Climate Change and Water Resources: The Challenges Ahead
Kathleen A. Miller

Changes in water resource availability, water quality and the destructive potential of storms and floods will play a central role in determining how climate change will affect human well-being, and the functioning of the natural systems on which we depend. The critical role of water may appear obvious, given its importance for agricultural productivity, human health and the functioning of ecosystems. It is perhaps less widely understood that water also plays a key role in the functioning of the climate system. In fact, global warming and changes in the water cycle are intricately linked.

While we have only an imperfect understanding of the local-scale details of the changes to come, the scientific community now has considerable confidence in projections of some of the key features and broad-scale regional patterns of future changes in the world’s water resources. The evidence strongly suggests that many areas the world that are already grappling with intense competition and growing demands for scarce water supplies may face steadily worsening water supply conditions in the future. Everywhere, climate change will throw a new monkey wrench into the business of water resource planning and policy development because the climatic and hydrologic patterns of the past will no longer provide a reliable guide to the future.

Perhaps the most helpful way to begin grappling with future water resource changes is to start by taking stock of what we know, what we don’t know, and why. This analysis will first provide a rough outline of the current state of scientific understanding of the likely impacts of climate change on the world’s water resources. It will then turn to the implications of these changes – and particularly the implications of unavoidable uncertainties – for water resource planning and policy negotiations.

Scientific Understanding of Changes in Climate and the Water Cycle
There is consensus on the basic science of the greenhouse effect, and it is well understood. Some of the major greenhouse gases—water vapor, carbon dioxide, methane and nitrous oxide—occur naturally in the atmosphere. They play a critical role in the Earth’s energy balance because they trap enough outgoing infrared radiation to make the surface of the Earth warm enough to support life. Concerns about climate change arise from the fact that human activities are releasing large quantities of these substances—and other even more powerful manufactured greenhouse gases such as halocarbons—into the atmosphere. Because carbon dioxide and many of the halocarbons have very long atmospheric lifetimes, the increased concentrations are likely to result in an enhanced greenhouse effect in the future.

The climate system will react to such an increase in heat-trapping capacity by setting in motion processes that will adjust the Earth’s energy balance to a new equilibrium. These processes include the release of latent heat through increased evaporation, plant transpiration and precipitation— in other words, acceleration of the hydrologic cycle. Hydrologic changes are, thus, an integral part of global climate change. In addition to accelerating evaporation, warming also increases the moisture-holding capacity of the atmosphere. Atmospheric water vapor, in turn, is a powerful greenhouse gas, so increases in the water content of the atmosphere will create a positive feedback that will tend to amplify the warming that humans have initiated by burning fossil fuels and engaging in other activities that release greenhouse gases. It is estimated that the water vapor feedback may be large enough to roughly double the impact of an increase in carbon dioxide alone.

Cloud cover will also change. Clouds play a dual role — both amplifying warming by absorbing outgoing infrared radiation and producing a cooling effect by reflecting away incoming solar radiation. The net effect of cloud-cover changes will depend on the details of changes in cloud characteristics, altitude and location. It remains unclear whether cloud changes will have a positive or negative impact on global average temperatures.

Other positive feedbacks include the warming effect of shrinking snow and ice cover as a darker earth-surface reflects less sunlight back to space, and the impacts of
warming on natural sources and sinks of carbon dioxide and methane. Changes in the extent of wetlands (and consequent methane generation) and changes in the uptake and release of carbon from the oceans accompanied previous periods of warming and cooling. The expected effects of future warming include increased production of methane by tropical wetlands, and a decline in the ability of the world’s oceans to remove CO$_2$ from the atmosphere, because the solubility of CO$_2$ in seawater diminishes as the water warms.$^{5-6}$ In addition, we are generating other pollutants that play a role in the earth’s energy budget. For example, tiny particles from combustion, especially sulphate aerosols, tend to produce cooling by reflecting incoming sunlight, while dust and soot deposits on snow surfaces have an opposite impact.

These feedbacks and attendant sources of uncertainty are incorporated in model simulations of future climate, and they result in a range of temperature change estimates for any given change in greenhouse gas concentrations. The physical uncertainties, however, are small compared to our inability to foresee the course of human activities and the resulting emissions of greenhouse gases.

Future greenhouse gas concentrations will depend on the pace and characteristics of future global economic development, changes in energy technology, land use change and population growth. Most importantly, greenhouse gas emissions will depend on the policies that we put in place to reduce the amount of climate change that will eventually occur. Pessimistic scenarios, in which there is rapid population growth, slow technical progress and continued heavy reliance on fossil fuels, are projected to result in much larger climate changes by the end of this century than are more optimistic scenarios in which slower population growth is coupled with a shift to clean, highly resource-efficient technologies and a transition toward a service and information-based economy. For the lowest emission scenario examined, the Intergovernmental Panel on Climate Change’s (IPCC) Fourth Assessment Report projects that global average temperatures would increase by 1.1°C to 2.9°C by the end of the century.$^7$ The projected increase for the high-end emission scenario is estimated to fall in the range of 2.4°C to 6.4°C.$^8$ Thus, different emission scenarios account for much of the uncertainty surrounding future projections of global temperature changes.
Despite international efforts to negotiate limits on the growth of greenhouse gas emissions, those emissions have increased rapidly in recent years. Measured in terms of CO$_2$ - equivalent, annual global emissions of the major greenhouse gases grew by 70 percent between 1970 and 2004, with an almost 10 percent jump between 2000 and 2004. The current atmospheric concentration of CO$_2$ is estimated to be 381 ppm (parts per million), by far the highest level experienced over the past 650,000 years. In the middle of the eighteenth century, prior to major industrialization, the concentration of CO$_2$ in the atmosphere stood at 280 ppm.

We are thus on course to experience substantial climate change before today’s children have lived out their lives. In fact, there is compelling evidence that climate change is already occurring. The IPCC Fourth Assessment Report concludes that global average temperature increased by approximately 0.74°C in the hundred years up to 2006, and that eleven of the twelve hottest years in the instrumental record (since 1850) occurred between 1995 and 2006. Furthermore, this warming is already having substantial impacts on many natural systems including dramatic declines in summer sea ice across the Arctic, changes in species ranges, shrinking mountain glaciers, declining snow cover and changes in precipitation and runoff patterns.

With regard to water resources, the local difference between precipitation and evaporation determines the amount of water available for runoff and groundwater recharge. Both will change. Precipitation changes will be critically important, but evaporation, which is controlled by changes in other climate variables, such as temperature, humidity, radiation, and wind speed, will also play a major role.

For any given emissions scenario, regional temperature change projections are reasonably consistent across climate models, with warming most pronounced in the Arctic and over land masses. Regional precipitation projections are less consistent, but global average precipitation will almost certainly increase with warmer temperatures. For a middle-of-the-road emissions scenario, climate models are projecting a 5% increase in global average annual precipitation over land masses by the end of this century.

Warming will also tend to increase the intensity of rainfall and snowfall events because storms will be carrying heavier moisture loads. Cartoons sometimes portray...
global warming as leading to balmy tropical climates in currently cold locations. In reality, however, winter will still happen – and if it is cold enough to snow, the chances for a big snowfall will likely increase. When temperatures are above freezing, we can expect to see increases in the likelihood of deluges that may overwhelm storm sewers and cause localized flooding. In areas not on the receiving end of the storm track, dry spells are expected to lengthen and intensify as the warmer atmosphere accelerates the evaporation of any available surface moisture. In other words, in different regions and seasons, global warming will increase the potential for both droughts and downpours.

Such global-scale hydrologic changes don’t tell us much about how water availability, water quality or flood risks will change at the local level. We do know that the changes will be far from uniform. The fact that global average precipitation is projected to increase does not mean that it will get wetter everywhere and in all seasons. In fact, all climate model simulations show complex patterns of precipitation change, with some regions becoming much drier and others wetter than they are now. However, the estimated patterns of precipitation change differ somewhat from one climate model to the next.

At best, it is possible to glean a very broad-brush picture of the regional odds of drier or wetter future conditions by comparing the projections coming out of the current generation of climate models. That was one of the exercises that the IPCC carried out in its recent assessment of the state of scientific understanding of climate change and its impacts. The research team examined future climate simulations from twenty-one different global climate models and evaluated the extent of agreement across the models on the direction and size of regional temperature and precipitation changes. The effort found that almost all climate models show that global warming will lead to wetter conditions at far northern and southern latitudes – in places such as Northern Canada, Russia and Antarctica. Runoff in the high latitudes of North America and Eurasia is expected to increase by ten to forty percent, based on these model projections. Greater total rainfall will also almost certainly occur in a band along the equator, especially over the oceans.
In the semi-arid sub-tropics, on the other hand, there is strong agreement across models that many areas are likely to become even drier. In particular, a drying trend appears likely for the Mediterranean basin; the U.S. Southwest and Northern Mexico (especially in winter); and Southern Africa and parts of Australia (in southern-hemisphere winter). The explanation for these trends is that warming will intensify the existing mechanisms by which the atmosphere moves moisture out of the subtropics and transports it to higher latitudes. In particular, the drying of subtropical land areas will tend to be amplified by the fact that any available surface water will evaporate more readily. Precipitation reductions also appear likely in those areas because the mid-latitude storm tracks will tend to move poleward while the high-pressure systems centered over the dry sub-tropics will expand in size. These changes will cause areas at the poleward edges of the sub-tropics to dry out. The estimated declines in average annual runoff in these areas are on the order of 10-30%, by the end of this century, assuming a middle-of-the road emissions scenario. The changes would be even larger if we continue on a high emissions path into the future. These findings are important and unwelcome news because some of the areas that appear to be facing a significant risk of desiccation are already struggling to stretch limited water supplies to meet the needs and desires of large and rapidly growing populations.

Apart from the broad scale regional patterns of likely wetting and drying, we have only a very hazy picture of how global warming will affect precipitation and water supplies at any given location. In general, there is much more uncertainty about changes in regional precipitation patterns than there is about regional temperature changes. The uncertainty arises partly from the strong latitudinal differences in projected precipitation changes. In the northern hemisphere, uncertainty about the direction of change in average annual precipitation is greatest in the mid-latitude transition zone between the drying sub-tropics and the far northern areas that are likely to become wetter. That includes most of the United States.

Uncertainty also arises from the limited ability of global climate models to capture all of the details of the physical processes that determine the location, amount and intensity of precipitation. For example, even slight differences in the location of storm
tracks in climate simulations carried out by different models can have large consequences for the estimated regional distribution of rainfall.

Coupled Atmosphere-Ocean General Circulation Models (AOGCMs) are currently the primary tool used to analyze the response of the climate system to increasing greenhouse gas concentrations, and changes in other factors, both natural and human-caused. The major climate models include tens of vertical layers in the atmosphere and the oceans, dynamic sea-ice sub-models and simulations of the effects of changes in vegetation and other land surface characteristics.\textsuperscript{18} The atmospheric part of a climate model is a mathematical representation of the behavior of the atmosphere based upon the fundamental, non-linear equations of classical physics. Climate models use a three-dimensional horizontal and vertical grid structure to track the movement of air parcels and the exchange of energy and moisture between parcels.

Despite tremendous advances in computing capability, it is still very time consuming and costly to use these models to simulate future climates. In order to economize on computing costs and produce results in a reasonable amount of time, most models use a relatively coarse horizontal resolution. Doing so enables the models to capture gross regional patterns, but does not allow them to accurately depict the effects of mountains and other complex surface features on local climates, nor to resolve fine scale weather events such as thunderstorms. The century-long model runs described in the recent IPCC Assessment Report typically use grid blocks that are about 180 kilometers on a side.\textsuperscript{19} A major downside of such coarse resolution is that it tends to smooth out important landscape features, so most AOGCMs see the mountains of western North America as a set of smooth ridges. Such smoothing leads to unrealistic reproduction of precipitation patterns – too little rain and snow falls on the mountains, and too much moisture makes it to the downwind side. Furthermore, neighboring mountain ranges tend to be blended together rather than being clearly distinguished. In the western U.S., for example, coarse resolution climate models tend to show the Great Basin as being wetter than the desert that it really is. That is because they see it as located on the upslope to the Rockies and don’t adequately capture the rain shadowing effect of the Sierra Nevada Mountains. Clearly, raw AOGCM output can’t be used directly to estimate changes in precipitation and runoff patterns, especially in mountainous areas.\textsuperscript{20}
Climate impacts researchers have developed several “downscaling” methods to improve the realism of regional climate change projections. The simplest method is to adjust an observed high-resolution climate record by change factors derived from a coarse resolution AOGCM. There are also statistical downscaling methods that can be tuned to correct for biases in a model’s representation of current climate. Another method involves using a high-resolution regional climate model to focus in on a particular area, where the boundary conditions for the regional model are driven by a coarser resolution AOGCM. Such methods can resolve some of the shortcomings of AOGCMs, but they are still limited in their ability to give reliable local-scale projections for future precipitation.\(^{21}\) This is an area of active research, but significant progress will likely take many years.

**Water Resource Impacts**

Our current limited ability to simulate future local-scale precipitation changes means that most of what we know with high-confidence about how climate change will affect water resources in mid-latitude areas, such as most of the United States, comes from the direct impacts of warmer temperatures on water availability and water quality. These impacts include shorter snow seasons, an earlier peak in spring runoff, sea-level rise, and increased evaporative losses from open water surfaces, soil, shallow groundwater, and water stored in vegetation.

Even these “sure-bet” changes may be quite problematic. Shorter snow seasons, in particular, could significantly reduce usable water supplies in large parts of the world that now draw their water from rivers supplied by the seasonal melting of mountain snowpacks and glaciers. In such areas, snow and ice are nature’s reservoirs. They store moisture over the course of the winter and release it during the spring and summer when it is likely to be valuable for downstream irrigation and urban uses. Future warming will cause runoff to occur earlier in snow-fed river systems – increasing the risk of winter and spring flooding, while reducing water availability in the late summer and early fall. Where streams are fed by glaciers, increased melting will tend to augment summer streamflows in the near-term, but glacial wastage will eventually reduce (and in some cases exhaust) that source of supply.\(^{22}\) The trend to earlier peak streamflow is already
apparent in mountainous areas of the Western United States, where warming temperatures as of 2002 had moved the spring runoff peak about one to four weeks earlier than it had been in 1948.23

Another troubling “sure-bet” is that warmer climate will make sea level rise inevitable, due both to the thermal expansion of the oceans and the melting of land-based ice. Rising sea levels would lead to impaired water quality for coastal cities that rely upon groundwater to serve their populations because saline water is likely to intrude into these aquifers.

Surface water quality is likely to be impaired directly by warmer temperatures because reduced dissolved oxygen levels under warmer conditions will cause natural self-purification processes in lakes and streams to slow down, while warming will tend to favor the growth of algae and bacteria. Water quality will suffer further if streamflows decline because pollutants will become more concentrated in the reduced water volumes. Intense rainfall events will also lead to episodes of poor water quality by washing sediment and a variety of pollutants including pesticides, organic matter and heavy metals into water bodies.

Even though only limited information is available about future changes in water supplies, water quality and flood risks, it is clear that the future will not be like the past. It is also clear that there is a potential for rather large and problematic hydrologic changes over the course of the coming decades. While there are very real uncertainties, we are not totally clueless. In fact, the scientific community is quite confident about the general character of several future changes, including projections that:

- earlier snow melt will alter the timing of streamflows in mountainous and high-latitude regions;
- sea levels will continue to rise;
- precipitation and runoff will tend to increase in far northern Eurasia and North America;
- the likelihood of heavy downpours will increase, especially in areas where there is an overall increase in precipitation, and;
some areas of the sub-tropics face a substantial risk of declining water availability.

It would be useful to begin planning for adaptation by focusing on those types of changes while enhancing our ability to cope with the remaining uncertainties.

The available evidence is adequate to allow us to identify some significant “hot spots” across the globe where the effects of climate change on water will likely present particularly difficult challenges. These are typically heavily populated regions facing a high likelihood of either significant reductions in water supplies or significant increases in flood risks.

In the wet tropics, densely inhabited Asian mega-deltas, such as the Mekong and Ganges-Brahmaputra are especially at risk for increased flood damages due to the combined impacts of sea level rise and increased river runoff during the monsoon season. Periods of intense precipitation over other heavily populated low-lying areas would increase flood-related risks to property, infrastructure and human safety. Some of that damage could be avoided by anticipating the altered risks and adjusting land-use plans, and infrastructure investments to accommodate the changes.

Another highly likely change for which we should begin preparing is the projected drying of sub-tropical areas. In the Mediterranean basin, the Near East, much of the U.S. West and parts of Central Asia, water is already very scarce relative to both population and current total water use. Further drying would be costly for these regions, and could delay progress toward internationally-agreed objectives for improving access to safe drinking water and sanitation. Runoff reductions would increase competition for available water resources and would increase the already intense pressures on aquatic ecosystems.

*Institutional Factors Affecting Adaptation*

Institutions governing water use—ranging from the local to international scale—will play an important role in determining the human and environmental impacts of increasingly scarce water in these regions. Institutional definitions of water rights and
obligations also determine whose interests are most at risk and who will bear the cost of any significant change in water availability.

For transboundary rivers and other internationally shared water sources, international compacts address the rights, obligations and allocation of risks among the countries sharing the resource. Sharing rules, in particular, affect both the distribution of the pain of supply reductions and the stability of cooperation. Some bilateral compacts specify a fixed allocation to one nation, leaving the other to absorb the risk associated with year-to-year fluctuations or a long-term decline in average flow but in many cases allocation rules and enforcement mechanisms are not clearly defined. Climate change could destabilize such agreements if it leads to conflicts over water allocation or causes a sharp drop in one or another country’s perceived payoffs from continued cooperation. In addition, compliance with the terms or spirit of an agreement could degrade as nations individually struggle to deal with changing water supplies. While armed international conflict over water is unlikely, a substantial decline in water availability or deterioration of water quality could create international tensions, especially if the possibility of such changes had not been anticipated when the terms of an agreement were negotiated.

The effects of changes in water availability within individual nations will depend importantly on the institutions that govern water allocation across various types of use and user groups. These institutions vary considerably across different geographical settings, countries and regions within individual countries. In some cases, local water users have substantial individual, corporate or small-group autonomy in deciding how to manage their water resources. In other cases, government agencies make decisions on water project construction and management, sometimes with limited regard to equity, efficiency or environmental stewardship. In addition, in many developing countries, informal settlements on the fringes of rapidly growing urban centers have little representation in water allocation decisions, and may be situated in areas that are especially vulnerable to floods and landslides. In such cases, under-represented communities and environmental values stand to suffer further if water availability declines or flood risks increase.
The diversity of water institutions can be understood as the product of historical efforts to solve the different types of problems and conflicts that arose in each context. In the western United States, for example, the doctrine of prior appropriation originated in early efforts to encourage settlement and to manage conflicts between successive waves of immigrants into the region. The “first in time, first in right” rule functioned to protect early investors in irrigated agriculture from competing water diversions by newcomers and it clarified who would be able to use water during times of shortage. It also encouraged the more junior water users to invest in reservoirs into which they could divert water during winter and spring before the start of the irrigation season. The West is now dotted with dams and reservoirs of various sizes and types, but the environmental consequences of all of that dam-building and the fact that the best sites have already been taken makes new reservoirs a less feasible option for the future. The institutional legacy of solutions to past problems is significant in the present context because it not only affects the efficiency and equitability of current water resource use, but it also affects our options for adapting to climate change. Although institutions evolve in response to changing circumstances, the process is often slow, painful and contentious. That being said, the solutions to water resource problems engendered by climate change will have to be worked out starting from the existing institutional context. The process of adaptation is thus likely to differ markedly across locations.

*Western U.S. water resources and climate change adaptation*

In the western U.S., the risk that a water user faces of experiencing a supply shortage depends on the seniority of water rights owned by that party. In addition, rights to stored water are legally distinct from rights to natural flows, and the characteristics of each right depend on the historical pattern of use. The vulnerability of various western water interests to climate change is a rather complex question. Seniority will be important, but other important factors could include differential reliance on stored water as opposed to natural flows, and historically determined seasonal limits on the exercise of some water rights.
In most cases, the most senior water rights on western streams are used for irrigated agriculture. In fact, in the seventeen contiguous western states, irrigation accounts for approximately 90 percent of consumptive water use. Some types of water use, such as instream flows for recreation or maintenance of aquatic habitats, have only recently been recognized as eligible for protection within the priority hierarchy. As a result, efforts to preserve these values must contend with the established claims of more senior users.

While water use statistics still reflect the region’s agricultural history, the West is a rapidly changing place. Western residents are increasingly interested in environmental and quality of life issues, and the “new” West is urban, young and growing rapidly. Recent census figures indicate that nine of the twelve fastest growing states in the United States are located in the West, with dry Nevada, Arizona and Utah topping the list. The U.S. West is thus well-acquainted with adapting to change, and climate change can be seen as yet one more type of change that will affect the region’s resource base. Population growth, increasing environmental concerns and resulting changes in the character of water demands have led to increased competition for western water, especially during drought periods.

Some of the approaches that western water users have devised to accommodate ongoing changes in water demands are likely to play a role in managing the new stresses introduced by climate change. One means by which cities have sought to reduce their vulnerability to droughts has been to purchase or lease more senior water rights. There is considerable variability from one state to the next in the cost and time required to work out such arrangements. Furthermore, to work well, water markets require high quality records on actual patterns of use, and such records are lacking in some states. Also required is a mechanism to protect other established water users from harm that could result from a change in the location or type of use. That potential harm arises from the web of physical interdependencies that develops in a stream basin, as return flows from each water diversion become part of the supply for downstream users. So, even where it is legally permitted, the process of moving the use of water from willing sellers to willing buyers may be cumbersome and contentious – or in some cases, prohibitively difficult.
Water markets will continue to play a role in realigning western water use with growing populations and changing demands, but permanently drying up agricultural land may not be the most effective way to promote flexible adaptation to climatic variability or to uncertain climate changes. Shorter-term water rental agreements, water banking arrangements and option contracts may provide a less contentious and more efficient alternative for protecting urban and environmental water uses from drought-related shortages. Some urban water utilities are incorporating these more flexible water market options in their toolkit for managing their vulnerability to droughts. The Metropolitan Water District of Southern California (Metropolitan) – a wholesale water supplier for urban water providers throughout much of Southern California – has executed a number of such agreements with agricultural water districts. In addition to numerous short-term water leases to cover drought-related supply shortfalls, Metropolitan has executed longer-term option contracts. For example, in 2004 Metropolitan and the Palo Verde Irrigation District entered into a 35 year agreement that gives Metropolitan the option to call for no irrigation on up to 29 percent of the land in the district in a given year. In exchange, the participating landowners receive an up-front payment to secure the option as well as annual water rental payments in years in which the option is exercised. Metropolitan estimates that the arrangement is capable of creating a water supply of up to 110,000 acre-feet.

Purchases of agricultural water aren’t the only way that western cities are dealing with water scarcity. Western cities also are increasingly turning to “demand management” – including conservation incentives, metering and increasing block-rate pricing to keep up with population growth. These programs can be quite successful in reducing per capita consumption, but in so doing, they also remove some of the slack for further demand reductions to respond to drought emergencies.

Reservoirs have played an important role in smoothing out the sharp seasonal peaks and troughs in water availability from western snow-melt dominated rivers, and they give water users some protection from short-term droughts. If their operation can be adjusted to respond to the earlier timing of peak snow-melt, reservoirs could help to soften that impact of a warming climate – but in most locations neither existing nor feasible new artificial reservoirs would be sufficient to fully offset the loss of natural
storage in the snowpack. In addition, storage projects can’t make water, and evaporative losses from surface reservoirs are expected to increase in a warmer climate. That means that building new reservoirs won’t help to address the possible long-term declines in average annual runoff.

In developing options for adapting to climate change, individual water-interested entities don’t need to work alone. Watershed planning efforts have sprung up all across the West, often with the active involvement of federal and state agencies. These processes have typically focused on engaging all relevant stakeholders in developing pragmatic solutions to pressing local problems. Although most of these dialogs have dealt only with near-term issues, the culture of collaboration that these efforts seek to promote could play a valuable role in working out innovative approaches to responding to the long-term risks posed by climate change.

At a larger scale, the ongoing multi-year drought in the U.S. Southwest prompted the U.S. Secretary of the Interior to ask the Bureau of Reclamation and other federal agencies to collaborate with the states in the Lower Colorado Basin to re-examine the operation of the major federal dams on that part of the Colorado River. Their task was to develop proposed guidelines for the coordinated management of storage in Lake Powell and Lake Mead and for water deliveries during periods of shortage. The evaluation process engaged numerous potentially affected interest groups as well as state and federal representatives, and concluded with recommending a precautionary strategy aimed at balancing the risk of supply shortages against other objectives. Climate change entered into the discussion, and the Secretary of the Interior cited it as the rationale for recommending that the guidelines be treated as “…interim in duration” – thus explicitly providing for future adjustments on the basis of experience and new information.38

Planning for Adaptation

Climate change is cropping up as a new issue on the planning agenda for water managers, especially in Europe, Australia and, more recently, the United States. In the United States, the American Water Works Association Research Foundation (Awwa Research Foundation) and the National Center for Atmospheric Research (NCAR)
contributed to the process by partnering to produce an educational primer on climate change, focused on the information needs of the urban water provider industry. In 2004, my colleague, David Yates and I began gathering input from water industry professionals who had already taken steps to evaluate their systems’ vulnerabilities to climate change, and to manage their risks. We used their input as case study material to make climate change more tangible to other water industry professionals.

In just the past few years, we have seen burgeoning interest in the subject across the water utility industry as well as more broadly among citizens interested in water policy and management. In particular, publication of the IPCC Fourth Assessment Report has helped to rivet the attention of the water management community and the general public on climate change and its implications for resource systems. Urban water providers, including several major utilities in the western states are now starting to take a leadership role in planning for adaptation to the impacts of climate change. Following a meeting in San Francisco on public utilities and climate change in January 2007, some the nation’s largest urban water providers led by the San Francisco Public Utilities Commission got together, and informally calling themselves “The Group of Eight,” have pledged to become leaders in implementing a proactive approach to planning for adapting to climate change and for mitigating the emissions of greenhouse gases associated with pumping, purifying and delivering drinking water and treating wastewater.

These utilities are cognizant of the current uncertainties regarding the effects of climate change on their local water resources, and they are handling it as a new source of risk. Work is underway to develop methods to incorporate consideration of climate-change risks in ongoing water utility planning efforts. For example, our team at the National Center for Atmospheric Research is collaborating with a set of water utility partners in a pilot project to characterize the uncertainty surrounding future changes in local-scale water resources. The project will then use that information to assess vulnerabilities, and to evaluate the possible performance of alternative management and system development options. The goal of the project is to develop both an assessment process and a set of decision support tools that will make it easier for water utilities to consider the impacts of climate change, and associated uncertainties, in the course of their ordinary planning activities. By explicitly accounting for uncertainty, this method
of analysis is likely to point to choices that will work well despite the fact that we can’t perfectly forecast how climate or most other relevant variables will change in the future. So, the assessment process will help organizations make decisions that are: robust to a wide range of possible changes; readily adaptable to changing circumstances or new information; and resilient to surprise.

Conclusion

It really isn’t too early to begin thinking about planning for adaptation to the likely effects of climate change. Future vulnerabilities to shrinking water supplies, altered flood risks and other climate change impacts will depend importantly on the evolution of settlement patterns and of land and water use over the coming years. While needed, planning efforts by single organizations or single sectors won’t be sufficient. Rather, it will be important to develop forums that will allow consideration of the big-picture issues, and that will promote clear communication and collaborative problem solving across all relevant interests. As we approach water resource planning for the coming century it will be increasingly important to recognize that past water resource conditions will not be a reliable guide to the future, and that our limited ability to forecast local-scale hydrologic changes makes uncertainty unavoidable.

It isn’t necessary or even sensible to try to immediately work out full-blown plans for adapting to a different future climate. But it is important to start building consideration of the possible effects of climate change into any current decisions that could have a lasting impact on vulnerability to climatic hazards or on the ease or difficulty of adapting to climate-related changes as they occur. It is also important to work toward a process for better coordination of the myriad decisions influencing the use and management of water resources. A good first step will be to focus on improving our ability to manage the effects of the types of hydrologic extremes – droughts and floods – that we know can occur even without global climate change. Beyond that, it would be good to take cues from the urban water industry’s emerging attempts to grapple with the risks posed by climate change. Their efforts endorse the value of systematically exploring options and taking a risk management approach to selecting the path forward.
NOTES

1 Institute for the Study of Society and Environment, National Center for Atmospheric Research, P.O. Box 3000, Boulder CO 80307.


5 Ibid.


7 The IPCC 2001 assessment process developed a set of emission scenarios to serve as a basis for comparable climate model projections. They represent a wide range of possible futures. The high and low emission scenarios referenced here are described as follows: A1FI = rapid economic growth, continued reliance on fossil fuels, converging world living standards, world population peaking in mid century and declining thereafter. B1 = population as in A1, rapid change toward service and information economy, emphasis on clean, highly resource-efficient technologies. 

8 Meehl, et al.


11 IPCC.

12 Meehl, et al.

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15 Richard Seager et al. “Model Projections of an Imminent Transition to a More Arid Climate in

It should be noted that the summer monsoon that supplies rainfall to northern Mexico and parts of the U.S.
Southwest is not well simulated in most climate models, and research on how that source of precipitation
would change is in its infancy.

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Operations for Lakes Powell and Mead-- Final Environmental Impact Statement. U.S Bureau of
Reclamation, Lower Colorado Region. Available online at:

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17 D. Nohara, A. Kitoh, M. Hosaka, and T. Oki, “Impact of climate change on river runoff,” Journal of
Hydrometeorology, 7 (2006), 1076-1089. These estimates are averages based on climate projections from
nineteen different climate models.

18 Le Treut, et al.

19 Ibid.

20 Filippo Giorgi and Linda O. Mearns,” Approaches to the Simulation of Regional Climate Change: A

21 Robert L. Wilby et al., Report Prepared for the IPCC Task Group on Data and Scenario Support for
Impacts and Climate Analysis (TGICA), Guidelines for Use of Climate Scenarios Developed from
Statistical Downscaling Methods (2004), available online at http://www.ipcc-

22 Pelto, M. S., 1993. Changes in Water Supply in Alpine Regions Due to Glacier Retreat, American
Institute of Physics Conference Proceedings: The World at Risk: Natural Hazards and Climate Change,
277: 61-67. Also see: Chris Hopkinson and Gordon J. Young, ”The Effect of Glacial Wastage on the Flow
1745-62.

23 Stewart, I.T., D. R. Cayan, and M. D. Dettinger, “Changes Toward Earlier Streamflow Timing Across
Western North America,” Journal of Climate 18, no. 8 (April 2005), 1136-1155.

24 Charles J. Vörösmarty, et al., “Global Water Resources: Vulnerability from Climate Change and

26 Here, the word “institutions” refers not to organizations, but rather to the body of formal constraints (rules, laws and treaties) and informal constraints (customs, conventions and behavioral norms) that guide individual and organizational behavior regarding the use and management of the resource. See e.g.: Douglass C. North, “Economic Performance Through Time,” *The American Economic Review* 84, no. 3 (June 1994), 359-368.


33 For example, some states define specific calendar dates within which an irrigation right can be exercised, while others limit the period of use to an amorphously-defined “irrigation season.” In the first case, an irrigator having first priority for naturally occurring flows during the months of May –August, but no access to storage, could be vulnerable to a seasonal shift in flow timing that caused the spring freshet to peak a month earlier and summer flows to dwindle. It is not yet clear if imprecisely defined irrigation seasons will be allowed to shift to reflect earlier snowmelt and longer growing seasons. In short, seniority, per se, is not the only determinant of vulnerability to the effects of climate change. Thanks to Douglas Kenney, University of Colorado School of Law for this information. See: Western Water Assessment – Water Rights and Climate Change Project website at: [http://wwa.colorado.edu/resources/western_water_law/water_rights_and_climate_change_project.html](http://wwa.colorado.edu/resources/western_water_law/water_rights_and_climate_change_project.html)

Consumptive water use is that portion of the water diverted from a source that is lost to evapotranspiration or percolation to deep, unusable aquifers. Irrigation typically consumes about half the water diverted.


39 Miller and Yates.


41 Awwa Research Foundation Project # 3132.