



Every watershed – an area of land where the ground and surface water drains to the same place – is unique. Local topography, geology and climate work together to determine how water moves through the system, where it moves to, peak flow times and the characteristics of the water itself, such as its temperature, nutrient levels, pH and cloudiness, known as *turbidity*. The Lower 48 states have a diverse collection of watersheds (2,110 total) and freshwater ecosystems. Below are descriptions of four different global climate change trends that impact freshwater resources and ecosystems.

Surface Temperature Changes

The trend of surface temperature warming over the last century is reflected in water temperature trends, as well as in the average annual duration and extent of ice cover in northern water bodies. Collectively, America's stream and river temperatures are now rising at a rate of 0.016 to 0.139 degrees Fahrenheit per year, due in part to an overall climate warming trend over the last century. The world's lakes are freezing an average of 5.8 days later and thawing 6.5 days earlier than they were at the beginning of the 20th century. See Appendix A for a chart of trends in average annual ice cover duration for lakes in the Northern U.S.

Water temperature directly affects:

- **Biological make-up of the stream.** Fish and other aquatic species are adapted to live in specific temperature regimes. Beyond a certain temperature, fish simply cannot live in certain waters. Trout, for example, begin to experience mortality when the water temperature exceeds 73.4 degrees Fahrenheit. Temperature increases below these thresholds do not kill fish but often impose physiological limits on their growth and development. The disappearance of the Brook Trout from streams in the Eastern United States has been linked to rising temperatures.
- **The length of the stratified season.** Temperatures also control the length of the *stratified season*. In the winter, a lake's warmest water is on the bottom and the coldest is on the top. In the spring, the warmer water moves to the surface – an event known as *overturning*. This marks the start of the *stratified season*, when a warm layer of generally nutrient poor water covers the lake surface, limiting productivity. In Lake Washington near Seattle, this overturning is happening 17 days earlier in the year than it did in the early 1960s, which corresponds to a 3.6 degree Fahrenheit increase in the region's temperature. In Lake Superior, the stratified season is now 25 days longer than it was 30 years ago, which corresponds to a 5.3 degree Fahrenheit increase in water temperatures and an 11 percent decline in ice cover.
- **Thermal power plants.** Thermal power plants require large inputs of water to keep their systems operating effectively and safely. Warmer temperatures mean more water is needed to keep these systems cool, which affects their operating efficiency.



The Brook trout has been eliminated from parts of the Eastern United States due in part to rising water temperatures. Image: U.S. Fish and Wildlife Service.

In addition to average temperatures, seasonal temperature distributions affect spawning cycles and the timing of fish hatchings. Temperatures also affect when fish begin their migrations – as in the case of salmon – or their movement to deeper waters, such as the summertime movement of Great Lakes whitefish. Changes in the timing of these annual events can have repercussions on fish populations as well as on other species in the aquatic ecosystems that depend on these fish for food.

Precipitation Changes

Precipitation is ultimately the source of all surface freshwater. Most estimates suggest a seven to 15 percent increase in total accumulated precipitation in the United States during the 20th century, with the largest increases felt in the Eastern and Central United States. Yet, it is not necessarily the total amount of rainfall that has the biggest impacts on freshwater ecosystems and water availability. Other key climate controlled precipitation factors include:

- **Rain to snow ratio:** Snow accumulation, particularly at high elevations, serves as a reservoir that gradually replenishes streams as it melts. Throughout the United States, a general warming trend has corresponded to more late fall and early spring precipitation falling as rain instead of snow, causing many snow reservoirs to get smaller and smaller. Also, warmer temperatures mean that snow melts earlier in the year. These factors combined cause annual peak stream flows to arrive earlier and year. In the West, these earlier peak flows can force water masters to discharge the water downstream to keep the dams from breaking, instead storing water in man-made reservoirs for use during the summer months. The region has experienced an 11 percent decline in snowpack over the last 50 years and peak flows are now occurring 10-40 days earlier in the year than they did in the 1950s. In the Northeast, a similar trend is occurring to a lesser extent, with peak flows coming 2.5 days earlier in the year than in the 1950s.
- **Late season low flows:** In addition to early season flooding, earlier peak flows and less snowpack mean that much of the annual water discharge has been spent by mid-summer, resulting in lower late-season low flows. This is particularly true in the Western United States where summertime rainfall is scarce. Rising temperatures also mean more evaporation from the watershed, which exacerbates the low flow problem. Lower stream levels generally mean warmer streams. Warmer streams are already likely affecting fish populations. In Idaho's Boise River watershed, for example, rising temperatures coupled with other related factors, such as more forest fires, have led to a 20 percent decrease in suitable Bull Trout habitat over the last two decades.
- **Extreme precipitation:** Over the 20th century, the number of heavy (95th percentile) and extreme (99th percentile) precipitation events increased by 14 and 20 percent respectively. Heavy rainfall events put sudden surges of water into local rivers and streams and account for the majority of rainfall related soil erosion. Sudden surges of water can disrupt stream beds where aquatic species lay their eggs, potentially impacting their reproductive success. The increased erosion from heavy rainfall increases water *turbidity*, or the amount of suspended solids in the water that make the water appear "cloudy." Sediment accumulation on streambeds can bury fish eggs, which can also impact reproductive success.

Changes in Atmospheric Composition

Carbon dioxide concentrations in the atmosphere have grown from 280 parts per million (ppm) in pre-industrial times to around 390 million ppm today. More carbon in the atmosphere allows algae, which form the base of aquatic food chains, to grow faster. However, these algae also tend to be less nutritious. Their bodies contain more carbon as opposed to nitrogen or phosphorous, which are the two other primary nutrients necessary for life.

In waters that have been *eutrophicated*, such as waters where nitrogen levels are high due to human fertilizer, higher carbon concentrations allow blue-green algae (also known as *cyanobacteria*) to grow even faster and outcompete the "green" algae. Blue-green algae poison potential competitors by secreting a toxin called *microcystin*, which kills off other algae and is toxic to birds, mammals and aquatic species. The toxin impacts human water supplies and forces closures of recreation areas.



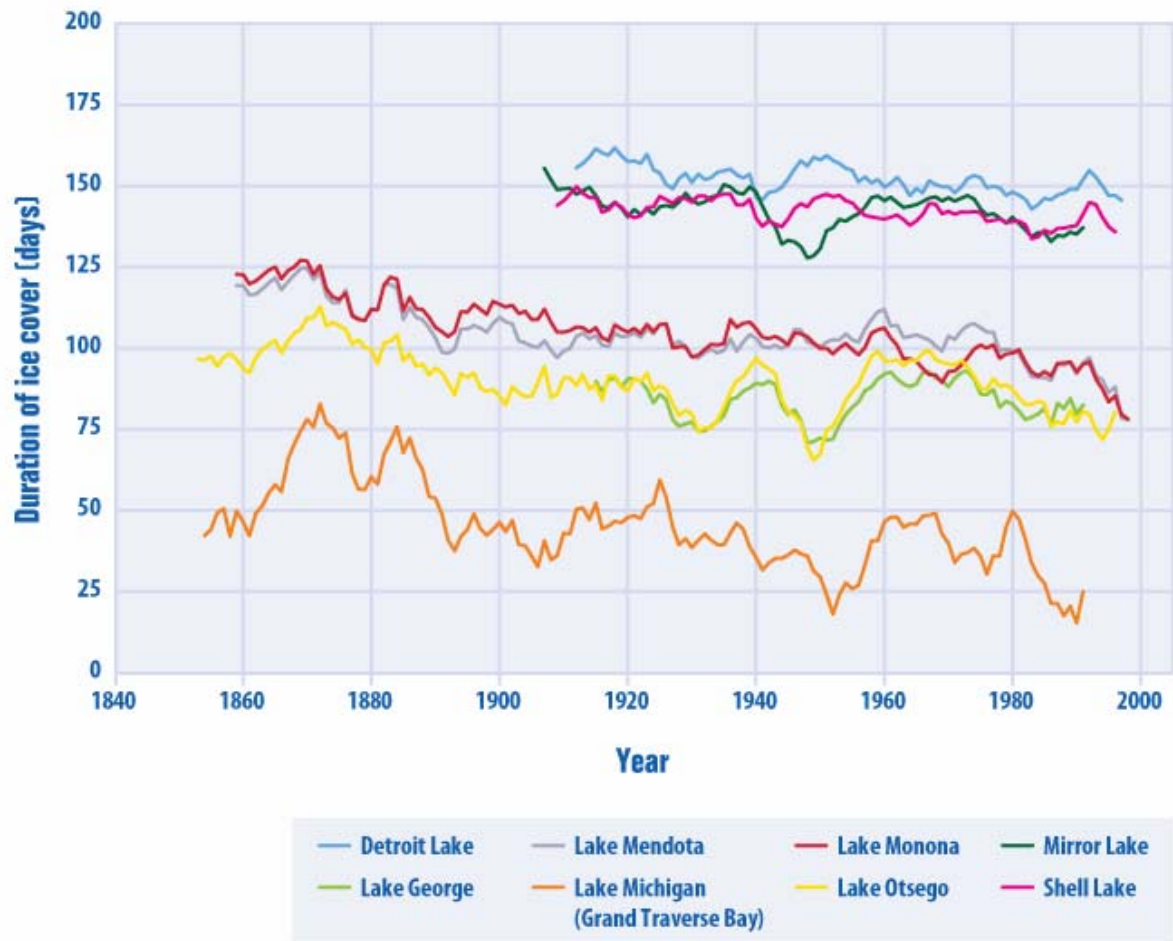
Image: A cyanobacteria bloom in a Delaware Pond. Image Courtesy of the State of Delaware.

Sea Levels

Sea levels are now rising at a rate of three millimeters per year. As they rise, the *fresh water/salt water interface*, or the boundary where saline ocean water impacts freshwater rivers, moves inland. Cities such as Philadelphia have water intakes that are close to this point. Both sea level rise and low river flows – with the saltwater intrusion point migrating further upstream during low flows – can affect the position of the fresh water/salt water interface. Also, blue-green algae can handle salt water better than green algae can and an inland saltwater advance can give blue-green algae an advantage in formerly fresh waters.

About 50 percent of the nation's water supply comes from groundwater aquifers. Many of these aquifers, such as the Biscayne Aquifer that provides water to Miami, are close to the ocean. In these coastal aquifers, a layer of freshwater sits on top of a denser layer of saltwater. As sea levels rise, this denser layer comes closer to the surface and moves further inland, invading what were formerly freshwater wells as it moves.

Appendix A: Trends in Annual Duration of Ice Cover



Above: Trends in annual duration of ice cover from eight Northern United States Lakes. Image from United States: Environmental Protection Agency - "Climate Change Indicators in the United States," 2010.

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