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Effects of Climate Change on Water Resources

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Climate change will affect water resources through its impact on the quantity, variability, timing, form, and intensity of precipitation. This paper provides an overview of the projected physical and economic effects of climate change on water resources in North America (with a focus on water shortages), and a brief discussion of potential means to mitigate adverse consequences. More detailed information on this complex topic may be found in Adams and Peck (forthcoming) and in the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4).

Global Climate Change and Precipitation

Models of climate change (GCMs) predict U.S. annual-mean temperatures to generally rise by 2° C to 3° C over the next 100 years, with greater increases in northern regions (5° C), and northern Alaska (10° C). Numerous other climatic effects are also expected. For example, U.S. precipitation, which increased by 5 to 10% over the 20th century, is predicted to continue to increase overall. More specifically, an ensemble of GCMs predicts a 20% increase for northern North America, a 15% increase in winter precipitation for northwestern regions, and a general increase in winter precipitation for central and eastern regions. Despite predictions of increased precipitation in most regions, net decreases in water availability are expected in those areas, due to offsetting increases in evaporation. A 20% decrease in summer precipitation, for example, is projected for southwestern regions, and a general decrease in summer precipitation is projected for southern areas. Although projected regional impacts of climate change are highly variable between models, the above impacts are consistent across models.

Global Climate Change and Water Resources

Additional effects of global climate change that have important implications for water resources include increased evaporation rates, a higher proportion of precipitation received as rain, rather than snow, earlier and shorter runoff seasons, increased water temperatures, and decreased water quality in both inland and coastal areas. The physical and economic consequences of each of these effects are discussed below.

Increased evaporation rates are expected to reduce water supplies in many regions. The greatest deficits are expected to occur in the summer, leading to decreased soil moisture levels and more frequent and severe agricultural drought. More frequent and severe droughts arising from climate change will have serious management implications for water resource users. Agricultural producers and urban areas are particularly vulnerable, as evidenced by recent prolonged droughts in the western and southern United States, which are estimated to have caused over $6 billion in damages to the agricultural and municipal sectors. Such droughts also impose costs in terms of wildfires, both in terms of control costs and lost timber and related resources.

Water users will eventually adapt to more frequent and severe droughts, in part by shifting limited water supplies towards higher-value uses. Such shifts could be from low- to high-value crops, or from agricultural and industrial to environmental and municipal uses. A period of delay is likely, however, because gradual changes in the frequency and severity of drought will be difficult to distinguish from normal inter-annual variations in precipitation. Economic losses will be larger during this period of delay, as compared to a world with instantaneous adjustment, but preemptive adaptation could also be costly given the uncertainty surrounding future climate.

Rising surface temperatures are expected to increase the proportion of winter precipitation received as rain, with a declining proportion arriving in the form of snow. Snow pack levels are also expected to form later in the winter, accumulate in smaller quantities, and melt earlier in the season, leading to reduced summer flows. Such shifts in the form and timing of precipitation and runoff, specifically in snow-fed basins, are likely to cause more frequent summer droughts. Research shows that these changes are already taking place in the western United States. Changes in snow pack and runoff are of concern to water managers in a number of settings, including hydropower generation, irrigated agriculture, urban water supply, flood protection and commercial and recreational fishing. Timing of runoff will affect the value of hydropower potential in some basins if peak water run-off occurs during nonpeak electricity demand. Energy shortages and resulting energy price increases will provide incentives to expand reservoir capacities or develop alternative energy sources.

If the runoff season occurs primarily in winter and early spring, rather than late spring and summer, water availability for summer-irrigated crops will decline, and water shortages will occur earlier in the growing season, particularly in watersheds that lack large reservoirs. Agricultural producers, in response to reduced water supplies and crop yields, will adjust their crop mix. Producers in irrigated regions might reduce total planted acreage, or deficit-irrigate more acres, to concentrate limited water supplies on their most valuable crops (e.g. onions and potatoes, rather than wheat and alfalfa). Producers in rain-fed regions might shift to crop species and varieties with shorter growing season requirements or greater drought tolerance, such as winter grains.

Cropping practices are likely to shift as well, perhaps towards reduced- or no-till technologies, which enhance water infiltration and conserve soil moisture, or towards irrigation technologies that are more efficient at the farm level (although not necessarily at the basin level). Producers may begin to supplement dwindling surface water supplies with groundwater resources, a response that has already been observed in many drought-stricken areas. These adjustments will mitigate a portion of private economic losses. They will also affect environmental quality, although the expected direction is more difficult to predict.

A shift in stream hydrographs to more winter flow may also disrupt the life cycle of cold water fish species, such as salmon, which depend on late spring flows to “flush” young salmon to the ocean, and on summer flows to moderate water temperatures. Unless winter runoff is captured and stored for late spring or summer use, fewer salmon smolt will survive migration and more frequent fish kills will occur from lethal stream water temperatures. Such environmental impacts will intensify debates about consumptive versus instream water uses, such as those ongoing in the Klamath and Platte River Basins.

Climate change is expected to affect water quality in both inland and coastal areas. Specifically, precipitation is expected to occur more frequently via high-intensity rainfall events, causing increased runoff and erosion. More sediments and chemical runoff will therefore be transported into streams and groundwater systems, impairing water quality. Water quality may be further impaired if decreases in water supply cause nutrients and contaminants to become more concentrated. Rising air and water temperatures will also impact water quality by increasing primary production, organic matter decomposition, and nutrient cycling rates in lakes and streams, resulting in lower dissolved oxygen levels. Lakes and wetlands associated with return flows from irrigated agriculture are of particular concern. This suite of water quality effects will increase the number of water bodies in violation of today’s water quality standards, worsen the quality of water bodies that are currently in violation, and ultimately increase the cost of meeting current water quality goals for both consumptive and environmental purposes.

Rising sea levels could also reduce water quality and availability in coastal areas. Recent projections of sea-level rise by the end of the 21st century range from 19 to 58 cm. A more dramatic increase in sea-level, on the order of meters rather than centimeters, is possible, but most scientists consider it a low probability risk. For example, complete melting of the Greenland Ice Sheet or West Antarctic Ice Sheet would trigger such a large rise. Rising sea levels could affect groundwater quality directly via saltwater intrusion. Radical changes to the freshwater hydrology of coastal areas, caused by saltwater intrusion, would threaten many coastal regions’ freshwater supplies.

Rising sea levels could also affect water availability in coastal areas indirectly by causing water tables in groundwater aquifers to rise, which could increase surface runoff at the expense of aquifer recharge. Water shortages will cause the price of water to rise, through monthly water bills or one-time connection fees for new homes and businesses. A sufficiently large price increase could affect the extent and pattern of urban growth throughout the United States. Costly water supply projects, such as desalination plants, pipelines, and dams will also become more economically attractive.

One final and important effect of the water resource impacts discussed above is the potential for more frequent and intense interstate and international water allocation conflicts. Water markets have the potential to prevent or diffuse such conflicts; however, the assignment of water rights to establish the market can create more conflict than it diffuses.

Coping With Changing Water Resources

Although subject to uncertainty, forecasts of climatic change offer a glimpse into possible future water resource impacts and challenges. Predicted impacts vary by region, but include increased temperatures and evaporation rates; higher proportions of winter precipitation arriving as rain, not snow; earlier and more severe summer drought, and decreased water quality. Water shortages, which currently result in substantial economics losses, will be more common in many regions because of these impacts. Such economic losses, which occur across a range of sectors, from agriculture to energy and recreation, have profound effects on local communities. More frequent shortages imply increased costs to society, although adaptation by water users will mitigate some portion of these costs.

Water resource users can reduce the negative effects of water shortages through a number of strategies. These include revising water storage and release programs for reservoirs, adopting crops and cropping practices that are robust over a wider spectrum of water availability, expanding and adjusting crop insurance programs (such as the Multi-Peril Crop Insurance program's Prevented Planting Provision), adjusting water prices to encourage conservation and the expansion of water supply infrastructure, and supporting water transfer opportunities. Damage from drought-induced wildfires can be minimized by using long range soil moisture forecasts to pre-position fire suppression resources and in the longer term, by changing land-use regulations to restrict development in areas facing increased fire risk.

The ability to anticipate and efficiently prepare for future water resource management challenges is currently limited, in part, by imprecise regional climate change models and long-term weather forecasts. Uncertainty about future climate conditions makes it more difficult to optimally prepare for and adapt to associated changes in water resource availability and quality. Imagine, for example, trying to prepare optimally for a water shortage when you are uncertain of when it will occur, how severe it will be, or how long it will persist. It may be tempting to make management plans based on the worst-case scenario; however, the opportunity cost of this "safety-first" approach can be high if the worst-case does not occur. Imperfect information ultimately increases the magnitude of economic losses (or reduce the magnitude of any potential economic gains) attributable to water resource changes.

Improvements in climate projections and long-term weather forecasts, such as forecasts based on the El Niño-Southern Oscillation phenomenon (ENSO), offer potential for reducing economic losses (or increasing economic gains) associated with climate change. More specifically, improvements in the ability to detect water shortages farther in advance, to more precisely forecast their location, intensity, and duration, and to use such forecasts to inform management strategies would enhance water users' confidence in regional forecasts, and their ability to efficiently prepare for and adapt to future water resource management challenges.

For More Information

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