# WATER SECTOR

Water is a central resource supporting human activities and ecosystems. The hydrologic (water) cycle,a fundamental component of climate,is likely to be altered in important ways by climate change. Precipitation is very likely to continue to increase on average,especially in middle and high latitudes,with much of the increase coming in the form of heavy downpours. Changes in the amount,timing,and distribution of rain,snowfall,and runoff are very probable,leading to changes in water availability as well as in competition for water resources. Changes are also likely in the timing,intensity, and duration of both floods and droughts,with related changes in water quality.

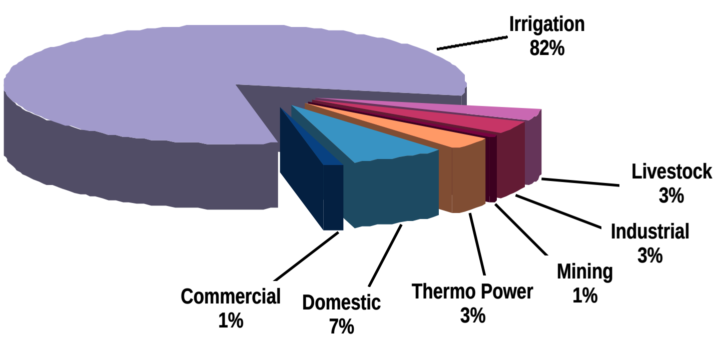
Snowpack serves as natural water storage in mountainous regions and northern portions of the US, gradually releasing its water in spring and summer. Snowpack is very likely to decrease as the climate warms,despite increasing precipitation, for two reasons. It is very likely that more precipitation will fall as rain,and that snowpack will develop later and melt earlier. As a result,peak streamflows will very likely come earlier in the spring,and summer flows will be reduced. Potential impacts of these changes include an increased possibility of flooding in winter and early spring,a reduced possibility of flooding later in the spring,and more shortages in summer.

Managed river systems provide opportunities to store water in reservoirs to dampen the effects of changes in flow regimes,but this does not come without environmental costs. Substantial infrastructure has been developed to store and transport water supplies. There are more than 80,000 dams and reservoirs in the US,and millions of miles of canals,pipes,and tunnels. Even in the absence of climate change,adapting to existing stresses (such as aging infrastructure and inadequate water supplies for growing areas) will be expensive. For a variety of reasons,large dams are no longer viewed as a cost-effective or environmentally acceptable solution to water supply problems,so other strategies must be developed.

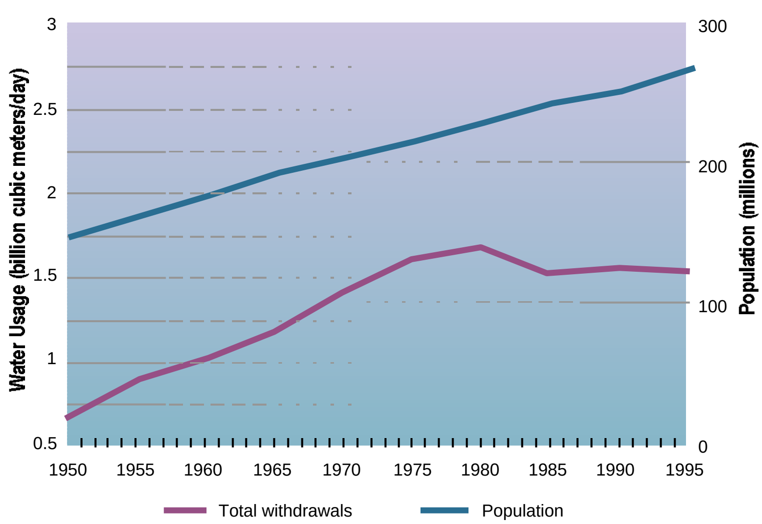
## KEY ISSUES

- Competition for Water Supplies
- Surface Water Quantity and Quality
- Groundwater Quantity and Quality
- Floods, Droughts, and Extreme Precipitation Events
- Ecosystem Vulnerabilities

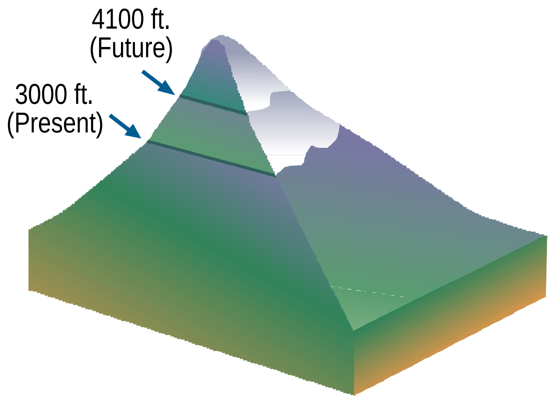
Total US Freshwater Consumptive Use




Water Withdrawals and Population Trends



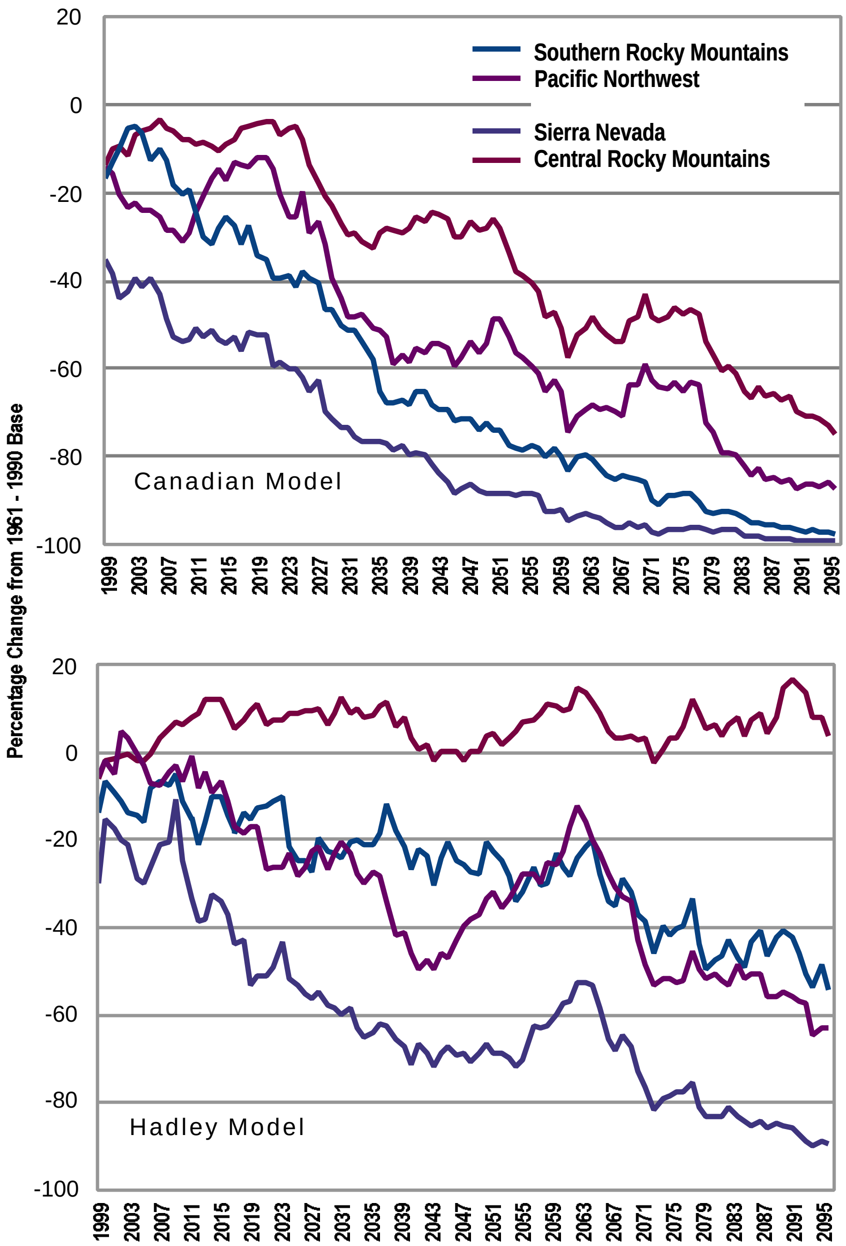

**Although US population has continued to increase, total water withdrawals have stablized over the last decade. Stabilization of total withdrawals is due to increased water use efficiency and recycling in some sectors, and a reduction in acreage of irrigated agriculture.**




**Rough estimate of how much snowlines in the Pacific Northwest are likely to shift by 2050, assuming about 4ºF warming.**

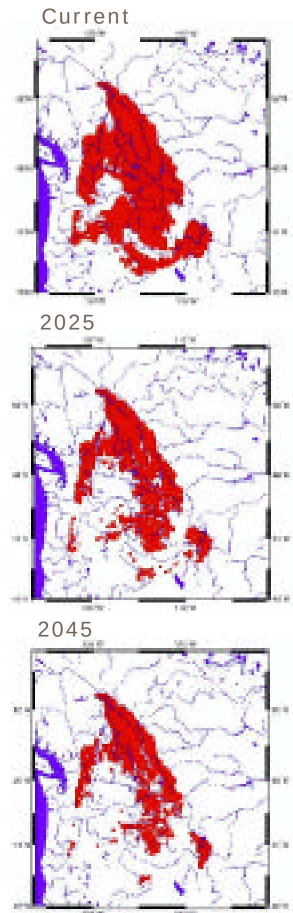
*Snowpack is very likely to decrease as the climate warms, despite increasing precipitation, for two reasons. It is very likely that more precipitation will fall as rain, and that snowpack will develop later and melt earlier. As a result, peak streamflows will very likely come earlier in the spring, and summer flows will be reduced.*

## Changes in Western Snowpack



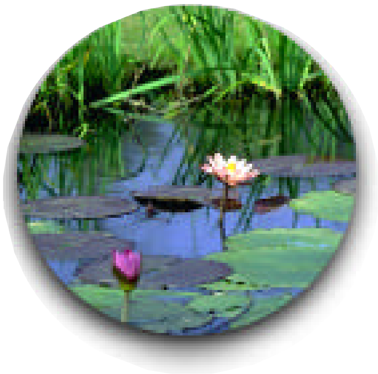

## Columbia Basin Snow Extent

(Washington & Oregon)




**In this model of Columbia Basin snow extent, complete loss of snow cover is projected at lower elevations. These maps are generated by downscaling output from global to regional climate models for the Columbia Basin.**

**Percentage change from the 1961-90 baseline in the April 1 snowpack in four areas of the western US as simulated for the 21st century by the Canadian and Hadley models. April 1 snowpack is important because it stores water that is released into streams and reservoirs later in the spring and summer. The sharp reductions are due to rising temperatures and an increasing fraction of winter precipitation falling as rain rather than snow. The largest changes occur in the most southern mountain ranges and those closest to the warming ocean waters.**



*In a warmer climate, hurricanes are likely to produce more rainfall. The frequency and intensity of droughts are also likely to increase in some areas due to higher air temperatures.*

**The Palmer Drought Severity Index (PDSI) is a commonly used measure of drought severity taking into account differences in temperature, precipitation, and capacity of soils to hold water. These maps show projected changes in the PDSI over the 21st century, based on the Canadian and Hadley climate scenarios. A PDSI of –4 indicates extreme drought conditions. The most intense droughts are in the –6 to –10 range, similar to the major droughts of the 1930s. By the end of the century, the Canadian scenario projects that extreme drought will be a common occurrence over much of the nation, while the Hadley model projects small changes in drought conditions.**

# WATER KEY ISSUES

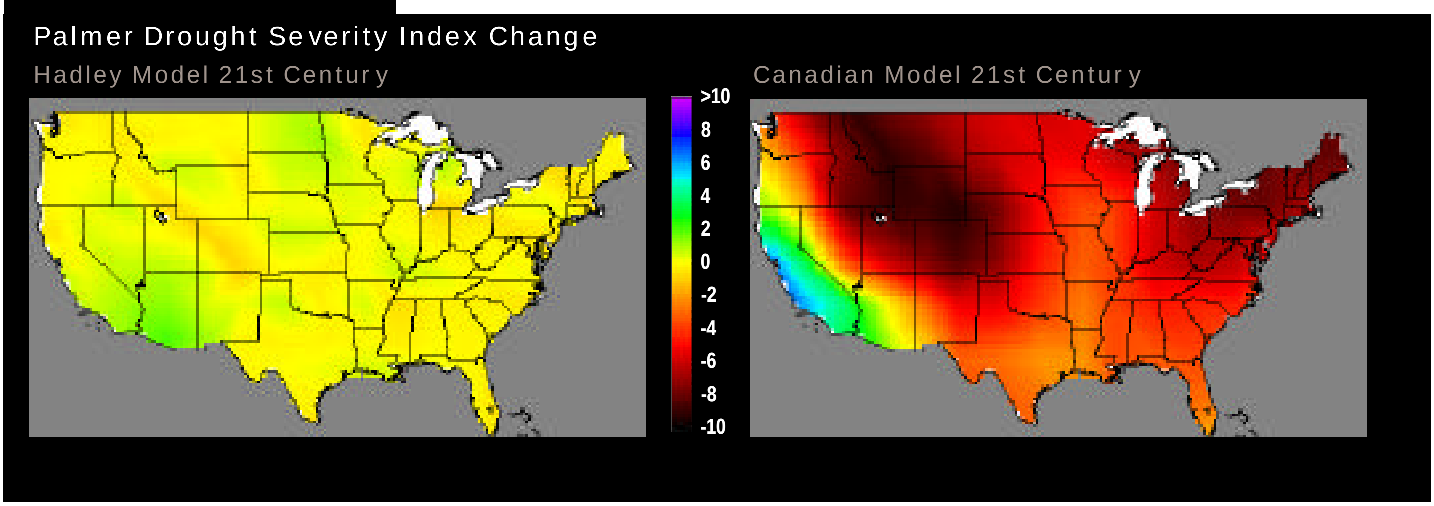
## Competition for Water Supplies

In many rivers and streams in the US,there is not enough water to satisfy existing water rights and claims.Changing public values about preserving instream flows,protecting endangered species,and settling Indian water rights claims have made competition for water supplies increasingly intense. Climate change will very likely exacerbate competition in regions where fresh water availability is reduced by increased evaporation due to rising air temperatures and changes in precipitation. In some areas,however, an increase in precipitation could possibly outweigh these factors and increase available supplies.

Significant changes in average temperature,precipitation,and soil moisture caused by climate change are very likely to also affect demand in most sectors, especially in the agriculture, forestry, and municipal sectors. Irrigation water needs are likely to change,with decreases in some places and increases in others. It is very likely that demand for water associated with electric power generation will increase due to the increasing demand for air conditioning with higher temperatures,unless advances in technology make it possible for less water to be used for electrical generation. Climate change is likely to reduce water levels in the Great Lakes and summertime river levels in the central US, thereby affecting navigation and general water supplies.

## Surface Water Quantity and Quality

Precipitation in the US has increased by 5-10% during the 20th century with much of this increase attributed to heavy and very heavy precipitation events.During this period,the relative increase in runoff has been even greater. More data and analyses are needed to see how increases in heavy precipitation are reflected in streamflow, but changes are likely in the future.Increases in global temperatures have been accompanied by more precipitation in the middle and high latitudes and increases in atmospheric water vapor in many regions of North America. These changes are significant and most apparent during spring through autumn in the contiguous US. Despite the overall increase in precipitation,however, it is likely that many interior portions of the nation will experience more extremes related to drought due to increased air temperatures. These changes in precipitation and evaporation are very likely to affect the quantity of surface water, with substantial regional variation.



Rising temperatures are very likely to affect snowfall and increase snowmelt conditions in much of the western and northern portions of the US that depend on winter snowpack for runoff. It is very likely that as the climate warms,less precipitation will fall as snow, the existing snowpack will melt sooner and faster, the runoff will be shifted from late spring and summer to late winter and early spring. This change in the timing of runoff will very likely have implications for water management, flood protection,irrigation,and planning.

Water quality is also likely to be affected by climate change in a variety of ways. For example,more frequent heavy precipitation events will very likely flush more contaminants and sediments into lakes and rivers, degrading water quality. Thus,it is likely that pollution from agricultural chemicals and other non-point sources will be exacerbated. In some regions,however, higher average flows will likely dilute pollutants, improving water quality. Where streamflows are reduced,increased salinity is a potential problem. Water quality issues include potential impacts on human health,such as increased incidence of water-borne diseases after flood events. Flooding can cause overloading of storm and wastewater systems,and damage water and sewage treatment facilities, mine tailing impoundments,and landfills,thereby increasing the risks of contamination.

Rising water temperatures and changes in ice cover are of particular importance to the ecology of lakes, streams,and their biological communities. Such changes are likely to affect how ecosystems function,especially in combination with chemical pollution. For example,when warmer lake water combines with excess nutrients from agricultural fertilizers (washed into the lake by heavy rains),algae blooms on the lake surface,depleting the ecosystem of oxygen and harming the other organisms in the system.

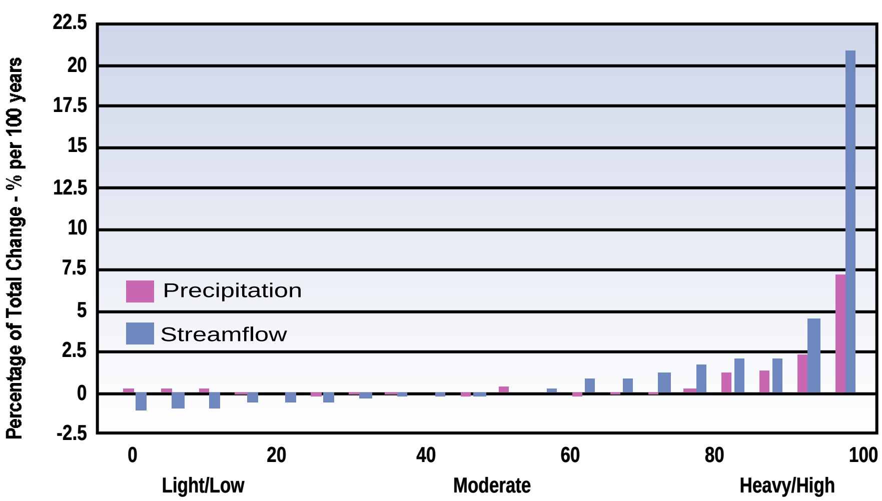
## Groundwater Quantity and Quality

Several regions of the US,including parts of California and the Great Plains region,are dependent on dwindling groundwater supplies. Groundwater supplies are less susceptible than surface water to short-term climate variability;they are more affected by long-term trends. Groundwater serves as the base flow for many streams and rivers. In many areas, groundwater levels are very likely to fall,thus reducing seasonal streamflows. Surface water temperature fluctuates more rapidly with reduced volumes of water, likely affecting vital habitats. Small streams that are heavily influenced by groundwater are more likely to have reduced streamflows and changes in seasonality of flows,likely damaging existing wetland habitats.

Pumping groundwater at a faster rate than it can be recharged is a major concern,especially in parts of the country that have no other supplies. In the Great Plains, for example, model projections indicate that increased drought conditions are likely, and groundwater levels are already dropping in parts of important aquifers such as the Ogallala.

The quality of groundwater is being diminished by a variety of factors including chemical contamination. Saltwater intrusion is another key groundwater quality concern,particularly in coastal areas where changes in freshwater flows and increases in sea level will both occur. As groundwater pumping increases to serve municipal demand along the coast and less recharge occurs,coastal groundwater aquifers are increasingly affected by seawater. Because the groundwater resource has been compromised by many factors,managers are looking increasingly to surface water supplies which are more sensitive to climate change and variability.

### Observed Changes In Streamflow and Precipitation (1939-99)




**The graph shows changes in the intensity of precipitation and streamflow, displayed in 5% increments, during the period 1939-99 based on over 150 unregulated streams across the US with nearby precipitation measurements (with most of the co-located gages from the eastern half of the US). As the graph demonstrates, the largest changes have been the significant increases in the heaviest precipitation events and the highest streamflows. Note that changes in streamflow follow changes in precipitation, but are amplified by about a factor of 3.**

# WATER KEY ISSUES

## Floods, Droughts, and Extreme Precipitation Events

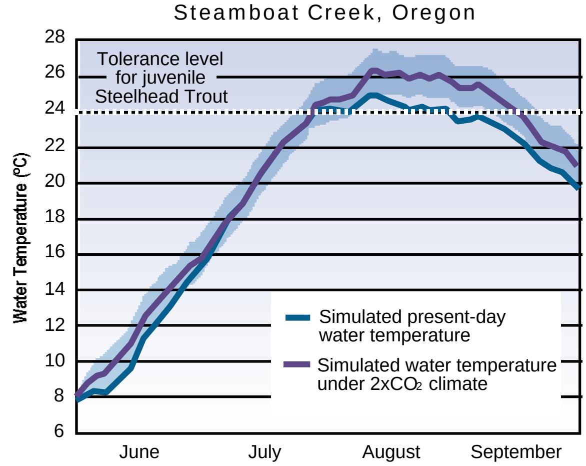
Changes in climate extremes are more likely to cause stress at the regional level than changes in the averages. Thus, changes in the timing of precipitation events, as well as increases in extreme events, are key concerns. Climate change is likely to increase flood frequency and amplitude in some regions, with major impacts on infrastructure and emergency management. The 1999 North Carolina flood, resulting from Hurricane Floyd, offers a recent example of the massive dislocations and multi-billion dollar costs that often accompany such events. In a warmer climate, hurricanes are likely to produce more rainfall. The frequency and intensity of droughts are also likely to increase in some areas due to higher air temperatures. This is likely to have wide-ranging impacts on agriculture, water-based transportation, and ecosystems. A recent example of such impacts is the 1995-96 drought in the agricultural regions of the southern Great Plains that resulted in about $5 billion in damages. The costs associated with floods and droughts include those incurred for building and managing infrastructure to avoid damages as well as costs associated with damages that are not avoided. These costs are in the billions of dollars and rising.

## Ecosystem Vulnerabilities

Species live in the larger context of ecosystems and have differing environmental needs. A change that is devastating to one species is likely to encourage the expansion of another to fill that niche in the system. Extreme conditions such as floods, droughts, and fire are critical to sustaining certain ecosystems, and changes in the frequency of these events are likely.

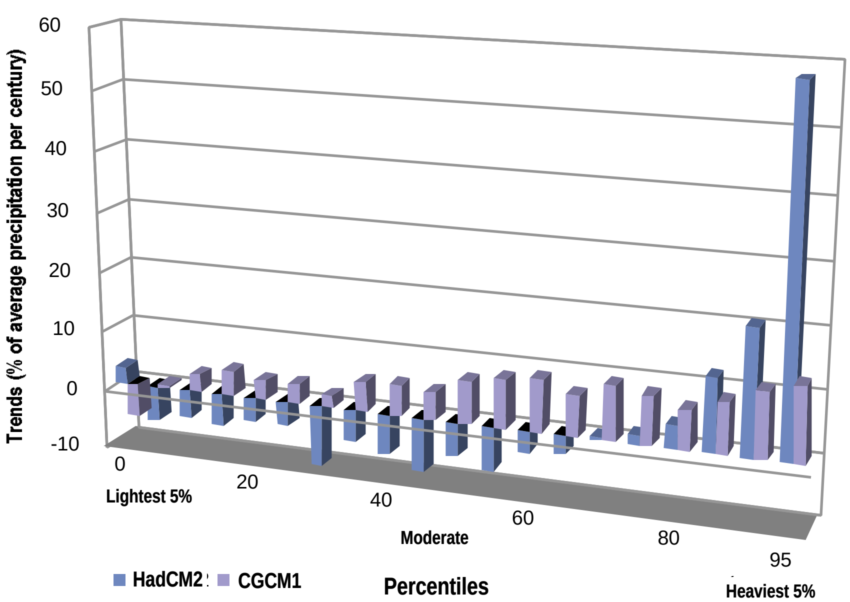
Rising temperatures in surface waters are likely to force out some cold water fish species such as salmon and trout that are already near the threshold of their viable habitat. Increasing temperatures also result in reduced dissolved oxygen in water, reducing ecosystem health. Temperature increases will very likely reduce ice cover and alter mixing and stratifica-

Summer Stream Temperatures
Steamboat Creek, Oregon




**Simulated summer stream temperatures under present day climate (blue) and simulated temperatures under about a twice current $CO_2$ climate (purple). The dashed line at 24ºC (75ºF) on the "water temperature" axis indicates the summer temperature tolerance of juvenile steelhead trout. Under doubled $CO_2$, the model suggests that the length of time within the year when the temperature tolerance limit is exceeded is more than twice as long as under simulated present-day climate conditions. Shaded area surrounding the doubled $CO_2$ temperature curve indicates an estimate of uncertainty.**

Projected 21st Century Change in US Daily Precipitation




**These projections by the Hadley and Canadian models show the changes in precipitation over the 21st century. Each models' projected change in the lightest 5% of precipitation events is represented by the far left bar and the change in the heaviest 5% by the far right bar. As the graph illustrates, both models project significant increases in heavy precipitation events with smaller increases or decreases in light precipitation events.**

tion of water in lakes,all of which are key to the nutrient balance and habitat value. The natural ecosystems of the Arctic,Great Lakes,Great Basin, Southeast,and the prairie potholes of the Great Plains appear highly vulnerable to the projected changes in climate. In regions where runoff increases, existing stresses and threats to biodiversity could possibly be reduced.

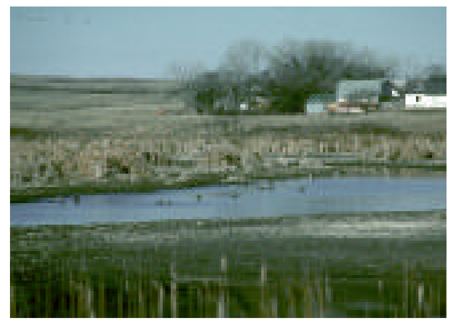
## Adaptation Strategies

Strategies for adapting to climate change range from changes in the operation of dams and reservoirs,to re-evaluating basic engineering assumptions used in facility construction,to building new infrastructure. Options also include water conservation,use of reclaimed wastewater, water transfers,and increasing prices (which encourages increases in efficiency of use). Because many of the impacts of climate change are not predictable,more flexible institutional arrangements are needed in order to adapt to changing conditions including not only climate change, but other existing stresses as well. Water rights systems vary from state to state, with even more differences at the local level. Most institutions related to water have not responded well to changing socioeconomic and environmental conditions.

Some have argued that an open market in water rights would help resolve conflict and increase efficiency because water would flow to the highest and best use based on willingness to pay. Although major social, equity, and environmental considerations must be addressed,market solutions appear to have great potential to help resolve supply problems in some parts of the US.

In considering adaptation mechanisms,it is important to point out that humans have a great ability to adapt to change,while natural ecosystems are likely to be more vulnerable. Some potential adaptation options for human water management in response to climate change and other stresses follow.

- Increase ability to shift water within and between sectors (including agriculture to urban).
- Use pricing and market mechanisms proactively to increase efficiency of water use.
- Incorporate potential changes in demand and supply in long-term planning and infrastructure design.
- Create incentives or requirements to move people and structures out of floodplains.
- Identify ways to manage all available supplies, including groundwater, surface water, and effluent, in a sustainable manner.
- Restore and maintain watersheds (for example, by restoring appropriate vegetation) as an integrated strategy for managing water quality and quantity. Restoring watersheds that have been damaged by urbanization, forestry, or grazing can reduce sediment loads and nutrients in runoff, limit flooding, and reduce water temperature.
- Reuse municipal wastewater, improve management of urban storm water runoff, and promote collection of rainwater for local use to enhance urban water supplies.
- Increase the use of forecasting tools for water management. Some weather patterns, such as those resulting from El Niños, can now be predicted with some accuracy, and this can help reduce damages associated with extreme events.
- Enhance monitoring efforts to improve data for weather, climate, and hydrologic modeling to aid understanding of water-related impacts and management strategies.



**Prairie pothole.**

*The natural ecosystems of the Arctic, Great Lakes, Great Basin, Southeast, and the prairie potholes of the Great Plains appear highly vulnerable to the projected changes in climate.*

**Land subsidence, caused by overpumping of groundwater, can result in earth fissures such as this near Eloy, Arizona.**

**Artificial groundwater recharge in the Santa Ana Riverbed, Orange County Water District, California.**

**The Central Arizona Project brings Colorado River water 330 miles uphill to Tucson and Phoenix, Arizona.**