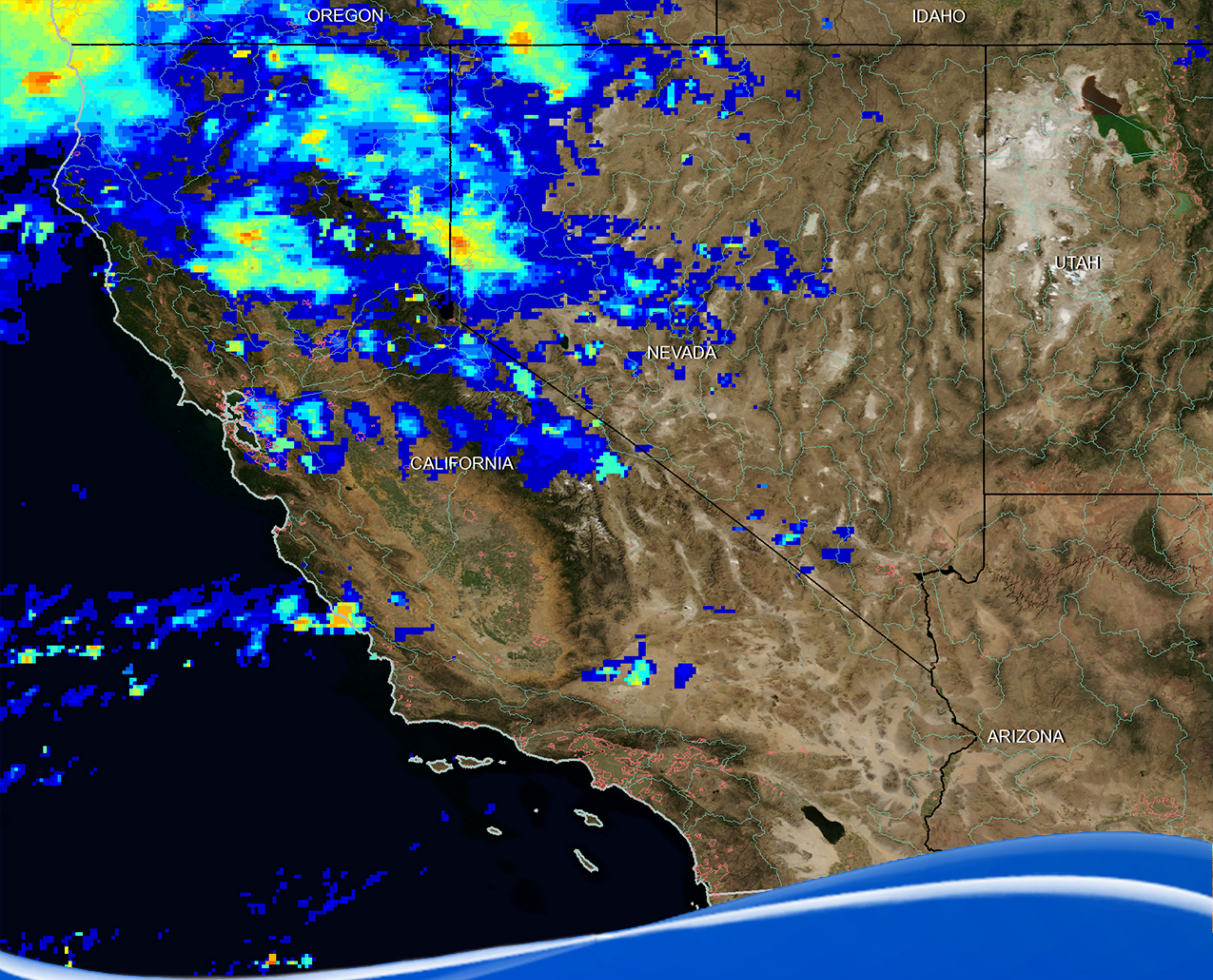

Achieving a Sustainable California Water Future Through Innovations in Science and Technology

California Council on Science and Technology
April 2014

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Cover Image: 12-hr satellite precipitation accumulation estimate (mm) on March 28, 2014 (20:00 UTC) over California, produced by the G-WADI PERSIANN-CCS System of the UC Irvine Center for Hydrometeorology and Remote-sensing (CHRS)

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Message from CCST

CCST is pleased to present “Achieving a Sustainable California Water Future through Innovations in Science and Technology,” a study designed to help inform the decisions California faces in navigating the challenges of meeting the state’s water needs in the face of population growth and climate change impacts over the coming years.

This report provides an overview of California’s water use cycle, the needs and challenges it faces at each stage of the cycle, and identifies innovation opportunities that the state could potentially pursue in the near future. The study builds on two CCST projects completed in recent years: the Innovate 2 Innovation reports, which assessed California’s innovation ‘ecosystem’, and the California’s Energy Future reports, which offered a comprehensive look at what would be required to reach California’s goals of reduced greenhouse gas emissions by 2050. In the former project, water was identified as one of the state’s major challenges where innovation had the potential to make a significant difference; in the latter, the relationship between water and energy - the water-energy nexus - was touched upon in most of the publications in the series.

This report represents input from more than a hundred and fifty water experts, including representatives from state, federal, and local agencies, academia, federal research laboratories, NGO’s and the private sector. It provides both near-term and long-term recommendations, to be pursued by a variety of agents. California’s water system is enormous, complex, and depends upon the successful cooperation and interaction of myriad of agencies at the federal, state and local level. The challenges faced by the state are complex, and so is the range of potential solutions. For this reason, in addition to the overall near- and long-term action items, the document also provides recommendations specific to each area of the water system. However, one thing is clear: innovation may be a tremendous driver in California, but strategic coordination will be necessary in order for it to be effective on a systemic basis. The way towards a sustainable water future lies not in a single technological fix, but rather in the selective and well-informed development and implementation of a California water strategy that utilizes a broad range of compatible technologies, policies and approaches.

We believe that the California Water Future project represents a valuable insight into the possibilities and realities of meeting California’s water needs over the decades to come, and hope that you will find it useful.

Charles F Kennel
Charles Kennel
Board Chair, California Council on
Science and Technology

Corey Goodman
Council Chair, California Council on
Science and Technology

Susan Hackwood
Susan Hackwood
Executive Director, California Council
on Science and Technology

Achieving a Sustainable California Water Future Through Innovations in Science and Technology

1. Executive Summary

Water Innovation Opportunities

California has a long history of success in leveraging innovations in science, technology, management and implementation strategies to improve its resource management, including its continued leadership in energy efficiency. The State's best strategy for dealing with its water challenges, both current and future, lies in taking a system management approach to water similar to the approach used for energy. Also, as with energy, innovative water technologies represent a sound business opportunity for California.

This report highlights innovations in science, technology, management, and implementation across a broad range of water supply, demand and management areas, and suggests strategies and recommendations for continued investment and support of innovation in California. It is our assessment, as detailed in this report, that continued innovation both through the development of new solutions and the broader application of proven successes can help California improve its water management and support a long-term healthy and sustainable water system. In order to be successful, however, we will need to align our efforts on an integrated set of strategies (roadmap) that will require leadership, action and investment by both the public and private sectors.

Background

This report builds upon the California Council on Science and Technology (CCST) 2011 assessment of California's innovation ecosystem, entitled "Innovate to Innovation" (i2i). The 2011 report identified the management of the California water resources as a serious challenge to California's long-term economic prosperity. This report provides a roadmap of innovations in science and technology that could, if effectively implemented, significantly improve the management of California's water system over multi-year cycles ranging from very low precipitation that can result in drought conditions to significantly above average precipitation that can result in severe flooding. The current study is also designed to complement the 2013 Update of the California Water Plan facilitated by the California Department of Water Resources (DWR) and the Governor's California Water Action Plan prepared by the California Natural Resources Agency, the California Department of Food and Agriculture, and the California Environmental Protection Agency.

Current Water Challenges

Water is a fundamental resource challenge facing California, and its planning and management is a critical underpinning of California's economy and environment. The impacts of climate change and weather variability, including potentially higher uncertainty in the magnitude of the Sierra Nevada snowpack, rising sea levels, and the prospect of increasingly severe and variable wet-dry conditions throughout the state, threaten the future availability and quality of California's water supply. Additionally, many of the state's aquifers continue to be significantly over-drafted. Historically, California has relied on large-scale engineering solutions to address its water needs and manage floods, building massive water systems based on dams, canals, and pipelines. The aging of this infrastructure, combined with climate change impacts and a growing population, increases the difficulty for the state to ensure adequate water supply for its residents, agriculture, businesses and environment.

Conclusions and Recommendations

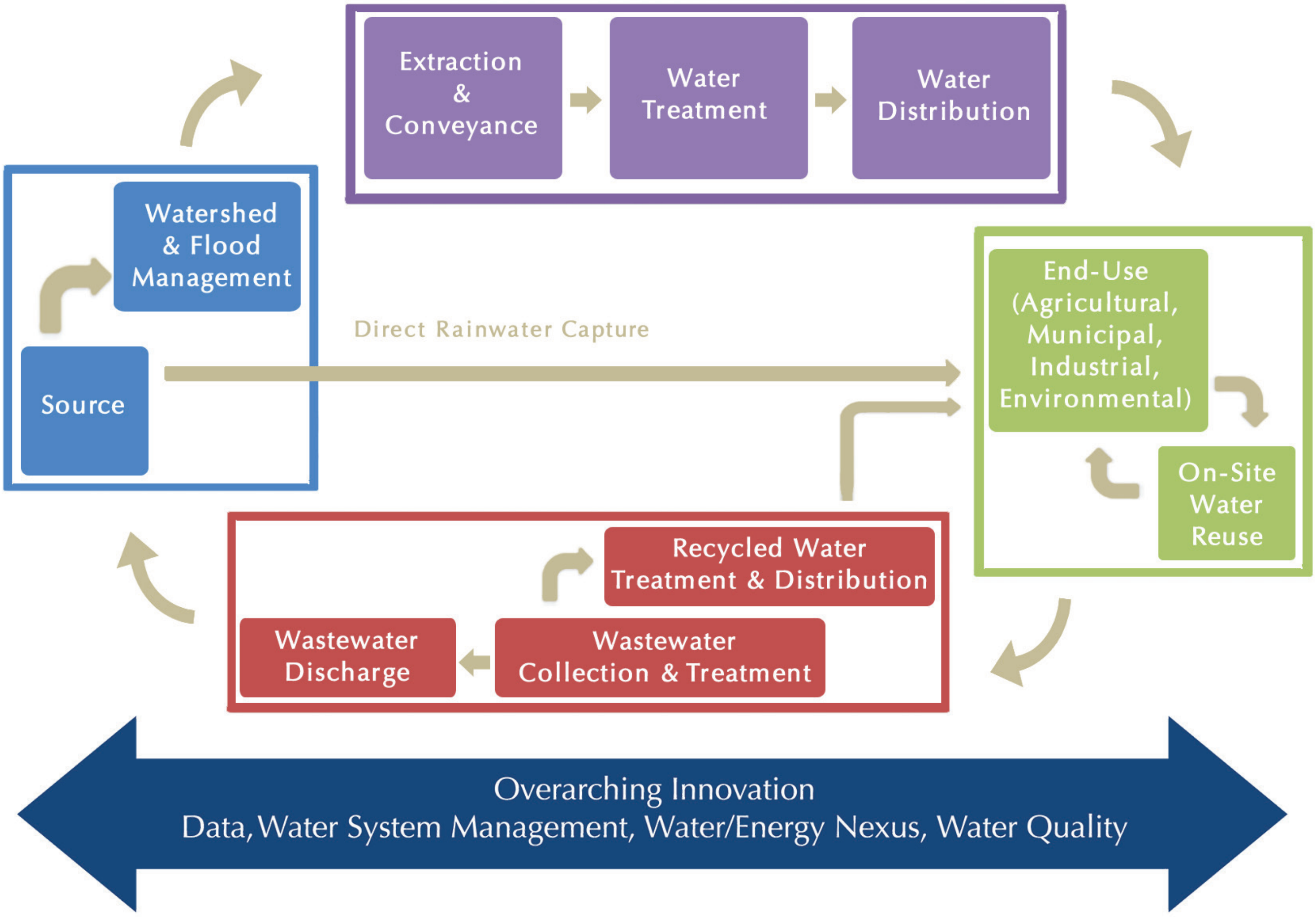
This report draws on a wide spectrum of water technology experts throughout the state, from academia, state and local agencies, non-governmental organizations, and the private sector, to identify and describe innovative water technologies and/or systems approaches with significant potential to help California achieve water sustainability. Our intent is to include technologies that can be introduced or more widely applied to California's water system(s) within the next five to ten years, and which are suitable for implementation at levels ranging from local to statewide. It is our belief that many of these recommendations lend themselves easily to the development of policy actions needed to support implementation. It is beyond the scope of this study to evaluate the economic viability or potential of individual technologies and other innovations.

High-Level Conclusions

The following high-level conclusions characterize the report and form the foundation for the detailed specific recommendations that follow.

1. **Innovation and policy action have delivered significant benefits and are essential for a sustainable water supply:** Advancements in science and technology such as low-flush toilets and drip irrigation, deployed through appropriate policy actions and economic incentives, have contributed to significant water savings and/or improved water use efficiency as demonstrated by high-level economic metrics (e.g. water use per capita, water use per dollar of GDP).
2. **The water use cycle frames the issues and opportunities:** The water use cycle provides a useful lens for the analysis of our water challenges. This systems approach clarifies many opportunities for science and technology innovation implementation – both using new technology and through expanded application of proven technology. Innovation opportunities exist at both the individual cycle block level and across the cycle as a whole. (See figure below.)

California's Water Use Cycle.



3. **An integrated systems management approach is a key to achieving multiple benefits:** The use of a systems management approach for the deployment of current and future innovations proposed in this report can achieve multiple benefits throughout the water use cycle including reduced water consumption at various steps, reduced energy needs, improved economic resiliency and enhanced environmental sustainability.
4. **The need for a comprehensive integrated information system is pivotal to implementing a systems management approach:** The collection of real time or near real time data on all elements of the hydrologic cycle is a key to good decision making and the analysis of trends and the development of fact-based

forecasts and recommendations. Currently, sufficient information does not exist in a form that allows sustainable management of California water resources.

5. **Opportunities abound for near and long term policy action and implementation:** Individually and collectively, many of these innovations lend themselves easily to policy action to encourage implementation and a broader level of public awareness, understanding and support.

Specific Recommendations

We have developed the following specific recommendations regarding particular technologies, management approaches and implementation strategies, along with actions that can achieve multiple benefits in the near term. These near-term actions are typical of many choices that are available. Investment and policy decisions should be based on the best use of options under consideration for the local, regional or statewide best interest. The order of the recommendations is based on the project team's general assessment of their importance and potential. We have also identified barriers to implementation and specific parties most logically responsible for facilitating adoption of these recommendations along with a list of possible next steps – all included after the recommendations below.

1. **Develop and implement an integrated water information management system** for water supplies, uses, and quality including precipitation, runoff, and storage; for surface water, groundwater, and water use. *In situ* and remote monitoring devices and networks should be expanded and linked to an integrated data management system, or implemented where not available but needed. A common portal, such as DWR's Water PIE and UC Davis' HOBBES, that forms the cyber core of a flexible data and information-management program and capable of supporting data analysis, trending and scenario forecasting, should be developed with a common set of standards to link data collection from all sources with an integrated data management system. **<u>Near-Term Actions:</u>** The Governor and key agencies should immediately take the lead to form a consortium of parties, including the State Water Resources Control Board and the Department of Water Resources as well as a broad coalition of water experts in academia, trade organizations and non-governmental organizations with the specific goals of (1) evaluating what is realistic and practical to do in the short term, (2) designing the data collection and management system to accomplish the near-term task while maintaining capability for future flexibility and then (3) fully implementing this recommendation.
2. **Expand the use of monitoring technology and management practices** including meters and advanced metering infrastructure (AMI) focused on system performance, all water and energy usage, including the monitoring of groundwater withdrawals, and the implementation of management practices for sustainability uses. **<u>Near-Term Actions:</u>** Encourage the metering of all water usage, both agriculture and urban, from all sources, to ensure system use efficiency, quantify demand, and optimize resources inputs for long-term sustainable and reliable water supplies.
3. **Improve water use efficiency in all sectors and at all stages of the water cycle** through applications of proven and developing technology and management practices.
    - In the **agricultural sector**, encourage and incentivize the expanded use of irrigation system designs, installation and management that help improve water use efficiency. Provide real-time information on system performance and field conditions to optimize decision-making. Promote the development of drought/salt tolerant plants, appropriate water treatment, and seek multiple benefits from agricultural practices like vegetative "filter strips" that benefit both water quality and the environment. **<u>Near-Term Actions</u>**: Employ technology that monitors system performance, including water and energy use and soil/water status, to also provide "alerts' regarding system changes that will often require corrective action.
    - In the **urban sector**, encourage and incentivize appropriate landscapes and efficient irrigation methods, the expanded use of high efficiency plumbing devices and appliances, the development of leak detection and management processes including the use of self-repairing materials for distribution systems capable of handling small to moderate leaks, the expanded use of on-site graywater and rain water/stormwater harvesting, and increased use of recycled water. **<u>Near-Term Actions:</u>** Encourage and accelerate the use/retrofit of water efficient landscapes and irrigation systems, and the retrofit of plumbing fixtures and water-using appliances with high-efficiency devices. Depending upon local conditions and priorities, encourage the use of graywater recycling systems in all new construction and major retrofit projects, the expanded use

of water recycling technologies and the construction of rain water/stormwater collection, treatment and retention systems.

- **In all sectors,** utilize proven "system thinking" strategies that facilitate holistic problem solving approaches such as foot-printing, goal setting and integrated system planning and design across the water use cycle.
  Near-Term Actions: Encourage the use of proven "system thinking" including smart water technology tools at the local, regional and statewide level to achieve multiple benefits for water savings, energy savings, economic resiliency and environmental protection.

4. **Restore and protect watersheds and enhance flood management planning including floodplain restoration** (constructed and natural) to increase recharge and groundwater storage, capture and retain storm-water runoff, reduce anthropogenic contamination and improve water quality, and provide for sustainable water systems.
   Near-Term Actions: Identify and support high impact actions to restore and protect watersheds including floodplains and encourage actions to improve the operation of these watersheds and the enhanced collection and storage, both surface and subsurface, of stormwater runoff utilizing proven commercial products and design approaches.
5. **Develop new and expand the application of proven chemical, physical, and biological water treatment technologies** for the treatment of surface water and groundwater with an emphasis on (1) salinity management and nitrate control and (2) recycling water with the appropriate quality for the intended use. **Near-Term Actions:** In addition to effective water conservation measures, expand recycling and the use of desalination and nitrate reduction technologies and other advanced water treatment technologies, where appropriate, to both broaden our portfolio of water sources and advance public health goals of increasing the availability of safe drinking water.
6. **Integrate water, energy and land use planning and management** to improve resilience and tap multiple benefits of reduced energy demand for water systems and reduced water demands from energy systems. **Near-Term Actions:** Encourage and facilitate investments, both public and private, in coordinated and integrated water and energy efficiency options and source-shifting of supplies to tap multiple benefits including greenhouse gas emissions reductions. Evaluate water, energy, and land-use plans and strategies based on multiple benefit criteria and incentivize these integrated solutions.
7. **Continue to support and fund initiatives by various public sector institutions** at the federal, state and local levels whose research will be integral to advancing innovation to address California's water challenges. **Near-Term Actions:** The Governor and key agencies, working with their local and federal counterparts, should take the lead for developing funding for the research that is critical for California's water future. Also encourage increased coordination between water-related entities/agencies at the federal, state, regional and local level. Going forward, California must act with some urgency as it will continually be water challenged.
8. **Expand the use of private sector initiatives** to identify and develop new technologies, techniques and services to include networks to broker information, and expand the use of public/private partnerships to accelerate development, piloting and commercialization of needed technologies. **Near-Term Actions:** The Governor's Office of Business and Economic Development, in collaboration with other government agencies and representatives of the public and private sector, should spearhead and assure that this recommendation is effectively implemented.
9. **Identify, evaluate, adapt and implement best practices** from around the U.S. and the world that can help California meet its water use efficiency, water treatment and water management goals. **Near-Term Actions:** Elected officials and appropriate state, local and federal agencies along with a network of individuals from academia, NGO's and others should develop and maintain relationships with key parties around the U.S. and the rest of the world, be open to innovations and seek out and implement best practices. A responsible State Official should be assigned the responsibility of assuring that this action is achieved.

Barriers to Implementation

Each recommendation including possible near-term actions has with it an associated set of barriers that must be addressed in order for the roadmap to be successfully implemented. The most significant barrier to the effective implementation of these recommendations is the lack of agreement on a strategic plan for water in the state and the lack of leadership to assure that the strategic plan is implemented, driven largely by the heavily fragmented nature of water resource management in California today. Once we address this issue, the next most significant barrier is insufficient funding, which is likely to remain a significant constraint over the coming years despite California's recent exit from years of deficits. The very complex legal infrastructure and arcane water rights laws further complicate any implementation planning. Resistance to the implementation of many of these recommendations will come from a number of invested parties and this could slow the process significantly. In addition, lack of public understanding and support for several of these actions is a challenge that must be dealt with.

Agents of Change

Each recommendation and proposed near term action has with it a set of parties who are critical to successful implementation. These include (1) federal, state, regional and local political leaders, (2) state, regional and local water agency leaders, (3) water experts in academia, the national labs, industry, non-government organizations (NGO's) and think tanks, and (4) the various stakeholders associated with each recommendation and its implementation plan. Overall, we encourage decision makers to create policy and funding approaches to implement the recommendations included in the report.

Next Steps

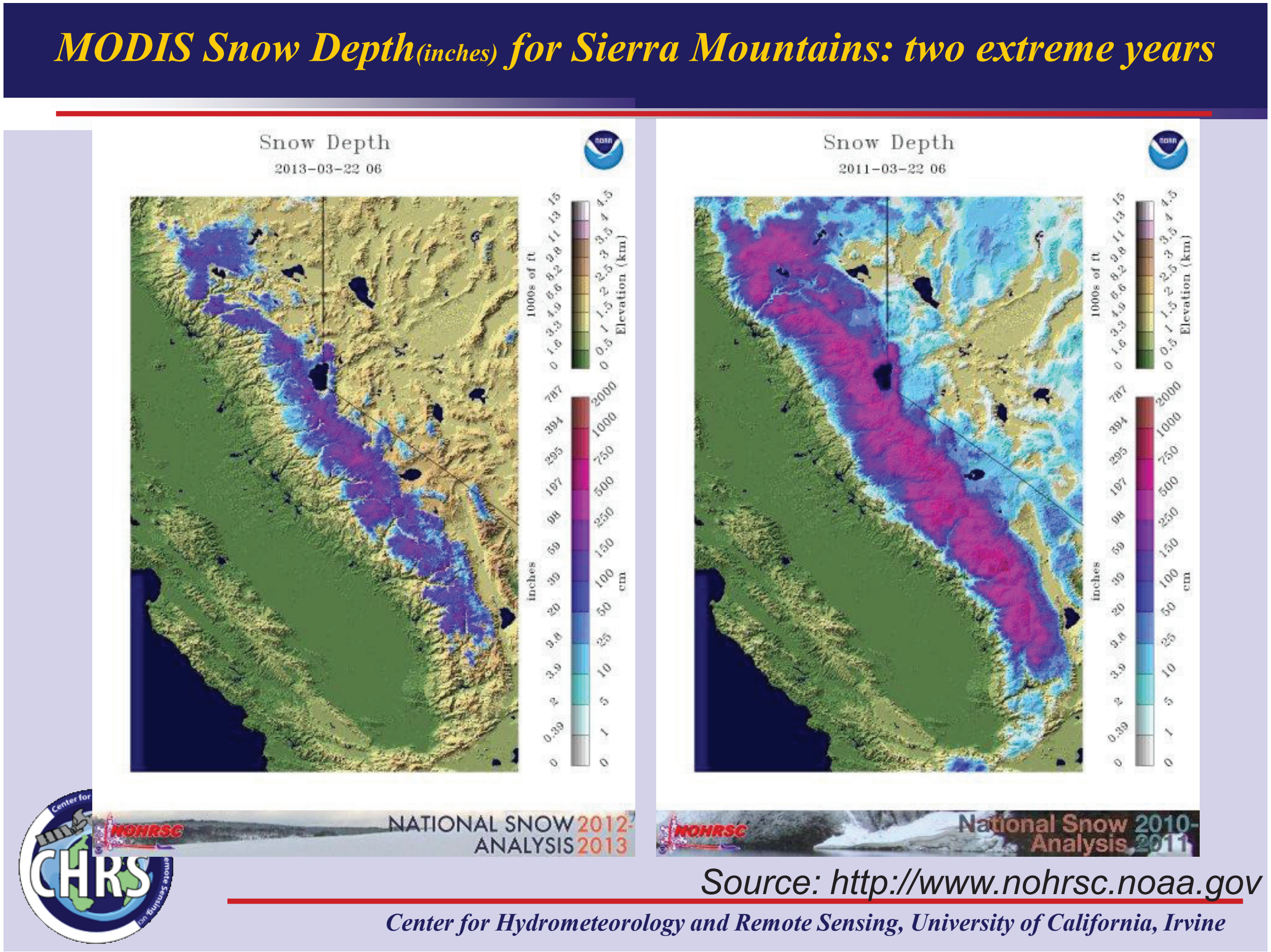
1. Develop implementation plans associated with each of the Near-Term Actions identified above including any policy actions required.
2. For the broader recommendation areas, an organized and disciplined approach is needed to assure that the roadmap proposed can be successfully implemented. This includes:
    a. The need to refine the tools and methods to quantify and assess the multiple benefits in water management needed to facilitate implementation of identified innovations.
    b. Where necessary, assess the economic viability of the identified technology innovations and assess the potential impact of these innovations on the overall California water system.
    c. Identify the policy actions required to encourage, incentivize or mandate the implementation of these recommendations where their economic viability and potential justify such actions.
    d. Develop detailed implementation plans including processes to assure buy-in from all involved stakeholders.
3. CCST could potentially conduct or facilitate the completion of these analyses, contingent upon securing adequate funding.

2. Introduction

This report builds upon the California Council on Science and Technology (CCST) 2011 assessment of California's innovation ecosystem, entitled "Innovate to Innovation" (i2i). The 2011 report identified the long-term management of California water system as a serious challenge to California's long-term economic prosperity. This report provides a roadmap of innovations in science and technology that could, if effectively implemented, significantly improve the management of California's water system over multi-year cycles ranging from very low precipitation that can result in drought conditions to significantly above average precipitation that can result in severe flooding. The current study is also designed to complement the 2013 Update of the California State Water Plan facilitated by the California Department of Water Resources (DWR) and the Governor's California Water Action Plan prepared by the California Natural Resources Agency, California Department of Food and Agriculture, and California Environmental Protection Agency.

Water is a fundamental resource challenge facing California, and its planning and management is a critical underpinning of California's economy. The impacts of climate change and variability, including potentially higher variability in the Sierra Nevada snowpack (see Figure 1), rising sea levels, and the prospect of increasingly severe and variable drought conditions throughout much of the state (Figure 2), threaten the future availability and quality of California's water supply. Additionally, many of the state's aquifers continue to be significantly over-drafted. Historically, California has relied on large-scale engineering solutions to address its water needs, building massive water systems based on dams, canals, and pipelines. The aging of this infrastructure, combined with climate change impacts and a growing population, increases the difficulty for the state to ensure adequate water supply for its residents, agriculture, businesses and environment.

Figure 1. Variability in snow cover between 2010-11 and 2012-13.

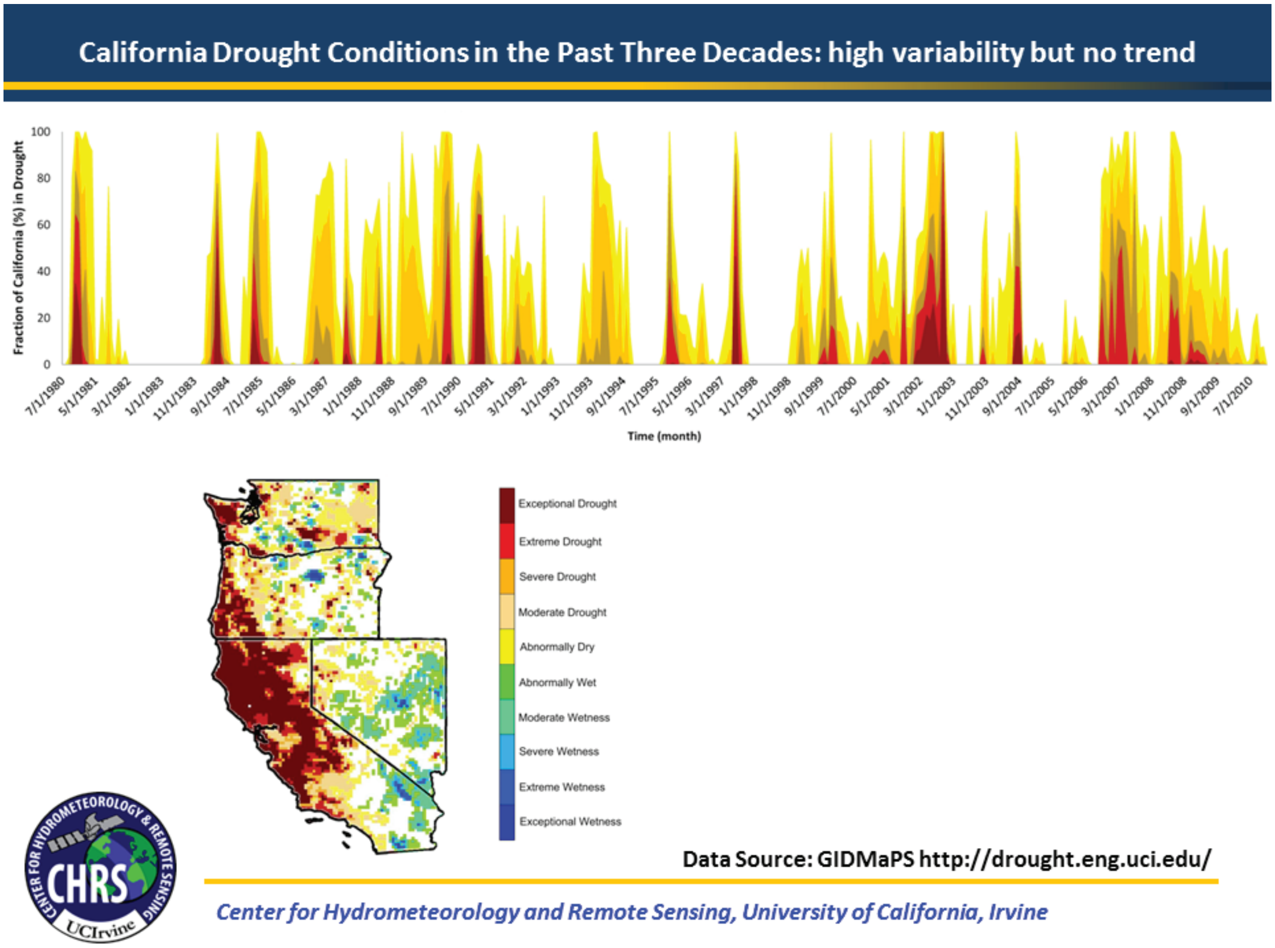


MODIS Snow Depth(inches) for Sierra Mountains: two extreme years

Source: http://www.nohrsc.noaa.gov

Center for Hydrometeorology and Remote Sensing, University of California, Irvine

Figure 2. Variability of drought conditions in California from 2000-2013.



Fortunately, California has a long history of success in leveraging innovations in science, policy, technology, and management strategies to improve its resource management. One of the best examples is California's continued leadership in energy-efficiency, from setting the first appliance efficiency standards in 1976 to consistently outperforming the rest of the nation in per-capita electricity consumption improvement for the past 40 years (see the per-capita energy consumption chart in Figure 3 below).[1] California's continued focus on energy efficiency has saved the state an estimated $65 billion dollars and helped make California more energy independent.[2]

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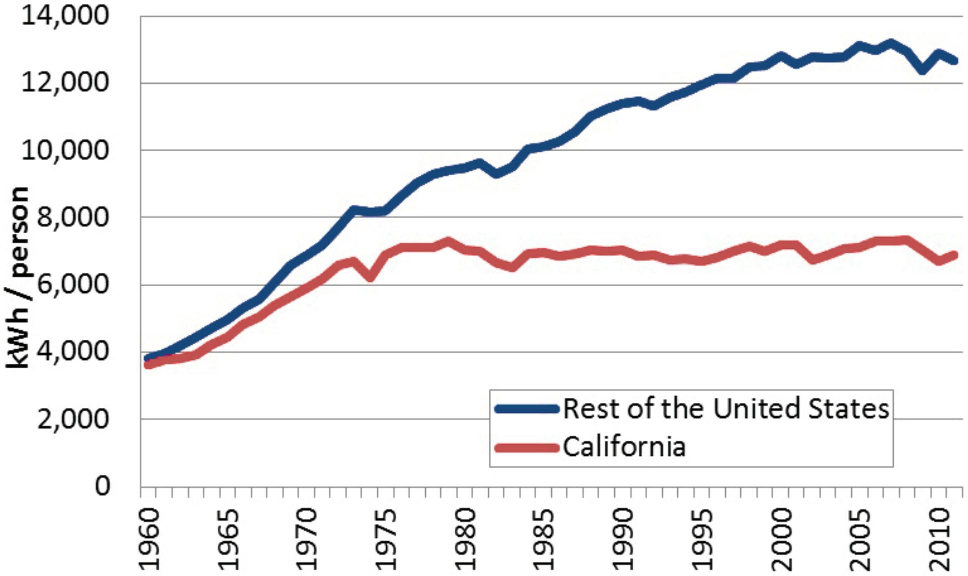
[1] Foster, B., Chittum, A., Hayes, S., Neubauer, M., Nowak, S., Vaidyanathan, S., Farley, K., Schultz, K. Sullivan, T. "The 2012 State Energy-efficiency Scorecard." American Council for an Energy-Efficient Economy (ACEEE), Report #E12C, October 2012. Washington, DC.

[2] Brown, Edmund G. Jr. "State of the State Address." 2013. Remarks as prepared January 24, 2013. http://www.gov.ca.gov/news.php?id=17906.

Figure 3. Per-capita electricity consumption, California vs. rest of the nation, 1960-2010.

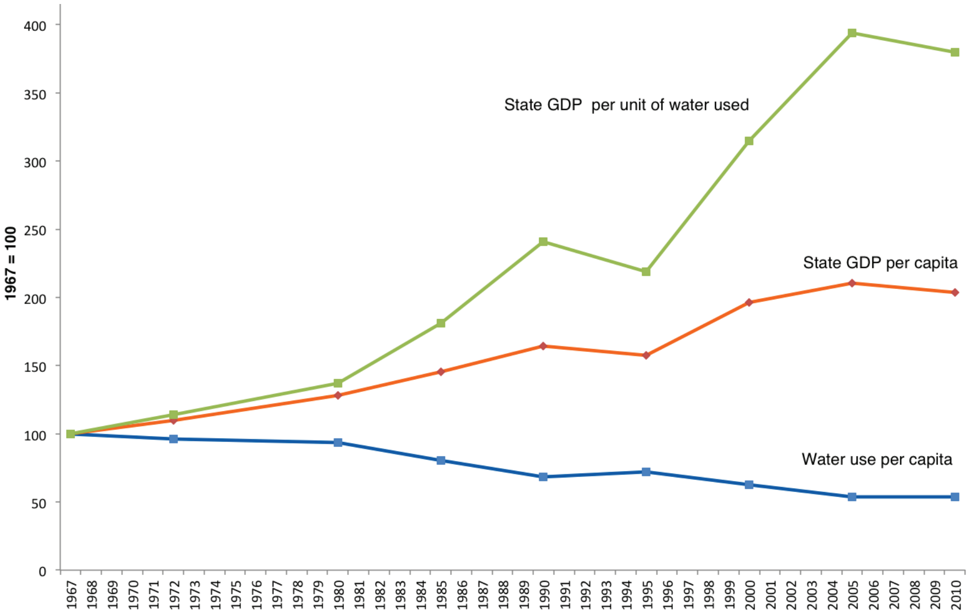


In addition to energy-efficiency leadership, California has already achieved significant accomplishments in its management and efficient use of water, both at the state and local levels. Figure 4 (below) shows how innovations in water have enabled California to quadruple its GDP per unit of water used in less than half a century, all while decreasing the overall per-capita water use of the state (Figure 4).[3]

Behind this improvement in efficiency and per-capita consumption are success stories in regional areas such as the greater Los Angeles area, which reduced total water use even while adding over one million residents, and the East Bay Municipal Utility District (EBMUD) just east of San Francisco, that has received widespread praise for its innovative, collaborative program to collect and recycle fats, oils, and grease (FOG) from restaurants and residents throughout its service area.

This report highlights innovations in technology, science, policy, and implementation across a broad range of water supply and management areas, and it suggests strategies and recommendations for continued investment and support of innovation in California. It is our assessment, as detailed in this report, that continued innovation both through the development of new solutions and the broader application of proven successes can help California improve its water-management and secure a long-term healthy and sustainable water system. In order to be successful, however, we will need to be aligned on an integrated game plan (roadmap) that will require leadership, action and investment by both the public and private sectors.

Figure 4. California state annual per-capita GDP per unit of water used.



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[3] Hanak, Ellen, Jay Lund, Barton "Buzz" Thompson, W. Bowman Cutter, Brian Gray, David Houston, Richard Howitt, Katrina Jessoe, Gary Libecap, Josué Medellín-Azuara, Sheila Olmstead, Daniel Sumner, David Sunding, Brian Thomas, and Robert Wilkinson, 2012. Water and the California Economy. Public Policy Institute of California. http://www.ppic.org/main/publication.asp?i=1015 (Figure updated to 2010 by Hanak, 10/13)

2.1 Objectives of the Report

This report draws on the input and expertise of a wide spectrum of water technology experts throughout the state, including those from academia, the national laboratories, state and local agencies, and the private sector, to identify and describe innovative water technologies and/or systems approaches currently under development or in the application process. The goal is to focus on those technologies and approaches that could be introduced or more widely applied to California's water system(s) within the next five to ten years. The scope of the report covers technologies suitable for implementation at a variety of levels ranging from local to statewide.

In doing so, we have developed specific recommendations regarding particular technologies, policies, and process changes. We have also developed broader action items for the state to pursue overall. In addition, we have identified specific agents who would be most logically responsible for adoption of these recommendations.

2.1.1 Background

Innovations in science and technology have long been recognized as a key driving force of economic growth, especially in high-tech economies such as California's.[4] However, the state has limited resources and is seeking ways to most effectively encourage and sustain an environment where innovation can flourish. Technological innovation in water is essential to enable California to tackle a growing challenge in the context of predicted population growth and climate change. It is also an investment and business opportunity particularly well-suited to California.

This report builds upon the California Council on Science and Technology (CCST) 2011 assessment of California's innovation ecosystem, entitled "Innovate 2 Innovation" (i2i).[5] The 2011 report identified the long-term management of California's water systems as a serious challenge to California's ability to remain a competitive environment for innovation in the future. The i2i study found that there is no consensus on how to simultaneously maintain water supply reliability, balance changes in water supply with demand and protect the environment. The study recommended that, in order to implement a more integrated water resource-management strategy, a science-and-technology-based 'roadmap' be developed with a framework of key issues where science and technology could "have the most positive impact in contributing to a sustainable, long-term water policy for the state."[6] Applied technology provides an important opportunity to improve existing water use. One of the goals of this study is to develop this roadmap to assist future planning and action in California to achieve a long-term, sustainable water supply.

2.1.2 Report Structure and Methodology

This report is structured to present an overview of the water management system in California, identifying specific areas where science, technology, and policy innovation can help achieve a more integrated and sustainable water resource management system.

The report first defines innovation and sustainable integrated water management. It then introduces the concept of the "water use cycle" to represent the complex infrastructure developed to extract water from nature, transport, treat, use, and recycle it, and then treat it again for discharge back into the environment.

The remainder of the report highlights recent innovations, as well as areas where additional innovation could have the greatest impact, first looking at technologies and innovations such as better data management that apply to the entire water use cycle, and then exploring each process within the cycle individually.

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[4] Charles W. Wessner and Alan Wm. Wolff, Editors; Committee on Comparative National Innovation Policies: Best Practice for the 21st Century; Board on Science, Technology, and Economic Policy; Policy and Global Affairs; National Research Council, "Rising to the Challenge: U.S. Innovation Policy for Global Economy." (2012)

[5] CCST i2i report (http://ccst.us/publications/2011/2011i2iES.php)

[6] California Council on Science and Technology, "California's Water Future: A Science and Technology-Based Water Innovation Roadmap." Sacramento (2011) p.1.

In order to accomplish the goals of the project, particularly the goals of making specific recommendations, the following process was followed:

- A project team was assembled that represented the science and technology community and which had strong connections to relevant policy.[7]
- The water use cycle was used as a framework for identifying and evaluating potential innovations.
- A process was created to identify relevant innovations associated with each water cycle element from a wide range of sources and to determine their readiness for adoption.

Information was gathered by an online survey targeting people with water expertise in California, through convening focus groups of water experts, meetings with the California's Water Plan Update Water Technology Caucus, the assessment of initiatives currently underway in the private sector in both established companies and startups and research and input by members of the project team.[8]

2.1.3 Defining Innovation

The purpose of this report is to highlight how innovations in science, technology, management, and policy can help California better manage its water resources. It is thus important to first define what we mean by innovation.

For the scope of this report, innovation is interpreted as ***the creation, development, and implementation of a new product, technology, policy or approach that has the aim of improving efficiency, effectiveness or competitive advantage in water management.***[9] As we explore the water cycle and the many processes occurring to extract, transport, treat, and use water throughout California, this report identifies innovations in technology that improve or replace existing processes and technologies, but also innovations in policy, pricing, financing, and other methods that enable improved water-system management.

Technology innovation includes a broad range of approaches: the development and deployment of new technologies; new and broader applications of existing technology; production changes; and organizational, management and cultural changes that can improve the condition and sustainability of our state's water resources. For the purposes of this report, these innovations in technology, science, policy, pricing, and other methods will collectively be referred to as innovations in "***technology and technique***."

Also, California "water" issues can be wide-ranging, and addressing all aspects is beyond the scope of this report. Our emphasis is on innovations, driven by either technology or policy applications, with the potential to achieve significant system efficiency and flexibility improvements.

2.1.4 Sustainable Integrated Water Management

Sustainable integrated water management is an increasingly important concept in water management. For the purpose of this report, our interpretation is guided by the vision of sustainable water use and management expressed in the 2009 California Water Plan Update, that is:

> *"California ... [should have as a goal] healthy watersheds and integrated, reliable, and secure water resources and management systems that: Enhance public safety, health, and quality of life in all its communities; Sustain economic growth, business vitality, and agricultural productivity; and Protect and restore California's unique biological diversity, ecological values, and cultural heritage."*[10]

This vision highlights three key focal points of sustainability: environment, society, and economy.

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[7] The project team is identified in Appendix A.

[8] A detailed overview of the project methodology can be found in Appendix D.

[9] Definition adapted from: London Economics. "Innovation in the water industry in England and Wales." Cave Review of competition and innovation in water markets, February 2009. http://archive.defra.gov.uk/environment/quality/water/industry/cavereview/.

[10] California Department of Water Resources (2009). California Water Plan Update 2009. Bulletin 160-09, California Department of Water Resources, Sacramento, CA, Volume 1, p. 2-12 (http://www.waterplan.water.ca.gov/cwpu2009/)

This vision and outline of sustainability can best be met by implementing an integrated water management approach, defined in the California Water Plan as:

> *"a philosophy and practice of coordinating the management of water and related resources for the purpose of maximizing economic and societal benefits while maintaining the sustainability of vital ecosystems."*[11]

Sustainable, integrated water management thus is the coordination of water and related resource-management activities to achieve public health and safety, maximize economic benefits and support long term growth while ensuring the restoration and health of our ecosystems such that they will meet the needs of future generations over multi-year cycles of drought and surplus.

2.2 Water Use Cycle

In order to determine how innovations in technology and technique might help improve the management of California's water system, it is necessary to establish a baseline framework for the system so that technologies may be aligned with the appropriate processes. Within California's water system, it is important to differentiate between the natural water systems, and the 'built environment' that has been engineered to extract, deliver and treat water from the natural systems for a variety of uses.

2.2.1 Natural Systems

The natural hydrologic cycle is best defined as continuous movement of water on, above and below the surface of the Earth. The cycle begins with the evaporation of water from the ocean and other exposed bodies of water (i.e., lakes, reservoirs etc.), and the transpiration from the leaves of plants and trees. As the moist air is lifted and cools, the water vapor condenses into clouds, and then falls back to Earth as precipitation. Some precipitation reaches the ground and flows as runoff along the surface in streams to rivers and eventually into the ocean, while some is absorbed into the ground, becoming part of the groundwater supply. Some precipitation falls as snow and accumulates during the winter. The snowpacks thaw and melt when spring arrives, and the melted water along with stormwater flows overland, feeding rivers and streams and ground water recharge; much of it eventually is carried back to the oceans, where the cycle begins again (Figure 5).

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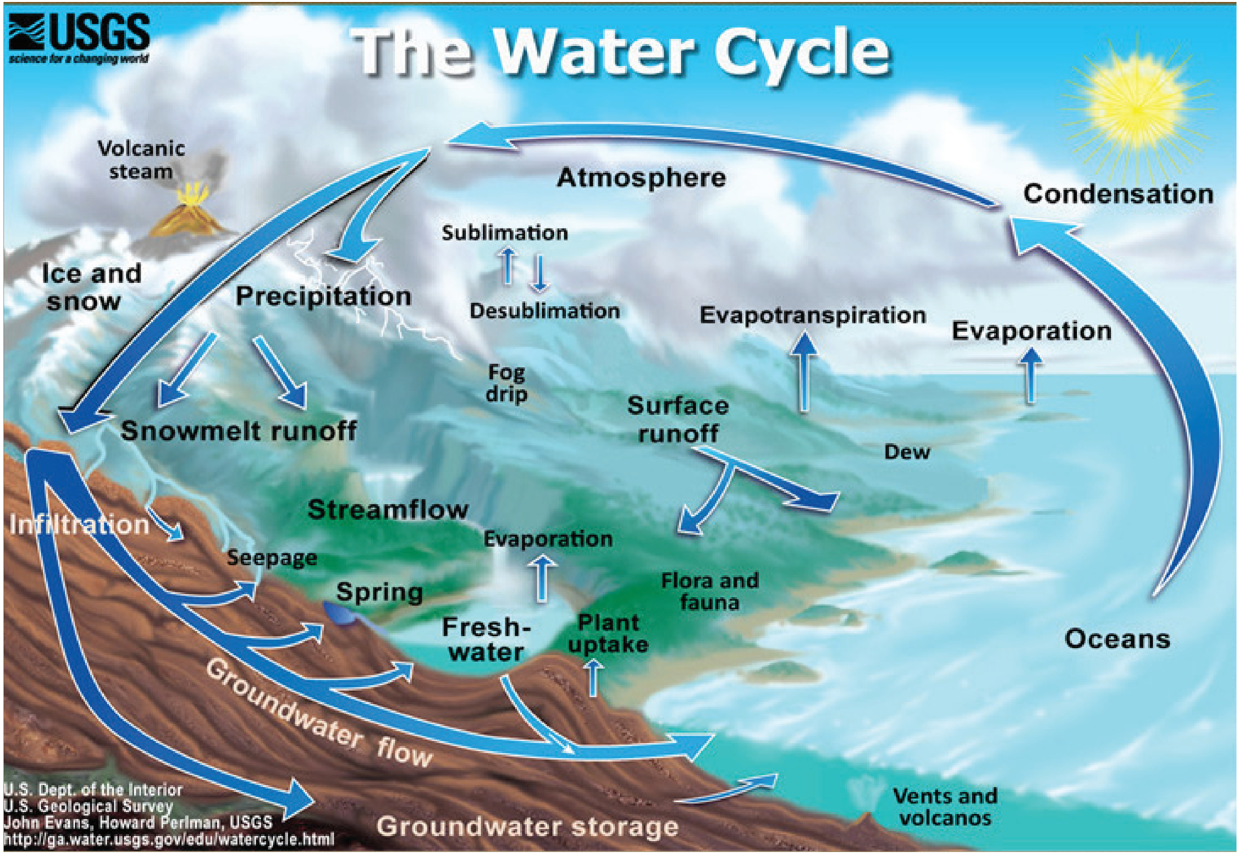
[11] CA DWR. "Strategic Plan for the Future of Integrated Regional Water Management in California: Development Approach." September 2012.

Figure 5. The Water Cycle. Source: U.S. Geological Survey (USGS).[12]



2.2.2 The Built Environment & the Water Use Cycle

In California, a complex infrastructure or "built environment" has been developed to divert water from natural systems, move it to places of use, treat and use it for a variety of purposes, and then discharge "used" water back to the environment. This cycle of taking water from a natural source, treating, transporting, using, collecting, and discharging it back to the source, is known as the water use cycle. The water use cycle highlights the interplay between the natural hydrologic system and the built environment of water management.

There are many components to California's water system. However, the cycle can broadly be divided into four 'top tier' categories: natural systems (the sources of water); engineered delivery systems (the infrastructure used to deliver the water throughout the state); water users; and post-use management (wastewater treatment, etc.).

2.2.3 Water Use Cycle: First Tier

1. **Natural Systems** – this includes the natural water source and watershed management to improve the quality, quantity, and availability of natural water.
2. **Pre-use Management** – includes the engineered delivery systems to extract and collect water from the natural source(s), transport it to treatment facilities, treat the water as required, and then finally distribute it to the point of use.
3. **Water Use and Potential Reuse** – includes the actual end-use of the water, as well as potential opportunities for reuse with or without additional treatment.
4. **Post-use Management** – includes the collection, treatment, and discharge of water back into the natural environment.

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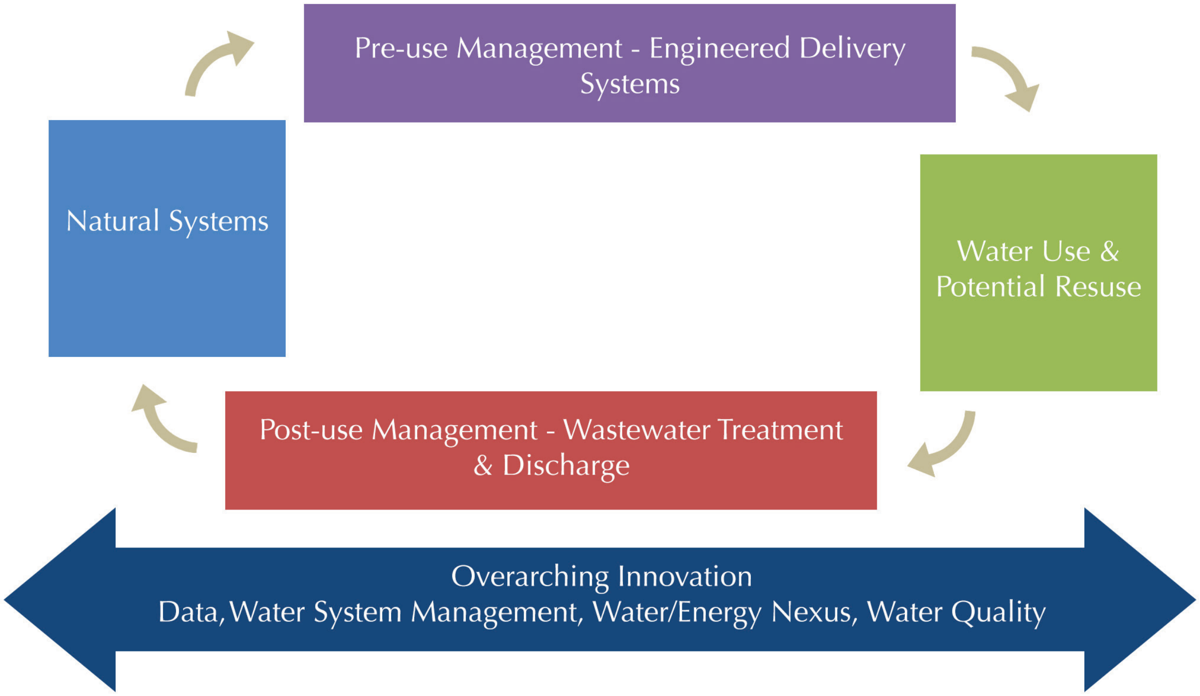
[12] "The Water Cycle, a Quick Summary. U.S. Geological Survey (USGS). http://ga.water.usgs.gov/edu/watercyclehi.html.

Figure 6. California's Water Use Cycle (first-tier categories).[13]



Within this first-tier framework of the water use cycle (Figure 6), technology innovations can be attributed or are being developed to the broad categories defined above. For example, innovations in appliances such as low-flow toilets, showerheads, and faucets would be categorized as "Water Use and Potential Reuse," while new meadow restoration strategies and state-of-the-art observation tools to observe and monitor would assist "Natural Systems." Some innovations, such as new membrane filtration technologies, would affect water treatment and could be categorized as both Pre-use and Post-use management.

Additionally, there are certain technology and technique innovations that apply throughout the entire water use cycle; these "overarching" innovations include the acquisition, management, and use of data, water system management, the relationship between energy and water and the co-benefits of energy savings that can be realized from water savings throughout the cycle, and advancements in water quality measurement and treatment. The concept of "systems thinking" as a part of water systems management also warrants discussion as an overarching theme, as changes made in one area (or box) of the water use cycle can have widespread impacts both upstream and downstream throughout the system.

It is helpful to explore each of the first-tier categories in greater detail to understand the key activities occurring throughout the water use cycle. The second-tier (Figure 7) depicts the key activities within each of the four categories. Some of these categories encompass multiple processes and/or contexts, and in some cases technologies may be applicable to multiple points within the system. However, the map is a useful guideline for sorting out where technologies have been or are being developed that may impact the water cycle.

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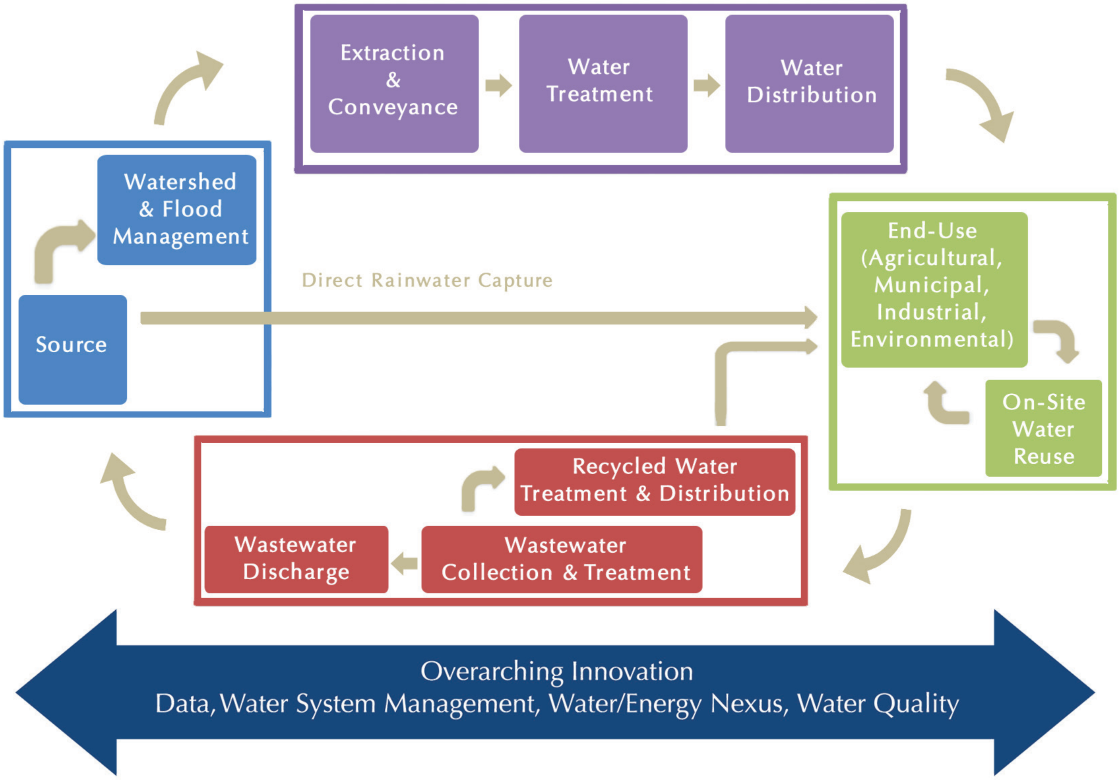
[13] This map of the water cycle is derived in large part from the diagram prepared by the California Energy Commission, "California's Water-Energy Relationship." Prepared in support of the 2005 Integrated Energy Policy Report Proceeding (04-IEPR-01E). November 2005, which was in turn based on methodology set for by Wilkinson, Robert C., 2000. *Methodology For Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy-efficiency Measures*, Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy-efficiency.

Figure 7. California's Water Use Cycle (second-tier categories).



In order to provide additional context into the components of the water use cycle, each of the individual boxes within Figure 7 is defined below:

Natural Systems

1. Available fresh water supplies over continental land surface come primarily from surface and groundwater sources. Precipitation falls to the ground in the form of rain and/or snow; that portion of the precipitation that becomes surface runoff is captured and stored in lakes and rivers, while some infiltrates through the soil as groundwater. The ocean is also a water source, as desalination technologies are able to treat this water within the water use cycle.
2. **Watershed Management** includes the processes and activities performed to restore, protect, and manage watersheds throughout the state including flood protection, storm-water collection and floodplain restoration. Innovations and other developments here can improve water quantity and quality throughout the water use cycle.

Pre-use Management

1. **Extraction and Conveyance** includes the processes and infrastructure developed to extract water from the natural sources and transport it to water treatment facilities. This includes pumping from groundwater, as well as California's sophisticated water transportation infrastructure, including the State Water Project and Central Valley Project.
2. **Water Treatment** includes the technologies and processes in place, including desalinization, to produce water for end-use. Much of this treatment produces potable water, but pre-use treatment can also produce water for agricultural, industrial, environmental and other uses.
3. **Water Distribution** includes the transportation infrastructure to move treated water from the treatment facility to the point of use by consumers.
4. **Water Storage** technologies and solutions exist throughout the pre-use management phase of the water use cycle. These solutions include groundwater banking, surface storage, and post-treatment storage in tanks and water towers

Use and Reuse

1. **Use** is the use of water by agricultural, municipal and industrial, and environmental users. Municipal and industrial sectors can be further subdivided into residential, commercial, and industrial uses.
2. **On-site Water Reuse** includes the technologies and processes developed to treat and reuse water at the point of consumption by end-users. This is differentiated from wastewater and recycled water where the treatment and reuse is decentralized.

Post-use Management

1. **Wastewater Collection and Treatment** includes the centralized collection of wastewater and the various treatment technologies and processes to produce water suitable for discharge back into the natural environment.
2. **Recycled Water Treatment and Distribution** includes additional centralized treatment, beyond or in place of wastewater treatment, for water recycling, as well as additional distribution networks in place to transport recycled water for appropriate treatment to the point of reuse.
3. **Wastewater Discharge** includes the processes and technologies in place to discharge water back into the natural environment.

These second-tier categories of the water cycle are used as the baseline framework for discussing specific technologies and their application throughout this report.

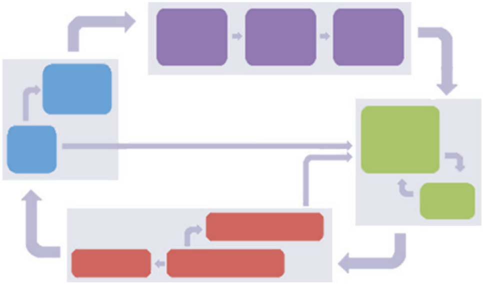
2.2.4 Structure of the Detailed Report (Sections 3 and 4)

Sections 3 and 4 below provide the details of our assessment of science and technology innovation opportunities across the Water Use Cycle. Section 3 addresses the potential opportunities associated with the overarching science and technology processes that span the entire Water Use Cycle (Data Collection and Management, Water Systems Management, the Water/Energy Nexus and Water Quality). Section 4 addresses science and technology innovation opportunities pertaining to specific processes throughout the Water Use Cycle, going from Watershed Management, to Extraction, Conveyance and Distribution, to Water and Wastewater Treatment to Agricultural Water Use and Urban Water Use.

Each sub-section provides a definition, an overview of the subject area including challenges that need to be addressed, a high-level discussion of technologies in use and under development, and a detailed description of various innovation opportunities along with case studies where appropriate, followed by a set of recommendations. The recommendations in each sub-section pertain to the innovation opportunities described in that section. They are not prioritized because the economics and potentials of these technologies, both on an absolute and relative basis, have not been systematically evaluated.

Sections 3 and 4 provide a broad survey of the technology innovation opportunities that could be useful over the next five to ten years. We have focused on those opportunities that seem the most promising according to the overall assessments of the water experts consulted in the course of the study. However, due to funding, capacity and time constraints, it was not possible to evaluate the relative economics of the various technologies, nor was it feasible to systematically assess the potential for the technologies to be scaled to address California-wide issues. Such an assessment is recommended as one of the next steps to be performed, followed by an assessment of the policy actions required to enable effective implementation.

3. Overarching Technologies and Innovation Opportunities



As discussed above, there are some areas where innovations in technology and technique have broad impact throughout the water use cycle. These overarching applications occur in both technology and technique, assisting in overall water management while tracking how changes in specific processes within the cycle impact other processes both upstream and/or downstream. The broad areas identified as having a pervasive and systemic impact on the water cycle in our study are ***water information, water system management, the water/energy nexus, and water quality.***

3.1 Water Information

Innovation is occurring throughout the water use cycle regarding how measurements are made and how data are gathered, managed, and used. It is thus valuable to define data as an overarching framework that applies to all steps in the cycle. Where water data and information are specific to individual steps within the water use cycle, they will be further highlighted during the discussion of that step of the cycle.

One approach to understanding emerging technology innovation opportunities related to data is to segment the topic of data into two key areas:

1. *Data Acquisition*: Data acquisition includes the gathering of data using various measurements and observations, from remote sensing and satellite observations to on-site, in-situ monitoring such as water sensors, meter readings, gauges, etc.
2. *Data Management and Use*: Data management covers the transfer of data from the acquisition point through formatting, storage, QA/QC, and other processing to turn data into information, and make that information available for end users. Data use includes use of data for decision support, including water-system planning, operation and management. This use also involves value-added steps such as modeling- and simulations-based forecasting and compliance reporting.

Investments in satellite remote sensing data, ground-based measurements and cyber-infrastructure have the potential to dramatically improve hydrologic information, improve the quality of the information about water availability, and improve water supply reliability. These improvements inform decision making by offering more accurate and timely information for predicting precipitation, runoff and water conditions across the state, particularly in the area of water supply. There are similar opportunities in other sectors. Satellite and aircraft remote sensing offer the only practical means for basin-wide measurement of snow properties, soil moisture, and other watershed conditions. A strategically deployed ground-observation system could compliment satellite and aircraft measurements, and provide continual and accurate estimates of snowpack, soil moisture, and vegetation state, necessary for quantification of water and energy balance across watersheds.[14]

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[14] http://iapreview.ars.usda.gov/research/publications/publications.htm?SEQ_NO_115=65316.

3.1.1 Data Acquisition

Definition

Data acquisition for the purpose of this report includes the gathering of data using various measurements and observations. It is the process of measuring real-world physical or chemical attributes using sensors and converting the concentration, magnitude or intensity of the attribute into digital numeric values using either *in situ* (on site) sensors or remote sensors that are typically deployed on a high-elevation observation platform (e.g. antenna), routed vehicles (e.g. ferries, busses), on an aircraft or satellite platform.

Overview

Adoption of advances in measurement technology varies considerably across the many water sectors. For example, some measurements use sensors based on very recent engineering developments and the state is installing state-of-the art atmospheric moisture measurements to improve the lead time for forecasting conditions such as large atmospheric rivers that can lead to severe flooding. In contrast, forecasts of seasonal runoff from the Sierra Nevada are based on a relatively small number of index measurements that use technology developed 50-100 years ago. Some government agencies have the ability to drive innovation in measurements through regulatory means such as compliance requirements or mitigation of flood risks to protect lives and property; other sectors lack focused drivers of new investment in data and information.

Innovation Opportunities

While advances in measurement are occurring in many areas, two sets of technological advances offer particular opportunities for maintaining the security and improving the sustainability of California's statewide water system. First, within the past few years low-cost embedded wireless-sensor technology –which, for the purpose of this report, captures the combined effect of the advances in the three areas of (1) embedded systems that can collect and process complex information; (2) new and novel sensors; and (3) wireless transmission of data – has matured and has found application in a variety of industrial and infrastructure settings. This has allowed the collection of much more data, covering wider areas of the water system, and corresponding increases in the accuracy of measurements of water impurities and fluctuations in volume. Second, selected remotely sensed, spatial-data products have also matured in recent years, and have now reached the level that they can be used for routine operations rather than just planning or studies. Other aircraft and satellite products are still following the long path of development and could see operational use in coming decades.

In situ (On Site) Data Acquisition

Current operational observation networks

The existing in situ data acquisition infrastructure operated and maintained in California by various federal and state environmental and resource management agencies provides a range of data and information that are critical to current water resource decision-making. A diverse range of ongoing research and prototyping activities in California provide a foundation for developing enhanced monitoring networks and information products that can be applied to support improved decision making. Examples of this ground-based infrastructure include the USGS stream-gauge network, the Snow Telemetry (SNOTEL) network maintained by NRCS for monitoring the winter snowpack, the USDA Soil Climate Analysis Network (SCAN) for monitoring soil moisture, the National Weather Service Cooperative Observer Program and associated network of weather stations, the NWS Doppler Radar Program, the California Irrigation Management Information System (CIMIS) network of reference evapotranspiration stations operated by DWR, and the California Statewide Groundwater Elevation Monitoring (CASGEM) network, also operated by DWR. The existing in situ observation systems, however, have limitations in terms of their level of deployment, spatial and temporal resolution, along with the fact that the systems were not designed for integration. These systems are therefore unable to serve the needs of advanced models and decision-support systems.

Use of Wireless Sensor Technologies

Low-cost wireless technology that can link a wide variety of sensors is now in routine use in many industries, but has just started to be introduced into water information systems. Wireless networks built from commercially available components, including data loggers that can interface with a wide variety of sensors and communications uplinks, have proven reliable in low-power, unattended applications, similar to that of meteorological stations or stream gauges. With wireless technology, sensors can be spatially distributed to provide not just index values at a point, but spatially – and, equally importantly, temporally representative measurements. For example, they can be added to snow-pillow sites, which measure snow depth and water equivalent in forest clearings or meadows on flat ground, to give representative measurements across gradients of elevation, aspect, slope and vegetation, or measure changes in contaminant concentration in rivers during storms or over tidal cycles. Sensor costs are sometimes in the tens rather than thousands of dollars each, they may have very low power requirements, and they offer the possibility for broader deployment. Given the pace of technological developments, systems must be flexible.

Greater attention needs to be paid to long-term system reliability. This includes timely identification of degraded sensor performance, sensor cleaning and recalibration, preferably automatically at remote sites by technology not requiring human intervention. It also includes the development of equipment less susceptible to vandalism, which is a significant problem for surface stations. This could include making the sensors more durable for locations prone to damage (e.g., resistant to being shot or impacted/damaged by natural events such as falling trees or earth slides) and/or those in inaccessible locations (e.g., mounted in locations difficult to reach, such as underneath bridges). Sensor systems should be conceived and designed to permit rapid and inexpensive replacement of system components.

Remote Data Acquisition

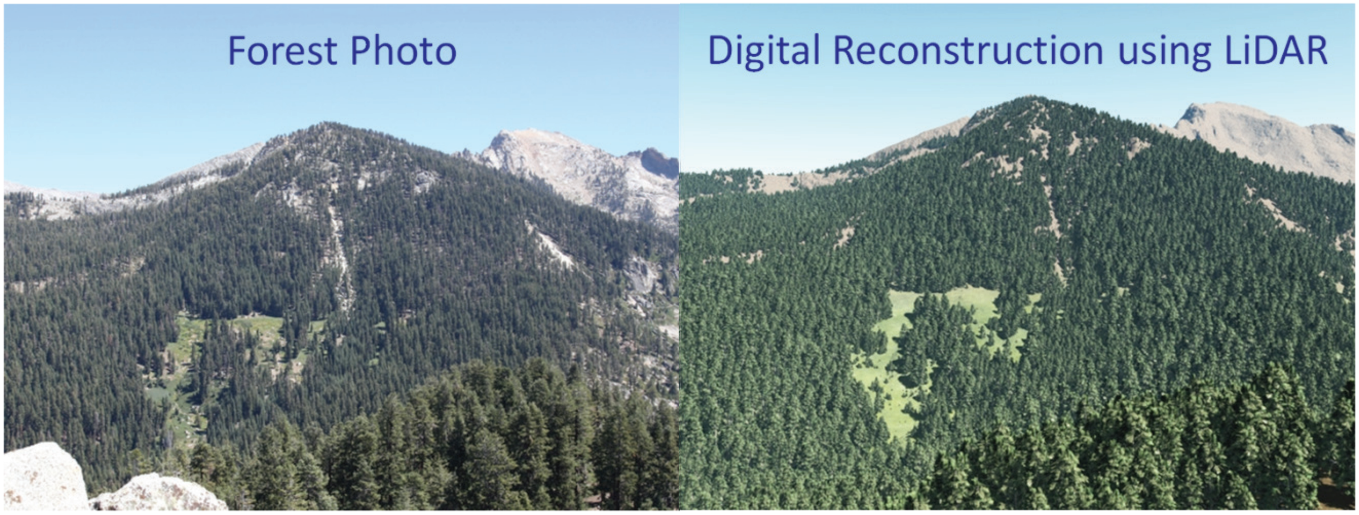
U.S. remote sensing agencies, including NASA, NOAA, USGS, and DOD have a long history of working with other government agencies and the private sector to develop and transition remote sensing technologies into operational use. While many of these programs over the past two decades have demonstrated the potential for routine application, they have not yet been routinely applied to water-resources decision-making. Familiar examples include the use of NOAA weather satellites in production and communication of weather forecasts, and the use of data from Earth observation satellites in the production of annual crop statistics by USDA. The National Weather Service routinely provides nationwide snowcover products that blend satellite data with forecast models. Promising recent research by NASA and university scientists in producing snowcover information has the great potential for providing regional forecasts in the Sierra Nevada. NASA and USGS currently have a number of active partnerships with California resource management agencies and organizations to develop new applications of remote sensing data for water management. While real-time value-added products have been developed, the next step is to bring them into use in prototype, experimental forecasts.

Application of LiDAR Technology

LiDAR (an acronym for Light Detection And Ranging) is a technology that combines the laser's focused imaging with radar's ability to calculate distances. It measures distant targets by illuminating them with a laser and analyzing the reflected light. Its application has proven effective in many areas.

LiDAR is being used routinely in research and various applications as diverse as ecosystem management and national security. LiDAR measurements from both drones and manned aircraft have the potential to augment ground-based sensors for measuring snow depth, and to develop ground-truth calibrations for tools predicting spatial snowcover from ground measurements. NASA and DWR are currently applying airborne LiDAR instruments and imaging spectrometers on airborne and satellite platforms to map land cover changes and snow water resources in watersheds in the Sierra Nevada and Rocky Mountains (Figure 8 below provided by Roger Bales).

Figure 8. Digital reconstruction of land cover changes using LiDAR.



Airborne and Space-based Remote Sensing Data Acquisition

DWR is also supporting ongoing work by NASA to map levee condition and integrity using airborne Synthetic Aperture Radar (SAR) instruments. Continuation and further exploitation of the ongoing near-monthly operational acquisitions by UAVSAR, an airborne Interferometric Synthetic Aperture Radar (InSAR) capability, over the Sacramento-San Joaquin Delta that provide detailed measurements of the integrity of the region's levees (e.g. identify subsidence, cracks, seepage) should become routine practice.

Airborne campaigns conducted by NASA in 2013 are also collecting hyperspectral remote sensing data as part of the preparation activities for the Hyperspectral Infrared Imager (HyspIRI) mission. Data collected by these missions will be used to conduct scientific research that will provide a foundation for applications for monitoring and assessment of watershed conditions, detection of invasive plant species, assessment of water quality indicators in the Bay-Delta and freshwater lakes in California and mapping of crop water stress (conditions where crops do not have access to sufficient water). Data on freshwater turbidity, salinity, and chlorophyll in particular is in demand, and remote monitoring of these parameters would make it much easier to quickly obtain data over a large geographical area or along the total length of river systems, allowing better, more rapid assessments of flood impacts, or other natural and man made disasters.

Recent advances in the use of remote sensing observations to estimate precipitation[15] are showing promise for better spatial coverage and higher temporal resolutions. Recent application of GRACE (Gravity Recovery and Climate Experiment) satellites in detecting gravitational anomalies has shown promising results with respect to the mapping of changes in terrestrial water storage at scales of ~150,000 km^2. Monitoring of groundwater fluctuations by remote sensing at spatial resolutions useful for local to regional water management, however, is in its infancy. Additional research and development is required to advance current capabilities both in space-based observation of precipitation and groundwater-level monitoring. Coordinated planning for *in situ* precipitation (both rain and snow) and groundwater-level monitoring and measurement over selected areas is critically important for calibration and accuracy assessment of the remotely sensed data.

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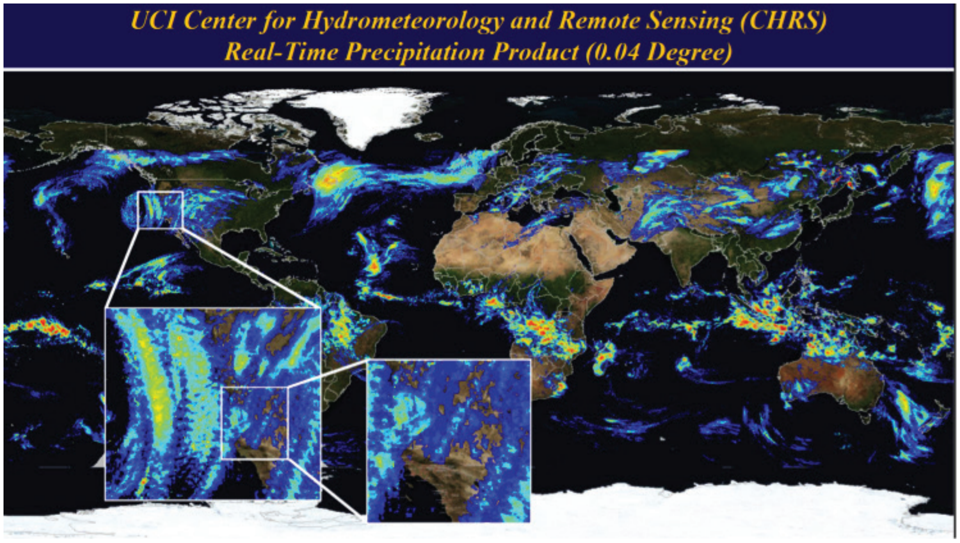
[15] E.g., CMORPH (Climate Prediction Center Morphing Technique, National Oceanic and Atmospheric Administration); PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks, University of California, Irvine Center for Hydrometeorology and Remote Sensing; TRMM (Tropical Rainfall Measuring Mission, NASA), et al.

Examples of a few technology innovation opportunities with potential for use in operational hydrology and water resources management practice are presented:

High Resolution Near-Real-Time Precipitation Observation from Satellites

An operational early-warning system for monitoring and forecasting imminent extreme precipitation and flood events requires timely observation of rainfall with high resolution both in time and space. Recent developments have demonstrated the effectiveness of using satellite-based remote sensing observations. Scientists at UC Irvine Center for Hydrometeorology and Remote Sensing (CHRS), with support from NASA, NOAA, Army Research Office (ARO) and in collaboration with the United Nations Educational, Scientific, and Cultural Organization's (UNESCO's) International Hydrologic Program (IHP) have been developing algorithms for retrieval of high-resolution (~4km)\ precipitation estimates from multiple satellite sensors at the global scale (Figure 9). This product known as G-WADI PERSIANN-CCS (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks Cloud-patch Classification System) can easily and quickly be accessed in near-real-time with an average latency of around one hour. The near-real-time nature of the data allows development of efficient operational and monitoring systems even over ungauged basins (Figure 9).[16]

Figure 9. High-resolution near-real-time precipitation satellite observation.



Other satellite-based products developed at UCI and available to the user community include:

- Drought monitoring and prediction using the Global Integrated Drought Monitoring and Prediction System (GIDMaPS) which integrates multiple remote sensing and model simulations for providing near-real-time drought information. GIDMaPS provides both historical data and seasonal (1-6 month) drought prediction.[17]
- In cooperation with NOAA's Climate Data Record (CDR) program, a long-term (~30 year) daily 25 km climate data records derived by combining real-time PERSIANN satellite data with historical infrared observations, has been delivered to NOAA's CDR program. This dataset is now available online for hydroclimate studies and precipitation variability impact assessment globally and regionally including California.[18]
- A database using the recently developed PERSIANN-CONNECT algorithm (Sellars et al. 2013) has been released for analysis of extreme storms, including Atmospheric Rivers (AR), which impact California. It offers a new methodology for transforming remotely sensed imagery of extreme weather events (e.g. typhoons or hurricanes) into organized 4-dimensional (4D) units or "objects".[19]

NASA-JPL Airborne Snow Observatory (ASO)

From a remote sensing standpoint, the ultimate innovation goal for measuring winter snow storage would be from satellites. However, at the present time no satellite retrieval gives accurate estimates of mountain snow water equivalent and the earliest that the global community will likely see such a system is year 2030. In the meantime, innovative methods are being developed and tested by scientists in NASA-JPL's Airborne Snow Observatory

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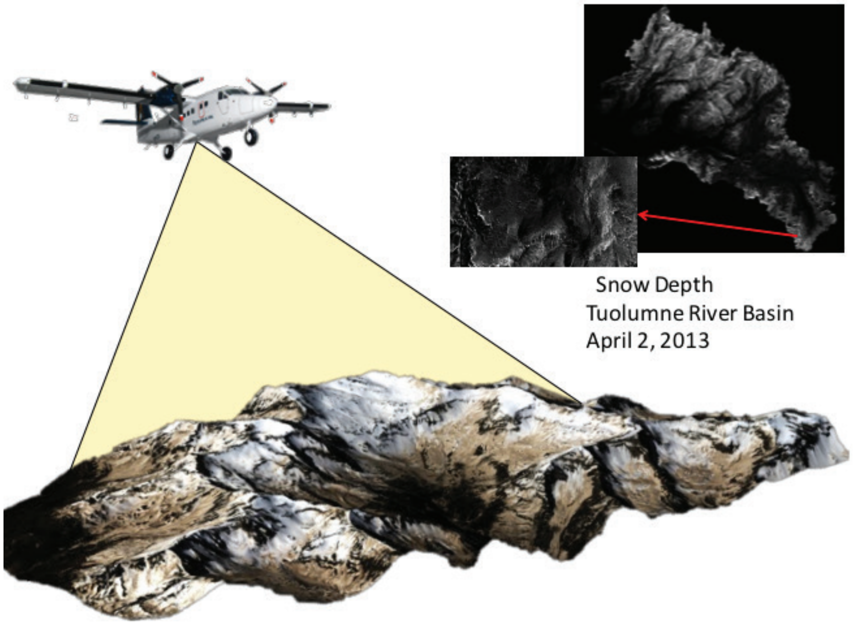
[16] http://hydis.eng.uci.edu/gwadi/
[17] http://drought.eng.uci.edu/
[18] http://www.ncdc.noaa.gov/cdr/operationalcdrs.html
[19] http://chrs.web.uci.edu/research/voxel/index.html

Figure 10. NASA Airborne Snow Observatory (ASO)



(ASO) group, combining scanning LiDAR and imaging spectrometer to measure the spatial distribution of snow water equivalent and snow albedo(reflection) across mountainous basins (Figure 10). This is a very promising approach and a major complement to the existing NRCS SNOTEL sites and California Cooperative Snow Surveys snow courses and pillows, which do not give us access to comprehensive knowledge of basin snow volumes and, given their elevation range, often melt out early in the snowmelt phase.

In 2013, the Airborne Snow Observatory flew over California's Tuolumne River Basin on a weekly basis, acquiring complete knowledge of the spatial distribution of snow water equivalent and snow albedo. These data were successfully used and evaluated for HetchHetchy Reservoir operation. JPL, in cooperation with DWR, has developed plans for the complete acquisition of timely snow information from ASO over the entire Sierra Nevada.

Recommendations

The following recommendations are made regarding both *in situ* and remote sensing technologies.

1. **Continue research and development of technologies for seamless integration of in-situ and remote sensing observation systems using mature wireless-sensor technology** to improve the spatial and temporal resolution of measurements of hydrometeorological variables.
2. **Develop practicable mechanisms for closer coordination between the scientific and technical experts** who develop, operate, maintain and use *in situ* sensor networks and remote sensing instruments, when this coordination can appreciably enhance the value of both data collection efforts.
3. **Adapt satellite-sensor output to operational use**, where it is demonstrated that the satellite readings represent mature technologies and are being produced on an ongoing basis, making them reliable sources of information for water-resources decision making over the long-term. Examples of this include the snow-covered area and albedo products (http://www.nohrsc.noaa.gov/nh_snowcover/), the UC Irvine real-time high resolution Satellite precipitation (http://hydis.eng.uci.edu/gwadi/) and global drought information (http://drought.eng.uci.edu/).
4. **Increase use of airborne-sensor platforms** as a complement to satellite platforms for sustaining data acquisition, providing a gap-fill between satellite missions, and as a cost-effective strategy for collecting data that is of very high value but for limited regions at limited times (e.g., snow water resources).
5. **Provide opportunities and incentives for meaningful partnerships between NASA, universities, state and local agencies, NGOs and the private sector to accelerate development and testing of new remote-sensor capabilities,** including accurately measuring chemical and physical attributes of fresh-water bodies from drones.
6. **Increase investments in capacity building for use of remote sensing in water resources management applications and decision-making processes and increase outreach and communication** to inform the water-resources management community of potential use and application of satellite data, as well as their limitations.
7. **Develop standardized strategies and protocols for quantifying uncertainty in measurements**, and communicating the uncertainty to models or decision-making processes that ingest the measurements.

3.1.2 Data Management and Use

Definition

For the purposes of this discussion, **data management** covers the transfer of data from the acquisition point through formatting, storage, quality assurance/quality control, and other processing to turn data into information, and making that information available for end users. **Data use** includes the use of data for decision support, including water-system planning, operation and management. This use also involves value-added steps such as forecasting and compliance reporting.

Overview

Efficient management of California's water system is dependent on effective decision making by everyone involved, including consumers and anyone who has a role in water management. Effective decision making, in turn, requires data that is accurate, timely, and relevant. While progress has been made at considerable expense at the state level in developing data portals, the large number, complexity and limited transparency of many of these portals has not resolved the data access, quality and comparability dilemma that exists for many users. This was a common message from nearly all study participants.

The core of technological advances in water information is the cyber-infrastructure that integrates disparate data streams, does the required quality assessment and control, synthesizes the data, integrates it with modeling, simulation, and forecasting tools, and delivers it to decision makers and other water stakeholders. A real-time intelligent water-infrastructure system is a cyber-physical system exhibiting both computational and physical elements. The link between these *cyber* and *physical* components is achieved through a real-time sensing backbone. The system management should be designed as a network of interacting elements with physical inputs and a coordinated suite of information-driven outputs, rather than a disparate set of models, control policies, and physical infrastructure as too often exists today.

One example of a move towards such an infrastructure is a collaboration among NASA, DWR, Western Growers, USGS, USDA, and CSU and UC scientists to map crop-water requirements statewide at the scale of individual fields using data from satellites and surface observation networks (Figure 11). In addition, the use of the relatively dense network of highly accurate Global Positioning System (GPS) stations and airborne and satellite interferometric synthetic aperture radar (InSAR) observations to measure surface/ground subsidence to provide information on groundwater depletion and irreversible compaction, is within reach for operational purposes. In this regard, NASA and DWR are developing plans to collaborate on mapping of surface deformation using synthetic aperture radar instruments, and to develop new soil moisture information products from the upcoming Soil Moisture Active Passive Mission scheduled for launch in 2014.

Figure 11. NASA satellite irrigation-management support.

NASA Satellite Irrigation Management Support

California currently faces a number of challenges in sustaining agricultural water supplies across the state, including periodic drought events, groundwater overdraft, and nitrate contamination of groundwater resources. Improving on-farm water use efficiency is an important component of addressing these challenges, and California growers need new information products to assist them in evaluating and improving irrigation management practices.

The Satellite Irrigation Management Support (SIMS) project is a NASA supported effort that is integrating publicly available data from earth observing satellites such as Terra, Aqua, and Landsat to map measures of crop canopy development at the field scale (30m / 0.25 acres) every eight days. By combining the satellite observations with data on reference evapotranspiration from the California Irrigation Management Information System, operated by the California Department of Water Resources, SIMS is able to map daily measures of crop water requirements across ~3.7 million ha of farmland in California. Data is distributed in near-real-time using a web services architecture that supports data visualization and data queries via web browsers and mobile devices.

In collaboration with partner growers, the SIMS project is also deploying wireless sensor networks to measure soil moisture, evapotranspiration, and drainage below the root zone on commercial farms across California. The project is using the field data as part of a verification and validation study, and is currently developing strategies to integrate data from satellites and surface networks to further improve field-scale measurements of crop water requirements.

Such systems can improve the link between computational and physical elements of water networks, dramatically increasing the adaptability, autonomy, efficiency, functionality, reliability, safety, and usability of these systems. Advances in measurement technology are necessarily accompanied by new decision-support systems that include modeling and analysis.

Innovation Opportunities

There is much to be gained by closer integration of remote sensing derived data and remote sensing data into common data-sets where the use of the derived data-sets provides important benefits to their users, coordinate information sharing and/or the development of common standards for remote sensing data and *in situ* data, and expand existing monitoring networks (both *in situ* and remote) using mature wireless-sensor technology to improve the spatial and temporal resolution of measurements of hydrometeorological variables. This would facilitate the improvement of the accuracy and spatial resolution of hydrologic resources, including: agricultural water use and mapping of crop water requirements; monitoring of coastal integrity; detection and mapping of biological invasive species; drought monitoring and impact assessment; groundwater monitoring; infrastructure management and ground subsidence; natural-resource conservation; snowpack monitoring; water quality; water supply and use; and water use efficiency.

Many elements of these technologies are sufficiently mature to move from demonstration to prototype, or core elements, of a water-information system. Recent advances in remote sensing technologies, wireless sensor networks, autonomous vehicles, cloud computing, mobile applications, data integration protocols, and advanced hydrometeorological modeling frameworks all provide opportunities to improve data and information products available to both the water resources management community and the diverse range of water users who are confronting these challenges. Remote sensing and water-resources management agencies in California have initiated a number of recent workshops in an effort to enhance communication and identify opportunities for joint research and development of new technologies and applications. Organizations such as the Western States Water Council and the California Water Foundation have also supported these efforts and played a critical role in bringing together different stakeholders. Continued investment in these coordination and planning efforts is critical.

In the area of water supply, together new satellite and ground-based data make possible the updating of forecast tools, and routine use of spatially explicit and temporally resolved hydrologic models. In groundwater banking, spatially distributed measurements permit optimization of recharge and extraction, including possible lower energy costs. Scheduling of flows for salinity management, hydropower production, and irrigation all become much more feasible under an integrated water-accounting system.

A critical technological opportunity is the cyber-infrastructure that links measurements, data processing, models and users. The current array of systems is fragmentary and not as user-friendly or accessible as it could be. A more unified system, based largely on tools already in use in other industries, would be a major step forward from what is currently available in the water area.

Integrated Data Management System

Efforts underway within the hydrologic research community provide a template that takes advantage of recent advances. Key design features of an enhanced data and information system include:

1. Distributed sensors and sensor networks dynamically transmit data directly into an information system/common portal, thus making data accessible to all users in real-time as they are collected.
2. Quality-assurance and quality-control procedures and algorithms are built directly into the information system.
3. Metadata clearly document data at all levels, from raw data to processed, mature products.
4. Recognizing that data is not information, there should be modeling, simulation, and visualization systems built into the data portal to facilitate appropriate *use* of the data. Providing automated interpretive products should not supplant availability of raw data.
5. The system/portal has the flexibility for multiple types of access, from user queries to automated and direct links with analysis tools and decision support systems.
6. Current and historic data from satellite and aircraft observations, ground-based networks and models are maintained and easily accessible.

The lack of shared data and data gaps results often in poor management of scarce water resources and costs California dearly. Currently, much of the water-related data generated in both the public and private sectors is stored on File Transfer Protocol (FTP) sites, which are not as accessible as standard websites. Building interactive web-based portals, with the ability to generate custom reports based on user needs, is essential.

There are a number of portals in existence and in development. However none is truly comprehensive, due to the wide range in data collection and management protocols. For example, the California Data Exchange Center (CDEC) is designed to accept land-based station (*in situ*) datasets and is not designed to accept data from satellites. An effective interactive portal needs to be able to connect and integrate data from a variety of sources.

Efforts currently underway in California to develop an effective interactive portal website include DWR's Water Plan Information Exchange (Water PIE) and UC Davis' HOBBES. HOBBES goal is to create data standards, systems and automatic network generators and provide a more comprehensive overview of multiple data sources.[20] Both Water PIE and HOBBES are still under development.

The standardization of the definition of metadata and the universal reporting of metadata will be an important component of any standardized protocol. Metadata provides information regarding the "who, what, when, where and why" about the data in the database including information pertaining to data collection and management quality-control measures. The metadata should also provide information regarding the uncertainty of the data.

Finally, critical challenges must be addressed with the level of resources for staffing and other needs required to provide the data in a usable format, maintain it, and keep it updated so that complete data sets are available for future users seeking the answers necessary for the management of California's waters.

Decision Support Models

Within the nexus of water infrastructure, institutions and information, there is great potential for technological innovation in water information to support effective operation of water infrastructure such as dams, groundwater-recharge projects, and salinity-management systems, and to improve the effectiveness of state, regional and local water institutions. Currently California's water information is spread across many individual entities that work in isolation from each other. There is no coordinated information system that tells managers, operators, and regulators how much water California has, where it is and what it is doing - this presents a number of decision-making challenges. The state would benefit from a coordinated information plan that cuts across water sectors, agencies and constraints. The plan should address modernization of systems to serve multiple uses (e.g. common Sierra Nevada measurements for informing planning, hydropower operation, water supply, flood forecasting, ecosystem restoration and forest management). For planning, it should assess costs and benefits, and identify financing options in the context of a range of scenarios that represent the most accurate available climate predictions.

Technological advances routinely drive better management and risk-informed decision-making. Some users of water information will readily adapt and take advantage of the large amount of information that can be made available through new measurement technology. Others will require technical assistance, and public agencies will likely make use of private-sector partners to provide additional services.

Visualization tools can better inform managers and educate a public about issues as diverse as water flow through the Delta, the link between forest management and runoff from the Sierra Nevada, and groundwater-surface water interactions in the Santa Ana River.

Information Sharing/Public-Private Partnerships

California also needs to make more of an effort to transition publicly funded research to the market. Workshops, technology fairs, forums or similar-purposed venues could facilitate this process. However, there is also a critical need to stimulate public and private investment in water-information technology, to move systems proven at the research scale to the scale of water decisions. For example, the American River basin has served as a test-bed for ground-

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[20] http://hobbes.ucdavis.edu/content/major-components?destination=node/2

based and remotely sensed technologies to better measure spatially distributed precipitation, snowpack and soil moisture, yet investments to bring these technologies and the innovative information they produce into operational use for decision making has lagged. Operational prototypes of core elements of a new water-information system, developed as partnerships between the operational and research communities, are needed to move forward.

Recommendations

Recommendations for cyber-infrastructure and data management include:

1. **Develop and implement an integrated water information management system** for water supplies, uses, and quality including precipitation, runoff, and storage; for surface water, groundwater, and water use. In situ and remote monitoring devices and networks should be expanded and linked to an integrated data management system, or implemented where not available but needed. The collection of real-time or near real-time data on all elements of the hydrologic cycle is critical for this integrated system to be most useful. A common portal, such as DWR's Water PIE and UC Davis' HOBBES, that forms the cyber core of a flexible data and information-management program and capable of supporting data analysis, trending and scenario forecasting, should be developed with a common set of standards to link data collection from all sources with an integrated data management system.
2. **Develop standardized protocols for distributed data storage, management, and use policy**, to ensure that data are consistent and linked to appropriate contextual metadata.
3. **Develop a set of standardized, interagency protocols for water use and quality measurement and reporting**. This should be carried out under the auspices of the California Natural Resources Agency, Department of Water Resources, California Environmental Protection Agency, Health and Human Services, Public Utilities Commission, Energy Commission, Bureau of Reclamation, State Water Resources Control Board, U.S. Environmental Protection Agency, U.S. Geological Survey, U.S. Army Corps of Engineers, and other stakeholders.

3.2 Water System Management

Definition

Water System Management is reflective of an emerging trend in water management to consider systemic impacts, both upstream and downstream, of new technologies and techniques. By adopting a broader perspective into the water system, additional efficiencies and opportunities can be identified that are not easily seen when water is managed at individual process (box) levels.

Overview

At the core of Water System Management is the concept of ***systems thinking.*** "Systems thinking" is the process of understanding how changes in the processes in the individual elements (boxes) of the water use cycle have upstream/downstream impacts on other individual processes (boxes) and the cycle as a whole.[21] Innovations in individual processes of the water use cycle can have quantifiable benefits or other impacts in other processes as well. A classic example of these "multiple benefits" is that improving water use efficiency decreases the volume of wastewater that needs treatment; this in turn reduces costs of wastewater collection, treatment, and disposal. Combined with risk management, decisions can be more effectively arrived at and distributed across stakeholders.

Applications of systems thinking range from organizations using new tools to quantify their water impact, setting objectives to reduce and/or monitor water usage, to exploring new approaches to water rate structures and price incentives.

Public and private sector applications of systems thinking have shown improvements in both the understanding of water supply impacts, as well as the smarter management of water resources. By considering individual water use cycle components collectively as a system, water managers can achieve and account for greater efficiency improvements and cost savings.

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[21] Jay Forrester, Pegasus Communications, Daniel Aronson: http://www.thinking.net/Systems_Thinking/st_innovation_990401.pdf.

In the public sector, systems thinking can help policymakers implement solutions that address a variety of environmental challenges. One public sector implementation of systems thinking within the public sector is the Water-Energy Team of the Climate Action Team (WET-CAT); this team is exploring the energy used in providing water throughout the water use cycle, and how climate change management strategies like greenhouse gas emission reductions affect water availability.[22]

At the federal level, the Environmental Protection Agency (EPA) has implemented a number of strategic programs aimed at protecting future water supplies by focusing on helping consumers use less water. EPA's WaterSense program is one example; in this program, products and services such as toilets, showerheads, and irrigation controllers that are at least 20% more water efficient than average products are certified with the WaterSense label.[23]

In the private sector, many large water users, especially in the food and beverage and mining, oil, and gas industries, are adopting systems thinking approaches to understand their business' impacts and manage resources more efficiently. By employing a variety of tools, from water footprinting to goal setting and risk analysis, many companies are discovering that the majority of their water impact lies outside of their traditional company boundaries. In fact, this water impact is often the highest in the supply chain, whether it is in the manufacturing of inputs to company products or in agriculture. Additionally, both supply-chain and internal operations impact local watersheds, and companies are increasingly recognizing this fact and taking action to restore impacted watersheds.

Innovation Opportunities

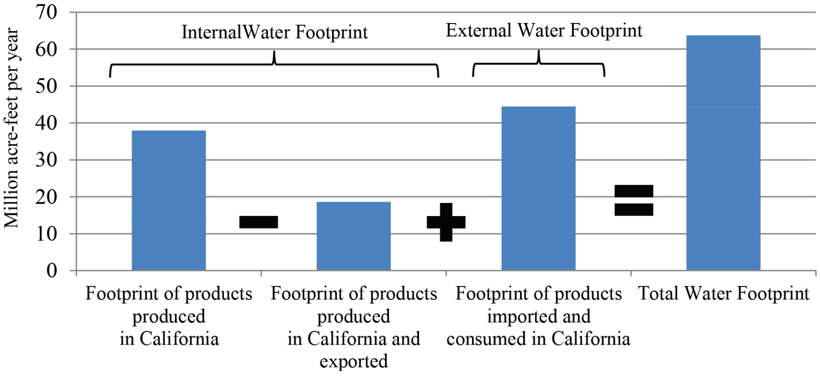
There are a number of innovations in Water System Management that have the potential for broad overarching application and impacts on the water use cycle.

Water footprinting is a tool that municipalities, states, and companies are increasingly leveraging to identify the water intensity of their organization, products, and supply chains. This tool helps organizations analyze their supply chains to mitigate inefficiencies and environmental impacts in both internal operations as well as the operations of their suppliers. The water footprint of a business is the total volume of water that is used directly or indirectly to run and support the business; it includes the water use of internal operations, as well as the water used throughout the business' supply chain.[24]

Statewide California Water Footprint

The Pacific Institute in December 2012 released its first iteration of California's water footprint, measuring the direct and indirect water consumed by the goods and services produced within the state, while also accounting for imports and exports of goods to other states and countries.[25] The study found that the state's water footprint was 64 MAF/yr, which equates on a per-capita basis to 1,500 gallons per person per day (Figure 12). While the California footprint is slightly below the national average (Figure 13), the U.S. water footprint is nearly twice the average per-capita footprint worldwide.[26,27]

Figure 12. California's total water footprint.



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[22] California Climate Change Portal. "Water-Energy Team of the Climate Action Team (WET-CAT)" Web. http://www.climatechange.ca.gov/climate_action_team/water.html.

[23] US EPA. "The WaterSense Label." http://www.epa.gov/watersense/about_us/watersense_label.html.

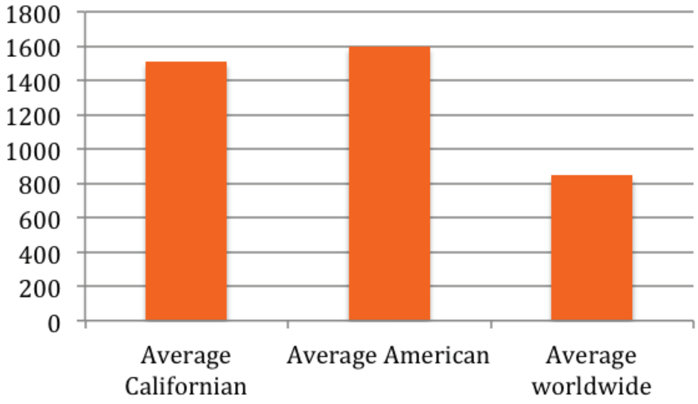
[24] Hoekstra, AY. Chapagain, AK. Aldaya, MM. Mekonnen, MM. "The Water Footprint Assessment Manual: Setting the Global Standard." Earthscan, 2011. London. pp. 60-65.

[25] Fulton, J. Cooley, H. Gleick, P. "California's Water Footprint." The Pacific Institute, Oakland, CA. December 2012. pp. 1-6.

[26] Fulton, J. Cooley, H. Gleick, P. "California's Water Footprint." The Pacific Institute, Oakland, CA. December 2012. pp. 1-6.

[27] Pacific Institute, "California's Water Footprint." December 2012.

Figure 13. Average water footprint, California, US, and world.



Several private sector corporations have made significant strides in reducing their water footprint. The case studies below highlight two examples and point to the potential for water-footprint reduction through private-sector leadership.

Patagonia's Our Common Waters

The clothing company, Patagonia, Inc., has a strong history of leadership in environmental sustainability, as evidenced by its Footprint Chronicles, an in-depth examination into its supply chain to identify and reduce social and environmental impacts. They have recently launched the "Our Common Waters" campaign as an effort to balance human water use with that of the natural environment. A key piece of this campaign is to develop an understanding of the company's water footprint, key areas of stress, and the water dependencies throughout Patagonia's supply chain.[28] Concerned with the freshwater use in manufacturing of its clothing throughout its supply chain, Patagonia has partnered with bluesign® technologies, a Switzerland-based organization that audits textile-manufacturing energy, water, and chemical usage; Patagonia in 2011 set a goal to transition 100% to bluesign®-approved fabrics by fall 2015.[29]

Decker's Outdoor Corporation Water Footprint

Goleta, CA-based Deckers Outdoor Corporation is the parent company of a number of footwear brands, including UGG, Teva, and Sanuk. Increasingly concerned with the water impact throughout the company's operations, Deckers worked with students at the Bren School of Environmental Science and Management at the University of California, Santa Barbara, to conduct a water footprint analysis throughout the supply chain.[30] The results of this study showed that the majority of Deckers' water footprint is from the material production and product assembly throughout its supply chain; Deckers facility water use accounted for only 4% of total 2010 water usage.[31] This analysis confirmed company suspicions, and has led Deckers to encourage its tanneries, the largest supply-chain water users, to implement more sustainable water practices. Highlights of this approach include a company decision to only work with tanneries with on-site water treatment facilities, as well as Deckers joining the Leather Working Group (LWG), an organization that certifies leather factories based on their environmental performance.[32]

Water conservation and restoration goals are increasingly being incorporated into private sector company corporate goals. These companies use a myriad of strategies to mitigate their water use and restore ecosystems directly or indirectly related to business operations worldwide. The case studies below highlight examples of water systems thinking employed by private sector corporations.

Coca-Cola's Suite of Water Goals[33]

Water management at Coca-Cola is focused on reducing water used per liter of product produced, as well as on ensuring the long-term sustainability of the watersheds affected by Coca-Cola's production process. Specifically, the company tracks water stewardship by the following corporate goals[34] in Figure 14.

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[28] "Patagonia's Water Footprint." Web. Patagonia. http://www.patagonia.com/us/patagonia.go?assetid=58846.

[29] "Patagonia's Water Footprint." Web. Patagonia. http://www.patagonia.com/us/patagonia.go?assetid=58846.

[30] Heyman, J. Kintz, R. Thayer, B. Van Abel, K. Way, K. "A Corporate Water Footprint: Deckers Outdoor Corporation." Bren School of Environmental Science and Management, April 2012.

[31] Heyman, J. Kintz, R. Thayer, B. Van Abel, K. Way, K. "A Corporate Water Footprint: Deckers Outdoor Corporation." Bren School of Environmental Science and Management, April 2012.

[32] Atkinson, William. "How Deckers Drives Partners to Conserve Water." *Sustainable Planet. August 17, 2012. https://www.sustainableplant.com/2012/08/how-deckers-drives-partners-to-conserve-water/*

[33] Coca-Cola. "Water Stewardship." 2011/2012 Sustainability Report. http://www.coca-colacompany.com/sustainabilityreport/world/water-stewardship.html#section-mitigating-riskfor-communities-and-for-our-system

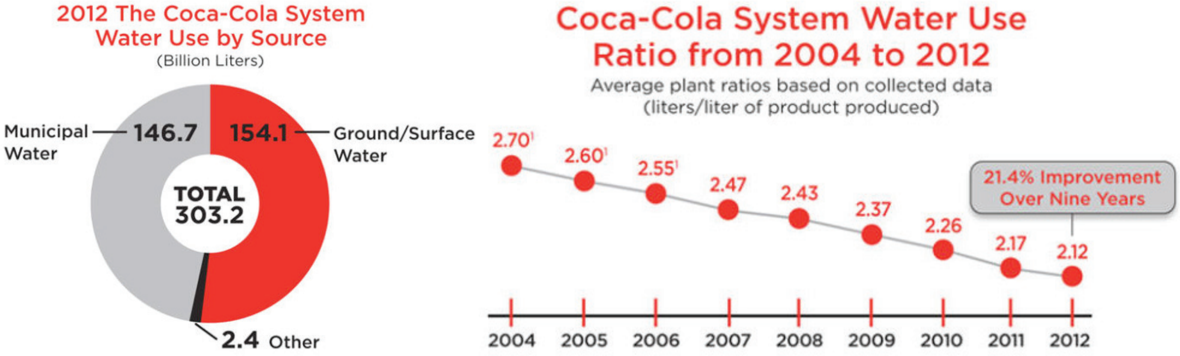
[34] Coca-Cola. "Setting a New Goal for Water Efficiency." 2013 Water Stewardship & Replenish Report. http://www.coca-colacompany.com/setting-a-new-goal-for-water-efficiency.

Figure 14. Coca-Cola's water goals.

Goal	Progress
1. By 2020, safely return to communities and nature an amount of water equal to what we use in finished beverages and their production	Based on 2012 production volume, Coca-Cola estimates that 52% of water used has been balanced with community and natural needs
2. Improve water efficiency in manufacturing operations by 25% by 2020 compared to 2010 baseline	Water efficiency improvements of 21.4% since 2004 and 5.9% since 2010
3. Assess water quality and quantity vulnerabilities for each bottling plant and implement locally relevant source water protection program by the end of 2012	By end of 2012, 91% of Coca-Cola's 863 bottling plants have completed vulnerability assessment, and 68% have implemented protection plans
4. By the end of 2010, return to the environment at a level supporting aquatic life the water used in system operations through comprehensive wastewater treatment.	By end of 2012, 91% of Coca-Cola's 863 bottling plants have completed vulnerability assessment, and 68% have implemented protection plans.

Coca-Cola has developed extensive water footprinting and other metrics to gauge its water use in operations and to identify areas of vulnerability within its supply chain and in the local communities of the bottling plants. The graphs below (Figure 15) highlight Coca-Cola's understanding of where their water comes from, and tracks efficiency improvements overtime.

Figure 15. Coca-Cola system water use by source, 2004-2012.



Another key area for Coca-Cola is the development of partnerships with water organizations and stewards around the world. Coca-Cola has partnered with organizations such as World Wildlife Fund, USAID, the U.S. Water Partnership, the Nature Conservancy, World Resources Institute, and many others to promote water stewardship throughout its operations. One example of Coca-Cola's partnership effort is the Replenish Africa Initiative, or Project RAIN, an effort funded by Coca-Cola and USAID to provide access to clean drinking water to over 2 million people in Africa by 2015.[35]

Ford Motor Company's Commitment to Corporate Water Reductions

Ford began its Global Water management Initiative in 2000, with a 3% year-over-year water-reduction target.[36] This program has been highly successful, and since 2000, Ford has seen a 62% reduction in water use per vehicle [Figure 16]. Key facets of Ford's program include building an understanding of the company's supply chain, mapping company operations using WBCSD's Global Water Tool to gauge water scarcity, and developing an understanding

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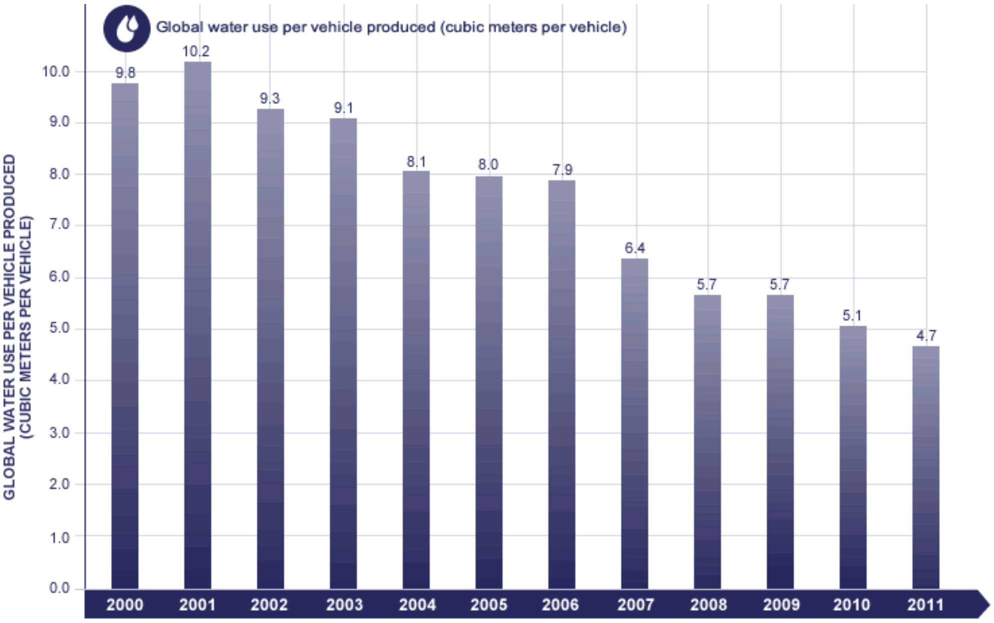
[35] "About Rain." The Coca-Cola Foundation. https://secure.thecoca-colaafricafoundation.org/africa-water-projects-rain.asp

[36] "Progress in Reducing Water Use." Ford Motor Company, Sustainability 2011/12. http://corporate.ford.com/microsites/sustainability-report-2011-12/water-reducing.

of the water use throughout the vehicle life cycle (raw materials, production, use, end-of-life disposal). To achieve these reductions, Ford has implemented a variety of technologies and techniques, including expanding its stormwater management systems and green roofs, and retrofitting manufacturing facilities with on-site wastewater recycling systems. Ford is also moving towards Minimum Quality Lubrication (MQL), a dry-machining process that lubricates parts with a fine spray of oil, as a replacement for the conventional wet-machining, which requires large amounts of water and other machining fluids to cool and lubricate parts for manufacturing.

Figure 16. Ford Motor Company global water use per vehicle produced, 2000-2011. Source: Ford Motor Company, Sustainability 2011/2012



In 2011, Ford set a new goal to reduce the amount of water used to produce each vehicle by 30% globally by 2015, using a 2009 baseline. From 2011 to 2012, Ford's water use per vehicle reduced by 8.5%, a strong start towards achieving this goal (Figure 16).

Miller Coors Pledge to Brew More Beer with Less Water

One of the key water-efficiency metrics within the beer industry is the water to beer ratio of a brewery. Miller Coors has emerged as a leader in this regard, reporting a record low 3.82:1 ratio throughout its operations in 2012.[37] This ratio is far below the industry standard of 5.00:1, reflects a 6.1% improvement over 2011 and is significant progress towards a 2015 goal of 3.5:1, a 15% reduction from the Company's 2008 baseline.

To achieve these reductions, Miller Coors has implemented efficiencies both within its breweries and throughout its agricultural supply chain. Extensive water footprinting and supply-chain analysis found that over 90% of the water used to produce its beer comes from the agricultural supply chain. Miller Coors has partnered extensively with its barley and hops suppliers to reduce this water use by encouraging farms to replace flood-irrigation practices with drip lines and by exploring new crop varieties such as dry-land (grown without irrigation) and winter-hardy barleys. Miller Coors has also implemented a number of water-saving solutions within its breweries, including water-reclamation systems to recirculate cooling water, switching to waterless lubricants and air rinsers on packaging and bottling lines, and installing more sophisticated water meters to provide real-time monitoring of water use in brewery operations.

Assessing water risk is an emerging concern both in the investor community and within companies' executive management. Increasing attention is being placed on companies' vulnerability to water scarcity and changes in water availability due to disasters, climate change, and other external factors. Investors are increasingly looking for companies to show that they understand and are actively working to mitigate the water-based threats to their businesses. A key trend in this area is the emergence of company disclosures focused on water risks and mitigation activities.

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[37] MillerCoors 2013 Sustainability Report, p. 24. http://www.millercoors.com/getattachment/GBGR/Brewing-for-Good/MillerCoors-2013-Sustainability-Report.pdf.aspx.

One key innovation here is in the disclosure options available to companies and investors. A number of questionnaire, analysis, and other tools are helping companies analyze their impact and report out their responses. For example, the Carbon Disclosure Project (CDP), an independent nonprofit organization based in the U.K., recently launched a Water Program to complement its climate change, supply chain, and forest management programs, where companies complete an annual questionnaire regarding their water risks and management strategies.[38] Company responses are publicly available, and CDP provides annual data analysis of water disclosures. Another innovative program to increase water scarcity awareness is the CEO Water Mandate, a public-private initiative developed by the UN Secretary General, which requires company CEOs to publicly pledge water sustainability practices and policies.[39]

Within the investment community, water risks and their related impacts on companies and the overall economy, are receiving increasing attention. For example, in February 2013, Goldman Sachs, along with General Electric and the World Resources Institute, held a summit entitled, "Water: Emerging Risks & Opportunities," that convened local, state, and federal agencies, private-sector companies, investors, and the academic community to address how capital, technology and innovation, policy, and energy can combine to encourage U.S. water sustainability.[40] Additionally, JP Morgan in 2008 issued a report highlighting the physical, regulatory, and reputational risks that companies face in relation to water.[41]

Strategic incentives, creative water pricing, and rate structures can encourage water conservation and reduce overall water-system management costs. Municipalities and water management agencies increasingly understand the system-wide impacts that water use efficiencies can have throughout the water use cycle. Innovative water pricing, incentives and rate structures are emerging to encourage water conservation and reduce overall system management costs. The city of Davis' consumption-based fixed rate pricing structure and the Irvine Range Water District's allocation-based conservation rate structure offer examples of paths forward.

Davis' Consumption-based Fixed-Rate Pricing Structure

The city of Davis, California, is transitioning from traditional fixed volumetric pricing where the majority of the rate is based on variable charges, to a consumption-based fixed rate (CBFR) structure where the majority of the rate structure is fixed based on historical meter readings (Figure 17). This structure provides a more stable, quantifiable, revenue stream for the city by reducing the dependence on revenue from variable charges. Additionally, it encourages residents to conserve water, as the current year's meter readings set the baseline supply charge for the following year's rate structure.[42]

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[38] Carbon Disclosure Project Water Program. [corporate responses and case studies available on web] https://www.cdproject.net/en-US/Programmes/Pages/cdp-water-disclosure.aspx.

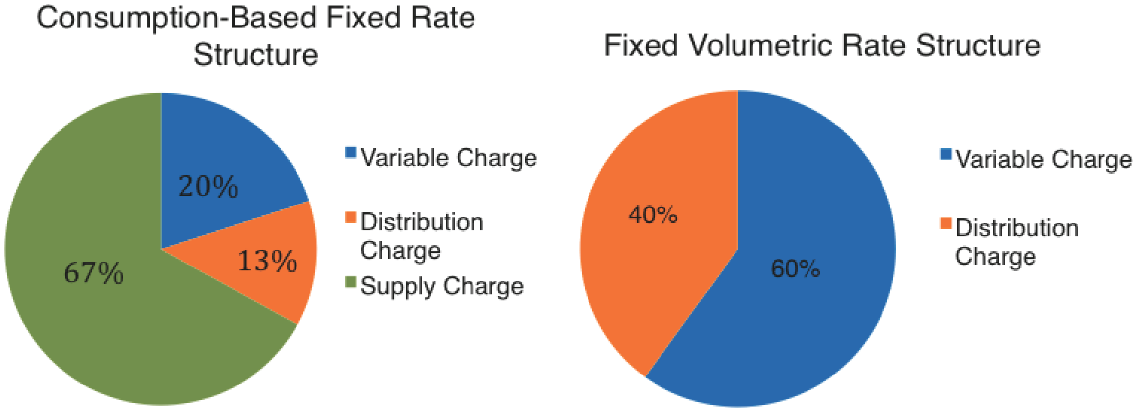
[39] CEO Water Mandate. https://www.cdproject.net/en-US/Programmes/Pages/cdp-water-disclosure.aspx.

[40] Goldman Sachs. "Water: Emerging Risks & Opportunities." Water Summit White Paper. March 2013. http://www.goldmansachs.com/our-thinking/our-conferences/water-conference/water-summit-white-paper-pdf.pdf.

[41] JP Morgan Global Equity Research. "Watching water: A guide to evaluating corporate risks in a thirsty world." March 2008. http://pdf.wri.org/jpmorgan_watching_water.pdf.

[42] "Notice to Property Owners of Public Hearing of Proposed Water Rate and Fee Increases." City of Davis, CA. Prop 218 Notice. January 2013. http://water.cityofdavis.org/Media/PublicWorks/Documents/PDF/PW/Water/Rates/Prop-218-Notice-Final.pdf.

Figure 17. The new Consumption-Based Fixed-Rate Structure in Davis, CA significantly increases the percentage of revenue derived from fixed supply charges.



Irvine Ranch Water District's Allocation-based Conservation Rate Structure

The Irvine Ranch Water District (IRWD) has long been a leader in water conservation, and its hallmark program, enacted in the 1990s, is the district's allocation-based conservation rate structure. Under the IRWD program, each utility customer receives an allocation of water based on climate, parcel size, irrigation infrastructure, and other factors. If customers use more than the allocated amount of water, they pay a conservation charge; this system sends economic price signals to the customer, encouraging water conservation. IRWD uses the additional income from the conservation charges for infrastructure and other efficiency improvements. Through the IRWD program, per-acre water consumption has decreased throughout the district, and less water is used for landscaping.[43]

Recommendations

Water system management will be a growing area of concern as utilities, municipalities, the investment community, and private sector companies continue to receive more and more information about their water use and the conservation opportunities that exist. The following recommendations are made for improving water system management.

1. **Highlight systems thinking** innovations/accomplishments/benefits including watershed approaches, water footprinting and the establishment of conservation goals as benchmark/standards and encourage widespread adoption. Municipalities successfully implementing systems thinking solutions should be highlighted to showcase the multiple benefits that can be achieved.
2. **Encourage a suite of water risk-management tools for assessment of company impacts and opportunities.** There are numerous products and tools emerging to help companies quantify their water impact and issue disclosures regarding their impacts. These tools have varying strengths and weaknesses; while no one standard has yet emerged, the encouragement of a diversified approach will overall strengthen the tools available and the depth of information reported and monitored.
3. **Leverage private sector initiatives** to identify and implement solutions to water-system management challenges. Recognition of the accomplishments of startup incubators, as well as established industry leaders, can encourage widespread distribution of innovations throughout the water use cycle.
4. **Encourage collaboration and public/private partnerships** to accelerate the development, piloting, and implementation of innovations in technology and technique.

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[43] "Conservation Water Structure." Irvine Ranch Water District. http://www.irwd.com/alwayswatersmart/conservation-rate-structure.html.

3.3 The Water/Energy Nexus

Innovations in both water and energy systems present interesting and important synergistic opportunities. This section addresses the water/energy nexus as an opportunity for integrated innovation. In many cases, improving water use efficiency provides significant energy savings. Innovations in technology and technique for water management, including source shifting and efficiency, have the potential to yield multiple benefits. On the other side of the equation, innovations in energy systems can reduce water inputs.

Definition

The water/energy nexus is the relationship between the use of water to extract, convert, and use energy, and the use of energy to extract, treat, deliver, and use water.

Water and energy are inherently interrelated; energy is required throughout the water use cycle, and water is required for many energy system processes. Innovations in water management can significantly reduce energy use, and innovations in energy systems can significantly reduce water use. The potential multiple benefits of the integrated management of water and energy are important aspects of the water/energy nexus.

Overview

Water is one of the largest electricity uses in California, accounting for approximately 19% of total electricity use and about 33% of the non-power plant natural gas use in the state.[44] The California Energy Commission (CEC) and the California Public Utilities Commission (CPUC) have both concluded that energy used for water presents large untapped opportunities for cost-effective energy-efficiency improvements and greenhouse gas (GHG) emissions reductions. The CEC commented that: “The Energy Commission, the Department of Water Resources, the CPUC, local water agencies, and other stakeholders should explore and pursue cost-effective water-efficiency opportunities that would save energy and decrease the energy intensity in the water sector.”[45] This aligns well with the objectives of the state’s Water Plan.

To understand innovation opportunities in science, technology, and management of the water/energy nexus, both sides of the equation must be considered: energy inputs to the water systems, and water inputs to the energy system.

Energy Inputs to Water Systems

Water systems are often energy-intensive. Moving large quantities of water over long distances and significant elevation changes, treating and distributing it within communities, using the water, and collecting and treating wastewater, together account for a major use of energy.[46]

> ***Energy intensity*** *of water is the total amount of energy required to make a unit of water available at a particular place.*

The total energy embedded in a unit of water used in a particular place varies with location, source and use. Pumping water at each stage is often energy-intensive. Other important energy inputs include thermal energy (heating and cooling) at the point of use and aeration in wastewater treatment processes.

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[44] California Energy Commission (2005). *Integrated Energy Policy Report*, November 2005, CEC-100-2005-007-CMF.

[45] California Energy Commission (2005). *Integrated Energy Policy Report*, November 2005, CEC-100-2005-007-CMF.

[46] Wilkinson, Robert C. (2000). *Methodology For Analysis of The Energy Intensity of California’s Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy-efficiency Measures*, Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy-efficiency; California Energy Commission (2005). *Integrated Energy Policy Report*, November 2005, CEC-100-2005-007-CMF: California Energy Commission (2005). *Integrated Energy Policy Report*, November 2005, CEC-100-2005-007-CMF: and Klein, Gary (2005). California Energy Commission, California’s Water – Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04-IEPR-01E) November 2005, CEC-700-2005-011-SF.

There are three broad categories of energy elements of water systems that correspond directly to the water cycle outlined earlier:

1. **Primary water extraction, conveyance, storage, treatment and distribution.** Extracting and lifting water is highly energy-intensive. Surface water and groundwater pumping requires significant amounts of energy depending on the depth of the source. Where water is stored in intermediate facilities, net energy is required to store and then recover the water. Within local service areas, water is treated, pumped, and pressurized for distribution. Local conditions and sources determine both the treatment requirements and the energy required for pumping and pressurization. Some distribution systems are gravity-driven, while others require pumping.
2. **Water use (on-site water pumping, treatment, and thermal inputs).** Individual water users require energy to further treat water supplies (e.g. softeners, filters, etc.), circulate and pressurize water supplies (e.g. building circulation pumps), and heat and cool water for various purposes.
3. **Wastewater collection, treatment, and discharge.** Finally, wastewater is collected and treated by a wastewater system (unless a septic system or other alternative is being used) and discharged Wastewater is sometimes pumped to treatment facilities where gravity flow is not possible, and the standard treatment processes require energy for pumping, aeration, and other processes.

The schematic flow diagram used in this study (Figure 7 in Section 2.2.3) is based on work originally supported by the California Institute for Energy-efficiency through the Lawrence Berkeley Lab.[47] This approach was refined as part of the CEC's 2005 Integrated Energy Policy Report process.[48] The methodology is applicable to water sources ranging from surface and groundwater supplies to desalination and recycling. It has now been used as the basic approach to calculating the energy intensity of water supplies by a number of entities, and the California Energy Commission, the Canadian government, and the WateReuse Foundation funded the development of an open-access computer model, developed by the Pacific Institute and the Bren School at UC Santa Barbara based on the methodology.[49,50]

The energy intensity of water varies considerably by geographic location of both end-users and sources. Water use in certain places is highly energy intensive due to the combined requirements of conveyance, treatment and distribution, and wastewater collection and treatment processes. Large energy-efficiency gains are possible through water efficiency improvements or through source switching (e.g. using recycled water in place of other sources for appropriate purposes) in part because energy is saved at multiple steps in the process.

Figure 18 shows the energy intensity of major water supply options for actual inland and coastal locations in Southern California.

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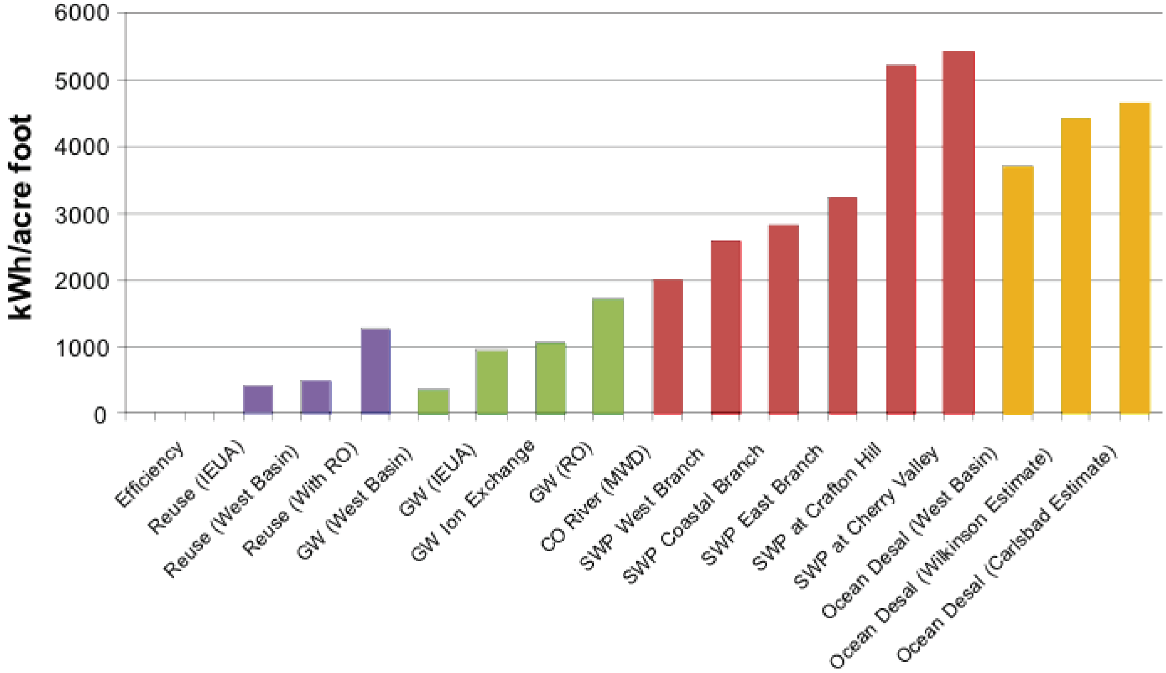
[47] Wilkinson, Robert C. (2000). Methodology For Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy-efficiency Measures, Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy-efficiency.

[48] California Energy Commission (2005). *Integrated Energy Policy Report*, November 2005, CEC-100-2005-007-CMF: California Energy Commission (2005). *Integrated Energy Policy Report*, November 2005, CEC-100-2005-007-CMF: and Klein, Gary (2005). California Energy Commission, California's Water – Energy Relationship. Final Staff Report, Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding, (04-IEPR-01E) November 2005, CEC-700-2005-011-SF.

[49] Cooley, Heather and Robert Wilkinson, 2012. Implications of Future Water Supply Sources for Energy Demands, and Computer Model with WESim User Manual, Pacific Institute and Bren School, University of California, Santa Barbara, for WateReuse Research Foundation, the California Energy Commission, and the Canadian Mortgage and Housing Corporation. Available at: http://www.pacinst.org/publication/wesim/

[50] The model is available at: http://www.pacinst.org/publication/wesim/

Figure 18. Energy intensity of selected water supply sources in southern California.[51]



Each bar represents the energy intensity, including conveyance, of a specific water supply source used at selected locations in Southern California.[52] The data are presented in kWh/af. Water conservation – e.g., not using water in the first place – avoids additional energy inputs along all segments of the water use cycle. Consequently, cost-effective water use efficiency is often the preferred water resource option from an energy perspective. For all other water resources, there are ranges of actual energy inputs that depend on many factors, including the quality of source water, the energy intensity of the technologies used to treat the source water to standards needed by end-users, the distance water needs to be transported to reach end-users, and the efficiency of the conveyance, distribution, and treatment facilities and systems.[53] In many cases, as indicated by the examples in the figure above, the treatment and use of local water supplies such as groundwater, seawater, brackish water, and wastewater, requires much less energy than imported supplies. Innovations in treatment processes, including membranes, pressure recovery, and other aspects, are further reducing the energy requirements of treatment. We expect this trend to continue.

Water Inputs to Energy Systems

The other side of the water/energy nexus is the water used in the production and use of energy. Water inputs to energy systems can be quantified to understand where water is used and how much is required for different energy sources and conversion technologies. The water intensity of energy is essentially the inverse of the energy intensity of water.

Water intensity *of energy is the total amount of water, calculated on a whole-system basis, required to produce a given amount of energy in a specific location.*

Water inputs to energy systems are highly variable. They depend on the primary energy source and on conversion technologies employed at each step in the process. For example, primary fuels such as fossil fuels and biomass often require water for production, and they sometimes 'produce' water as a by-product of extraction. There is even

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[51] IEUA: Inland Empire Utilities Agency (ieua.org); West Basin MWD: West Basin Municipal Water District (westbasin.org); DWR: Department of Water Resources (water.ca.gov); GW: Ground water; SWP: State Water Project.

[52] For the imported water indicated by the red bars, treatment energy is not included. The figures are for untreated water delivered to urban southern California.

[53] Wilkinson, Robert C. (2000). Methodology For Analysis of The Energy Intensity of California's Water Systems, and an Assessment of Multiple Potential Benefits Through Integrated Water-Energy-efficiency Measures, Exploratory Research Project, Ernest Orlando Lawrence Berkeley Laboratory, California Institute for Energy-efficiency.

a significant consumptive water use by hydroelectric systems when evaporation from surface water impoundment is taken into consideration. Bio-fuels often require water for irrigation of crops as well as for production processes. It is important to note that both renewable and non-renewable energy sources can be either water thrifty or water intensive depending on a number of factors including technologies deployed. Every water input at each step needs to be accounted for to develop a comprehensive water-intensity metric.

Water is increasingly viewed as a limiting factor for thermal power plant siting and operation. The USGS estimates in its most recent analysis that 48 percent of all U.S. freshwater and saline-water withdrawals were used for thermoelectric power.[54] Although cooling systems account for the majority of water used in power generation, water is also used in other parts of the process: water may be used to mine, process, or transport fuels (e.g. coal slurry lines). These processes may have important local impacts on water resources.

The U.S. national laboratories have been working for several years on an “Energy/Water Nexus” effort.[55] In 2007 they submitted a report to Congress entitled “Energy Demands on Water Resources Report to Congress on the Interdependency of Energy and Water”.[56] As with other analyses of the issue, the report found that some energy systems are highly dependent on large volumes of water resources (and vulnerable to disruptions), while other energy sources are relatively independent of water. Water use for renewable forms of energy varies substantially. Solar photovoltaics, wind turbines, some geothermal and concentrating solar power (CSP) systems that employ dry cooling technology, and landfill gas-to-energy projects have minimal water use. In contrast, irrigated bio-energy crops could potentially consume exponentially more water per unit of electricity generated than thermoelectric plants. Geothermal plants that don’t employ dry cooling technology may also have high water requirements. Finally, although reservoirs often have multiple purposes (e.g. flood control, water storage, and recreation), evaporative (consumptive) losses from hydroelectric facilities per unit of electricity are higher than many other forms of generation.

Thermoelectric freshwater withdrawal per unit of energy generated and the impact of this withdrawal depends largely on thermal-cooling technology used. Currently there are two main types of cooling technologies used in power plants: once-through cooling and recirculating cooling.[57] Once-through cooling systems withdraw water from a natural water body, use it for heat exchange, and return it to the water body at a higher temperature after one cycle of use. Recirculating (closed loop) technologies include wet cooling towers and cooling ponds. Wet recirculating systems use water over multiple cooling cycles and have much lower gross withdrawals than once-through cooling systems, even though recirculating systems have higher evaporative losses. Most new plants, especially those built after 1970, use some form of recirculating cooling which require less water to be extracted from surface or ground water sources once the recirculating systems are filled.[58] The adverse environmental impacts on native species due to a combination of thermal barriers and thermal pollution associated with the return of heated water to the natural system (except usually where ocean cooling is utilized) are the reason that once through cooling is largely not utilized today.

Thermoelectric cooling technologies that use smaller amounts of water than recirculating cooling (specifically dry cooling and hybrid wet/dry cooling systems) or no water at all are also possible, but their use in the U.S. is minimal at present largely due to their energy inefficiency because of impact on back pressure and high auxiliary loads, also known as an energy penalty. The economic and environmental benefits of different cooling technologies depend on various factors. Dry cooling is not appropriate in all locations, depending on climate conditions and other factors. Non-thermal power production should also be considered as an option.

The distribution of cooling technologies across the U.S. shows a distinct east/west pattern: a larger percent of the states in the east still heavily rely on once-through cooling, reflecting generally the greater availability of water of

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[54] Hutson, Susan S., Nancy L. Barber, Joan F. Kenny, Kristin S. Linsey, Deborah S. Lumia, and Molly A. Maupin, 2005. Estimated Use of Water in the United States in 2000, U.S. Geological Survey, Circular 1268, (released March 2004, revised April 2004, May 2004, February 2005) USGS, P.1. http://water.usgs.gov/pubs/circ/2004/circ1268/index.html

[55] See for example Sandia’s website at: http://www.sandia.gov/energy-water/

[56] See “Energy Demands on Water Resources Report to Congress on the Interdependency of Energy and Water” U.S. Department of Energy, December 2006, http://www.sandia.gov/energy-water/congress_report.htm

[57] Electric Power Research Institute (EPRI). Water Use in Power Generation (2008).

[58] Macknick, J., Newmark, R., Heath, G., and Hallett, KC. A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies. National Renewable Energy Research Laboratory (March 2011).

the required quantity and quality. For a few western states (e.g., California, Oregon, Nevada, Utah, and New Mexico), the freshwater withdrawal is mostly for recirculating cooling. States in the southeast use a mix of cooling technologies, with both once-through and recirculating systems in use and with an increasing use of dry cooling.

Over the period from 1950 to 2005, thermoelectric freshwater water use has increased from 30 billion gallons per day (bgd) to 143 bgd (excluding saline surface water withdrawals, which are largely associated with coastal thermoelectric plants). The total thermoelectric withdrawals have shown minimal change from the mid 1970s, and have been in the range of 126-143 bgd between 1975 and 2005. Over this period, electricity generation more than doubled from 1,911 billion gigawatt hours (Gwh) to 4,055 billion Gwh. The relatively constant water withdrawal despite this large increase in generation reflects a transition from once-through cooling systems to recirculating wet cooling systems, with much lower water withdrawals per unit of electricity generated.[59]

Innovation Opportunities

The focus of technology development and policy for much of the past century was on the supply side of both the energy and water equations. Since the 1970s, however, technological innovation has increasingly been applied to the demand side, the improvement of the *efficiency of use* of energy and water resources. ("*Efficiency*" as used here describes the useful work or service provided by a given amount of water or energy.)

Improvements have been made in the ability to secure the *services and benefits* desired from each unit of water and energy. Various technologies, from electric motors to pumps and plumbing fixtures have vastly improved use efficiencies. It is clear that substantial economic and environmental benefits can be cost-effectively achieved through further efficiency improvements in water and energy systems.

New water supplies are increasingly coming from improved efficiency and alternative sources such as recycling.[60] Devices such as plumbing fixtures and membrane filters are part of our "infrastructure" system, and innovations at the demand-side of the equation can provide savings on the supply side.

As noted in the previous section, the vast majority of once-through cooling systems in use today were constructed prior to 1970, and most new plants use some form of wet recirculating cooling system. There is significant opportunity to expand the use of thermoelectric cooling technologies that use less water.

Recommendations

1. **Further integrate water and energy planning at the statewide level.** The state's key water- and energy management agencies have made important strides in identifying areas where water and energy planning can be integrated, and water and energy plans are incorporating the nexus. This good work should be enhanced and expanded.
2. **Incorporate the water/energy nexus into local and regional water and energy plans and assessments.** Urban and agricultural water management plans, for example, are beginning to build in energy data and analysis. This should become standard practice in planning processes.
3. **Incorporate energy and emissions reductions benefits into water conservation and alternative supply analysis.**
4. **Utilize multiple benefit analysis** to determine cost-effectiveness of investments in both water and energy systems.
5. **Develop stronger co-funding strategies for water and energy agencies,** and craft supportive policy structures to enable water and energy entities to tap linked water/energy improvement opportunities.
6. **Expand use of "low-water" use renewable energy producers and also expand the use of water efficient cooling technologies** in thermoelectric power facilities.
7. **Incorporate water demands of all energy technologies in the planning process for energy systems.**

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[59] Hannegan, Bryan. " Water and Electricity: Living at the Energy-Water Nexus." White paper, Electric Power Research Institute, May 5, 2013.
[60] California Department of Water Resources. Volume II: Resource Management Strategies. California Water Plan – 2009 Update.

3.4 Water Quality

Definition

Water quality refers to the chemical, physical and biological characteristics of water. It is a measure of the condition of water relative to the requirements of any need or purpose, and is assessed using a set of standards against which compliance can be assessed. The standards in California used to assess water quality relate to health of ecosystems, safety of human contact and drinking water, and the needs of agriculture.

Overview

Water quality is a concern at multiple stages of the water use cycle, and there are many innovations emerging to measure water quality, detect contaminants, and remediate poor quality water.

In **Natural Systems**, water-quality management efforts in watershed management serve to protect natural ecosystems, and improve water quality upfront before it is extracted and conveyed throughout the water use cycle. In **Pre-use Management**, water quality is a key concern during water treatment processes, as water must meet specific standards for potable, agricultural, and industrial water quality. In **Use and Reuse**, water quality must be monitored to ensure it continues to meet quality standards. For on-site reuse, water-quality monitoring and treatment ensures that pathogens and other contaminants are removed from effluent before reuse. In **Post-use Management**, regulations and standards must be met for wastewater treatment prior to discharging water back into the environment. Additionally, water recycling requires monitoring to ensure pollutants have been removed prior to reuse.

Innovation Opportunities

There are a few key innovations in water quality management and technology.

1. **Matching Sources to Uses**. One key management innovation is the recognition that not all water uses require the same water quality. Rather, water of varying qualities can be effectively used for specific and appropriate needs.
2. **Improvements in Contaminant Detection**. There have been significant advancements in contaminant detection both in thresholds detectable and in the timeliness of water testing processes.
3. **Expanded Use** of water treatment technology innovations. (See section 4.3) These innovations offer new options for managing all phases of the water use cycle.

Matching Sources to Uses

Traditionally, water often is treated to higher standards than required for the type of actual use of the water (e.g., use of potable water for landscape irrigation). The recent innovation occurring here is the acknowledgement that not all water uses require the same water quality; leveraging new technologies and techniques, water can be treated to standards aligned for specific uses, and changes in distribution infrastructure and recycling practices can enable greater reuse of wastewater for non-potable applications such as irrigation, reducing overall water use and saving money from reduced treatment costs.

One application of this innovation occurs in agriculture. Agricultural water managers can match water of higher levels of salinity to specific crops such as sugar beets[61] that can tolerate salinity-laden water, while preserving lower salinity water for more sensitive crops such as avocados[62] or dry beans and certain other crops grown in the Sacramento-San Joaquin Delta.[63] Additionally, in conjunctive use areas, high-quality surface-water can be used to periodically “flush” salts out of the rootzone, where the predominant water source is groundwater with elevated salinity levels.

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[61] V. Chinnusamy and J-K. Zhu, “Stress signaling and mechanisms of plant salt tolerance,” Genetic engineering 02/2006; 27:141-77. DOI:10.1007/0-387-25856-6_9 .

[62] California Department of Water Resources. “Chapter 16: Matching Water Quality to Use.” California Water Plan – 2009 Update. Volume 2: Resource Management Strategies. 2009.

[63] G. Hoffman, “Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta, Final Report” (California Environmental Protection Agency, State Water Resources Control Board) January 5, 2010.

Additionally, in urban settings, the increases in water reuse and recycling programs reflects this shift in thinking towards matching sources to uses. At the municipal level, “purple pipe” recycled water systems are emerging to deliver water for non-potable demands such as irrigation, toilet and urinal flushing, or for industrial cooling. At the residential level, rainwater harvesting and other direct reuse programs such as “Laundry to Landscape,” where wastewater from clothes washers is diverted directly to landscape irrigation, are increasingly supported by incentives and rebates and is carried out in accordance with water quality protection directives.

The more effective matching of sources to use in California, whether groundwater or surface water, requires basin plans to be effectively and routinely updated, as required by the Federal Clean Water Act (CWA), to reflect the current beneficial uses and water quality objectives throughout each basin. Basin plans are a regulatory instrument required by the Federal CWA and they are the backbone of regulatory and other actions to protect water quality. Though mandated by both the Federal CWA and the California Water Code, the required, periodic (triennial), and effective updating of basin plans has been a meager effort at best since the passage of the Federal CWA in 1972 due to lack of the necessary, dedicated resources.

Improvements in Contaminant Detection

There have been many advances in contaminant detection due to both the incorporation of new technologies, as well as the integration of these technologies with data transmittal and software-management solutions. The primary innovations are a reduction of the turnaround time to identify contaminants, and improvements in the thresholds achievable by detection systems.

Real-time or Near-Real-time Detection

Traditional water-quality testing required that samples be sent to external labs with results delivered days to weeks after sampling; under this system, by the time contaminated water is detected, it has usually already been distributed and used throughout its network. New sampling methods, technologies, and software can now perform analysis in real-time or near-real-time for some contaminants and operationally important parameters (e.g. pH; temperature; dissolved oxygen; salinity; inorganics such as nitrate and nitrite, and total organic carbon), improving response time to reduce distribution of contaminated water. Many detection systems are able to measure samples in 15-minute increments, with field analysis and continuous monitoring capabilities available for water managers as part of system monitoring solutions offered by a number of established and start-up companies throughout the private sector.

Accurate Detection at Lower Thresholds

There are a number of different technologies in development for detection of very low contaminant concentrations including bioluminescent bacteria, microbial biosensors, algae detection, light-based water-refraction analysis, and others. Successful development of these or other technologies that provide contaminant detection at quantifiable limits at or below contaminant public health goals will enable water managers to more accurately and quickly detect contaminants, allowing greater effectiveness in overall water-quality management.

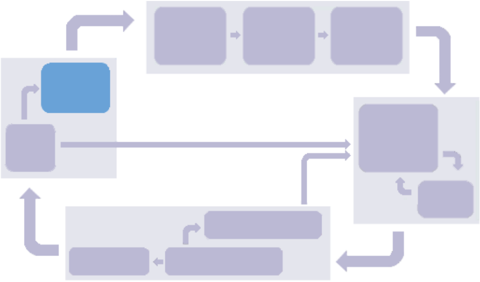
Recommendations

1. **Support Expanded Source-Use Matching**. While important advancements have been made in matching sources to uses, significant opportunities remain to incorporate recycled water programs for agricultural, residential, and municipal applications.
2. **Encourage Use of Rapid Detection Solutions**. Increased use of real-time or near-real-time detection can reduce incidences of the distribution and use of contaminated water. Often rapid-detection solutions can be used in conjunction with traditional testing to provide early-warning contaminant detection and response.
3. **Update basin plans (a regulatory instrument) on a triennial basis to fully incorporate current beneficial and water-quality objectives** for each sub-basin of each water basin in California.
4. **Invest in programs to promote water reuse** and to address the “toilet-to-tap” perception expressed by many individuals as a reason for being opposed to reusing, indirectly or directly, wastewater treated to meet the standards for its intended use, this use being a wide spectrum of uses including direct potable reuse.

4. Sector-Specific Technologies and Innovation Opportunities

Following are assessments of technologies that are applicable primarily to a limited portion of the second-tier water-cycle categories.

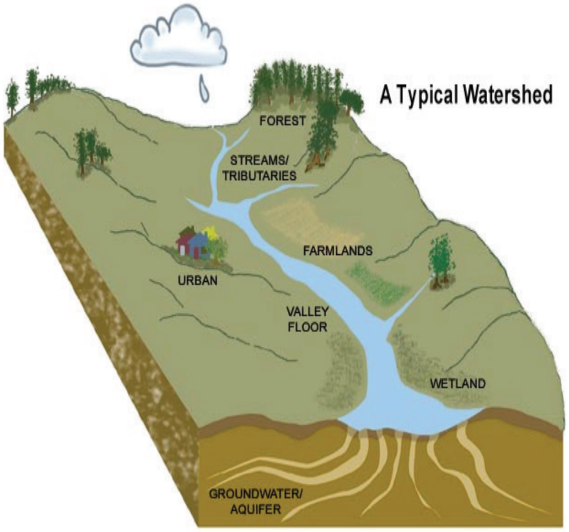
4.1 Watershed Management



Definition

Watershed management refers to actions taken that are intended to optimize the performance of a watershed to meet diverse environmental and human needs. According to the U.S. Environmental Protection Agency, “A watershed approach is the most effective framework to address today’s water resource challenges.”[64] A watershed is defined by the EPA as “an area of land where all of the water that is under or drains off of it goes into the same place.”[65] Figure 19 below depicts a simplified watershed, usually bounded by ridgelines that define the flow of water across land and draining underground into a common body of water such as a lake, river, ocean or ground water basin. Watersheds are urban as well as rural. Watershed health and performance is a function of the many basic physical, chemical, and biological elements of a system that include the “... hydrologic cycle, nutrient and carbon cycling, energy flows and transfer, soil and geologic characteristics, plant and animal ecology and the role of flood, fire and other large-scale disturbance.”[66]

Figure 19. Simplified watershed.



Overview

Throughout California and the rest of the United States, many watersheds have been damaged by a variety of human activities such as extensive road and trail construction, excessive logging, stream diversions, and the overgrazing of livestock. Additionally, the impacts of climate change often alter natural ecosystem dynamics, further threatening watersheds. Watershed management plans and practices present opportunities to improve and restore watersheds to their natural state, improving both the quantity and quality of the water that passes through them en route to other downstream uses. Some watershed management activities, such as flood protection, restoring riparian areas and the fuel management of forests, provide improvements primarily in water quality, while activities such as meadow and forest restoration can increase the quantity of water captured by the watershed. Watershed management strategies in both urban and rural areas can provide both water supply and water-quality benefits.

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[64] US EPA at: http://water.epa.gov/type/watersheds/approach.cfm

[65] “What is a Watershed?” United States Environmental Protection Agency. http://water.epa.gov/type/watersheds/whatis.cfm.

[66] EPA, op.cit.

Innovation Opportunities

A watershed management discussion should address both a public-works approach focused on policy, regulatory and funding issues integral to watershed management, and a science-based approach focused on technology innovation that can further enhance the management of a watershed. There have been innovations along both fronts of watershed management, and the integration of policy and technology provides opportunities for management to have the greatest impact.

1. **Increasing Sophistication of Watershed Planning**. A number of watershed planning guides and models have been made available to assist states and regions in their watershed planning. Their increasing use of data has added complexity to watershed modeling and can provide more realistic depictions of watershed management benefits.
2. **Payments for Watershed and Ecosystem Services**. There have been recent developments in programs that offer incentive payments to farmers and landowners in exchange for the management of their property to provide broader ecosystem and/or watershed benefits.
3. **Emergence of Low-Impact Development**. Low-Impact Development (LID) incorporates key facets of responsible watershed management into land-use and development plans, reducing the watershed impact of new and existing development projects.
4. **Flood Protection, Floodplain Restoration and Stormwater Capture.** Strategies such as levee setback and runoff management provide opportunities to improve wildlife habitats, air and water quality, while also facilitating greater storage and groundwater recharge.
5. **Stakeholder Involvement.** Involve stakeholders at all stages of the process.
6. **Indicators/Report cards.** Metrics and indicators help establish a foundation for action. The use of indicators and metrics to identify and track status and trends over time should be included.

Increasing Sophistication of Watershed Planning

There have been a number of recent advances in watershed planning to disseminate best practices taking advantage, for example, of more sophisticated modeling techniques to provide more accurate watershed data. Additionally, successful implementation of watershed management plans provides numerous ecosystem benefits while also serving as examples for future planning efforts. In urban applications, important social and economic benefits in addition to environmental gains are available.[67] Three examples are noted here.

EPA Watershed Handbook

The U.S. Environmental Protection Agency (EPA) advocates watershed management throughout the country, and has taken a leadership role in outlining watershed management best practices, as well as providing model-specific guides for watershed practitioners. The EPA's "Handbook for Developing Watershed Plans to Restore and Protect Our Waters" outlines the watershed planning process in detail, provides technical guidelines and assistance on multidimensional watershed models such as the Better Assessment Science Integrating Point & Non-point Sources (BASINS) model, and consolidates EPA, USGS, and other water databases for use by watershed planners nationwide.

Figure 20. Aerial Photograph of Bear Valley Meadow, showing the benefits of meadow restoration.

Sierra Nevada Mountain Meadow Restoration

The Sierra Nevada Mountains are an important component of California's freshwater supply, as the annual snowmelt supplies water throughout the state. Mountain meadows, though they represent only a tiny fraction of mountain land, play a critical

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[67] See for example the Center for Watershed Health in Southern California at http://watershedhealth.org/Default.aspx#

role in maintaining healthy watersheds and mitigating flood events. Many mountain meadows have been degraded over time due to overgrazing, stream diversions, and extensive road and trail construction. Efforts are underway to restore mountain meadows throughout the Sierras. Healthy meadows filter and store water, improving water quality and stream flow while also providing numerous fish and wildlife habitat benefits. The Bear Valley Meadow (Figure 20) situated between the Sacramento Valley and Lake Tahoe and owned by PG&E as part of the Drum-Spaulding hydroelectric project, offers an opportunity to showcase the benefits of meadow restoration. Led by American Rivers, meadow restoration efforts are underway using hydrologic analysis to restore the meadow, improve water flows and provide a safe habitat for many endangered species, migratory birds, and numerous wildflowers.

Ranch and Rangeland Watershed Planning

Individual ranches throughout California are increasingly recognizing the benefits of watershed management planning, and are managing their land to benefit watershed and wildlife habitat alongside their traditional ranching land-uses. For example, the Byrne Brothers Ranch in Tulelake, California, has been working with the U.S. Forest Service to develop a pasture system that allows multi-year rotational cattle herding, distributing grazing to mitigate land impacts. Additionally, the Byrne ranch has installed a number of solar-powered wells to facilitate off-stream watering for their livestock, allowing the restoration of key riparian zones within the ranch.[68]

Restoration of Floodplains

Many rivers have become highly modified over time due to human activities of all sorts including mining, particularly in the upper reaches of the watershed, which resulted in direct disturbance to the stream and the introduction of mining debris to streams. Also, extensive use of imported mercury in the Sierra Nevada to recover gold has resulted in mercury being a legacy pollutant found in many Sierra Nevada streams and a significant component of the mercury load found downstream throughout the Sacramento-San Joaquin Delta and San Francisco Bay system. As a result, users of these bodies of water, including fisherpersons and individuals depending on Delta food gathering and fishing for primary subsistence, are at an increased risk of adverse health effects due to significant consumption of methylmercury. This situation can be addressed through several approaches including restoring and operating the Sacramento-San Joaquin Delta and Sacramento Bay system and associated wetlands so that methylmercury formation is minimized to the greatest extent possible.

The restoration of floodplains to these rivers, including the setback of levees protecting the built environment, greatly expands benefits offered by the restored river. These benefits can include providing for wetland development, improving wildlife habitat for aquatic and terrestrial species, increasing recreation opportunities, trapping additional nutrients and sediment, improving air and water quality, and increasing opportunities for water storage, groundwater recharge, and stormwater and flood management.

Urban Watershed Management

Sustainable stormwater management and green infrastructure use natural processes to capture and treat water and manage runoff at either the parcel or neighborhood scale. A good example of innovative approaches is Elmer Avenue and the Elmer Paseo, located in the Sun Valley sub-watershed of the Los Angeles River. The area is at the confluence of runoff from sixty acres of residential land. Because these neighborhoods lacked storm drains, all runoff flowed on the streets. This caused flooding, degraded street surfaces, and increased pollution downstream. These conjoined problems were turned into opportunity through the installation of multi-benefit green infrastructure to reduce runoff and conserve water.

The Elmer Avenue Neighborhood Retrofit Projects capture, treat, and infiltrate runoff from sixty acres using two under-street infiltration galleries, bioswales along the public right-of-way and in the Paseo, permeable surfaces for walkways and driveways, rain gardens in front yards, and rain barrels to utilize and capture water from downspouts, as well as drought-tolerant landscaping and drip irrigation to lower water usage and utility bills. During a year with

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[68] Macon, Dan. “Grazing for Change: Range and Watershed Management Success Stories in California.” California Cattlemen’s Association, pp. 10-12. http://www.carangeland.org/images/Grazing_for_Change.pdf.

average rainfall, these projects will contribute over 13 million gallons of water to critical water supply stored in the San Fernando Groundwater Basin.[69]

Payments for Watershed and Ecosystem Services

A relatively new market-based incentive has emerged where beneficiaries of watershed services pay farmers and landowners for implementing sustainable watershed management on their land. These so-called Payments for Watershed Services (PWS) are a subset of the Payments for Ecosystem Services (PES) approach to broader environmental conservation and management. The rationale behind PWS is that financial incentives can tip the balance for landowners considering multiple uses for their land. Currently, most PWS programs are setup to pay incentives once it is shown that sustainable watershed practices have been adopted; however, advances in data acquisition and monitoring could potentially facilitate the awarding of incentives based on the measured improvements in watershed quality that results.

Mokelumne Watershed Environmental-Benefits Project

Figure 21. The Mokelumne River at Walnut Creek, where a pilot market-based incentive program is being implemented.

The Mokelumne River is important to the environmental and economic health of Northern California, providing water for municipal and agricultural supply, wildlife habitat, energy production, and a variety of recreational activities.[70] The Mokelumne River at Walnut Creek[71] (Figure 21) originates in the Sierra Nevada Mountains and flows through the Central Valley before joining the Sacramento-San Joaquin River Delta. The Mokelumne watershed is piloting a PWS program that will provide financial incentives for landowners along the river who implement conservation practices such as sustainable grazing, riparian habitat restoration, erosion control, and forest restoration and fuels reduction. While this program is still in its design phase, it represents a significant step forward and if implemented effectively, could serve as a model for PWS programs throughout the State.

Emergence of Low Impact Development for Stormwater Management, Floodplain Restoration and Groundwater Recharge

Low-Impact Development (LID) is a sustainable land-development approach that prioritizes stormwater management to capture precipitation as close to its source as possible for groundwater recharge. Applicable to both new development and re-development projects, LID can be effectively used for urban, agricultural, and rural development. Key facets of LID include preserving or recreating natural drainage flows, reducing impervious surfaces, rainwater harvesting, and retaining the natural features and hydrology of the watershed and landscape. Effective LID reduces, controls, and treats runoff, reduces contaminants, and protects water quality and quantity.

There are many redevelopment or retrofit examples of LID throughout California. Common projects include a suite of solutions such as green roofs, rain barrels, permeable paving, or bioretention areas to capture precipitation and reduce runoff. New developments designed according to LID principles seek to retain the natural watershed activities of the site by reducing the disturbance of the land development.

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[69] See http://elmer.watershedhealth.org

[70] Mokelumne Watershed Environmental Benefits Program: Overview and Vision. *Environmental Defense Fund*. http://www.edf.org/sites/default/files/mokelumne-program-description.pdf.

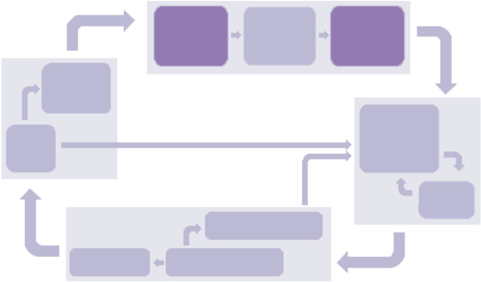
[71] Mokelumne Watershed Environmental Benefits Program: Overview and Vision. *Environmental Defense Fund*. http://www.edf.org/sites/default/files/mokelumne-program-description.pdf.

Recommendations:

Significant opportunities exist for advancing watershed management practices using improved data acquisition, improved database management and access, and enhanced modeling capabilities to support specific actions to help optimize watershed management as part of an overall water supply management program. Accordingly, some specific recommendations that would benefit improved watershed management practices include:

1. **Improve Watershed Data and Performance Modeling.** Improvements in the cost effectiveness of data acquisition and modeling can have significant impacts on watershed planning. Real-time and continuous watershed data would improve scenario planning and analysis capabilities, and detailed surface and groundwater data would help watershed managers more accurately measure runoff and storage capacity within their watersheds
2. **Continue to Encourage LID and Green Infrastructure Retrofits.** LID techniques are effective in managing stormwater, and can have significant positive watershed impacts. A variety of Best Management Practices (BMPs) are being developed to highlight LID successes and quantify the cost and water savings of specific LID techniques. California should consider adopting policies establishing mandatory LID requirements for new construction and redevelopment projects throughout the state.
3. **Increase Groundwater Recharge Opportunities**. Increasing groundwater recharge, through reduced runoff and increasing surface permeability, could improve the health and reliability of California watersheds. Additional research to understand location-specific groundwater age, recharge potential and effective recharge strategies employed throughout the world offers an opportunity to develop and implement best practices throughout California.
4. **Promote Flood Protection and Floodplain Restoration**. In addition to increasing the opportunity for groundwater recharge, floodplain restoration offers other important environmental services that should be implemented including providing for wetland development and substantially increasing habitat for aquatic species, wildlife habitat enhancement,providing a trap for nutrients and sediment, and stormwater and flood management. Innovations to promote in this area include levee setback, as well as policy innovations to restrict development within floodplains.
5. **Explore Additional Watershed and Ecosystem Services Programs**. PWS and PES have begun to be implemented in California, but the incorporation of additional ecosystem services identified by the U.S. Forest Service such as carbon sequestration, erosion control, nutrient cycling, soil formation, and primary productivity could provide benefits for watershed management practices.
6. **Evaluate and Address Mercury Contamination of Water and Sediment**. Mercury is present in many California streams mostly as a result of mercury mining in the Coast Range or historic gold mining practices in the Sierra Nevada; it is found in unsafe concentrations in many fish used as a food source. There are promising opportunities for further research to identify best practices to mitigate the environmental impact of mercury and potentially other contaminants. Key areas of research could focus on strategies to control mercury methylation by managing the aerobic state of ponds and wetlands, as well as seeking opportunities to cost-effectively reclaim mercury from water bodies without significant habitat disruption.

4.2 Extraction, Conveyance, Storage, and Distribution



Definitions

Extraction and Conveyance include the processes and infrastructure developed to extract water from natural sources and transport it to point of use or water treatment facilities. Extraction includes groundwater pumping and diversion of rivers and streams, while conveyance occurs through California's sophisticated water transportation infrastructure, including the State Water Project, the Central Valley Project, and the Colorado River Aqueduct.

Water Storage is required throughout the pre-use management phase of the water use cycle and oftentimes prior to final disposal of wastewater. Storage solutions include short-term storage to satisfy near-term water demand, as well as long-term storage to collect water during dry seasons for use during droughts and dry seasons.

Water Distribution includes the water transportation infrastructure to move water from the storage location or treatment facility to the point of consumption by water users.

Overview

Water extraction, conveyance, storage, and distribution processes are key steps in the water use cycle. They enable water to reach treatment facilities, and also transport treated water to the point of use. Water and energy inefficiencies throughout these processes can result in significant costs; innovations in the technologies and techniques required to extract, move, and store water can thus result in significant savings statewide.

Innovation Opportunities

There are a number of important innovations, some of which are listed below, that have the potential to significantly improve extraction, conveyance, and distribution processes in California.

1. **Variable-Frequency Drive Pumps (Extraction, Various)**. Variable-Frequency Drive (VFD) pumps enable water managers to tailor pumping requirements to specific volume and flow-rate demands.
2. **In-Conduit Hydropower (Conveyance, Distribution)**. Innovations in the ability to produce hydropower from existing canals and other conveyance infrastructure offer the potential of a new energy source, as well as opportunities for infrastructure components to go off the grid.
3. **Leak Identification and Mitigation (Distribution)**. Advancements in leak-detection technologies, including acoustic, robotic, and data analytics-based detection methods, could allow rapid detection and reduce the volume of non-revenue water lost to inefficiencies and leakages. This includes both closed conduit and open channel conveyance.
4. **Trenchless Infrastructure Repair (Distribution)**. Innovations in trenchless pipe lining solutions enable quick leak repairs without the costs of digging up entire pipelines.
5. **Groundwater Banking Potential (Storage).** The increased use of groundwater banking offers opportunities to expand storage capacity.
6. **Canal Lining to Reduce Seepage (Conveyance)**. Earthen canals throughout the conveyance infrastructure allow water to seep into the ground during transportation, reducing the volume of water available for urban and other uses. Lining canals, either with concrete, PVC, or other materials, greatly reduces seepage and can represent an additional water supply for urban users when groundwater recharge is NOT desired.
7. **Emergence of Water Markets and Water Transfers as Additional Supply Options.** Water transfers have emerged as a new option to acquire additional water supplies. Markets have emerged for both short-term and long-term/permanent transfers.

8. **Modernizing Groundwater Basin Management to Allow Credit for Stormwater Capture.** Agencies and others should receive credit for stormwater infiltration.

Variable-Frequency Drive Pumps

An important innovation in water extraction is the development of variable-frequency drive (VFD) pumps. The advantage of VFD pumps is primarily in energy savings, as the power output of the pumps can be tailored specifically to the volume, flow rate, and demand of the water being pumped.[72] VFD pumps have many applications throughout the water use cycle, including use in irrigation pumping, water distribution, and wastewater management when systems have highly variable demands.

In-Conduit Hydropower

California has developed a sophisticated infrastructure to transport water from the point of extraction from natural sources to water treatment facilities across the state; this infrastructure includes the State Water Project, Central Valley Project, and many other local and regional projects. While this infrastructure leverages a number of pumping stations to lift water up and over high elevation points along its path, for the majority of its route, water flows downhill via gravity.

Pressure Reduction

The gravity flow results in an accumulation of water pressure along the infrastructure; while the traditional practice has relied on pressure-reduction valves (PRVs) to alleviate the pressure buildup, an innovation opportunity exists to either capture the excess pressure and convert it to energy, or to replace the PRV with a turbine that performs the functions of the PRV while producing energy as well.

Figure 22. San Diego's Rancho Penasquitos Pressure-Control Facility

SDCWA Rancho Penasquitos Facility. One example of a pressure-based hydro facility is the San Diego County Water Authority's (SDCWA) Rancho Penasquitos Pressure-Control Hydroelectric Facility (Figure 22).[73] *This facility provides SDCWA with greater flexibility for managing water throughout its network, and is equipped with a 4.5 megawatt (MW) turbine capable of producing enough electricity to power approximately 5,000 homes.*[74]

Low-Power Energy Generation

In addition to PRV energy generation, small or micro-hydro generators can be installed along canals, pipes, and rivers to generate sufficient energy to power devices throughout the infrastructure network such as sensors, probes, and data communication devices that measure water flows.[75] The expansion of these micro-hydro generators would allow these systems to be run predominantly off the grid.

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[72] California Energy Commission, "Variable Drive Pumps" http://www.energy.ca.gov/process/pubs_list.html#water

[73] Photo from San Diego County Water Authority Website, http://www.sdcwa.org/pressure-controlhydroelectric-facility

[74] "Rancho Penasquitos Pressure Control Hydroelectric Facility." *National Hydropower Association*. Outstanding Stewards of America's Water Award, 2008. http://www.hydro.org/about-nha/awards/osaw/2008-winners/san-diego-county-water-authority/. http://www.sdcwa.org/pressure-controlhydroelectric-facility.

[75] One example here is Hydrospin, an Israeli company developing in-conduit microgenerators.

Leak Identification and Mitigation

The key focus of innovation in water distribution is the detection, mitigation, and repair of system leaks. Water leaks lead to wasted or unaccounted for water, often referred to as "non-revenue water" (NRW); the amount of NRW in a system can be significant, with some estimates as high as 30% of system water pumped but not paid for. Distribution-management systems are available to water utilities that can measure water flows and water pressure over time to detect abnormalities that may signal a leak within the system. Leak-mitigation systems with advanced sensors and metering technology automatically shut off water if leaks are detected, and can send text, email, or other automated notifications to water managers.

Leak-repair innovations include unmanned inspection robots that can navigate distribution infrastructure, gathering 360-degree video and GPS coordinates for digital transmittal to data analysis software for decision support.[76]

Trenchless Repair

Traditionally, repairing pipeline breakages required long trenches to be built so that repair crews could access the pipeline, assess damage, and repair the pipe; this excavation is an expensive and time intensive activity, often disrupting roadways. However, a variety of new trenchless repair systems offer significant savings over traditional trench repairs. Technologies are emerging to replace pipe lining to repair leaks from manhole to manhole, eliminating the need to dig up entire pipelines. The innovation is in a resin lining that is applied and then hardens in place to re-line broken or leaking pipes; these linings can be applied either by hand for shorter-interval pipes, or by remote controlled robotic sprayers.[77] Trenchless repair helps reduce NRW in a distribution system, reducing the time and expense of leak repairs.

Groundwater Banking

Groundwater banking is an innovation that enables water districts and private enterprises to deliberately store water in aquifers during wet years for extraction and use during dry years. Water is physically diverted to aquifers through seepage pits and/or pumping. (This presents an opportunity for additional water security, as water resources can be stored locally and extracted upon demand. While this capability is somewhat limited by geology and connections to existing conveyance infrastructure within California, groundwater banking has been most widely used by Kern County as well as the Metropolitan Water District of Southern California (MWDSC). The Kern County groundwater bank can store up to 5.7 MAF of water, and has extracted over 3.4 MAF of water from its groundwater bank since 1978.[78] In Southern California, MWDSC and its member agencies estimate that there could be over 3.2 MAF available for groundwater banking across its service area.[79] MWDSC has withdrawn groundwater from the Kern County banks, as well as additional basins in the Coachella and Mojave Basins.[80]

Canal Lining

The California conveyance infrastructure is composed of a vast network of canals used to transport water long distances from its source to point of use. Traditional earthen canals can perform this task, but a significant percentage of water is lost along the way due to water seeping into the ground. In many areas, such as the eastern side of the San Joaquin Valley water seepage from canals provide important recharge to groundwater basins historically provided by the free flow of local streams and rivers. However, by lining canals with impermeable materials, seepage can be drastically reduced, and water managers have additional water supplies available for use. Any proposed

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[76] E.g., Redzone Robotics (http://redzone.com/).

[77] Liquiforce, Acuro are 2 examples of this technology.

[78] "Kern County Water Agency Reflects on Importance of Groundwater Banking for Future Planning and Habitat Conservation." Kern County Water Agency. June 7, 2011. http://www.kcwa.com/Documents/Press%20Releases/2011/Groundwater%20Banking%20%20HCP%20PR.pdf.

[79] "Groundwater Assessment Study: A Status Report on the Use of Groundwater in the Service Area of the Metropolitan Water District of Southern California." Metropolitan Water District of Southern California, Report Number 1308, September 2007. pp. III-17 – III-20. http://www.mwdh2o.com/mwdh2o/pages/yourwater/supply/groundwater/PDFs/GARChapter3.pdf.

[80] Hanak, Ellen. Stryjewski, Elizabeth. "California's Water Market, By the Numbers: Update 2012." Public Policy Institute of California, November 2012. pp. 36-40. http://www.ppic.org/main/publication.asp?i=1041

lining of canals must always consider third-party impacts. The traditional canal lining material has been concrete, but lighter, less costly alternatives such as PVC and other plastics are being explored as potential lining materials.

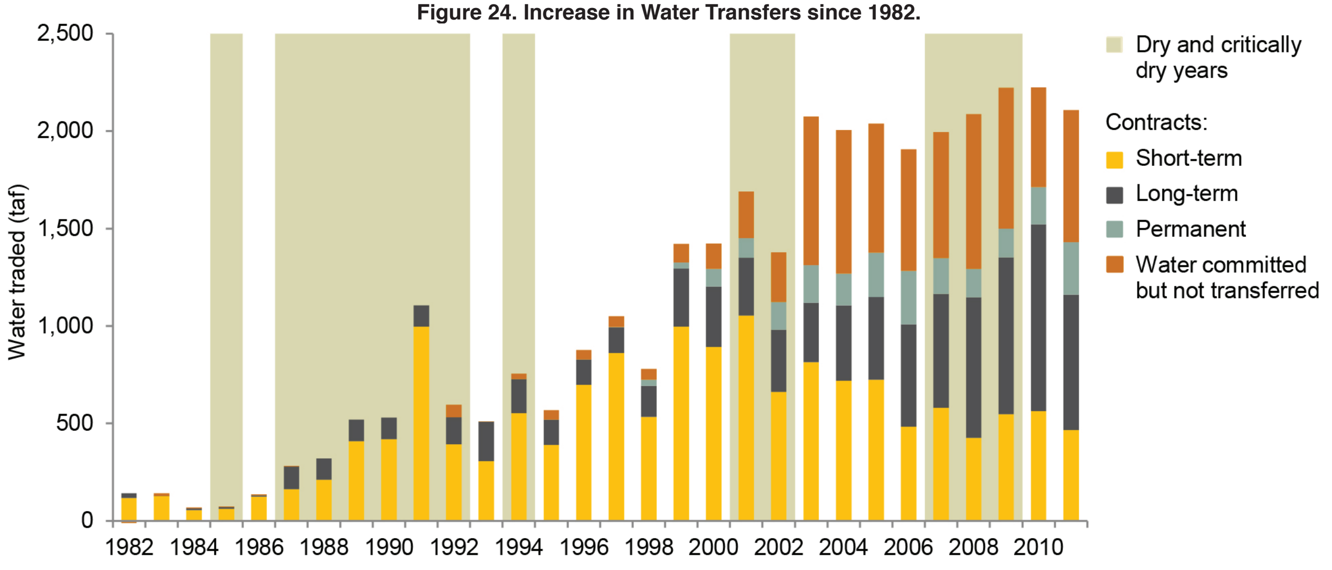
Figure 23. All-American Canal Lining Project.

Coachella and All-American Canal Lining Projects Southern California has benefited from two recently completed canal lining projects on the Coachella and All-American Canals (Figure 23).[81] *These canals transport water from the Colorado River to the Coachella and Imperial Valleys, together representing over 200 miles of conveyance infrastructure.*[82] *Parallel concrete-lined canals were constructed alongside 23 miles of the All-American Canal and 35 miles of the Coachella Canal, resulting in additional water conservation of 93,700 acre-feet: 67,700 acre-feet from the All-American Canal and 26,000 acre-feet from the Coachella Canal. Per the 2003 agreement, the San Diego County Water Authority receives 77,700 acre-feet of water, or about 13% of its 2012 water supply.*[83]

Emergence of Water Markets and Water Transfers as Additional Supply Option

Water transfers have emerged as a new option to acquire additional water supplies. A water transfer is defined as a voluntary change in the way water is distributed among users, often through a temporary or permanent exchange of water rights.[84] Markets have emerged for both short-term and long-term/permanent transfers. Transfers have increased steadily over the last 30 years (Figure 24), with long-term and permanent transfers becoming increasingly common.[85]

Figure 24. Increase in Water Transfers since 1982.



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[81] Photo from Coffman Specialties Website: http://www.coffmanspecialties.com/projects/all-american-canal/.

[82] "Coachella Canal and All-American Canal Lining Projects." CA Department of Water Resources. http://www.dpla.water.ca.gov/sd/environment/canal_linings.html.

[83] "Canal Lining Projects." San Diego County Water Authority. Web. http://www.sdcwa.org/sites/default/files/files/publications/canallining-fs.pdf.

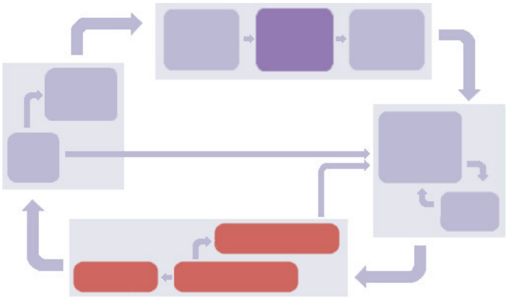
[84] CA State Water Plan, Volume 2, Chapter 7 (2009.) – [This may be updated to a different section in Update 2013.]

[85] PPIC Water Market by the Numbers November 2012.

Recommendations

1. **Consider changing distributed-generation regulations to encourage additional hydropower solutions.** Distributed-generation regulations should be structured such that incentives are aligned to encourage additional generation such as in-conduit hydropower solutions.
2. **Strengthen local groundwater management.** While local groundwater management has achieved some recent progress, more comprehensive groundwater basin management that manages withdrawals by all users could improve the reliability of groundwater banking in providing dry-year water supply throughout California.
3. Where practical **facilitate groundwater recharge** through decentralized and centralized designs and strategies.
4. **Support expansion of water transfers and markets throughout California** with appropriate consideration of all costs and benefits including third parties and the environment.
5. **Develop conduits with low-friction factors** (minimize energy dissipation) and resistance to corrosion and the detection, mitigation, and repair of system leaks.
6. **Expand focus on leak detection and mitigation** in all steps of the water cycle to reduce losses and improve efficiency.

4.3 Water/Wastewater Treatment



Definition

Water treatment is the employment of one or more of a number of physical, chemical, and/or biological processes to render a feed stream suitable for its intended use whether that use is for domestic, agricultural, public health, manufacturing, or recreational purposes.

Overview

Today, the line is increasingly blurred between the categorization of water and wastewater treatment due to stricter regulatory standards for acceptable concentrations of both anthropogenic and natural constituents in drinking water. In particular, the food processing and electronics industries require very high-quality water to meet their quality standards. Further, all used water, whether the discharge originates in a home, industrial facility, or from an agricultural field, may become someone's water supply unless the discharge is into seawater in which case the water quality of the discharge must protect environmental values whether in the marine or inland environments.

While water/wastewater treatment technologies include a very large number of specific physical, chemical and biological processes[86] which we address in general, the processes we are focusing on in detail here have been determined to require further development to address the current most critical water quality problems in California. These processes include:

1. Membrane filtration for salinity management with a focus on marine and brackish waters and reused water as the feed stream, and the disposal of membrane filtration-derived brine stream into a marine environment where environmentally safe, or, as is normal for brine streams resulting from the treatment of brine streams in inland areas, the management of the brine stream in a manner that does not result in environmental degradation;

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[86] Water Treatment: Principles and Design, 3rd ed., Crittenden, J.C., R. Trussel, D.W. Hand, K.J. Howe, and G. Tchobanoglous, MWH Global, 2012; Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management, EPA Report, March 2013; Water Treatment Plant Design, 5th ed., Randtke, S.J. and M.B. Horsley, American Society of Civil Engineers, 2012.

2. Biological treatment with focuses on the treatment of domestic wastewater using constructed wetlands, and the use of biological contactors for removing nitrate from groundwater to be used for drinking water and from treated wastewater prior to its discharge or reuse; and the biological digestion of biosolids both for energy production and the modification of the biological residuals to products suitable materials for use as a fertilizer;
3. Ion exchange and related processes for the removal of nitrates and other contaminants of concern from source waters being treated for use as drinking water, and as a viable treatment process for some industrial wastewaters and as a pretreatment process for other salt concentration technologies (e.g., reverse osmosis); and,
4. Disinfection processes for the inactivation of pathogens in water prior to its use as drinking water and prior to its discharge after any use for which it can be contaminated with pathogens. This should be carried out without the production of toxic disinfection by-products.

California's growing water demand must be satisfied in part by both rigorous water-conservation and water recycling requirements. Water recycling can satisfy some of California's water needs with most of the recycled water being used for nonpotable uses. Nevertheless, the recycling of water for reuse generally requires additional water treatment with the water-quality goals being dependent upon the use intended for the recycled water.

The State Water Resources Control Board's (SWRCB) adopted policy on water recycling[87] presents considerable detail regarding numerous regulatory requirements for water recycling in addition to the need of an effective recycling program for California as an important step to promote water supply sustainability. Importantly, the SWRCB policy sets the very definitive goal shown below:

> *We declare our independence from relying on the vagaries of annual precipitation and move towards sustainable management of surface waters and groundwater, together with enhanced water conservation, water reuse and the use of stormwater.*

Enmeshed in any consideration of water recycling is the issue of compounds of interest generally found in very low concentrations in some of our water supplies. These compounds, Endocrine Disrupting Compounds (EDCs) and Pharmaceuticals and Personal Care Products (PPCPs) currently are largely unregulated but considerable investigation is now underway focused on their public health and environmental impacts.

Other sources of water are becoming increasingly important to satisfy California's present and future water needs: saline marine waters and brackish inland waters with the product water to be used for multiple beneficial uses, and oftentimes formerly high quality groundwater now contaminated with nutrients (e.g., nitrates) from agricultural practices that must be treated for nitrate removal prior to its beneficial use for drinking water. Nitrate contamination of groundwater is a very serious issue, especially for the many disadvantaged communities in California who do not have the financial resources necessary to address this serious public health problem.

Figure 25. Salinity accumulation in evaporation pond in the San Joaquin Valley.

Salinity Management

Salinity management is an important part of California's water management portfolio today. The State Water Resources Control Board has mandated that all California water basin plans, a planning and action document required by the Federal CWA and the California Water Code, be updated with viable salinity management plans by 2014. This requirement is particularly critical for California's Central Valley where the San Joaquin Valley portion of the Central Valley receives in excess of one million tons of salt annually (Figure 25).

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[87] Recycled Water Policy, SWRCB, http://www.waterboards.ca.gov/water_issues/programs/water_recycling_policy/docs/recycledwaterpolicy_approved.pdf, 2013

This increase of salinity in San Joaquin Valley soils and groundwater adversely impacts production from irrigated agriculture, and even changes the types of crops that can be grown over time in some areas. Salinity must be managed if the San Joaquin Valley is to avoid progressing into desertification, a condition that has occurred repeatedly since ancient times whenever irrigated agriculture has been practiced without effective salinity management.

Using increasingly more saline water for domestic, commercial, industrial and agriculture needs results in increasing energy and other process costs for treating the saline water where an alternative water source of better quality is not available. Likewise, waters transported from the Sacramento and San Joaquin water basins to Southern California and elsewhere are experiencing increasing levels of salinity over time, a factor that can result in additional treatment costs.

Nitrate treatment

Biological treatment to remove nitrates from drinking water sources can take the form of:

1. Fixed-bed or fluid-bed reactor vessels in which indigenous bacteria present in the source water colonize on the reactor media. These organisms, gaining energy from a carbon source such as acetic acid that is fed to the reactor vessel, can effectively remove the nitrate from the source water converting it to nitrogen gas.
2. The surface of membranes contacted by the source water containing nitrate and through hydrogen gas permeates and enters the water stream thereby providing an energy source for use by the indigenous bacteria that have colonized the surface of the membrane. These organisms on the surface of the membrane and in contact with the water stream can effectively convert the nitrate in the water stream to nitrogen gas.

In both of the above treatment processes the water typically requires minimally both filtration and disinfection before it can be introduced to a drinking water distribution system.

Wastewater treatment facilities are normally constructed using concrete and steel, or take the shape of ponds for the treatment of wastewater where sufficient available land exists such as for small communities in rural areas. However, recent innovation has led to the use of constructed wetlands for wastewater treatment thereby resulting, not only in the effective and economical treatment of wastewater, but for the addition of a critical beneficial use, wetlands for the support of wildlife. Constructed wetlands in some locations provide a low-technology and low-energy approach for utilizing physical and chemical processes for trapping suspended solids and providing an environment in which pollutants, including inorganic and organic nitrogen forms, are converted to plant material, absorbed by wetland sediment, or enter the atmosphere.

Anaerobic digesters are commonly used to treat the biological solids resulting from domestic and industrial wastewater, and they are increasingly being used to treat manure from confined animal facility operations (CAFOs). The most common CAFOs in California are dairies. Sludge (digestate) from all anaerobic digesters treating biosolids contains large amounts of organic nitrogen that is a significant threat to groundwater when applied to plants or when applied to land as a disposal operation for the sludge. Development is required to process the organic sludge so that a large amount of the organic nitrogen is in the form of inorganic nitrogen, a form readily available for plant growth, and is stable permitting its storage until it is needed for fertilization. This development for sludge from anaerobic digesters would produce a product that could displace some synthetic fertilizer with a savings in the energy required for the production of the synthetic fertilizer.

Disinfection

A critical part of the water/wastewater treatment train is the disinfection process. Oxidants such as chlorine and ozone have widespread use and the technology for dispersing these into the water stream has been well developed. However, the use of oxidants when the target water stream contains the precursors for trihalomethane and certain other toxic disinfection by-products (DBPs) can result in the formation of one or more of these DBPs in excess of their Maximum Contaminant Limit (MCL). Chlorine as hypochlorous acid, as hypochlorite, or as a chloramine can result in deleterious environmental impacts to aquatic life forms. For these reasons continued development is required for processes such as the use of ultraviolet light and chemicals whose use does not result in public health and/or environmental issues either directly or through secondary products resulting from their use.

Innovation Opportunities

Membrane-Based Water Treatment

Membrane technologies filter water by passing it through a porous material. Membranes come in a wide range of pore sizes and compositions depending on the desired contaminate to be filtered, and different types of membranes are often used in combination to achieve a particular water treatment objective. They range from membranes capable of removing only relatively large particulate material and algae to those capable of removing dissolved compounds such as various salts. Types of membrane filters - from largest particle size to smallest - include microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), electrodialysis reversal (EDR), and reverse osmosis (RO).

There are actually three separate treatment contexts in which membrane technology is typically used for water treatment, and each possesses distinct performance and situational requirements and constraints. These include microfiltration and ultrafiltration for removal of particulate/colloidal matter and even some dissolved species when combined with coagulation. The above are also utilized as pretreatment of feed water for membrane desalination via NF or RO technologies. RO membranes are used primarily for seawater desalination and for water reuse (e.g., producing a reusable water having a high beneficial use from municipal and other wastewaters), while both NF and RO are used for brackish water desalination (typically inland applications), and water reuse (e.g., producing a reusable water having a high beneficial use from municipal and other wastewaters). RO is preferred in water reuse applications where it is desired to provide barrier protection against the passage of bacteria and viruses.

Continuing research is needed on membrane separation technologies focused on making membranes more robust: more durable, capable of handling wider ranges and combinations of contaminants, more resistant to fouling, more resistant to disinfectants, and having a longer operational life. Having higher-permeability membranes would lead to reduced treatment-plant footprint and thus lower capital cost. However, operation at higher water flux would require more effective fouling control. There are also opportunities for improving membrane process integration and for developing optimal plant configuration that would enable lower energy consumption over a wide range of plant sizes.

The need for more adaptable control systems is essential, particularly for the treatment of brackish and reused water where contaminants may vary significantly in type and concentration over time, and where water-capacity demand and energy cost may also vary. Such control systems would also significantly benefit from better information about the water being treated with this information being obtained by the use of *in situ* sensors., soft sensors and advanced control technologies. Treatment-facility use of renewable energy such as solar technology or locally available biofuels could also reduce overall energy demands on the state.

In part, the application of membrane filtration in California, particularly the management of reverse-osmosis brine streams resulting from the membrane filtration of seawater, could be refined based on research conducted for water treatment facilities in operation in the United States outside of California and overseas. Overall, application of membrane treatment technologies in California, and the U.S. in general, lag significantly behind other areas of the world such as Israel, countries in the Arabian Gulf and Mediterranean, and Australia, which face even more restricted water resources than California.[88] Israel, for example, currently produces about 40% of its potable water from seawater desalination, and recycles over 80% of its municipal wastewater, compared to just 13% for California.[89]

Additionally, the disposal of brine streams in inland areas is a problem that currently has few viable alternatives. While one alternative is the creation of brine disposal areas where water with high salinity is discharged into managed, engineered ponds, this requires considerable land and the ponds must be constructed with liners and systems to detect leakage through the liners if the soil properties are such that any leakage would result in the degradation

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[88] Brenner, A., 2012. “Limitations and Challenges of Wastewater Reuse in Israel,” Clean Soil and Safe Water: NATO Science for Peace and Security Series C: Environmental Security, pp. 3-9.

[89] Newton, D., Balgobin, D., & Badyal, D. (State Water Resources Control Board) and Mills, R., Pezzetti, T., & Ross, H.M. (Department of Water Resources). Results, Challenges, and Future Approaches to California’s Municipal Wastewater Recycling Survey. (2011)

Figure 26. Membrane bank in a desalination plant.

of underlying groundwater. Therefore, it is imperative to develop membrane desalination technologies (Figure 26) that enable high recovery so as to minimize the volume of generated brine while also allowing harvesting of product salts from the brine stream.

Biological-Treatment Technologies

Biological-treatment technologies include those processes carried out in a reactor (an enclosed system), in a constructed environment (e.g., engineered wetlands) or *in situ* and in an oxic or anoxic environment depending upon process requirements for the transformation of target pollutants to other entities that are not environmental pollutants (i.e., the transformation of the nitrate ion in source water for drinking water to nitrogen gas is an important nitrogen treatment goal for California). The use of either fixed or fluid-bed reactors for the removal of excessive concentrations of nitrate from water that is to be used as drinking water is an evolving technology that requires an electron source such as acetic acid that is added to the reactor.

Biological water treatment is best viewed not as a stand-alone solution but as one component of an integrated system, often in conjunction with membrane-based treatment systems.

Effective wastewater recycling is challenging because it requires multiple treatment systems operating in conjunction with each other. The development of improved biological filtration and better use of local, low-energy treatment options make this potentially more feasible. In many cases, biological treatment is able to convert substances in water from being either hazardous or difficult to remove via conventional means to less harmful or more easily filtered substances. Examples are 1) the conversion of selenate in water to elemental selenium that can be removed with coarse filtration, and 2) the use of engineered wetlands for the treatment of domestic and certain industrial wastes.

For some applications naturally occurring bacteria can be used to effectively treat some synthetic and naturally occurring organic compounds and some inorganics including perchlorate and nitrate with the resulting chemical products having little or no threat to human health or the environment. Oftentimes, as in the removal of nitrate from a drinking-water source using a biological contactor, the biologically treated water may be placed directly in the distribution system after filtration and disinfection following process approval by the California Department of Public Health. A relatively small amount of organic sludge must be periodically disposed.

Biosolids resulting from the treatment of domestic and certain industrial wastewaters are typically treated in a digester (Figure 27) using an anaerobic process, particularly if the production of methane is desired with the methane being used to offset in-plant energy needs or to provide fuel for electrical generation. Biosolids from confined animal operations also are increasingly being treated in anaerobic digesters. The primary products from anaerobic digestion are gas (hydrogen sulfide, carbon dioxide and methane with the latter being about 70% of the total volume) and digested sludge consisting of stabilized organic solids. The stabilized organic solids typically would contain no heavy metals if they are from confined animal operations and, therefore, should be an important source of fertilizer for crops. However, most of the

Figure 27. Digesters for treating animal wastes.

nitrogen introduced into the digester is comprised primarily of organic nitrogen and it typically remains in this form after digestion. This makes the digestate a suboptimal fertilizer because after application to plants the organic nitrogen fraction mineralizes slowly to inorganic nitrogen, which is much more easily utilized by plants in a phase requiring nutrients. Organic nitrogen is poorly assimilated in its organic form in the root zone when nutrients are taken up by plants for growth. Instead, a substantial fraction of the organic nitrogen may move down into the vadose zone from where it eventually can contribute to nitrate contamination of groundwater as it continues to degrade to more oxidized forms.

More development and recognition should be given to engineered wetlands and restored meadows as treatment approaches. These biologically-based treatments can offer effective, low-technology, energy-conscious (solar energy) treatment for contaminated waters including secondary treated domestic wastewater and waters containing many emerging organic contaminants.[90]

Development of a digester process that produces a stabilized digestate stream having a considerable portion of the nitrogen in the inorganic form is required. An added incentive for confined-animal activities to adopt this technology is the additional revenue stream that could be realized by the marketing of a stabilized fertilizer with a considerable portion of the nitrogen in the form of inorganic nitrogen.

The need for more adaptable and effective control systems for biological treatment and other treatment systems is essential, particularly for the treatment of surface waters and wastewaters where contaminants may vary significantly in type and concentration over time. Such control systems would also significantly benefit from better information about the water being treated with this information typically being obtained by the use of *in situ* sensors.

Ion-Exchange Treatment Technology

Compounds that dissolve in water generally form ions that are the electrically charged elements or moieties that comprise the compound resulting in both negatively and positively charged ions (anions and cations, respectively) being present in the water. Compounds that possess an anion such as nitrate can produce adverse health effects if the water is consumed by babies and pregnant mothers. Hardness causing compounds typically contain cations such as calcium and magnesium and anions such as bicarbonate and carbonate. When these ions precipitate out of solution, they build up on the inside of pipes, resulting in increased resistance to flow (a decrease in pipe diameter and an increase in friction) and increased energy requirements, particularly if the pipe is part of a domestic or industrial heat-exchange system (an example of the former is a water heater and an example of the latter is a water cooling system for an electrical generating plant).

Charged ions can be contacted with ion exchange resins that are formulated for the compound for which removal from the water stream is desired. The exchange resin must have positively charged resin sites to which anions with weak binding forces such as chloride are attached if the target ions are nitrate, bicarbonate or carbonate. Likewise, if calcium or magnesium is targeted for removal from the feed stream, the exchange resin must have negatively charged sites to which cations having weak binding forces such as sodium are attached. As the binding sites on the exchange resin approach saturation with the targeted ions, the removal efficiency of the exchange resin decreases, and in the case of resins used for nitrate or hardness removal, the exchange resin must be regenerated with water of high sodium chloride concentration in order to overcome the binding forces of the target contaminant (ion) with the resultant removal of the contaminant from the ion-exchange system.

The high concentration of the contaminant removed from the ion exchange system must be managed so that it does not contribute to health and environmental problems. For this reason home ion exchange systems have been banned in some communities due to the chloride discharged to receiving waters the home ion exchange systems backwash and recharge process typically is plumbed to discharge to the sewer where it becomes part of the discharge to receiving waters.

While ion exchange may be an economically viable alternative for removing nitrate from drinking water, it currently oftentimes will not be selected because of the additional costs for managing the brine stream. Innovation opportunities

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[90] Environmental Protection Agency, "Constructed Treatment Wetlands" (August 2004)

include the development of ion-exchange hardware and operational procedures that significantly decrease the amount of backwash water that is discharged. The brine from ion-exchange units can also be managed by packaging the exchange resins in canisters and when the resins in the canisters no longer effectively remove the target ions from the feed water stream, removing the canisters to a location where they can be backwashed and the cumulative backwash from multiple canisters can be transported to a site where it can be safely discarded (e.g., a wastewater treatment plant that discharges to a marine or other highly saline waters).

Disinfection Treatment Technologies

Disinfection is typically one of the last treatment processes in treatment trains for both water treatment and wastewater treatment and is considered the primary process for inactivating or destroying pathogens. Water delivered for human consumption or contact and to the environment must meet stringent standards for bacteria, viruses, and protozoa and helminthes. The most commonly used disinfectants are strong oxidants such as ozone and chlorine. However, these disinfectants form various DBPs when the precursors for these contaminants are present in the water being disinfected. Further innovation is necessary to develop chemical disinfectants that do not react with precursors to form deleterious substances including disinfection by-products (DBPs). Chemical disinfectants that could be candidates for widespread use include bromochlorodimethylhydantoin (BCDMH) and peracetic acid (PAA) with the former showing limited toxicity when evaluated as a wastewater disinfectant.[91]

An alternative to the disinfection of water by ozonation or chlorination now being more widely deployed is UV disinfection. An Ultraviolet (UV) disinfection system transfers electromagnetic energy from a mercury arc lamp to an organism's genetic material (DNA and RNA). When UV radiation penetrates the cell wall of an organism, it destroys the cell's ability to reproduce. UV radiation, generated by an electrical discharge through mercury vapor, penetrates the genetic material of microorganisms and retards their ability to reproduce.[92] However, some microorganisms have shown the ability to repair the damage caused by the UV and then continue to grow and reproduce. An area requiring innovation is the development of UV systems outputting higher-energy UV light at the desired frequency of 250 to 270 nm to achieve greater disinfection efficiency. One such system is microwave-powered.

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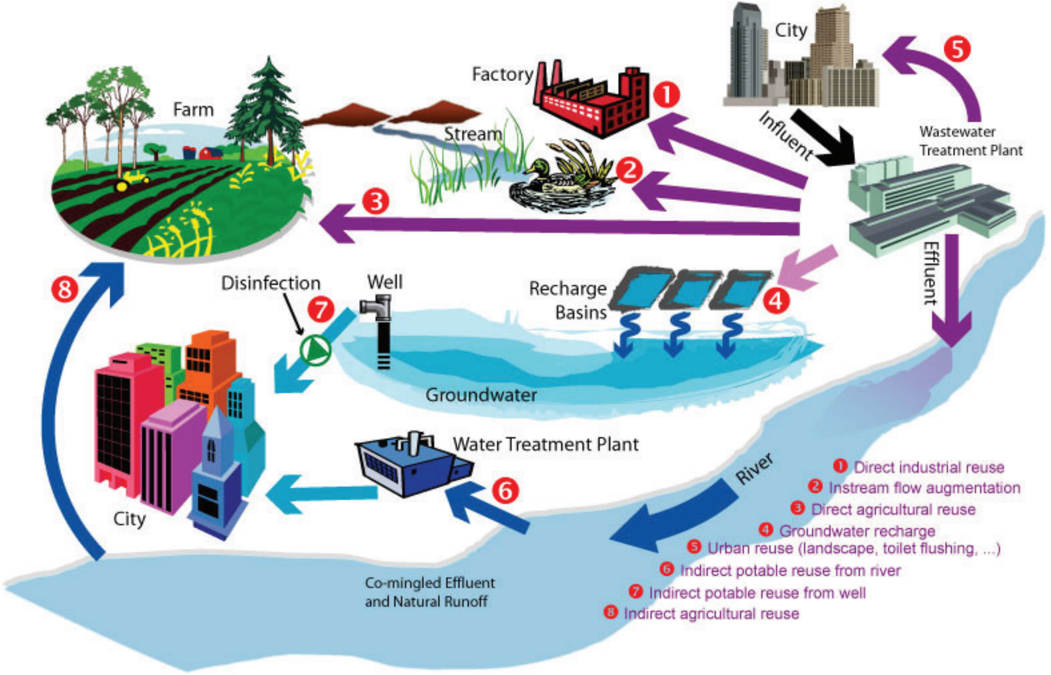
[91] Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management, EPA 832-R-12-011, March 2013

[92] Wastewater Technology Fact Sheet - Ultraviolet Disinfection, EPA 832-F-99-064, September 1999

Water Recycling

Figure 28. Overview of water recycling. Source: http://www.water.ca.gov/recycling/



The effective implementation of water recycling (Figure 28) will require extensive innovation of both operational and treatment technologies to achieve California's goals for water recycling, while achieving the greatest economy in costs for both water treatment and conveyance and energy production and transmission. Interestingly, increasing progress is being made in programs that can lead to direct water recycling for potable use where practical. Nevertheless, the greatest gains in water recycling, as can be seen in the above diagram, will probably be found in nonpotable or indirect potable reuse of water such as treating water for recharge to groundwater where it can be withdrawn for multiple uses. A basic tenet in water recycling is to treat water only to the required quality required for its reuse thereby realizing both energy and treatment savings.

Addressing the removal or attenuation of Pharmaceutical and Personal Care Products (PPCPs) and Emerging Organic Compounds (EOCs) will require considerable innovation focused on the development of effective control technologies. A well-designed treatment train, possibly consisting of coagulation and settling, filtration, and oxidation using a chlorine compound and/or ozone perhaps with a free radical promoter, will be required for treatment and removal of PPCPs and EOCs from water. Considerable research and prototype development and testing is an important requirement involving not only the employment and refinement of current technologies for the removal of PPCPs and EOCs from water, but the seeking of new technologies for this purpose.

While nanoparticles have been suggested as having wide applicability in wastewater and water treatment to remove many contaminants including PPCPs and EOCs, there remains the serious question of the health effects of nanoparticles on public health and the environment particularly given their increasing abundance due to their use in a number of industrial processes. The public health and environmental issues should be resolved as part of investments made for the further development of nanoparticle technology for water and wastewater treatment.

Recommendations

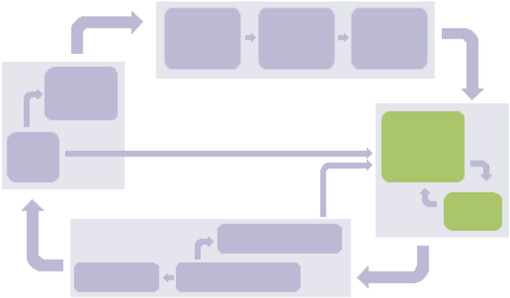
1. **Further develop and deploy more robust general-purpose membranes**, with an emphasis on lower cost, higher permeability and lower energy use and those that remove contaminants not efficiently removed (e.g. boron, other contaminants of emerging concern, etc.) for use in seawater desalination, brackish water treatment, and wastewater and water reuse applications.
2. Continue developing **energy recovery technologies** for application to membrane separation technologies.

3. **Further develop and deploy smart self-adaptive control technologies** to insure more dependable operation of water/wastewater-treatment facilities including treatment facilities that are remotely located (distributed treatment).
4. **Further develop and deploy advanced water treatment technologies** capable of efficient removal from water of salinity, arsenic, nitrate and other nutrients, pharmaceutical and personal care products (PPCPs), emerging organic contaminants (EOCs), and other contaminants of economic and/or public health concern.
5. **Deploy brine-management technologies already often used outside California on a significantly larger scale** for brine disposal into marine environments, and for the management of brine streams (including salt harvesting) in inland areas.
6. **Further develop and deploy wastewater cleanup and recycling technologies focused on providing water for uses other than drinking** (i.e., irrigation, process water, groundwater recharge, etc.).
7. Further develop technologies to **reduce chemical use and increase energy efficiency**, such as engineered wetlands for wastewater treatment and ecosystem enhancement.
8. **Develop and deploy anaerobic-digestion technology that converts liquid waste streams from confined-animal operations into a stabilized fertilizer** with a considerable portion of the nitrogen in the inorganic form.
9. Continue development of disinfection technologies for water that provide **better disinfection efficiency** for waterborne human pathogens while not creating additional public health and environmental hazards.

4.4 Water Use, With a Focus on Water Users

Water management in California is the balancing of water supplies with water demand. Traditionally, water users would extract water as needed from the supply, use the water, and then discharge it when finished. As water demands increased, California would need to identify and procure additional supplies and build additional infrastructure to meet the increased demand, retaining this balance. However, more recently, a renewed focus has been placed on the demand side of the balance; as additional water supply is becoming harder to acquire, managers are now looking to reduce water demanded by water users. Efforts to encourage efficiency and conservation in water use can realize multiple benefits as highlighted in the Water System Management section of this report (Section 3.2), specifically in significant reductions in capital costs for infrastructure, treatment, and watershed management activities. Water users include agricultural, urban (municipal and industrial), and in some cases, environmental entities.

4.4.1 Agricultural Water Use Efficiency



Definition

The question of how much water agriculture uses in California is determined by the volume it consumes. Confusion sometimes arises when various methods are used to illustrate agriculture's use on a comparative basis. For the purposes of this report, **dedicated water** (agricultural, municipal, industrial, and environmental uses) is one way to look at the percentage of ***consumptive*** total use. For the period from 1998 to 2005, an average of 62.4 million acre-feet (MAF) annually was dedicated for all uses. Agriculture net water use during this time was 25.8 MAF or approximately 41%. Another way to look at agricultural use is to look at the percentage of **"extracted" water** – i.e., the uses of water that exclude environmental. Using this definition (the ratio of agricultural use to agricultural plus urban use), agriculture consumes 80% of the water supply. Clearly as a major consumer of

California's water supplies whichever definition we use, agriculture must make every effort to effectively manage its allocation. The adoption of innovative technologies and techniques will be an integral part of this effort.

Any definition of water use efficiency will depend on the scale (e.g., basin or farm). At the basin level, water that is lost through run-off or deep percolation from an irrigated field is many times picked-up as a water source to irrigate another field or fill some other beneficial use such as ground water recharge. This reuse of water will typically produce a higher measure of water use efficiency at the basin level than is measured at the field or farm scale.

However, on-farm water use efficiency or irrigation efficiency (IE) is a measure of how much applied water is used beneficially. A general equation for irrigation efficiency would be:

$$IE = \text{Beneficial Use of Applied Water} \,/\, \text{Total Applied Water}$$

These values are a combination of distribution uniformity (DU) and the timing and amount of water applied. There are numerous variables that affect the IE, including the type of irrigation system, soil(s), crop, and precision in the timing and amount of water applied.

Examples of water use at the field level not deemed beneficial could be water that moves beyond the rootzone or water that flows off the irrigated field. In practice, water not used by the crop or to support its growth (salinity management, cooling, frost protection) can be seen as non-beneficial use.

In conclusion, water use efficiency needs to be viewed at the appropriate scale. Where over-irrigation may be seen as lost water and thereby non-beneficial at the field level, the same water may be recognized as a "water source" to the next farm and beneficial at the basin scale when utilized later by another farm or municipality.

It should be noted that the belief held by some that changing furrow irrigation systems to drip will yield significant water savings was addressed by Davenport and Hagen over 30 years ago[93] when they correctly stated "It is erroneous to conclude that a particular irrigation system such as sprinkler or drip requires only a fraction of the water applied by systems such as furrow or border-strip… Because of the recoverability and reusability of field runoff and deep percolation, it is even more erroneous to conclude that decreasing runoff and deep percolation will proportionally reduce the state's net water deficit."

Overview

The interactions among water, energy and food are numerous and substantial. Water is used for food production, which is among the largest consumer of global fresh-water supplies. Food production impacts the water sector through potential land degradation, changes in runoff, exploitation of groundwater withdrawals, water quality and availability of water and land for other purposes such as the environment and urban use.

There must be a holistic approach to managing the use of agricultural water supplies making possible the efficient first use and effective reuse of water whenever feasible. While surface water supplies attract significant discussion, achieving sustainability for ground water supplies will be critical to agriculture's long-term viability.

Water measurement and soil moisture monitoring technologies are expected to be important tools in reaching this goal. Actions should be guided by principles that consider the multiple goals of water and energy management that achieve the desired benefits of water supply sustainability, enhancing local environments, and minimizing deep percolation, while optimizing crop economic returns (Figure 29).

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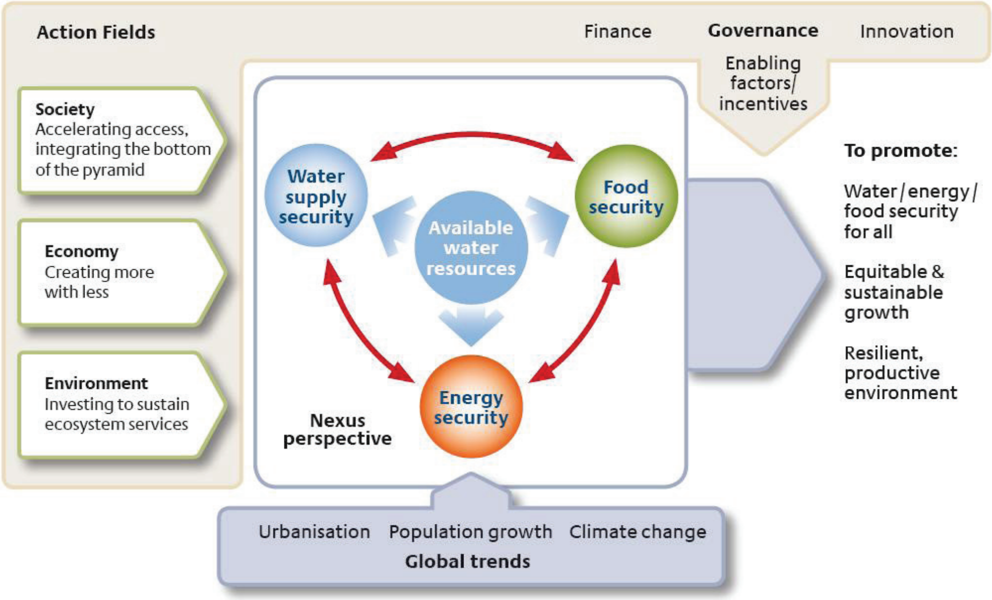
[93] Davenport, David C. and Robert M. Hagen. Agricultural Water Conservation in California, With Emphasis on the San Joaquin Valley. Department of Land, Air, and Water Resources. University of California at Davis, Davis, CA. October 1982.

Figure 29. Factors in a holistic approach to managing agricultural water supplies.



Irrigated agriculture is one of the most critical human activities sustaining civilization. The current world population of 7 billion people is sustained in large part by irrigated agriculture. USDA statistics show that 17% of cultivated crop land in the United States is irrigated. Yet this acreage produces over 50% of total U.S. crop revenues.[94] According to the Food and Agriculture Organization of the United Nations the approximate 3,114 million acres (ac) under rainfed agriculture, corresponding to 80% of the world's total cultivated land, supply 60% of the world's food, while the 684 million acres under irrigation, the remaining 20% of land under cultivation, contribute the other 40% of the food supplies.[95] On average, irrigated crop yields are 2.3 times higher than those from rain-fed ground. These numbers demonstrate that irrigated agriculture will continue to play an important role as a significant contributor to the security of the world's food supply.

The California Department of Food and Agriculture reported that 81,500 farmers and ranchers received $34.8 billion for their output in 2009. The state produces more than 400 different agricultural commodities, supplying nearly half of U.S.-grown fruits, nuts and vegetables. Nearly all the agricultural production in California is made possible by irrigation supplied by a vast and integrated water infrastructure.

The increased yields that have resulted from mechanization and other modern measures come at a high energy price, as the full food and supply chain claims approximately 30% of total global energy demand. Energy fuels land preparation, fertilizer production, irrigation and the sowing, harvesting and transportation of crops. The links between food and energy have become quite apparent in recent years as increases in the price of oil lead very quickly to increases in the price of food.

California's unique geography and Mediterranean climate have allowed the State to become one of the most productive agricultural regions in the world. The Sierra Nevada Mountain range, which lines the eastern edge of the State, captures and stores winter precipitation that can be then used for summer irrigation in the Central Valley. This water, combined with the Mediterranean climate permits the growing of a great number of crops. California produces over 250 different crops and leads the nation in production of 75 commodities. California is the sole U.S. producer of more than 12 different commodities including almonds, artichokes, dates, figs, raisins, kiwifruit, olives, persimmons, pistachios, prunes and walnuts.[96] Nearly all this production requires irrigation. In an average year

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[94] USDA Economic Research Service, Irrigation & Water Use: Background, http://www.ers.usda.gov/topics/farm-practices-management/irrigation-water use/background.aspx#.Umxb9SgTQkk.

[95] Dowgert, Michael F. "The Impact of Irrigated Agriculture on a Stable Food Supply." Proceedings of the 22nd Annual Central Plains Irrigation Conference, Kearney, NE., February 24-25, 2010.

[96] California Department of Food and Agriculture. California Agriculture Statistics Review, 2012-2013. Sacramento, CA. (www.cdfa.ca.gov/statistics

California agriculture irrigates 9 million acres and applies roughly 33.2 million (gross) acre-feet of water (net use of 25.8 MAF).[97]

California's population growth and greater awareness of environmental water requirements has increased the pressure on California agriculture to use water more efficiently and to make more water available for urban and environmental uses. Decreasing agricultural water use is difficult for several reasons. First, California agricultural water use when considered on a broad regional scale, for the most part, is very efficient. Individual fields and farms in some regions may have low efficiencies, but water that is not used on one farm or field is often used on a nearby farm or field. Secondly, for most crops, production and yield is directly related to crop water use. A decrease in applied water will often directly decrease yield. The key is management strategies that improve water use efficiency without decreasing yield.

Innovation Opportunities

A number of growers and interested individuals provided significant input in the discussion on the use of technology in agriculture for the purpose of improving water use efficiency. It is clear that data monitoring, data collection and reporting are common tools used among successful grower operations. Study participants provided broad geographic representation and highlighted common denominators such as the use of flow measurement and soil moisture technologies. It is clear that leading growers are achieving high water use efficiency in their day-to-day farming operations. However, it is also evident that significant opportunities exist for other growers to adopt similar strategies and technologies in the pursuit of improving agricultural water use efficiencies.

There are a number of technologies and management strategies available that benefit water use efficiencies while improving yields and production standards. These technologies and management strategies provide for better irrigation scheduling and crop-specific irrigation management that often not only optimize water use, but also save energy and decrease growers' costs.

It is critical that both district-level and on-farm water systems take advantage of new technologies, science and equipment. Computers and communication devices allow for better information and control decision-making in near realtime. Large data sets can be continuously monitored, with alerts and record keeping forming the basis for better decision-making opportunities.

Case Study

Technology Provides Improved Water Use Efficiency

An important measure of agricultural water use is yield per unit of water or water use efficiency (WUE). An excellent example of this is found at Stamoules Produce Company, located in Mendota, CA, who adopted AirJection® Irrigation technology. This process adds about 15% air by volume to the water delivered to the root zone of plants via the subsurface drip irrigation method. This process provides much needed air to the root zone. The concept was developed by Mazzei Injector Company and through a partnership with the Center for Irrigation Technology, the process was validated and moved to commercialization.[98]

Stamoules Produce has employed AirJection® Irrigation technology since 2005 on 1,500 acres of vegetables. After 8 years of use in growing honeydews, corn, peppers and cantaloupes, all crops realized an increase in yield over the farm average with cantaloupes obtaining the largest yield increase of 23%. The difference of 201 boxes of cantaloupes per acre translates to a total increase of over 1,300,000 boxes during the 8-year period on the cumulative crop area of 6,480 acres.

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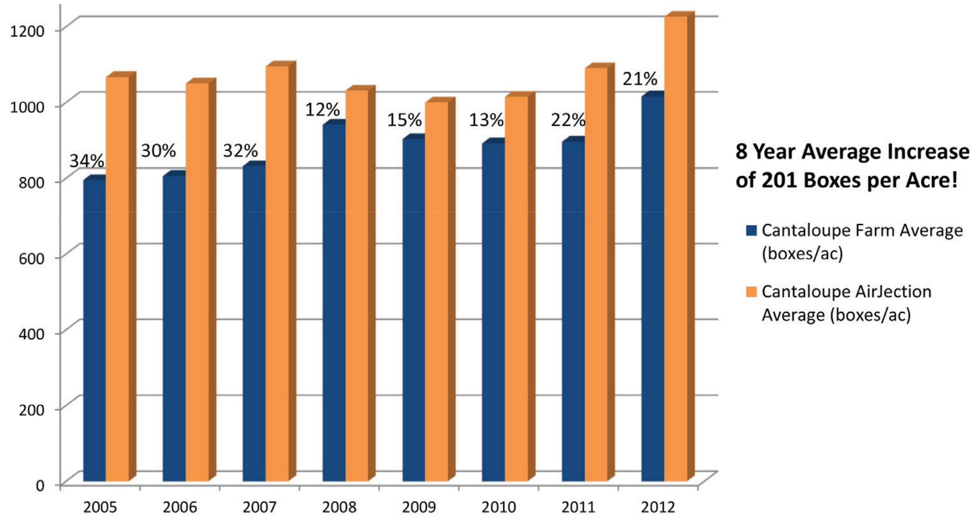
[97] Canessa, P., S. Green and D. Zoldoske. 2011. Agricultural Water use in California: A 2011 Update. Staff Report, Center for Irrigation Technology, California State University, Fresno. 80 pp.

[98] Goorahoo D., D. Adhikari, D. Zoldoske, F. Cassel S., A. Mazzei, and R. Fanucchi. 2008. Potential for AirJection® Irrigation in Strawberry Production. pp 152-155 In : Takeda, F., D.T. Handley, and E.B. Poling (ed.). Proc. 2007 N. American Strawberry Symposium. North American Strawberry Growers Association, Kemptville, ON Canada.

The additional energy cost is estimated at $0.054 per additional box. The initial installation cost was $209,580. The added net return to the grower over the 8-year period was $3,723,000 estimated at $3.00 per box. No additional water or fertilizer was required by the fields employing AirJection® technology over conventionally farmed fields. This translated into a 23% increase in water use efficiency or the equivalent of nearly 1,500 additional acres and water under conventional drip methods. Figure 30 shows average yield differences over an eight year period on cantaloupe production between conventional and AirJection® technology. The differences were statistically significant.

Figure 30. Cantaloupe yield differences with AirJection® technology, 2005-2012



On-Farm Technology Adoption

Irrigation Scheduling

Deciding when and how much water is needed for a crop is critical to the total amount of water applied to the field and what is ultimately seen as beneficial use. A number of different scheduling techniques have been developed that can use either one or a combination of soil based, plant based or weather-based measurements to determine the correct timing and amount of water. Using a more scientific approach to scheduling has generally been shown to optimize the amount of water applied while maximizing yields.

Tailwater Return Systems

In order to provide adequate water to the low end of the field, surface irrigation systems may require that a certain amount of water be spilled or drained off as tailwater. Tailwater return systems catch this runoff and typically pump it back to the top of the field for reuse. This approach has shown to significantly improve the applied water uniformity of surface irrigation systems. These systems are common in parts of California, but opportunities for broader use exist in other parts of the state.

Irrigation System Improvements

Irrigation system improvement involves modifying the irrigation method or use of hardware and software to properly apply water to the field while minimizing water losses. For example laser-leveling furrows, combining furrow and sprinkler systems, and changing from surface irrigation (flood, furrow and border check) to drip/micro systems have all proven to be effective methods. Changing from surface irrigation to pressurized systems can increase irrigation distribution uniformity and decrease applied water. However, with certain soil types and application methods, surface irrigation has been shown to be very efficient. In California there has been a trend to shift from surface irrigation to pressurized systems, particularly as growers shift from annual to permanent crops (trees/vines).

System Audits

Approximately 3 million acres of California farmland is currently irrigated by the drip/micro method.[99] A significant portion of this acreage has irrigation systems that are over 10 years old. A number of recent evaluations or audits of these systems has indicated decreases in Distribution Uniformity (DU) from a design criterion of around 90%,

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[99] California Water Plan Update 2013, Chapter 2: Agricultural Water use Efficiency, Table 2-1.

to current levels of DU ranging as low as 30% to 67%.[100] This decrease is attributed to several factors, including emitter plugging, mechanical damage to distribution tubing and/or reduced pump discharge pressures. An economic review suggests that replacing failing equipment can restore the DU to high-levels while reducing overall operating pressures. Furthermore, the cost of these changes in many cases can be recouped in less than one year of operation through savings of water, energy and/or fertilizer.

The importance of improved DU can be illustrated in comparing an intended 1.0-inch application of water across a field between a distribution uniformity of 70% vs. 90%. A 70% DU will apply an average of 1.42 inches of water to the wettest quarter of the field and only an average of 0.7 inches of water to the driest quarter of the field (ratio of over 2 to 1), where as a distribution uniformity of 90% will apply an average of 1.12 inches of water to the wettest quarter of the field and 0.9 inches of water to the driest quarter of the field (ratio of 1.2 to 1). Obviously the latter conditions will support better water-management and potentially improved crop yields.

Irrigation District System Improvements

Canal Lining

Lining canals with high seepage rates has been shown to provide significant water savings. This is especially important where the underlying groundwater is saline/brackish and the water cannot be reused without treatment. However, in most areas of California, canal seepage works as a critical component of groundwater recharge. In some cases, canal lining is now being removed in parts of southern California to improve both groundwater quality and quantity.

Canal Structure Improvements

Replacing or improving canal structures can improve an irrigation district's ability to manage and control water and reduce spillage. Key elements of this focus on improved delivery schedules as growers shift from surface to pressurized irrigation systems and new regulations that require accurate reporting of water deliveries.

To achieve this level of monitoring and control, many irrigation districts are installing remote-monitoring control systems that allow districts to measure flow or water depth and allow the district to remotely operate control structures or devices. Remote monitoring and control systems can provide significant improvements in water delivery to farmland (timing and amount).

Key benefits of integrated district/farm systems

- Reduced/eliminated groundwater pumping
- Reduced energy costs
- Enabled volumetric billing
- Encouraged adoption of drip/micro irrigation
- Improved overall resource management

Recommendations

1. **Increase the adoption of water measurement (flow and total) and soil moisture sensing technologies** to increase farm water-management data, accuracy and control.
2. **Promote the expanded use of high-efficiency irrigation distribution systems**, provide necessary maintenance, and utilize proper irrigation scheduling methods to optimize water and energy use efficiency.
3. **Encourage universal adoption of one or more technologies for irrigation scheduling**, including remote sensing, weather based, and/or crop/soil based technologies.
4. **Develop cost-effective irrigation system performance information monitoring platforms** for evaluating irrigation performance criteria in real time, including both water and energy.
5. **Integrate water-district deliveries on a real-time delivery basis to farms** to maximize water use efficiency, and support drip/micro irrigation methods.

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[100] Unpublished report, "Irrigation Systems Water/Energy Assessment", Center for Irrigation Technology, California State University, Fresno, September 30, 2013.

6. **Use agricultural water and land whenever appropriate to provide local environmental benefits** (e.g. flooded rice ground to provide seasonal wetlands for migratory birds and reproduction habitat for fish and aquatic life).
7. **Identify opportunities for shared use for water supplies** (e.g. water exchanges between agricultural and urban users)
8. **Identify opportunities for local groundwater treatment (primarily salts) as a new or alternate water source for irrigation.**
9. **Expand the use of water meters** or other measurement devices to quantify agricultural water use both at the district and farm levels.
10. **Promote the use of drought and/or salt tolerant agriculture.**
11. **Understand third-party impacts before implementing any large-scale changes in water diversions and/or agricultural practices.**
12. **Work collaboratively to develop Integrated Regional Water-management plans** that secure long-term sustainable water supply.

Irrigated agriculture needs to broadly adopt both emerging and existing technologies across the farming community. Numerous examples exist where growers are operating at exceptional levels of efficiency with water and energy inputs. Additionally, these growers are collecting and utilizing real-time inputs from the field to effectively manage and document these efficiencies.

4.4.2 Urban Water Use Efficiency

Definition

Urban water use efficiency (often also called “municipal and industrial” (M&I) or “commercial, industrial, and institutional” (CII)) involves technological and/or behavioral improvements in indoor and outdoor residential, commercial, industrial, and institutional water use that lowers demand and per-capita water use and results in benefits to water supply and/or water quality.

Overview

There have already been a number of innovations in technology and technique, yet significant opportunities remain to improve urban water use efficiency. Urban water conservation is often the least expensive method of acquiring additional water supplies, avoiding expensive infrastructure and pumping costs and energy. The State Water Plans have consistently listed urban water use efficiency as the largest new water supply source in the state in the coming decades.[101] Recent studies have suggested that the majority of new urban water savings will be found outside the home in landscape and other uses. The Pacific Institute has estimated that existing technology could be implemented to save over 2.3 million acre feet of water per year (MAF/yr), over one third of California’s total 2000 urban water use (~7 MAF/yr).[102]

Case Study: Los Angeles

As an example of what is possible with consistent attention to urban water conservation, consider the water use conservation efforts of the city of Los Angeles. Since the early 1970s, faced with a rapidly growing population and concerns over future water availability, Los Angeles has developed a suite of solutions, including incentives, retrofits, regulations and restrictions, water recycling, and more. The result of these efforts, as shown by Figure 31, is the relatively steady citywide water deliveries for the past 40 years despite a population growth during this time period of over one million people.[103]

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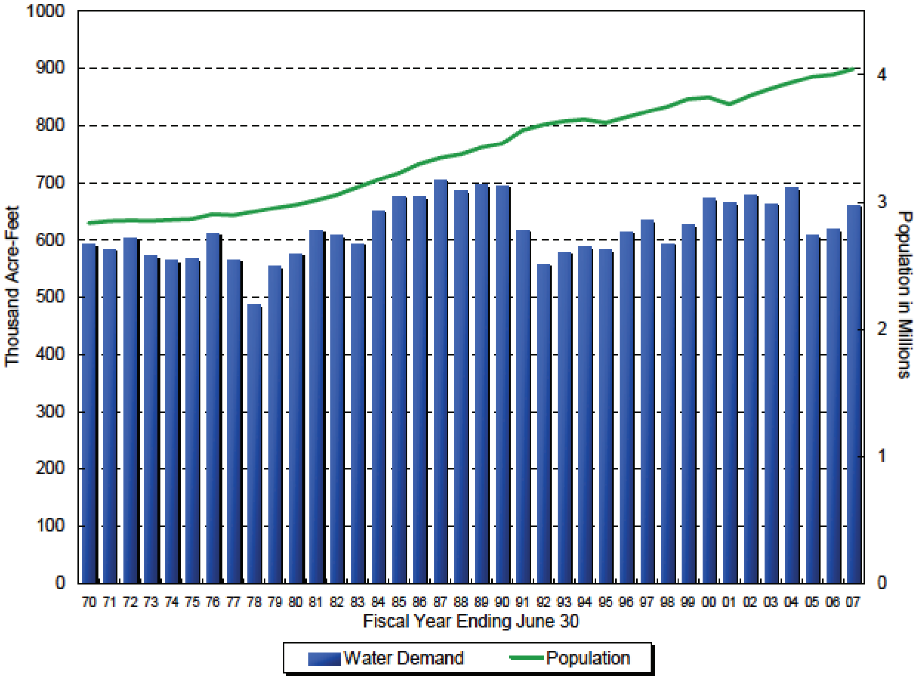
[101] See California State Water Plans (2005, 2009, and draft 2013); http://www.waterplan.water.ca.gov/.

[102] Gleick, P.H. Haasz, D. Henges-Jeck, C. Srinivasan, V. Wolff, G. Cushing, K.K. Mann, A. “Waste Not, Want Not: The Potential for Urban Water Conservation in California.” *The Pacific Institute*. November 2003. http://www.pacinst.org/wp-content/uploads/2013/02/waste_not_want_not_full_report3.pdf.

[103] “Securing L.A.’s Water Supply.” Mayor Antonio R. Villaraigosa, LADWP, May 2008.

Figure 31. Los Angeles water demand and population, 1970-2007[104]

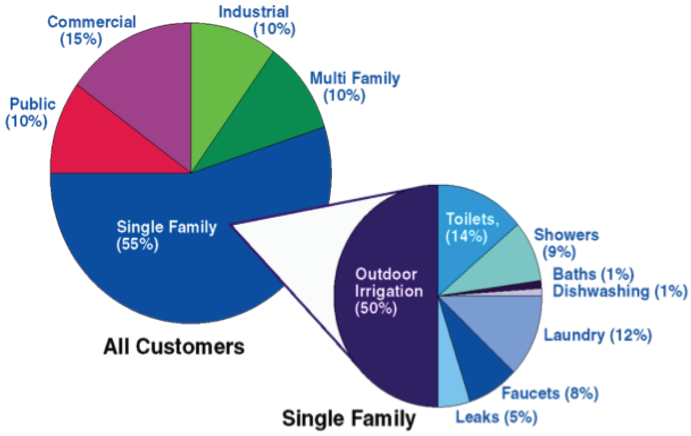


The Statewide Opportunity

In November 2009, following up on Governor Schwarzenegger's plea for a solution to water challenges in the Sacramento-San Joaquin Delta, the California legislature adopted "The Water Conservation Act of 2009" (SB X7-7), which set a goal of reducing urban per-capita water use by 20% by December 31, 2020.[105]

Per Figure 32 below, the majority (55%) of urban water use is by single-family residential users. Single-family uses can be further divided into indoor and outdoor water uses, with outdoor use (landscaping) accounting for approximately 50% and indoor uses such as toilets, showers, and laundry comprising the remaining 50%. As the largest segment of urban water use, efficiencies achieved in the residential sector, both indoor and outdoor, can have significant impacts on overall urban water demand.

Figure 32. Urban Water Uses*[106]*



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[104] "Securing L.A.'s Water Supply." Mayor Antonio R. Villaraigosa, LADWP, May 2008.

[105] "The Water Conservation Act of 2009." Senate Bill Sb X7-7. California Department of Water Resources. 2009.

[106] California Urban Water Conservation Council, 2010.

Innovation Opportunities

There are a number of innovations in technology and technique targeting urban water use reductions; many municipalities and utilities see the potential savings from conservation as a key future water source, and companies are developing products and financing solutions to help achieve these savings. Below are some of the key innovations in urban water use:

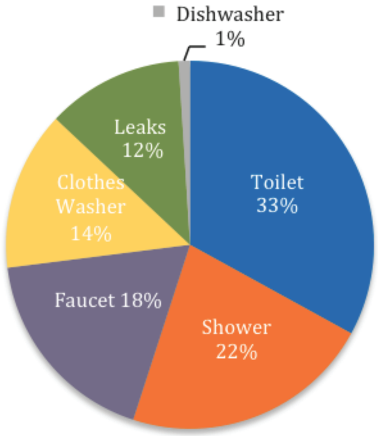
1. **Efficient Fixture Retrofits.** Water-efficient fixtures on the market today achieve the same performance as traditional fixtures while using a fraction of the water. Financing solutions are emerging to enable more ratepayers (customers) to install these fixtures.
2. **Advanced Metering and Real-Time Information.** Water managers are benefitting from advanced metering technology that provides real-time or near real-time information about their water-infrastructure systems. This data helps system optimization, and many managers have made individual water use information available to customers to influence water use behaviors.
3. **Growth of Capture and Reuse.** Water capture and reuse systems have grown both in the technologies available, as well as in the number of installations throughout California, from rainwater harvesting to stormwater management, graywater reuse, and onsite wastewater treatment.
4. **Outdoor Water Use Efficiency.** There have been a few key innovations targeting reduction of outdoor urban water use, including precision-irrigation solutions (SMART controllers and soil moisture sensors), as well as policies encouraging native landscaping to reduce water demand throughout the ratepayer base.

Efficient Fixture Retrofits

There are many new innovations focused on reducing indoor water use, including improvements in the water efficiency of water-using fixtures and a variety of strategies to induce customers to finance the purchase and installation of these fixtures.

Figure 33 shows an average breakdown of indoor water use in a California home.[107] Toilets and showers consume the majority of indoor water, with faucets and washing machines also significant contributors. Innovations in the efficiencies of these fixtures present an opportunity to perform the same functions with less water, shrinking the overall pie. Innovative products currently on the market provide performance well below national standards (i.e. a significant improvement from the standard); toilets with flush volumes as low as 0.8 gallons per flush (gpf) have been released, and many manufacturers now offer faucets and showerheads with flow rates of 0.5 to 1.0 gallons per minute (gpm).

Figure 33. California Indoor Water Uses, 2000.



Toilet Flush Efficiency Gains.

In the United States, toilets account for approximately 30% of residential indoor water consumption.[108] California has recently set stringent efficiency standards for toilets, requiring a maximum of 1.28 gallons per flush (gpf) for all new toilets installed starting in 2014, an improvement over the national standard of 1.6 gpf established in 1992,[109] and has also been adopted by the EPA WaterSense program as the minimum standard to qualify as a high-efficiency toilet (HET) and earn the WaterSense label.[110] Toilet manufacturers have continued to innovate and push the envelope, producing toilets requiring as little as 0.8 gpf (Figure 34). These high-efficiency toilets are generally comparable in price to 1.6 gpf toilets, and they offer significant

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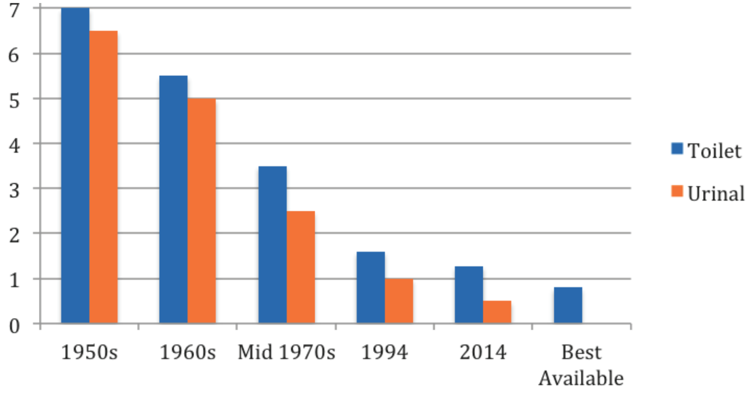
[107] Gleick, P.H. Haasz, D. Henges-Jeck, C. Srinivasan, V. Wolff, G. Cushing, K.K. Mann, A. “Waste Not, Want Not: The Potential for Urban Water Conservation in California.” *The Pacific Institute*. November 2003. http://www.pacinst.org/wp-content/uploads/2013/02/waste_not_want_not_full_report3.pdf.

[108] “Conserving Water.” United States Environmental Protection Agency. Green Home Solutions. Web. http://www.epa.gov/greenhomes/ConserveWater.htm.

[109] Energy Policy Act of 1992. Public Law 102-486, 102nd Congress. Washington, D.C. (Oct. 24, 1992).

[110] Vickers, Amy. “The Energy Policy Act: Assessing its Impact on Utilities.” American Water Works Association, Journal AWWA, 1993. pp. 56-62.

Figure 34. Toilet and urinal water use.



*** Note that flush efficiencies prior to 1970s represent average performance available.**
**** Note also the Best Available Urinal volume is 0 for waterless urinals**

water and cost savings for end consumers.[111] Additionally, the reuse of graywater for toilet flushing offers additional opportunities to reduce potable water used in toilets.

Policy changes and the increased installations of more efficient fixtures have reduced the average toilet flush efficiency in California from approximately 3.75 gpf in 1997 to around 1.6 gpf by 2005.[112]

Financing Innovation for Retrofits

While efficient fixtures can reduce the amount of water required by appliances, equally important are strategies to encourage widespread adoption of these efficient fixtures. Throughout California, there have been a number of innovative financing solutions employed to incentivize customers to adopt efficient fixtures in their homes and businesses.

One example of a water conservation program is “Niagara Green Cities,” a turnkey program that utilities leverage to install low-flow toilets, showerheads, and aerators for their water customers. The Elsinore Valley Municipal Water District employed the Green Cities program in 2011, offering an incentive program to its customers for the replacement of toilets with flush volumes of at least 1.6 gpf. Over 1600 customers received low-flow products with estimated savings of 118 acre-feet per year (AF/yr).[113]

Windsor Efficiency PAYS®

The town of Windsor, CA, has launched the Windsor Efficiency PAYS® program, a water-conservation initiative that allows residents to receive efficiency upgrades and “Pay As You Save®” for the upgrades through surcharges on water bills.[114] PAYS® certified and pre-qualified contractors install the efficiency upgrades and ensure that water savings exceed the related surcharges for the upgrades. Windsor offers 2 packages, the Basic Package, which includes showerheads, toilets, and faucet aerators, and the Basic Plus which can include drought-resistant landscaping, high-efficiency washing machines, and CFL light bulbs. Additional upgrades for larger appliances are eligible for PAYS® with some up-front payment.

Advanced Metering and Real-Time Information

Water managers are benefitting from advanced metering technology that provides real-time or near-real-time information about their water infrastructure systems. This data helps managers optimize their systems to improve leak detection and repair, and it highlights large water users within their system for conservation efforts.

Advanced Metering Offers Many Utility-scale Benefits

An advanced metering infrastructure (AMI) is a growing trend in water utility management to more accurately monitor and measure urban water usage. While there are a variety of different service providers and system setups, AMI generally consists of a system of “smart” meters capable of sending and receiving usage and other information

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[111] One example of a commercially available .8 gpf toilet is the Niagara Stealth System, introduced in 2009 (http://www.niagaraconservation.com).

[112] Mayer, P.W. DeOero, W.B. Opitz, E.M. Keifer, J.C. Davis, W.Y. Dziegielewski, B. Nelson, J.O. “Residential End Uses of Water.” *American Water Works Association Research Foundation*, 1999. & DeOreo, W.B. Mayer, P.W. Martien, L. Hayden, M. Funk, A. Kramer-Duffield, M. Davis, R. “California Single-Family Water Use Efficiency Study.” Aquacraft, Inc. July 20, 2011.

[113] “Elsinore Valley Municipal Water District.” *Niagara Conservation*. http://www.niagaraconservation.com/resources/dyn/files/782661z1809e5a4/_fn/Elsinore_CaseStudy+3.12+Final.pdf

[114] Windsor Efficiency PAYS®. Water & Energy Upgrades that pay you to save. Web. http://www.townofwindsor.com/index.aspx?nid=819.

to a centralized meter management software platform. There are many benefits of AMI, including quicker detection of leaks and greater flexibility in water pricing.

Non-revenue water mitigation (leak detection and mitigation)

One of the primary benefits of AMI is its potential to reduce "non-revenue water" (NRW), which is defined as water lost through leaks and other unmetered activity. A traditional water metering system requires meter readers to physically visit each meter to record water usage; this activity is time-intensive, and thus meters are often read only monthly or bi-monthly, increasing the potential for leaks to go unnoticed for significant time periods, wasting water and driving up customer bills. AMI provides increased accuracy in measuring and monitoring water usage; with remote meter readings multiple times per day, the identification of leaks via abnormalities such as 24- hour usage or spikes in withdrawals is much quicker and more accurate.

Pricing Flexibility

While residential use accounts for the largest percentage of urban water use, for commercial and industrial customers, the top few water users often account for the vast majority of the remaining water use. The time-specific meter readings offered by AMI can help utilities design time-of-use structures for these large users to incentivize water withdrawals when water supply is most robust, reducing stress on the infrastructure. The increased information provided by AMI can have additional benefits for all customers, and more accurate metering can promote piloting and/or adoption of innovative system-wide pricing strategies.

San Francisco Leads California AMI Deployments

The city of San Francisco is the first large municipality in California to implement AMI throughout its distribution network, installing the Aclara STAR network starting in 2010. When fully deployed to the approximately 170,000 municipal meters, the city will receive readings four times per day, allowing SFPUC to better monitor systemwide usage, and to make the data available online to its customers.[115]

Information Sharing Influences Customer Behavior

Additionally, there is an innovation in "behavioral change," as many water utilities are beginning to offer ratepayers increasing access to information about their individual water use and how it relates to their neighbors and average utility users. The simple sharing of information has led to increased conservation efforts, and utilities have developed comparison contests to recognize large water-conservation improvements within the ratepayer base.

Capture and Reuse

Water capture and reuse systems have grown both in the technologies available, and in the sheer number of installations throughout California, from rainwater harvesting to stormwater management, graywater use, and onsite wastewater treatment.

Rainwater Harvesting

Rainwater harvesting is an effective strategy to capture precipitation for use on-site with applications that include watering lawns and flushing toilets. While traditional rainwater harvesting has consisted of large rain-barrels that capture rainfall from the roof, new innovations such as low-profile, modular containers and even water "pillows" are now available to capture precipitation and store it often out of sight until it is needed. Rainwater harvesting conserves water, as rainfall can be used for applications normally performed by treated potable water. It also reduces pollution from runoff of rainfall to storm drains and water bodies, and it can provide households with a free source of water for irrigation and gardening, reducing outdoor urban water use.

San Diego Rain-Barrel Rebate Program

San Diego, due to its location in relation to the major natural and built water infrastructure throughout the state, faces high costs for potable water. In addition to seeking alternative water supplies such as the planned Carlsbad

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[115] Clancy, Heather. "Could Smart Meters stem $14 billion in Annual Water Losses?" GreenBiz. August 15, 2013. Web.

Desalination Plant, San Diego offers a broad portfolio of incentive programs for residential and commercial customers, ranging from irrigation incentives to fixture retrofits and landscape turf replacements. In March 2013, San Diego launched a pilot “Residential Rainwater Harvesting Rebate Program.” This program offers rebate incentives of $1 per gallon of rain barrel storage capacity installed, from a minimum size of 50 gallons up to 400 gallons ($400).[116] San Diego offers a number of rainwater harvesting guidelines and system construction advice to its customers so that rainwater can be captured and stored effectively.

Stormwater Management

Stormwater management has long been an urban concern of water utilities that manage municipal pollution levels and runoff volumes to enable groundwater infiltration, especially in Southern California where large percentages of annual precipitation can fall in a single winter rainstorm. However, a key innovation in stormwater management is the recent interest that commercial and residential sectors have taken in developing their own stormwater management systems. An example of commercial/residential stormwater management is the green roof; these roofs capture rainfall to be used onsite for irrigation, toilet flushing, and other purposes, help regulate building heating and cooling, and reduce the “urban heat-island effect.”[117] Other stormwater management solutions include increasing the permeability of the landscape, often by replacing paved surfaces with vegetation or permeable paving, or by interspersing vegetated “bioswales” in parking lots to reduce runoff.

Figure 35. Green roof of the California Academy of Sciences, San Francisco, CA, captures and retains over 90% of its annual precipitation.

CA Academy of Sciences Living Roof

One of the most complex green roofs is the 2.5 acre “Living Roof” atop the California Academy of Sciences building in Golden Gate Park in San Francisco (Figure 35).[118] This roof houses over 1.5 million native CA plants specifically chosen because they thrive in the San Francisco climate. The Living Roof reduces runoff, capturing and retaining over 90% of its annual precipitation, and it keeps the interior of the Academy of Sciences Building cooler by an average of about 10 degrees.[119]

Silicon Valley Corporate Campus Plans include Water Conservation

In the private sector, office buildings are increasingly looking towards innovative stormwater management solutions for their water and recreational benefits. For example, Silicon Valley-based giants Apple, Facebook, and Google are all developing plans for new campus headquarters that include extensive green roofs complete with trails and cafes, native landscaping, an increase in permeable landscapes, and thoughtful management of precipitation and runoff.[120]

Figure 36. Water drawn from Disneyland’s World of Color is recycled through Orange County’s Groundwater Replenishment System in lieu of direct discharge to the ocean.

Disney Goes Above and Beyond in Water Recycling

Disneyland Resort has implemented a number of innovative water management and recycling practices, most notably working with the Orange County Water

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[116] “Residential Rainwater Harvesting (Rain Barrel) Rebate Pilot Program.” Rebates and Incentives. The City of San Diego: Water Conservation. Web. http://www.sandiego.gov/water/conservation/residentialoutdoor/resrainwaterharvesting.shtml.

[117] Environmental Protection Agency. Reducing Urban Heat Islands: Compendium of Strategies. (October 2008) Chapter 2: Green Roofs.

[118] Photo credit: Ari Michelson

[119] “The Living Roof.” California Academy of Sciences. Web. http://www.calacademy.org/academy/building/the_living_roof/.

[120] Burrows, Peter, “Silicon Valley Tech Giants Plan Super-Green Campuses,” BusinessWeek Innovation & Design (3/14/13), http://www.businessweek.com/articles/2013-03-14/silicon-valley-tech-giants-plan-super-green-campuses.

District to send water drained from the park's major water features through the County's Groundwater Replenishment System in lieu of discharging the water directly to the ocean (Figure 36).[121] Disney has also been recognized for the widespread use of permeable paving materials in parking lots and walkways throughout the resort.[122]

Graywater

The reuse, either with or without treatment, of graywater in the urban sector provides significant water-efficiency and conservation opportunities. Graywater in California includes wastewater from bathtubs, showers, bathroom sinks, and washing machines (collectively known as 'light' graywater), as well as wastewater from kitchen sinks and dishwashers ('heavy' graywater). Specifically excluded is toilet wastewater due to its likelihood of contamination (also known as blackwater).[123] Light graywater can often be reused directly on-site, while heavy graywater and blackwater generally need to be transported to a centralized water treatment facility prior to reuse. Graywater use can significantly reduce onsite potable-water usage, reducing energy costs and customer water charges.

Graywater has a variety of indoor and outdoor uses; indoor uses are primarily for toilet flushing (often with treatment), while outdoor uses include subsurface irrigation systems, backup irrigation for drought periods, groundwater recharge, and use as firebreak.[124] Graywater systems range from simple collection of used water in buckets to sophisticated systems to capture, treat, and transport graywater to its point of reuse. One increasingly popular graywater use is "laundry-to-landscape" where the wastewater infrastructure from clothes washers is modified to allow diversion to landscape irrigation; these systems are especially promising for drought prone regions such as Southern California, as they can significantly reduce residential outdoor potable water use (currently ~50% of residential single-family water use). Cities are encouraging onsite graywater use; for example, San Diego has removed graywater irrigation permitting requirements for washing machine systems less than 250 gallons per day, and is working to streamline the permitting process for shower and bathtub graywater.

Onsite Wastewater Treatment and Reuse

As an alternative to centralized wastewater treatment, many urban facilities are exploring decentralized, onsite wastewater treatment for some or all of their wastewater. These systems range in size and scope and include everything from complete wastewater treatment and discharge systems in lieu of centralized wastewater to simpler treatment of graywater for reuse in toilets or landscaping.

San Francisco Public Utilities Commission: Living Machines Wastewater System

The San Francisco Public Utilities Commission (SFPUC) provides water and wastewater services for the city of San Francisco, and its HetchHetchy Power System provides energy for all San Francisco municipal facilities. SFPUC is headquartered at 525 Golden Gate Avenue, a state-of-the-art, LEED Platinum-certified building that features a number of innovative energy, sustainability, and water management solutions. The SFPUC headquarters uses 60% less water than comparable office buildings due to its incorporation of rainwater harvesting for irrigation, and a Living Machine® system that treats and reuses the building's wastewater for flushing toilets. The Living Machine system is an onsite biological treatment system that mimics tidal wetland ecological processes, using microorganisms to consume wastewater nutrients, and gravity and pumps to simulate tidal cycling, accelerating the water treatment process.[125] The Living Machine has a 5,000-gallon-per-day capacity, and is fully integrated into the building; the wetland treatment cells are located both within the lobby as well as outside on the city sidewalk, containing native, low maintenance plants ideal for urban environments.[126]

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[121] http://blog.touringplans.com/2012/02/10/disneyland-first-trip-2012/

[122] Tully, Sarah. "Disney recycles bay water in 'visionary' way." Orange County Register. October 22, 2009. Web. http://ocresort.ocregister.com/2009/10/22/disney-recycles-bay-water-in-visionary-way/22509/.

[123] Cohen. Yoram. "Graywater – A Potential Source of Water." UCLA Institute of the Environment and Sustainability. 2009. http://www.environment.ucla.edu/reportcard/article.asp?parentid=4870.

[124] Wholly H2O. "Graywater Use in California Single and Multi-Residential Units: Potential Best Management Practices." 2012. http://www.whollyh2o.org/graywater.html.

[125] "San Francisco Public Utilities Commission Selects Living Machine ® Systems for Water Recycling, Water Savings in New 'Green' Office Building." BusinessWire. February 15, 2011. http://www.businesswire.com/news/home/20110215005589/en/San-Francisco-Public-Utilities-Commission-Selects-Living

[126] "San Francisco Public Utilities Commission." Living Machine Systems, Portfolio. http://www.livingmachines.com/Services/Case-Studies/SF-PUC-Case-Study-080913.aspx

Outdoor Water Use Efficiency

Outdoor water use accounts for approximately 50% of residential water use in California (Figure 32). This water is predominantly used to water lawns, often during the dry, hot summers in Southern California. There have been a few key innovations targeting reduction of outdoor urban water use, including policies encouraging drought resistant landscaping and precision irrigation solutions, to reduce water demand throughout the ratepayer base.

Figure 37. Bay-Friendly Garden.

Drought Resistant Landscaping

A recent policy innovation has emerged as many cities are encouraging their water customers to replace lawns and other water-intensive plants with native, drought resistant landscaping. For example, Alameda County's Waste Management Authority has developed a landscape-rating system to help county residents understand the types of plants and watering strategies they can employ to reduce water use, maintenance costs, runoff, and greenhouse gas emissions.[127] Available at stopwaste.org, the Bay Friendly Landscape Program (Figure 37)[128] highlights the innovation of matching landscaping appropriately to the climate.

Long Beach Water's Lawn-to-Garden Program

The Long Beach Water Department has enacted several incentive programs to encourage water conservation by residences and businesses throughout the district. The Lawn-to-Garden (L2G) program encourages households to replace water intensive turf grass with native, water efficient landscaping, paying $3.00 per square foot of lawn replaced.[129] For businesses, the Proven Water Savings Incentive Program awards an incentive payment of $0.76 per 1,000 gallons of water saved per year. This program encourages a variety of commercial upgrades including turf replacement, irrigation systems, water recirculation, and cooling tower efficiencies. In addition to the incentives, the water savings achieved from this program should help businesses save even more on their water bills.[130]

Precision Irrigation

By closely monitoring, evaluating, and controlling the amount of water used for irrigation, overwatering can be avoided and water use reductions and efficiencies can be achieved. These "precision irrigation" innovations include a variety of sensors that continually monitor soil moisture as an indicator of water needs, as well as weather-based irrigation controllers that only apply water when there is insufficient natural precipitation. Additionally, "smart" controllers and sprinklers are emerging that have the capability to be custom-programmed with specific plant and plot-size information for a variety of irrigated zones, applying water at or below infiltration rates while meeting plant water demand, eliminating run-off, and reducing deep percolation.

Soil Amendments

Another recent innovation in outdoor water use efficiency is the use of soil additives and amendments to reduce the amount of water required for lawn and crop growth. Some important amendments include low-water grass seed, as well as polymers that can be injected just below the root zone that hold many times their weight in water and release excess moisture into the soil over time to prevent runoff from overwatering.

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[127] "Bay Friendly Rated Landscapes." Alameda County Waste Management Authority. http://www.stopwaste.org.

[128] Photo from Alameda County stopwaste.org website. http://www.stopwaste.org/home/index.asp?page=141.

[129] "Lawn-to-Garden Turf Replacement Program." Long Beach Water Department. http://www.lblawntogarden.com/.

[130] "Proven Water Savings Incentive Program." Long Beach Water Department. http://www.lbwater.org/pws.

Recommendations

While innovations in technology and technique have helped reduce urban water use, there are still many opportunities for additional water conservation in this area. The key recommendations for urban water use focus more on enabling wider adoption of water-saving technologies than the development of additional technologies themselves.

1. **Encourage expanded commercial/residential stormwater management**. Stormwater management solutions provide many benefits for urban water use, reducing pollution and runoff, and enabling customers to save money watering their lawns and flushing toilets. Policies that support stormwater management solutions would help innovations in this area to achieve wider adoption.
2. **Support broader implementation of graywater systems**. Provide information on technology options and where appropriate support installation and use of graywater systems.
3. **Expand drought-resistant landscaping applications using incentives and other techniques**. Many municipalities, especially throughout Southern California, offer financial incentives for urban customers to replace lawns with drought resistant landscaping. Expansion of these incentives could further reduce outdoor urban water use.
4. **Broaden Appliance Retrofit Incentives.** In order to enable more households and businesses to take advantage of retrofit incentive programs, the targeted thresholds of the programs themselves should be broadened. For example, most toilet-retrofit programs offer incentives only for the replacement of toilets using greater than 3.5 gallons per flush, the average flush volume prior to the Energy Policy Act of 1992. In California, high-efficiency toilets (<=1.28 gpf) will be required of all new toilets starting in 2014; incentives aligned towards replacing 1.6+ gpf toilets would enable more widespread participation.
5. **Promote Adoption of Advanced Metering Infrastructure (AMI)**. AMI can provide multiple benefits to utilities and their customers, enabling near-real-time water use information and quicker identification of leaks. Additional pilots and full-scale installations of AMI could further demonstrate AMI's benefits both locally and statewide.
6. **Utilize More Water-Rate Structure Adjustments to Motivate Behavior Change**. While information provided by AMI and other smart metering can be effective in encouraging customer behavior change, a rate-structure adjustment that significantly increases the cost of excessive water use could also be used to encourage consumer behavior change.

5. Summary Findings and Conclusions

A central issue facing implementation of any technological improvements to California's water systems is one of **strategic coordination**. This is evident in the increased importance of sustainable integrated water management and the coordination of water and related resource management activities with an eye to long-term benefits and growth, as well as the growing focus on the water-energy nexus at the state and national level. The most effective improvements can be achieved not through the application of any single technological solution, but through the selective and well-informed coordination of multiple technologies and strategies designed to complement and reinforce each other.

The critical element of such coordination is comprehensive, real-time information. We have noted an emerging trend in water management to consider systemic impacts, both upstream and downstream, of new technologies and techniques (systems thinking). By adopting a broader perspective into the water system, additional efficiencies and opportunities can be identified that are not easily seen when water is managed at individual process levels.

Sustainable water management will require innovation in science and technology as well as in management practice and policy. As seen above, each section of this report contains recommendations specific to different sectors of California's water systems. The action items in the following section, however, are an overall priority list for accelerating the state's path toward sustainability. These action items are individually and collectively those actions that could be taken to utilize innovations (both new developments and broader applications of proven methods) in technology and technique to help ensure that California has a sustainable water management program that meets the needs of the state over the long-term.

This report draws on a wide spectrum of water technology experts throughout the state, from academia, state and local agencies, non-governmental organizations, and the private sector, to identify and describe innovative water technologies and/or systems approaches with significant potential to help California achieve water sustainability. Our intent is to include technologies that can be introduced or more widely applied to California's water system(s) within the next five to ten years, and which are suitable for implementation at levels ranging from local to statewide. It is our belief that many of these recommendations lend themselves easily to the development of policy actions needed to support implementation. It is beyond the scope of this study to evaluate the economic viability or potential of individual technologies and other innovations.

We include both high-level conclusions and specific recommendations, including actions which can achieve multiple benefits in the near term. Together, these conclusions and recommendations create the foundation for a roadmap for success in the management of California's water future. They build on initiatives already underway by state agencies including DWR, the national labs and our state institutions of higher learning as well as local agencies/water districts, NGOs, the federal government, and the private sector.

5.1 High-Level Conclusions

The following high-level conclusions characterize the report and form the foundation for the detailed specific recommendations that follow.

1. **Innovation and policy action have delivered significant benefits and are essential for a sustainable water supply:** Advancements in science and technology such as low-flush toilets and drip irrigation, deployed through appropriate policy actions and economic incentives, have contributed to significant water savings and/or improved water use efficiency as demonstrated by high-level economic metrics (e.g. water use per capita, water use per dollar of GDP).
2. **The water use cycle frames the issues and opportunities:** The water use cycle provides a useful lens for the analysis of our water challenges. This systems approach clarifies many opportunities for science and technology innovation implementation – both using new technology and through expanded application of proven technology. Innovation opportunities exist at both the individual cycle block level and across the cycle as a whole.

3. **An integrated systems management approach is a key to achieving multiple benefits:** The use of a systems management approach for the deployment of current and future innovations proposed in this report can achieve multiple benefits throughout the water use cycle including reduced water consumption at various steps, reduced energy needs, improved economic resiliency and enhanced environmental sustainability.
4. **The need for a comprehensive integrated information system is pivotal to implementing a systems management approach:** The collection of real time or near real time data on all elements of the hydrologic cycle is a key to good decision making and the analysis of trends and the development of fact-based forecasts and recommendations. Currently, sufficient information does not exist in a form that allows sustainable management of California water resources.
5. **Opportunities abound for near and long term policy action and implementation:** Individually and collectively, many of these innovations lend themselves easily to policy action to encourage implementation and a broader level of public awareness, understanding and support.

5.2 Specific Recommendations

We have developed the following specific recommendations regarding particular technologies, management approaches and implementation strategies, along with actions that can achieve multiple benefits in the near term. These near-term actions are typical of many choices that are available. Investment and policy decisions should be based on the best use of options under consideration for the local, regional or statewide best interest. The order of the recommendations is based on the project team's general assessment of their importance and potential. We have also identified barriers to implementation and specific parties most logically responsible for facilitating adoption of these recommendations along with a list of possible next steps – all included after the recommendations below.

1. **Develop and implement an integrated water information management system** for water supplies, uses, and quality including precipitation, runoff, and storage; for surface water, groundwater, and water use. *In situ* and remote monitoring devices and networks should be expanded and linked to an integrated data management system, or implemented where not available but needed. A common portal capable of supporting data analysis, trending and scenario forecasting should be developed with a common set of standards to link data collection from all sources with an integrated data management system. **<u>Near-Term Actions:</u>** The Governor and key agencies should immediately take the lead to form a consortium of parties, including the State Water Resources Control Board and the Department of Water Resources as well as a broad coalition of water experts in academia, trade organizations and non-governmental organizations with the specific goals of (1) evaluating what is realistic and practical to do in the short-term, (2) designing the data collection and management system to accomplish the near-term task while maintaining capability for future flexibility and then (3) fully implementing this recommendation.
2. **Expand the use of monitoring technology and management practices** including meters and advanced metering infrastructure (AMI) focused on system performance, all water and energy usage, including the monitoring of groundwater withdrawals, and the implementation of management practices for sustainability uses. **<u>Near-Term Actions:</u>** Encourage the metering of all water usage, both agriculture and urban, from all sources, to ensure system use efficiency, quantify demand, and optimize resources inputs for long-term sustainable and reliable water supplies.
3. **Improve water use efficiency in all sectors and at all stages of the water cycle** through applications of proven and developing technology and management practices.
   - In the **agricultural sector**, encourage and incentivize the expanded use of irrigation system designs, installation and management that help improve water use efficiency. Provide real-time information on system performance and field conditions to optimize decision-making. Promote the development of drought/salt tolerant plants, appropriate water treatment, and seek multiple benefits from agricultural practices like vegetative "filter strips" that benefit both water quality and the environment. **<u>Near-Term Actions</u>**: Employ technology that monitors system performance, including water and energy use and soil/water status, to also provide "alerts' regarding system changes that will often require corrective action.
   - In the **urban sector**, encourage and incentivize appropriate landscapes and efficient irrigation methods, the expanded use of high efficiency plumbing devices and appliances, the development of leak detection and management processes including the use of self-repairing materials for

distribution systems capable of handling small to moderate leaks, the expanded use of on-site graywater and rain water/stormwater harvesting, and increased use of recycled water. **<u>Near-Term Actions:</u>** Encourage and accelerate the use/retrofit of water efficient landscapes and irrigation systems, and the retrofit of plumbing fixtures and water-using appliances with high-efficiency devices. Depending upon local conditions and priorities, encourage the use of graywater recycling systems in all new construction and major retrofit projects, the expanded use of water recycling technologies and the construction of rain water /stormwater collection, treatment and retention systems.

- **In all sectors,** utilize proven "system thinking" strategies that facilitate holistic problem solving approaches such as foot-printing, goal setting and integrated system planning and design across the water use cycle. **<u>Near-Term Actions:</u>** Encourage the use of proven "system thinking" including smart water technology tools at the local, regional and statewide level to achieve multiple benefits for water savings, energy savings, economic resiliency and environmental protection.

4. **Restore and protect watersheds and enhance flood management planning including floodplain restoration** (constructed and natural) to increase recharge and groundwater storage, capture and retain storm-water runoff, reduce anthropogenic contamination and improve water quality, and provide for sustainable water systems.
   <u>Near-Term Actions:</u> Identify and support high impact actions to restore and protect watersheds including floodplains and encourage actions to improve the operation of these watersheds and the enhanced collection and storage, both surface and subsurface, of stormwater runoff utilizing proven commercial products and design approaches.
5. **Develop new and expand the application of proven chemical, physical, and biological water treatment technologies** for the treatment of surface water and groundwater with an emphasis on (1) salinity management and nitrate control and (2) recycling water with the appropriate quality for the intended use. **<u>Near-Term Actions:</u>** In addition to effective water conservation measures, expand recycling and the use of desalination and nitrate reduction technologies and other advanced water treatment technologies, where appropriate, to both broaden our portfolio of water sources and advance public health goals of increasing the availability of safe drinking water.
6. **Integrate water, energy and land use planning and management** to improve resilience and tap multiple benefits of reduced energy demand for water systems and reduced water demands from energy systems. **<u>Near-Term Actions</u>:** Encourage and facilitate investments, both public and private, in coordinated and integrated water and energy efficiency options and source-shifting of supplies to tap multiple benefits including greenhouse gas emissions reductions. Evaluate water, energy, and land-use plans and strategies based on multiple benefit criteria and incentivize these integrated solutions.
7. **Continue to support and fund initiatives by various public sector institutions** at the federal, state and local levels whose research will be integral to advancing innovation to address California's water challenges. **<u>Near-Term Actions:</u>** The Governor and key agencies, working with their local and federal counterparts, should take the lead for developing funding for the research that is critical for California's water future. Also encourage increased coordination between water-related entities/agencies at the federal, state, regional and local level. Going forward, California must act with some urgency as it will continually be water challenged.
8. **Expand the use of private sector initiatives** to identify and develop new technologies, techniques and services to include networks to broker information, and expand the use of public/private partnerships to accelerate development, piloting and commercialization of needed technologies.
   <u>Near-Term Actions:</u> The Governor's Office of Business and Economic Development, in collaboration with other government agencies and representatives of the public and private sector, should spearhead and assure that this recommendation is effectively implemented.
9. **Identify, evaluate, adapt and implement best practices** from around the U.S. and the world that can help California meet its water use efficiency, water treatment and water management goals. **<u>Near-Term Actions:</u>** Elected officials and appropriate state, local and federal agencies along with a network of individuals from academia, NGO's and others should develop and maintain relationships with key parties around the U.S. and the rest of the world, be open to innovations and seek out and implement best practices. A responsible State Official should be assigned the responsibility of assuring that this action is achieved.

5.3 Barriers to Implementation

Each recommendation including possible near-term actions has with it an associated set of barriers that must be addressed in order for the roadmap to be successfully implemented. The most significant barrier to the effective implementation of these recommendations is the lack of agreement on a strategic plan for water in the state and the lack of leadership to assure that the strategic plan is implemented, driven largely by the heavily fragmented nature of water resource management in California today. Once we address this issue, the next most significant barrier is insufficient funding, which is likely to remain a significant constraint over the coming years despite California's recent exit from years of deficits. The very complex legal infrastructure and arcane water rights laws further complicate any implementation planning. Resistance to the implementation of many of these recommendations will come from a number of invested parties and this could slow the process significantly. In addition, lack of public understanding and support for several of these actions is a challenge that must be dealt with.

5.4 Agents of Change/Division of Responsibility for Implementation

Each recommendation and proposed near term action has with it a set of parties who are critical to successful implementation. These include (1) federal, state, regional and local political leaders, (2) state, regional and local water agency leaders, (3) water experts in academia, the national labs, industry, non-government organizations (NGO's) and think tanks, and (4) the various stakeholders associated with each recommendation and its implementation plan. Overall, we encourage decision makers to create policy and funding approaches to implement the recommendations included in the report.

5.5 Next Steps

1. Develop implementation plans associated with each of the Near-Term Actions identified above including any policy actions required.
2. For the broader recommendation areas, an organized and disciplined approach is needed to assure that the roadmap proposed can be successfully implemented. This includes:
    a. The need to refine the tools and methods to quantify and assess the multiple benefits in water management needed to facilitate implementation of identified innovations.
    b. Where necessary, assess the economic viability of the identified technology innovations and assess the potential impact of these innovations on the overall California water system.
    c. Identify the policy actions required to encourage, incentivize or mandate the implementation of these recommendations where their economic viability and potential justify such actions.
    d. Develop detailed implementation plans including processes to assure buy-in from all involved stakeholders.
3. CCST could potentially conduct or facilitate the completion of these analyses, contingent upon securing adequate funding.

Appendix A: Steering Committee

The CWF Steering Committee, responsible for the planning, oversight of the work, and final product review was comprised of the following:

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The California Council on Science and Technology adheres to the highest standards to provide independent, objective, and respected work. All work that bears the Council's name is reviewed by Board members, Council members, and Senior Fellows. In addition, the Council seeks peer review from external technical experts. Our focus on rigorous peer review results in a protocol that ensures the specific issue being addressed is done so in a targeted way with results that are clear and sound.

Many individuals contributed detailed information about various programs and aspects of the California water system. In particular we thank Thomas Painter and Duane E. Waliser, Jet Propulsion Laboratory; Forrest Melton, NASA Ames Research Center; Jeff Dozier, UC Santa Barbara; Roger Bales, UC Merced; and Scott Sellars, UC Irvine, for their essential input and contributions to the document.

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Appendix D: Methodology

Information was gathered by an online survey targeting people with water expertise in California, through focus groups of water experts, discussions with the California's Water Plan Update water technology subgroup, the assessment of initiatives currently underway in the private sector in both established companies and startups and research and input by members of the project team.

An important component of the assessment included the identification of technologies already in place with the potential for broader application, and the identification of emerging technologies with the potential for broader application within the near future.

Online survey

CCST administered an online questionnaire targeted to water professionals in state and local government, academia, federal funded laboratories, and related industries.[131] Over 700 potential participants were directly contacted via email between July and October 2012.

Among other information, the questionnaire asked respondents to identify:

- What important, existing technologies are being used that have the potential for more broad application?
- If the State had money to invest, what technology would you recommend for investment? Why?
- How big of an impact could commercialization of the technology have on improvement in California's water quality, and/or water-related ecosystem?
- What are the potential roadblocks related to commercialization of this technology?
- Are there regulatory issues that must be addressed in applying this technology?

102 responses were received. Approximately forty percent of respondents were from either state or federal agencies, with the largest state contingent coming from the Department of Water Resources and regional water control boards; most federal responses were from the USDA. Approximately twenty percent were from faculty at the University of California. Responses were also obtained from Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, JPL, industry consultants, nonprofit environmental organizations, CSU campuses, and private university academia.

The technology areas suggested by the survey responses fell primarily into the following nine areas, which were used to structure the ensuing focus groups:

1. **Data acquisition - data collection/onsite monitoring (**onsite monitoring of water flow rate, water quality and environmental conditions);
2. **Data acquisition – data collection/remote sensing** (the use of **remote sensing** to evaluate snowpack and other water supply and quality conditions);
3. **Data management**(access to and use of data and modeling);
4. **Water treatment technologies -membrane filtration based**;
5. **Water treatment technologies – physical, biological and chemical (other than membrane filtration);**
6. **Watershed managementincluding groundwater recharge**;
7. **Agricultural water use efficiency**; and
8. **Urban water use efficiency**.

Focus group meetings convening experts in each of these was conducted via teleconference between January and April 2013, using subject matter experts some of whom participated in the survey and others who did not, to discuss and refine the suggestions provided by the survey and to add new ideas. 35 people participated in the focus groups; 11 of these experts had already participated in the online survey.

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131 The complete questionnaire can be found in Appendix E.

Feedback and discussion of the survey results was also solicited at several meetings, including the California Water Monitoring Council (1/10/13) and three regional meetings of the California Water Plan's Water Technology Caucus (4/10/13, 4/22/13, and 4/29/13) as well as through a meeting with the federally funded laboratories at Lawrence Livermore/Sandia on 4/19/13.

Appendix E: Online Survey Questionnaire

Water Technology Survey
Version 8, 6/26/12

Instructions

- Please take a few minutes to help identify key areas of interest and research for which you have familiarity.
- If you do not believe you have sufficient expertise to answer a particular question, you do not need to supply an answer.
- You will be given an opportunity to review your entries before submitting the form.
- If you have additional comments or input that do not fit in the survey, please send them to decillis@ccst.us.

Thank you for your time. The confidentiality of your response to this survey will be strictly maintained in accordance with practices similar to those of the National Academy of Science.

Name ______________________________

Organization ______________________________

Position/Title ______________________________

Email ______________________________

Phone ______________________________

1. What is your primary area(s) of expertise/interest within the general area of water science, engineering and technology?

2. What one category best describes your job title? (Please check only one.)

- ○ Executive (General Manager, Commissioner, Board Member, City Manager, Municipal Supt., Mayor, President, Vice President, Owner, Partner, Director, etc.)
- ○ Management/Non-Engineering (Division Head, Section Head, Manager, Dept. Head, Comptroller, etc.)
- ○ Design and Engineering/Both Managerial and Non-Managerial (Chief Engineer, Civil Engineer, Mechanical Engineer, Elect. Engineer, Environmental Engineer, Planning Manager, Field Engineer, System Designer, etc.)
- ○ Scientific/Non-managerial (Chemist, Biologist, Biophysicist, Researcher, Analyst, etc.)
- ○ Purchasing (Purchasing Agent, Procurement Specialist, Buyer, etc.)
- ○ Operations (Foreman, Operator, Maintenance Crewman, Service Representative, etc.)
- ○ Marketing and Sales/Non-Managerial (Market Analyst, Marketing Representative, Salesperson, Sales Representative, etc.)
- ○ Professorial (Educator, Teacher, etc.)
- ○ Other (If category is “Other”, please specify.)

3. Within your area of expertise/interest, what important, existing technologies are being used that have the potential for more broad application?

4. What promising technologies are EMERGING in your area(s) of expertise/interest (included are information technology needed to be developed to better support integrated data analysis for water-management)?

5.1. If the State had money to invest, what technology would you recommend for investment? Why?

5.2. How long before the technology could be commercialized?

5.3. What is the potential unit water savings and net water savings across California related to commercialization of the technology?

5.4. How big of an impact could commercialization of the technology have on improvement in California's water quality, and/or water-related ecosystem?

5.5. What might be the economic impacts of the technology for California?

5.6. What are the potential roadblocks related to commercialization of this technology?

5.7. What are the energy use characteristics of this technology?

5.8. What is the projected cost (capital and O&M) associated with this technology?

5.9. What are potential positive and negative impacts on the environment (e.g. land-use, water quality, carbon footprint, noise, hazardous waste products, etc.)?

5.10. Are there regulatory issues that must be addressed in applying this technology?

5.11. Are there social/cultural issues of concern (e.g. drinking treated wastewater)?

5.12. Please provide a list of reports, articles, etc. on the technology.

6. What information technology is needed to be developed to better support integrated data analysis for water-management?

7. What other promising areas of water related research should be explored?

8. What do you see as the most critical barriers to new innovative technology and implementation strategies?

9. Which water related technologies or research areas, in your opinion, have been less successful? Why?

10. Please list three to five individuals together with their contact information in the academic, public, and private sectors who have in-depth knowledge and experience in your area(s) of water expertise/interest.

11.1. What suggestions do you have regarding research areas beyond your area of expertise/interest that have promise we might consider?

11.2. Who should we contact in these promising areas to find out more about the opportunity? (Please provide contact information if available.)