Preparing for Climate Change in the Pacific Northwest: A Discussion of Water Resources Adaptation Pathways

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Overview

Our goal in this paper is to construct a broad framework for creating appropriate water policy to cope with the regional impacts of climate change, to outline the kinds of planning efforts that could most usefully incorporate climate change information, and to discuss some important institutional issues associated with the facilitation and implementation of long-range adaptation strategies. We close by presenting a catalog and discussion of some potential adaptation strategies that could compose the elements of specific long-range plans, including conventional infrastructure changes, conservation and demand management, technical innovations, water banks and water markets, and improvements in hydrologic forecasting, information systems, and associated water management practices.

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Introduction

Global climate change, its regional implications, and its likely effects on Pacific Northwest (PNW) water resources are discussed in two companion papers Mote (2001) and Hamlet et al. (2001a).

The impacts on the PNW that are projected with the greatest certainty are likely reductions in snow pack and summer streamflow in PNW river basins, particularly west of the Cascades and in the southern parts of the Columbia basin, by the 2020s. These changes in streamflow will adversely affect PNW water resources systems, due to limited reservoir storage available and a corresponding limited ability to adapt (for the status quo) to significant changes in streamflow timing.

To date there has been a very limited amount of long-term planning for PNW water resources that has been appropriately informed by available climate change scenarios or information on climate change. We argue that long-term planning incorporating climate change scenarios and information is a crucial element in the process of managing water systems in the region.

Designing a policy response to address the potential impacts to PNW water systems in the 21st century due to global warming is challenging, and must address many different kinds of impacts at different spatial and temporal scales in different areas of the region. **Climate is also only one stressor among many on PNW water systems, which highlights the fact that regional water policy must successfully address the combined effects of multiple stresses on regional water systems.** At the same time climate is changing, so are the demands that society places on the region's water resources.

A Framework for Creating Water Policy to Cope with Climate Change

We argue that the process of coping with climate change is composed of three fundamental activities:

1. Problem assessment and determination of regional vulnerabilities,
2. Long-term planning efforts resulting in the creation and refinement of specific adaptation strategies, and
3. Incorporation of these preferred adaptation strategies into regional water policy and water law

In this framework, long-term planning is the mechanism by which adaptation strategies are created from various available options to deal with the potential problems identified (e.g., reductions in summer water supplies). Incorporation of these planning alternatives into water policy and water law is the mechanism by which the coping strategies are actually implemented. Each of the steps outlined above is critical in successfully coping with climate change. **If planning exercises fail to address the pertinent issues associated with climate change, subsequent water policy based on this planning will be ineffective at averting impacts.** Similarly, if well-conceived planning recommendations do not find their way into water policy, there will be no actions associated with planning and the impacts of climate change are likely to be more problematic.

Identifying Planning/Policy Arenas that Should Incorporate Climate Change Information

In the framework described above, long-term planning is a central element in the process of attempting to reduce the PNW's vulnerability to climate change. Because of the time scales involved, certain kinds of water planning (and associated changes in water policy) can benefit the most from incorporating climate change information. There are many criteria that could be employed in identifying such water resources planning arenas; for example:

1. *Piggybacking:* Planning is in progress or required for other reasons (climate change assessment adds relatively little cost to an existing planning process)
2. *Rare opportunity*: The planning arena is unlikely to be revisited in the next several decades due to cost or other considerations
3. *Sensitivity*: The water system in question is highly sensitive to reductions in snowpack and summer streamflow, or to other changes in streamflow timing.
4. *Durability*: High costs and/or long economic life span associated with decisions addressed by a particular planning process
5. *Irreversibility*: Planning decisions made now that may irreversibly increase future vulnerability
6. *Inflexibility*: Limited ability to respond to rapid changes in climate without long-term planning

Many PNW water management agencies are conducting, or must in the future conduct planning efforts that meet all or many of these basic screening criteria. Several examples follow:

<u>Example 1: Salmon Recovery Efforts in the Columbia River Basin</u>
Extensive planning efforts and associated interactions between a large number of different management entities and Native American tribes in the Columbia River basin are occurring in an effort to recover threatened salmon stocks, some of which are listed under the Endangered Species Act (Miles et al., 2000). Climate change information should be included in these studies because:

- The planning efforts are in progress for other reasons, and climate information would not be expensive to incorporate

- Salmon recovery plans are potentially sensitive to changes in snowpack and streamflow timing associated with regional warming,
- Changes in water management policy associated with planning will be extremely difficult to achieve, will probably span multiple decades, and will be difficult and costly to alter after the fact,
- There is a very limited ability to change Columbia basin water policy quickly in response to short-term changes in climate, which increases the importance of long-term planning efforts.

Example 2: Changes to Binational Agreements between the U.S. and Canada

Several important agreements associated with the Columbia River Treaty (1964) regarding the control of downstream power benefits from Canadian projects expired in 1998 (Duncan dam), 1999 (Keenleyside dam), or will expire in 2003 (Mica dam), with control reverting to provincial authority in British Columbia. Furthermore, the treaty itself will expire in 2024, and it can be renegotiated at any time at the request of either Canada or the U.S. These current changes in the international agreements between Canada and the U.S. and the expected future changes by 2024 will have implications for future hydropower production and instream flow which may require additional transboundary agreements between Canada and the United States. Climate change information should be considered in forging such agreements because:

- The existing transboundary agreements probably must be revisited anyway (particularly in the context of energy production, and instream flow),
- Any subsequent agreements between Canada and the U.S. will be costly to implement, and negotiations are unlikely to be repeated in several decades,
- Significant changes in snowpack and summer streamflow are likely in the Columbia basin within 20-40 years which may create disparities between water availability in Canada and the U.S.,
- Any subsequent agreements may span multiple decades and may be difficult to change,
- If the treaty amendments do not take climate change into account, vulnerability to climate change may be increased
- Changes to transboundary agreements cannot be made quickly in response to changes in climate.

Example 3: Proposed USACOE Flood Study

The Northwest Power Planning Council has formally asked the US Army Corps of Engineers to carry out a comprehensive planning study in the next five years regarding flood control in the Columbia River basin. This study would benefit from the inclusion of climate change information according to the criteria above because:

- The study is proposed for other reasons,

- The costs of the proposed planning study are high, and it is unlikely to be repeated in the next 25 years,
- The impacts of flooding are potentially sensitive to changes in snowpack and streamflow timing associated with regional warming,
- Any changes in flood control policy associated with the proposed planning study will probably span multiple decades and will be difficult to change after the fact,
- There is a limited ability to change flood control policies quickly in response to short-term changes in climate.

<u>Example 4: Seattle Public Utilities (SPU) Long-Term Planning</u>
SPU routinely conducts long-term planning exercises to help determine future needs for the water system supplying Seattle's water and other service areas which use Seattle's system as their primary source. Such studies would benefit from the inclusion of climate change information according to the criteria above because:

- Long-term planning is routinely performed for other reasons,
- Changes in snowpack and streamflow timing associated with regional warming are most pronounced in moderate elevation basins in the Cascades (Hamlet et al., 2001),
- Infrastructure changes are expensive to implement and routinely take several decades to approve and construct,
- Water planning for Seattle may significantly affect regional development, which may potentially affect water demand and regional vulnerability to reductions in summer water supplies.

Dealing with Uncertainty

Long-term water planning has always been conducted in the face of uncertainty about the future, and long-term planning for climate change will have to cope with many uncertainties that probably cannot be fully resolved before significant impacts would occur. Decreases in summer water supplies are very likely to accompany regional warming, and this is quantified in the degree of reduction associated with "middle-of-the-road" climate scenarios in several watersheds (Hamlet et al., 2001a). The uncertainties in these results may be more fully resolved as the tools for evaluating climate change impacts improve and ongoing observations more fully document the effects to the region. However, even if the uncertainties are not reduced, the implications for regional water planning remain much the same.

In the context of long-term water planning, incorporating climate change information will simply add the constraint of reduced summer water supplies to a host of other uncertain considerations. If, on one hand, planning alternatives can be developed that are robust to estimated decreases in summer water supplies, then the region will have reasonable strategies in place for coping with climate change that can inform and guide regional water policy. Such actions are also likely to reduce the vulnerability of PNW water systems to existing stresses associated with natural climate variability and increasing human populations.

If, on the other hand, regional water planning is done without regard for potential changes in summer water supplies associated with climate change, future reductions in water supply are likely to cause unanticipated impacts for which there will be little planned recourse. Given the very low speed at which water system infrastructure, and water demand associated with existing development, can realistically be altered in response to changing conditions, this is a serious consideration.

Institutional Considerations and New Designs

In Hamlet et al. (2001a) we introduce a few of the most basic institutional considerations which are adding to the existing stresses on water management systems in the PNW. The widespread impacts associated with the 2001 drought (Mapes, 2000a,b; Bernton, 2001) and the likely impacts of climate change on the regional hydrology and water supply in the PNW put in bold relief the region's very limited ability to respond effectively to low flow conditions (Gray, 1999; Miles et al., 2000). These limitations suggest that planning for a societal response capability which will facilitate adaptation to climate change and minimize vulnerabilities needs to be based on criteria of comprehensiveness, flexibility, and efficiency of use to cope with the increasing scarcity and conflict which progressively lower summer streamflows are likely to generate.

We argue that the current management system governing the use of water in the PNW is inadequate to face the major challenges which are likely to materialize as a result of climate change and continued development of the region. The problem at base is an unusually high degree of fragmentation in the authority to plan, and actually to manage, the use of water in the region as a whole.

In the U.S., two sets of institutional structures govern water in the PNW, as indeed they do in the entire western U.S. State law typically governs allocations of water for use and consumption, while Federal law delegates the right to manage water to Federal agencies, licenses private and public entities to manage water for hydropower and irrigation, and regulates private and public users relative to the in-stream use of water, especially concerning fish (Willard, 2000). As Duncan (1994) has pointed out, inter-use coordination is virtually nonexistent at both state and Federal levels and jurisdictional fragmentation has developed to extreme degrees cutting across mosaics of Federal, state, tribal, and private lands. The result is that the region has little or no capacity to manage water resources across all uses or across the varying space scales involved (i.e., from county to international scales). **The fact is that no comprehensive, regional structure exists that has the authority to plan proactively and to coordinate or even harmonize planning**

in response to existing stresses such as regional development, the demands of ESA listing of salmonids, projected population growth over the foreseeable future, and anticipated changes in climate. Although the institutional framework is different in Canada, similar institutional concerns regarding the ability to manage water across different uses and spatial scales are present (Cohen et al., 2000).

These same institutional considerations apply to binational water agreements between Canada and the U.S. (most notably the Columbia River Treaty) but with additional layers of complexity deriving from the constraints of international law, issues regarding sovereignty over natural resources, and differences in water resources objectives, water law and water management entities in the two countries. Climate change may create new conflicts between Canada and the U.S. with regard to entitlements for streamflow in the Columbia River. Most of the substantive reductions in winter snowpack over the next 40 years associated with expected temperature increases are shown to occur in the U.S. portion of the Columbia basin, whereas more than half of the reservoir storage located on the major tributaries is in Canada (Hamlet et al., 2001a). This suggests that the importance of snowpack and reservoir storage in Canada will increase with regional warming, particularly in the context of instream flow in summer. Furthermore, current agreements between Canada and the U.S. emphasize the release of reservoir storage in winter for flood control and hydropower, but make no explicit provision for the release of storage in summer. This suggests that forging mutually beneficial agreements between Canada and the U.S. with regard to the enhancement of summer streamflows may constitute one important avenue for coping with these potential changes in basin conditions (Hamlet and Lettenmaier, 1999b).

What then is to be done? Facing the future implied by the climate change scenarios discussed by Mote (2001) and Hamlet et al. (2001a) requires a capability to plan comprehensively on a watershed basis at two levels. One level would involve binational agreements between Canada and the United States (as discussed above), and national and regional organizations responding to legislative mandate to coordinate planning activities (Duncan, 1994; Cohen et al., 2000). The other level would create an interface with states, provinces in Canada, and counties on the basis of a consistency provision similar to that which exists in the U.S. Coastal Zone Management Act (Public Law 104-150). The combined focus would be on implementation, which would also imply a requirement for a significant monitoring and enforcement capacity. How such an institution could be designed should be the subject of a continuing dialogue between the parties involved.

A comprehensive agenda for more effective management of water resources in the PNW under conditions of climate change presents extraordinary challenges to the region. A comprehensive agenda would include, in addition to the above:

1. Formal authorization to all relevant state, provincial, national, and regional agencies to include climate change scenarios in their long term planning.
2. Explicit consideration of technological innovation in water planning to ensure that all necessary conservation and infrastructure changes are identified and achieved.
3. Implementation of necessary changes to water law.
4. Ensuring that national agencies have the resources they need to develop the best possible hydrologic forecast capability and that all user communities develop their understanding of such forecasts and use them in their seasonal/interannual and long-range planning activities. This capability would be enhanced if the Federal Government in the U.S. would organize a national climate service as a matter of priority.
5. Consideration of transboundary agreements between the U.S. and Canada in the context of changes in streamflows crossing the international boundary.
6. Design and implement a comprehensive monitoring system to keep track of climate changes and their impacts and to ensure that regional planning objectives are being met (discussed below).

The formidable challenges inherent in implementing changes in regional water management institutions and water policy, however onerous, must ultimately be weighed against the potential risks associated with permitting uncontrolled impacts to occur in the absence of well-conceived strategies for adaptation.

Adaptation Strategies for Reducing Regional Vulnerability to Climate Change

Incorporating climate change information into regional planning should ultimately result in planning alternatives and water policy that are increasingly robust to the likely impacts of climate change (e.g., reductions in summer streamflow). It is not our intention here to discuss, in detail, planning studies or specific policy responses that may be required to cope with various problems in different parts of the region. Such planning exercises must ultimately be conducted in an ongoing partnership between the managing entities responsible for the water systems and their stakeholders. The following discussion, rather, is intended to present a catalog of some basic adaptation strategies that may be useful in creating planning responses to reductions in summer streamflow that are likely to accompany climate change.

It should be noted that the adaptation strategies listed are not equally viable in different areas of the region. Advanced waste water treatment, for example, may be an effective adaptation strategy in municipal and industrial water supply systems, but would have relatively little applicability to the problems facing the Columbia basin as a whole.

Conventional Changes in Infrastructure

Increase Usable Storage

Increasing usable water storage will decrease vulnerability of PNW water systems to changes in streamflow timing by increasing the ability to transfer water from winter to summer that will be lost as regional snowpack decreases. Building new surface water storage reservoirs is likely to be extremely problematic; however, expanding the capacity of existing storage reservoirs or using groundwater (either natural or forced recharge) may provide opportunities to increase usable storage.

Diversify Sources of Water Supply

Diversifying the primary source of water may reduce the vulnerability of the PNW to changing climate. Use of surface water, groundwater (natural or forced recharge), reverse osmosis treated ocean water, and treated waste water as alternate sources for urban water supply is likely to increase the robustness of water systems to different scenarios of changing climate. Increased use of groundwater, for example, may make water supply systems more robust to increasing swings in the availability of surface water supplies each year, provided the long term water availability does not change very much.

Connect Regional Water Systems

Connecting water supply systems decreases vulnerability to climate change in two ways: by decreasing the vulnerability to local impacts (which tends to increase the yield of the combined system as compared with the sum of the individual systems), and by decreasing the vulnerability of the region to the specific location of human development and associated increases in water demand. The robustness of the connected systems is enhanced if different parts of the combined system have diverse sources in place. The proposed intertie between Tacoma and Seattle is an example of a connection between regional resources designed to increase flexibility.

Conservation and Demand Management

Conservation and demand management have long been recognized as effective means of extending the yield of water resources systems, and some water management agencies in the PNW are currently recognized as leaders in water conservation. Demand reduction is an important means of reducing the vulnerability to climate change, because peak demand usually occurs in summer in the PNW, and climate change will likely reduce summer water availability. Some avenues for improving conservation and/or demand management that have been proposed (though not necessarily endorsed by the Climate Impacts Group) are listed below:

- Implement more efficient application methods for irrigation water (discussed below), which could decrease water use per irrigated acre;
- Reduce irrigated acreage by increasing crop yields, or more closely matching demand for food to agricultural production***;***
- Adopt agricultural and land management practices that reduce soil moisture loss,
- Make use of new technology that would allow for increased water use efficiency (e.g., high efficiency plumbing fixtures and appliances for household use) by providing incentives for their purchase and use;
- Educate the public about the economic, social, and environmental benefits of efficient water use;
- Create water banks (discussed below) to trade water rights between users; and
- Introduce market forces in water management systems to adjust demand to supply and to distribute impacts during periods of water shortage (discussed below).

Improvements in Hydrologic Forecasting, Information Systems, and Associated Water Management Practices

Improved Streamflow Forecasts for Water Management

As PNW water resources systems are increasingly stressed by competing demands for water and reductions in supply, the importance of effective seasonal and year-to-year water management increases. Streamflow forecasts based on winter and spring snowpack measurements are currently used in many PNW water systems. These forecasting systems improve the performance of PNW water management (as compared with management without forecasts) and will continue to be useful for water management in the future, but improvements are also likely to be needed.

One important aspect of water management that should be re-examined in the context of climate change is the common practice of using of the historic streamflow record as a risk assessment tool. **If relatively rapid changes in climate occur, it is likely that the historic record of streamflows will become a very poor basis for water management decisions.** In particular, the common practice of determining the supply limitations of water systems based on a critical period from the historic record is likely to become increasingly problematic. One alternative that is being pursued by researchers is to develop advanced streamflow forecasting tools based on linked climate and hydrologic models. These kinds of streamflow forecasting tools may eventually provide a better assessment of future streamflows than the historic record (Hamlet and Lettenmaier, 2000). More sophisticated assessment of the combined effects of climate change and climate variability (i.e. with regard to observed decade-to-decade cycles of precipitation) may also usefully inform climate monitoring and water planning efforts.

Long-range streamflow forecasts that are being produced on an experimental basis with lead times of roughly 12 months also show promise in improving reservoir operations in the Columbia River basin in fall and early winter on a year-to-year basis (Hamlet and Lettenmaier, 1999a; Hamlet and Lettenmaier, 2000, Hamlet et al., 2001b, Wood et al., 2001), which may also create greater robustness to changes in water supply associated with climate change.

Climate Information and Monitoring

Climate monitoring systems can provide important inputs to long and medium-range water planning. Such systems provide ongoing validation for climate change scenarios (upon which long-range planning should be based) and may also be used to "trigger" contingency plans designed to cope with unexpected changes in climate.

Experimental climate information systems have improved markedly in recent years, but at present, there is neither a regional, national, or global climate monitoring system in place. The lack of a comprehensive climate monitoring system prevents easy and precise documentation of regional changes in climate (which instead must be painstakingly assembled from a limited array of weather observations) and reduces scientists' confidence in climate information provided to PNW resource managers. For these reasons, development of a national climate monitoring system, with regional data distribution and application centers, should be a high priority in preparing for climate change (see also the discussion of institutional considerations above).

Technical Innovations

High Efficiency Delivery Systems for Irrigated Agriculture

East of the Cascades, irrigation accounts for most of the consumptive water use (most notably in the Central Columbia, Snake, and Yakima River basins). Given that increases in storage may be impossible to implement, improving the efficiency of water use in these areas is an important avenue for adapting to potential reductions in summer water supply that are likely to accompany climate change. Technological innovations such as high-efficiency sprinkler systems, or drip irrigation systems may provide a straight-forward avenue for reducing consumptive water use in these areas. Energy costs savings would also accompany reductions in water use. It should be noted, however, that significant changes in water law would be needed to take advantage of these technical opportunities (see the discussion of water banks and water markets below).

Advanced Waste Water Treatment

West of the Cascades, use of high-grade wastewater treatment and water reuse shows promise for radically increasing water use efficiency in some applications. The city of Yelm, Washington, for example, is a planned community that will implement treatment of 100% of its wastewater to grade-A[3] quality. Some of this reclaimed water will be used for watering landscaping and golf courses, strongly reducing demand that must be supplied by the primary resource (ground water) in summer, and the remainder will be applied to wetlands where it will return to the aquifer. Sequim, Washington is installing similar systems in an attempt to decrease effective demand on the primary water source.

Reverse Osmosis

In coastal areas, reverse osmosis water treatment (which is capable of treating wastewater or sea water to drinking water standards by forcing water through permeable filtration membranes) currently costs about $1.00 per cubic meter[4] to treat and deliver (Shamir, 2000) and is a relatively energy intensive process, but is becoming cheaper and more energy efficient with increased development of membrane technology, and may ultimately become an attractive drought relief option in coastal areas[5], particularly if no other additional sources are available.

Water Banks and Water Markets

Western water law in general does not permit reductions in water use without loss of the water right, nor flexible transfer of water rights among different uses or users of water. These characteristics of western water law are formidable obstacles to increasing water use efficiency in areas with large irrigation demand (e.g., the Yakima and Snake River basins). Water banks, which can facilitate the transfer of water among different uses and users of water during times of shortage, and water markets, which attempt to match supply and demand and to allocate impacts between various potential users via a market system, are some controversial changes to current water law that have been proposed to attempt to increase the flexibility of irrigation systems in the face of increasing conflicts over water and potential changes in water supply. Water banks are intended to increase the amount of water put to beneficial use, and to increase the robustness of water systems to drought impacts by providing increased flexibility in matching supply to demand. A water bank was successfully implemented in 1976 in Idaho under the control of the Idaho Water Resource Board, and a formal program for annual

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[3] Grade A treated wastewater is suitable for all non-potable uses, such as lawn watering of public parks and playgrounds.

[4] For reference, Seattle's municipal water customers pay about $2.50 per 100 cf ($0.89 per cubic meter) for water in summer.

[5] The California Department of Water Resources, for example, lists six operational reverse osmosis desalination plants with capacities in excess of 2 million gallons per day (Bulletin 160-98: California Water Plan, California Department of Water Resources).

water leases was approved in 1979. Specific kinds of water transfers under a controlled market structure have also been approved in California.[6] The potential benefits and problems associated with water banks and water markets have been widely discussed (Whittlesey et al., 1986; Gaffney, 1993; Miller, 1996; Green and Hamilton, 2000). An important difficulty in assessing the performance of water banks and water markets stems from the fact that to date there have been very few exploratory applications of these techniques in the U.S.

Summary and Conclusions

Climate change is likely to result in reduced snowpack and summer streamflow in the PNW, which will adversely affect the region's water resources systems (Hamlet et al., 2001a).

The process of adapting PNW water systems in the face of climate change may be viewed as a three step process:

1. Problem assessment and determination of regional vulnerabilities,
2. Long-term planning efforts resulting in the creation and refinement of specific adaptation strategies, and
3. Incorporation of these recommended adaptation strategies into regional water policy and water law

Climate change potentially affects a wide range of long-term water planning in the PNW, and should be explicitly included in these efforts. Because of the time scales involved certain kinds of planning arenas have a higher priority in the context of climate change. Some basic criteria that may be used for identifying these planning arenas are:

1. Piggybacking: Planning is in progress or required for other reasons (climate change assessment adds relatively little cost to an existing planning process)
2. Rare opportunity: The planning arena is unlikely to be revisited in the next several decades due to cost or other considerations
3. Sensitivity: The water system in question is highly sensitive to reductions in snowpack and summer streamflow, or to other changes in streamflow timing.
4. Durability: High costs and/or long economic life span associated with decisions addressed by a particular planning process

[6] The Central Valley Improvement Act (Public Law 102-575, Title 34, October 1992) authorized a number of changes affecting the management and development of the Central Valley Project (CVP) which encompasses the Sacramento and San Joaquin River basins in California. These included the institution of tiered water pricing for new and renewed contracts; and a water transfers provision, including sale of water to users outside the CVP service area.

5. Irreversibility: Planning decisions made now that may irreversibly increase future vulnerability
6. Inflexibility: Limited ability to respond effectively to unexpected short-term changes in climate (i.e. the importance of long-term planning is elevated because planning at shorter time scales would be ineffective)

Uncertainties are present in the problem assessment stage (Mote, 2001; Hamlet et al., 2001a), but the challenges to long-term water planning efforts are relatively insensitive to this uncertainty. At present, long-term planning efforts should add the constraint of reduced summer water supplies to a host of other uncertain future projections. Additional contingency planning to account for uncertainties may be appropriate in some cases.

Institutional considerations will also play an important role in the ability of the PNW to create and implement appropriate water policy to cope with climate change and future regional development. In particular we argue that the current inability to manage regional water resources effectively across different uses and spatial scales is creating increased vulnerability to low flow conditions and potential changes in climate.

A number of adaptation pathways are available that could be used in creating long-term planning strategies, including conventional infrastructure changes, conservation and demand management, technical innovations, water banks and water markets, and improvements in hydrologic forecasting, information systems, and associated water management practices.

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