COMMITTEE REPORT

Climate change and water resources

Global warming is a fact, and water resource managers need to plan accordingly.

AWWA's Public Advisory Forum

Global climatic change—the greenhouse effect—is here to stay. Although uncertainties remain about the nature and extent of climatic changes that will occur, most among the scientific community believe changes in the hydrologic cycle and to water resource management systems will be significant. Water managers, policy-makers, and the public should begin to consider the implications of climatic change for long-term water planning and management. AWWA's Public Advisory Forum has discussed this problem for the past two years. The recommendations it offers in this article are not for specific changes in operations, for complicated or costly new infrastructure or development, or for irreversible actions. Instead, they are recommendations for thoughtful analysis of water systems' vulnerabilities to unprecedented climate change and for attention, planning, and continued vigilance in response to this situation. As the proverb says, to see the future is good, but to prepare for it is better.

Climatic conditions influence all decisions about long-term water planning, the design and construction of new water supply infrastructure, the type and acreage of crops to be grown, urban water allocations and rate structures, reservoir operation, and water supply management. Past water planning and management relied on the assumption that future climatic conditions would be the same as past conditions. Human activities may have begun to change the world's climate; most in the scientific community believe global climatic changes will occur unless society reduces its emissions of gases from burning fossil fuels and its destruction of forests. This contingency makes it important for water managers, policymakers, and the public to consider the implications of climatic change for long-term water planning and management.

Although consensus is growing that global climatic change is under way and will probably change the hydrologic cycle, there is little certainty about the form these changes may take or when they might be clearly detected. As a result, although global climatic changes may become evident within the next several decades or even earlier, researchers are not yet able to accurately determine how such changes will affect water supply systems or water demand.

In the late 1980s, the World Meteorological Organization and the United Nations Environment Programme, with the cooperation of more than 120 nations, developed a multiyear scientific assessment of climate change under the auspices of the Intergovernmental Panel on Climate Change (IPCC). This panel of leading climatologists published its initial findings in 1990[1] and released a complete reassessment in 1995.[2] Among the principal conclusions of the report were the following statements:

> We are certain [that] emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface.
>
> We calculate with confidence that continued emissions of these gases at present rates would commit us to increased concentrations for centuries ahead. The longer emissions continue to increase at present-day rates, the greater reductions would have to be for concentrations to stabilise at a given level.

The IPCC forecasts a rise of 1.8–6.3°F (1–3.5°C) by 2100. Even the lowest estimate is a rate of warming greater than any seen in the last 10,000 years.[2]

The Second World Climate Conference, which was held in Geneva in late 1990, issued the following statement for water managers and planners:

> The design of many costly structures to store and convey water, from large dams to small drainage facilities, is based on analyses of past records of climatic and hydrologic parameters. Some of these structures are designed to last 50 to 100 years or even longer. Records of past climate and hydrological conditions may no longer be a reliable guide to the future. The design and management of both structural and nonstructural water resource systems should allow for the possible effects of climate change.[3]

A separate study conducted by the American Association for the Advancement of Science focused on the implications of global climate changes for the water resources of the United States and concluded:

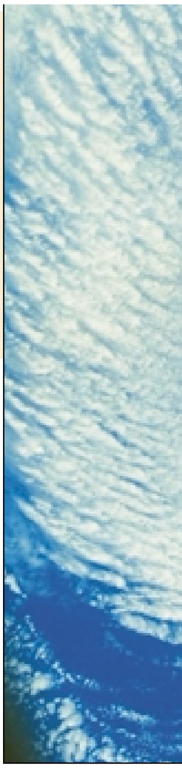


PHOTO: NASA

Among the potential effects of climatic changes from global warming are changes in the intensity, timing, and severity of major storms.

> Among the climatic changes that governments and other public bodies are likely to encounter are rising temperatures, increasing evapotranspiration, earlier melting of snowpacks, new seasonal cycles of runoff, altered frequency of extreme events, and rising sea level. . . . *Governments at all levels should reevaluate legal, technical, and economic procedures for managing water resources in the light of climate changes that are highly likely.*[4] [emphasis added in original]

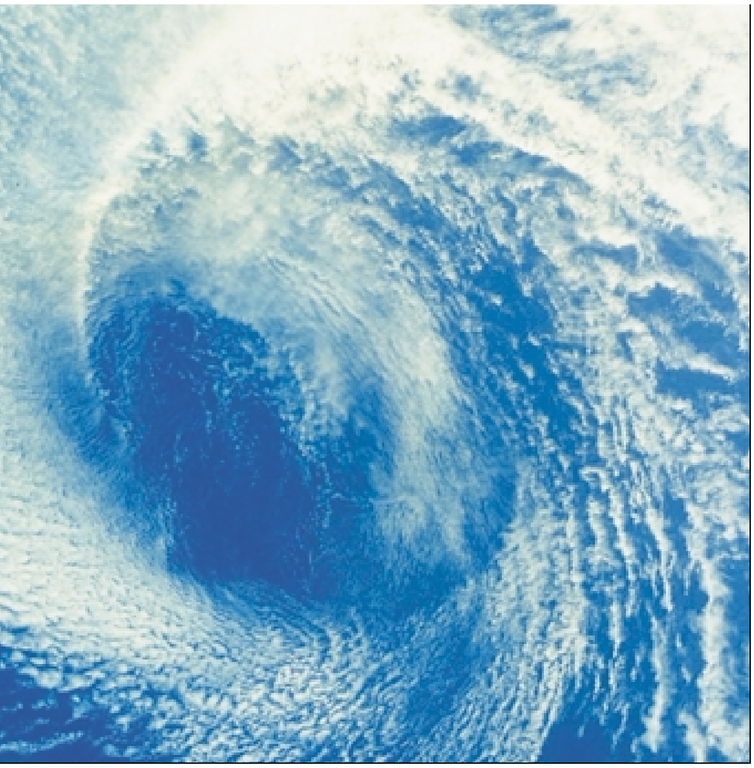
Similarly, the most recent report on water to the IPCC stated that freshwater resources throughout the world may be significantly affected and current freshwater problems will be made worse by the greenhouse effect.[5] This report urges water managers to begin "a systematic reexamination of engineering design criteria, operating rules, contingency plans, and water allocation policies" and states with "high confidence" that "water demand management and institutional adaptation are the primary components for increasing system flexibility to meet uncertainties of climate change." This emphasis on demand management marks a change in traditional water management approaches, which have relied on construction of new facilities.

Potential effects of climate changes on water resources are numerous

Among potential effects of climatic changes on water resources are higher global and regional temperatures; increases in global average precipitation and evaporation; changes in regional patterns of rainfall, snowfall, and snowmelt; changes in the intensity, severity, and timing of major storms; increases in sea level, which could cause saltwater intrusion into drinking water sources of coastal cities; and other geophysical effects. Should they occur, these changes could also alter water demand, supply, and quality.

Many uncertainties remain about the timing, direction, and extent of these climatic changes, as well as about their societal implications. Despite these uncertainties, which complicate rational water resource planning for the future, here is a summary of what water managers and hydrologists might expect based on current understanding.

Models estimate temperature, evaporation, and precipitation. During the past two decades, improvements in modeling of the climate have permitted more realistic estimates to be made of regional evaporation and precipitation patterns. If the global average temperature rises, evaporation of water from land and water surfaces will increase. Reviews of state-of-the-art climate models[2,6] suggest that global average evaporation and precipitation could increase



3–15 percent for an equivalent doubling of atmospheric carbon dioxide (CO_2) concentration. The greater the warming, the larger these increases.

Increases in precipitation would occur more consistently and intensely throughout the year at high latitudes. With a doubling of atmospheric CO_2 concentrations, models show moister atmospheres (i.e., increases in specific humidity) and greater precipitation in high latitudes and tropics throughout the year and in midlatitudes in winter. In many estimates, summer rainfall decreases slightly over much of the northern midlatitude continents. Other changes in midlatitudes remain highly variable and ambiguous. Information about changes in precipitation in subtropical arid regions is scanty, but even small changes in these arid zones can have significant implications for ecological and human systems.

Land surface may dry. Soil moisture is an important factor for agricultural production and environmental conditions. If precipitation increases, then increases in evaporation because of higher temperatures may also be greater, leading to a net drying of the land surface. Research indicates that the incidence of droughts in the United States (measured by soil moisture conditions) is likely to increase as temperatures rise—even if precipitation increases—because of increased evaporation.[7] This finding has also been seen in detailed hydrologic modeling of specific river basins (e.g., the Colorado, where maintaining current river runoff would require large increases in precipitation as temperatures and evaporative losses rise).[8]

All climate models predict a general increase in soil moisture at the high northern latitudes in winter. Most also predict large-scale drying of the earth's surface over northern midlatitude continents in summer.[5] Drying in these regions could have significant effects on agricultural production and water demand.

Snowfall and snowmelt patterns to change. In basins with substantial snowfall and snowmelt, temperature increases could have three effects: an increase in the ratio of rain to snow in cold months, a decrease in the overall duration of snowpack season, and an increase in the rate and intensity of warm season snowmelt. As a result, average winter runoff and average peak runoff would both increase, peak runoff would occur earlier in the season, and drying of warm-season soil moisture would be faster and more intense.[5,9] All of these would affect reservoir storage capacity and operation.

Frequency and intensity of storms will change. Climatic extremes can produce severe social effects. As a result, there is great concern about what global climatic changes may do to the variability of climatic conditions (i.e., the frequency and intensity of extremes). In one study,[10] the total global area over which precipitation fell decreased, even though global mean precipitation increased; this implies more intense local storms and runoff. Other studies suggest that wet areas may become wetter and dry areas drier—exactly the opposite of what water managers and planners would like.[11,12]

Other changes in variability are also likely. There are some indications that day-to-day and year-to-year variability of storms in the midlatitudes will decrease. At the same time, evidence from both model simulations and empirical considerations suggests that the frequency, intensity, and area of tropical disturbances may increase.[2] More modeling and analytical efforts are needed in this area.

Runoff changes expected. Many estimates of changes in runoff because of climatic change have been developed using detailed regional hydrologic models of specific river basins.[5,13] The models suggest that some significant changes in the timing and magnitude of runoff are likely to result from quite plausible changes in climatic variables. For example, in a series of studies of basins in the western United States and in Greece, temperature increases of 3.6–7.2°F (2–4°C) with no change in precipitation result in decreases in runoff of up to 20 percent.[8,14–16]

Also, the authors of the 1995 IPCC report conclude the following:

> [The] flood-related consequences of climate change may be as serious and widely distributed as the adverse impacts of droughts. . . . There is more evidence now that flooding is likely to become a larger problem in many temperate regions, requiring adaptations not only to droughts and chronic water shortages, but also to floods and associated damages, raising concerns about dam and levee failure.[5]

Some regions may be subjected to increases in both droughts and floods if climate becomes more variable. Even without increases in variability, both problems may occur in the same region. In the western United States, for example, where winter precipitation falls largely as snow, higher temperatures would increase rainfall and decrease the amount of snow, contributing to high winter and spring runoff—the period when flood risk is already highest. At the same time, summer and dry-season runoff would decrease because of a decline in snowpack and accelerated spring melting.[14,15]

Begin planning now for the future

Although many scientific uncertainties remain, the Public Advisory Forum of AWWA believes sufficient scientific understanding exists of the current causes and future consequences of potential global climatic change to begin to track this issue and reevaluate current policies.

- Although water management systems are often flexible, adaptation to new hydrologic conditions may come at substantial cost. Water professionals should consider reexamining engineering design assumptions, operating rules, system optimization, and contingency planning for existing and planned water management systems under a wider range of climatic conditions.
- Agencies should explore the vulnerability of both structural and nonstructural water systems to plausible future climate changes, not just past climatic variability.
- Governments at all levels should reevaluate legal, technical, and economic approaches for managing water resources in light of possible climate changes.
- Water agencies should explore opportunities for partnerships with local, state, and federal agencies; transportation authorities; and electric utilities to reduce demand for fossil fuels by seeking increased efficiencies in building energy and automobile use, and development and use of alternative renewable energy sources.
- Cooperation of water agencies with leading US and international scientific organizations can facilitate the exchange of information on the state-of-the-art thinking about climatic change and its effect on water resources.
- The timely flow of information about global change from the scientific community to the public and the water management community would be valuable, and AWWA's Public Advisory Forum encourages the development and expansion of such lines of communication.

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About the authors: *The Public Advisory Forum (PAF), created by AWWA in 1993, is made up primarily of representatives of organizations or individuals with perspectives that have not traditionally been a part of AWWA. The PAF charge is to advise AWWA in matters of policy, programs, and services that concern consumers. Current or former PAF members who prepared this report are Peter Gleick (primary author), Jerry Biberstine, Allen Buckingham, Tony Dearness, Anita Highsmith, Joel McTopy, Larry Morandi, Jim Perron, Melissa Stanford (chair), and Linda Stevens.*