Hastings Environmental Law Journal

Volume 14
Number 2 *Summer 2008*

Article 2

1-1-2008

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Planning for and adapting to the uncertainty that climate change brings to water resources is the most significant challenge before California's water managers this century. Confronting this new reality, water managers must act strategically as climate change both increasingly threatens public health and safety and long-term water supply reliability. Above all, the California water management community must embrace an entirely new way of thinking about California's water and other natural resources.

Challenges

Recently the nation has witnessed a fundamental shift in the understanding of climate change. Climate change, a term that describes the alteration of temperature and precipitation patterns caused by global warming, is dramatically challenging our historic methods of water resources management. While the natural trend of cyclical global warming and cooling is well documented, the international scientific community has concluded with overwhelming consensus that the collective impacts of human activity on the Earth has led to a rapid acceleration of this cycle. Specifically, human activities are causing increased concentrations of carbon dioxide and other greenhouse gases (GHG) in the Earth's atmosphere, which are changing the climate. In just the past few years, climate change has evolved rapidly from a peripheral, distant concern to an immediate call to action.

Of the many aspects of California society affected by climate change, water — its quality, control, and availability — will be one of the resources most impacted by warming temperatures and changing precipitation patterns. In fact, it is already clear that:

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- The water past can no longer be solely relied upon to forecast the water future;

- Precipitation and runoff patterns are changing and are expected to change even more dramatically, increasing the uncertainty for water supply, flood management, and ecosystem functions;

- California must invest significantly and consistently in monitoring, researching, and understanding our climate, water resources, and environment;

- California must radically improve its flood and drought preparedness, response, and recovery plans and functions;

- Water managers and users — businesses, institutions, individuals — can play a key role in the reduction of GHG emissions and the stewardship of water and other natural resources; and

- An array of water management strategies can be implemented in ways to better address the uncertainties of changing water patterns.

While the challenges are daunting, California must take action to both mitigate and adapt to climate change.

California's Water Crisis

California's concerns over the availability, quality and distribution of water are, of course, nothing new. Water management in California is an extraordinarily complex issue and, with a growing population, continuing changes in land use, and declining public investments in water infrastructure, becomes increasingly contentious and complicated with each passing year. Contemporary water managers must unfortunately navigate a minefield of competing interests and regulations in order to reliably provide quality water to farms, businesses, and homes, while concurrently protecting the environment.

A survey of California's water landscape yields an assortment of crises, in varying stages of dysfunction. For example, the Sacramento-San Joaquin Delta, the hub of California's water supply and delivery system, faces serious ecosystem challenges as well as seismic risk and sea level rise that threaten water supply reliability. Of course, the Delta is not the only water dilemma confronting the state. Groundwater supplies, especially in Southern California and the Central Valley, suffer from overdraft and contamination. The Colorado River, an important source of water for much of Southern California, is in the midst of a historic drought. And despite the threat of water scarcity in the long-term, the threat of too much water in the short-

term — combined with an aging flood protection system, development in floodplains, and flood protection designed for an agricultural era — has created unacceptable flood risks in many areas of the state.

Climate Change and Water in the 20th Century: What's Happened Already

While the exact conditions of the future remain elusive, there is no uncertainty about the changes that have already taken place. For instance, California and other western states have already witnessed a change in the seasonal timing of snowmelt. Throughout the West, snowpack is melting earlier, shifting more of the annual river runoff from the spring, when there is often not enough water to refill reservoirs, to the winter, when there is often too much water to manage. For example, the Department of Water Resources (DWR) estimates that during the 20th century, spring runoff on the Sacramento River was reduced by one million acre-feet. Over the past century, sea level rose seven inches along California's coast. A disturbing pattern has also emerged in California's floods, namely, an increase in peak flood flows on many of the state's rivers during the last half-century, many of which have devastated communities.

Climate Change: The Water Challenge of the 21st Century

During this century, the impacts of climate change could fundamentally undermine last century's development of California's water resources, along with the economic prosperity and quality of life that development helped produce. The California water management community has invested in, and now depends upon, a system that relied on historic hydrology as an accurate guide to the future for both water supply and flood protection. We now recognize that historic hydrology may have limited utility as a forecasting tool in the future.

Drought: Loss of Natural Snowpack Storage

One of the most critical impacts for California water management is the anticipated reduction in the Sierra Nevada snowpack — California's largest surface "reservoir"—that currently provides an annual average of 15 million acre-feet of water and releases it over a period of several months. Based upon historical data and climate and hydrological modeling, DWR projects that the Sierra snowpack will experience at least a 25 percent reduction by mid-century, posing a significant threat to California's water supply reliability with the prospect of longer and dryer droughts.

Flooding: Higher Peak Flows, Increased Storm Variability

The amount of snow (and its water content) is critical, but so is the timing of runoff into river and streams. Rising snowlines due to climate change will allow a greater portion of the Sierra Nevada watersheds to contribute directly to storm runoff. Along with changes in the amount of the snowpack, scientists project greater storm intensity, which could in turn result in even more direct runoff and flooding. Flood protection, for the purposes of insurance, has traditionally been measured against the "100 year" flood event, which refers to the level of flood flows expected to be equaled or exceeded at least once in a 100-year period (or with a 1-percent chance of striking in any given year). With the changes to California's hydrology, what is currently considered a "100-year flood" will strike more often, leaving communities with lower levels of safety if they do nothing. As peak flows and precipitation change over time, we must factor a new level of safety into the design, operation and regulation of flood control facilities.

Sea Level Rise: Threat to Public Safety

Even the most conservative projection from the Intergovernmental Panel on Climate change (IPCC) predicts at least another seven inches of sea level rise by the end of this century.[1] For Californians who live in or near the Delta, or who rely upon drinking water or agriculture irrigated by Delta exports, the most critical impact of rising seas — even of a mere half foot — may be the increased pressure on an already vulnerable levee system. Catastrophic levee failures could inundate Delta communities and interrupt water supplies throughout the state. Even without levee failures, sea level rise will increase the intrusion of seawater into currently overdrafted coastal aquifers, as well as Delta water supplies, degrading drinking water quality and altering aquatic habitat.

Hydroelectricity; The Other Water-Energy Nexus

Climate change is anticipated to have an adverse impact on hydroelectric generation, which is California's largest source of energy produced without greenhouse gas emissions. Heavier rainfall and flooding can strike at times when water cannot be stored in reservoirs due to lower levels that must be maintained for flood control. Increased or fluctuating water inflows to reservoirs may exceed hydroelectric generation capacity, forcing water releases over spillways and resulting in lost hydropower

1. Sea level could rise even more dramatically, two feet or more, depending upon ice cap melting in Greenland and western Antarctica, about which there remains great uncertainty.

potential. Higher snow elevations, decreases in snow pack, and earlier melting results in less water that can be stored for power generation during hot summer months, when energy demand is highest in California. The impact is compounded by anticipated increases in energy use due to higher temperatures and greater water demands at a time when less water is available. These conditions may force greater dependency on fossil fuel generation that produces greenhouse gases.

Additional Impacts

Beyond the receding snowpack, bigger floods, and rising oceans, climate change will have a variety of other impacts to water management. Climate change will increase evapotranspiration rates, thereby increasing the amount of water needed for crop irrigation. Warmer water will distress many fish species and require the additional cold-water reservoir releases. Changes in the timing of flows will affect water quality. On one extreme, flood peaks may wash more pollutants off watersheds, challenging treatment plant operations, while on the other extreme, lower summer and fall flows may provide less dilution of contaminants. A warmer and drier climate will increase the frequency and intensity of wildfires as well, affecting watersheds and water quality.

Changing Climate and Changing Institutions

Much like California's water infrastructure, the state's institutions have also evolved over the past century assuming that historical hydrology is a trustworthy guide to the future. As climate change affects the amount, form, distribution, variability, and timing of water in the state's many watersheds, legal systems supporting the diversion, use, and quality of water will also have to adapt to a changing climate. Hydrologic changes will also affect water temperature and dilution flows, which could affect existing permitting of discharges and return flows.

The Imperative to Act; Mitigating *and* Adapting to Climate Change

Climate change thus compounds the dilemmas already facing California water managers, who must play dual roles in tackling this challenge. The first of these roles is in *mitigation*, which refers to the reduction of greenhouse gas (GHG) emissions from water-related energy use that contributes to the changing climate. Water utilities necessarily use energy to provide quality and reliable water to customers, who in turn use energy for a myriad of individual water uses. Agencies then must use energy to safely collect, treat, and dispose of wastewater to protect public health and the environment. Water in California, though, also provides enormous benefits to California's energy system and climate change mitigation efforts

through the generation of clean hydroelectric power, California's largest source of GHG emissions-free electricity.

At a global scale, GHG emissions must be reduced to slow the effects of warming and climate change, and California is already leading the world to enact major GHG reductions on an ambitious timeline. In 2006, Governor Arnold Schwarzenegger and the California Legislature enacted Assembly Bill 32 — *The Global Warming Solutions Act* — into law. AB 32 requires a statewide cap on GHG emissions, reductions in emissions from major stationary sources, and the development of a mandatory reporting system for these emissions. The Governor's Climate Action Team is overseeing the implementation of AB 32, including a multi-agency Water-Energy Subgroup tasked with the development of GHG mitigation strategies for energy consumption related to water use.

While doing its part to reduce GHG emissions, the California water community must concentrate its efforts on *adaptation*, which is essential to respond to the changes that are unfortunately inevitable. The scientific community asserts that even if the world were somehow able to suddenly cease all GHG emissions, the Earth's temperature would continue to rise for at least another century as a result of society's legacy of GHG emissions. As a result of climate change, conflicts between water supply, flood management, and environmental stewardship — each currently in peril due to other stressors — could be pushed to the brink.

Despite the ominous nature of climate change's predicted impacts, though, there is still time to act. As understanding of climate change increases, the challenge for California's water community is to develop and implement strategies that improve resiliency, reduce residual risk, and increase sustainability, for water and flood management systems, even in the face of uncertain future water conditions. To be successful, these adaptation strategies must be implemented collaboratively at the state, regional, and local levels, and integrated to maximize their effect.

A New Vision for California Water Management

Framework for Action

With climate change upon us, California has entered a new century on the verge of the next great leap forward in both water and flood management. Fundamentally, California must invest far more in its capacity and flexibility, in the face of great uncertainty, to sustainably manage water and other natural resources in the future. In 2005, the state has laid the foundation for this next great advance in the *California Water Plan Update* 2005 (*Water Plan*), the state's strategic plan for water resources. Consistent with the "Framework for Action" for the *Water Plan*, state, federal, regional, and local governments must work cooperatively on two critical initiatives:

- maintain and improve statewide water management systems
- promote and practice integrated regional water management

A Contemporary Model for Statewide Water Management Systems

Statewide water management systems must adapt as the climate changes. Most importantly, we must build upon a legacy of multi-purpose water projects to better integrate flood planning and management with all other aspects of water planning and management. At the same time, the ongoing challenge of non-climate ecosystems stressors, such as pollution, habitat degradation, and invasive species, must be reduced in anticipation of new stressors caused by climate change. As global warming erodes California's snowpack storage, better management of watersheds, floodplains, and aquifers is critical. A 21st century water management system for California must integrate these aspects of water management with common sense land use decisions for the benefit of water supply reliability, water quality, and ecosystem health and stability. Moreover, building flexibility and resilience into statewide water management systems will be vitally important in order to support regional self-sufficiency efforts throughout California, and to allow for the sharing of supplies during emergencies.

Environmental stewardship

Effective management of flood protection, water supply, and water quality is inextricably tied to the sustainability of ecosystems and the benefits they provide. The seasonal inundation of floodplains can maintain and enhance ecosystem function for a variety of aquatic and terrestrial species, providing for biodiversity and resilience of our ecosystems. With a changing hydrology, California must plan now for rivers to adapt and change in protected corridors. Flood corridors can also provide for ecosystem connectivity that may be the most important focus of sustainability in a changing climate, and provide opportunities for parks, recreation, and the preservation of agriculture and open space. Furthermore, riparian forests and vegetation have the ability to sequester carbon, reduce water temperatures, and improve water quality, while providing for public safety as well. Floodplain management must thus work to restore natural floodplain processes and incorporate environmental stewardship as a guiding principle.

Infrastructure integrity

Even with a renewed emphasis on natural processes, structural solutions to flood management will continue to play a major role in public safety. However, infrastructure built in the first half of the 20th century is

already challenged by the increasing flood peaks in the second half. Where possible, existing systems must be modified to increase channel capacities — via levee strengthening and construction of setback levees — to provide for adequate conveyance of flood flows where existing development now limits natural floodplain processes. Moreover, water management facilities in general need to develop robust back-up systems to respond to the greater uncertainty presented by climate change.

Comprehensive water supply management

At the other extreme, climate change will also bring more severe droughts to California. In addition to its public safety benefits, better floodplain management, in combination with the establishment and expansion of spreading basins, can provide opportunities to recharge groundwater basins with floodwaters, especially in the Central Valley, where many basins are overdrafted. Dams, floodplains, and aquifers must be managed conjunctively to store water when it is available, to carry California through the dryer times ahead. With a smaller Sierra snowpack, opportunities for better managing surface and groundwater storage will be even more important. Land use decisions must consider the protection of groundwater recharge areas, minimize impacts on water quality, and reduce runoff.

The Potential of Regional Water Management

During the last half of the 20th century, California began to meet much of its increasing water demands through the development of local and regional projects. Regions are increasing their self-sufficiency and diversifying their water supply portfolios. Increased regional self-reliance can reduce dependence on the distressed Sacramento-San Joaquin Delta and reduce the amount of water that must be pumped and transported across the state, thereby reducing the amount of energy required for water conveyance.

Many climate change adaptation strategies are necessarily region specific. Due to the regional variability of a number of factors, including geography and population — one size will not fit all. Investments in statewide systems are critically important, but dynamic and extensive regional planning must complement these investments. While State government has considerable authority to manage statewide water and flood activities, the vast majority of decision-making and funding authority and responsibility remains at the local and regional level.

Integrated Regional Water Management Planning

Over the past decade, many California water managers have recognized the value of regional planning and are applying the principles of Integrated

Regional Water Management (IRWM). IRWM is an inclusive approach for determining the appropriate mix of water demand reduction, supply enhancement, and water quality improvement actions, to provide the best long-term balance between the costs of water reliability and quality actions and the benefits of those actions. While IRWM has long been recognized to be important in water management planning, the challenges posed by climate change make it a critical strategy for adaptation.

Integrated Regional Water Management requires a collaborative effort to manage all aspects of water resources within a region. IRWM is distinct from traditional approaches to water resource management because it promotes the integration of all facets of water management. This integration considers goals for water supply, wastewater, flood and storm water management, and environmental water needs, with a better understanding of the costs of unreliability. Only after such integration can a comprehensive evaluation of the tradeoffs between actions to enhance reliability and quality and the costs of making those enhancements be accomplished, from which more informed decisions can then be made. IRWM transcends jurisdictional, watershed, and political boundaries; involves multiple agencies, stakeholders, individuals, and groups; and attempts to address the unique regional issues and differing perspectives of all parties involved through the development of mutually beneficial solutions.

IRWM actions provide a broad variety of benefits, including managing existing and future water demands most efficiently; improving the availability and quality of water supplies; providing flexibility to deal with extreme hydrological events, such as droughts and floods; and restoring and enhancing ecosystems to help sustain natural resources.

Developing Regional Self-Sufficiency

In order to adapt to the impacts of climate change, population growth, and other stressors, every region of the state should invest in strategies that improve regional water supply self-sufficiency to reduce risk. As mentioned earlier, climate change, along with environmental and regulatory pressures, will make exports from the Delta, the Colorado River, and other sources more uncertain in the future. Improved capacity to meet local demand with local supply is needed, particularly in times of drought or following a natural disaster, such as an earthquake. Regional self-sufficiency must be improved by:

- increasing the efficiency of agricultural and urban water use;
- expanding the distribution and reuse of wastewater;
- creating new storage, both above and below ground, to store water in times of surplus and to diversify sources of supply;

- improving integration both flood and water management through the development of surface and groundwater conjunctive use strategies;

- implementing local stormwater management programs;

- building facilities to reclaim or desalt otherwise poor quality sources of water; and

- making land use decisions that minimize new water demand, protect water quality, and promote recharge of groundwater.

Flexible Options for Unique Regions

The *California Water Plan Update* 2005 describes 25 resource management strategies, which can be compared to individual tools in a toolbox. Just as the mix of tools will vary depending on the job, the combination of strategies will vary from region to region depending on the individual situations surrounding water supply and use, climate, projected growth, and environmental and social conditions. California's regions cannot meet all of their water objectives with a single or even just a handful of strategies. Investments for new infrastructure and for the repair of aging facilities at the state level must occur, but regional investments for self-sufficiency are equally important. Every region of California must build a diverse water portfolio that balances cost-effective water supplies and demands while protecting the environment.

Conclusion

As Californians move beyond recognition of the impacts of climate change, state and regional water managers must simultaneously embrace both mitigation and adaptation approaches. While some climate change predictions are indeed dire, the good news about climate change is that adapting to its impacts is complementary to adapting to the other major changes — in population, land use, economics — in California's future. As is often the case, there are opportunities in all challenges, even one as great climate change. Most of all, there is the opportunity for California to lead the world on adapting to climate change as it has in so many other arenas.