GRAPPLING WITH UNCERTAINTY: WATER PLANNING AND POLICY IN A CHANGING CLIMATE

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ABSTRACT It has become increasingly clear that human-caused global warming is occurring and will undoubtedly continue into the foreseeable future. Acceleration of the hydrologic cycle and sea-level rise will be inevitable consequences of such warming, resulting in large and widespread impacts on water resource availability, flooding hazards and water quality. While the general characteristics of future hydrologic changes are beginning to emerge from climate modeling efforts, the specific
regional details of changes in precipitation and runoff are far from clear. Substantial uncertainty arises from limits on our ability to measure and model the relevant climate system details that drive precipitation variability. An even larger source of uncertainty is the unknown future trajectory of greenhouse gas emissions. Water planners are thus caught in a conundrum of knowing that future water resource conditions are likely to be very different from those of the past, but not knowing the magnitude, or perhaps even the direction of those changes. Planning for adaptation to climate change may be further hindered by the politicization of the climate change issue and by concerted efforts to create public confusion regarding the nature of the scientific process and the credibility of research results. The way forward will require attention to both objectives and process. In particular, it will be important to focus on planning options that are robust to uncertainty, resilient to surprise, and readily adaptable to changing conditions and new information. With respect to process, there will be a growing need to facilitate representation of the wide variety of ecological, water use, and aesthetic values that can be derived from water resources in a way that avoids derailment by interests seeking to deny the reality of climate change. Effective adaptation will require an institutional environment that helps to build shared understandings of rights, obligations, and the likely effects of alternative adaptation options.

I. INTRODUCTION

There is now compelling scientific evidence that global climate change will have significant and far-reaching impacts on water resource availability, water quality, flood risks, and the sustainability of ecological resources. A long-term warming trend is clearly evident, and it cannot be explained by natural sources of climate variability. Because atmospheric

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1. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE AND WATER: IPCC TECHNICAL PAPER VI 140 (B. Bates et al. eds., 2008) [hereinafter IPCC TECHNICAL PAPER VI].
concentrations of greenhouse gases are continuing to grow almost unabated, this warming will undoubtedly continue into the foreseeable future.3

Changes already are apparent in temperatures, atmospheric moisture, and precipitation patterns that are fully consistent with model projections of warming due to increased greenhouse gas concentrations.4 The warming that has occurred over the past few decades has contributed to rising sea levels (largely due to thermal expansion of the oceans), reductions in Arctic sea ice, losses in land-based ice, changes in precipitation intensity, and earlier snow-melt runoff in many mountainous areas across the globe.5

The rapidly accumulating body of scientific research is helping to clarify the broad features of the water resource changes that will accompany future global warming. Future warming is expected to increase global average annual precipitation and change its regional distribution — leading generally to wetter conditions in the far-north and drying in many parts of the subtropics.6 At mid-latitudes, especially at the watershed scale, future changes in the total quantities and temporal variability of precipitation and runoff remain difficult to predict.7

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4. IPCC Synthesis Report, supra note 3, at 23.


Uncertainty is hardly a novel concept in the water policy and management arena, but prospective climate change upsets established approaches for understanding and managing hydrologic uncertainty. Climate change also introduces new uncertainties regarding the value of water in alternative uses. Warmer temperatures and shifting precipitation regimes will cause changes in domestic, industrial, and agricultural water demands. Furthermore, it will alter the functioning of aquatic ecosystems and their ability to generate ecosystem services such as water purification and fish and wildlife sustenance. While we can foresee the general nature of this suite of supply and demand side changes, our ability to quantify these impacts at relevant local scales remains extremely limited.

It has been widely noted that climate change will reduce the accuracy of standard engineering approaches for evaluating water resource reliability and flood hazards. In particular, water managers have historically relied on rather short hydrologic records to estimate the severity and likelihood of high or low stream flow conditions. Such an approach misses both the possibility of long-term natural climate regime shifts and the impacts of anthropogenic climate warming. As urban water providers and other members of the water management community have become more aware of the inadequacy of traditional assumptions, they have begun to explore new methods for incorporating information about climate change in their long-range planning. It is relatively straightforward to update engineering practices to reflect a changing understanding of hydrologic uncertainty, but a similar attempt to update water law will likely present greater challenges.

It would be fair to say that growing uncertainty will be one of the key challenges posed by climate change for water planning and policy formation. When considering proposed changes in water law to facilitate effective adaptation to climate change, we will need to directly confront the challenge of increasing uncertainty. This new policy context also presents an

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opportunity to think more broadly about how we want to manage our water and what institutional changes might be appropriate to maintain a desirable balance among the many values that can be derived from water resources. In thinking about that balance, it is important to understand the fundamental interconnections among all of the water uses and other activities that affect the flow or quality of water as it moves through a watershed or groundwater system. Any substantial change in total water availability, flow variability, seasonal timing, or water quality characteristics may have impacts reverberating across this entire web of interconnections.

Two threads appear especially relevant to a discussion of the role of water law in facilitating adaptation to climate change. The first relates to the tension between the value of certainty and the need for flexibility. The second relates to the need to manage the interactions among multiple uses of a water resource to avoid harmful externalities and to ensure adequate provision of resource services that are best characterized as public goods.

Regarding the first thread, a general observation is that increased uncertainty makes flexibility a more desirable attribute for the institutional arrangements governing water allocation and the regulation of water-related activities. Doremus and Hanemann argue that this need runs counter to the historical thrust of much of the current body of water law, which has focused on creating secure expectations for water availability and freedom from flood-related losses—e.g., by promoting investments to stabilize flows. However, legal certainty regarding how rights and obligations will change under any specific future climate realization can promote effective adaptation. It can do so by clarifying options for negotiations, thus creating flexibility and reducing the potential for conflicts.

Regarding the second thread, the legal community has long recognized that water is characterized by intrinsic interconnections among different uses and values. Any activity that consumes or manipulates water, alters watershed characteristics, or affects water quality has the potential to affect other uses and ecosystem services flowing from the resource. In general, the significance of these potential spillover effects tends

to increase with increasing water use relative to natural flows, and much of water law can be understood as an effort to manage these interactions to avoid undue harm. To understand how this body of law may affect adaptability to climate change, it is useful to consider how changes in climate could affect these interconnections.

There may be physical impacts on the web of water-use externalities. For example, warmer temperatures may increase evaporative losses and reduce return flows from irrigation diversions, thus reducing supply security for other water users. In addition, the adverse impacts of a given rate of diversion on water quality, water temperatures, and aquatic ecology are likely to be worsened by reduced natural flow volumes and warmer ambient stream temperatures. In turn, such changes would narrow the window for environmentally acceptable use of stream water for power-plant cooling, requiring changes in the operation of water storage facilities. Physical changes in flow regimes also might interact with legal definitions of water rights to reallocate the risk of a shortfall between different sets of water users. For example, where fixed calendar dates have been used to define water diversion rights, storage rights, or interstate compact delivery obligations, a shift to earlier seasonal runoff could potentially increase water availability for some users while reducing it for others.14

Issues that should be considered include the extent to which there is legal clarity regarding who bears the risk associated with such changes and whether that allocation of risk is equitable, economically efficient, and environmentally responsible. I propose these three criteria as useful cornerstones to organize an analysis of the extent to which a set of legal arrangements facilitates effective adaptation to the impacts of climate change on water resources.

In the following discussion, I will first provide an overview of the current state of scientific understanding regarding the impacts of climate change on water resources. I will then discuss the problem of planning for adaptation to the impacts of climate change – first from the perspective of urban water utilities and then more broadly from a watershed perspective. That discussion will highlight the role of decision support tools to facilitate analysis of options and provide transparency for multi-stakeholder negotiations. I will then touch upon the role of law

in promoting effective forums for such negotiations and conclude with observations on lessons that can be learned from current efforts to incorporate consideration of climate change in water policy and planning.

II. CLIMATE CHANGE—STATE OF THE SCIENCE

A. Global Overview

While I have emphasized the increased uncertainty that climate change poses for water policy and planning, it is important to understand that we are not entirely in the dark. The basic processes governing the role of water in the climate system are well-understood, and a good deal is known about how the hydrologic cycle will respond to increased concentrations of greenhouse gases. If we want to promote effective adaptation to climate change, it is helpful to begin by taking stock of what we do and do not know about how climate change will affect water resources.

One thing that we surely know is that global warming and acceleration of the hydrologic cycle are inextricably linked. We also know that human activities are altering the Earth’s energy balance by releasing into the atmosphere large quantities of heat-trapping gases, including carbon dioxide, methane, nitrous oxide, and other more powerful and long-lived manufactured greenhouse gases such as halocarbons. The climate system will react to such an increase in heat-trapping capacity by setting processes in motion 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, thereby causing acceleration of the hydrologic cycle. Thus, hydrologic changes are an integral part of global climate change.

Warming also increases the moisture-holding capacity of the atmosphere, creating a positive feedback that will tend to amplify — perhaps roughly doubling — the initial warming caused by human activities. Other positive feedbacks include the
warming effect of shrinking snow and ice cover as a darker earth-surface reflects less sunlight back to space, as well as the impacts of warming on natural sources and sinks of carbon dioxide and methane. For example, future warming could increase the production of methane by tropical wetlands and reduce the ability of the world’s oceans to remove CO₂ from the atmosphere, because the solubility of CO₂ in seawater diminishes as the water warms.

Cloud cover also will 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. It remains unclear whether cloud changes will have a positive or negative impact on global average temperatures. The outcome will depend on the details of changes in cloud characteristics, altitude, and location. 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, resulting 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. So far, most assessments of the future trajectory of climate change have relied on a handful of hypothetical emissions scenarios that differ on the basis of assumed rates of technical change, population growth, pace of economic growth, and organization of the global

FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 97 (S. Solomon et al. eds., 2007) [hereinafter Le Treut et al., Historical Overview].

21. Id. at 21–22.
22. Id. at 21–22.
23. IPCC Working Group I, supra note 5, at 3.
24. Id. at 9.
25. See Gerald Meehl et al., Global Climate Projections, in CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS. CONTRIBUTION OF WORKING GROUP I TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 747 (S. Solomon et al. eds., 2007) [hereinafter Meehl et al., Global Climate Projections].
26. IPCC Working Group I, supra note 5, at 3.
27. Id.
28. Meehl et al., Global Climate Projections, supra note 25, at 828.
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2010] 29 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.30 The projected increase for the high-end emission scenario is estimated to fall in the range of 2.4°C to 6.4°C.31 Thus, different emission scenarios account for much of the uncertainty surrounding future projections of global temperature changes.

At present, the disappointing outcome of the 2009 Copenhagen Conference of Parties suggests that the global community is unlikely to significantly slow the pace of rising greenhouse gas emissions any time soon. If we continue on the present course, atmospheric concentrations of greenhouse gases could increase more quickly than most pessimistic scenarios that were considered in the IPCC’s Fourth Assessment Report.32

B. Moving from Global Climate to Regional and Local Scale Water Availability

Regional temperature change projections are reasonably consistent across climate models, with warming most pronounced in the Arctic and over land masses.33 Regional precipitation projections are less consistent, but climate models typically project an approximately 2% increase in global average annual precipitation for each degree Celsius of warming.34 The changes will be far from uniform.35 The fact that global average precipitation is projected to increase does not mean that it will get wetter everywhere and in all seasons.36 In fact, all climate model simulations show complex patterns of precipitation change, with some regions becoming much drier and others turning wetter than they are now.37

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29. The IPCC Third Assessment process developed a set of emission scenarios to serve as a basis for comparable climate model projections. NEBOJA NAKICENOVIC ET AL., INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, EMISSION SCENARIOS 5 (2000).
30. Meehl et al., Global Climate Projections, supra note 25, at 749.
31. Id. at 749.
32. WMO reports that global atmospheric concentrations “...of carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O) have reached new highs in 2008 with CO2 at 385.2 ppm, CH4 at 1797 ppb and N2O at 321.8 ppb: higher than those in pre-industrial times (before 1750) by 38%, 157%, and 19%, respectively.” WORLD METEOROLOGICAL ORG., supra note 3, at cover page.
33. Christensen et al., Regional Climate Projections, supra note 6, at 907.
35. Christensen et al., Regional Climate Projections, supra note 6, at 914.
36. Id. at 896.
37. Id. at 850.
The estimated regional patterns of precipitation change differ somewhat from one climate model to the next.\textsuperscript{38} A very broad-brush picture of the regional odds of drier or wetter future conditions is available from the climate model inter-comparison work that the IPCC carried out as part of the Fourth Assessment process.\textsuperscript{39} Scientists 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.\textsuperscript{40} 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 10\% to 40\% based on these model projections.\textsuperscript{41} Greater total rainfall will also almost certainly occur in a band along the equator, especially over the oceans.\textsuperscript{42}

In the semi-arid subtropics, on the other hand, there is strong agreement across models that many areas are likely to become even drier.\textsuperscript{43} 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).\textsuperscript{44} 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.\textsuperscript{45} 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.\textsuperscript{46} Precipitation reductions also appear likely in those areas because the mid-latitude storm tracks will tend to move

\textsuperscript{38} Id. at 873.
\textsuperscript{39} Christensen et al., \textit{Regional Climate Projections}, supra note 6, at 852.
\textsuperscript{40} Id. at 854, tbl 11.1.
\textsuperscript{41} Kundzewicz et al., \textit{Freshwater Resources and their Management}, supra note 7, at 183.
\textsuperscript{42} Christensen et al., \textit{Regional Climate Projections}, supra note 6, at 860.
\textsuperscript{43} Id. at 881.
\textsuperscript{44} Seager et al., \textit{Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America}, 316 \textit{Science} 1181, 1181 (2007). 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. See Bureau of Reclamation, U.S. Dept of the Interior, \textit{Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead: Final Environmental Impact Statement, Appendix U} (2007).
\textsuperscript{45} U.S. Bureau of Reclamation, Lower Colorado Region, supra note 44, at 23; Christensen, \textit{Regional Climate Projections}, supra note 6, at 849.
\textsuperscript{46} Kundzewicz et al., \textit{Freshwater Resources and their Management}, supra note 7, at 184–87.
poleward while the high-pressure systems centered over the dry subtropics will expand in size.\(^{47}\) These changes will cause areas at the poleward edges of the subtropics to dry out.\(^{48}\) The estimated declines in average annual runoff in these areas are on the order of 10% to 30% by the end of this century, assuming a middle-of-the-road emissions scenario.\(^{49}\) The changes would be even larger if we continue on a high emissions path into the future.

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. 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 subtropics 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.\(^{50}\) In addition, limited computing resources require that long-term climate simulations be run on relatively coarse spatial resolutions.\(^{51}\) This enables the models to capture gross regional circulation patterns, but it 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.

Thus, 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 rather than from projected precipitation changes. These high-confidence 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. The

\(^{47}\) IPCC TECHNICAL PAPER VI, supra note 1, at 35–37.
\(^{48}\) Christensen et al., Regional Climate Projections, supra note 6, at 849.
\(^{49}\) See D. Nohara et al., Impact of climate change on river runoff, 7 J. HYDROMETEOROLOGY 1076 (2006). These estimates are averages based on climate projections from nineteen different climate models.
\(^{50}\) Christensen et al., Regional Climate Projections, supra note 6, at 866.
\(^{51}\) IPCC WORKING GROUP I, supra note 5, at 6.
amount of water available for runoff and groundwater recharge in any locality will depend on changes in the balance between precipitation and evapotranspiration.\textsuperscript{52} Precipitation changes will be critically important, but evaporation, which is controlled by temperature, humidity, radiation, and wind speed, will also play a major role. In addition, changes in vegetation will alter both runoff processes and the loss of water back to the atmosphere through plant transpiration.

Warming also will increase the intensity of rainfall and snowfall events because storms will be carrying heavier moisture loads. Increases in precipitation intensity are already occurring, and future changes in rainfall rates are expected to substantially exceed the change in average annual global precipitation, especially for short duration events.\textsuperscript{53} While precipitation will tend to be heavier when it occurs, these events may be fewer in number.\textsuperscript{54} Dry spells are likely to become both longer and more intense as the warmer atmosphere accelerates the evaporation of any available surface moisture.\textsuperscript{55} In other words, in different regions and seasons, global warming will increase the potential for both droughts and downpours.

III. INFORMATION, INSTITUTIONS AND ADAPTATION

A. The Planning Problem

Such changes pose substantial challenges for long-term water planning, but the challenges are not insurmountable. Let us first consider the planning problem from the perspective of urban water utilities. The first thing to note is that while climate change is a new source of uncertainty, it certainly is not the only source of uncertainty. When an urban water provider develops long-term plans for infrastructure investments and supply commitments, it faces a wide set of uncertainties such as: population growth; changes in development patterns and household water use habits; new demands for environmental flows and associated regulatory requirements; and changes water use by competing users of the resource. Long-term water


\textsuperscript{53} Geert Lenderink & Erik Van Meijgaard, Increase in hourly precipitation extremes beyond expectations from temperature changes, 1 NATURE GEOSCIENCE 511, 511 (2008).

\textsuperscript{54} IPCC TECHNICAL PAPER VI, supra note 1, at 66.

\textsuperscript{55} Id. at 107.
planning has always been an exercise in decision making under uncertainty. Thus, from the perspective of a water utility, the most sensible way to think about adaptation to climate change is to simply integrate this new source of uncertainty into the utility’s ordinary, ongoing planning process. In fact, in the United States and several other countries, the urban water industry is attempting to do just that.\textsuperscript{56}

An important first conceptual step has been to develop a systematic framework for incorporating consideration of climate change into the planning process. Parallel efforts by different research teams have come to similar conclusions, recommending multi-step planning processes.\textsuperscript{57} These steps typically include:

- defining organizational objectives;
- identifying vulnerabilities;
- proposing options for addressing the vulnerabilities;
- developing models of the water supply system through which one can run different scenarios of changes in climate and other relevant variables;
- selecting a range of scenarios that spans the uncertainty space;
- evaluating the performance of the decision options under the set of scenarios; and
- applying a decision rule to identify the most desirable alternative.\textsuperscript{58}

Certainly, this very sparse description of the decision support framework hides many of the complex issues that arise at each step. The point that I would like to make is that municipal water providers are making substantial efforts to develop a systematic approach to understanding and responding to the risks posed by climate change. These efforts will be useful not only for urban water planning, but also could provide a set of tested procedures for coordinating broader, watershed-wide efforts to anticipate and plan for the impacts of climate change.

\textsuperscript{56} The Water Research Foundation is an industry-funded research program that is coordinating research and educating industry professionals regarding the implications of climate change for urban water utilities. It is supporting the development of decision support tools to assist adaptation planning. See Water Research Foundation, http://www.waterresearchfoundation.org (last visited Sept. 2, 2010). In addition, the Water Utilities Climate Alliance is a collaborative effort of 10 large U.S. urban water utilities serving more than 36 million customers that also is funding research and playing an active role in calling for public sector research support and policy attention to these issues. Water Utilities Climate Alliance, http://www.waterresearchfoundation.org (last visited Sept. 2, 2010).

\textsuperscript{57} WATER UTILITY CLIMATE ALLIANCE, supra note 10, at 64. See DAVID YATES & KATHLEEN MILLER, CLIMATE CHANGE IN WATER UTILITY PLANNING: DECISION ANALYTIC APPROACHES (2011).

\textsuperscript{58} See YATES, supra note 57.
Two steps in the above sequence require significant input from the scientific community. These are the development of appropriate system models and the generation of a credible range of local-scale climate scenarios. The final step — applying a decision rule to select a course of action — can be informed by objective analysis but also requires subjective judgment about choice of an appropriate decision rule. That choice will depend on both the nature and extent of the uncertainties that we are facing.

Regarding model development, Integrated Water Resource Management ("IWRM") models are very useful tools for understanding the flow of water through a watershed and the impacts of alternative water management strategies. If properly designed and calibrated, such models can simulate the response of a managed water resource system to changes in patterns of precipitation, temperatures and other climate variables, as well as to changes in patterns of water use and system operations. To be useful for evaluating climate change response options, an IWRM model must be able to credibly represent the impacts of factors related to the bio-physical system. These include climate, topography, land cover, surface water hydrology, groundwater hydrology, soils, water quality, and ecosystems, which work together to shape the availability of water and its movement through a watershed. The model also must adequately represent the management system, including how water is stored, conveyed, allocated, and delivered within or across watershed boundaries. It is also important to be able to simulate the effects of changes in factors driving human water demands and environmental water needs.

An example of a flexible modeling platform for the development of such climate-sensitive IWRM models is the Water

Evaluation and Planning Version 21 ("WEAP") tool.\textsuperscript{63} WEAP integrates a range of physical hydrologic processes, including rainfall-runoff and snow physics, with the management of demands and installed infrastructure by simulating the water balance for a user-constructed, link-and-node representation of a water management system.\textsuperscript{64} WEAP allows for analysis of a large number of scenarios, thus facilitating exploration of multiple uncertainties and evaluation of the robustness of management strategies in light of those uncertainties. For example, the analyst can use WEAP to evaluate the impacts of alternative sequences of local weather conditions (e.g. temperature, precipitation, humidity, and wind speed), reflecting uncertainty about future climate arising from both natural variability and the effects of anthropogenic climate change.\textsuperscript{65} The analyst also can explore the effects of uncertain changes in other variables, such as land use patterns, pollutant loadings, vegetation characteristics, and water demands for municipal, industrial, hydropower, fish and wildlife, and recreational uses.\textsuperscript{66} A number of urban water utilities are now using WEAP in their efforts to simulate the impacts of climate change on their systems and to evaluate their response alternatives.\textsuperscript{67}

The selection of appropriate climate change scenarios for analysis is often a stumbling block, because, as noted, the range of future changes suggested by climate model runs may be very wide. In addition, analysts will usually need to perform some type of downscaling to translate results from the coarse resolution of global climate models to a resolution that is sufficiently fine to capture the effects of mountains and other topography on the location and other characteristics of precipitation.\textsuperscript{68} This can be a laborious process, making it impractical to consider more than a handful of different scenarios.

One technique for paring down the possibilities is to use the large range of available climate model projections to develop pseudo-probability distributions for climatic changes and then select a sample of scenarios spanning that distribution for


\textsuperscript{65} See YATES, supra note 57.

\textsuperscript{66} See YATES, supra note 64.

\textsuperscript{67} See YATES, supra note 57.

\textsuperscript{68} Wilby et al. 1998; Wilby et al. 2004; Fowler and Wilby 2007; Fowler et al. 2007.
detailed analysis. For example, a technique developed by Tebaldini and coauthors combines the simulations from a large number of climate models into “Bayesian” probability distributions by applying weights to individual model results to penalize bias and rewarding convergence. One can then use the resulting regional probability distributions of temperature and precipitation change to guide the development of local-scale synthetic weather sequences to be run through an IWRM model. Another approach has applied statistical methods to create bias-corrected regional climate simulations from the full set of global climate model runs developed for the IPCC Fourth Assessment Report. One can select a subset of scenarios representing the full range of those projections for further analysis.

A heavy dose of caution is needed, however, in interpreting the current range of climate model results in probabilistic terms. There are many “known unknowns” in climate science that are the object of active, ongoing research programs, and there are probably “unknown unknowns” as well. Under conditions of deep uncertainty, it is not possible to credibly define probability distributions.

A number of thinkers have pointed out that searching for an “optimal” decision in such circumstances is severely hampered by the absence of reliable estimates of probabilities. Instead, they recommend searching for “robust” solutions – decisions that are likely to perform adequately, regardless of what realization the deeply uncertain variables actually transpires.

71. Bias-corrected, downscaled regional climate scenarios based on the output of the 21 climate models used for the IPCC Fourth Assessment have been made available online by the U.S. Department of Interior Bureau of Reclamation and Lawrence Livermore National Laboratory. World Climate Research Programme, *Bias Corrected and Downscaled WCRP CMIP3 Climate Projections*, http://gdo-dcp.ucclnl.org/downscaled_cmip3_projections/ (last visited Aug. 28, 2010).
73. Le Treut et al., *Historical Overview*, supra note 20.
75. GROVES, supra note 74; LEMPERT ET AL., supra note 74.
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when faced with profound uncertainty, one might want to adopt a decision rule that focuses on minimizing the chances of committing to a decision that one would later regret. In this light, water planning for adaptation to climate change should not attempt to map out a full sequence of future projects or a full set of required criteria for the operation of such projects. Rather, the focus should be on identifying near-term decisions that best preserve options to take appropriate actions as the need arises. As described by Lempert, et al.:

The goal is to discover near-term policy options that are robust over a wide range of futures when assessed with a wide range of values. Robust strategies will often be adaptive – that is, they will be explicitly designed to evolve over time in response to new information.  

By developing decision support tools to assist the analysis and implementing techniques to explicitly examine the significance of multiple sources of uncertainty for the performance of their planning options, the urban water industry is exploring analytical methods that may prove useful in larger policy discussions regarding adaptation to the effects of climate change on water resources.

B. Multi-stakeholder planning and markets: tools to address climate change?

Urban water providers are typically interested in a number of objectives in addition to their primary missions of providing safe, reliable, and affordable water service to their customers. These other objectives may include environmental stewardship and good relations with watershed neighbors. However, in many cases, the urban water providers are relatively small players at the table, and they certainly cannot represent the full range of values at stake.

Some analysts argue that water allocation decisions are best left in private hands. Specifically, these thinkers hold that where there are clearly defined and well-documented water rights, water markets and other types of voluntary negotiations

76. LEMPRT ET AL., supra note 74.
can be counted upon to channel water to its most highly valued use, and institutional shortcomings account for widespread evidence of present-day failures to achieve such a happy state. Many analysts have described the advantages of water markets in providing incentives for efficient water use, economizing on the cost of collecting information, and providing flexibility to react to changing circumstances including the impacts of climate change. In a recent paper, Jonathan Adler echoes arguments made more than a quarter-century ago by F.J. Trelease, which drove home the points that water users have the best information about the value of water, and moreover, if climate change causes water to become more scarce and there are no institutional or transaction cost impediments, self-interested water users will reallocate the resource from lower to higher valued uses.

Such arguments are valid to a point, but they typically fail to consider the fact that considerable transaction costs may be required for efficient water market transactions. Water market enthusiasts also tend to ignore or downplay the public good nature of many of the ecosystem services provided by water resources, as well as the pervasive externalities inherent in water use and management. They also often ignore spatial

79. Clayton, supra note 78.
81. Adler, supra note 80.
82. Trelease, supra note 80, at 82 (providing an especially colorful example of this point: “The bureaucrat trying to decide the best use of water as between agriculture and industry will have to investigate, hold hearings, hire experts, finance a university study and make findings. The manager of the Tootsie Textile Company and Farmer Jones, sitting at the bargaining table, can tell the answer in a minute by a glance at the bottom line of last year's books.”).
83. See, e.g., LAWRENCE J. MACDONNELL, U.S. GEOLOGICAL SURVEY, GRANT AWARD # 14-08-001-G1538, THE WATER TRANSFER PROCESS AS A MANAGEMENT OPTION FOR MEETING CHANGING WATER DEMANDS (1990). See also WATER SCI. AND TECH. BOARD, NAT'L RESEARCH COUNCIL, WATER TRANSFERS IN THE WEST 118 (1992) (arguing that “...transferring water is no simple matter; thus no simple and inexpensive process will be able to meet the needs of buyers, sellers, governing bodies and affected third parties equitably”); Dan Tarlock, General Stream Adjudications: A Good Public Investment?, 133 J. CONTEMP. RES. & EDUC. 52 (2006).
84. See, e.g., ROBERT A. YOUNG, DETERMINING THE ECONOMIC VALUE OF WATER: CONCEPTS AND METHODS (2005). For example, the aesthetic beauty and healthy stream ecology provided by adequate stream-flows are amenities that can be jointly enjoyed by many users, and while voluntary organizations can potentially represent their interests in market transactions, the difficulty of excluding non-payers creates an incentive to free-ride on others’ investments. This will typically lead to under-provision of such public good services by private markets.
85. Examples of interdependencies within an irrigation district include the fact that the technical efficiency of water delivery increases as a function of the volume of water flowing through a ditch system. Thus, the district as a whole could be adversely affected if individual irrigators could make unrestricted transfers of their water outside
heterogeneity in water availability, the high cost of water transport, and the critical dependence of water delivery on non-malleable infrastructure. These features must be adequately incorporated in any assessment of the performance of proposed adaptation options.

Water markets clearly have an important role to play in the adaptation process, but they are not a panacea. There is also a clear need for broader public-sector input into long-range water planning, including local-level input from a variety of stakeholders who use water or value the ecosystem services that it provides. Ruth Menzen-Dick forcefully makes this point in describing the repeated failures of water policies based entirely on one or another assumed policy panacea. She notes that no single approach: markets, centralized state planning, or water-user associations, holds the magic key to efficient water policy in all circumstances. Rather, she argues that there is a need for a polycentric combination of institutional approaches: “Instead of a single pillar, a more appropriate image is a tripod or stool, in which state, collective and market institutions each play a role.”

Possible pathways for watershed-scale adaptation to climate change include bumbling along with piecemeal efforts by disparate water users to secure their individual interests in a changing environment. Alternatively, a collaborative joint planning approach could potentially identify opportunities to more effectively manage the risks posed by climate change, including opportunities to improve the operation of water markets. Water user associations and watershed management organizations will clearly be key players in this process. Recent decades have seen a proliferation of such entities, and they take a wide variety of forms in response to the local context and the particular problems that prompted their creation. The efforts of these collaborative organizations to deal with ongoing water-related policy problems will provide organizational templates and a rich set of lessons for extending the planning process to consider appropriate responses to the impacts of climate change. A considerable body of research documents the various forms

87. Meinzen-Dick, supra note 86, at 15205.
89. PAUL SABATIER ET AL., SWIMMING UPSTREAM: COLLABORATIVE APPROACHES TO WATERSHED MANAGEMENT (Paul Sabatier et al. eds., 2005).
taken by these organizations, their effectiveness and longevity, the issues they have encountered in building mutual trust and understanding, and dealing with intense conflicts of interest among participants.\textsuperscript{90} Among the lessons arising from this experience is that water managers and users are not the only ones who should be at the table. To be most effective, multi-stakeholder planning processes should help to bridge gaps between land-use and water resource planning – functions that now typically are conducted by separate agencies, often with limited coordination.\textsuperscript{91}

It would not make sense to rush out and begin creating new planning forums for the sole purpose of thinking about how to adapt to climate change, but it would make sense to begin bringing consideration of climate change into the conversation in existing multi-stakeholder water-policy forums. The key question is how to do that effectively. Particular care will be needed to avoid derailment by the ongoing politicization of climate change. Therefore, it will help to start by putting climate change in the proper context as a significant long-term stress, but recognize that it is not the only issue requiring attention. Many things are changing in our relationship with water resources. In the United States, the most pressing stresses relate to the ongoing redistribution of population into relatively arid parts of the country and increasing competition in many other states between environmental water needs and agricultural, municipal, and industrial uses.\textsuperscript{92} Other ongoing changes include our growing understanding of aquatic ecosystems, the conditions needed for their healthy functioning, and the value of the ecosystem services that they provide.\textsuperscript{93} Current thinking emphasizes the need to mimic natural patterns of high and low flows, allowing the entire assemblage of the species in a river system to experience the variety of natural conditions needed for critical life cycle processes.\textsuperscript{94} Focusing on the issues that require immediate attention, while building consideration of climate change into the analysis of policy options, will likely be the most effective approach.

\textsuperscript{90} Saratier et al., \textit{supra} note 89. \textit{See also} Edella Schlager et al., \textit{Embracing Watershed Politics} (2008).
\textsuperscript{92} See, e.g., Dept of Interior, \textit{Water 2025: Preventing Crises and Conflict in the West} (2003).
\textsuperscript{94} S. Postel & B. Richter, \textit{supra} note 93.
Transparency will be critical to the effective functioning of multi-stakeholder planning processes. Participants will naturally come into such forums with very different perspectives as to what is important and which values should receive highest priority. They may even attempt to game the process by exaggerating the importance of their own values and preferred outcomes. Skillful facilitators can help a planning effort to be honest about value differences and to work past such strategic behavior. Perhaps a bigger stumbling block to effective collaborative planning arises when participants come into a planning process with fundamentally different understandings of how the system works and how it will likely respond to the planning options under consideration. This is where investments in the observation, monitoring, and modeling of water resource systems can make an important contribution. If participants have a shared understanding of what is and is not known about how the whole integrated system functions and if they have the tools to mutually explore the implications of uncertainty, they will be in a better position to identify robust and desirable courses of action.

C. Water Law and Climate Change – Some Concluding Thoughts

What legal changes are needed to facilitate efficient, equitable, and environmentally responsible adaptation to the impacts of climate change? Should we mandate that climate change be explicitly considered in all long-term public water planning processes? That approach would mimic the approach taken in the U.K., where national regulatory agencies require water utilities to develop long-range plans, where climate change is to be considered.95

I doubt that a mandatory approach would be well-received in the United States given the current political environment. It might be more effective to begin by implementing reforms that make sense for dealing with the many other stresses that climate change is likely to exacerbate. In particular, legislation to support drought planning, updated policies for flood plain management, and improved coordination between water and

land-use planning would be sensible first steps. Another valuable first step would be to increase funding for monitoring of actual water uses and for basic watershed science, including physical and ecological observations and the development and testing of IWRM models. Reforms also should promote increased flexibility to adjust both water use patterns and regulations to changes in water availability and flood characteristics.