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Fifth Draft of Possible Recommendations
Water Adaptation Policy Work Group
July 25, 2007

Introduction

The consensus of the scientific community is that warming caused by human emissions of greenhouse gases likely will have significant effects on water supplies and availability in many parts of the world, including the American West. A 2007 report of the Intergovernmental Panel on Climate Change states:

> Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. With regards to snow, ice and frozen ground (including permafrost), there is high confidence that natural systems are affected. . . Based on growing evidence, there is high confidence that the following types of hydrological systems are being affected around the world:
>
> - increased run-off and earlier spring peak discharges in many glacier- and snow-fed rivers;
> - warming of lakes and rivers in many regions, with effects on thermal structure and water-quality. . .
>
> In the course of the century, water supplies stored in glaciers and snow cover are projected to decline, reducing water availability in regions supplied by meltwater from major mountain ranges . . . Warming in western mountains [in North America] is projected to cause decreased snowpack, more winter flooding, and reduced summer flows, exacerbating competition for over-allocated water resources.[1]

The American Water Works Association, the primary trade group of water management professionals, has concluded, "global warming is a fact and water managers need to plan accordingly." *[Citation needed]*

The projected effects of climate change on Colorado's water supplies and water quality include:

[1] N. Adger et al, Summary for Policymakers, pages 2, 3, 7, 12. Footnotes and cross references omitted. In Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report. April 6, 2007.

- **Reduced snowpack and streamflow.** Most water used in Colorado comes from streamflow that originates as snowmelt. There is a consensus of climate model projections that warming will continue in Colorado, leading to more of the winter precipitation falling as rain and less as snow, lesser snowpack accumulation, earlier runoff, and more evaporation. Computer models are still unclear as to what changes may occur in this region with respect to the total amount and timing of precipitation. However, studies do indicate that a substantial increase in precipitation would be needed to offset the reduction in streamflow from more evaporation caused by warmer temperatures.
- **More drought**. The frequency, duration, and severity of droughts are projected to increase, further reducing water supplies and making water use restrictions more likely.
- **Earlier snowmelt**. Warmer weather is expected to melt mountain snowpack earlier. An early melt potentially increases evaporative losses, reduces summer streamflow, and disrupts established patterns of the timing of water capture and use under existing water rights.
- **Intense precipitation**. Precipitation is expected to be more concentrated or intense, potentially making the capture and storage of water more difficult. Increases in flooding are projected, with risks to lives, property, water quality, and the environment.
- **Increased water needs**. The growing season is expected to be longer and warmer. This will increase the water requirements of some crops and other plants. Irrigation of landscapes account for roughly half of the municipal water use along the urban Front Range. Increases in water use in other sectors, particularly agricultural uses with senior water rights, could reduce the supplies available to others, including municipal providers, with more junior water rights. Water use for cooling buildings and other weather-dependent uses could increase with temperatures.
- **Degraded water quality.** Water quality is projected to degrade due to reduced streamflow, increases in forest fires and subsequent runoff of sediment, higher stream temperatures, and other factors. This potentially will increase water-supply maintenance and treatment costs. Sedimentation in water-supply systems is expected to increase and this could decrease water storage capacity and increase maintenance costs.
- **Interstate compact calls**. Reduced streamflow and increased water use could increase the contention over interstate allocations, which are based on "normal" precipitation and streamflow expectations.
- **Secondary impacts.** A number of important secondary impacts have the potential to affect water management, including more forest fires which can lead to increased runoff causing sedimentation of reservoirs, and forest-pest outbreaks which may affect total runoff and runoff timing.

Several climate change studies have investigated possible effects on future flows of the Colorado River, the state's largest source of surface water, which is not just used on Colorado's Western Slope but also is also diverted for use in cities and farms east of the Continental Divide (and, overall, supplies water to more than 30 million people in seven states). The studies consistently project that climate changes will lead to Colorado River flows being reduced below those seen in

1905-2000. Recent studies project reductions in river flows ranging from a very significant reduction of up to 50% by Hoerling and Eicheid to 11% by Christiansen and Lettenmaier. For the Colorado River, any reduction would be significant. Similar studies have not yet been conducted with respect to other river systems in Colorado.

Many of these predicted impacts have already begun to be observed across the West. These changes are projected to have far-reaching effects in Colorado.

It likely will be harder to meet our water needs in the future. Phase 1 of the Colorado Water Conservation Board's Statewide Water Supply Initiative projected that even with some additional conservation measures and no change in the climate there could be a net increase in demand of 630,000 acre-feet of water per year to meet just the municipal and industrial needs of the population projected to live in the state in 2030. This illustrates how the combined pressures of population growth and climate change will be doubly challenging.

Water engineering and management will need to change. They have generally been based on assumptions that the future will look like the past. Reservoir design, flood planning, municipal yield are but three of the critical water management areas where good engineering practice has dictated the use of historical hydrology in planning. As the globe warms, past assumptions about municipal yield, supply, demand, flood control and other water management issues based on historical hydrology will become less valid.

Agriculture consumes a significant majority of the water used in Colorado, so if climate change produces a more restricted water supply over the long term it will have a commensurately greater impact on agricultural water consumption than on consumption by others in the state. In the event of shortages, there likely will be transfers of water from agricultural uses to other uses, such as for municipal and industrial purposes.

The combination of changes in water availability and the application of the legal regimes governing water uses may affect both individual water users and the state as a whole. Changes in runoff timing could affect whether holders of water rights have water when they need it. For example, more water could well be available earlier in the spring and less in late spring and summer than in the past. State or regional water shortages may trigger the application of interstate compact requirements that could lead to additional water restrictions in Colorado.

All in all, the projected effects on water supplies and quality represent what may well be Colorado's greatest vulnerability to climate change.

References *[Need to add exact cites]*

M. Hoerling and J. Eischeid, Past Peak Water in the Southwest
N. Christensen and D. Lettenmaier, A Multi-model Ensemble Approach …
IPCC, Working Group II
B. Udall and G. Bates, Climatic and Hydrologic Trends in the Western U.S.

Water Adaptation Policy Work Group
Summary List of Policy Options

	Policy Option
WA-1	Need for Leadership
WA-2	Consideration of Climate Change in Water Decisions
WA-3	Colorado River Water Availability
WA-4	Interstate Compacts
WA-5	Climate and Hydrologic Data
WA-6	Drought Vulnerability Assessments and Planning
WA-7	Regional Modeling
WA-8	Water Conservation
WA-9	Agriculture
WA-10	Energy and Water
WA-11	Information Exchanges
WA-12	Recreation and Tourism
WA-13	Water Quality and the Environment
WA-14	Groundwater
WA-15	Colorado Water Institute

WA-1
Need for Leadership

Recommendation

1. Federal, state and local public officials in Colorado who have general responsibility for the health, safety and welfare of the citizens of the state, or a particular responsibility for meeting the consumptive and non-consumptive water needs of Coloradans, should exercise leadership in addressing the identified causes of, and adapting to, the impacts of climate change upon water supplies. Even if greenhouse gas emissions are reduced, scientists believe that our climate is likely to change enough to significantly impact current flow regimes. These effects could pose substantial risks to the economic, social and environmental well-being of the state. Accordingly, our public officials should give a high priority to identifying and implementing actions designed to respond, in a

responsible and coordinated manner, to the potential adverse effects of climate change on our water resources and the full range of beneficial uses associated therewith. Key public officials to whom this recommendation apply include our elected representatives to Congress, the Governor and other officials in the executive branch of state government, members of the Colorado General Assembly, elected and appointed officials in local governments, water providers, and officials in public colleges, universities, and research institutions.

WA-2
Consideration of Climate Change in Water Decisions

Recommendations

1. All Colorado water managers should investigate the vulnerabilities to climate change of the water supply systems they manage and determine how they will continue to meet future water needs in light of those vulnerabilities. In planning changes in future water supply systems and operating current ones, water providers should no longer assume the future will necessarily be like the past. Most water-supply planning in Colorado is based on the past hydrology of some recent period. New plans should consider both the substantial variations in regional climate now understood to have occurred in the more distant past and potential climate changes and their effects. Colorado water managers should also:

   A. Assess the vulnerability of their supplies and systems to climate change effects.

   B. Identify and preserve adaptation options.

   C. Apply risk management and adaptive management.

   D. Explore phased approaches to adjust with climate changes.

   E. Consider increasing water system reliability, diversity and flexibility.

   F. Use “no-regrets” planning of actions that would produce benefits even if the climate does not change as now projected.

   G. Create and participate in regional efforts to model and analyze the impacts of climate change.

2. Water suppliers should carefully consider the appropriate roles under a changed climate of:

A. **Reuse.** A reduction in the water available for first use within a municipal system could also reduce water available for reuse including use in water recycling systems, river exchanges and augmentation plans. Municipal sources from non-tributary groundwater wells and from water rights that were transferred from very senior agricultural rights may not see a reduction in water available for the first use and reuses. Some municipal water rights cannot be reused. Suppliers should analyze their system vulnerability.

B. **Conservation.** See recommendation WA-7, below.

C. **Storage.** The value of new or enlarged storage in reducing the impacts of climate change on municipal water supplies is being debated in the west. Some believe that reduced streamflow would mean there would no longer be additional water available for storage in new or enlarged reservoirs. Others believe new storage could play a role along with other measures to smooth out what could become even more variable supplies and the effects of more intense precipitation events. Reservoirs could also continue to help redistribute the timing and location of available streamflow to the time and place of societal and environmental needs.

D. C**onjunctive use.** Water suppliers should consider the value of storing surface water flows in underground aquifers where feasible and when there are excess water supplies, for subsequent use during drier years.

3. The state government should provide assistance to water providers that do not have the resources needed to consider the effects of climate change on the water supply systems they manage to help them do so.

References *[Need to add exact cites]*

American Water Works Association. Climate Change Primer for Water Providers (2006) and Climate Change Webcast (2007)

Stratus Consulting. Climate Change Report for Denver Water. (2006)

National Research Council. Colorado River Study (2007)

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Water Utility Climate Change Conference, San Francisco (2007)

WA-3
Colorado River Water Availability

The 2007 version of the Colorado Water Conservation Board (CWCB) annual project authorization bill (SB-2007-122) directed the CWCB to evaluate how much remaining Colorado River water the State of Colorado has to develop. Section 15 of that law states:

> (1) In addition to any other appropriation, there is hereby appropriated, out of any moneys in the Colorado water conservation board construction fund not otherwise appropriated, to the department of natural resources, for allocation to the Colorado water conservation board, for the fiscal year beginning July 1, 2007, the sum of five hundred thousand dollars ($500,000), or so much thereof as may be necessary, for the board to evaluate water availability in the Colorado river basin and its tributaries. The board shall work in full consultation with, and with the active involvement of, the basin roundtables. The study shall consider current and potential future in-basin consumptive and non-consumptive needs. The board, in consultation with the basin roundtables, shall recommend whether additional study or phases of study should be undertaken.

This is an essential public policy question. Under 2005 legislation, HB-2005-1177, the state of Colorado is engaged in a broad public effort to take a comprehensive evaluation of Colorado's future water needs and identify solutions to meet the identified needs. Through the HB-1177 process and the companion Statewide Water Supply Initiative (SWSI) process, a number of new projects have been proposed in the future. These projects range in size from small local projects to improve water use efficiency to large multi-state, multi-billion dollar projects that would convey water as far away as Flaming Gorge Reservoir to the Colorado Front Range.

Determining now much Colorado River water is available to Colorado under various federal statutes, state statutes, interstate compacts and international treaties (commonly referred to as the "Law of the River") is going to be a complicated and difficult endeavor. The issue is complicated by the potential impacts of climate change. For decades, Colorado water officials have assumed that the state could develop at least 3.0 million acre feet per year. However, this conclusion is based on the basic assumption that in the future, the Colorado River flows will be similar to the most recent past (1905-2000). Scientific studies, however, project that Colorado River flows will actually be reduced as a consequence of climate change.

Recommendation

1. To ensure that the new Colorado River water supply study is complete, relevant, widely accepted, and useful for future decision-making, the state government should ensure that the potential effects of climate change are considered in the study.

WA-4
Interstate Compacts

Interstate compacts to which Colorado is a party apportion among our state and other states the right to make beneficial consumptive use of interstate rivers and related water supplies. Several compacts, including the Republican River Compact and the Rio Grande Compact, contain mechanisms to adjust Colorado's apportionment based on climatic conditions. Others, such as the Colorado River Compact, contain requirements for delivery to downstream states of at least specified minimum amounts of water, causing Colorado (and in the case of the Colorado River, other upper basin states) to bear a greater share of any significant shortage. In the case of the Colorado River, therefore, the operation of the compact can serve to increase Colorado's vulnerability to climate change-driven water shortages.

Although it is a popular topic of discussion, the idea of renegotiating interstate compacts is not particularly realistic or appealing. All of the signatory states to compacts in the western United States are suffering from varying degrees of water shortage and will be adversely affected by water shortages brought about by climate change. Each signatory state would have a similar goal in any compact negotiation, namely to acquire a greater share of the available supply for its citizens.

Recommendations

1. Colorado should not assume that interstate compacts can or will be renegotiated to reduce the effects that climate change may have on the amount of water available for use in the state. Planning based upon assumed changes in compacts would likely lead to nothing but frustration and disappointment.

2. The state government should develop for each major river basin where one does not now exist a mechanism to deal with potential compact calls should they occur for any reason.

WA-5
Climate, Hydrologic, and Climate-Impact Data

Understanding and adapting to the effects of climate change on water supplies will require good information on what changes are occurring, with respect to such key elements as temperatures, precipitation, snowpack, the timing of snowmelt, and stream flows. The data-collection systems that currently exist to gather this information were not designed to track changes in climate, and so may be incomplete to meet today's needs. Also, many of the programs for collecting and disseminating these data have deteriorated or have been diverted over the last quarter-century, with the result that many long-term climate and streamflow records have been interrupted.

Recommendations

1. A task force appointed by the state government, with participation by invited federal agencies and research organizations, should assess the data and data systems that are

needed to enable water suppliers and others in Colorado to understand and adapt to the possible effects of climate change on water supplies and water quality in the state, and identify gaps in current data and data systems.

2. The state government and water users should support additional data collection with an emphasis on preserving and extending long-term records.

3. Colorado's representatives in Congress, our state and local governments, and water providers should support re-definition of agency priorities and, where necessary, increases in federal funding for collection and assessment of key data related to the potential effects of climate change on the state's water supplies.

4. *To come*: Support new data collection on impacts and adaptive management.

WA-6
Drought Vulnerability Assessments and Planning

New section to come

WA-7
Regional Modeling

Climate change will impact water supply by changing the amount and timing of stream flows and the amount and timing of water requirements for agricultural, industrial, non-consumptive and municipal uses. A water ~~user~~ supplier requires estimates of future water use to plan its own system and operations, but also to understand how competing water rights will affect its water supply.

The nature of future water-supply conditions can be estimated based on projections of future climate conditions from climate models, but such estimates require that the models' output be translated into projected stream flows and water requirements at relevant locations. Because current climate models use large grids (with a typical grid cell covering one-fourth of Colorado), model results must be mapped to a finer level of detail prior to translation to stream flows.

Several scientific studies have made projections of the possible effects of climate change on water supplies in the Colorado River basin, but these studies are at scales too large for local water supply planning. The state's other river basins have not been studied even at large scales. Some larger water providers have conducted studies to begin to estimate the potential impact of climate change on their systems.

Making estimates of future water supply conditions presents a number of technical challenges:

- **Scale/Translation.** For the ~~reasonable~~ near future, climate model data will be available at scales that are far too large for planning and decision making by water suppliers and users. Until climate projections become available in appropriate scales, planners will require some method of mapping large-scale climate projections to scales appropriate for planning purposes. Planners also require that climate projections be translated into stream flows. Many techniques are currently available to re-map and translate climate projections, and new techniques are becoming available. These can be broadly categorized as process-oriented or statistical techniques.

- **Water rights response.** Almost all water-supply models in Colorado rely on historical records of water rights yields, calls, or both. Climate-change induced changes in stream flows and water use will affect the yield of individual water rights and the pattern of calls. Historical water-rights yields and calls can no longer be depended on to represent future conditions.

- **Uncertainty.** Projections of future climate contain much uncertainty, arising from projections of future policy and economic responses (which are necessary to estimate future greenhouse gas concentrations), and from simulations of future climate responses. Further uncertainty is introduced by re-mapping and translation methods.

Collecting the data and constructing and running the models necessary to project future stream flows is a substantial effort. Many smaller municipalities and most individual agricultural users will not have the resources to make these assessments. Further, virtually every productive watershed in the state is shared by many water users, so if water users make independent assessments, the result will be much duplication of effort.

Recommendations

1. The state government, water providers, and others should cooperate in:

   A. Developing information from climate models on the possible effects of climate change on consumptive and non-consumptive water supplies in each of the state's major river basins.

   B. Developing common practical tools and databases for re-mapping and translation of climate model outputs. These tools should allow for flexibility on the part of water providers to choose from a variety of approaches to assessing climate change effects.

   C. Setting up and maintaining a clearinghouse of up-to-date climate projection data.

   D. Undertaking demonstration projects to assess the feasibility of making basin-wide assessments of water rights yields and call patterns in support of the individual water-supply modeling of water providers.

WA-8
Water Conservation

Decreasing river flows and lake and reservoir levels that are the expected by-product of climate change provide will provide great interest in and opportunities to step up water conservation throughout Colorado.

Role of the state government. While the bulk of conservation work needs to be carried out by individual water providers and water users throughout Colorado, state agencies can play an important role by providing funding and technical assistance and helping shape regional and state-wide education and message development.

Planning. State laws require conservation planning by water providers, but those laws have not been enforced. Recent additions to state laws require conservation planning and conservation goal-setting by water suppliers obtaining state funding for water related activities. Substantial state funding to assist with conservation and drought planning is available in the form of planning and implementation grants from the Colorado Water Conservation Board.

Municipal water supplier dilemma. Water conservation is favored by many water suppliers as a cost-effective means to decrease the need for new water development. The risk of a drying climate poses a new dilemma for water suppliers. Do the suppliers use the water saved from conservation to: (1) supply new population growth, (2) reserve some or all of the saving to protect against shrinking supplies; or (3) set aside some savings for environmental purposes such as improving river habitat? If the supplier uses the savings exclusively to supply growth in its service area, water efficiency is increased but more people become dependent on the same supply of water. If that supply shrinks, the additional savings needed to provide for the essential human uses in that supplier's service area might substantially impact landscapes and businesses within the service area. Water suppliers need to recognize that the choices are very case-specific and a given volume of saving can usually only be used for one choice. The saved water probably cannot do double duty. Water suppliers should carefully consider the risks and potential tradeoffs of this dilemma.

With respect to the conservation of agricultural water, see recommendation WA-9, below.

Recommendations

1. Municipal water providers should determine the potential for water conservation saving in their municipal water system. Providers should consider measures that are cost-effective for both the utility and customers and that accomplish significant water savings. Evaluations should address all customer segments, particularly those that demand the greatest volume of water or place the greatest burden on the water system in terms of peak use.

2. Municipal water providers should determine the best use of conservation savings such as reserving the savings for adaptation to climate change, using the savings to supply new growth, or using the savings for environmental purposes.

3. For municipal water providers reserving the saving for adaptation to climate change, it is recommended that the following conservation methods be considered and implemented where appropriate. These methods should also serve well for providers using conservation savings for purposes other than adaptation to climate change.

A. Specific demand management measures for municipal water providers include:

- Rate structures that reward conservation and provide incentive to avoid water waste.
- Rebate programs that encourage customers (both residential and business) to install high efficiency water fixtures (e.g., toilets and clothes washers).
- City ordinances and utility programs that encourage efficient irrigation.
- Business and residential audits that identify property-specific water issues and educate the customer on how to curb demand.
- Education programs that deliver a consistent conservation message to all.
- Water loss reduction programs that decrease treatment costs and plant capacity needs.
- Using non-potable water supplies for landscape or other appropriate water use whenever possible and metering this use, just as is done for treated water.

B. As municipal landscapes' irrigation accounts for roughly half of total annual municipal water use, it deserves special attention. Outdoor water conservation measures for municipal water providers include:

- Incentives and requirements to amend the soil before planting new landscapes.
- Encouraging Xeriscape to boost the prevalence of water-saving landscapes. For new development, consider limiting the amount of turf as a percentage of total landscaped area. For existing development consider turf removal incentives for both residential and commercial customers. Landscape changes may lower owner's maintenance costs.
- Increasing efficiency by changing watering habits (decreasing the numbers of watering days per week and lowering the amount of time per sprinkler zone).
- Irrigation improvements, including rains sensors (that turn off sprinkler systems during rain) and more efficient sprinkler head placement and water pressure.

4. New development and redevelopment measures. There is a special opportunity for additional conservation savings in new developments and redeveloped properties. State and local governments should consider requiring or providing incentives to residential and commercial developers and builders to use state-of-the-art conservation practices. Water providers may not have the authority to require such practices but they can work with state and local governments in recommending the conservation practices and may have opportunities to provide incentives.

5. Ongoing evaluation by municipal water providers. Water providers should evaluate the actual impacts of conservation on system yields and reliability through model runs and reasonable assumptions about technological and behavior savings that may be expected from customers before and after the implementation of conservation measures. Mechanisms must be devised and applied to effectively and accurately monitor and to report to the state government for its use in water supply planning program information on savings in order to evaluate this impact.

References

American WaterWorks Association, "*Water Resources Planning (M50), Second Edition*," *2007*.

Colorado Foundation for Water Education, "Citizen's Guide to Colorado Water Conservation," 2004.

Metro Mayors Caucus and Colorado WaterWise Council, "Best Management Practices for Water Conservation and Stewardship," 2005; found at www.coloradowaterwise.org

Pacific Institute, "Waste Not, Want Not: the Potential for Urban Water Conservation in California," 2003.

WA-9
Agriculture

Agriculture consumes a significant majority of the water resources apportioned to the state by interstate compact, and the state rights supporting that water use are generally the most senior in Colorado. If climate change produces a more restricted water supply over the long term there will be a movement of water use from lower intensity uses such as agriculture to higher intensity uses, such as municipal supplies. Consequently, climate change will have a commensurately greater impact on irrigated agriculture in the state. Because of the close relationship between agricultural production and water consumption it will be necessary to develop strategies that trade some measure of increased productivity for a known amount of actual conservation.

However, it is unreasonable to assume that increased efficiencies in agriculture will necessarily result in a long-term quantity of "saved" water that can be made available to municipalities. The opportunity to reuse water saved by efficiency improvements may be limited by downstream water rights and interstate compacts that depend on return flows. Also, the reality is that if water supplies become scarcer, the law of economics will lead to the amount of land in irrigated agriculture being reduced in order to provide supplies to municipalities.

There could be an important role for increased agricultural efficiency in providing supplies for non-consumptive uses. Water that is not released from storage or not diverted from streams

because of increased efficiency in agriculture could be used to better manage in-stream flows to the benefit of non-consumptive uses. Realizing this potential will require operating agreements and possibly changes in the law.

Recommendations:

The state government, agricultural water users and municipal water users should:

1. Try to develop operating arrangements (such as fallowing/leasing programs) that minimize the disruption of agricultural economies as water is transferred from agriculture to municipal uses, while not unduly hindering the operation of Colorado's important market in water and water rights.

2. Develop operating agreements, funding sources and, if necessary, legislation, to allow agreements among willing parties to undertake efficiency improvements in agriculture for the benefit of non-consumptive uses.

WA-10
Energy and Water

Water and energy are inextricably linked. Drinking water requires energy for water treatment, distribution, heating, and wastewater treatment. Energy production requires water for cooling of thermal plants or water for generating hydropower. The strong connection between water and energy provides opportunities to reduce greenhouse gases and reduce water supply vulnerabilities by conserving water and by examining increasing hydropower generation. On the other hand, both energy production and water supplies may be impacted by reductions in water availability.

Thermal power production—principally to cool steam at fossil fuel plants—requires large amounts of water. In 2000, fossil fuel plants in Colorado withdrew 20 billion gallons (just over 61,000 acre-feet), consuming 500 gallons per megawatt-hour generated. Increased source water temperatures may require additional water diversions for the same cooling effect. But for those thermal generation plants that utilize dry cooling systems, water consumption would not be impacted.

Proposed new sources of energy including ethanol and oil-shale production also have large water requirements. New demands should be evaluated in terms of relative production efficiencies and in the case of oil shale development potential impacts to junior users of the Colorado River. Ethanol production with corn grown in Colorado requires approximately 1000 gallons of water per gallon of ethanol produced, if you include water used to grow the corn. Oil shale production uses roughly 200 gallons of water for each barrel of oil, such that a full production scenario for Colorado of one million barrels of oil daily is projected to require somewhere between 180-270

million gallons per day (or 200,000-300,000 acre-feet per year) for retorting the shale and related power needs.

Many new proposed water supply projects in Colorado involve moving water over significant distances because of the scarcity of undeveloped water near population centers. Unallocated water is usually far downstream or even across mountain ranges from the anticipated point of use. In these cases Colorado's geography may impose potentially significant pumping requirements, with the potential for significant increased greenhouse gas emissions.

Hydropower can provide energy without consuming water and without generating carbon. However, some hydropower facilities in the United States have resulted in adverse environmental effects, including blocked fish passage, decrease in sediment transport, and water quality impacts. New hydropower as an energy solution to climate change requires a close examination of environmental impacts. Possibilities include new hydropower facilities, improving the efficiency of existing plants, and examining whether existing water storage and conveyance facilities may have hydropower additions.

Colorado's geography provides for a unique synergy between water providers and energy generation through the use of hydroelectric power. Communities, especially front-range water providers, may have ideal attributes for development of small hydroelectric projects at existing facilities – significant volumes of water flowing from higher elevations to water treatment facilities at lower elevations. But climate change or drought conditions could pose challenges to hydropower generation located in snowmelt-dominated basins as water supplies decrease.

Recommendations

1. The state government and utilities should evaluate cooling technologies on all new electricity generating facilities. Closed-loop recycling and dry-cooling use much less water than once-through cooling. Wind and solar generating facilities use no water, and should continue to be promoted, however, recognizing its limitations for base load generation.

2. Public education campaigns about climate change in Colorado should include efforts to:

- Make visible and understood the links among water conservation, energy conservation and carbon dioxide.
- Encourage both energy and water conservation.

3. Water providers and others should consider the greenhouse gas emissions to result from new water projects and activities. The state government should provide guidance on limiting such emissions and should encourage alternatives that minimize them.

References

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Energy Information Association (EIA) 2000, Form 767, Steam-Electric Operation and Design Report, Schedule V, Cooling System Information, Section A, Annual Operations.

Bartis, J.T., et al., Oil Shale Development in the United States: Prospects and Policy Issues. RAND Corporation. Santa Monica, CA (2005).

Clark, J. R. Nuclear energy proposed for production of shale oil. Oil and Gas Journal, vol 104(26) (2006), at 18-20.

WA-11
Information Exchanges

Climate change presents complex policy, planning and operational issues to water users, water managers and appointed and elected officials. Planning for adaptation requires an understanding of the potential impacts of climate change, of the probabilities that particular impacts will occur and of the range of potential technical and policy responses to those impacts. While there is no shortage of information about climate change, much of that information exists at two extremes: academic journal articles, research reports and policy analyses; or articles in the popular press (not to mention the entertainment industry). It is difficult and inefficient for water resource managers to use the academic resources, but the reliability of the information in the popular press is doubtful.

Likewise, the sophistication of water-dependant organizations in Colorado covers a very wide range. Large organizations, such as large utilities or large water conservancy districts, have their own technical staff, while a small town or a small mutual ditch might have only a part-time manager or maintenance person.

For these reasons it will be difficult to convey information about climate change to the broad spectrum of water users throughout the state. But, on the other hand, Colorado is blessed with exceptional technical, research and educational resources in the fields of climate, water resources and policy.

Recommendations

1. The state government, education and research institutions appropriate nonprofit organizations, or other entities should develop, publish, and circulate at least one publication (or set of related publications), using either traditional or electronic media,

that addresses an audience of water resources professionals, managers and policy makers. Such a publication should translate research products to useful practice- and policy-oriented information. In order to be authoritative, such a publication will need some degree of peer review.

2. The state government, education and research institutions, appropriate nonprofit organizations, and/or other entities should:
    - Provide practice-oriented information about climate change;
    - Host information exchanges among water management organizations, at both the policy and technical level, where they can trade experiences, successes and failures;
    - Conduct research oriented toward practical issues of water resources management and policy in the face of climate change; and
    - Provide opportunities for training and education in specific, practice-oriented topics related to climate change.

3. The state government, water-provider organizations, education and research institutions, appropriate nonprofit organizations, and/or other entities should encourage and facilitate cooperative working relationships among water-provider organizations in order to facilitate joint adaptive responses.

4. The state government, water-provider organizations, education and research institutions, appropriate nonprofit organizations, and/or other entities should develop training and education opportunities for elected officials with respect to climate change in Colorado and ways to reduce the state's contributions and vulnerabilities to it, including with respect to climate change effects on water quantity and quality in the state.

5. *To come*: regarding National Integrated Drought Information System

WA-12
Recreation and Tourism

Climate change's effects on Colorado's snow and water resources are likely to have a wide range of impacts on the opportunities for recreation and tourism in the state and the industries that support them. These impacts threaten to decrease the intrinsic and economic value of resources that currently bring enjoyment to millions of residents and add billions of dollars to the State's economy.

Several recreational and tourism impacts include:

- **Fishing**. Scientists project that warmer trout streams will eliminate or reduce trout populations in many, perhaps most, streams in the West where they are now found. Lower summer flows may make trout more susceptible to disease and angling pressure.

Angling and related activities are estimated to bring hundreds of millions of dollars annually to Colorado's economy.

- **Skiing**. Scientists project that less snow and warmer temperatures likely will mean shorter ski seasons and fewer days of champagne powder.

- **Rafting and Boating**. Earlier and quicker spring runoff could change the timing of and shorten the prime season for river running. (Rafting was estimated to have $135 million in economic benefit in the state in 2006). Lakes and reservoirs could have decreased levels in summer, affecting boating.

- **Hunting**. Scientists project that climate change could lead to fewer wetlands, which could leave fewer nesting ponds for ducks and geese and few hunting spots in the fall. Vegetation changes may affect elk and deer food supply at different elevations.

- **Camping, Hiking, and Biking.** Projected further increases in forest fires could mean more forest closures and campfire restrictions. The aesthetic value of streams could decrease if summer flows drop.

Recommendations

1. State government agencies, with invited participation by federal agencies, should undertake studies to evaluate possible impacts of climate change on recreation and tourism in Colorado. Responsible state agencies include the Division of Wildlife, Colorado State Parks, Water Quality Control Division, Air Pollution Control Commission, and Colorado Water Conservation Board. Responsible federal agencies include the Forest Service, Bureau of Land Management, Fish and Wildlife Service, Corps of Engineers, Department of Agriculture, and Environmental Protection Agency.

2. The potential impact of climate change on outdoor recreation and tourism underscores how essential it is for natural resource management agencies to take advantage of their responsibilities and relationships with the public to set an example in decreasing greenhouse gas emissions while at the same time preparing for impacts on Colorado's valuable waterways. Government agencies and businesses managing and providing outdoor recreation and tourism opportunities and services should take visible actions to reduce their emissions of climate change and to adapt to the effects of climate change, and educate the public on the risks of climate change and actions that can be taken to reduce it and respond to it.

3. The Colorado Water Conservation Board should evaluate its instream flow program for any changes needed in its administration to reflect the effects of climate change on the purposes for which the program was established.

4. The state government, with invited participation by appropriate federal agencies and others, should investigate habitat protection and enhancement needs for terrestrial and aquatic species particularly vulnerable to climate change.

References

Todd Pickton and Linda Sikorowski, "The Economic Impacts of Hunting, Fishing, and Widlife Watching in Colorado"; found at http://wildlife.state.co.us/About/Reports/EconomicImpacts/

Colorado River Outfitters Association, "Commercial River Use in Colorado: 2006 Year End Report"; found at http://www.croa.org/media.htm

WA-13
Water Quality and the Environment

Climate change can have significant impacts on the water quality of our rivers and lakes and the associated aquatic ecosystems.

Climate driven increases in water temperature, seasonal decreases in flow, and changes in the intensity and duration of precipitation events can all influence water quality standards and designated beneficial uses. Potential impacts include:

- Increased pollutant runoff from more frequent and severe rainfall events.
- Periodic drought related low flows below aquatic life needs.
- Loss of anticipated dilution flows.
- Channel reconfiguration and sediment transport through flooding.
- Reduced dissolved oxygen levels in water bodies.
- A loss of, or change in, biodiversity.
- An increase in forest fires and accompanying run-off concerns.
- Reduced populations of cold water fish such as trout.
- Reduction in aquatic and riparian biodiversity.
- Threatened and endangered species, including four fish species native to the Colorado River and its main tributaries, likely will face additional pressure due to changes in stream flows, increases in water temperature, and degradation of other habitat elements.

Climate-induced hydrologic modifications may similarly affect the implementation of water quality regulatory programs, such as compliance with wet-weather mandates (combined sewer overflow and stormwater best-management practices); the establishment of permit effluent limitations based on "low flow" averages; and the listing of water bodies as impaired under Section 303(d) of the Clean Water Act due to increased pollutant loadings, elevated temperature

or the mere loss of flows. Water-resource allocation decisions designed to adapt to changes in water availability will also hold implications for water quality. For example, there may be a tendency to expand reuse programs, necessitating additional protective reuse regulations, or to adopt enhanced treatment techniques, such as reverse osmosis, with attendant brine disposal concerns.

Climate change may also have broad effects on natural ecosystems, including those where snow cover and stream flows are dominant features. The Intergovernmental Panel on Climate Change, in fact, says that such effects are already being observed around the world, from such factors as reduced snow cover and increased temperature of water bodies. Section WA-12 on recreation and tourism, above, mentions the potential effects of climate change on trout and angling. Also potentially adversely affected by climate are threatened and endangered aquatic species, including four fish species native to the Colorado River and its tributaries, which are vulnerable to changes in stream flows and other stresses. Riparian areas, including wetlands may be at risk, particularly if there is an extended and deeper low flow period. Increases in forest pests, disease and fire would lead to more runoff of sediments into streams and lakes, worsening water quality and harming aquatic ecosystems. Invasion of some plant species may soak up more water supplies, further reducing runoff.

Recommendations

1. The state government and others, with invited participation by the federal government, should undertake additional data gathering and research on water quality impacts related to climate change, along with a re-examination of certain regulatory programs under both the Clean Water Act and the Safe Drinking Water Act. EPA and certain states have commenced an examination of these issues and their efforts should be utilized in the development of a response strategy.

2. The state government should consider ways to enhance protection of aquatic and riparian ecosystem. They should consider methods of further reducing stressors on ecosystems, protecting core habitat areas, increasing the size and extent of fish populations, and monitoring aquatic and riparian ecosystems to quickly detect any deterioration in their health.

References

EPA Website on Climate Change: http://www.epa.gov/climatechange/

Memorandum from Benjamin Grumbles, EPA Assistant Administrator for Water, to office Directors on Climate Change and the National Water Program, dated March 2, 2007.

Climate Change Science Program Synthesis and Assessment Product 4.4, Preliminary Review of Adaption Options for Climate Sensitive Eco-Systems and Resources (EPA et. al., to be completed December, 2007)

WA-14
Groundwater

The tributary groundwater supplies in the state are expected to respond to the effects of climate change in a manner very similar to that of the surface stream systems to which they are connected. As the surface stream flows diminish their ability to replenish groundwater systems declines commensurately; as surface irrigation supplies diminish the ability of those irrigation systems to recharge the groundwater declines; and as "conservation" and improved efficiency in agricultural irrigation practices increase in response to climate change there is a resulting loss in return flows to the groundwater systems.

Nontributary groundwater systems, such as the Denver Basin, are believed to be relatively immune to the effects of climate change. On the other hand, they are effectively non-replenishing from natural sources and as tributary systems are affected by climate change, the temptation to continue to rely upon them and mine the water within them will increase, hastening their ultimate elimination as viable source of water supply.

Recommendations

1. Colorado should reduce the use of groundwater for irrigation supplies in groundwater-dependent basins including the South Platte, the Republican, the Arkansas and the Rio Grande until recharges match discharges from pumping, natural losses, and the obligations to neighboring states under our compacts.

WA-15
Colorado Water Institute

Water is the key natural resource for economic development in the state. The management of this resource is done within a complex environmental and legal framework. Many demands are put on this resource, and in recent times, due to climate variability, the water system has been stressed. Climate change has the potential to further stress the water supply and quality. Better integrated planning for the management of water and policy decisions is needed that better utilizes the expertise in fundamental and applied research in climate and water resource management and technology. While many groups within the state deal with water issues, those groups are fragmented, often redundant, and individually under-funded. As a result, we are not reaching our full potential in addressing climate and water-adaptation strategies

Other states (such as Arizona and California) have developed new models for approaching water management activities. These new approaches:

- Are partnerships of select state and federal agencies, research universities that have expertise in water, and the governor's office.
- Have a strong mandate for the development of sound water management and conservation practices.
- Explicitly examine climate-change impacts and adaptation strategies for water resource management.
- Examine the interface between water and energy.
- Incorporate latest research into decision-modeling.
- Provide evaluation and assessment of water-adaptation strategies and implementation plans.
- Provide policy analysis.
- Actively participate in policy development including participation in drought task forces and other water-related task forces, e.g., watershed management groups.
- Interface with federal agencies, particularly the Bureau of Land Management, Forest Service, Bureau of Reclamation, and National Oceanic and Atmospheric Administration.
- Provide education and training for a variety of constituencies.
- Develop enhanced information for stakeholders.
- Provide a web-based clearinghouse of information needs and resources for water management.

Recommendation:

1. A Colorado Water Institute should be formed. It should be a consortium and partnership of state research universities (such as Colorado School of Mines, Colorado State University, and the University of Colorado-Boulder); state agencies (such as the Division of Water Resources, the Department of Public Health and Environment, the Colorado Water Conservation Board, the Office of Economic Development and International Trade); federal agencies (such as the National Oceanic and Atmospheric Administration's Earth System Research Laboratory and the National Weather Service's Regional Office); other relevant institutions (such as the National Center for Atmospheric Research); and the governor's office. The CWI should not be a state agency. It is realized that the formation of such an institute may require the reallocation of resources in current water activities and organizations that are supported by the state. The benefits would be a more visible, integrated, and collaborative approach to planning, adaptation, and management of water resources within the state that includes the impacts of climate variability and climate change. Many of the recommendations in this report would be incorporated as part of the mission of the CWI.