Precipitation 1949 to 2005



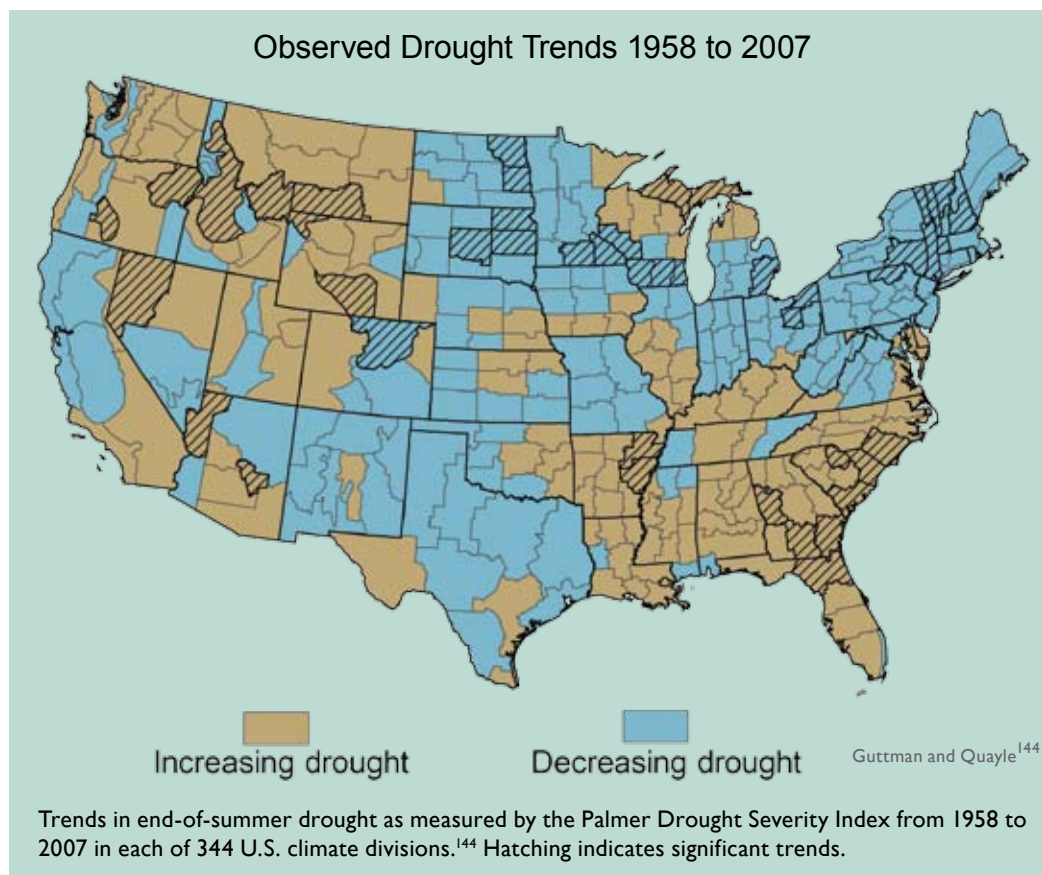
Trends in winter snow-to-total precipitation ratio from 1949 to 2005. Red circles indicate less snow, while blue squares indicate more snow. Large circles and squares indicate the most significant trends.¹⁴³ Areas south of 37°N latitude were excluded from the analysis because most of that area receives little snowfall. White areas above that line have inadequate data for this analysis.

The additional atmospheric moisture contributes to more overall precipitation in some areas, especially in much of the Northeast, Midwest, and Alaska. Over the past 50 years, precipitation and streamflow have increased in much of the Northeast and Midwest, with a reduction in drought duration and severity. Much of the Southeast and West has had reductions in precipitation and increases in drought severity and duration, especially in the Southwest.

In most areas of the country, the fraction of precipitation falling as rain versus snow has increased during the last 50 years. Despite this general shift from snow to rain, snowfalls

Observed Water-Related Changes During the Last Century¹⁴²

Observed Change	Direction of Change	Region Affected
One to four week earlier peak streamflow due to earlier warming-driven snowmelt	Earlier	West and Northeast
Proportion of precipitation falling as snow	Decreasing	West and Northeast
Duration and extent of snow cover	Decreasing	Most of the United States
Mountain snow water equivalent	Decreasing	West
Annual precipitation	Increasing	Most of the United States
Annual precipitation	Decreasing	Southwest
Frequency of heavy precipitation events	Increasing	Most of the United States
Runoff and streamflow	Decreasing	Colorado and Columbia River Basins
Streamflow	Increasing	Most of East
Amount of ice in mountain glaciers	Decreasing	U.S. western mountains, Alaska
Water temperature of lakes and streams	Increasing	Most of the United States
Ice cover on lakes and rivers	Decreasing	Great Lakes and Northeast
Periods of drought	Increasing	Parts of West and East
Salinization of surface waters	Increasing	Florida, Louisiana
Widespread thawing of permafrost	Increasing	Alaska



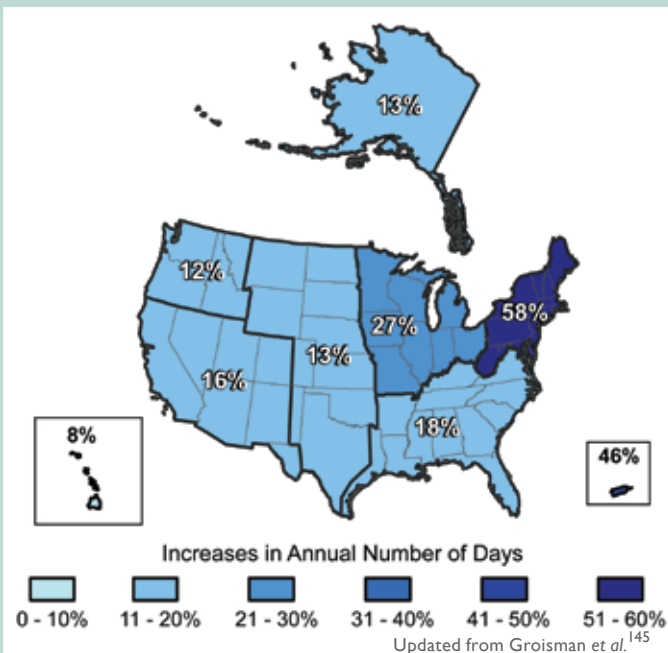
along the downwind coasts of the Great Lakes have increased. Factors contributing to this increase include reduced ice cover due to warming, which lengthens the period of open water. In addition, cold air moving over relatively warm, open lake water induces strong evaporation, often causing heavy lake-effect snow. Heavy snowfall and snowstorm frequency have increased in many northern parts of the United States. In the South however, where temperatures are already marginal for heavy snowfall, climate warming has led to a reduction in heavy snowfall and snowstorm frequency. These trends suggest a northward shift in snowstorm occurrence.⁶⁸

Floods and droughts are likely to become more common and more intense as regional and seasonal precipitation patterns change, and rainfall becomes more concentrated into heavy events (with longer, hotter dry periods in between).

While it sounds counterintuitive, a warmer world produces both wetter and drier conditions. Even though total global precipitation increases, the regional and seasonal distribution of precipitation changes, and more precipitation comes in heavier rains (which can cause flooding) rather than light events. In the past century, averaged over the United States, total precipitation has increased by about 7 percent, while the heaviest 1 percent of rain events increased by nearly 20 percent.⁶⁸ This has been especially noteworthy in the Northeast, where the annual number of days with very heavy precipitation has increased most in the past 50 years, as shown in the adjacent figure. Flooding often occurs when heavy precipitation persists for weeks to months in large river basins. Such extended periods of heavy precipitation have also been increasing over the past century, most notably in the past two to three decades in the United States.¹¹²

Observations also show that over the past several decades, extended dry periods have become more frequent in parts of the United States, especially the Southwest and the eastern United States.^{146,147} Longer periods between rainfalls, combined with

Increases in the Number of Days with Very Heavy Precipitation (1958 to 2007)



The map shows the percentage increases in the average number of days with very heavy precipitation (defined as the heaviest 1 percent of all events) from 1958 to 2007 for each region. There are clear trends toward more days with very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

higher air temperatures, dry out soils and vegetation, causing drought.

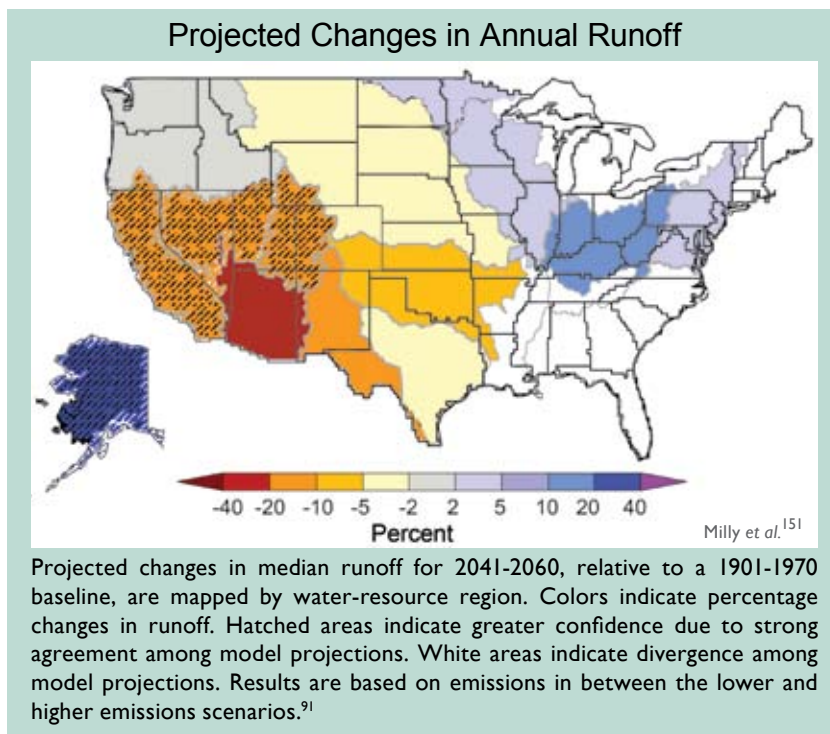
For the future, precipitation intensity is projected to increase everywhere, with the largest increases occurring in areas in which average precipitation increases the most. For example, the Midwest and Northeast, where total precipitation is expected to increase the most, would also experience the largest increases in heavy precipitation events. The number of dry days between precipitation events is also projected to increase, especially in the more arid areas. Mid-continental areas and the Southwest are particularly threatened by future drought. The magnitude of the projected changes in extremes is expected to be greater than changes in averages, and hence detectable sooner.^{49,68,90,142,148}

Precipitation and runoff are likely to increase in the Northeast and Midwest in winter and spring, and decrease in the West, especially the Southwest, in spring and summer.

Runoff, which accumulates as streamflow, is the amount of precipitation that is not evaporated, stored as snowpack or soil moisture, or filtered down to groundwater. The proportion of precipitation that runs off is determined by a variety of factors including temperature, wind speed, humidity, solar intensity at the ground, vegetation, and soil moisture. While runoff generally tracks precipitation, increases and decreases in precipitation do not necessarily lead to equal increases and decreases in runoff. For example, droughts cause soil moisture reductions that can reduce expected runoff until soil moisture is replenished. Conversely, water-saturated soils can generate floods with only moderate additional precipitation. During the last century, consistent increases in precipitation have been found in the Midwest and Northeast along with increased runoff.^{149,150} Climate models consistently project that the East will experience increased runoff, while there will be substantial declines in the interior West, especially the Southwest. Projections for runoff in California and other parts of the West also show reductions, although less than in the interior West. In short, wet areas are projected to get wetter and dry areas drier. Climate models also consistently project heat-related summer soil moisture reductions in the middle of the continent.^{115,142,146,149}

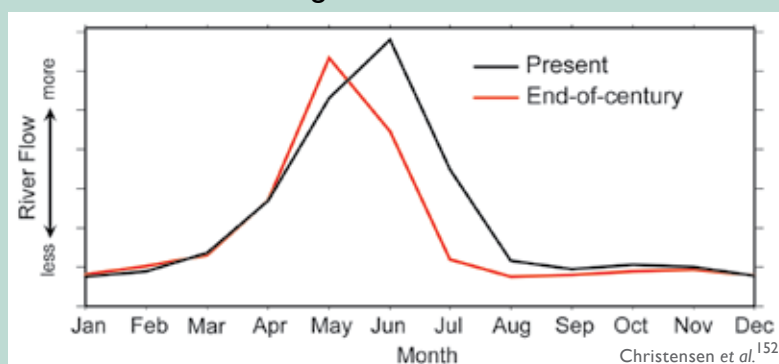
In areas where snowpack dominates, the timing of runoff will continue to shift to earlier in the spring and flows will be lower in late summer.

Large portions of the West and some areas in the Northeast rely on snowpack as a natural reservoir to hold winter precipitation until it later runs off as streamflow in spring, summer, and fall. Over the last 50



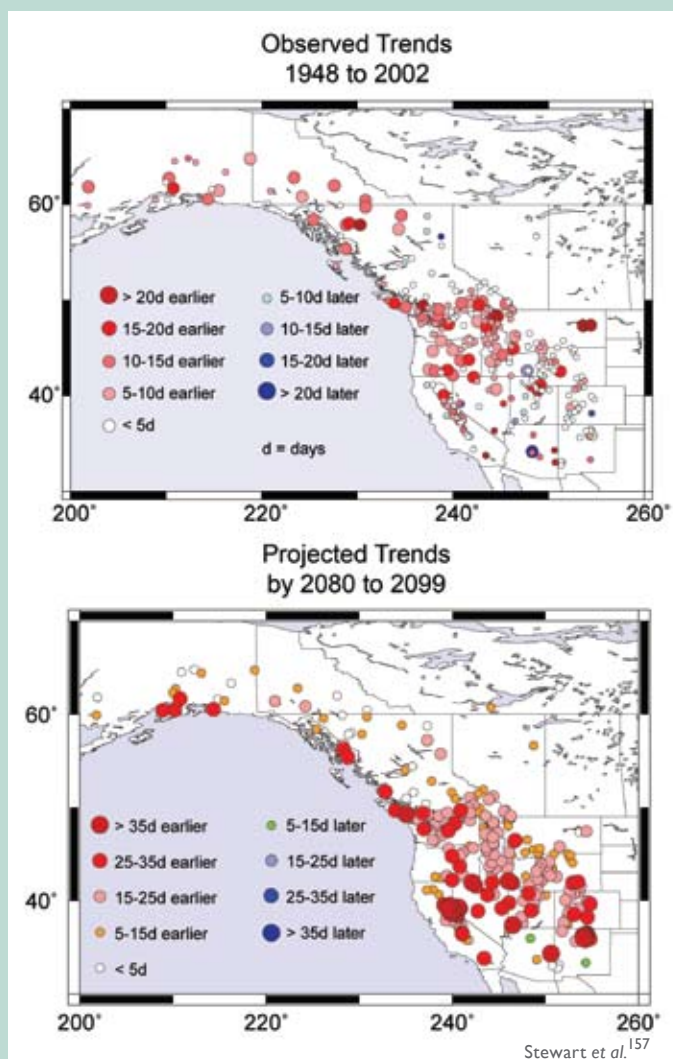
years, there have been widespread temperature-related reductions in snowpack in the West, with the largest reductions occurring in lower elevation mountains in the Northwest and California where snowfall occurs at temperatures close to the freezing point.^{142,153} The Northeast has also experienced snowpack reductions during a similar period. Observations indicate a transition to more rain and less snow in both the West and Northeast in the last 50 years.^{143,154-156} Runoff in snowmelt-dominated areas is occurring up to 20 days earlier in the West, and up to 14 days earlier in the Northeast.^{157,158} Future projections for most snowmelt-dominated basins in the West consistently indicate earlier spring

Simulated Changes in Annual Runoff Pattern



General schematic of changes in the annual pattern of runoff for snowmelt-dominated streams. Compared to the historical pattern, runoff peak is projected to shift to earlier in the spring and late summer flows are expected to be lower. The above example is for the Green River, which is part of the Colorado River watershed.

Trends in Peak Streamflow Timing



Top map shows changes in runoff timing in snowmelt-driven streams from 1948 to 2002 with red circles indicating earlier runoff, and blue circles indicating later runoff. Bottom map shows projected changes in snowmelt-driven streams by 2080-2099, compared to 1951-1980, under a higher emissions scenario.⁹¹

runoff, in some cases up to 60 days earlier.^{157,159} For the Northeast, projections indicate spring runoff will advance by up to 14 days.¹⁵⁰ Earlier runoff produces lower late-summer streamflows, which stress human and environmental systems through less water availability and higher water temperatures.¹⁴⁵ Scientific analyses to determine the causes of recent changes in snowpack, runoff timing, and increased winter temperatures have attributed these changes to human-caused climate change.^{34,160,161}

Surface water quality and groundwater quantity will be affected by a changing climate.

Changes in water quality

Increased air temperatures lead to higher water temperatures, which have already been detected in many streams, especially during low-flow periods. In lakes and reservoirs, higher water temperatures lead to longer periods of summer stratification (when surface and bottom waters do not mix). Dissolved oxygen is reduced in lakes, reservoirs, and rivers at higher temperatures. Oxygen is an essential resource for many living things, and its availability is reduced at higher temperatures both because the amount that can be dissolved in water is lower and because respiration rates of living things are higher. Low oxygen stresses aquatic animals such as coldwater fish and the insects and crustaceans on which they feed.¹⁴² Lower oxygen levels also decrease the self-purification capabilities of rivers.

The negative effects of water pollution, including sediments, nitrogen from agriculture, disease pathogens, pesticides, herbicides, salt, and thermal pollution, will be amplified by observed and projected increases in precipitation intensity and longer periods when streamflows are low.¹⁴⁶ The U.S. Environmental Protection Agency expects the number of waterways considered “impaired” by water pollution to increase.¹⁶² Heavy downpours lead to increased sediment in runoff and outbreaks of waterborne diseases.^{163,164} Increases in pollution carried to lakes, estuaries, and the coastal ocean, especially when coupled with increased temperature, can result in blooms of harmful algae and bacteria. However, pollution has the potential of being diluted in regions that experience increased streamflow.

Water-quality changes during the last century were probably due to causes other than climate change, primarily changes in pollutants.¹⁴⁹

Changes in groundwater

Many parts of the United States are heavily dependent on groundwater for drinking, residential, and agricultural water supplies.¹⁶⁴ How climate change will affect groundwater is not well known,



Heavy rain can cause sediments to become suspended in water, reducing its quality, as seen in the brown swath above in New York City's Ashokan reservoir following Hurricane Floyd in September 1999.

but increased water demands by society in regions that already rely on groundwater will clearly stress this resource, which is often drawn down faster than it can be recharged.¹⁶⁴ In many locations, groundwater is closely connected to surface water and thus trends in surface water supplies over time affect groundwater. Changes in the water cycle that reduce precipitation or increase evaporation and runoff would reduce the amount of water available for recharge. Changes in vegetation and soils that occur as temperature changes or due to fire or pest outbreaks are also likely to affect recharge by altering evaporation and infiltration rates. More frequent and larger floods are likely to increase groundwater recharge in semi-arid and arid areas,

where most recharge occurs through dry streambeds after heavy rainfalls and floods.¹⁴²

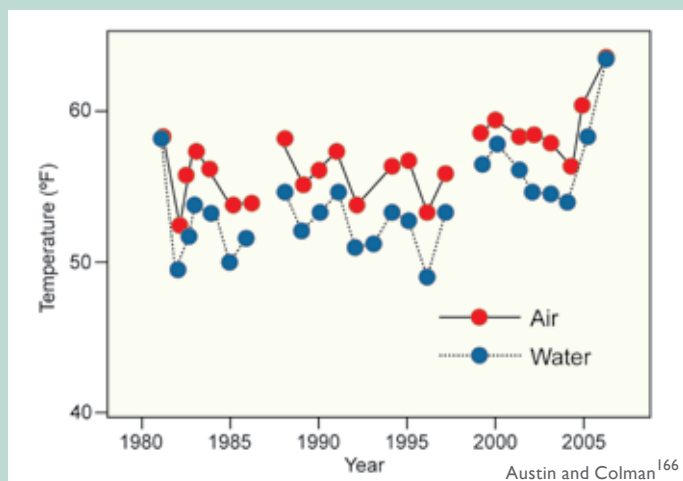
Sea-level rise is expected to increase saltwater intrusion into coastal freshwater aquifers, making some unusable without desalination.¹⁴⁶ Increased evaporation or reduced recharge into coastal aquifers exacerbates saltwater intrusion. Shallow groundwater aquifers that exchange water with streams are likely to be the most sensitive part of the groundwater system to climate change. Small reductions in groundwater levels can lead to large reductions in streamflow and increases in groundwater levels can increase streamflow.¹⁶⁵ Further, the interface between streams and groundwater is an important site for pollution removal by microorganisms. Their activity will change in response to increased temperature and increased or decreased streamflow as climate changes, and this will affect water quality. Like water quality, research on the impacts of climate change on groundwater has been minimal.¹⁴⁹

Climate change will place additional burdens on already stressed water systems.

In many places, the nation's water systems are already taxed due to aging infrastructure, population increases, and competition among water needs for farming, municipalities, hydropower, recreation, and ecosystems.¹⁶⁷⁻¹⁶⁹ Climate change will add another factor to existing water management challenges, thus increasing vulnerability.¹⁷⁰ The U.S. Bureau of Reclamation has identified many areas in the West that are already at risk for serious conflict over water, even in the absence of climate change¹⁷¹ (see figure next page).

Adapting to gradual changes, such as changes in average amounts of precipitation, is less difficult than adapting to changes in extremes. Where extreme events, such as droughts or floods, become more intense or more frequent with climate change, the economic and social costs of these events will increase.¹⁷² Water systems have life spans of many years and are designed with spare

Lake Superior Summer Air and Water Temperatures 1979 to 2006



The recent large jump in summer water temperature is related to the recent large reduction in ice cover (see *Midwest* region).

capacity. These systems are thus able to cope with small changes in average conditions.¹⁷² Water resource planning today considers a broad range of stresses and hence adaptation to climate change will be one factor among many in deciding what actions will be taken to minimize vulnerability.¹⁷²⁻¹⁷⁴

Rapid regional population growth

The U.S. population is estimated to have grown to more than 300 million people, nearly a 7 percent increase since the 2000 Census. Current Census Bureau projections are for this growth rate to continue, with the national population projected to reach 350 million by 2025 and 420 million by 2050. The highest rates of population growth to 2025 are projected to occur in areas such as the Southwest that are at risk for reductions in water supplies due to climate change.¹⁶⁷

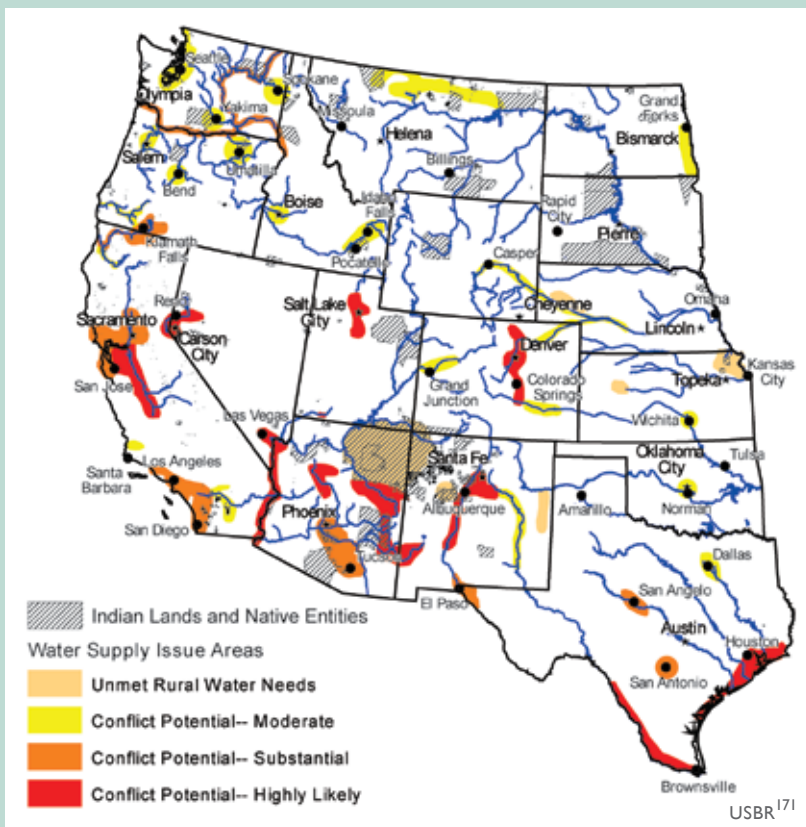
Aging water infrastructure

The nation’s drinking water and wastewater infrastructure is aging. In older cities, some buried water mains are over 100 years old and breaks of these lines are a significant problem. Sewer overflows resulting in the discharge of untreated wastewater also occur frequently. Heavier downpours will exacerbate existing problems in many cities, especially where stormwater catchments and sewers are combined. Drinking water and sewer infrastructure is very expensive to install and maintain. Climate change will present a new set of challenges for designing upgrades to the nation’s water delivery and sewage removal infrastructure.¹⁶⁸



Damage to the city water system in Asheville, North Carolina, due to heavy rain in 2004.

Potential Water Supply Conflicts by 2025



The map shows regions in the West where water supply conflicts are likely to occur by 2025 based on a combination of factors including population trends and potential endangered species’ needs for water. The red zones are where the conflicts are most likely to occur. This analysis does not factor in the effects of climate change, which is expected to exacerbate many of these already-identified issues.¹⁷¹

Existing water disputes across the country

Many locations in the United States are already undergoing water stress. The Great Lakes states are establishing an interstate compact to protect against reductions in lake levels and potential water exports. Georgia, Alabama, and Florida are in a dispute over water for drinking, recreation, farming, environmental purposes, and hydropower in the Apalachicola–Chattahoochee–Flint River system.^{175,176}

The State Water Project in California is facing a variety of problems in the Sacramento Delta, including endangered species, saltwater intrusion, and potential loss of islands due to flood- or earthquake-caused levee failures.¹⁷⁷⁻¹⁸² A dispute over endangered fish in the Rio Grande has been ongoing for many years.¹⁸³ The Klamath River in Oregon and California has been the location of a multi-year disagreement over native fish, hydropower, and farming.^{184,185} The Colorado River has been the site of numerous interstate quarrels over the last century.^{186,187} Large, unquantified Native

American water rights challenge existing uses in the West (see *Southwest region*).¹⁸⁸ By changing the existing patterns of precipitation and runoff, climate change will add another stress to existing problems.

Changing water demands

Water demands are expected to change with increased temperatures. Evaporation is projected to increase over most of the United States as temperatures rise. Higher temperatures and longer dry periods are expected to lead to increased water demand for irrigation. This may be partially offset by more efficient use of water by plants due to rising atmospheric carbon dioxide. Higher temperatures are projected to increase cooling water withdrawals by electrical generating stations. In addition, greater cooling requirements in summer will increase electricity use, which in turn will require more cooling water for power plants. Industrial and municipal demands are expected to increase slightly.¹⁴⁶

The past century is no longer a reasonable guide to the future for water management.

Water planning and management have been based on historical fluctuations in records of stream flows, lake levels, precipitation, temperature, and water demands. All aspects of water management including reservoir sizing, reservoir flood operations, maximum urban stormwater runoff amounts, and projected water demands have been based on these records. Water managers have proven adept at balancing supplies and demand through the significant climate variability of the past century.¹⁴² Because climate change will significantly modify many aspects of the water cycle, the assumption of an unchanging climate is no longer appropriate for many aspects of water planning. Past assumptions derived from the historical record about supply and demand will need to be revisited for existing and proposed water projects.^{142,151,174}

Drought studies that consider the past 1,200 years indicate that in the West, the last

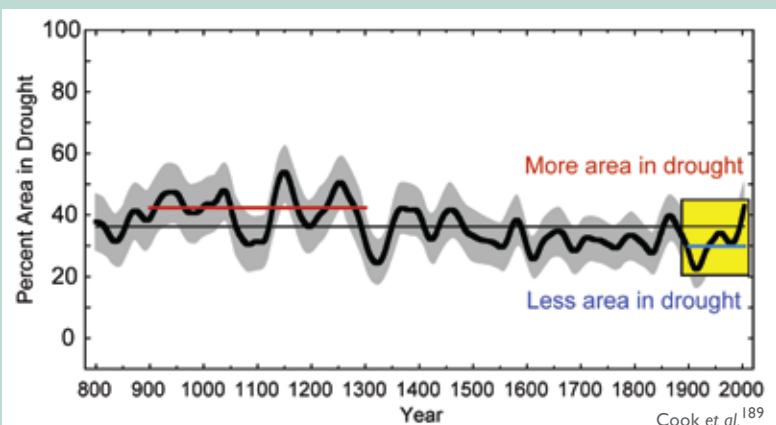
century was significantly wetter than most other centuries. Multi-decade “megadroughts” in the years 900 to 1300 were substantially worse than the worst droughts of the last century, including the Dust Bowl era. The causes of these events are only partially known; if they were to reoccur, they would clearly stress water management, even in the absence of climate change (see figure below).^{97,149,189}

The intersection of substantial changes in the water cycle with multiple stresses such as population growth and competition for water supplies means that water planning will be doubly challenging. The ability to modify operational rules and water allocations is likely to be critical for the protection of infrastructure, for public safety, to ensure reliability of water delivery, and to protect the environment. There are, however, many institutional and legal barriers to such changes in both the short and long term.¹⁹⁰ Four examples:

- The allocation of the water in many interstate rivers is governed by compacts, international treaties, federal laws, court decrees, and other agreements that are difficult to modify.
- Reservoir operations are governed by “rule curves” that require a certain amount of space to be saved in a reservoir at certain times of



Long-Term Aridity Changes in the West



The black line shows the percentage of the area affected by drought (Palmer Drought Severity Index less than -1) in the West over the past 1,200 years. The red line indicates the average drought area in the years 900 to 1300. The blue horizontal line in the yellow box indicates the average during the period from 1900 to 2000, illustrating that the most recent period, during which population and water infrastructure grew rapidly in the West, was wetter than the long-term average (thin horizontal black line).¹⁸⁹ Droughts shown in the period 1100-1300 significantly exceed those that have occurred over the past 100 years.

year to capture a potential flood. Developed by the U.S. Army Corps of Engineers based on historical flood data, many of these rule curves have never been modified, and modifications might require Environmental Impact Statements.¹⁵¹

- In most parts of the West, water is allocated based on a “first in time means first in right” system, and because agriculture was developed before cities were established, large volumes of water typically are allocated to agriculture. Transferring agricultural rights to municipalities, even for short periods during drought, can involve substantial expense and time and can be socially divisive.

- Conserving water does not necessarily lead to a right to that saved water, thus creating a disincentive for conservation.

Total U.S. water diversions peaked in the 1980s, which implies that expanding supplies in many areas to meet new needs are unlikely to be a viable option, especially in arid areas likely to experience less precipitation. However, over the last 30 years, per capita water use has decreased significantly (due, for example, to more efficient technologies such as drip irrigation) and it is anticipated that per capita use will continue to decrease, thus easing stress.¹⁴⁹



Highlights of Water-Related Impacts by Sector	
Sector	Examples of Impacts
Human Health	Heavy downpours increase incidence of waterborne disease and floods, resulting in potential hazards to human life and health. ¹⁶³
Energy Supply and Use	Hydropower production is reduced due to low flows in some regions. Power generation is reduced in fossil fuel and nuclear plants due to increased water temperatures and reduced cooling water availability. ¹⁹¹
Transportation	Floods and droughts disrupt transportation. Heavy downpours affect harbor infrastructure and inland waterways. Declining Great Lakes levels reduce freight capacity. ¹⁹²
Agriculture and Forests	Intense precipitation can delay spring planting and damage crops. Earlier spring snowmelt leads to increased number of forest fires. ¹⁹³
Ecosystems	Coldwater fish threatened by rising water temperatures. Some warmwater fish will expand ranges. ⁷⁰

Adaptation: New York City Begins Planning for Climate Change

The New York City Department of Environmental Protection (DEP), the agency in charge of providing the city’s drinking water and wastewater treatment, is beginning to alter its planning to take into account the effects of climate change – sea-level rise, higher temperatures, increases in extreme events, and changing precipitation patterns – on the city’s water systems. In partnership with Columbia University, DEP is evaluating climate change projections, impacts, indicators, and adaptation and mitigation strategies.

City planners have begun to address these issues by defining risks using probabilistic climate scenarios and considering potential adaptations that relate to operations/management, infrastructure, and policy. For example, DEP is examining the feasibility of relocating critical control systems to higher floors in low-lying buildings or to higher ground, building flood walls, and modifying design criteria to reflect changing hydrologic processes.

Important near-term goals of the overall effort include updating the existing 100-year flood elevations using climate model projections and identifying additional monitoring stations needed to track changes. DEP will also establish a system for reporting the impacts of extreme weather events on the City’s watershed and infrastructure. In the immediate future, DEP will evaluate flood protection measures for three existing water pollution control plants that are scheduled for renovation.¹⁹⁴

Spotlight on the Colorado River



The Colorado River system supplies water to over 30 million people in the Southwest including Los Angeles, Phoenix, Las Vegas, and Denver. Reservoirs in the system, including the giant lakes Mead and Powell, were nearly full in 1999, with almost four times the annual flow of the river stored. By 2007, the system had lost approximately half of that storage after enduring the worst drought in 100 years of record keeping.²⁹ Runoff was reduced due to low winter precipitation, and warm, dry, and windy spring seasons that substantially reduced snowpack.

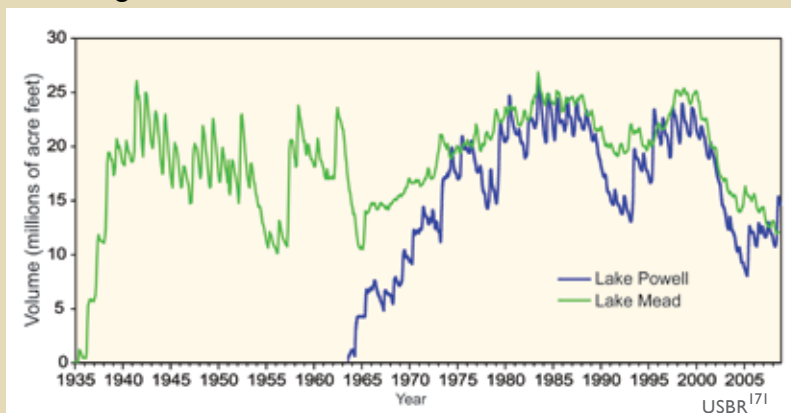


Matching photographs taken 18 months apart during the most serious period of recent drought show a significant decrease in Lake Powell.

Numerous studies over the last 30 years have indicated that the river is likely to experience reductions in runoff due to climate change. In addition, diversions from the river to meet the needs of cities and agriculture are approaching its average flow. Under current conditions, even without climate change, large year-to-year fluctuations in reservoir storage are possible.¹⁵² If reductions in flow projected to accompany global climate change occur, water managers will be challenged to satisfy all existing demands, let alone the increasing demands of a rapidly growing population.^{167,195}

Efforts are underway to address these challenges. In 2005, the Department of Interior's Bureau of Reclamation began a process to formalize operating rules for lakes Mead and Powell during times of low flows and to apportion limited water among the states.¹⁹⁶

Change in Water Volume of Lakes Mead and Powell



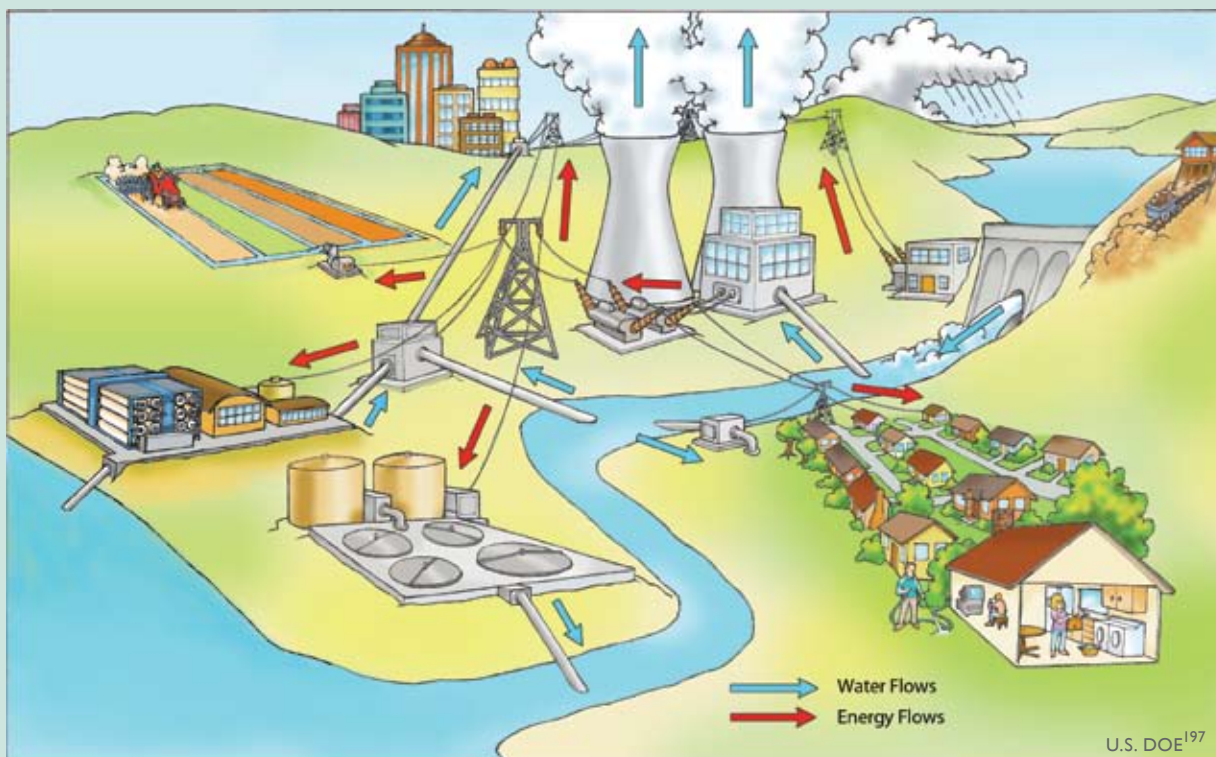
The filling of Lake Mead (green) was initiated in 1935, and that of Lake Powell (blue) in 1963. In 1999, the lakes were nearly full, but by 2007, the lakes had lost nearly half of their storage water after the worst drought in 100 years.

Water and Energy Connections

Water and energy are tightly interconnected; water systems use large amounts of energy, and energy systems use large amounts of water. Both are expected to be under increasing pressure in the future and both will be affected by a changing climate. In the energy sector, water is used directly for hydropower, and cooling water is critical for nearly all other forms of electrical power generation. Withdrawals of freshwater used to cool power plants that use heat to generate electricity are very large, nearly equaling the water withdrawn for irrigation. Water consumption by power plants is about 20 percent of all non-agricultural uses, or half that of all domestic use.¹⁹⁷



In the water sector, two very unusual attributes of water, significant weight due to its relatively high density, and high heat capacity, make water use energy intensive. Large amounts of energy are needed for pumping, heating, and treating drinking water and wastewater. Water supply and treatment consumes roughly 4 percent of the nation's power supply, and electricity accounts for about 75 percent of the cost of municipal water processing and transport. In California, 30 percent of all non-power plant natural gas is used for water-related activities.^{198,199} The energy required to provide water depends on its source (groundwater, surface water, desalinated water, treated wastewater, or recycled water), the distance the water is conveyed, the amount of water moved, and the local topography. Surface water often requires more treatment than groundwater. Desalination requires large amounts of energy to produce freshwater. Treated wastewater and recycled water (used primarily for agriculture and industry) require energy for treatment, but little energy for supply and conveyance. Conserving water has the dual benefit of conserving energy and potentially reducing greenhouse gas emissions if fossil fuels are the predominant source of that energy.



Water and energy are intimately connected. Water is used by the power generation sector for cooling, and energy is used by the water sector for pumping, drinking water treatment, and wastewater treatment. Without energy, there would be limited water distribution, and without water, there would be limited energy production.