U.S. Perspective on the Water-Energy-Food Nexus

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U.S. Perspective on the Water-Energy-Food Nexus

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Executive Summary

Water, Energy, and Food: Mutual Security through a Nexus Approach

Water, energy, and food systems are interconnected in a nexus because they draw from common stocks of natural resources and require connected infrastructures to provide essential inputs to society. Their nexus is the shared set of spaces where they are interdependent and where management decisions cause cascading effects on security of these vital resources. Effective management is required to anticipate the interactions and feedbacks that occur across the water-energy-food nexus as it responds to drivers of growth, climate change, and natural disasters in a world of growing complexity.

The mutual security of these systems and lessons from U.S. experiences were studied at a June 23-24, 2014 workshop in Golden, Colorado. Colorado State University in partnership with the U.S. Army Corps of Engineers Institute for Water Resources and the U.S. Department of State convened the workshop. The main question to workshop participants was how to plan and manage jointly and effectively across the nexus for the range of contextual situations of resources and institutional capacities found in the U.S. The workshop built on outcomes of previous forums to contribute to the international dialog by studying lessons drawn from U.S. experiences during decades of development, discovery, and challenges.

In addition to lessons learned about management across the nexus in a nation with diverse climate and cultures, insights were sought about core international goals such as security, justice and equity, poverty alleviation, and sustainable development. The U.S. has experiences ranging across more than 50 states and territories and tens of thousands of local governments and special purpose organizations, as well as a dynamic private sector that includes both for-profit and not-for-profit organizations. On top of these, think tanks and thought leaders contribute substantially to the rich knowledge base that has been built about water management experiences. To draw from this reservoir of knowledge, the workshop focused on case studies to frame specific lessons about governance, infrastructure and technology, financing, and public-private partnerships. It probed interconnected issues such as irrigated crops for biofuels, multi-purpose hydropower reservoirs, lease of agricultural water for electric power generation, and inland navigation.

While the number of cases reviewed was limited, common elements occurred across them, such as that water-energy-food nexus issues are complex and meaningful only when the scale and context are defined. No matter the level of complexity, there is a clear need to understand the nexus through study of the flows and stocks of resources and interdependencies among systems, but even more importantly, to find successful paths to shared governance to strengthen resilience of the linked systems.

Infrastructure management is a critical issue for security across the nexus, both in renewal of aging infrastructure with a triple bottom line approach and preparing for climate change and new thresholds of extreme events. As society modernizes, advanced planning before disasters is needed to provide the opportunity and blueprint for rebuilding more resilient and efficient infrastructure. This means that managers in the water, energy, and food sectors must coordinate their future infrastructure plans with the disaster preparedness sector, which has its own set of nexus issues. Competition for resources is another recurring theme. For example, agriculture faces competition for limited water and land resources from the growing urban, energy, and industry sectors. Joint governance of these sectors offers possibilities to develop shared uses and decisions about common property resources.

The clearest picture of nexus interactions is normally at the local level, where players and issues can be better defined than at higher systemic levels. The cases showed most potential for success through actions where stakeholders can forge cooperation directly, but scaling the lessons to higher policy levels is critical to provide a supportive enabling environment for them. However, no matter what happens at higher governance levels, success or failure in crosscutting problem areas is determined mainly at these local levels where multiple variables and mixtures of players and goals define the problems. As groups confront their issues locally, problem identification and solutions should be bottom-up and not top-down. It is especially important that flexibility of conflicting regulations and policies at higher levels is increased. For example, one grass-roots case showed negative consequences of on-farm regulation, but co-benefits occurred from a cooperative and flexible team approach. On the other hand, failure occurs in complex higher-level cases where there are tight regulations and weak incentives for parties to stay engaged. An important challenge to confront is to achieve cooperation across the nexus, especially considering the imbalance among water user needs, as for example the large water consumption for irrigation compared to the small consumptive use of energy production.

To motivate such local actions, the cases showed a clear need for a catalytic force such as a crisis or regulatory deadline to stimulate action to identify a convening authority, confer authority to make decisions, create a process to work within, and provide leadership to steer the process. In any of these situations, flexible processes are needed to provide for the highest and best use of shared resources and that stakeholders perceive a fair process so they are willing to share risks.

While nexus action mainly occurs at the local level, broad policy is determined at higher levels of governance. Given that water users may be suspicious of the motives of government, agencies without regulatory mandates can be involved with beneficial results to enable success. They make contributions to capacity building and serve as convening authorities to bring in models and other decision resources. For example, the U.S. Army Corps of Engineers and its involvement in river basin planning and management and management of the Inland Waterway System exhibit critical governmental roles across the nexus and show the role of the federal government in systems ownership and operation, as opposed to a purely regulatory role.

Policy barriers are formidable, especially the loss of flexibility and added constraints through regulatory controls and stovepipe approaches among the stakeholders. In confronting these, national-level water, energy, and food policy choices should identify tradeoffs between economic, social, and environmental strategies that work across the nexus and result in improved and shared security. To promote this, governments and policy scientists should encourage synergies and innovation among sectors by coordination, providing data and funding for technology development, and providing incentives and partnership forums when neither the market nor regulation achieve the desired goals. Governments and policy designers can encourage synergies among sectors and innovations that accelerate nexus security by policies that promote tradeoffs and co-benefits across economic, social, and environmental systems. In many cases, the most effective role for government is helping coordinate across sectors and with entities at regional and local levels, providing data and funding for technology development, and a combination of incentives and disincentives where market forces run counter to desired goals.

In many cases, the federal government must be careful to be policy informing but not policy-prescriptive, recognizing sovereignty of state, tribes, and allowing the right entity to make decisions and have enforcement authority when needed. Federal and state support programs can undermine incentives, but water users are also highly dependent on some federal water programs such as reservoir operations. Business and the non-governmental entities also play important roles in addressing the resource challenges faced by the world today.

The identification of strategies will vary with the context and determine the shades of governance needed, whether by regulation or enablement. A key to governance success is involvement of willing participants. Creating non-coercive incentives for participation can increase their willingness. These should be based on common regional goals. Parties should also trust each other and have an unbiased administrative or mediating entity. Governance should have appropriate and manageable scales and processes, and roles and responsibilities must be specified clearly with flexibility in the arrangements. It is also important to identify when the government should play a role at all. A structured mechanism for conflict resolution is required to facilitate groups, and it might increase the chance of collaboration if participants perceive that an external entity might make the decision in the absence of their consensus.

While shared governance processes are essential for the nexus, they add time and cost requirements, and it is important that stakeholders perceive the outcomes as being worth their investments in mutual planning and problem solving. Working on shared issues can involve multiple players who enter and leave the problem-solving process without consequences to themselves, and patience and persistence are required.

Given the extensive funding requirements of infrastructure, finance is a main driver of the nexus. Single-sector projects with limited partners may seem more accountable, but partnerships to build and operate infrastructure systems are needed to pool resources. New organizational structures to take advantage of the public and private sector approaches are needed. Again, local projects and partnerships will normally work better than large-scale programs.

Articulating a U.S. vision for water, energy, and food security that highlights the potential synergies of the nexus approach will help encourage policy initiatives at all levels of governance and is recommended as a next step. This vision may also help inform our outreach initiatives with international partners, with consideration of their unique contextual situations and realization that U.S. experiences have sometimes worked against integration. Aspects of this vision include infrastructure development and management, disaster resilience, sustainable development, water and energy efficiency, public-private partnerships, and responsibilities for implementation.

The challenge to be confronted in formulating a vision applies in the U.S. as it does to other nations: how can non-coercive collective action for water resources management be marshaled to increase security across the water-energy-food nexus? Intergovernmental and public-private cooperation is required no matter the context, and across the globe many cultures and governance systems are at play. The conclusion of this point, and the starting point for the next step, would be to ask: What specific institutional changes should be made to take advantage of lessons learned about water resources management in the U.S. and to provide incentives to overcome barriers to success such as lack of cooperation, inflexible structures, and stovepipe decision-making? These questions apply directly to the water-energy-food nexus, but they also apply to broader questions of managing resources and infrastructure to serve the economy, society, and the environment better.

Report from the U.S. Nexus Workshop

Water, Energy, and Food: Mutual Security through a Nexus Approach

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U.S. Nexus Workshop

June 23-24, 2014; Golden, Colorado

Given the many pressures on water, energy, and food systems, it is essential that national and regional strategies for development and sustainability recognize the interdependencies among them and not plan for isolated sectors. To address this need, a U.S. Nexus Workshop was convened in Golden, Colorado by Colorado State University in partnership with the U.S. Army Corps of Engineers Institute for Water Resources and the U.S. Department of State on June 23-24, 2014. The goal of the workshop was to draw from U.S. experiences to identify useful lessons about the nexus approach to management of water-energy-food systems. Building on previous forums about policy and public sector issues, the workshop focused on cases relating to technology, financing, public-private partnerships, and governance. Twenty-three experienced practitioners and scholars met in Golden to share case studies and their perspectives on food, energy, and water management and security. The workshop outcomes are designed to contribute to the ongoing dialogues about the water-energy-food nexus with sets of U.S. examples, assessment of current practices and challenges, proposed methodologies to improve management and governance, and identification of best practices and selected case studies to present in international forums such as World Water Week, the Nexus Dialogue, and the World Water Forum.

Definitions and Clarification

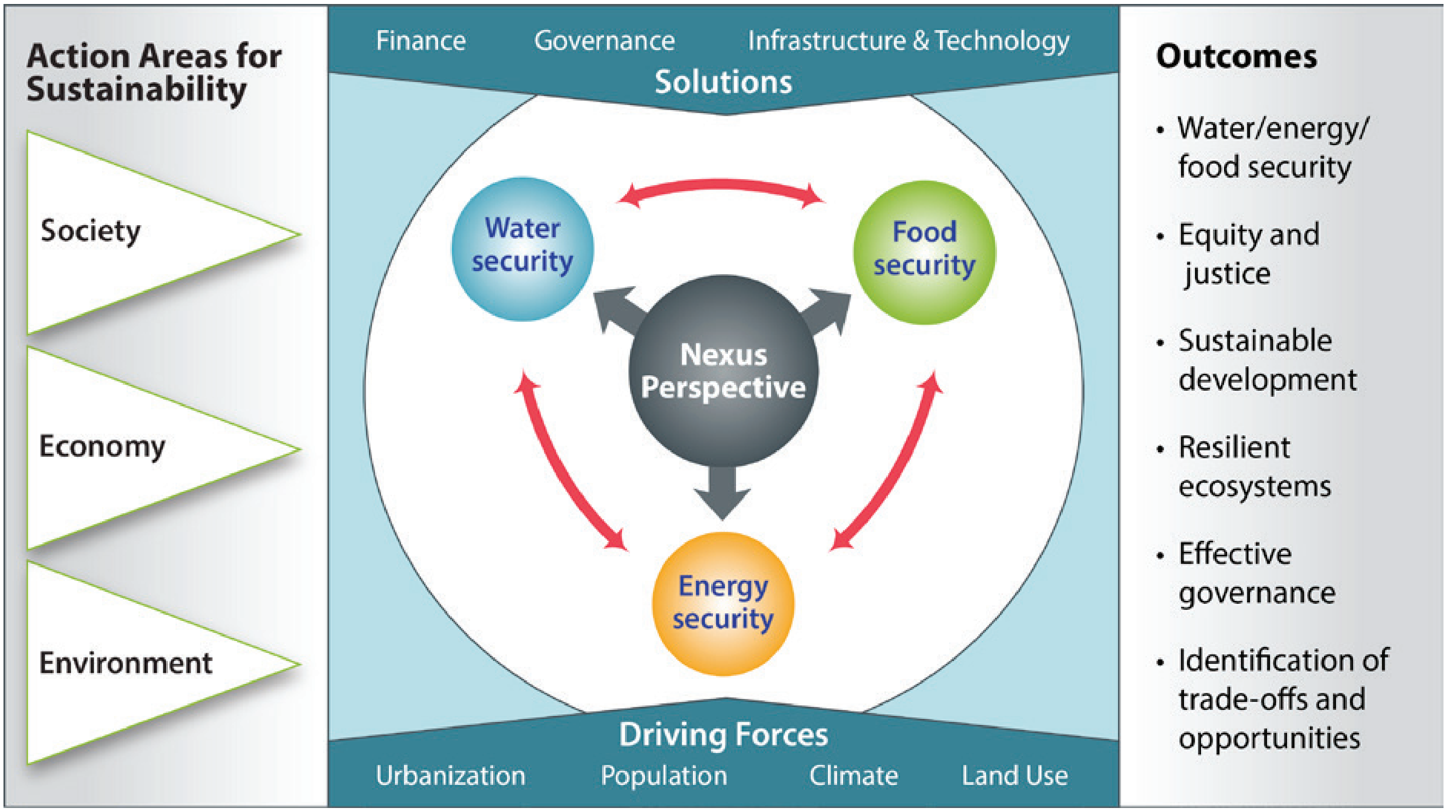
The water-energy-food nexus focuses on the intersection among the three systems shown in the figure below. The nexus approach requires us to consider tradeoffs and goals when making decisions involving all three systems, with emphasis on security, reliability, and access for all three sectors.

The linkages among the systems exhibit feedbacks as water, food, and energy are managed. As the natural environment and infrastructure work together to provide water supplies, which nourish food and energy systems, these in turn create health and prosperity for society at the same time that food and energy impact water and natural systems. Society, the economy, and the environment are the action arenas for the nexus and determine levels of sustainability, which are driven by the global trends shown. The nexus approach using finance, governance, infrastructure, and technology provides the positive outcomes shown in the figure on the following page.

The water-energy-food nexus is one of many systems involving resources and society, and its effects cannot be addressed in isolation from other systems. The nexus approach implies co-management, such as through the concept of Integrated Water Resources Management (IWRM). These concepts recognize that water is the key resource underpinning energy and food security, especially in the developing world where poverty cannot be reduced without physical security from the ravages of floods, droughts, and other extreme events. The complexity of these interacting issues can make concepts such as IWRM difficult to understand, and underscores the need to explain the nexus approach clearly, especially its feedback and adaptive features.

Workshop Background

As background for the June 23, 2014 U.S. Nexus Workshop, the team reviewed the literature about U.S. water management experiences and outcomes from previous international forums that addressed security of water-energy-food systems. The evidence to show need for the nexus approach was compelling. For example, in the U.S., thermal plants produce about 80% of electric



Adapted from: Hoff, H., Understanding the Nexus. Background Paper for the Bonn2011 Conference: The Water, Energy and Food Security Nexus. 2011, Stockholm Environment Institute: Stockholm.

power and use 41% of total water withdrawals for cooling, returning most of it to streams and reservoirs with elevated temperatures that impact water quality and ecosystems. A significant fraction of the energy generated is used for water handling, including wastewater, pumping, desalination, and water treatment. Another 37% of U.S. freshwater withdrawal is for irrigation, and pumping water for agricultural production (28% of surface water and 67% of groundwater withdrawals) also requires a great deal of energy, which is projected to increase substantially by 2030.

Given the evident interdependences between water, energy, and food systems, the nexus approach is required to integrate management and governance and help maximize benefits. While expecting to find only win-win-win solutions is unrealistic in a federal system with many players, it should help identify the best tradeoffs between conflicting objectives and produce benefits across sectors through cooperation where all sectors are improved and one sector does not gain at the expense of others. A top-down approach based on theory may not lead to the needed integration and a broad-based dialogue and engagement of all stakeholders is required, often requiring considerable time and effort. It is important to realize, of course, that the U.S. federal system is different from that of nations that lack extensive local government and rely on a national water ministry.

The main question addressed at the workshop was how to plan jointly for resilient water, energy, and food security while considering contextual situations of resource endowment and development status. Presently, the institutional capacity for effective management of water lags behind technologies in many nations, hampered as managers are by lack of resilient infrastructure, transparency, and adequate skills to manage the delivery of services to the populace.

A number of national and international conferences and symposia have identified general aspects of water-energy-food issues. These recognize, for example, that water, energy, and food systems are interconnected, interdependent, and rely heavily on water infrastructure. Also, they have identified different structures and mixes of public and private involvement in the water, energy, and food sectors, such as the cases posted by the Global Water Partnership from around the world. The emphasis on national-level and public sector solutions shows that the dialogue about the water-energy-food nexus can benefit from more emphasis on partnerships with local governments, non-governmental organizations (NGOs,) and the private sector, but this need has not been high on the agendas of international NGOs or donor organizations.

Workshop Outcomes

The workshop featured general presentations about the nature of the problems and the nexus approach, and participants presented cases to highlight U.S. lessons learned and transferable concepts. To illustrate the range and conclusions of the case studies, their key points are shown in the following table*.

Case Study	Location	Issues	Key Points relating to the nexus
Corporate Water/Food/ Energy Goals (Coca-Cola North America)	International and national	Sustainable agriculture	Requires multi-stakeholder involvement, common goals, incentives, long-term vision, public engagement, and sufficient data. Upscaling from pilots is challenging.
Columbia River Treaty Nexus	International USA and Canada	Trans-boundary governance, planning, and operations	Requires flexibility, advance planning, collaborative approaches, effective governance and dispute resolution mechanisms, with shared data, and models to manage uncertainty.
Agricultural Water Conservation	Nationwide, especially in the West	Securing water supplies in stressed river basins	Municipalities, industries, and energy sectors can partner with irrigation districts to buy conserved agricultural water, especially during droughts when food production is inefficient.
Constructed Treatment Wetlands	Nationwide	Energy saving	Energy can be saved in treating water by taking advantage of the pollutant removal capability of wetlands.
Critical Infrastructure Partnership Advisory Council	Nationwide	Protection of the Nation's critical infrastructure	Requires cross-government and public-private partnerships, collaboration and trusted information sharing, and private-sector participation.
Defining, Measuring and Improving Corn Sustainability	Nationwide	Sustainable corn production	This resulted in 53% reduction in irrigation water (energy savings as well) and 28% decrease in irrigated land. Can mitigate drought effects.
Energy Conservation	Nationwide	Energy saving	Holistic water and energy approach is demanded. Energy implications of water decisions should be addressed. Conservation options through enhancing pumping technology.
Recycled Water	Nationwide	Water and energy saving, environmental enhancement	Can create locally-controlled water supply, decrease diversions from ecosystems, decrease wastewater discharges, reduce pollution, enhance habitats, and save energy.
Recycling Materials	Nationwide	Energy saving	Recycling materials significantly reduces energy consumption (e.g., up to over 70% for recycling steel).
Research Implications for Decision Making at the Energy-Water Nexus	Nationwide	Water availability for energy generation	Challenges are resiliency of power plants to climate change, population growth, and lack of data. Both short and long-term water supply for energy generation must be considered.

Case Study	Location	Issues	Key Points relating to the nexus
Green Infrastructure	Nationwide	Energy saving	Natural ecosystems can be an energy-efficient treatment option.
The Nexus and the Inland Navigation System	Nationwide	Energy saving	Public Private Partnerships to increase reliability of inland navigation, which can conserve energy for transportation. Waterways managed by multiple Districts with compatibility of models a problem.
Thermoelectricity Generation (TG)	Nationwide	Energy sector's water efficiency	Technology can help to decrease water use, discharges, and vulnerability to water shortages. Hybrid cooling is promising in some regions.
Infrastructure Sustainability Policy	Nationwide	Promoting water sector's sustainable infrastructure	Keys are asset management, water and energy efficiency, infrastructure financing and pricing water services, as well as alternative technologies.
Integrated Energy-Water Planning in the Western and Texas Interconnections	Western and Texas	Water supply security for electricity generation	Keys for success: convening electric transmission and water planners to develop long-term plans and incorporating competing demands for water energy sector Decision Support System tools.
Catawba-Wateree River Basin Water Supply Master Plan	North and South Carolina	Water supply security in the future	Long-term, basin-wide strategies developed by engaging stakeholders to share resources and responsibilities.
Fossil Fuel Exploration and Production Nexus	Wyoming	Putting produced water in use; Hydro-fracking water supply	Water from coalbed methane can supply irrigation and environmental demands. Hydro-fracking demands large volumes of water for short-term use. Temporary transfer law enabled shift of use under existing rights.
Xcel Energy Water-Energy-Food Nexus	Colorado	Energy sectors water supply	A blackout can leave other sectors out of water. Water and energy efficiency should be balanced. Arrangements address core needs with flexibility and diversity through partnerships.
CALFED Program	Northern California	Resolving conflicts; enhancing ecosystems, water quality, and reliability	Agreements require key stakeholders, increasing public awareness, and guaranteed political and financial support. Initiative with government funding requires successful governance to endure.
Geysers Geothermal Power Plant Municipal Wastewater Recharge	Northern California	Water supply for cooling geothermal facilities	Low quality water, such as municipal wastewater, brackish or saline groundwater, can be used for geothermal energy generation.

Case Study	Location	Issues	Key Points relating to the nexus
Opportunities at the California Water-Energy Nexus	Northern California	Understanding energy intensity of water delivery (EIWD)	To develop a system-based understanding of EIWD requires data with good resolution and compatible for different sectors, tools to handle the data, and integrated data.
Southern CA Ag-Urban Transfer	Southern California	Agricultural water conservation to supply urban demand	Substituting Water Project supply with less energy intense water, Water Authority saves energy but with environmental and food security consequences.
Navajo Generating Station	Central Arizona	Sustainably securing energy supply of water transfer	Energy utilities should consider water impacts. Water utilities should consider their future energy demands. Stakeholders and government agencies have disparate interests and priorities.
Supplying Southern Nevada: Challenges and Solutions	Southern Nevada	Assuring secured future water supply	Conservation, partnerships, flexible water use agreements, alternate supplies, and diversified portfolios help secure future water supply.
NEWBA "Grass-Roots" Approach	Colorado	Agricultural water conservation	Practical ideas and grower-to-grower education encourages participation. A grass-roots approach is more powerful than traditional research or legislative approach. Cost sharing is effective.
Facing the Challenges: Water-Energy Nexus in Austin, Texas	Austin, Texas	Optimizing water sector energy efficiency and energy sector water efficiency	Water and energy utilities can integrate policies to meet demands. Utilities can collaborate to employ renewable energy. Conservation should be practiced on demand-side and supply-side

*More detail on each of the case studies can be found online at http://www.cwi.colostate.edu/workshops/NEXUS2014/

U.S. Experiences

These cases and water policy in the U.S. offer useful lessons about water governance and technology, with attention to governance for food and energy insofar as it relates to the nexus. As the connector, water extends into the other policy areas and is a logical focus for discussion. The nation has achieved rising levels of safe water service, cleanup of wastewater, development of a national stormwater program, focus on green infrastructure, reduced levels of per capita urban demand, improved energy efficiency, development of water recycling systems, and operating water infrastructure to meet environmental, energy, water supply and flood risk management demands. At the same time, difficult challenges remain, especially at the regional scale such as in achieving sustainable water solutions.

Conventional water management practices in the U.S., which roughly though imperfectly converge toward the principles of IWRM, have led to improvements in water use efficiency despite steady population growth. Freshwater demand has leveled off since 1975 despite a 33% increase in population. Farm efficiencies have increased in terms of yield per acre and reduced water demand, as has energy efficiency, which is driven by regulations, subsidies, and new technologies. Despite this progress, economic and locational factors indicate that higher water scarcity and stress will be experienced in the future, especially in the western states, and significant challenges remain. For example, agricultural production imposes loads of nutrients and sediments to waterways, presenting a significant environmental policy issue and linkages of water and energy require study and policy development, most recently in the case of hydraulic fracturing.

The U.S. has experienced many challenging large scale situations, such as the California Bay-Delta and its CALFED program, Atlanta's difficulty in obtaining an increased water supply for its growing population, regional groundwater depletion in the Ogallala Aquifer, and growth of the Gulf of Mexico hypoxic dead zone. However, notable successes have also occurred in water and energy conservation, recycled water systems, desalination, agricultural water efficiency, green infrastructure, and good quality of drinking water.

While the number of cases studied at the workshop was limited, common elements occurred across them. These include the need for a catalytic force such as a crisis or regulatory deadline to stimulate action involving a convening authority, conferring of authority to make decisions, creation of a process model to work within, and the emergence of leadership to steer the process. An archetype of this sequence of elements might involve a pending regulatory or legal action, appointment of an arbitrator or referral of the issue to a judicial panel, an order for the parties to work out their issues, appointment of stakeholders to represent the parties, and emergence of citizen leaders to catalyze and lead the solution process. This model has been evolving in the U.S. for decades as demonstrated by the national estuary program, negotiation of treaties such as the Columbia River Treaty, and resolution of the Platte River relicensing issue involving energy, hydropower, and environmental values.

Potential U.S. contributions to nexus solutions include many experiences across water-energy-food systems, but one over-arching lesson emerged from the workshop: No matter what happens at higher governance levels, success or failure in cross-cutting problem areas is determined mainly at local levels. Based on scale, the local level is the venue for a range of problem types. It can involve a small village seeking to work out water supply and energy issues, but the urban scale can also be gigantic, as for example with the case involving the challenge of water supply to the Las Vegas area. The local level can also extend to relatively large watersheds, as for example with the case involving CALFED and to regional levels, where problems of river basins occur, such as the Catawba-Wateree River relicensing case.

A common element is that water-energy-food nexus issues are complex and only meaningful when the scale, context, and mixture of players and issues are defined. At local levels, multiple attributes of time, space, and mixtures of players and goals define the problems, but effective problem identification and solutions should be bottom-up and not top-down. It is also important to reform conflicting regulations and policies at higher levels. An example of success at the grass roots level is the NEWBA case. Given the negative consequences of attempts to regulate on-farm activities, the bottom-up approach is preferable when it can be made to work to the benefit of all parties. The case demonstrated that by showing the added benefits of a team approach in a real-time situation, cooperation and success can result. Failure is exemplified by complex cases such as CALFED where there are no apparent benefits at the bottom-up level for the parties to remain at the table.

While water management is multi-scale, many issues can be resolved at the local level where stakeholders can interact directly and negotiate tradeoffs and co-benefits. This may create scale conflicts when local water issues involve regional or national energy or food issues, or when local food or energy producers deal with policies from higher levels. Agricultural issues scale from the local field to international commerce. Likewise, watersheds often span state boundaries. Energy production, generation, and transmission tend to have regional implications but water and land decisions made by energy companies have very localized impacts on water and agriculture. Getting involvement at the right scale will be key to nexus participation.

Once problem scale and context are defined, nexus solutions require identification of incentives or regional benefits and getting the right players involved. An effective and successful approach should have detailed plans that include clear management goals; advance planning to reduce uncertainty of future water, energy, and food requirements; incorporation of flexibility in planning to increase its adaptability to changing conditions (for example when there is high flood or drought, the water is correspondingly taken out of or stored in a reservoir); and employment of a collaborative approach to increase the efficiency of implementation, oversight, and issue resolution (for example, in the Columbia River Treaty, Canada stored 1,000,000 AF of water in their reservoirs to meet the U.S. endangered species problems, a win-win situation).

Knowing that problems must be solved at local levels is necessary but not sufficient to explain use of the water-energy-food nexus approach. The catalyst and especially leadership are needed to forge successful partnerships, seek out winning solutions that bridge conflicting objectives of the players and persevere across the many barriers and disappointments that inevitably occur in the long term processes that the water-energy-food nexus requires. An example of the required leadership was when Pat Mulroy, the director of a local water agency, took initiative to extend the interests of water supply in Las Vegas to a regional and international level. Institutional arrangements are also needed to provide the venue for leadership, such as the formal International Boundary Water Commission and the informal Seven Basin States working group.

Leadership takes on a catalytic role, working within a framework defined by a convening authority that can provide the roles of independent facilitator toward a consensus–building process. An example was the appointment of a facilitator by Duke Energy to work independently with stakeholders on the Catawba River relicensing program. In this situation, a Supreme Court case was settled and success achieved as a result of the facilitated process.

In any contextual situation, it is critical to identify flexible processes, such as water sharing, where the highest and best use for shared resources occurs and stakeholders perceive a fair process worthy of their support and participation. No matter what brings them to the table in the first place, they require these co-benefits to remain there and to be willing to share risks. CALFED illustrates the consequences of lack of co-benefits, whereas the Columbia River and the Catawba relicensing cases illustrate situations where stakeholders remained engaged.

Education is a major area for a U.S. contribution, particularly when international university students come to the U.S. and are taught nexus thinking. However, education is needed at all levels, particularly when a project or infrastructure upgrade will affect people's lives, recreation, or utility rates. Involving the public in energy and water conservation or efficiency programs requires a definite educational process. In many cases in the U.S., energy or water efficiency tends to involve a systems or smart-building approach. Educational programs have demonstrated the propensity for people to conserve when they see how their uses compare to neighbors. Real life demonstrations of promising and practical ideas encourage participation and adoption of winning ideas.

Disaster preparedness planning should include provisions to rebuild water-energy-food infrastructure based on smart systems for the future. Additionally, disasters or extreme events can help encourage participation that was previously lacking. For example, in the case of Catawba-Wateree River Basin, a record-setting drought helped people to realize they are not going to always have water.

Governance, Infrastructure, Financing, and Partnerships Across the Nexus

Drawing from the goal to improve security of water-food-energy systems with an integrated approach, the workshop participants were asked to determine major lessons learned about the nexus in regard to governance, infrastructure and technology, financing, and partnerships.

Governance

Case studies that showed successful governance include: Duke Energy (Catawba-Wateree River Basin Water Supply Master Plan), Western Resource Advocates (Navajo Generating Station Case Study), USACE (Columbia River Treaty Nexus Presentation), and SNWA (Supplying Southern Nevada: Challenges and Solutions). They illustrated governance across the nexus that extends to policy, regulation, institutions, and enablement where the nexus provides a shared space to work out issues involving multiple players. The application of governance will vary by the issue, as for example from the NEWBA grass roots approach to the Navajo Generating Station case, involving incentives and regulation over a vast region. The importance of enablement is shown when initiatives such as CALFED fail when they see government funding withdrawn without a successful governance structure in place.

A key to governance success is involvement of willing participants, and creating non-coercive incentives for participation based on common regional goals can increase their willingness. Parties should also trust each other and an unbiased administrative or mediating entity. Governance should have appropriate and manageable scale and process, and roles and responsibilities must be specified clearly with flexibility in the arrangements. It is also important to identify when the government should play a role. A structured mechanism for conflict resolution is required. It might increase the chance of collaboration if participants perceive that an external entity might make the decision in the absence of their consensus.

Often, the time and expense of shared governance processes seem formidable and it is important that stakeholders perceive the outcomes as being worth the time to spend on mutual planning and problem solving. Working out shared issues takes a long time and can involve multiple players entering and leaving the problem solving process. An example of a long term process required is the transfer of water from the Imperial Irrigation District to San Diego, which has taken years to complete.

While the local level is where nexus action mainly occurs, policies are normally determined at higher levels of government. Given that the motives of regulatory agencies may be inherently suspect by water users, agencies without regulatory mandates can be involved with beneficial results. These agencies make contributions on capacity building and serving as convening authorities as well as to bring in models and other decision resources. The U.S. Army Corps of Engineers and its involvement in river basin planning and management is an example, and the Inland Waterway System case provides an example of a governmental role across the nexus.

Infrastructure and Technology

While governance is critical, infrastructure and technology are also required for security across the nexus, especially to recognize the need for flexibility to make systems more robust and resilient against shocks. The cases show many examples of nexus interactions where efficiencies can be realized by infrastructure and technology development and management. It is important to consider their flexibility towards changing conditions such as climate and diverse portfolios help to develop flexible and resilient systems, such as illustrated by the Xcel Energy and SNWA cases.

Aging infrastructure is a large issue in the U.S. experience. With a replacement value exceeding one trillion dollars, the issue ranges from local water pipes to giant dams, such as those managed by the U.S. Army Corps of Engineers and Bureau of Reclamation. Whereas much of the larger infrastructure was built with federal funding and the capital resources of private electric power utilities, now the upkeep and renewal has become the major issue. A case in point is the system of Inland Waterways that is managed by the Corps and the large Bureau of Reclamation reservoir and hydroelectric systems, including those requiring retrofits to achieve environmental benefits.

Technology choices should be evaluated with a systems approach. For example, where hydropower generates a region's electricity demand, if wind energy generation is planned, it might be in excess of total energy demand. This is the case in some places such as Oregon. Since different entities/utilities provide these two sources of energy, each of them prefers to continue generating energy (even in excess of actual demand) to increase revenue.

It is also important to remember that "one size fits all" does not apply. Geography, climate, existing infrastructure, resource availability, and culture influence selection of practical solutions and supporting infrastructure and technology choices.

Integrative technologies are helping to create the utility of the future to jointly manage energy, water, and environmental residuals. The best example was at Disney World, where they operate under a goal of zero waste and full integration across sectors. Technology can support the nexus in the food sector, but investment payback is most favorable for high value products. To achieve food security in many cases, subsidies are required. In Saudi Arabia, for example, fruits, vegetables, and dates can easily pay for the cost of desalination, pumping, and water transfer, but subsidies are required for alfalfa, wheat, and other commodity crops.

Renewable resources tend to be less energy dense and require more land area, potentially impacting the food sector. Renewable energy benefits from a nexus approach, as it impacts food production, water, and land. The challenge is to optimize or find a balance between water use and land use for renewables. Optimizing systems through reducing water and energy use simultaneously should be the goal. Co-location of energy and agricultural activities can be achieved as in the case of wind turbines and cattle grazing but large solar facilities co-located with crop production presents a greater challenge.

Distributed energy, drinking water and wastewater systems offer promise of greater resilience and reliability in campus-based systems, island systems, disaster recovery areas, military bases, and similar isolated or contained areas. However, distributed systems tend to be energy-intense or water-intense. Optimizing distributed systems to be most efficient on the limiting resource while gaining efficiencies in both water and energy use and production is a key consideration. Utilizing waste streams as sources of water and energy can help achieve triple bottom line considerations.

Low quality water, such as municipal wastewater effluent, brackish, or saline groundwater, can sometimes be used in energy generation, e.g., for geothermal generation. However, co-location of a power plant and wastewater plant can be challenging. Also, the negotiation and administration process may take a long time.

Technology can be employed to share real-time data with users and stakeholders to increase their awareness and participation. Decentralized data can be collected and integrated with centralized data. For example, in the Tri-State Generation & Transmission case study (NEWBA "Grass-Roots" Approach), they used decentralized and centralized data as well as a data sharing approach to increase engagement. Similarly, integrating high-resolution energy and water utility data allowed researchers at UC Davis to map the energy intensity of water delivery at the neighborhood level for a large urban area east of the San Francisco Bay.

Water infrastructure has also evolved to support the food and energy sectors as well as the environment. Multipurpose reservoirs support water supply for agricultural and municipal purposes as well as hydropower as a renewable energy resource. Additionally, navigation systems are important for maintaining food and energy security. The inland water system is often the most fuel-efficient way to transport goods, and in the U.S. most of these goods transported are energy and agricultural products. Inland waterways are underutilized for shipping in many developing countries, which constrains economic growth. Increasing efforts in the U.S. to operate these systems to meet ecological demands enable water infrastructure to support the nexus with minimal effects on the environment.

Financing

Finance is a main driver of the nexus and future funding should maximize funding tradeoffs between sectors across the nexus. In the U.S. a financing gap of about $27 billion annually has been projected by the U.S. EPA to meet required clean water and drinking water capital needs and satisfy operations and maintenance costs. Likewise, aging infrastructure remains an issue throughout the United States. Climate change effects may escalate these costs, and adaptation strategies need to be developed.

Federal and state subsidies for large energy and water projects, particularly in the West, have created resource inefficiencies in the water-energy nexus. These subsidies have promoted inefficient and energy-intensive water use by hiding the true resource costs. Government funding for energy and water projects should target sustainable development and efficient use of financial resources.

The U.S. Army Corps of Engineers is working to increase public-private partnerships on inland navigation infrastructure projects, and currently 50% of new projects are funded from the inland navigation trust fund, based on taxes at pumps. The challenge is to incorporate the costs of infrastructure improvements and ongoing maintenance.

General financing tools available to public entities include rates, fees, bonding, pay-as-you-go, subsidies, and taxing. Ideally, subsidies should be implemented in a way that directs behavior toward sustainable production. Rates and fees can be establishes to discourage inefficient consumption. Public-private partnerships and watershed based budgeting are other financing options, as in the case of inland waterways. Tradeoffs among different options (e.g., taxing and subsidies, different sectors, etc.) should be considered.

The public may or may not choose to pay for more sustainable products (as mentioned in the Coca-Cola case). Geography, economics, environmental and social justice may impose rate increases to the users (as in the SNWA case). Another effective financing approach is cost sharing as presented by Tri-States GTE (NEWBA "Grass-Roots" Approach), where the energy sector, agricultural vendors, and growers participated in sharing the costs.

In system finance, management organizations may encounter conflicts among objectives. For example, water conservation helps greatly with both water as a resource and with energy conservation. Yet, lower water sales result in lower revenues and can create hardship or the need for rate structure modifications for utilities. Opposition to government spending results in lower maintenance budgets for federal facilities and puts the water-energy-food nexus at risk in some cases.

Partnerships

The interaction between sectors of the nexus implies the importance of developing partnerships to involve all different stakeholders and sectors in problem solving. Local, regional and cross-sector partnerships are key to managing conflict and disaster responses. Flood and drought are significantly more challenging if response and recovery efforts are implemented piecemeal or in isolated portions of an impacted river basin. Implementation of monitoring and data sharing programs greatly benefit from partnerships to support data collection.

An example of an effective partnership is cost sharing at the USACE, where federal entities find local partners to share planning and construction costs. Non-federal sponsors can be sought to build generating units on existing reservoirs, where development has been planned. Case studies that provided good examples included: Duke Energy (Catawba-Wateree River Basin Water Supply Master Plan), Western Resource Advocates (Navajo Generating Station Case Study), USACE (Columbia River Treaty Nexus Presentation), and Argonne National Laboratory (Geysers Geothermal Power Plant Municipal Wastewater Recharge).

NGOs and donor organizations can be critical partners in providing a catalyst or resources to bring nexus thinking to a local or regional problem. NGOs often serve to provide a voice in the decision making process for dispersed or those not well represented communities but tend to focus on certain issues and sectors. NGOs often work in an advocacy manner and bring a unique view to problems that can be very useful.

Public-private partnerships build social capital and local understanding of issues. Creating new relationships where people can understand what utilities and food producers are doing can move solutions along more rapidly, particularly when engagement occurs early in the process rather than after a project is in the construction phase. Water and energy conservation initiatives can also benefit greatly from partnerships between water utilities and energy utilities in a given region, as the two types of organizations are often serving the same households. Identifying and effectively engaging a broad array of stakeholders early requires effective public-private partnerships and ongoing relationships.

Unique Roles of Government and the Private Sector

Policy barriers are challenges to a nexus approach. National water, energy, and food policies must find tradeoffs between environmental sustainability and economic affordability. For this purpose, governments and policy designers should find ways to encourage synergies among different sectors and implement innovations that accelerate nexus security. In many cases, the most effective role for government is helping coordinate across sectors and entities, providing data and funding for technology development, and a combination of incentives and disincentives where market forces run counter to desired goals.

In many cases, the federal government must be careful to be policy informing but not policy-prescriptive, recognizing sovereignty of state, tribes, and allowing the right entity to make decisions and have enforcement authority when needed. Federal and state support programs can undermine incentives for crop producers and water and wastewater services to make cost-effective decisions. Examples include the lack of regulatory requirements where government funding has resulted in some utilities often waiting until direct and indirect costs become unbearable before they rehabilitate infrastructure. The lack of federal legislation for wastewater recycling has slowed its development, even though the development of recycled water is very promising. The only national guideline on non-potable water reuse provided by the U.S. EPA is partially based on a review and evaluation of current state regulations, not on rigorous risk assessment methodology. Hydraulic fracturing is not completely regulated under federal legislation, creating uncertainties associated with the type of chemicals used in the process and their impact on water and the environment.

The business or private sector also plays an important role in addressing the resource challenges faced by the world today. For example, companies can directly impact resource management within their businesses and indirectly help by encouraging their product users. Through a collaborative partnership between the United Nations Global Compact and the Government of Sweden, the CEO Water Mandate was created and launched at the Leaders Summit in July 2007. As a private-public initiative, it concentrates on creating strategies and solutions to contribute positively to the emerging global water crisis. There are currently 530 UN Global Compact participants from the U.S. (http://www.unglobalcompact.org), out of which 19 companies have endorsed the CEO Water Mandate. One difficulty observed for the private sector is maintaining a long-term consistent vision as CEOs and market conditions change.

In many situations in the U.S., public utility commissions and municipal utilities are empowered as the decision-maker and policy setter. Local government and the private sector often work effectively together and can be a catalyst for bringing together sectors and stakeholders for collaboration. One factor noted in the U.S is the changing role of government. As public values and national funding priorities shift, there has been increased emphasis placed on government agency engagement with sector actors and stakeholders.

International Application of the Nexus

The need for the nexus approach has been studied in international conferences over the past forty years, although using different terminology. As a result, Millennium Development Goals were established in 2000, with several focusing on water-related issues involving poverty, hunger, and sustainability. To address these, secure water, energy, and food production systems and corresponding infrastructure are required, but the stovepipes of sector-based approaches hinder achievement.

One example where the energy-water nexus is needed is in India, where blackouts, partially caused by subsidies for unrestricted agricultural pumping, combined with delayed monsoons, rapid urbanization, and aging infrastructure resulted in six million people without electricity for days. In China, development of unconventional gas resources is moving rapidly, revealing problems of where energy reserves and thermoelectric power generation are located versus where water is available. Energy demand for water desalination is increasing in arid places, and regions such as the UAE are actively pursuing renewable energy powered desalination. Inland waterways are underutilized for shipping in many developing countries, which constrains economic growth.

As it seeks to identify its relationships to other nations, the U.S. has made water a foreign policy priority, especially to build multi-level capacity in developing countries. It has developed Principles for Advancing Food Security and a Feed the Future Initiative. It has developed a Blueprint for a Secure Energy Future with a strategy using conventional and unconventional sources. The U.S. is the largest bilateral donor to international humanitarian organizations, including water-related services and it is also a major donor to multilateral development banks, which contribute heavily to water sector financing. The U.S. also provides support for project financing through loans and loan guarantees, risk insurance, and export credits.

The U.S. State Department works through partnerships to achieve a water-secure world. These partnerships seek to build political will and support national level planning processes, leverage expertise, technology and resources, and promote water security. In 2011, the Secretary of State signed a Memorandum of Understanding with the World Bank on cooperation toward a water-secure future. Potential activities include new technologies for access to safe drinking water, rehabilitation of watersheds and wetlands, promoting water efficiency through improved irrigation, remote sensing to improve water resources management, public-private partnerships for water infrastructure and development, and knowledge sharing. The State Department works to develop cooperation and partnerships on these issues at all scales (local, regional, international). The water-energy-food nexus can offer an entry point for international exchanges leading to bigger transboundary water issues.

Nexus Challenges and Opportunities

Moving into the future, the main challenge is how to plan and manage for water, energy, and food security in different cultural and political contexts. These sectors have traditionally been separated by policy boundaries, as well as by different academic and managerial cultures. When they intersect, it is usually a dual sector interaction: energy/water, food/water, food/energy. Occasionally, all three sectors interact, such as in the case of reservoirs that serve irrigation, hydropower, environmental, and drinking water needs. Biofuel production that competes with the food sector for water and land resources is another example, as is the transportation of food and energy via navigable waterways. Theses interactions involve a complex web of issues that need collective action. Policy is difficult to formulate, and many reports gather dust on the shelf. New challenges of urbanization, public health, and even civil disorder threaten programs of improvement.

Sustainable development requires both technological and institutional innovation. At present, the formulation of institutions for the effective management of water lags behind engineering technologies in many regions. Effective management is lacking throughout the developing world, hampered as they are by lack of transparency, corruption and lack of adequate skills to manage the delivery of services to the populace.

The nexus approach may challenge the way state and local governments are organized and approach regulatory roles. The complexity of the nexus approach may make it easy to miss a major issue. The nexus in and of itself is not a selling point but it may help regions address issues such as jobs or other economic or environmental goals.

While much of the international dialog on the water-energy-food nexus centers on meeting the U.N.'s Millennial Development Goals and forthcoming Sustainable Development Goals in the post-2015 agenda, the perspective within the U.S. differs markedly, particularly at the local and regional levels, as they do not need to pursue poverty reduction goals and are at a much different level of development. At the provider level, the economic reality facing those in the food or energy or water sector is to provide the product to the end consumer in a reliable, cost effective way that minimizes externalities such as environmental pollution and maximizes social values. Incorporating water and agriculture concerns into an energy provider's mandate, for example, complicates an already difficult set of responsibilities. A changing mindset within private companies and public utilities to incorporate consideration of when a nexus approach may provide cross-sector benefits and larger social gains is underway in the U.S., particularly where water or other resources are under pressure, but much remains to be done. Policy initiatives that provide non-coercive incentives to optimizing cross-sector tradeoffs are needed to accelerate progress.

Articulating a compelling U.S. vision for water, energy, and food security is recommended as a next step to highlight potential synergies of the nexus approach. This may also help inform our outreach initiatives with other international partners. Aspects of this vision include disaster resilience, sustainable development, water and energy efficiency, public-private partnerships, and responsibilities for implementation. Issues such as aging infrastructure, development of competitive renewable energy, and advances in water treatment and reuse provide opportunities to rethink operation of our water, energy, and transportation systems for triple bottom line objectives. In particular, advanced planning before disasters occur will provide the opportunity and blueprint for rebuilding more resilient and more efficient infrastructure after the disaster. Catalysts other than natural disasters, such as endangered species, resource conflicts, and plant relicensing will also provide opportunities for rethinking infrastructure and operations, but will require leadership that is ready and willing to consider more than solving the immediate problem and a willingness to incorporate consideration of multiple uses and benefits. These leaders must have the vision to maximize up-front local engagement with the goal of gaining local and regional benefits across sectors and stakeholder groups.

International goals for poverty alleviation and equity invoke the water-energy-food nexus but often without recognition of the role infrastructure must play. Adequate water, energy, and food infrastructure is a large component of U.S. success in securing these basic human needs and cannot be overlooked. Many transferable lessons can be learned from U.S. failures and successes in infrastructure planning, evaluation, stakeholder engagement, construction, governance, and operations.

Sumary of Case Studies

Contents

Summary of Case Studies

1. Water/Food/Energy Nexus Case Study (Coca-Cola)

Presented by Jonathan Radtke, Director of Water Resource Sustainability, Coca-Cola North America

The Coca Cola Company's sustainability framework–called "Me, We and the World"–is about three things: people, communities, and the environment. As a company, we are committed to achieving ambitious goals in each of these areas. Within this framework, we are hyper-focused on three priorities that have the biggest impact on our business and for the people and communities we serve: Well-Being, Women, and Water. In the water stewardship space, our goal is to balance our water use, or in other words, achieve "water neutrality." We work to safely return to nature and communities an amount of water equivalent to what we use in our beverages and their production. This is performed through reduction, recycling, replenishment, and risk management. They also actively promote sustainable agriculture to:

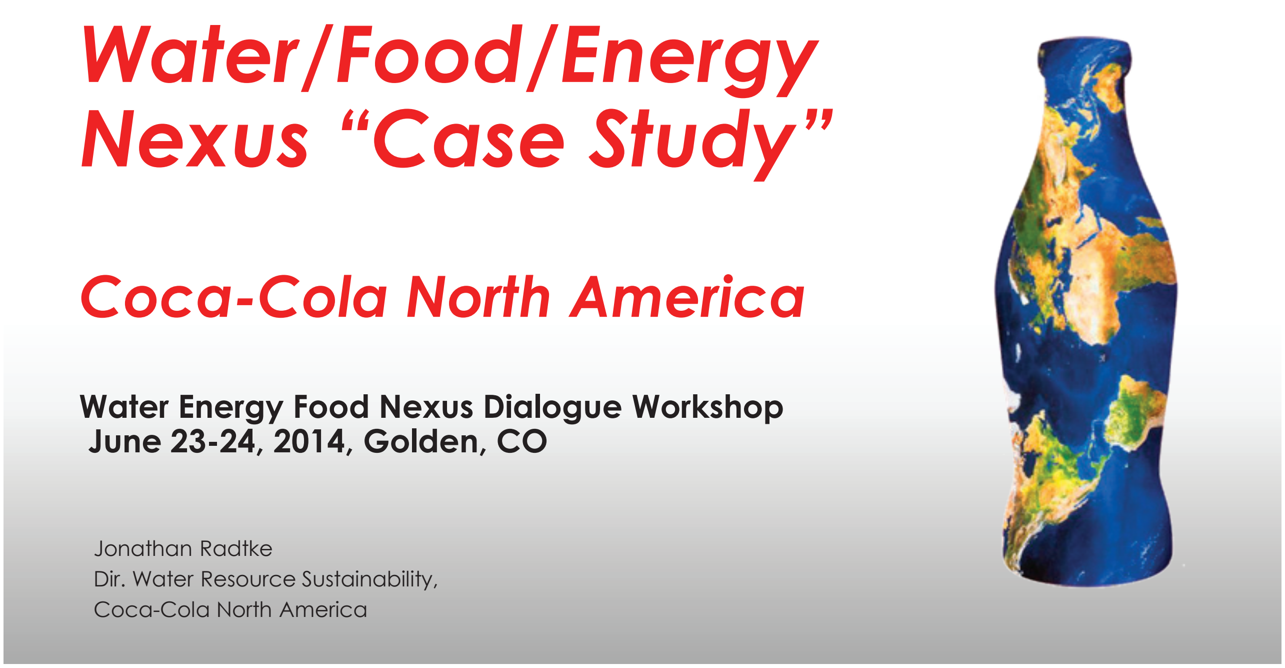
- Enhance brand by improving social and environmental outcomes at the farm
- Increase continuity and resiliency of their agricultural supply chains through more strategic supplier relationships
- Support required top line growth through increasing yields
- Protect their license to operate in developing geographies dependent on agricultural economies

For their Sustainable Agriculture Replenish Projects, which include treatment wetlands, variable rate irrigation, and no-till farming, they partner with farmers, WWF, NRCS, CSU, MSU, Walmart, etc. Based on their nexus approach studies, the followings are concluded: a nexus approach needs multiple stakeholders, who understand common goals; it is challenging to upscale from pilot to wide-spread adoption; incentives are required to get stakeholders involved; a long-term vision is required. They also identified gaps as: not all sectors are engaged; government policies/subsidies don't align with sustainability strategies and goals; there is a lack of public engagement/understanding. They believe that contribution of corporate sector can influence supply chain, leverage political clout, influence peer companies, and promote communication with consumers.

For more information:

http://www.coca-colacompany.com/sustainabilityreport/world/water-stewardship.html

http://www.coca-colacompany.com/water-stewardship-replenish-report/



Why Sustainable Agriculture?

Vision 2020 growth	+	Ag ingredient supply constraints	+	Global trends magnifying market forces	=	Changed operating conditions for TCCC
• Double revenue by 2020 • **Requires 2x sourcing of agricultural ingredients**		• Population growth • Emerging global middle class • **Biofuels** • **Climate volatility** • **Water stress** • Soil degradation and yield decline • R&D investment lag		• Social media • Increased power of civil society • Connectedness • Globalization • Increasing power & declining trust in corporations		• Increasing brand risk tied to sourcing • **Increasing risk of supply disruptions** • **Rising cost and price volatility of key ingredients** • Changing consumer preferences

Business value at stake

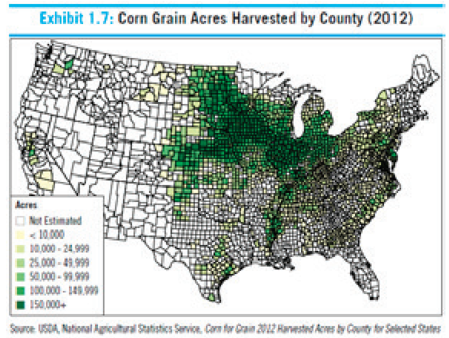
Our sustainable ag commitment can:

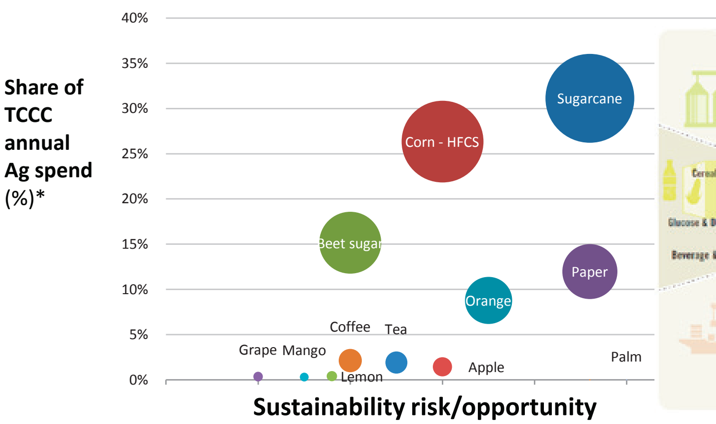
- Enhance brand by improving social and environmental outcomes at the farm
- Increase continuity and resiliency of our ag supply chains through more strategic supplier relationships
- Support required top line growth through increasing yields
- Protect our license to operate in developing geographies dependent on agricultural economies

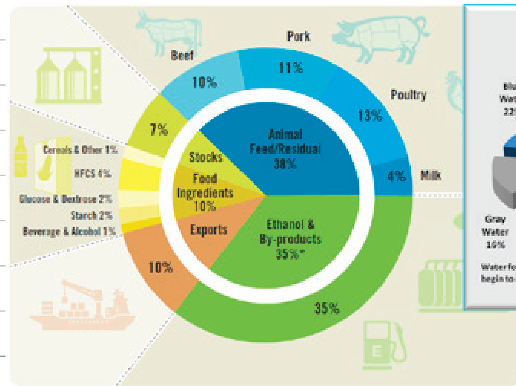
Coca-Cola Technical Classified - Internal use Internal Use Grow + Protect + Sustain 4

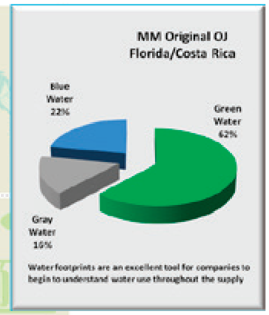
Our ag supply chains are critical to achieving our revenue goals and protecting our brands

- TCCC system ag system spend over **$12.5 billion** annually
- Primary Ag ingredient in US is **corn**
- "Sustainable sourcing" based on our SAGP









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Sustainable Agriculture Replenish Projects

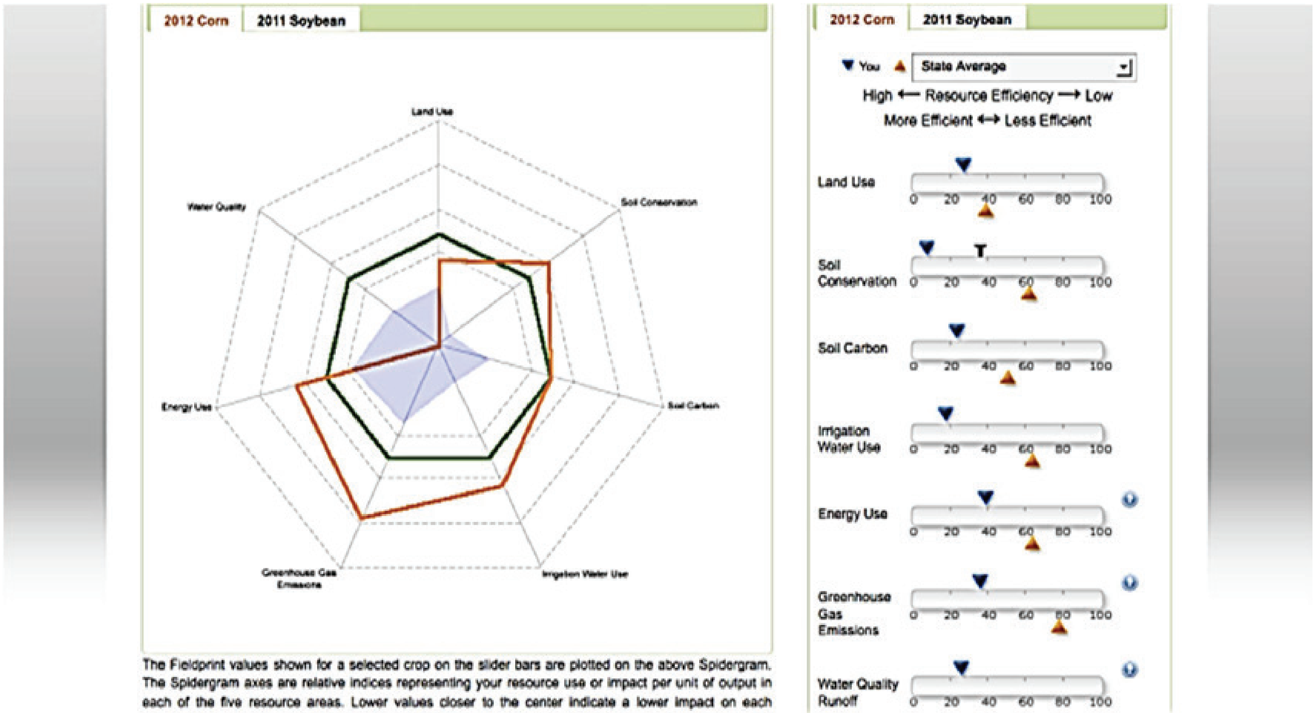
(Partners: Farmers, TNC, WWF, NRCS, FtM, CSU, MSU, Walmart, etc.)

Treatment Wetlands

VRI

No-Till Farming

Innovative Tool - Fieldprint Calculator



Field Print Calculator is a handy "farmer recruiting tool". Fieldprinting helps producers' farm management decision-making to ultimately increase agricultural efficiency, water quality and source water quantity protection across the watershed

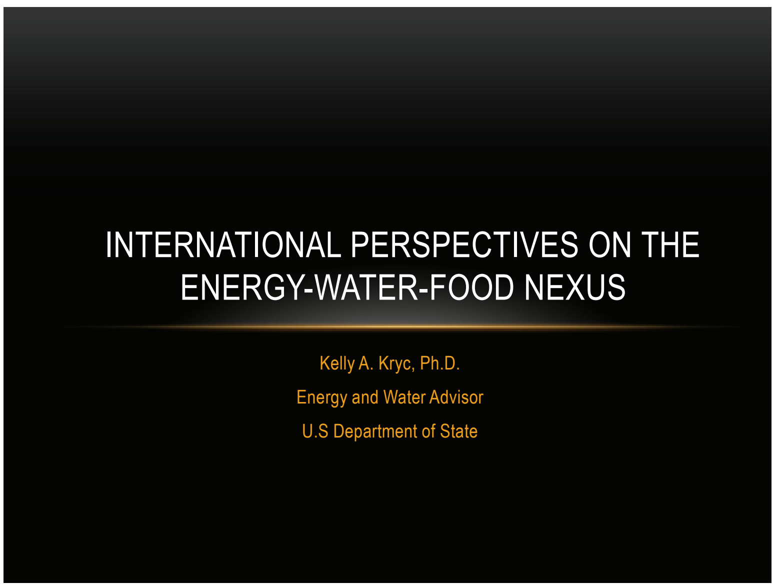
Preliminary Results from Nexus Case Study on Corn

- Lessons Learned from Nexus Approach
  - Need multiple stakeholders – understand common goals
  - Pilot scale to wide-spread adoption
  - Incentives
  - Need long-term vision
- Identified Gaps
  - Not all sectors are engaged
  - Government policies/subsidies don't align with sustainability strategies and goals
  - Lack of public engagement/understanding – more data?
- Contribution of Corporate Sector
  - Influence supply chain
  - Leverage political clout
  - Influence peer companies
  - Communicate to consumers
- Global Application
  - Technology transfer

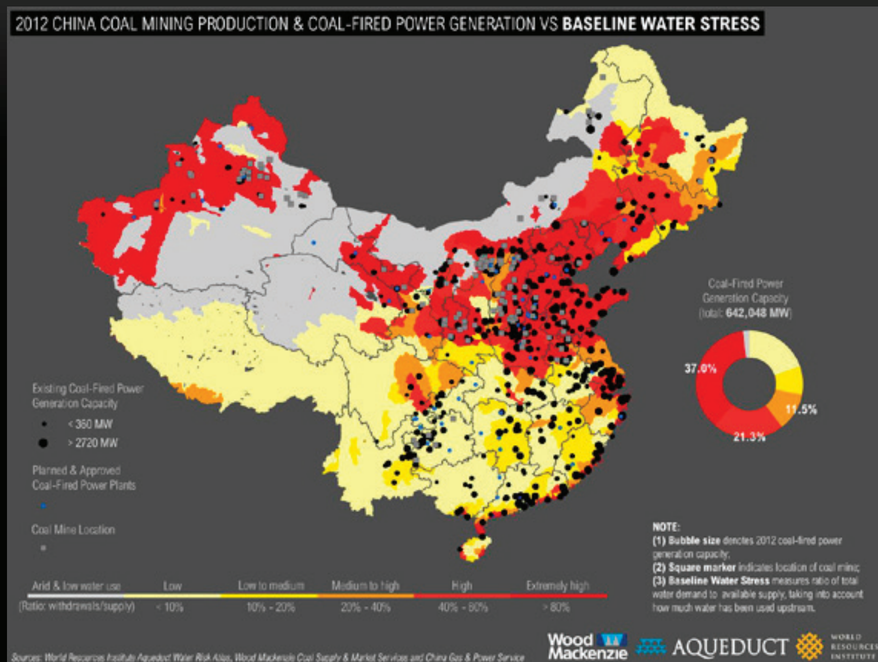
2. International Perspectives on the Energy-Water-Food Nexus

Presented by Kelly A. Kryc, Energy and Water Advisor, U.S Department of State

The energy-water nexus is an important issue for the United States domestically and internationally as we strive to strike a balance between energy access and supply and sustainable development of our natural resources. By 2050, 80% more energy, 55% more water, and 60% more food will be required to supply population demands. To overcome this global challenge, governments and industry should work together and use innovative technologies and policies and also share experiences in what works and what doesn't. Solving the problem requires new ways of cooperating and coordinating across sectors from local to international scales. Sufficient data acquisition, technology development and employment, increased synergies, and incentivizing conservations are keys to solve the problems associated with this global challenge. We need to better understand the problem, the connections, and the impacts by generating, using, and openly sharing improved sources of data. We can implement existing, innovative, off-the-shelf technologies that promote energy and water efficiency, use non-traditional sources of water for energy production and generation, or create water and energy from waste. Energy and water decision-makers must work together to ensure that decisions made by one sector don't impact the other. We can help by strengthening institutions and establishing mechanisms for joint planning and development across sectors. Incentives are an effective tool to encourage conservation of water and energy. We can start working to create policy and regulatory frameworks that strengthen local capacity and enable businesses to serve as a catalyst for change.



CHINA



UNITED ARAB EMIRATES

MORE WITH LESS

- The energy/water nexus is an important issue for the United States domestically and internationally as we (and others) strive to strike a balance between energy access and supply and sustainable development of our natural resources.
- By 2050, there will be 9 billion people on earth requiring 80% more energy, 55% more water, and 60% more food than today.
- This is a global challenge, but there are solutions.
- Governments and industry working together can overcome these challenges using innovative technologies and policies and sharing our experiences in what works and what doesn't.
- Solving the problem requires new ways of cooperating and coordinating across sectors at local, national, regional, and international scales.

NEXT STEPS

- **Get data**. We need to better understand the problem, the connections, and the impacts by generating, using, and openly sharing improved sources of data.
- **Deploy technology**. We can implement existing, innovative, off-the-shelf technologies that promote energy and water efficiency, use non-traditional sources of water for energy production and generation, or create water and energy from waste.
- **Work together.** Energy and water decision-makers must work together to ensure that decisions made by one sector don't impact the other. We can help by strengthening institutions and establishing mechanisms for joint planning and development across sectors.
- **Use incentives.** Incentives are an effective tool to encourage conservation of water and energy. We can start working to create policy and regulatory frameworks that strengthen local capacity and enable businesses to serve as a catalyst for change.

NEXT STEPS

- Internationally, the State Department is supporting nexus dialogues to share best practices that can help countries address their energy and water challenges.
- The United States is committed to finding and implementing solutions to these problems and welcomes the opportunity to partner with other governments in this effort.

CHARGE TO PARTICIPANTS

- Summarize current practices
- Identify key challenges
- Propose new methodologies to improve management and governances
- Define best practices and select case studies to communicate internationally

IUCN IWA

NEXUS DIALOGUE ON WATER INFRASTRUCTURE SOLUTIONS

7th World Water Forum 2015
Daegu & Gyeongbuk, Rep. of Korea

3.Columbia River Treaty Nexus Presentation

Presented by Jim Barton, U.S. Army Corps of Engineers, Northwestern Division, Chief, Columbia Basin Water Management Division

This case study involves the implementation of the Columbia River Treaty (Treaty) between the U.S. and Canada. The Columbia River System is a very large and diverse river system that is comprised of close to 100 different water resource projects that are operated by many different entities to achieve a number of different objectives. Approximately 15% of the basin is in Canada, but on average about 38% of the river flow originates in Canada. The U.S. and Canada signed a Treaty in 1964 that is focused on flood risk management and hydropower. This Treaty provides an excellent framework for trans-boundary governance, planning, and operations that can be used to address water and energy security.

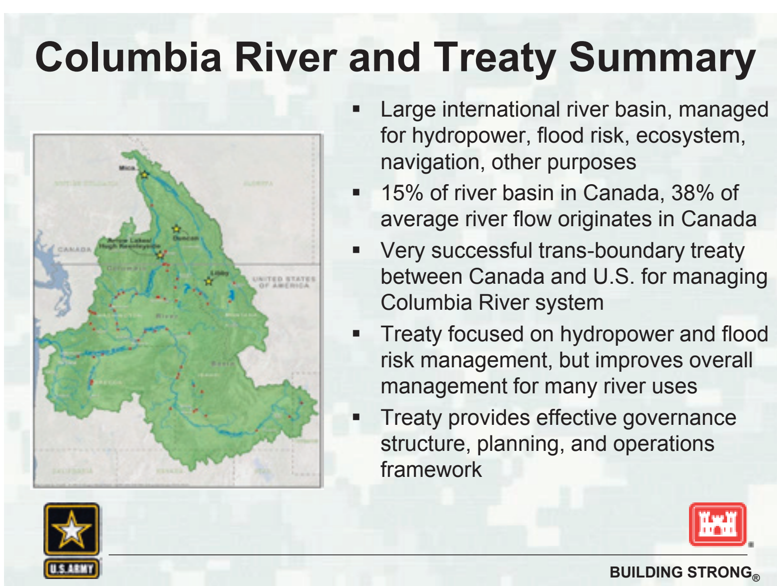
Some of the key lessons that can be learned from this Treaty are that it: (1) provides good processes and procedures for trans-boundary water management planning and operations; (2) incorporates flexibility and advance planning to help manage the uncertainty in river operations; (3) is based on a collaborative approach with an effective governance structure and dispute resolution mechanisms that can be used if needed; and (4) incorporates shared data, models, and analysis.

For more information:

http://www.nwd-wc.usace.army.mil/PB/PEB_08/crt.htm

http://www.crt2014-2024review.gov/Default.aspx

http://www.crt2014-2024review.gov/files/10aug_hyde_treatypastfuture_finalrev.pdf



Key Lessons Learned

- Treaty provides clear water management plans and procedures: improves ability to achieve goals and objectives, reduces chances for miscommunication
- Treaty requires advance planning: reduces uncertainty about meeting future energy and water requirements, etc.
- Treaty incorporates flexibility: adaptable to changing conditions
- Treaty involves collaborative approach: encourages innovative solutions to new requirements and challenges
- Treaty utilizes effective governance structure: enables effective implementation, oversight, and issue resolution
- Treaty requires shared data, models, and analysis: ensures transparency, use of latest technology

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Gaps

- Treaty primarily focused on hydropower and flood risk management, does not formally include other purposes such as ecosystem as a primary focus
- Funding available for some water resource projects in basin inadequate for increasing operating demands being placed on aging infrastructure

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Contribution to Water Energy Food Nexus

- Provides good model for international water management collaboration in a complex river system
- Allows both U.S. and Canada to achieve changing energy, water, and related objectives through advance planning and analysis

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Other Examples

- Pacific Northwest Coordination Agreement: Regional agreement among public and private hydropower owners in Pacific Northwest to plan and coordinate operation of their projects as if they were one utility, optimizing energy production

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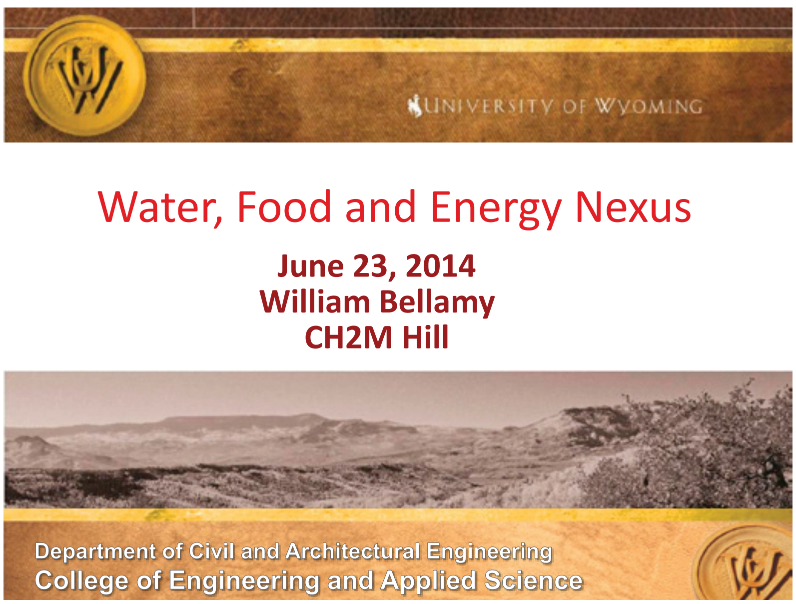
4. Water, Food, and Energy Nexus

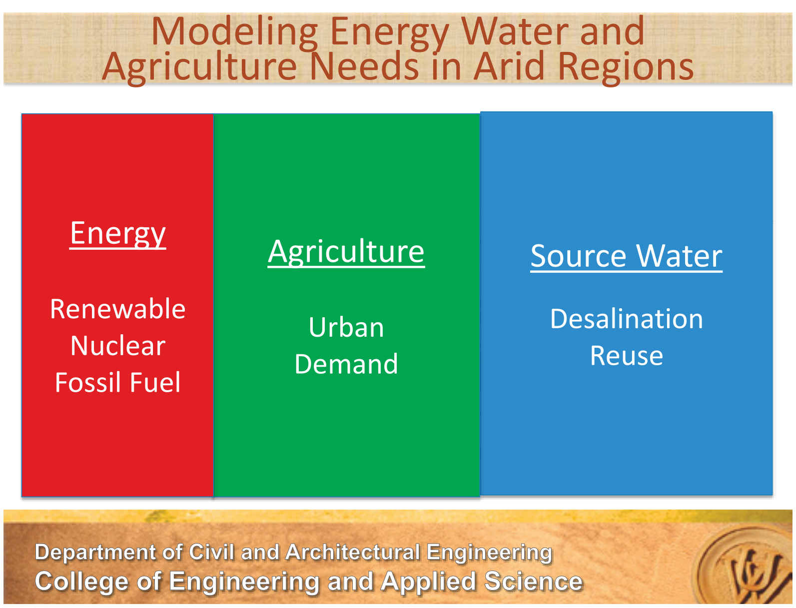
Presented by William Bellamy, Fellow and Senior Vice President of Water Technologies, CH2MHILL; Professor of Practice, University of Wyoming

This case is based on balancing water, power, and agricultural needs in Saudi Arabia. It analyzes food security based on cost of water by desalination of sea water with renewable energy, i.e. solar energy. They used an integration of salt management technologies to supply agricultural water. For water source, they used desalinated water, groundwater, treated groundwater, and treated pervaporation water. The irrigation system was equipped with standard spray or drip irrigation, and pervaporation system. They also used hydroponics to grow plants.

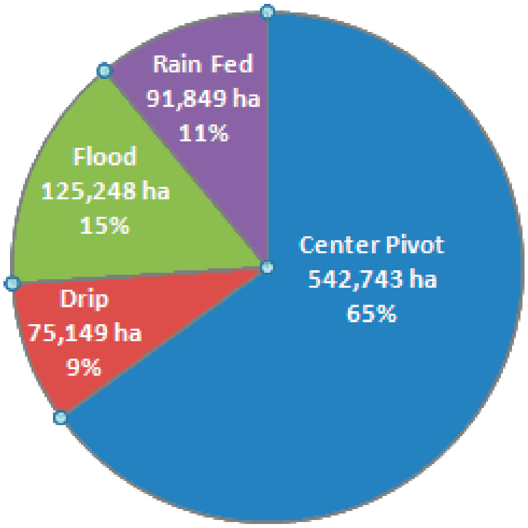
Main lessons learned from this study include:

- Each case has specific needs and different drivers that must be considered
- Dynamic simulation provides a tool to consolidate information for assessment and decisions making
- A wide range of expertise is necessary to integrate technology's involved (water, energy, ag, modeling)
- Today's technologies are effective and can be integrated into a full energy, water, food program
- Costs are high but economically achievable
- Policy and governance must lead to initiate change (e.g., secure loans, subsidies, policy changes, etc.)



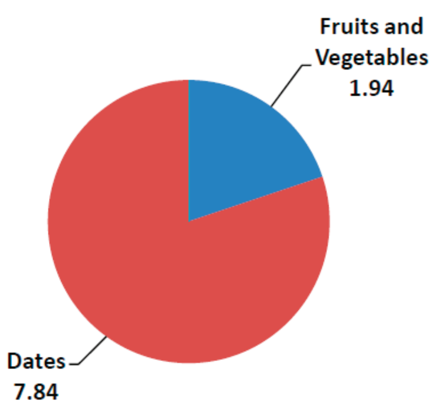


Agriculture Water Use in Saudi Arabia

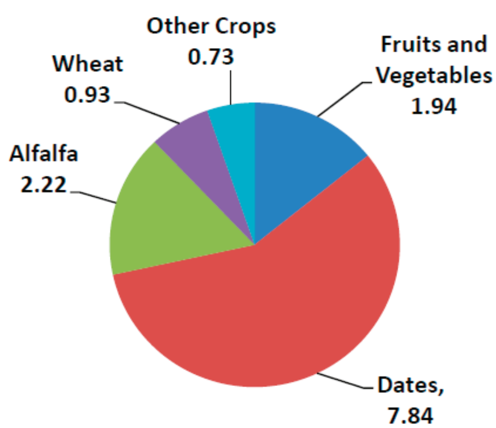


Department of Civil and Architectural Engineering
College of Engineering and Applied Science

Balancing Water Power and Ag Needs in Saudi Arabia



Full Cost of Water



Subsidies Required

Analysis of food security based on cost of water
Desalination of sea water with renewable energy

Department of Civil and Architectural Engineering
College of Engineering and Applied Science

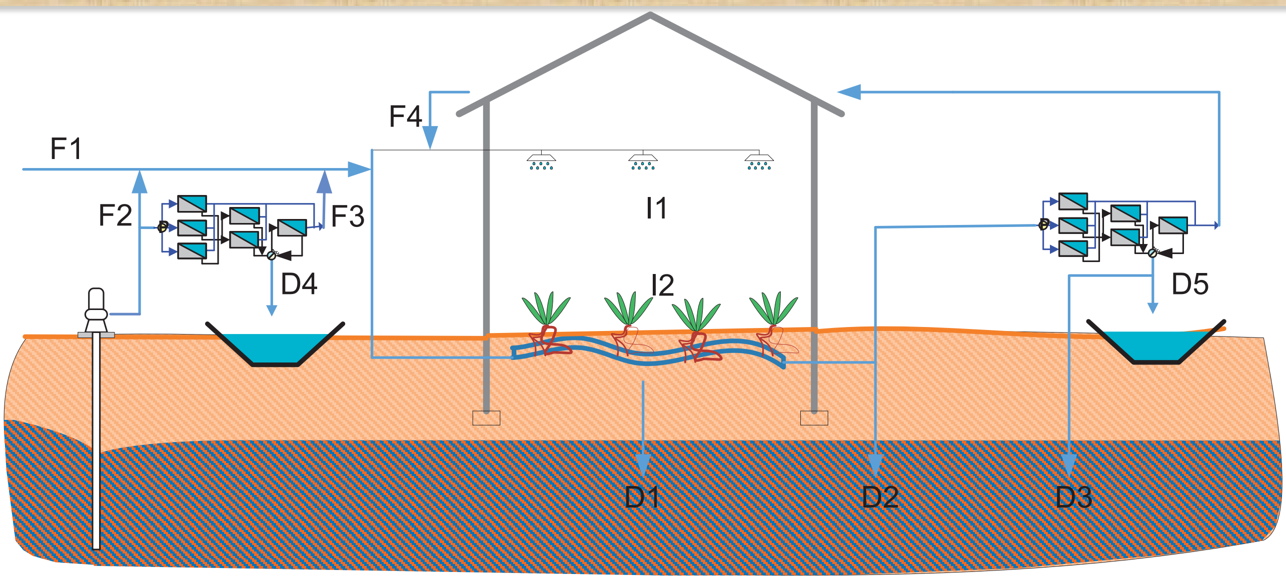
Solar Project Experience and Modeling from US Companies

Department of Civil and Architectural Engineering
College of Engineering and Applied Science

MED and RO Desalination Technologies

Department of Civil and Architectural Engineering
College of Engineering and Applied Science

Integration of Salt Management Technologies



- Water sources
  - Desalinated water (F1)
  - Ground water (F2)
  - Treated ground water (F3)
  - Treated pervaporation water (F4)
- Irrigation waters
  - Standard spray or drip irrigation (I1)
  - Pervaporation system (I2)
- Water discharge or drain
  - Discharge from greenhouse drainage (D1)
  - Tail water from pervaporation (D2)
  - RO brine to evaporation pond (D3)
  - RO brine to evaporation pond (D4)

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Pervaporation Research with High Salinity Water – University of Wyoming

Contact: Satish Muthu, smuthu@uwyo.edu, or Dr. Jonathan Brant at UW

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Hydroponics and drip irrigation in Saudi Arabia

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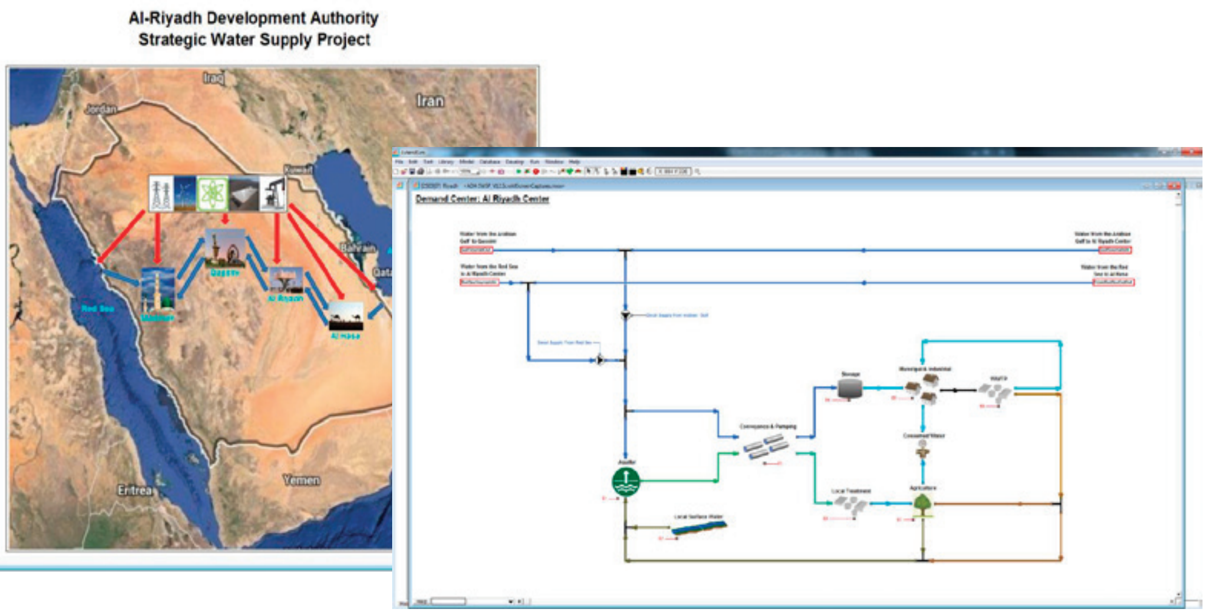
Dynamic Simulation Balancing Energy Water and Agriculture



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Lessons Learned

- Each case has specific needs and different drivers that must be considered
- Dynamic simulation provides a tool to consolidate information for assessment and decisions making
- A wide range of expertise is necessary to integrate technology's involved (water, energy, ag, modeling)
- Today's technologies are effective and can be integrated into a full energy, water, food program
- Costs are high but economically achievable
- Policy and governance must lead to initiate change (e.g., secure loans, subsidies, policy changes, etc.)

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5. Agricultural Water Conservation

To secure water supplies in stressed river basins, especially in the West, water conservation agreements have been gaining attention over the last decade. In 2008, the Western Governors' Association in their publication, Water Needs and Strategies for a Sustainable Future: Next Steps, identified that "…states, working with interested stakeholders, should identify innovative ways to allow water transfers from agriculture to urban use while avoiding or mitigating damages to agricultural economies and environmental values." In Southern California, municipalities partner with irrigation districts and pay for agricultural water conservations to use the conserved water. The conservation methods typically practiced are enhancements in irrigation delivery system, on-farm irrigation efficiency improvements, land fallowing programs, and environmental conservation [1].

Among different water conservation methods, fallowing agreements have largely been practiced in Southern California [2]. Although there are concerns that these types of agreements may ultimately result in redirecting agricultural water to the other users, in several cases, the parties have successfully become to an agreement to leave agricultural lands for fallowing and transfer the corresponding water to the municipal sector. Examples include the consensus between the Imperial Irrigation District and San Diego County Water Authority in 2003, where they agreed to transfer 200,000 acre-feet of water per year from the irrigation district for a 45-year period subject to be renewed for another 35-year period. The district must fallow agricultural lands for the first 15 years and then implement efficiency-based conservation practices [3]. Another example is the agreement between the Palo Verde Irrigation District and the Metropolitan Water District in 2004. They agreed to transfer 25,000 to 118,000 AF/year from agricultural water to urban Southern California for 35 years. This water is saved by fallowing 7% to 28% of each agricultural land [4, 5]. Yuma Mesa Irrigation and Drainage District and the Central Arizona Groundwater Replenishment District (CAGRD) have also signed a 3-year pilot agreement, effective as of January 2014, to save about 9,000 acre-feet per year water, through fallowing 1,500 acres of agricultural lands. This water will initially be used to conserve water in the Colorado River system to be maintained in Lake Mead. It is also seen as a supply acquisition strategy for groundwater replenishment by CAGRD [2]. However, while planning for agricultural water conservations, it is important to assure that these practices will not reduce crop yield, as food deficit is going to be a problem for the growing population.

For more information:

http://cwi.colostate.edu/publications/sr/22.pdf

https://wrrc.arizona.edu/arizona-land-fallowing

http://agwaterconservation.colostate.edu/

6. Constructed Treatment Wetlands

As natural water filtration systems wetlands play an important role in removing water pollutants, such as nutrients and sediments. The pollutant removal capability of wetlands would save a considerable amount of energy that would otherwise be used to treat water.

Wetlands can also help flood control and groundwater recharge. The "no net loss" wetland policy in the United States requires rebuilt of wetland destroyed for development in the same size and watershed. However, artificial wetlands require more energy.

Link(s) for more information:

http://water.epa.gov/type/wetlands/restore/cwetlands.cfm

http://www.epa.gov/owow/wetlands/pdf/ConstructedW.pdf

http://water.epa.gov/type/wetlands/constructed/upload/guiding-principles.pdf

7. Critical Infrastructure Partnership Advisory Council

The U.S. Department of Homeland Security (DHS) is responsible to protect the Nation's diverse and complex critical infrastructure. In 2006, DHS issued the National Infrastructure Protection Plan (NIPP), which was updated in 2009, as a unifying framework to integrate efforts that improve the protection of the Nation's critical infrastructure. In February 2013, Presidential Policy Directive 21: Critical Infrastructure Security and Resilience (PPD-21) was declared as: "proactive and coordinated efforts are necessary to strengthen and maintain secure, functioning, and resilient critical infrastructure—including assets, networks, and systems—that are vital to public confidence and the Nation's safety, prosperity, and well-being." NIPP is currently under revision as part of implementation of PPD-21.

The Critical Infrastructure Partnership Advisory Council (CIPAC), established by the DHS Secretary, and national critical infrastructure partnership structures aim to enable the collaboration and trusted information sharing required to enhance the protection of the Nation's critical infrastructure. CIPAC is an advisory council which promotes coordinating, communicating, and sharing effective practices across critical infrastructure sectors, jurisdictions, or specifically defined geographical areas. It values the private-sector participation in the critical infrastructure mission as an essential planning strategy. As an effective entity that has increasingly enabled cross-government and public-private partnerships, CIPAC's general achievements include [6]:

- Member institutions increased from 962 in 2012 to 1,130 in 2013.
- In 2012, 60 working groups held a total of 199 meetings and in the first half of 2013, 42 working groups held a total of 100 meetings under CIPAC. These meetings aimed for information sharing, training and exercises, research and development, program evaluation, strategic planning, risk management, and sector-specific metrics development.
- For the third year in a row, through the Regional Partnership Engagement effort, CIPAC convened more than 300 participants, representing 257 critical infrastructure owners and operators from almost all sectors. The participants discussed steps that DHS can take to better satisfy owner/operator security and resilience goals and to strengthen the value of the public-private partnership.

For more information:

http://www.dhs.gov/sites/default/files/publications/CIPAC_2013_annual_report.pdf

8. Defining, Measuring, and Improving Corn Sustainability

Presented by Jon Holzfaster, Farmer, National Corn Growers Association

Field to Market is a diverse alliance working to create opportunities across the agricultural supply chain for continuous improvements in productivity, environmental quality, and human well-being. The group provides collaborative leadership that is engaged in industry-wide dialogue, grounded in science, and open to the full range of technology choices. As part of the national Field to Market sustainability initiative, the National Corn Growers Association and its partners are working to define, measure and promote sustainability overall – including water use.

In Field to Market's first report, released early in 2009, they looked at environmental resource indicators in five areas including: water use and quality, land use and biodiversity, soil loss, energy use and climate change. This report helped establish trend in corn's impacts over the past 20 years and established a baseline for future work. In 2012, a second report was released that updated the timeframe for the measurement and included socioeconomic indicators as well. According to this report, irrigation water used per-bushel has decreased by 53% from 1980 to 2011. Volume per irrigated acre also decreased 28% during this period. Average per-acre water use (per irrigated acre) was 12.0 acre inches in 2011 compared with 16.8 acre inches in 1980.

In 2012, corn growers experienced the worst drought in years, a drought that cut four billion bushels from overall production. In spite of this, production per-acre overall was phenomenal in the states most impacted by drought. Conservation practices, precision farming and better hybrids and biotech all played a role and will continue to do so in the future.

http://www.fieldtomarket.org/news/2012/field-to-market-releases-national-report-on-agricultural-sustainability/

http://www.fieldtomarket.org/report/national-2/PNT_SummaryReport_A17.pdf

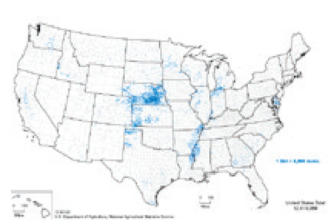
NCGA

Defining, Measuring and Improving Corn Sustainability

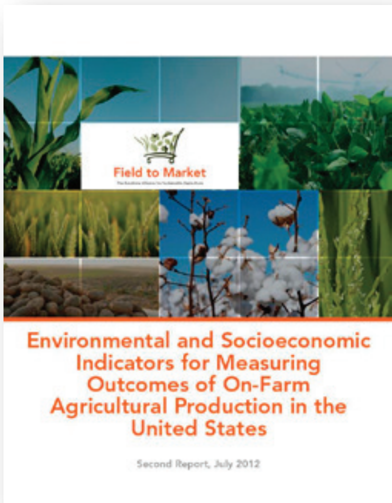
Jon Holzfaster, June 2014

Irrigation and Corn

- Less than 15% of corn acres are irrigated.
- Irrigated corn accounts for less than 20% of total irrigated cropland acres in the United States.
- Through evapotranspiration, corn returns more water to atmosphere than is used in irrigation.



Field to Market 2012 Report

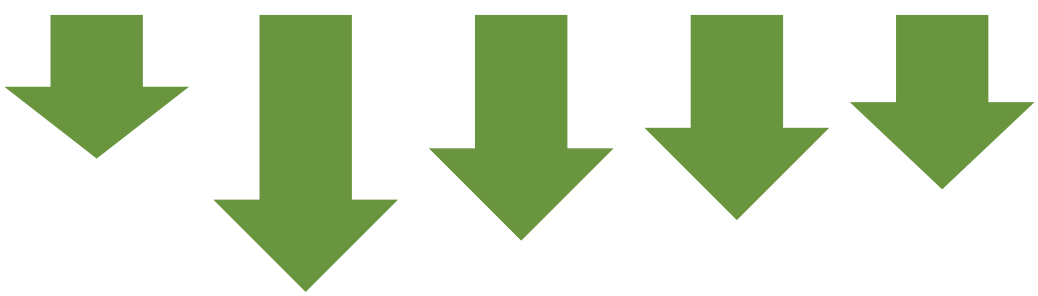


- Looked at five environmental indicators from 1980-2011
- Including irrigation
- Added specific socioeconomic indicators for the first time also

NCGA

Corn's Impacts, 1980-2011

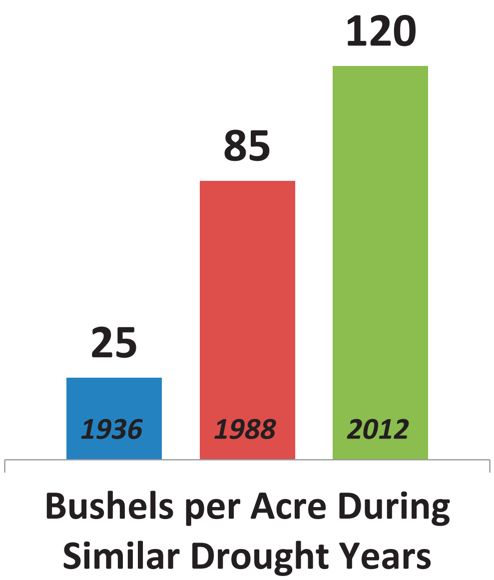
Land Use	Soil Loss	Irrigation	Energy	Climate
Amount of land to produce one bushel of corn	Soil loss per bushel, above a tolerable level	Irrigation water use per bushel	Energy used to produce one bushel	GHG emissions per bushel



30%	67%	53%	43%	36%

NCGA

Corn Growing in Times of Drought



In 2012, several factors helped corn farmers harvest more corn per acre compared to other bad drought years. Examples:

- Practices that are more sustainable, such as conservation tillage
- Mapping technology so farmers can meet their fields' specific challenges better
- Stronger plants due to better hybrids and biotechnology

NCGA

Improving Ethanol Production

	2012 Corn Ethanol	2008 Corn Ethanol
Yield (gallons/bushel)	**2.82**	**2.78**
Thermal Energy (Btu/gallon, LHV)	**23,862**	**26,206**
Electricity Use (kWh/gallon)	**0.75**	**0.73**
DDG Yield (dry basis) including corn oil (lbs/bu)	**15.73**	**15.81**
Corn Oil Separated (lbs/bushel)	**0.53**	**0.11**
Water Use (gallon/gallon)	**2.70**	**2.72**

NCGA

9. Energy Conservation

Energy conservation can be effectively practiced in water supply and treatment. Due to their high energy demand, enhancing and updating the technology of pumps is one of the most straightforward energy conservation options [7, 8]. In early '90s, it was estimated that 880 million kWh (30% of total use) can be saved in treatment plants by load shifting, variable frequency drives, high-efficiency motors and pumps, equipment modifications, and process optimization [7]. The energy crises in 2000 and 2001 forced a number of California water agencies to join an energy and conservation campaign. In one year, they reduced their energy use by up to 15% by employing some techniques such as: adjusting operation schedules, increasing water storage, utilizing generators, optimizing cogeneration and installing efficient water system equipment, variable frequency drives, and advanced equipment controls [7].

A range of approaches for energy savings are also emerging in the water sector. These include [9]:

- A holistic water and energy management approach to: develop local water sources instead of transferring water great distances; use advanced transport and treatment management systems; employ energy efficient water system products (e.g. premium efficiency pumps and motor systems, new types of low pressure membrane filtration, more energy efficient ultra-violet disinfection technology, advanced aeration equipment, and energy recovery systems for desalination)
- Research and development on innovative and energy efficient water treatment technologies such as: membranes to desalt at much lower pressures, with higher yields; ultraviolet disinfection with less energy demand; real-time monitoring systems for raw water quality to control and optimize instantaneous treatment process; and decentralized treatment systems to improve the water and energy use efficiency
- Behavioral changes through the incorporation of sustainability considerations and new design, management and operational philosophies
- Identify and address energy implications of water policy decisions through better coordination among resource management agencies
- Using lessons learned from other industries, such as the oil industry, in terms of exploring alternative ways of operating

For more information:

http://www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.PDF

http://www.gao.gov/new.items/d11225.pdf

http://www.johnsonfdn.org/sites/default/files/conferences/whitepapers/10/05/13/Johnson_Foundation_Environmental_Forum_Examining_U.S._Freshwater_Systems_and_Services_Nov16.pdf

10. Recycled Water

Water recycling has numerous benefits. It can create dependable, locally-controlled water supply, decrease the diversion of water from sensitive ecosystems, decrease wastewater discharges, reduce pollutions, enhance wetlands and riparian habitats, and save energy [10]. As the leader of other countries in terms of volume of recycled water, United States reuses 7% to 8% of its treated municipal effluent [11]. Some countries, however, have set vigorous targets to reuse their treated effluents. For example, Australia has planned to increase its water reuse to 30% by 2015. Israel currently reuses 70 percent of its municipal wastewater effluent [11]. Water reuse is rapidly growing in California [12], especially for large users in industry (refineries, agriculture), commercial irrigation facilities (golf courses), groundwater recharge, and landscaping [13]. With current recycling rate of about 500,000 AFY, the 2020 and 2030 targets of using recycled water are 1.5 and 2.5 million AFY, respectively [14]. To meet these goals, numerous projects are being funded at the federal (Bureau of Reclamation), state ($1.25 billion through the Safe, Clean and Reliable Drinking Water Act of 2010) and local (Metropolitan Water District and others) levels. The State Water Resources Control Board issued a mandate to increase wastewater reuse levels from 2009 by 200,000 AFY in 2020 and by an additional 300,000 AFY in 2030.

For more information:

http://water.epa.gov/infrastructure/drinkingwater/pws/

http://www.epa.gov/region9/water/recycling/brochure.pdf

http://www.water.ca.gov/groundwater/casgem/

http://water.epa.gov/infrastructure/drinkingwater/pws/

11. Recycling Materials

In 2009, 34% of waste generated in the United States was recovered. It included recycling 25% of all electronics at the end of their useful lives, 25% of all produced glass, 7.1% of all plastics, 28% of all plastic bottles, and 66.2% of all steel containers produced. With the highest recycling rate, more than 50% of the steel produced in this country over the past 50 years has been recycled [15]. In addition, in 2010, 58.1% of all aluminum beverage cans and 63.5% of U.S. papers (89% increase since 1990) were recycled [15].

Recycling aluminum also creates 97% less water pollution than making new metal from ore [16]. The energy that is saved by not producing one aluminum can be used to recycle twenty cans. In 2010, an energy equivalent of 17 million barrels of crude oil was saved in the U.S. just from recycling cans [15]. Forty percent less energy is consumed by producing recycled paper rather than producing new paper, and 84% energy can be saved by manufacturing recycled PET instead of making it from raw material. Recycling steel may also consume 60% to 74% less energy than producing it from virgin materials [15].

For more information:

http://www.kab.org/site/PageServer?pagename=recycling_facts_and_stats

http://www.cancentral.com/funFacts.cfm

Presented by Kristen Averyt, Associate Director for Science, Cooperative Institute for Research in Environmental Sciences; Former Director of the Western Water Assessment, University of Colorado at Boulder

Electricity sector is responsible for about 35% of total US GHG emissions, 41% of total withdrawals, and 5% of total consumptive use. On the other hand, water sector accounts for approximately 13% of the US electricity supply. Main water challenges of the energy sector include insufficient water availability, too warm incoming and outgoing water. While the West is currently experiencing water stress due to lifecycle energy intensity of water, exacerbated situations are projected in the future (2041-2060) and water stress will spatially be expanded to the Midwest and to some extent to the East. As for the future, projected changes in water stress will simply be as a function of climate driven changes to water supplies. As populations grow and environmental requirements become more stringent, demand for electricity at drinking water and wastewater utility plants is expected to grow by approximately 20%. It is critical to assure the water security of energy generation due to climate change and population growth. During planning, not just short-term, but long-term water availability for energy generation should be taken into account. Other main concerns that need to be addressed include:

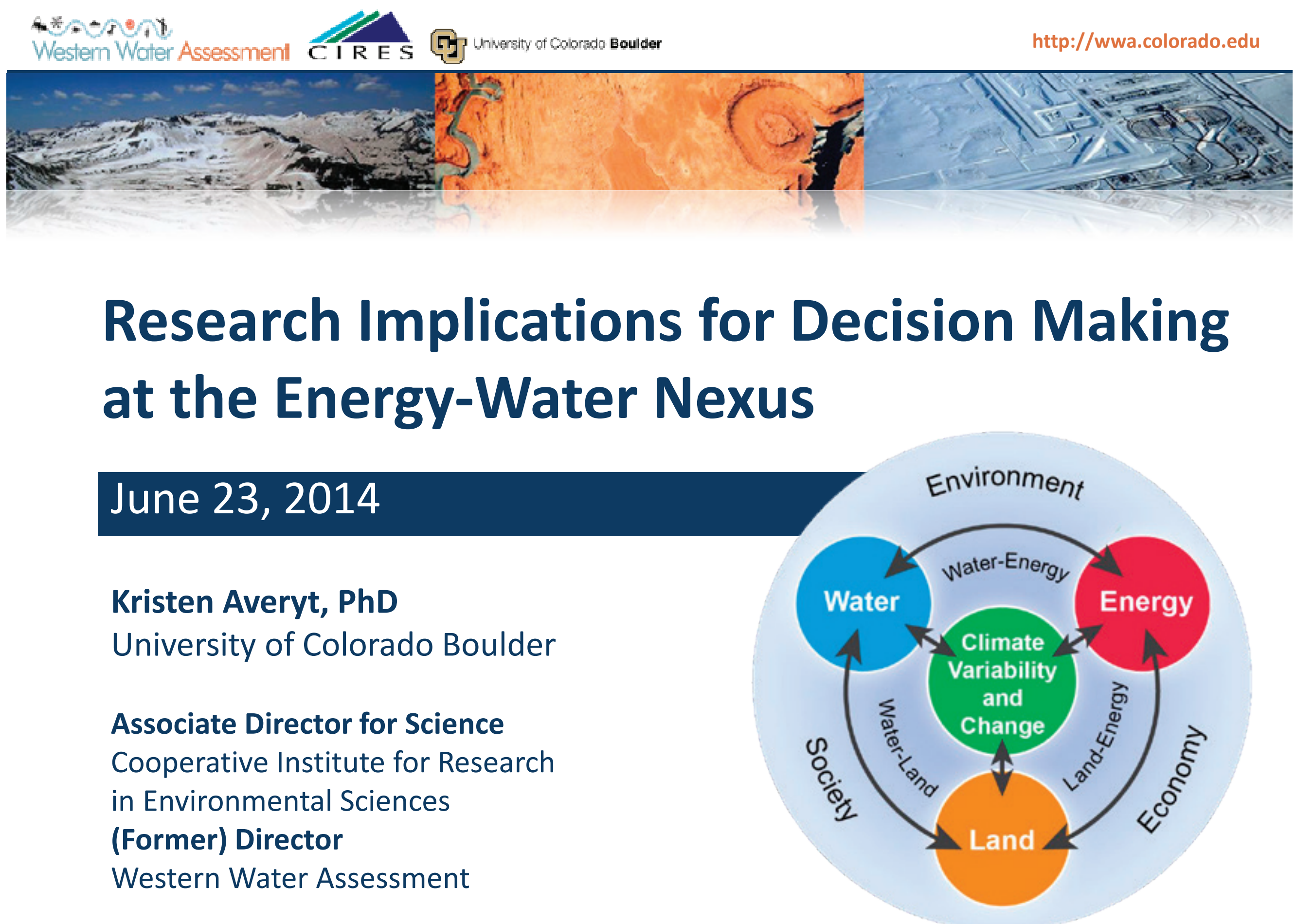
- Are power plants resilient to future extreme weather?
- Will there be enough power to get clean water where it needs to be when it needs to be there?
- Do we have enough data with acceptable quality?

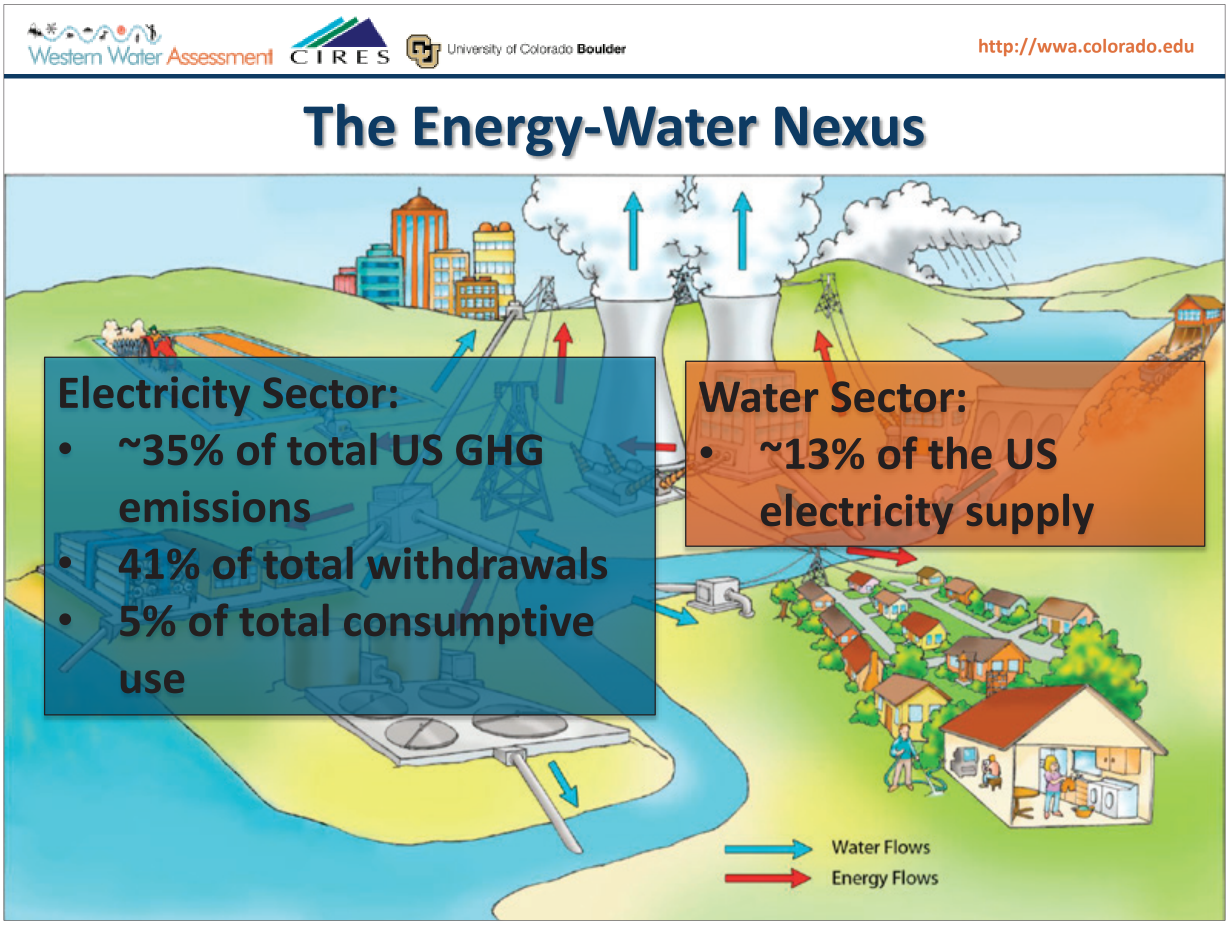
For more information:

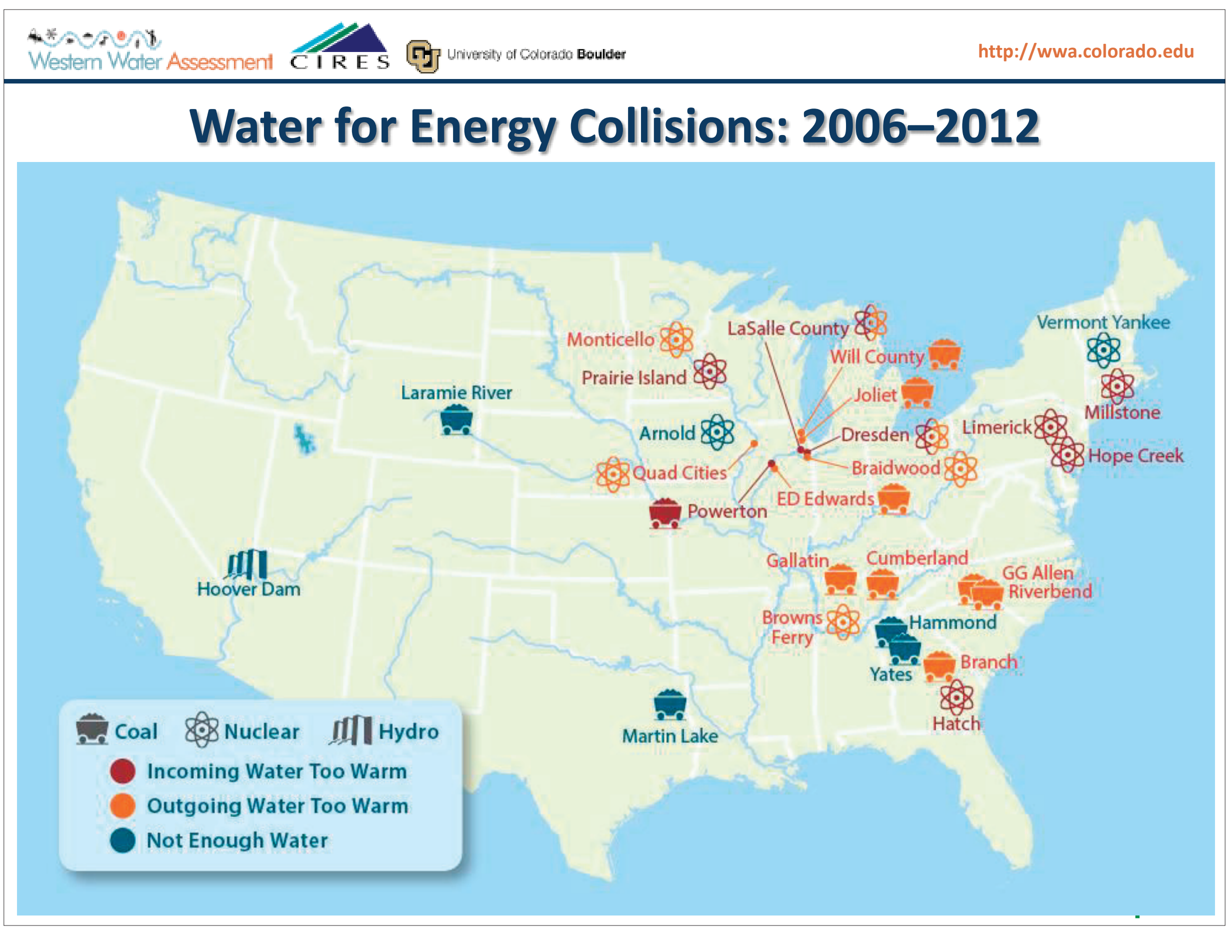
http://iopscience.iop.org/1748-9326/8/3/035046/pdf/1748-9326_8_3_035046.pdf

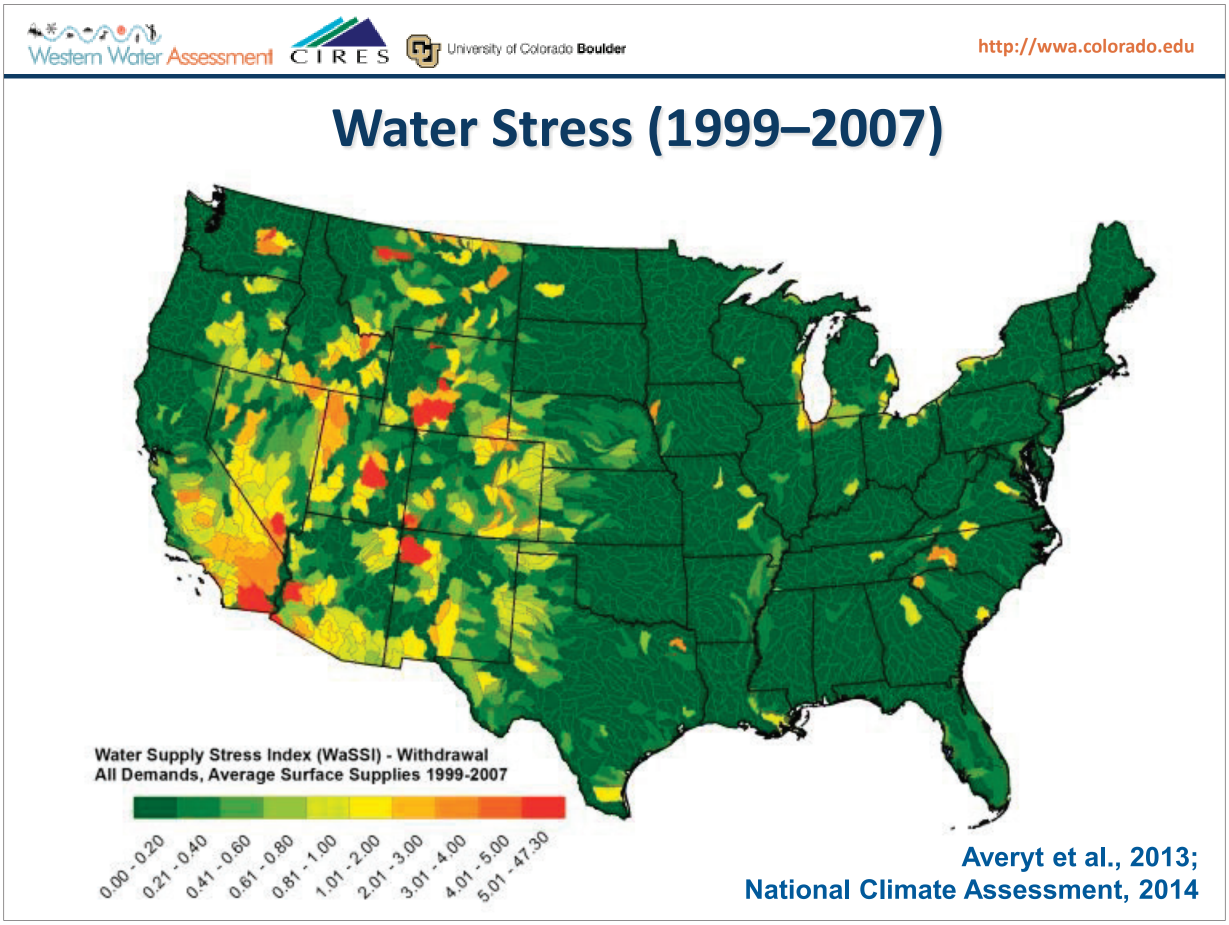
http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-21185.pdf

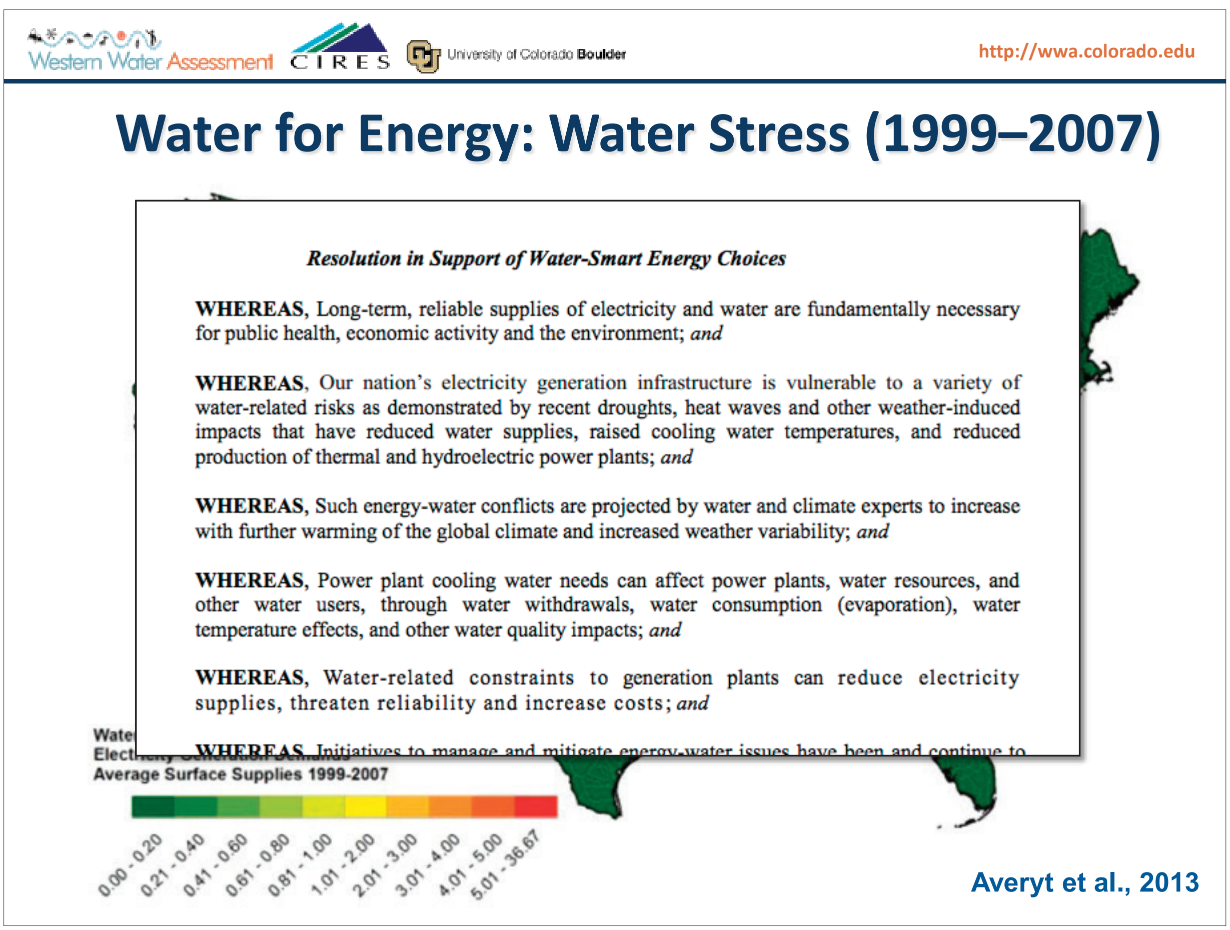
http://iopscience.iop.org/1748-9326/8/1/015001/pdf/1748-9326_8_1_015001.pdf

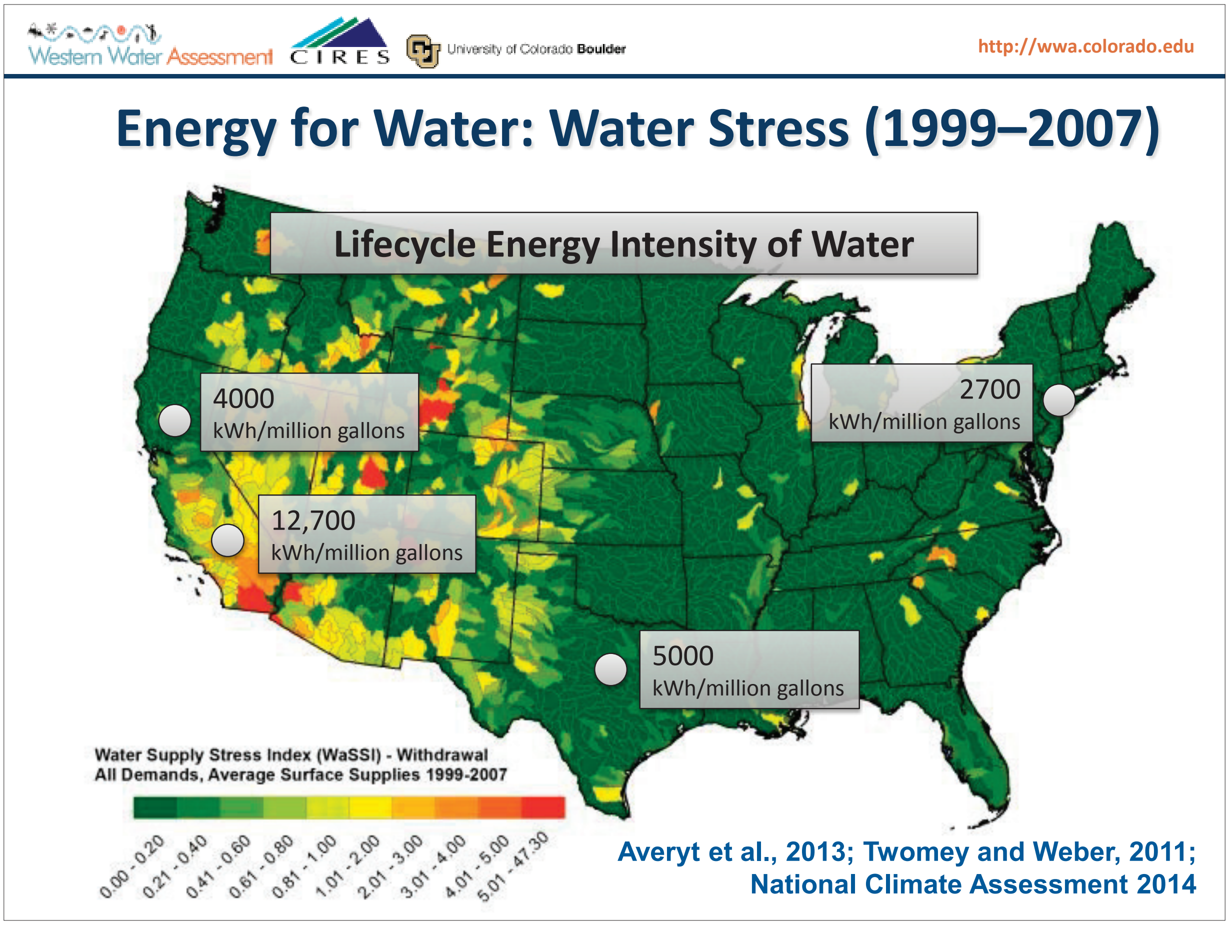


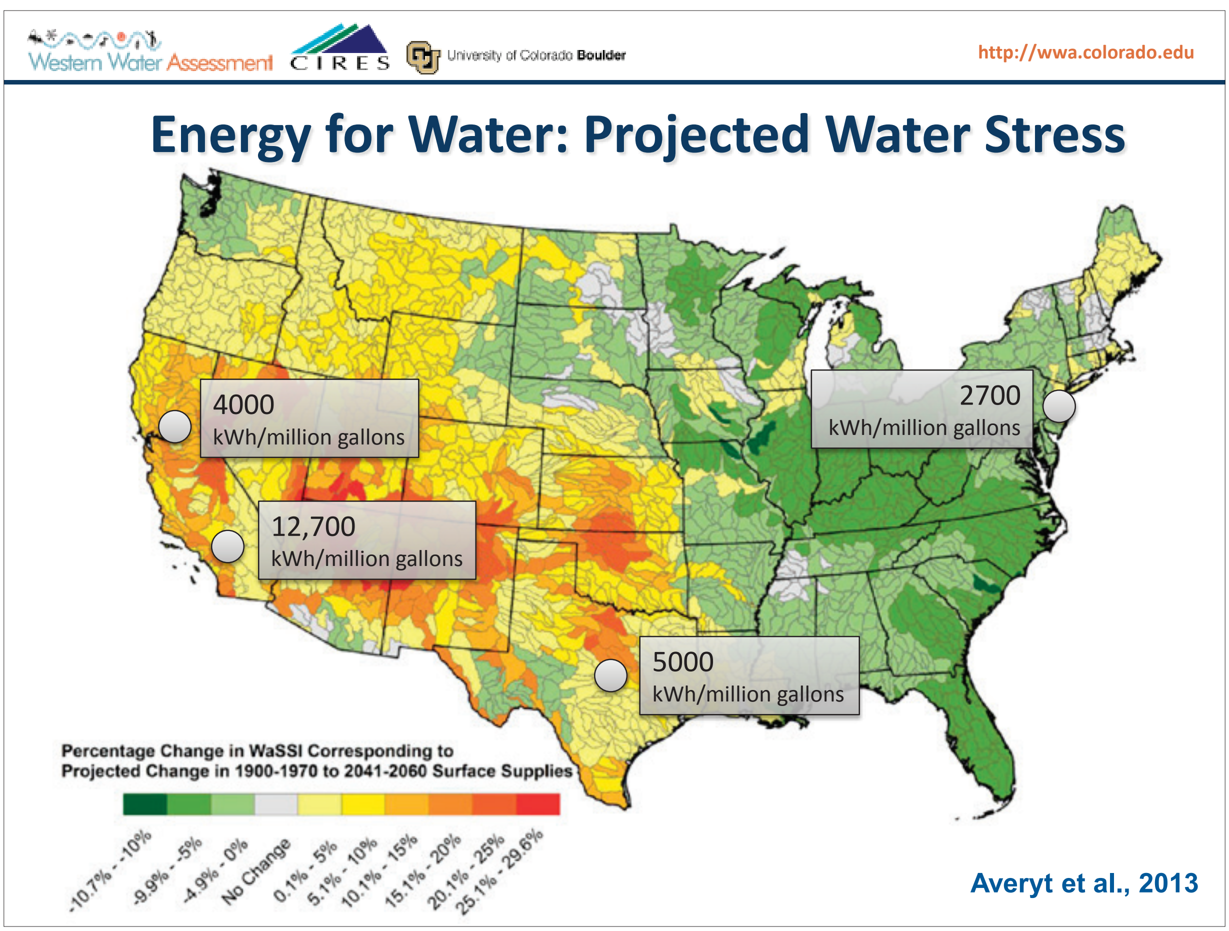

Western Water Assessment
CIRES
University of Colorado Boulder
http://wwa.colorado.edu
The Energy-Water Nexus
Electricity Sector:
• ~35% of total US GHG emissions
• 41% of total withdrawals
• 5% of total consumptive use
Water Sector:
• ~13% of the US electricity supply
Water Flows
Energy Flows


Western Water Assessment
CIRES
University of Colorado Boulder
http://wwa.colorado.edu
Water for Energy Collisions: 2006–2012
Monticello
LaSalle County
Will County
Vermont Yankee
Prairie Island
Joliet
Millstone
Laramie River
Arnold
Dresden
Limerick
Hope Creek
Quad Cities
Braidwood
Powerton
ED Edwards
Gallatin
Cumberland
GG Allen
Riverbend
Hoover Dam
Browns Ferry
Hammond
Yates
Branch
Hatch
Martin Lake
Coal
Nuclear
Hydro
Incoming Water Too Warm
Outgoing Water Too Warm
Not Enough Water


Western Water Assessment
CIRES
University of Colorado Boulder
http://wwa.colorado.edu
Water Stress (1999–2007)
Water Supply Stress Index (WaSSI) - Withdrawal
All Demands, Average Surface Supplies 1999-2007
0.00 - 0.20
0.21 - 0.40
0.41 - 0.60
0.61 - 0.80
0.81 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 47.30
Averyt et al., 2013;
National Climate Assessment, 2014


Western Water Assessment
CIRES
University of Colorado Boulder
http://wwa.colorado.edu
Water for Energy: Water Stress (1999–2007)
Resolution in Support of Water-Smart Energy Choices
WHEREAS, Long-term, reliable supplies of electricity and water are fundamentally necessary for public health, economic activity and the environment; and
WHEREAS, Our nation's electricity generation infrastructure is vulnerable to a variety of water-related risks as demonstrated by recent droughts, heat waves and other weather-induced impacts that have reduced water supplies, raised cooling water temperatures, and reduced production of thermal and hydroelectric power plants; and
WHEREAS, Such energy-water conflicts are projected by water and climate experts to increase with further warming of the global climate and increased weather variability; and
WHEREAS, Power plant cooling water needs can affect power plants, water resources, and other water users, through water withdrawals, water consumption (evaporation), water temperature effects, and other water quality impacts; and
WHEREAS, Water-related constraints to generation plants can reduce electricity supplies, threaten reliability and increase costs; and
Average Surface Supplies 1999-2007
0.00 - 0.20
0.21 - 0.40
0.41 - 0.60
0.61 - 0.80
0.81 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 36.67
Averyt et al., 2013

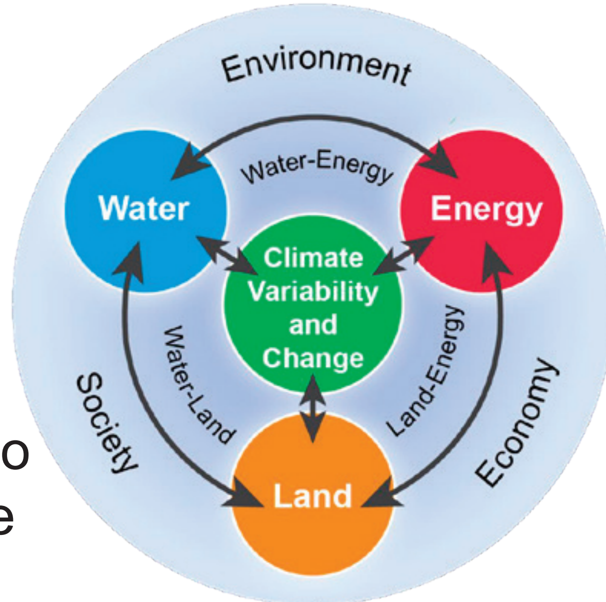

Western Water Assessment
CIRES
University of Colorado Boulder
http://wwa.colorado.edu
Energy for Water: Water Stress (1999–2007)
Lifecycle Energy Intensity of Water
4000 kWh/million gallons
12,700 kWh/million gallons
2700 kWh/million gallons
5000 kWh/million gallons
Water Supply Stress Index (WaSSI) - Withdrawal
All Demands, Average Surface Supplies 1999-2007
0.00 - 0.20
0.21 - 0.40
0.41 - 0.60
0.61 - 0.80
0.81 - 1.00
1.01 - 2.00
2.01 - 3.00
3.01 - 4.00
4.01 - 5.00
5.01 - 47.30
Averyt et al., 2013; Twomey and Weber, 2011;
National Climate Assessment 2014


Western Water Assessment
CIRES
University of Colorado Boulder
http://wwa.colorado.edu
Energy for Water: Projected Water Stress
4000 kWh/million gallons
12,700 kWh/million gallons
2700 kWh/million gallons
5000 kWh/million gallons
Percentage Change in WaSSI Corresponding to
Projected Change in 1900-1970 to 2041-2060 Surface Supplies
-10.7% - -10%
-9.9% - -5%
-4.9% - 0%
No Change
0.1% - 5%
5.1% - 10%
10.1% - 15%
15.1% - 20%
20.1% - 25%
25.1% - 29.6%
Averyt et al., 2013

Western Water Assessment CIRES University of Colorado Boulder http://wwa.colorado.edu

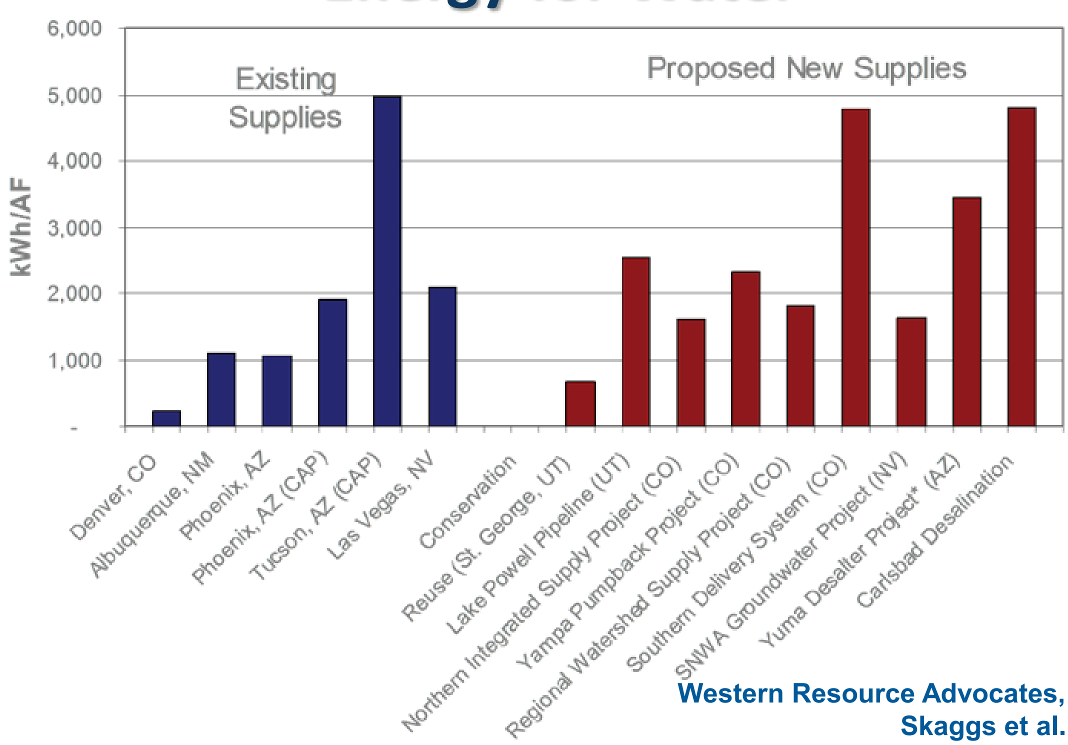
Are power plants resilient to future extreme weather?

Will there be enough power to get clean water where it needs to be when it needs to be there?



Western Water Assessment CIRES University of Colorado Boulder http://wwa.colorado.edu

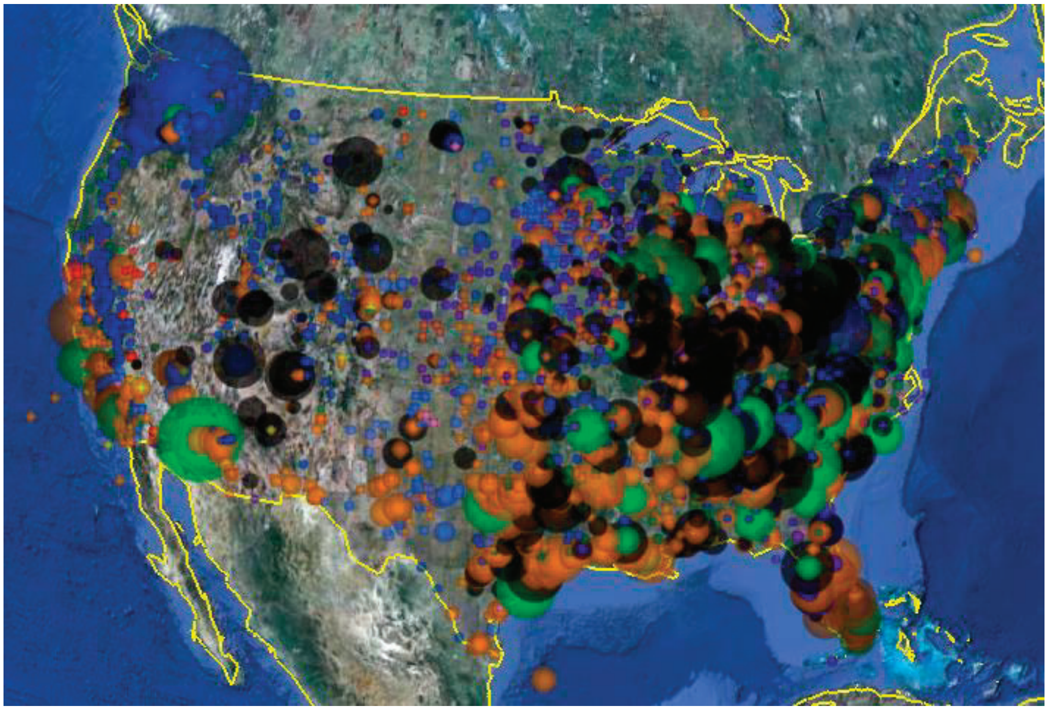
Energy for Water



Western Resource Advocates, 2011; Skaggs et al., 2012

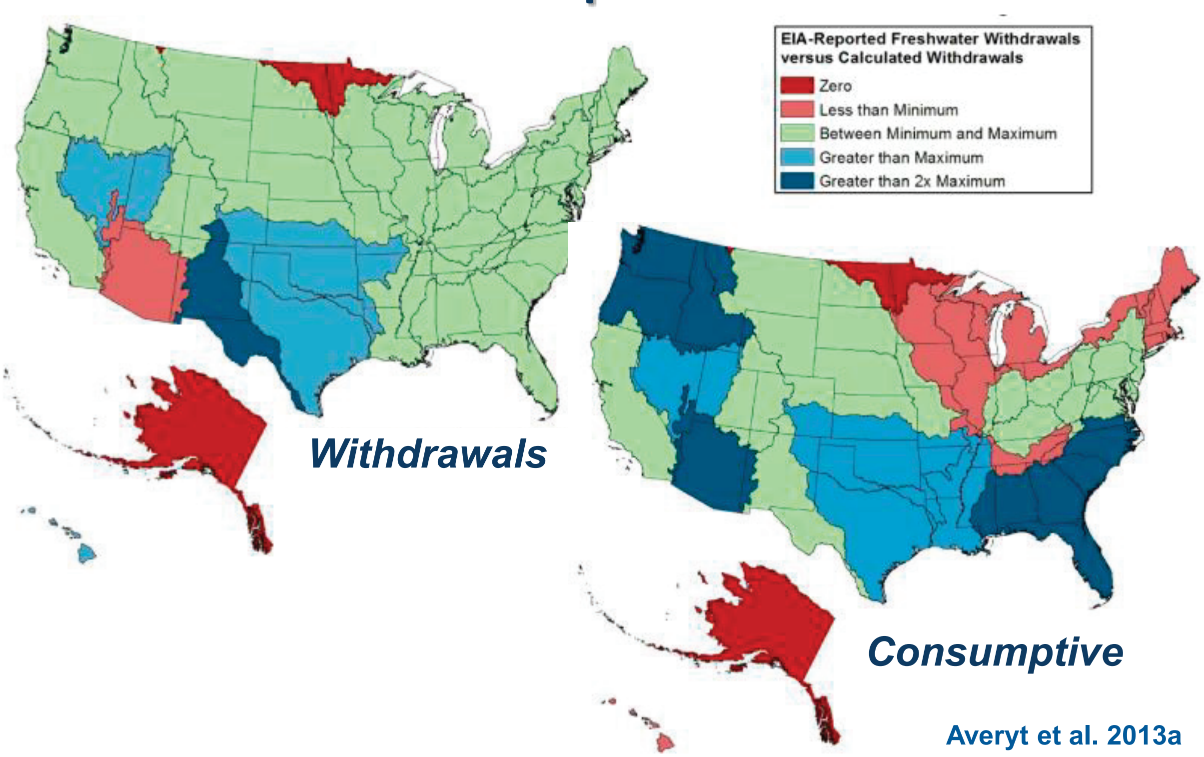
Western Water Assessment CIRES University of Colorado Boulder http://wwa.colorado.edu

Water for Energy: Poor…no, TERRIBLE data



Western Water Assessment CIRES University of Colorado Boulder http://wwa.colorado.edu

Discrepancies



Averyt et al. 2013a

13. Green Infrastructure

Natural ecosystems have the capability of cleaning water without using any energy. These systems can be seen as an energy-efficient treatment option. For this purpose, protected areas need to be maintained and used to help avoid significant costs and associated energy demands of traditional treatment works [17, 18]. New York City (Catskills region), San Francisco (Hetch Hetchy) and Portland, Oregon (Bull Run) currently take advantage of these systems and rely on watershed protection and management for their potable supply treatment [13, 19].

For more information:

http://water.epa.gov/type/wetlands/methods_index.cfm

http://waterinthewest.stanford.edu/sites/default/files/Water-Energy_Lit_Review.pdf

http://www.ncbi.nlm.nih.gov/pubmed/17195871

http://pubs.acs.org/doi/abs/10.1021/es071594%2B

14. The NEXUS and the Inland Navigation System

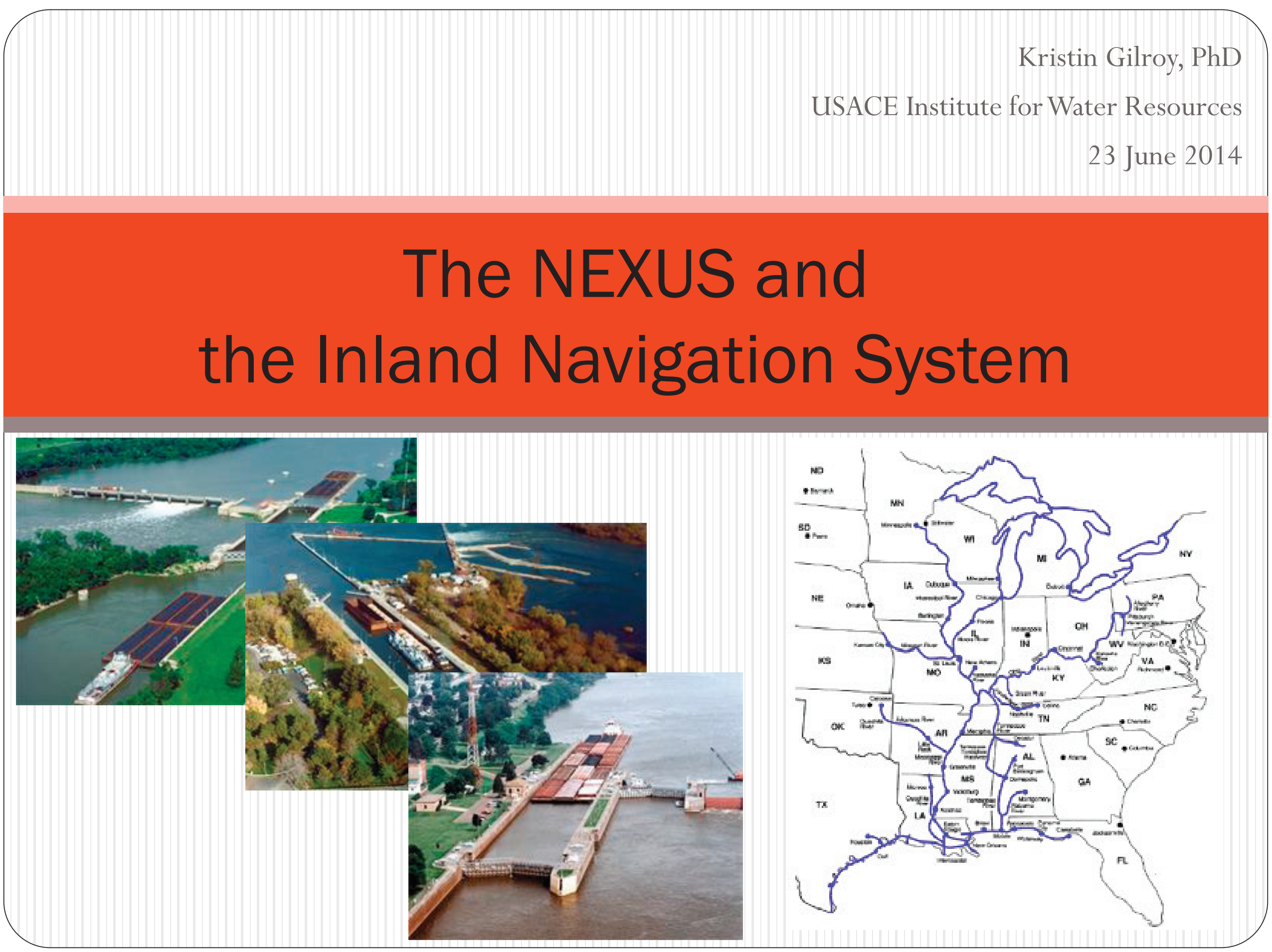
Presented by Kristin Gilroy, Institute for Water Resources, US Army Corps of Engineers

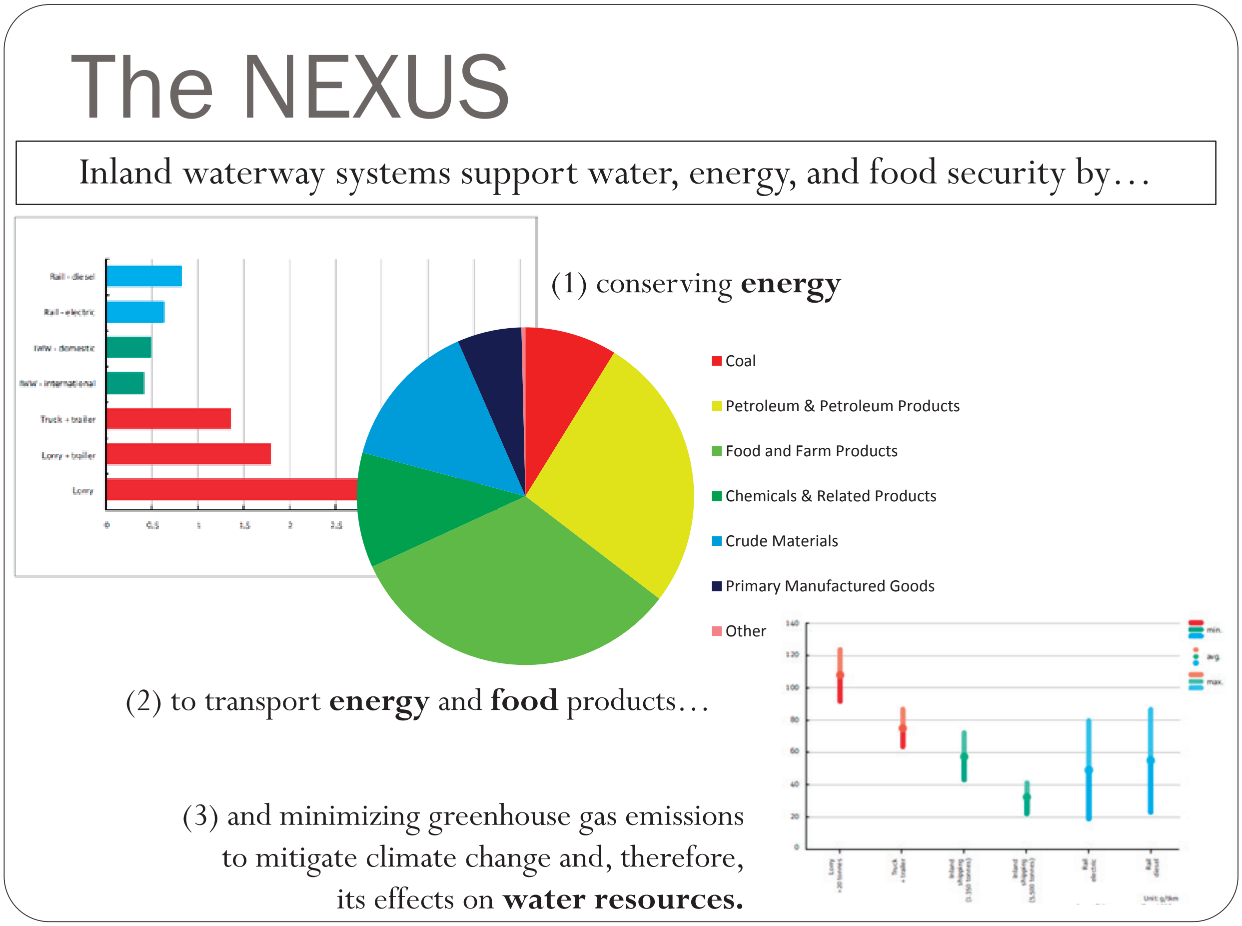
Inland waterway systems support water, energy, and food security by conserving energy during food and energy transportation and therefore by minimizing greenhouse gas emissions. Floods, droughts, and infrastructure failures threaten the function of these systems, which may result in consequences such as stockpiled products, ceased operations, switched to overland mode, and altered production to shippers as well as delay costs, lost revenue, and logistical expenses to carriers. Appropriate uses of governance, technology, and financing methods are required to operate and maintain a reliable navigation system.

Proper governance should balance uses between navigation, water supply, hydropwer, flood risk management, and the environment across states and countries. International Joint Commission makes decisions on applications for projects, such as dams and diversions that affect the natural level and flow of water across the boundary. Changing water levels can affect drinking water intakes, commercial shipping, hydroelectric power generation, agriculture, shoreline property, recreation, fisheries, wildlife, wetlands and other interests. Technology can be used for planning. Decision-making support tools can be developed to plan operations and maintenance, e.g. operating reservoirs in series to meet multi-objectives. In addition, technology can be used to enhance equipment, e.g. sliding gates to minimize unplanned outages, etc. Financing influences the reliability of infrastructure component. The challenge associated with financing is to come up with a way to manage system of deteriorating infrastructure without increasing the budget. Some solutions could be to develop watershed-based budgeting plans, and to share risks and revenues with private sector along the inland waterways system, would likely still require an increase in taxes to create revenue for private sector.

For more information:

http://www.corpsnets.us/docs/other/05-NETS-R-12.pdf





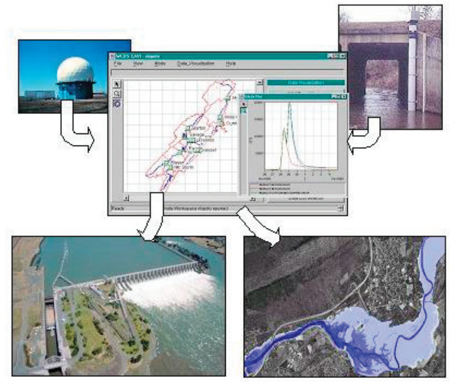
The NEXUS
Inland waterway systems support water, energy, and food security by…
Rail - diesel
Rail - electric
IWW - domestic
IWW - international
Truck + trailer
Lorry + trailer
Lorry
(1) conserving energy
Coal
Petroleum & Petroleum Products
Food and Farm Products
Chemicals & Related Products
Crude Materials
Primary Manufactured Goods
Other
(2) to transport energy and food products…
(3) and minimizing greenhouse gas emissions
to mitigate climate change and, therefore,
its effects on water resources.

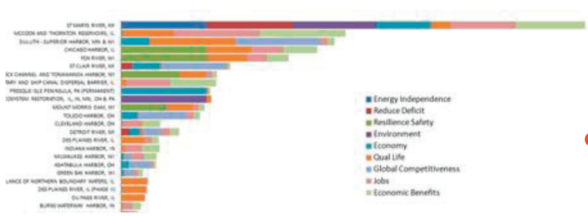
2008 Closure of
Upper Mississippi River
Upper Mississippi River System
MINNESOTA
Major flood event caused closures from
Communication between public and private sector
were essential to minimize effects
Threats to the success of the system:
Floods, Droughts , and
Infrastructure Reliability (i.e., failures)
We need to combine appropriate use of
governance, technology, and financing methods
to operate and maintain a reliable system
MISSOURI

Governance
Interstate
Mississippi River Basin Commission formed in 1879
Congress charged the MRC with the mission to develop plans to improve the condition of the Mississippi River, foster navigation, promote commerce, and prevent destructive floods
Today's mission is to lead sustainable management and development of water related resources for the nation's benefit and the people's well-being
International
Boundary Waters Treaty (1909)
Provides general principles for preventing and resolving transboundary water issues
International Joint Commission (1912)
Regulate shared water uses
Investigate transboundary issues & recommend solutions
2007 IJC Great Lakes Study
To update 30-yr old regulation plan for outflows to meet all water use objectives
http://www.mvd.usace.army.mil/About/MississippiRiverCommission(MRC).aspx
http://ijc.org/en_/IJC_History

Technology

- Systems modeling through Corps Water Management System (CWMS)
- World Association for Waterborne Transport Infrastructure (PIANC)



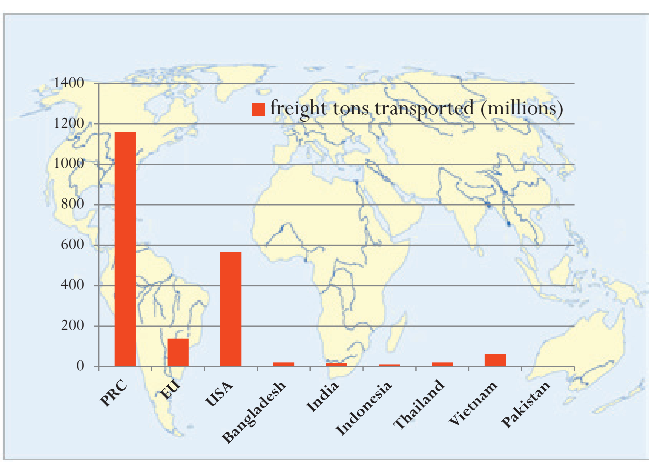


Financing

- Challenge: How to manage system of deteriorating infrastructure without increasing the budget?
- Potential Solutions
  - Public-Private Partnerships
  - Watershed based budgeting

International Applications

Inland waterways are under utilized in many developing countries, which constrains economic growth



The United States can assist through

- Governance
  - Mekong River Basin and Mississippi River Basin Commission Agreement
  - Shared Vision Planning Case Studies
- Technology
  - Systems modeling software and training
  - Promote involvement in PIANC
- Financing
  - Watershed based budgeting

15. Thermoelectricity Generation

Open-loop cooling facilities use substantially more water than close-loop or dry cooling facilities. In 1972, the Federal Water Pollution Control Act and Section 316(a) of the Clean Water Act, which regulate intake structures and thermal pollution discharges, established restrictions on open-loop cooling systems. It resulted in a declining trend in the construction of open-loop cooling power plants and only 10 of these plants have been built since 1980 [20]. Closed-loop cooling plants, with less water requirements, lower discharges, and less vulnerability to water shortages, have been the main substitute of open-loop system since then. Hybrid cooling technology, which uses both wet and dry cooling components that can be used either separately or simultaneously is in its early phases of development. These systems may reduce water requirements of wet systems by up to 80%, while they do not have the disadvantages of dry cooling systems. Therefore hybrid cooling technology can be seen as a promising way to secure energy generation in the future while imposing less stress on water resources.

For more information:

http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf

16. Infrastructure Sustainability Policy

To promote sustainable infrastructure within the water sector, the U.S. EPA has issued its Clean Water and Drinking Water Infrastructure Sustainability Policy [21]. Guided by this policy, EPA has developed the Water Infrastructure: Moving toward Sustainability program, which provides technical support and financial resources to states to increase water and energy efficiency in water, wastewater, and stormwater infrastructure. The agency works with partners across the water sector and a broad group of stakeholders to help implement practices on three levels [22]:

- Sustainable Water Infrastructure: To sustain infrastructure that is used for the collection and distribution systems, and treatment plants in water-related services
- Sustainable Water Sector Systems: To sustain any aspect of the utilities and systems that provide water-related services
- Sustainable Communities: To promote the role of water services in extending the broader goals of the community

EPA has identified the following four key areas of action to assure sustainability of water infrastructure: asset management, water and energy efficiency, infrastructure financing and the price of water services, as well as alternative technologies and assessment. To promote and maintain sustainable water systems, EPA has two management frameworks: Effective Utility Management Initiative and the Safe Drinking Water Act's Capacity Development Program. In addition, to advance community sustainability, EPA is collaborating with the states of New York, Maryland, and California to identify ways in which projects that promote smart growth and other sustainable practices can be incentivized [22].

For more information:

http://water.epa.gov/infrastructure/sustain/Clean-Water-and-Drinking-Water-Infrastructure-Sustainability-Policy.cfm

http://water.epa.gov/infrastructure/sustain/

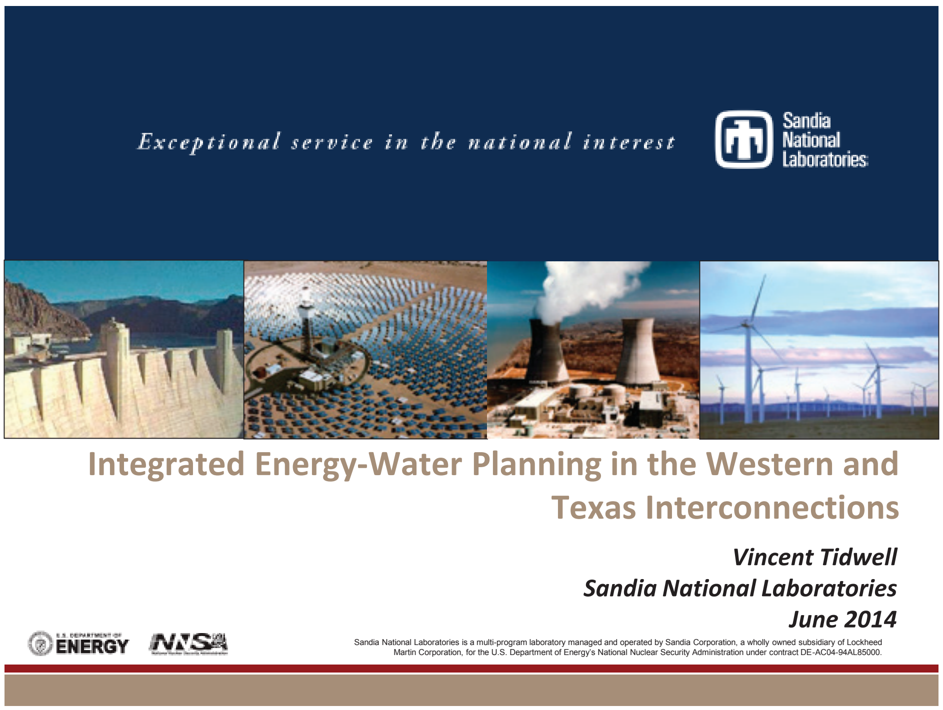
17. Integrated Energy-Water Planning in the Western and Texas Interconnections

Presented by Vincent Tidwell, Sandia National Laboratories

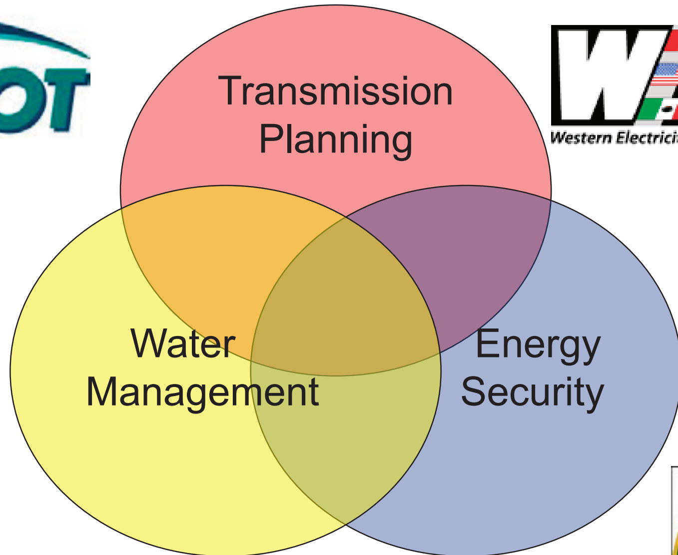
While long-term regional electricity transmission planning has traditionally focused on cost, infrastructure utilization, and reliability, issues concerning the availability of water represent an emerging issue. Thermoelectric expansion must be considered in the context of competing demands from other water use sectors balanced with fresh and non-fresh water supplies subject to climate variability. An integrated Energy-Water Decision Support System (DSS) is being developed that will enable planners in the Western and Texas Interconnections to analyze the potential implications of water availability and cost for long-range transmission planning. The project brings together electric transmission planners (Western Electricity Coordinating Council and Electric Reliability Council of Texas) with western water planners (Western Governors' Association and the Western States Water Council).

For more information:

http://energy.sandia.gov/?page_id=1741



Integrated Planning



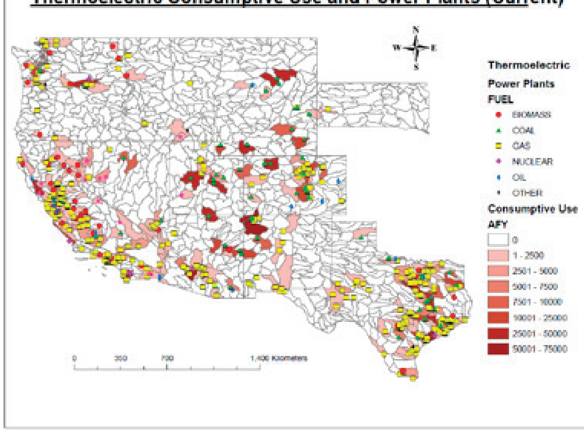
Western Governors' Association
Serving the Governors of 19 States and 3 US-Flag Pacific Islands

WSWC Western States Water Council

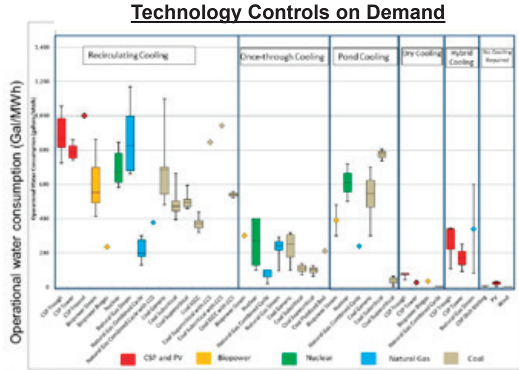
Western Electricity Coordinating Council

Mapping Thermoelectric Water Demand

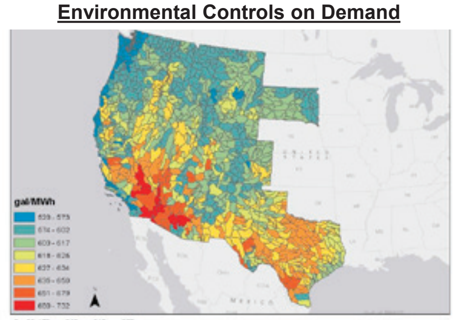
Thermoelectric Consumptive Use and Power Plants (Current)



Technology Controls on Demand



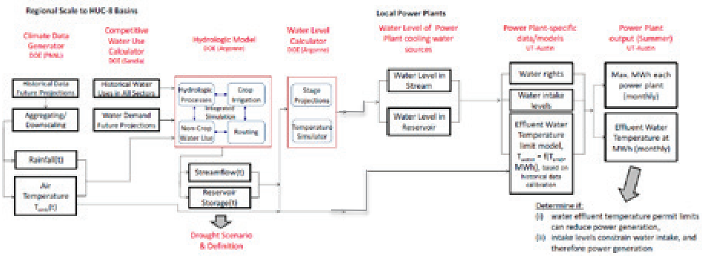
Environmental Controls on Demand



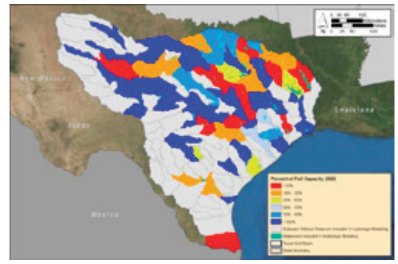
NREL 2012

Climate Impact on Existing Plants

Climate Modeling Scheme

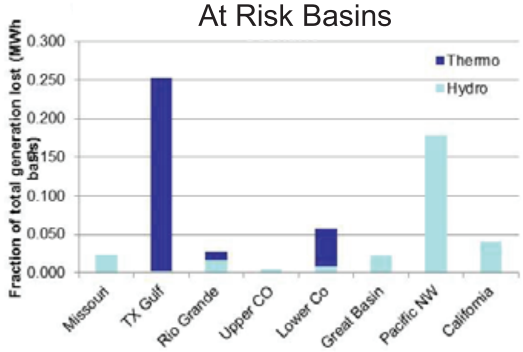


Water Availability Impact



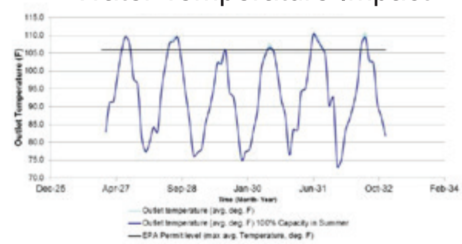
ANL 2013

At Risk Basins



ANL 2012

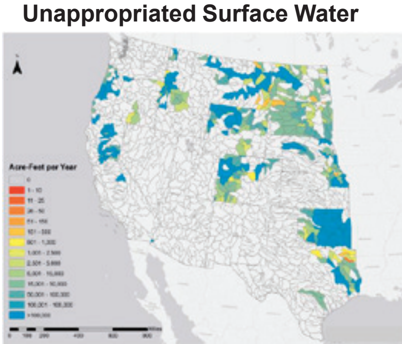
Water Temperature Impact



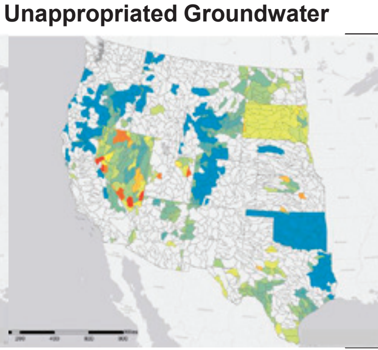
ANL 2013

Water Availability

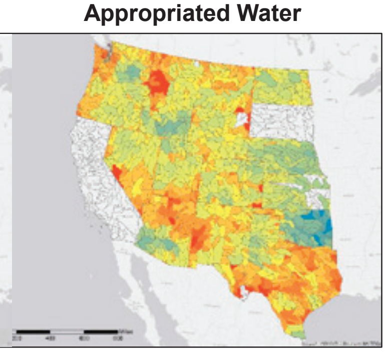
Unappropriated Surface Water



Unappropriated Groundwater

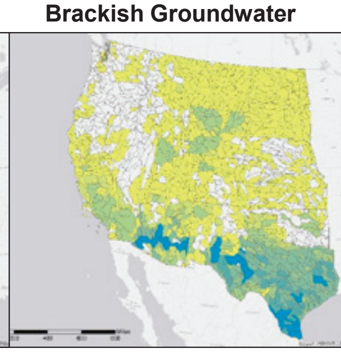


Appropriated Water

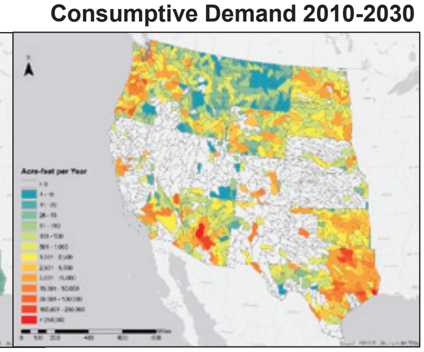


Municipal Wastewater

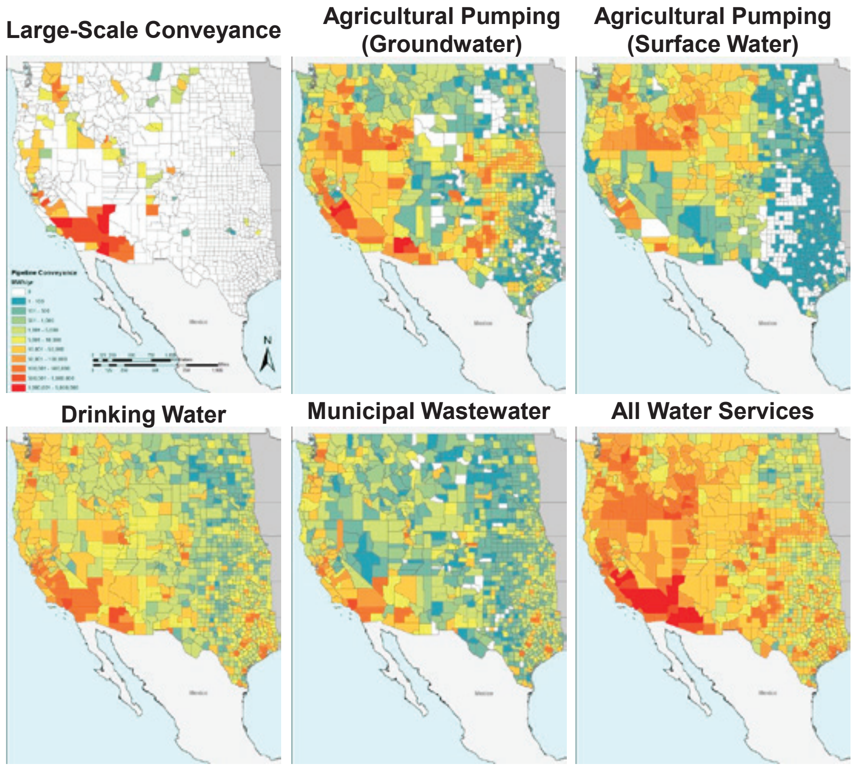
Brackish Groundwater



Consumptive Demand 2010-2030



Energy for Water Services



Perspectives

- Did approaching the case from the perspective of water, energy and food together as a nexus affect the results? Yes, results forthcoming.
- What are the main lessons learned from the case, with emphasis on the nexus approach? Big need to change planning culture and communication.
- Did these lessons learned identify important gaps in governance, public/private partnerships, data, financing, or infrastructure/technology? Gaps in appreciation of competing sector and communication.
- What does the business sector you represent contribute to the Water Energy Food Nexus approach? What can be transferred globally? Improved understanding, data, modeling tools and technology.
- Are there other examples in your sector of wider adoption of best practices to advance water, energy, and food security? What can be done to encourage wider adoption? DOE Water Energy Tech Team (WETT) along with interagency cooperation.

18. Catawba-Wateree River Basin Water Supply Master Plan

Presented by Jeff Lineberger, Director - Water Strategy and Hydro Licensing, Duke Energy

Communities along the hardest working river in the Carolinas have an approaching problem. Without significant effort to manage water consumption and improve supplies, this generation could see a time when there will not be enough water flowing in the Catawba-Wateree River to support more people moving into the heart of North or South Carolina, new industry and jobs, more electricity production and maintenance of the quality of life we currently enjoy.

The non-profit Catawba-Wateree Water Management Group has worked with stakeholders for more than four years to address this complex issue. Through much collaboration, they have designed a basin-wide Water Supply Master Plan that can help ensure the region's shared water supply will fully support growing needs into the next century.

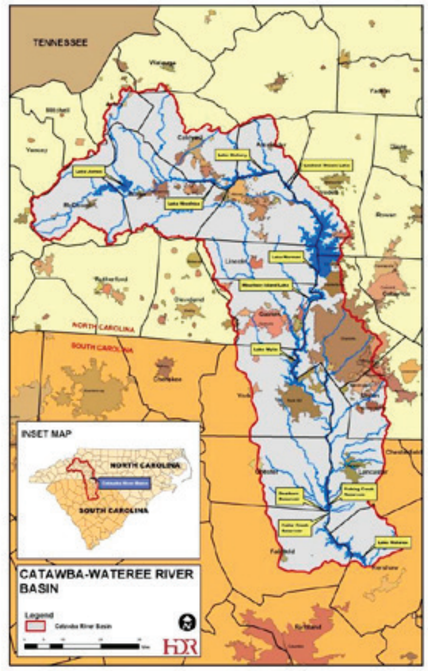
The Water Supply Master Plan is the most significant water supply management and planning endeavor undertaken in the Catawba-Wateree River Basin since original construction of the eleven-reservoir system by Duke Energy in the 1900s. The Water Supply Master Plan includes:

- Input and guidance from a 19-member public stakeholder team representing environmental interests, lake users, various local governments and state agencies
- Updated long-term water use projections in the Basin (to the Year 2065) and an updated, complex water quantity model
- Evaluation of numerous options to extend the available water supply
- New long-term Basin-wide strategies to increase the Basin's water yield by more than 200 million gallons per day, ensuring sustainable water supplies through 2100, decades beyond current expectations.

http://www.catawbawatereewmg.org/

Catawba-Wateree (CW) River Basin

- 11 interconnected reservoirs licensed by the Federal Energy Regulatory Commission (FERC)
  - Completed 1904-1963 (spanning 225 river miles)
  - 79,895 surface acres, 1,795 miles shoreline
- Modest water availability
  - Avg. inflow – 5,806 cubic feet per second (cfs)
  - Avg. annual precipitation – 46 inches
  - **Usable Storage = 776,747 acre-feet = 252 billion gallons ≈ 7% of annual basin precipitation**
- **Duke Energy electric generation – 8,591 MW (25% of our Carolinas' generation)**
  - 13 conventional hydro stations (845 MW)
  - 2 nuclear stations (4,516 MW)
  - 2 coal-fired stations (3,230 MW)
- Most densely populated river basin in NC
- **Reservoirs serve as the drinking water source for 18 public water systems (2 million customers)**
- Several large industrial water intakes
- 2 states, 17 counties, 30+ municipalities
- Over 25,000 lake neighbors
- Over 10 million recreation visits per year



2

Water Supply Master Plan

- **Extends water yield by 200+ million gallons per day (mgd) = 50 years**
  - Instead of reaching *modeled water yield* in 2050, we'd reach it in 2100
  - Sustains future basin growth potential
- Improves drought resiliency for vulnerable water intakes
- Prepares us for future climate change and population growth
- Promotes cooperation between water users and stakeholders in the river basin
- Balance of strategies (supply, demand, drought response) for enhancing water supply

3

Key Elements Driving the Master Plan

- **Cooperation**
  - 70-Party Comprehensive Relicensing Agreement (2006)
  - CW Drought Management Advisory Group (CW-DMAG) (2006)
  - CW Water Management Group (CWWMG) (2007)

- **Conflict**
  - Growth and competing uses
  - Water withdrawal fee proposal (2005)
  - SC 401 Water Quality Certification (2009)
  - SC v. NC Supreme Court Case Settlement Agreement (2010)
  - Business impacts
- **Climate**
  - Drought of Record (1998 - 2002)
  - New Drought of Record (2007 – 2009)
- **CWWMG and CW-DMAG Approach – Shared Resource = Shared Responsibility**
  - Plan and manage like it's "our water resource"
  - If one Large Water Intake Owner fails, we all fail

4

Lessons Learned

- **Get the science and engineering right**
  - Good modeling tools with good data are essential to good decisions
  - Know the state of the local practice versus what others are doing
  - Focus on implementable solutions
  - Consider the long-term

- **Social and political factors are also very important**
  - Diversity of planners
  - Water use priority setting is inevitable during severe droughts
  - Careful not to under-estimate level of effort for broad, effective communications
  - Health of the waterway and quality of life must balance economic development
- **All users / uses aren't equally capable of water conservation (every day) or water use restrictions (drought)**
  - Individual utility investments can benefit entire basin
- **Gaps**
  1) Funding to Develop Plan – filled by NC, SC and Duke Energy Foundation
  2) Implementation Funding and Staff – TBD
  3) Data – sedimentation impacts, tributary flows, water use
  4) Governance Mosaic – Riparian (NC), Regulated Riparian (SC), Advisory (CWWMG, River Basin Advisory Commission, others)

5

Energy and Water Sectors

- **Global Transfers**
  1) Both sectors contribute essential services
     - Electricity / drinking water
     - Public health and safety
  2) Managers of multi-use reservoirs need broad perspective
     - We serve the same public
     - Shared resource = shared responsibility
  3) Science + engineering is only half of the job
  4) Difficult to focus the public on long range (50+ years) plans

- **Wider Adoption - Joint Integrated Resource Planning (IRP)???**
  - IRP (20-yr look ahead) required of electric public utilities
  - Public water systems
    - Individual plans
    - Local Water Supply Plans (NC), Permitting Limits (SC)
  - Is more formal joint planning in our future?

- **More info – www.catawbawatereewmg.org**

6

19. Case study illustrating water energy food nexus

Presented by Larry MacDonnell

Substantial quantities of water are produced as a byproduct of oil and gas development. Most of that water is unusable for other purposes because of its poor quality; thus, it is either reinjected or contained in pits and evaporated. The large volumes of water generated as a byproduct of coal bed natural gas development, however, often are of a quality suitable for other use such as for irrigation. Nevertheless, states decided not to require its use. Consequently, large volumes of usable water either were simply discharged into surface water systems or were contained and evaporated. Despite the view that water is scarce in states such as Colorado, New Mexico, and Wyoming, it has proved to be uneconomic to find uses and cheaper simply to discharge or evaporate it. In this case the importance of energy production clearly outweighed our interest in careful use of our limited water resources.

For more information:

http://energy.usgs.gov/EnvironmentalAspectsEnvironmentalAspectsofEnergyProductionandUse/ProducedWaters.aspx#3822110-overview

http://capitolwords.org/date/2007/04/18/S4672-4_more-water-more-energy-less-waste-act/

https://www.govtrack.us/congress/bills/110/s1116#summary

CBM produced water management as a case study illustrating water energy food nexus

Larry MacDonnell

Nexus Dialogue Workshop – June 23, 2014

Golden, Co

Produced water as a byproduct of oil and gas production

- Large volumes of water are produced in association with oil and gas production (15 to 20 billion barrels (bbl; 1 bbl = 42 U.S. gallons) generated each year in the United States; equivalent to a volume of 1.7 to 2.3 billion gallons per day. Argonne, Produced Water Volumes and Management Practices (2009))
- A “waste” product; management and disposal a major concern
- Very little applied to beneficial use, such as irrigation

Coalbed Methane Production

- Began in the 1990s
- Peaked in 2008
- Virtually all production from Colorado, New Mexico, and Wyoming

Produced water in Powder River Basin in Wyoming

- According to 2009 report:

since 1987, 4.784 billion bbl of water have been produced from coal beds [more than 600,000 acre-feet]. Approximately 54% has been discharged to ephemeral and perennial streams, 35% has been managed using off-channel pits, 5% has been reused for irrigation projects, 3% has been managed through injection, and 3% has been treated and then discharged into streams.

Argonne, Produced Water Volumes and Management Practices

Why so little beneficial use of all this water?

- In some cases, water quality is a concern
- But, according to a National Academy of Sciences panel:

“Even where CBM produced water is intentionally put to beneficial use, the cost of implementation of such use almost universally exceeds any realized economic gain in the current regulatory and economic climate.”

Management and Effects of Coalbed Methane Produced Water in the United States (2010)

Policy Choices

- Promotion of energy development outweighs concerns about making beneficial use of water
- Without regulation requiring beneficial use of produced water, not economic
- Tells us something about the relative economic value of water

20. Xcel Energy Water-Energy-Food Nexus Case Study

Presented by Richard Belt, Senior Water Resources Analyst, Xcel Energy

Xcel Energy partners with agricultural communities to buy their recharge credits and contracts long-term with them to use a portion of their excess water. The water right remains under the agricultural community's own enterprises. Using agricultural water for energy generation is especially more beneficial during a drought, when there is not enough water for agricultural production. If there is a power blackout, all sectors may remain out of water as well. Xcel Energy pays substantial amount of money to agricultural community to use their water, because power plants need substantially less water. One criticism is that these water transactions have high costs, but they are easily affordable for energy companies. Xcel Energy also trades with municipalities. It has the right to some high quality water sources, which are good for domestic use. The company trades this water with lower quality water from municipalities, which is good for energy production, so water treatment costs are reduced. This trade also reduces some capital costs for both parties. In the case when the government is involved in energy supply (as in some countries), if trades help the utility to make all the water needs, it creates a great Public-Private Partnership lesson. In addition, some water conservation practices at Xcel Energy include: using recycled effluent at some plants, installing a hybrid cooling plant at Pueblo, and using their wastewater to spray emission flows. From this company's experiences, they have the following key conclusions:

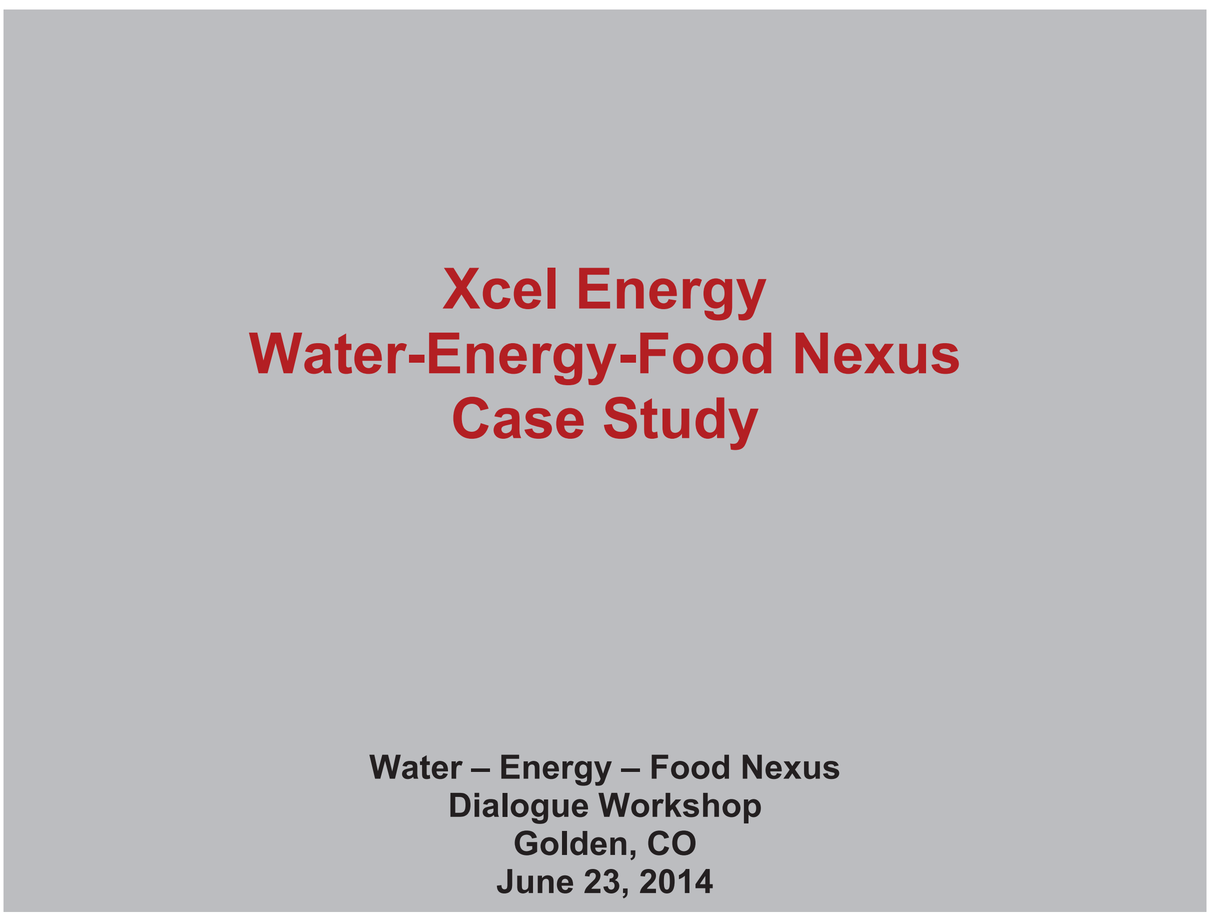
- Private water markets work
- Natural "nexus" partnerships may be location-based, quality-based, or drought-based
- All water issues have a local scale
- When developing arrangements, core needs should be addressed
- Water supply flexibility and diversity enable partnerships

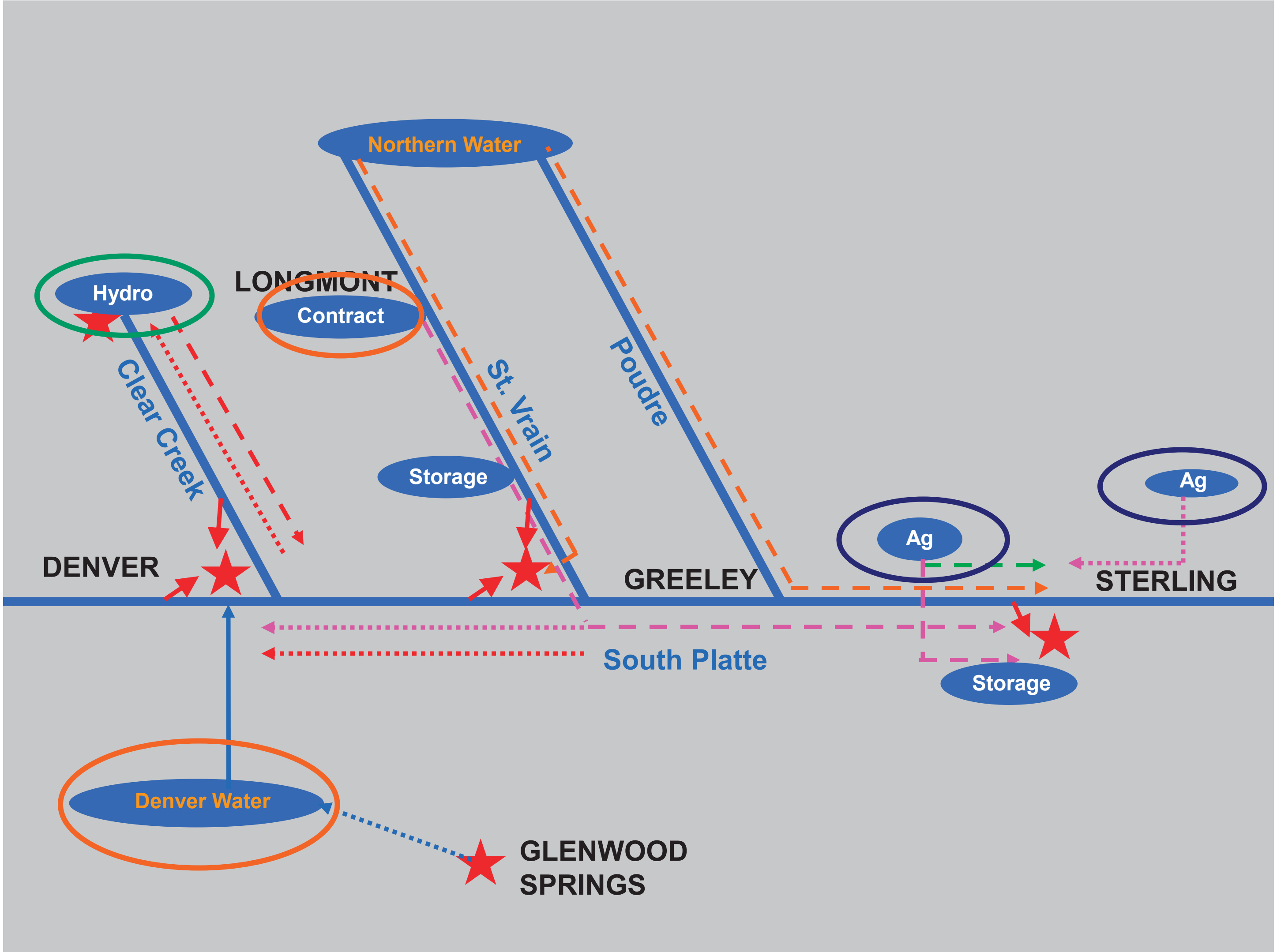
For more information:

http://www.xcelenergy.com/staticfiles/xe/Corporate/CRR2012/environment/water-management/conservation.html

http://www.xcelenergy.com/staticfiles/xe/Corporate/CRR2012/environment/water-management/supply.html

https://www.xcelenergy.com/staticfiles/xe/Corporate/CRR2013/environment/water-management.html





Nexus-related partnerships

- Traditional multiple use
  - Environmental/recreational
  - Hydropower
  - Municipal
  - Thermoelectric
- Trades
  - Appropriate water quality for use
  - Avoided capital expense – for both parties
- Interruptible supplies
  - Source of agriculture revenue
  - Drought resilience
  - Timing to minimize impact

Lessons

- Private water markets work
- Natural "nexus" partnerships
  - Location-based
  - Quality-based
  - Drought-based
- All water issues are local
- Develop arrangements that address core needs
- Water supply flexibility and diversity enable partnerships

Knowledge gaps

- How does it work?
  - Structure
  - Operation
  - Administration
- Which partners?
  - Need
  - Fit
- When? (Key consideration)
  - When should it start?
  - Should it end? When?

Industry "best" practices

- Water supply diversity and flexibility
- Repowering/combined cycle gas generation
- Renewables
- Demand-side management
- Technology
  - Alternative water supplies
  - Alternative cooling technology
  - Emission controls
- Good water stewardship practices

21. CALFED Bay-Delta Program

Presented by Masih Akhbari, Research Assistant and Program Aide, Colorado Water Institute, Colorado State University

California has been dealing with serious conflicts over its water resources management for decades. Debates over whether or not to transfer water from the Delta region to users elsewhere, and how to transport the water, have been the root causes of the conflicts in this state [23]. The conflicts became more complex after more limitations were imposed to the supplying system due to new environmental regulations enacted to protect the region's ecosystem.

To find a solution, a variety of innovative ideas have been developed. However, they lacked an overall framework. California Bay-Delta Program (CALFED) was initiated in 1995 as the most comprehensive effort to resolve water resources conflicts in the region and to address three main areas: ecosystem health, water quality, and water supply reliability. The "problem area" was defined as the Delta, and the "solution area" as all areas hydraulically connected to the Delta or relying on its water supplies, mainly Sacramento and San Joaquin Rivers [24]. CALFED intended to respond to the conflicts through a series of agreements and revisions that have involved federal and state legislation, and stakeholder accords [25]. Early in the program, the CALFED agencies decided the program needed to engage the public, particularly from identified interest groups or NGOs. One of the best and earliest achievements of CALFED was public awareness and their participation in water conservation activities [23]. CALFED has not been able to eliminate the zero-sum aspect of the game through collaborations, negotiations, and collective decision-making by stakeholders [23]. A review by the Little Hoover Commission found CALFED to be "costly, underperforming, unfocused, and unaccountable" [26]. Elimination of the strong support from the political leadership in Washington and Sacramento, after President Bush was elected, caused the situation at CALFED to begin a slow decline [27]. New leadership who was less supportive of CALFED, creation of the California Bay-Delta Authority (CBDA) without enough authority, and depletion in external funding secured earlier from Congress and the state taxpayers were other reasons for the decline of CALFED [28].

Based on the CALFED program experience, it can be concluded that an agreement may be reached by involving all key stakeholders, increasing public awareness, and providing guaranteed political and financial support. If you create an initiative that requires government funding, and if it is withdrawn without a successful governance structure in place, then the activity will not succeed.

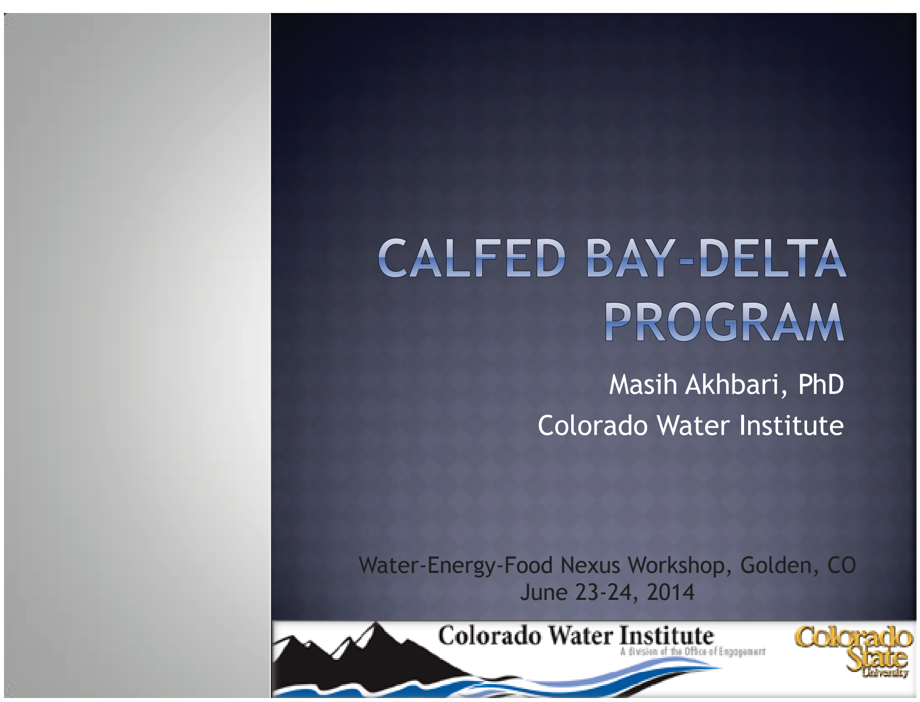
For more information:

http://calwater.ca.gov/content/Documents/library/309.pdf

http://www.bvsde.paho.org/bvsacd/encuen/calfed.pdf

http://www.sciencedirect.com/science/article/pii/S1462901109000963

http://www.lhc.ca.gov/studies/195/report195.html



This case focuses on a decision about balancing water for food, cities, energy, and environment

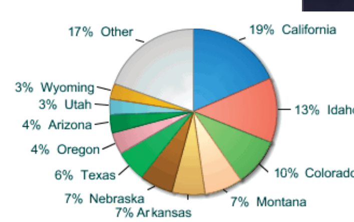
The case emerged due to gridlock reaching back many years about water allocation among the sectors for:

- Environmental purposes in the Bay-Delta area
- Supply irrigation water for agricultural activities
- Supply urban demands (in both Northern and Southern California)
- Hydropower generation in Northern California

- Most fertile soils in the United States
- Significant agricultural activities (Central Valley)
- Several hundred aquatic species
  - More than a hundred are threatened or endangered

WATER AND ENERGY USE

- 14.2% of total irrigated acres in the U.S.
- Produces half of the nation's fruits and vegetables
- The largest surface-water withdrawals
- The highest increase in total freshwater withdrawal by 2050



Source: Kenny, J.F., et al. 2009, *Estimated use of water in the United States in 2005*. USGS Report

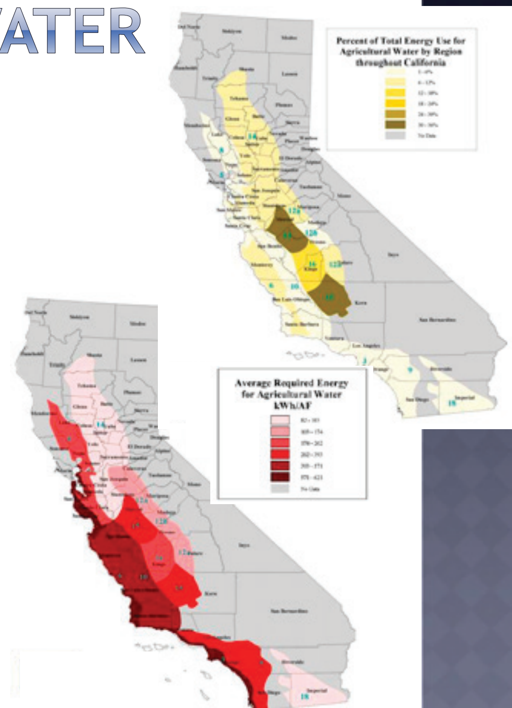
- About 2/3 of precipitation falls in the North
- ~75% of Californians live in the South
- Federal, state, and local project supply ag water
- To meet water demands in Southern California, water is pumped and transferred through the 3,000 miles of pipelines, tunnels and canals

Water transfers to agricultural lands and southern residents is highly energy-intensive

http://aquadoc.typepad.com/waterwired/2009/04/the-baydelta-imbroglio.html

ENERGY USE FOR WATER

- Groundwater supplies ~30 to 46% of the State's water
- Water sector accounts for an estimated use of ~6.9% of the state's electricity and 20% of the state's total energy use
  - Settlement patterns, topography, and climate patterns



Source: Burt, et al. 2003, *California Agricultural Water Electrical Energy Requirements*, ITRC Report No. R 03-006

CALFED BAY-DELTA PROGRAM

The main subject of conflicts among stakeholders in California has been the limited supply of water.

The most comprehensive effort to resolve the conflicts was the CALFED Program

- Initiated in 1995
- CALFED Policy Group: 25 federal and state agencies

Intended to respond to the conflicts through a series of agreements and revisions that have involved federal and state legislation, and stakeholder accords

Addressing three main problem areas in the Bay-Delta:

- Water supply reliability
- Water quality
- Ecosystem health in the Delta

CALFED'S EFFECTIVENESS

- CALFED was successful in the first decade of its implementation and it gained an advanced scientific understanding of the Delta
- One of the best and earliest achievements of CALFED was public awareness and their participation into water conservation activities
- CALFED failed to:
  - reverse the decline of the Delta ecosystem
  - improve the reliability of water supply
  - adopt new paradigms of governance
- CALFED had no power to restrict diversions, set water quality standards, levy charges, or make infrastructure investments

> **"Costly, Underperforming, Unfocused, and Unaccountable"**
>
> Little Hoover Commission

DRIVERS OF FAILURE

- Elimination of the strong support from the political leadership in Washington and Sacramento
- Creation of the California Bay-Delta Authority without enough authority
- Depletion in external funding secured earlier from Congress and the state taxpayers
- Fundamental opposition of interests
- Significant disagreements about the property rights

LESSONS LEARNED

Identify feasible, transparent, and coherent solutions, which can lead to agreement among the competing parties

- Involve all key stakeholders in planning and decision-making processes
- Increase public awareness about the consequences of non-cooperation
- Provide guaranteed political and financial support
  - The Bay-Delta region has been selected as one of the Critical Conservation Areas and will receive increased attention and be financially supported by the Regional Conservation Partnership Program recently launched by the USDA

If you create an initiative that requires government funding, and if it is withdrawn without a successful governance structure in place, then the activity will not succeed.

22. Geysers Geothermal Power Plant Municipal Waste Water Recharge

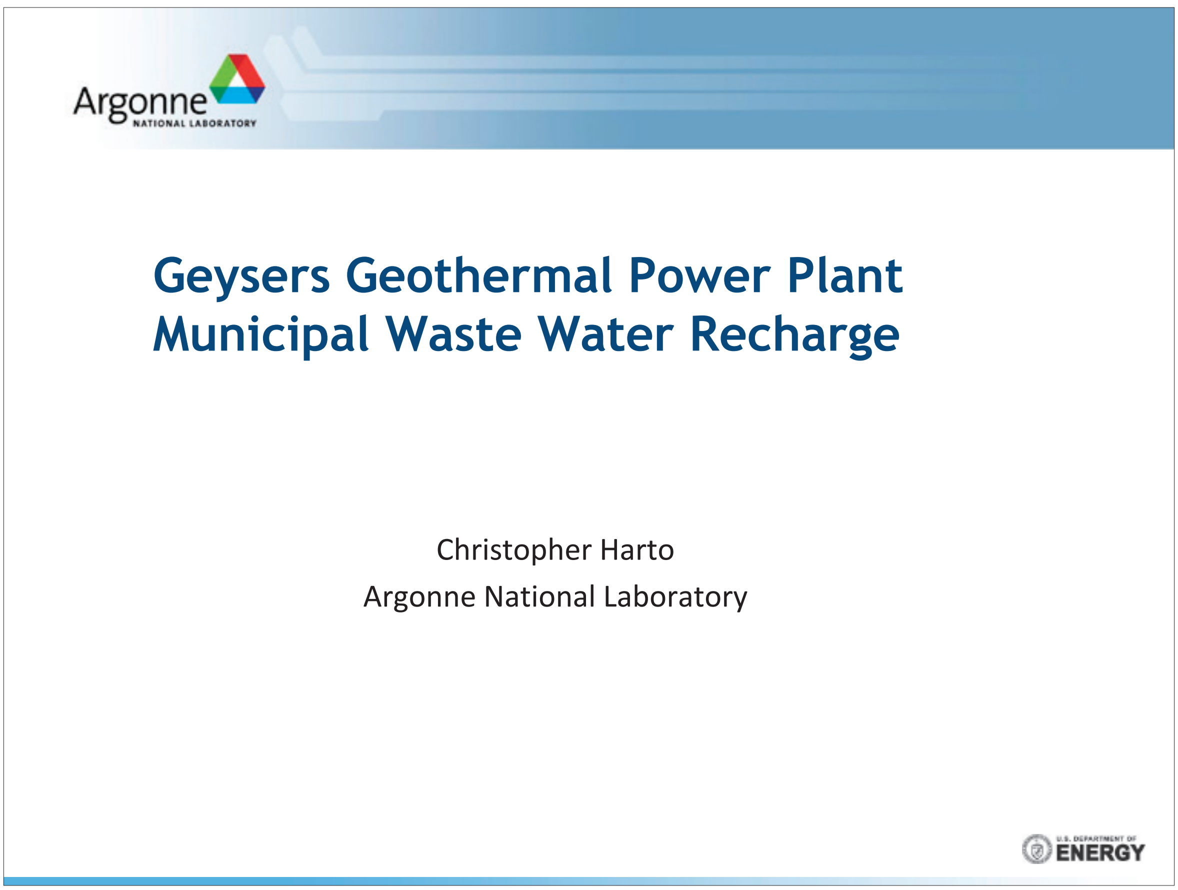
Presented by Chris Harto, Energy/Environmental Systems Policy Analyst, Natural Resource Economics and Systems Analysis Team, Argonne National Laboratory

Geothermal power plants utilize condensed geothermal steam for cooling. The majority of these plants are located in water stressed regions. Total water consumption of these plants will potentially increase due to growth in geothermal development by 2030. In Northern California, high value irrigated agricultural activities (mostly vineyards) limit increased water supply to energy companies. Failure in water supply results in reduced power production. To avoid this problem, Argonne National Laboratory has come up with the idea of using wastewater for cooling. They have built two large scale wastewater injection projects totaling 20 million gallons of waste water a day. These projects have improved local water quality, as low quality wastewater is consumed in the geothermal power plants and freshwater is remained in the reservoirs. Although successful, it is challenges to implement this method in other locations since in many areas municipal waste water effluent is discharged into the local watershed and provides in stream flow and may be used by downstream users; pipeline projects can be costly and sometimes challenging to implement. The alternative opportunity is to use brackish or saline groundwater for supplementary injection in many geothermal systems.

Link(s) for more information:

http://www.geysers.com/numbers.aspx

http://www.watereducation.org/userfiles/Brostrom_Peter.pdf



The Geysers Geothermal Field

- 75 miles north of SF CA in Sonoma and Lake Counties
- 15 power plants with a total 725 MW capacity
- Field covers 45 square miles

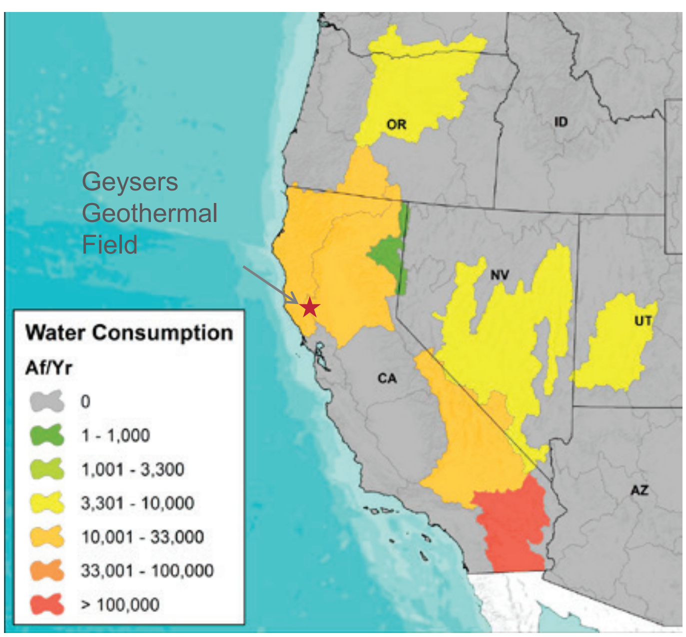
- Power plants utilize condensed geothermal steam for cooling
- Over time this results in reduced power production due to reservoir drawdown

- Two municipal waste water pipelines have been built to provided water to recharge the reservoir and increase/maintain power production

http://www.geysers.com/numbers.aspx

2

Potential Increase in Water Consumption from Growth in Geothermal Development by 2030



3

Water Recharge Pipelines

- Two large scale wastewater injection projects have been built totaling 20 million gallons of waste water a day
- Southeast Geysers Effluent Pipeline
  - Completed in 1997
  - 29 mile pipeline (later extended to 40 miles)
  - 9 million gallons per day of secondary treated wastewater
  - First project of it's kind in the world
  - Resulted in 70MW increase in power output
  - Project improved local water quality
- Santa Rosa Geysers Recharge Project
  - Completed in 2003
  - 42 mile pipeline
  - 11 million gallons per day of tertiary treated wastewater
  - Cost over $200M and took 10 years from planning to completion
  - Resulted in 100 MW increase in power output

4

Impact on Local Wine Growers

- California produces around 90% of the wine produced in the US with a retail value of $23B
- Napa, Sonoma, and Napa counties surrounding the Geysers Geothermal Field contain the largest concentrations of wineries in the state
- The majority of Vineyards in CA are irrigated
  - 1.7M acre-ft/year for irrigation[1]
- Advantages of Project to Local Agriculture:
  - Preserves existing surface and groundwater sources
  - Reduced pollutant discharges to surface water bodies

[1] http://www.watereducation.org/userfiles/Brostrom_Peter.pdf

5

Challenges, Alternatives, and Additional Examples from the Energy Sector

- Challenges in Implementation in other Locations
  - In many areas municipal waste water effluent is discharged into the local watershed and provides in stream flow and may be used by downstream users
  - Pipeline projects can be costly and sometimes challenging to implement, so it may not be the optimum use of resources in all cases

- Alternative Opportunities
  - Brackish or saline groundwater may be able to be used for supplementary injection in many geothermal systems

- Additional Examples from the Energy Sector
  - Palo Verde Nuclear Plant, 3.3 MW, Outside of Phoenix, AZ uses reclaimed waste water
  - Growing use of recycled flowback and produced water from oil and gas production for hydraulic fracturing of new wells

6

23. Opportunities at the California Water-Energy Nexus

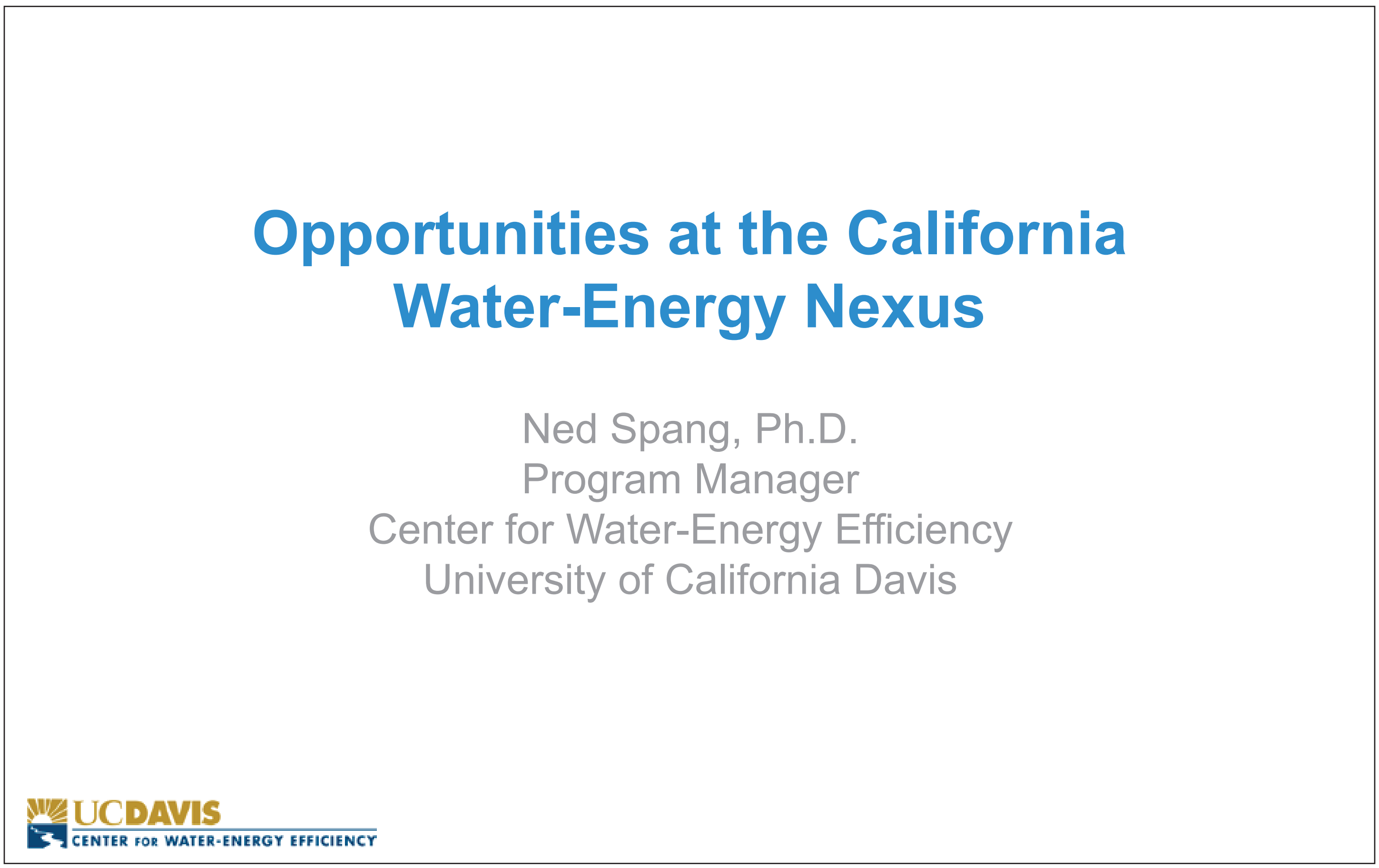
Presented by Ned Spang, Program Manager, Center for Water-Energy Efficiency, UC-Davis

Using East Bay Municipal Utility District in Northern California as a case study, researchers at the Center for Water-Energy Efficiency (CWEE) at UC Davis developed a methodology for calculating at a high resolution the energy intensity of water treated and delivered to customers of a major metropolitan water district. This method extends previous efforts by using highly granular data, including hourly data from supervisory control and data acquisition (SCADA) system components, to produce a system-based understanding of the delivered water's energy intensity. We found significant variations in the energy intensity of delivered potable water within the service territory due to seasonal and topographic effects. This method enhances our understanding of the energy inputs for potable water systems and can be applied to the entire water life cycle. A nuanced understanding of water's energy intensity in an urban setting enables more intelligent, targeted water conservation efforts to secure both water and energy savings that take seasonal, distance, and elevation effects into account.

For more information:

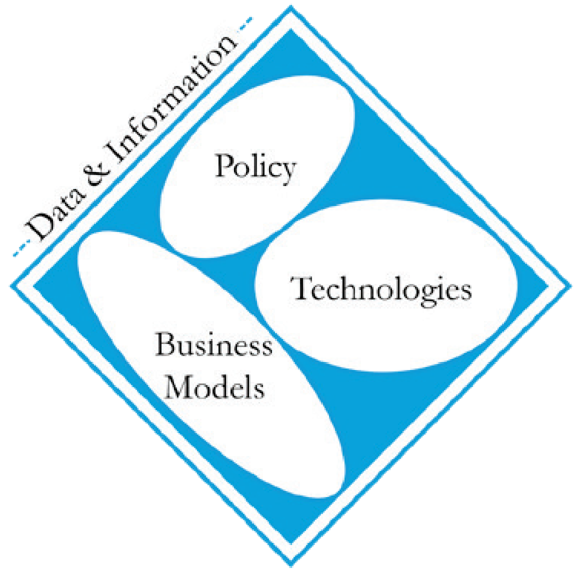
http://cwee.ucdavis.edu/projects/accounting-for-waters-energy-intensity

http://www.etccca.com/sites/default/files/reports/ET12PGE5411_Embedded%20Energy%20in%20Water_0.pdf



The Information Bottleneck

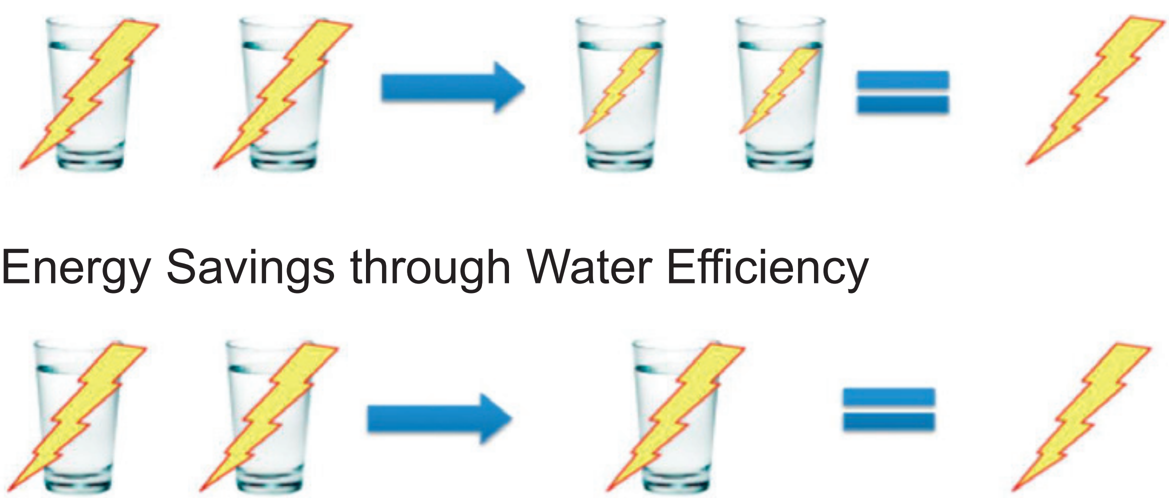
- California' active water-energy agenda
  - AB 32
  - CPUC Guidance
  - WET-CAT
- But limited by availability of actionable data



Saving Energy with Water

Energy Efficiency of Water System

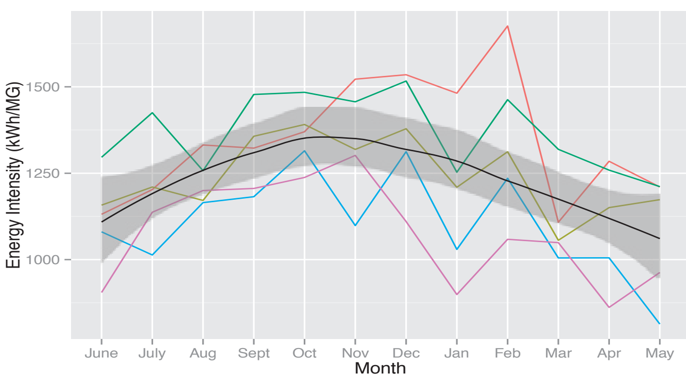
Energy Savings through Water Efficiency

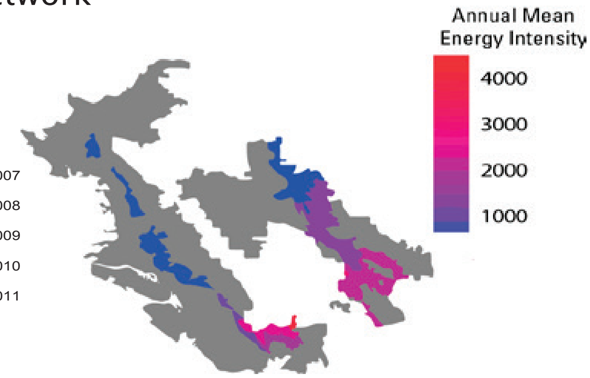


UC DAVIS CENTER FOR WATER-ENERGY EFFICIENCY

Case Study: East Bay MUD

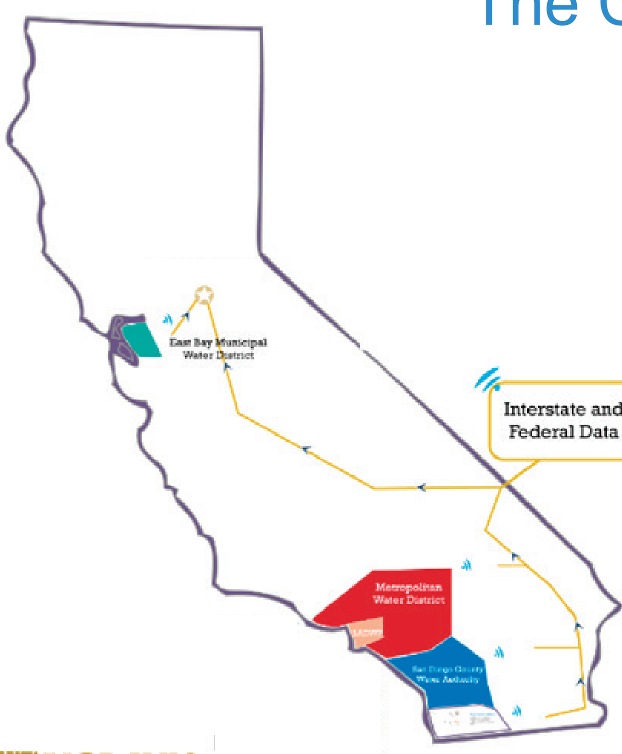
- Results:
  - 10-12% monthly variation around the annual mean
  - >12X difference across the distribution network

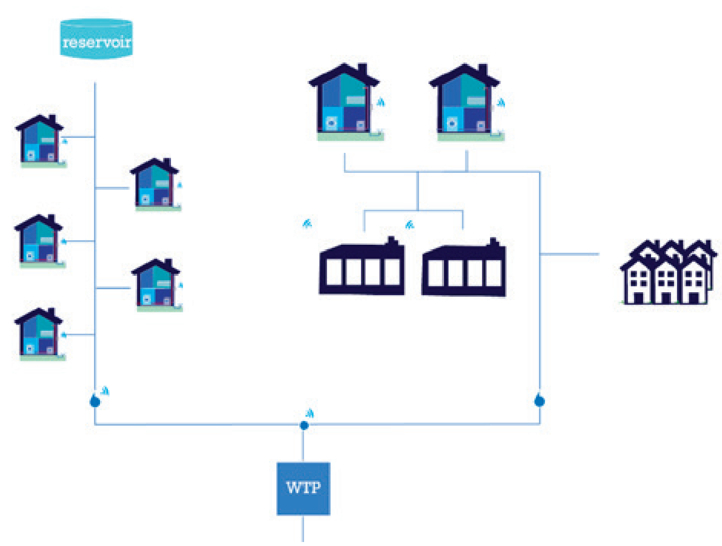




UCDAVIS
CENTER FOR WATER-ENERGY EFFICIENCY

The Complexity





- Multiple scales
- Multiple and overlapping jurisdictions

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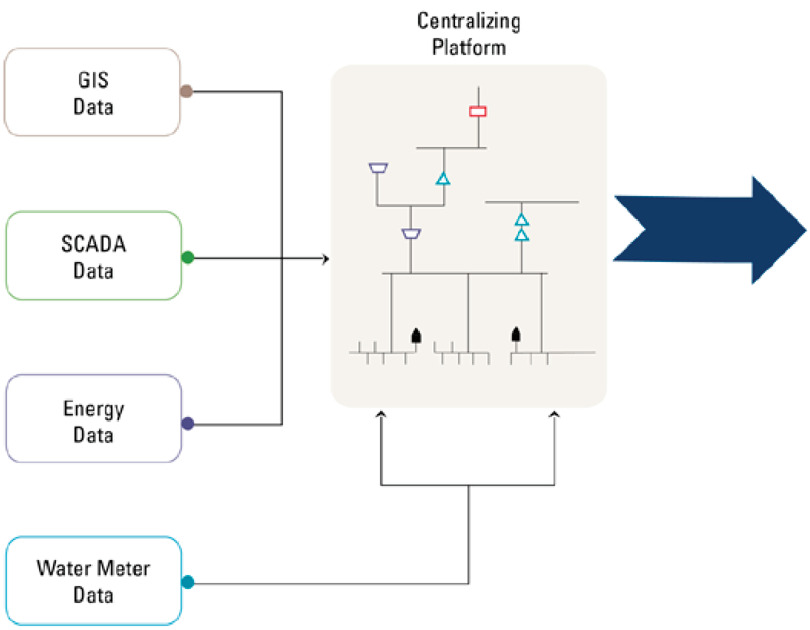
Opportunities



ANALYTICS

Water Benefits

- Water Use Benchmarking
- Targeted Conservation
- Leak Loss Detection
- Monitoring and Verification

Energy Benefits

- Energy Savings
- Demand Response
- Peak Shaving/Shifting
- Energy Storage
- Monitoring and Verification

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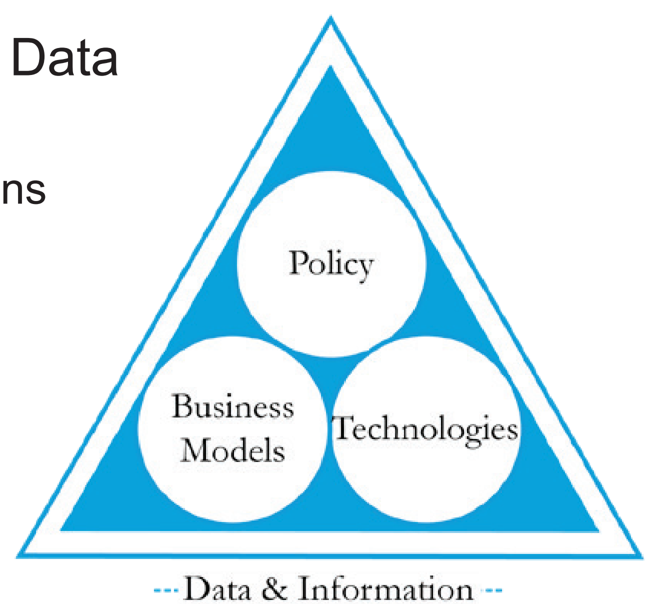
Next Steps

- Aligning Water and Energy Data
  - Common data platform
  - Security and privacy provisions
  - Suite of analytics
  - Funding (e.g., PGC)
  - Stakeholder engagement
- Drive Innovation in Policy, Technology, and Business Models



24. Southern California Ag-Urban Transfer

Presented by Michael Cohen, Senior Research Associate, Pacific Institute

The 2003 water conservation and transfer agreement between California's Imperial Irrigation District (IID) and San Diego County Water Authority (SDCWA) is the largest agriculture to urban water transfer in the U.S. The transfer agreement calls for an annual increase in the volume of water effectively moved from the Imperial Valley to San Diego, from 10,000 acre-feet (AF) in 2003 to almost 200,000 AF in 2020, and 200,000 AF per year from 2023 to 2047, with a provision for a 30 year extension. Through the year 2017, the transfer agreement and supporting authorization require the delivery of 'mitigation water' to the Salton Sea, to offset the direct impacts of decreased inflows due to the transfer. The delivery of the mitigation water ceases at the end of 2017. IID diverts Colorado River water at Imperial Dam. Under the transfer agreement, IID forgoes a prescribed diversion volume, while SDCWA diverts that same volume 142 miles upstream, from Lake Havasu. The transfer agreement has several clear energy implications that have not been studied to date: 1) IID receives Colorado River water via gravity and in fact generates a nominal amount of energy from this water; 2) Colorado River water flowing through Lake Havasu and Parker Dam generates about 70 kWh per AF per year; 3) delivering Colorado River water to SDCWA requires about 1900 kWh/AF/y; 4) SDCWA's other major supply, from California's Bay-Delta via the State Water Project (SWP), requires about 3100 kWh/AF/y to deliver to its service area. To the extent that SDCWA substitutes Colorado River water for its SWP supply, the transfer generates a net energy savings. To the extent that SDCWA is simply augmenting its existing SWP supply, the IID transfer represents additional net energy consumption. Through at least 2017, the transfer agreement also affects crop production, because the transfer agreement requires that IID land be taken out of production to generate water for delivery to SDCWA. Currently, about 30,000 acres of land are taken out of production in IID each year to generate water for transfer. Most of this land would otherwise have been planted in alfalfa, potentially affecting the availability of forage for southern California dairies. After 2017, the fallowing requirement expires, though IID may not be able to generate sufficient water from efficiency and conservation practices by that time and so may need to continue to fallow land. In either case, after 2017 IID is no longer required to deliver mitigation water to the Salton Sea, at which point the Sea will begin to experience profound ecological changes. The IID-SDCWA transfer agreement represents an interesting nexus of water, energy, food, and environmental changes that have not been studied to date.

For more information:

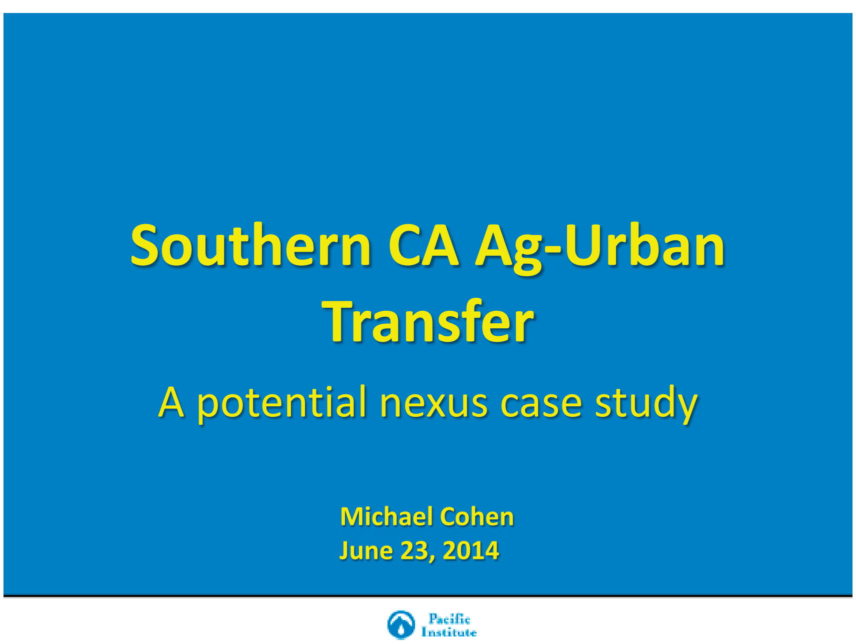
http://www.sdcwa.org/quantification-settlement-agreement

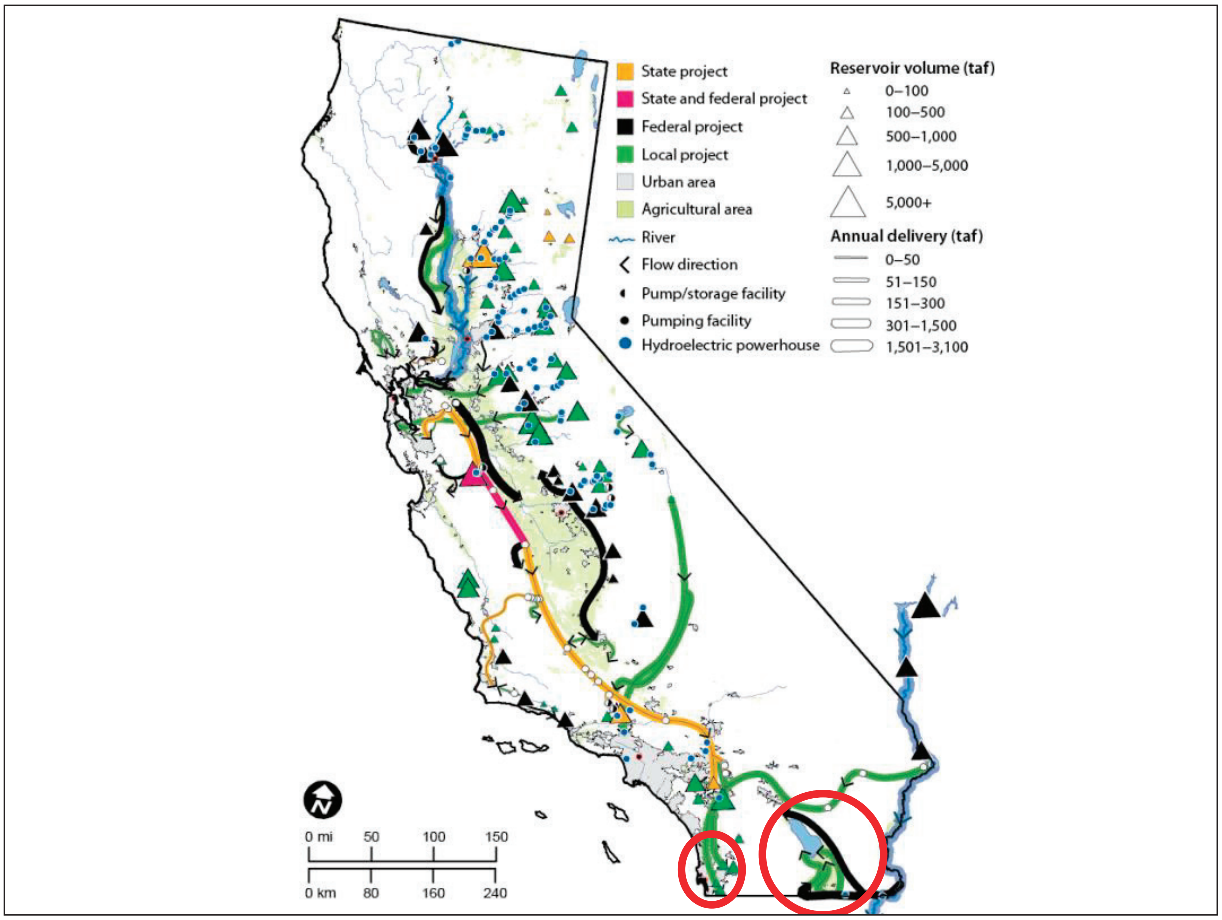
http://www.iid.com/Modules/ShowDocument.aspx?documentid=921

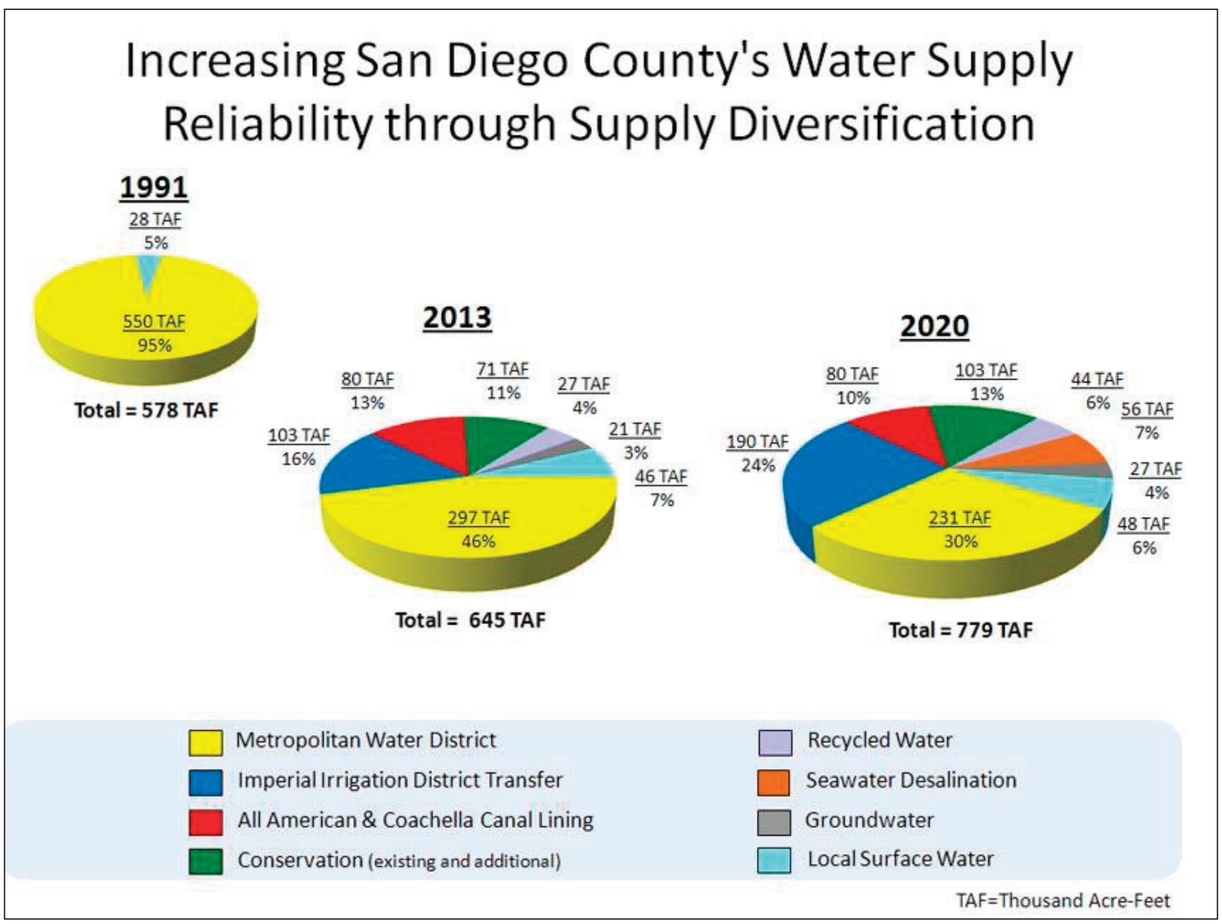
http://www.aquapedia.com/quantification-settlement-agreement/

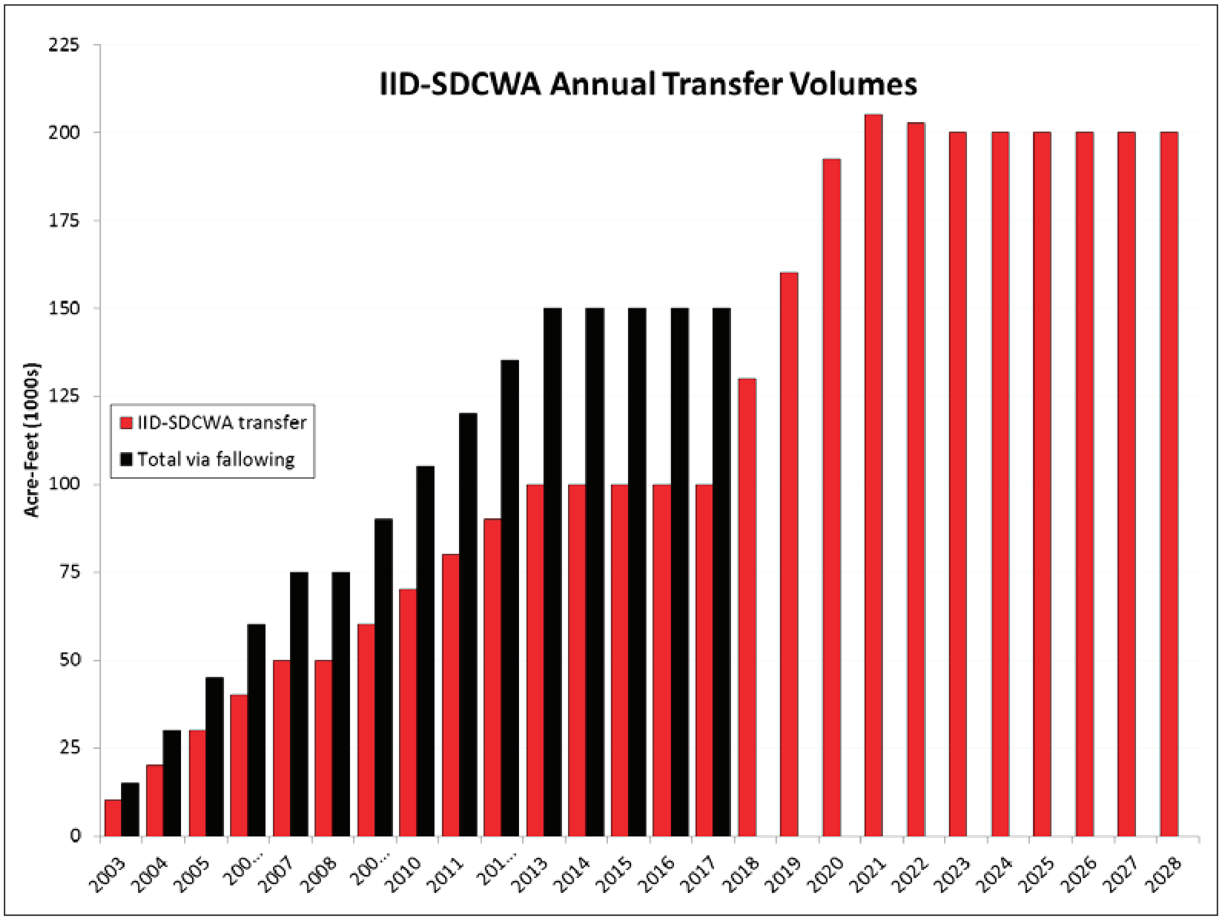
http://www.sdcwa.org/sites/default/files/files/FifthAmendment-iid-sdcwa.PDF

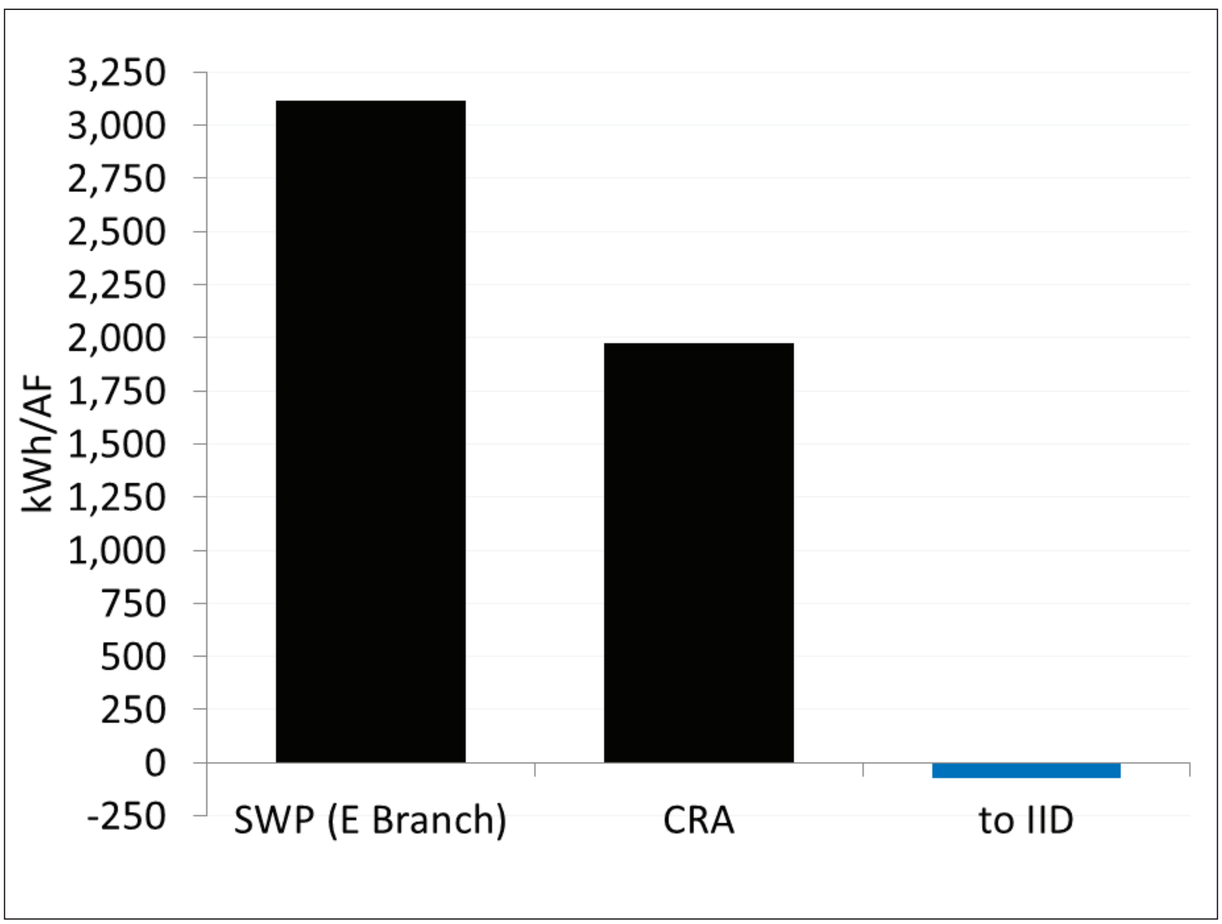
http://www.crb.ca.gov/Board%20Folders/2011/8%20Aug/Tab%205/IID%20Letter.pdf

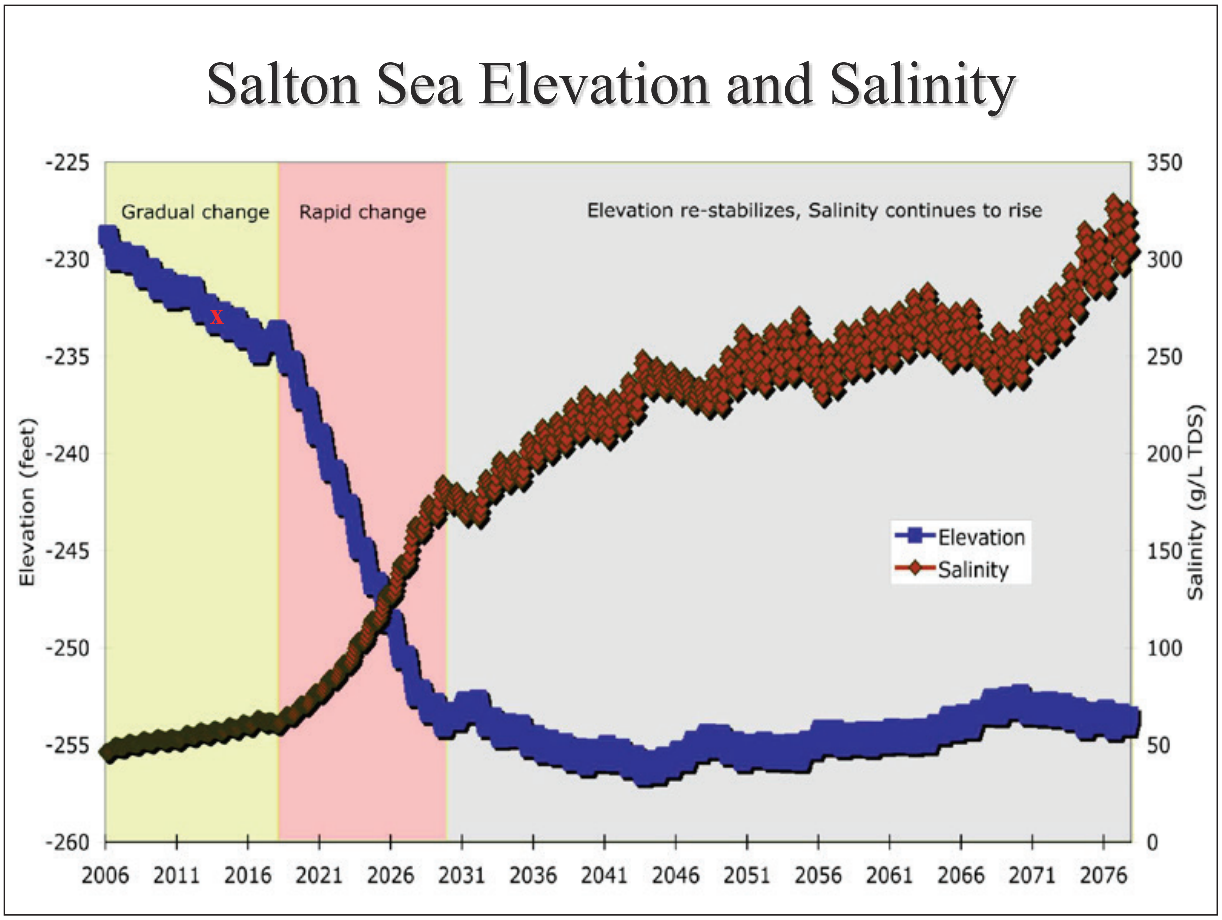



State project
State and federal project
Federal project
Local project
Urban area
Agricultural area
River
Flow direction
Pump/storage facility
Pumping facility
Hydroelectric powerhouse
Reservoir volume (taf)
0–100
100–500
500–1,000
1,000–5,000
5,000+
Annual delivery (taf)
0–50
51–150
151–300
301–1,500
1,501–3,100
0 mi 50 100 150
0 km 80 160 240


Increasing San Diego County's Water Supply Reliability through Supply Diversification
1991
28 TAF 5%
550 TAF 95%
Total = 578 TAF
2013
80 TAF 13%
71 TAF 11%
27 TAF 4%
103 TAF 16%
21 TAF 3%
46 TAF 7%
297 TAF 46%
Total = 645 TAF
2020
80 TAF 10%
103 TAF 13%
44 TAF 6%
56 TAF 7%
190 TAF 24%
27 TAF 4%
231 TAF 30%
48 TAF 6%
Total = 779 TAF
Metropolitan Water District
Imperial Irrigation District Transfer
All American & Coachella Canal Lining
Conservation (existing and additional)
Recycled Water
Seawater Desalination
Groundwater
Local Surface Water
TAF=Thousand Acre-Feet


IID-SDCWA Annual Transfer Volumes
Acre-Feet (1000s)
IID-SDCWA transfer
Total via fallowing
225
200
175
150
125
100
75
50
25
0
2003
2004
2005
200...
2007
2008
200...
2010
2011
201...
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028


kWh/AF
3,250
3,000
2,750
2,500
2,250
2,000
1,750
1,500
1,250
1,000
750
500
250
0
-250
SWP (E Branch)
CRA
to IID


Salton Sea Elevation and Salinity
Gradual change
Rapid change
Elevation re-stabilizes, Salinity continues to rise
Elevation (feet)
Salinity (g/L TDS)
Elevation
Salinity
-225
-230
-235
-240
-245
-250
-255
-260
350
300
250
200
150
100
50
0
2006
2011
2016
2021
2026
2031
2036
2041
2046
2051
2056
2061
2066
2071
2076

25. Navajo Generating Station Case Study

Presented by Stacey Tellenhuisen, Senior Energy/Water Policy Analyst, Western Resource Advocates

Navajo Generating Station (NGS), a 2,250 MW coal plant, provides revenues to Navajo and Hopi Tribes, and contributes to air quality problems. It supplies power demand of the Central Arizona Project (CAP), which delivers Colorado River water to Phoenix, Tucson, Tribal lands, and agricultural lands. Excess power sales contribute to the Lower Colorado River Development Fund. In Feb. 5, 2013, the U.S. Environmental Protection Agency issued a proposed Best Available Retrofit Technology (BART) rule for Navajo Generation Station to reduce emissions of nitrogen oxide (NOx) from the power plant. This rule has the most stringent NOx standard in the U.S. and requires installation of Selective Catalytic Reduction technology, which costs $ 544 million, with the possibility that costs exceed $1.1 billion if additional air filters are required. CAP, along with the other stakeholders, including Gila River Indian Community, the Navajo Nation, Salt River Project, the Environmental Defense Fund, the U.S. Department of the Interior and Western Resource Advocates, developed an alternative "Better than BART" plan for NGS. This proposal addresses EPA's NOx emissions while protecting the future of the NGS. The plan has two alternatives and both reduce NOx emission eve greater than the EPA's proposed rule. Based on this plan:

- 1 Unit (or equivalent) will be retired in 2020;
- Plant owners mitigate economic impacts on local communities
- Department of Interior (DOI): CO2 Reduction Commitment (3%/year) for its unit, or 11.3 million metric tons by 2035
- DOI: Clean Energy Development Commitment;
- DOI: Evaluate transition from NGS to cleaner sources of energy
- Bureau of Reclamation: mitigate impacts on cost of water

Main takeaways from this study are:

- Are energy utilities reporting – and valuing – water use today?
- Are water utilities considering future energy demands? Their reliance on energy? GHG emissions (and future costs)?
- Are we recognizing the positive trends underway?

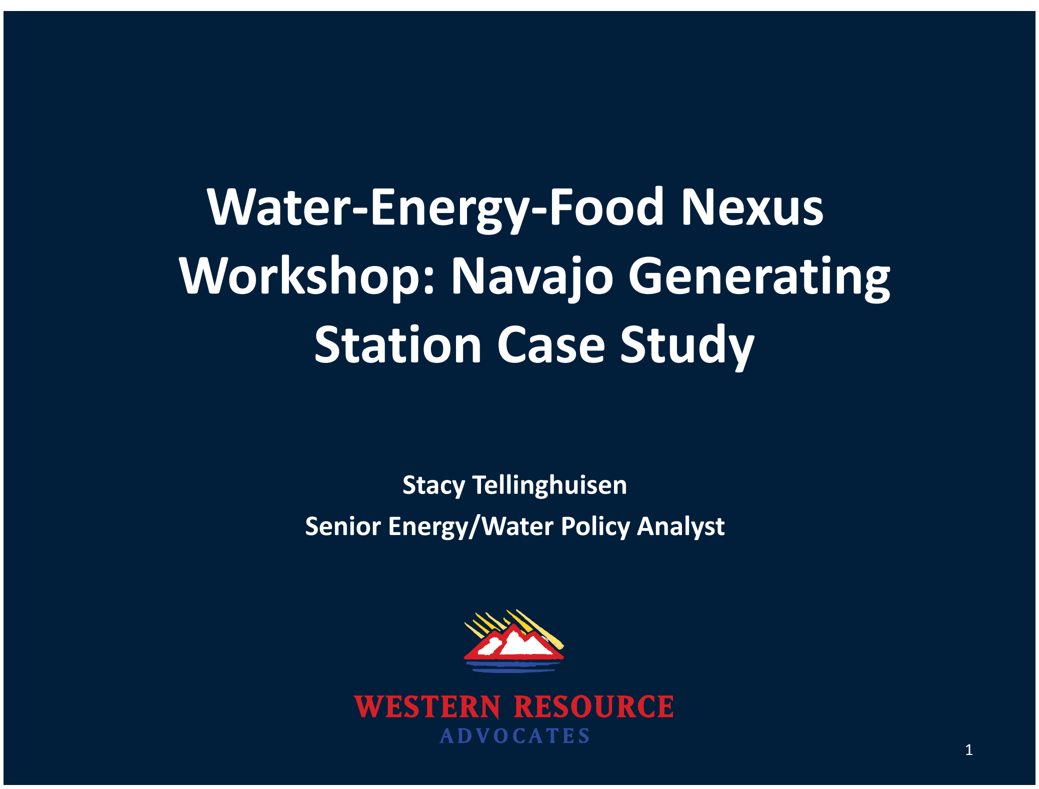
For more information:

http://www.ngspower.com/

http://www.cap-az.com/index.php/public/navajo-generating-station/twg-bart-proposal

http://www.ngspower.com/twg.aspx

http://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Drought%20Management/LDIG/Summaries/2013/9.11.13/CAP%20Better%20than%20BART%20handout.LDIG%20091113.pdf



The Challenge

- Navajo Generating Station – 2,250 MW coal plant
- Department of Interior owns ~25% of the plant
- Plant provides revenues to Navajo and Hopi Tribes, and contributes to air quality problems
- Power pumps Central Arizona Project water
- Water is delivered to Phoenix, Tucson, Tribal lands, and agricultural lands
- Excess power sales contribute to the Lower Colorado River Development Fund

Base map source: http://www.ezilon.com/maps/united-states/arizona-geographical-maps.html

Western Resource Advocates

2

The Impetus

- NGS faced pending EPA regulations (regional haze)
- Several plant owners terminating contracts
- President Obama announced climate change action

Base map source: http://www.ezilon.com/maps/united-states/arizona-geographical-maps.html

Western Resource Advocates

3

Solutions

Alternative to BART Agreement

- Better than BART NOx reductions;
- 1 Unit (or equivalent) retired in 2020;
- Plant owners – mitigate economic impacts on local communities
- Department of Interior – CO2 Reduction Commitment (3%/year) for its unit, or 11.3 million metric tons by 2035
- DOI – Clean Energy Development Commitment;
- DOI – Evaluate transition from NGS to cleaner sources of energy
- Bureau of Reclamation – mitigate impacts on cost of water

Western Resource Advocates

4

Takeaways

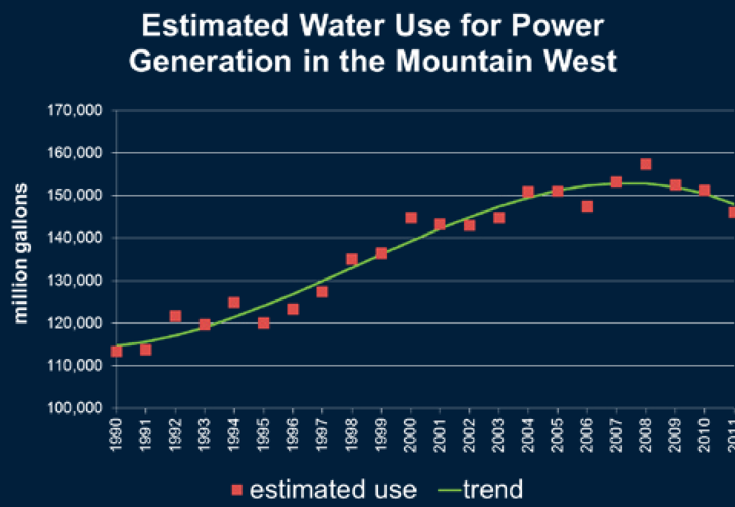
- Stakeholders – and government agencies – have disparate interests and priorities (e.g. water costs, Trust obligations, CO2 reduction goals, etc.)
- Key #1: breaking the link between energy, water, climate, and money
- Key #2: leadership at Bureau of Reclamation

Western Resource Advocates

5

Takeaways

- Are energy utilities reporting – and valuing – water use today?
- Are water utilities considering future energy demands? Their reliance on energy? GHG emissions (and future costs)?
- Are we recognizing the positive trends underway?



Western Resource Advocates

6

26. Supplying Southern Nevada: Challenges and Solutions

Presented by Zane Marshall, Director, Water & Environmental Resources, Southern Nevada Water Authority

Southern Nevada's population is projected to increase by an annual average of 1.2% through 2050. Nevada's water share from the Colorado River is 0.3 million acre-feet, which is not enough to supply urban water demands in Southern Nevada. To address unique water supply challenges, Southern Nevada Water Authority (SNWA) requires out-of-the-box solutions, including:

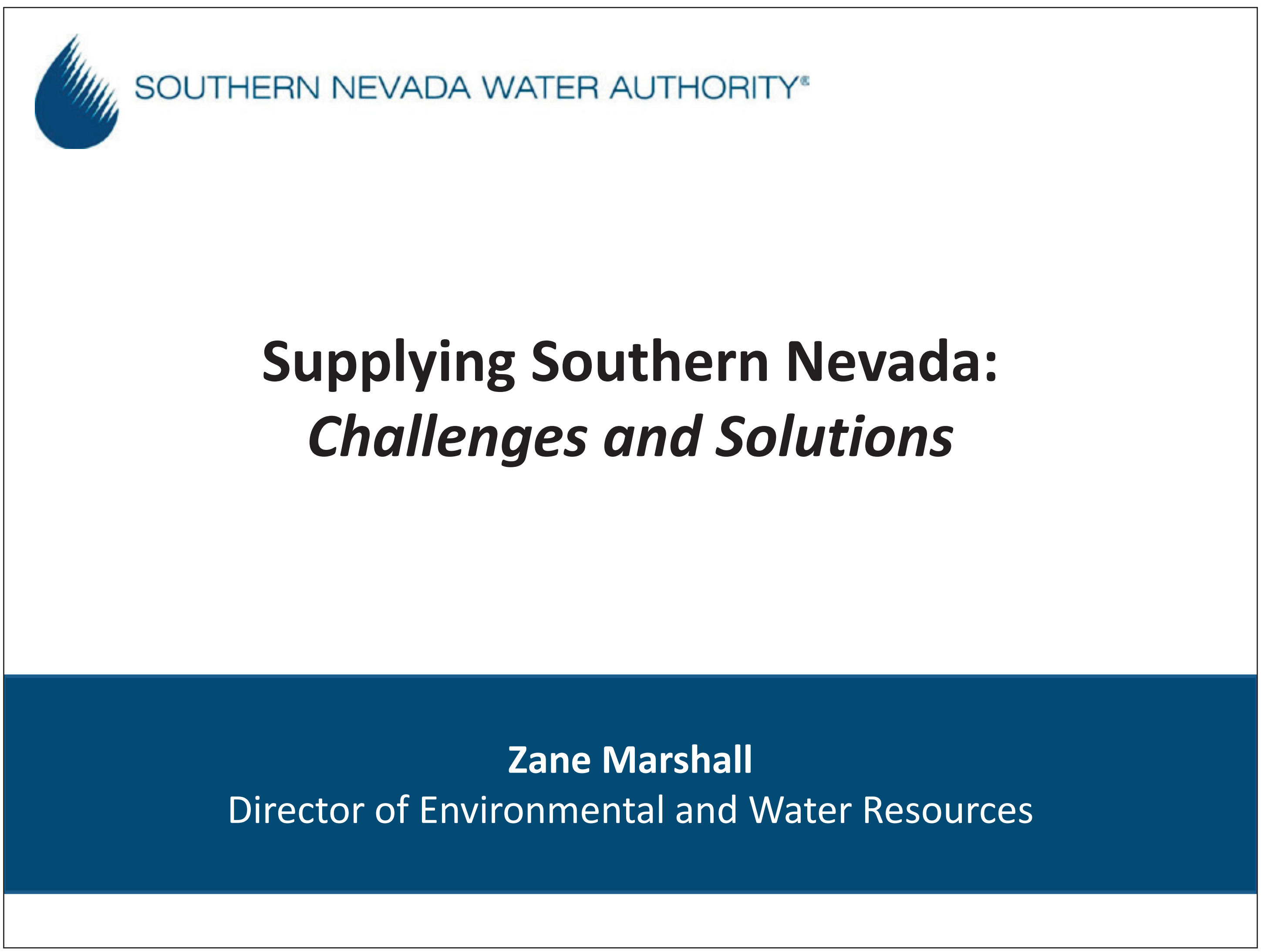
- Aggressive conservation
- Forging partnerships (Regulatory, public, private, NGO)
- Developing flexible water-use agreements
- Seeking alternate supplies

The SNWA has purchased and leased Nevada surface water rights, which were previously used for agriculture, along the Virgin and Muddy Rivers. These water transfer agreements are mutually beneficial for both parties. Resources help diversify resource portfolio and SNWA pays assessments, contributing to long-term stability of the irrigation company. These partnerships with agricultural users can be beneficial without impacts to food production. The agreements also provide environmental benefits to maintain Lake Mead water elevations and to keep water in the tributaries that would have otherwise been used for agriculture. SNWA has also planned for in-state groundwater projects as a water supply separate from the drought-stricken Colorado River. Modification of Nevada's water law allows for Intentionally Created Surplus. These policy changes required significant efforts and a lot of time.

For more information:

http://www.snwa.com/ws/cac_recommendations.html

http://www.snwa.com/ws/cac.html



SOUTHERN NEVADA WATER AUTHORITY®

What We Do:

Regional water supply planning

Conservation programming

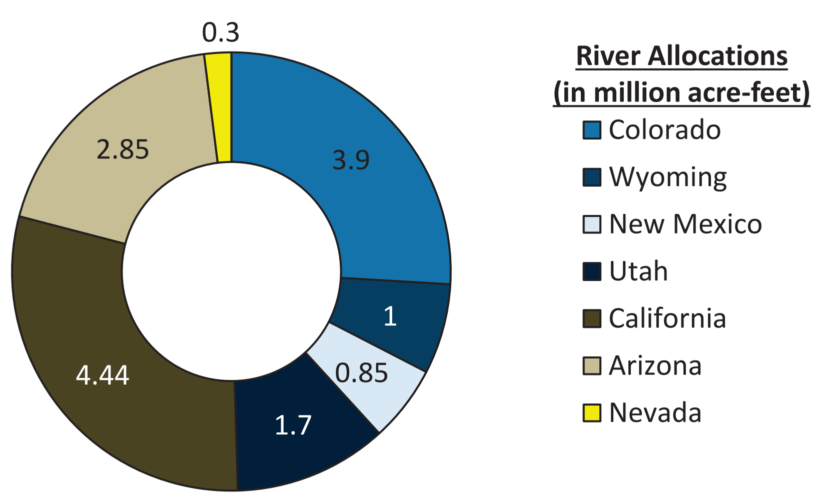
Water Quality

Facility construction

Operate Major Regional Facilities

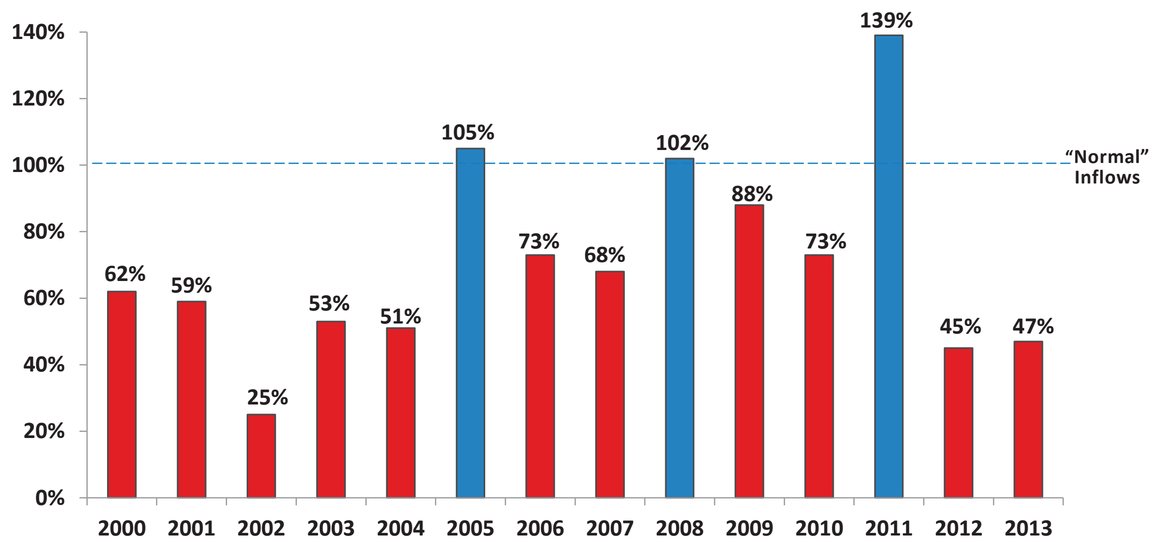
2

Nevada receives 300,000 acre-feet of Colorado River water annually.



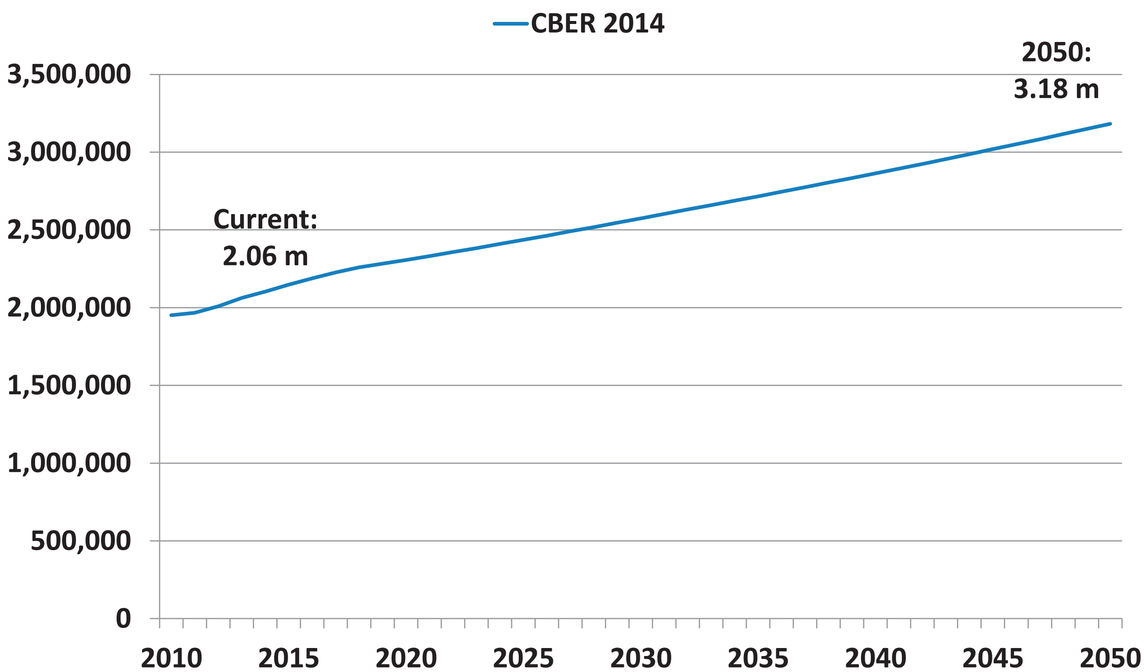
3

Lake Powell's annual inflows continue to be below normal.



4

In addition to dwindling supplies, Southern Nevada's population is expected to grow by nearly 1 million residents over the next 35 years.



5

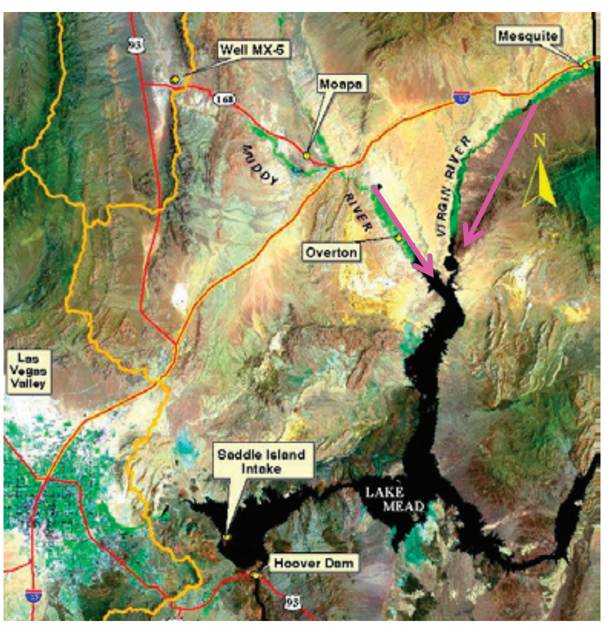
What We're Doing:

Addressing Southern Nevada's unique challenges requires out-of-the-box solutions:

- **Aggressive conservation**
- **Forging partnerships (Regulatory, public, private, NGO)**
- **Developing flexible water-use agreements**
- **Seeking alternate supplies**

6

Water Right Leases/Purchases

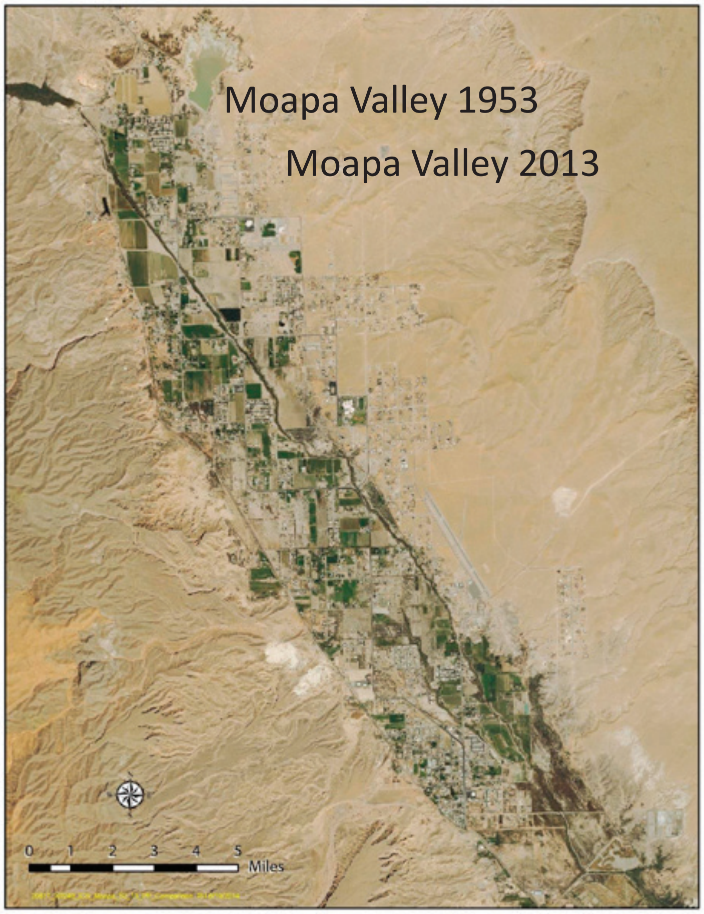


The SNWA has purchased and leased Nevada surface water rights along the Virgin and Muddy Rivers.

Water Rights pre-date Boulder Canyon Project Act: pre-1929.

These water rights were previously used for agriculture (forage crops).

7
7



Agricultural areas experiencing urbanization

Muddy River purchases began in 1997 through Requests-for-Offers

Agreements with Irrigation Companies facilitating leases/ purchases

The agreements have been mutually beneficial for both parties.

Willing Seller

- Individual shareholder's decision
- Irrigation companies agree to not divert SNWA water or leave in ditch; SNWA becomes last turnout

Willing Buyer

- The additional supplies help protect Lake Mead water elevations
- Resources help diversify resource portfolio
- SNWA pays assessments, contributing to long-term stability of the irrigation company

9

SNWA Acquisitions

Own: ~15,000 afy
Lease:
- Long-term ~5,000 afy (>20 years)
- Short-term ~11,000 afy (1 to 3 years)

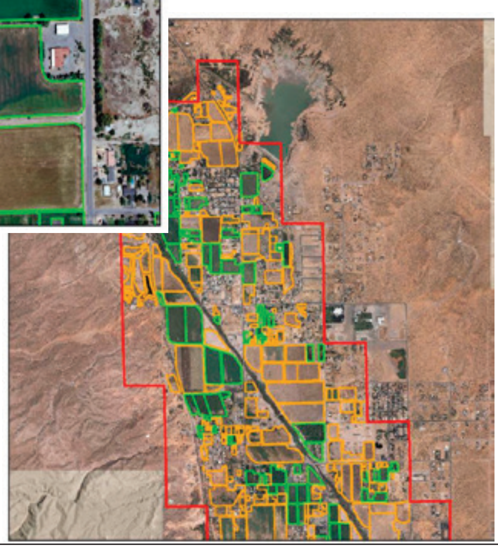
Acreage represented by owned/leased shares ~ 3,500 arces
- Roughly a third already out of production when acquired
- SNWA does not own land

Leases ranged from $250/af to $130/af as economy and SNWA need for water has changed

Verification / Accounting process

Intentionally Created Surplus
Administered by Bureau of Reclamation

SNWA utilized 6-inch resolution aerial photography acquired 3 times per year



Muddy River:
Total water budget to demonstrate flows to Lake Mead

Virgin River: acreage verification

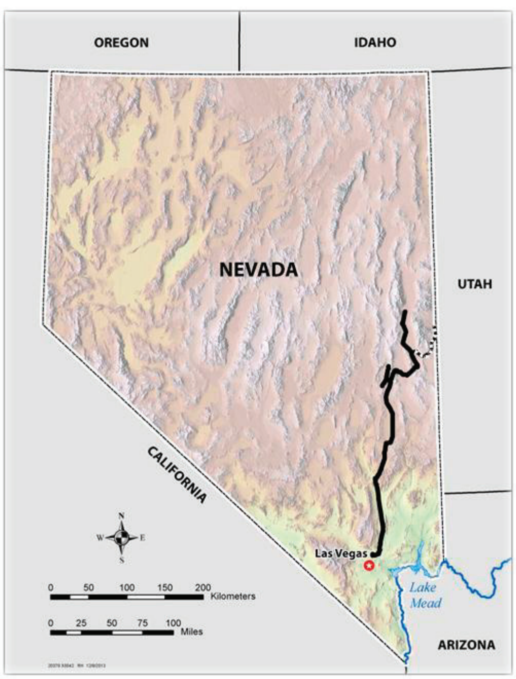
Checked and Certified by Nevada State Engineer and USBR

Beyond the benefits the leases/purchases affords to the parties, it is also provides environmental benefits:

- Maintains Lake Mead water elevations
- Keeps water in the tributaries that would have otherwise been used for agriculture

12

In-State Groundwater Project



Groundwater Development Project alignment

A water supply separate from the drought-stricken Colorado River is necessary to meet Southern Nevada's long term demands.

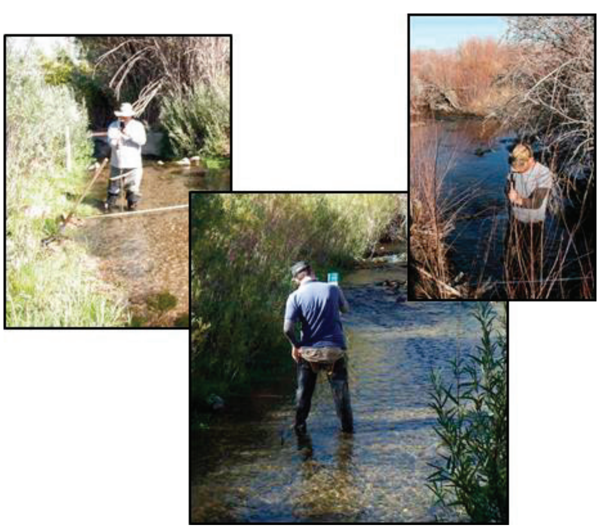
14

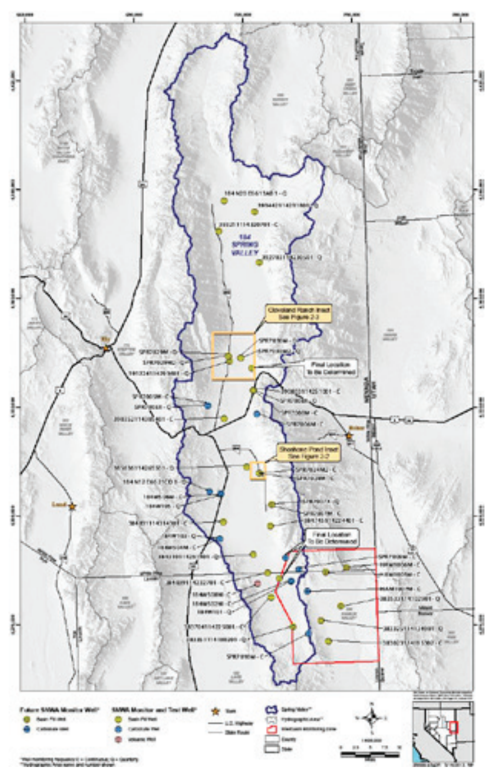
To support future development of the project, the SNWA has purchased several ranches in the project area:

- Support sustainable resource management
- Allows the SNWA to meet state and federal requirements
- Provides access to resources
- Promote community engagement

The properties also support environmental monitoring efforts:

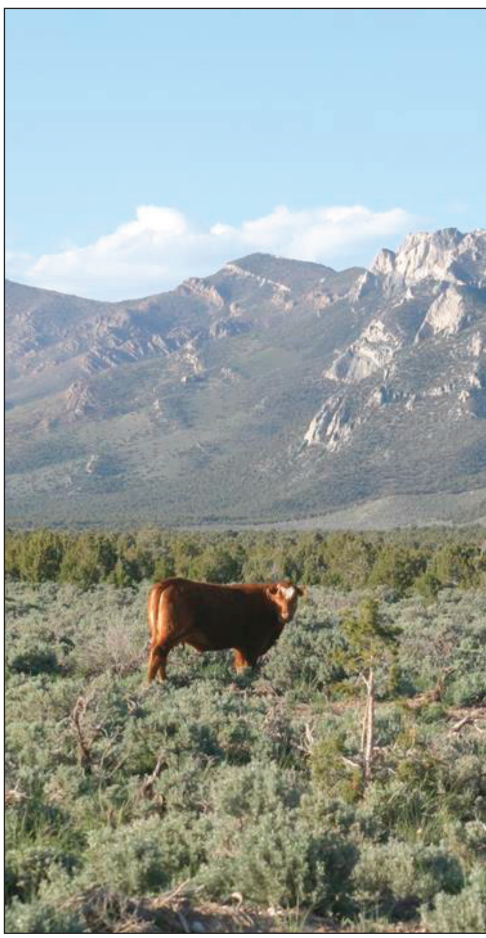
- >200 Hydrologic sites
- 15 Climatological sites
- 44 Biological sites





Safeguards are in place to protect existing water users:

- Nevada water law (prior appropriation)
- Federal stipulations among affected federal agencies
  - Stakeholder-led workgroups and management teams
- Extensive, state-approved monitoring and management plans
- An established history of managing watersheds and sensitive environments (Las Vegas Wash)



Partnerships with agricultural users can be beneficial without impacts to food production:

- **Meets existing and anticipated M&I demands**
- **Beneficial to environment**
- **Flexible in nature**
- **Avoids future conflicts**

27. NEWBA "Grass-Roots" Approach

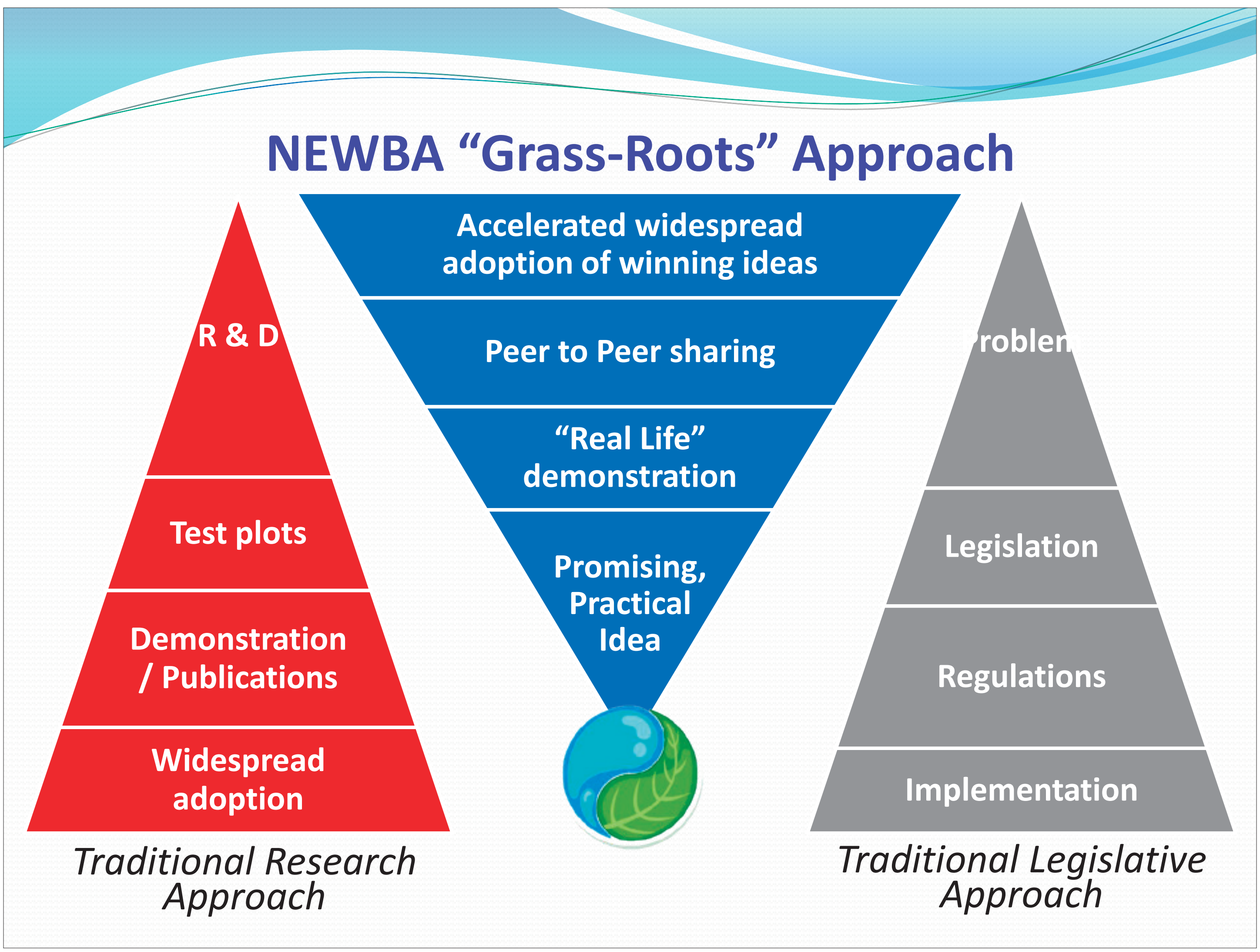
Presented by Laura Chartrand, Water Resources Policy Advisor, Tri-State Generation & Transmission

Traditional research approach would start with research and development, and then continue by test plots, demonstrations/publications, and widespread adoption. Traditional legislative approach, on the other hand, would start with problem identification, and continue with legislation, regulation, and implementation. Nebraska Water Balance Alliance's (NEWBA) Grassroots Approach, which is believed to be more powerful than the traditional research and legislative approach, starts with specification of promising and practical ideas, and continues with "real life" demonstration to engaging parties, peer to peer sharing, and results in accelerated widespread adoption of winning ideas. This approach was tested in a small scale in Nebraska and was concluded to be very successful. The main lessons learned from this case were summarized as:

- "Real life" studies help shorten learning and adoption curve for new technologies
- Grower concerns with technology must be addressed to gain confidence
- Localized weather is required to make good decisions
- Data must be "real time"
- Telemetry and flow meter must be compatible
- Pressure Gauge readings should be on dashboards
- Residue management is especially important when water is limited

For more information:

http://www.nebraskawaterbalance.com/



Real Time Management

Water Data

2013

1. Real Time Consumptive Water Use:

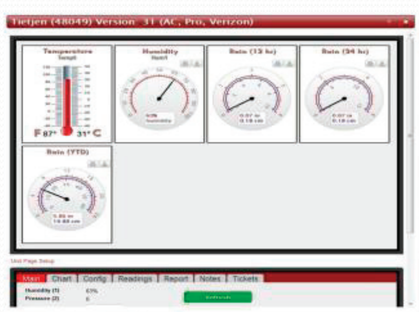
- Weather Stations record Evapotranspiration (ET)
- Record planting and emergence dates
- Record daily growth stages

Real Time Management

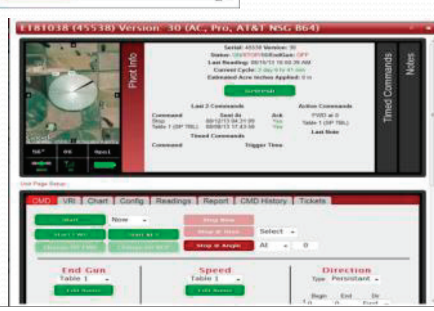
Water Data

2013

2. Real Time Water Application:



Ag Sense
Crop Link



Ag Sense
Field
Commander

Comparing:

- Flow meter
- Power company energy readings
- Pressure gauges

Cross check for accuracy

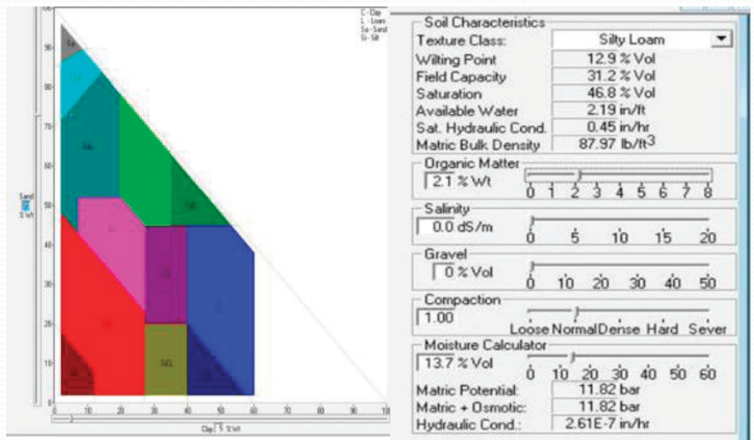
Real Time Management

Water Data

2013

3. Real Time Water Availability in the soil

Soil Texture Triangle



What did we learn?

2012

- **"Real life" studies** help shorten learning and adoption curve for new technologies
- **Grower concerns** with technology must be addressed to gain confidence
- **Localized weather** required for good decisions
- Data must be **"real time"**
- More study of **nitrates** is needed

What did we learn?

2013

- **Telemetry and flow meter** must be compatible
- **Sprinkler package** problems -- greater than anticipated
- **Pressure Gauge** readings should be on **dashboards**.
- **Nitrogen movement** is higher than expected
- **Residue management** is especially important when water is limited

Real Time Management

Team Approach

2013

28. Facing the Challenges: Water-Energy Nexus in Austin, Texas

Austin, located near the center of energy-rich and water-stressed Texas, is one of the fastest growing cities in the U.S., with 80% population growth from 1990 to 2011 [29]. This rapid growth has made it challenging for the public electricity and water suppliers to provide reliable and affordable services while promoting environmental sustainability. However, Austin suppliers have successfully integrated and strategized programs and policies to sustainably meet the public demands. Austin Energy, as the 8th largest public electricity utility in the U.S., serves more than 400,000 customers and Austin Water, as its 5th largest consumer, which uses 210,000 MWh electricity to pump and treat 200 million m3 water and 100 million m3 wastewater [30].

Energy and water conservation initiatives are important aspects of the city. Austin Energy initiated the Green Building Program in 1990. A citizen driven effort terminated a substantial development over a local aquifer the same year. This effort was followed by the adoption of the city's Save Our Springs ordinance in 1992 to ensure sustainable use of water resources [31]. Austin Water and Austin Energy continuously measure the amount of energy used in providing water services, water use in thermoelectric generation, and the average water use in water and energy services to use these data in optimizing water and energy use and keeping costs down.

Austin Energy has conserved 700 MW in demand-side and targeted an additional conservation of 800 MW peak-day demand by 2020. Meanwhile, Austin Water is making comprehensive water conservation efforts, such as a tiered rate structure and weekly watering schedules for landscaped areas, which has reduced peak seasonal demand. In addition, the two utilities collaborate in generating renewable energy and reducing greenhouse gas emissions [31]. Additional demand-side energy savings are practiced in the city by distribution of high-efficiency kitchen and bathroom aerators and showerheads, as well as rebates to buying high-efficiency dishwashers, washing machines, auxiliary water and irrigation system upgrades [32]. In addition, Austin Water employed Green Choice, Austin Energy's 100% wind energy program, in 2011 resulting in an 85% reduction in the water utility's greenhouse gas emissions. The utility has also reduced its surface water withdrawals through its reclaimed water program and supplies low cost water to energy generation facilities operated by Austin Energy and the University of Texas [31].

For more information:

http://www.statesman.com/news/news/local/austin-property-taxes-jump-38-over-past-decade/nRprf/

http://www.yumpu.com/en/document/view/13766054/austin-energy

http://unesdoc.unesco.org/images/0022/002257/225741e.pdf

http://aceee.org/w-e-program/city-austin-multifamily-energy-and-wat

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Background Paper for the Nexus Workshop
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Background Paper for the Nexus Workshop

U.S. Perspective on the Water-Energy-Food Nexus

Masih Akhbari, Neil Grigg, and Reagan Waskom

1. Introduction

Following the Millennium Summit of the United Nations in 2000, eight Millennium Development Goals were established. Among them were: to eradicate extreme poverty and hunger, to ensure environmental sustainability, and to develop a global partnership for development [2]. To achieve these goals, secure water supplies, energy generation, and food production are required while balancing environmental, social, and economic issues [3]. The sectoral approach might fail to recognize important connections between different systems and might find suboptimal solutions for the entire global system, while being optimal for specific sectors [4].

A nexus approach that integrates management and governance across sectors and scales would help improve water, energy, and food security [5]. Developments in one area will have major effects on the other, and we can no longer continue planning for each sector independently. While expecting to find win-win-win solutions is unrealistic, a nexus approach should help identify the best trade-offs between conflicting objectives [4]. The main question here is how to sustainably plan for water, energy, and food for a country or a region. It can be achieved by consideration of resource endowment, development status, and resilient thinking in the planning process [6]. Resource endowment accounts for the natural resource wealth of the country or region in relation to water and energy sources and agricultural land as well as the availability of human, financial, and institutional resources [6]. Co-management of water, energy, and food resources helps increase resource efficiency and productivity. Different sectors of the nexus and their relationships are discussed below.

1.1. Nexus Definition of Water, Energy, and Food

Water: "A water system supplies water for human use, whether for drinking, irrigation, or industry, [collects and conveys wastewater and stormwater,] and treats wastewater to protect public and ecological health. Pipes, home faucets, water towers, treatment plants, watersheds, and estuaries are key parts of the water system" [7].

Energy: "An energy system includes everything it takes to generate and distribute electricity as well as steps required to produce and distribute fuels. Power plants, rooftop solar panels, transmission lines, coal mines, and oil refineries are all parts of the energy system" [7].

Food: "A food system includes the activities, resources, and people

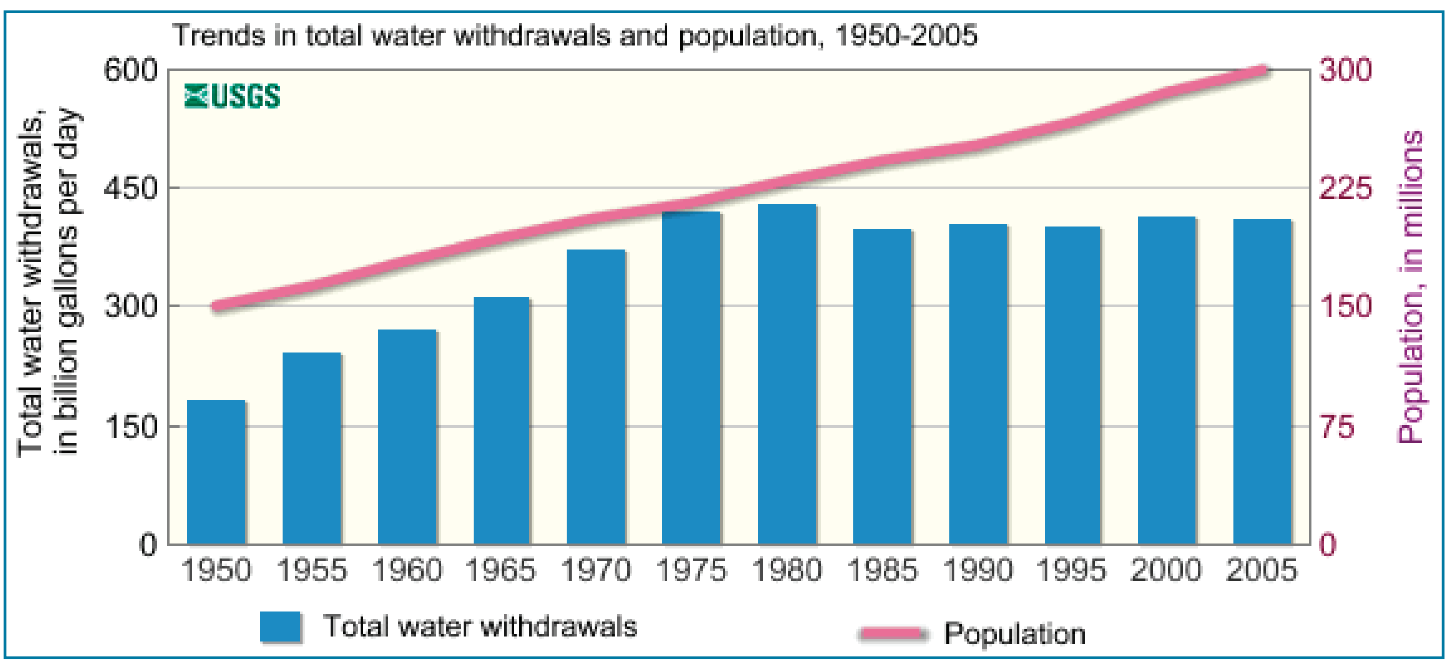


Figure 1. 1950-2005 trends in total water withdrawals and population [11]

involved in bringing food from the farm to the table. Crops, feedlots, trucks, fertilizers, markets, and even our own kitchens are all part of the food system" [7].

1.2. Integrated Water Resources Management versus the Nexus Approach

The nexus approach that integrates management and governance across sectors and scales has similarities to the concept of Integrated Water Resources Management (IWRM). IWRM has been defined by the Global Water Partnership as "a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and environment [8]." Both IWRM and the nexus approach focus on policy and decision-making changes that enhance human welfare, improve social equity, help sustainable growth, and protect environmental resources. They are both based on concepts that: sector-focused planning and decision making are unlikely to result in environmentally, socially and economically sustainable development; promotion of greater coordination among sectors is needed; and the potential consequences of one sector's decisions on the other sectors must be acknowledged [9]. In spite of these areas of agreement, different interpretations of broad concepts such as IWRM and the nexus approach will continue and attempts to reach consensus definitions are unlikely to survive from one sector to another.

While opinions about these broad integrated approaches differ, distinctions between IWRM and the nexus approach can be drawn. With the nexus approach, the broad goals of IWRM are affirmed, but specific actions are also sought to increase security of water, food, and energy systems. "The key difference between the nexus and IWRM is that IWRM starts with the water resource when considering the interrelationships between water, food and energy. In an idealized form, the nexus approach seeks to look at all three elements as an interrelated system [9]." It could be said, of course, that IWRM can be used as a platform to consider the nexus, but once again, it is a matter of interpretation.

1.3. Water in the U.S.

Water is a critical limiting factor in energy and food production and security. Despite a population growth of about 24 percent in the U.S. from 1985 to 2005 [US Census Bureau], total water withdrawals have

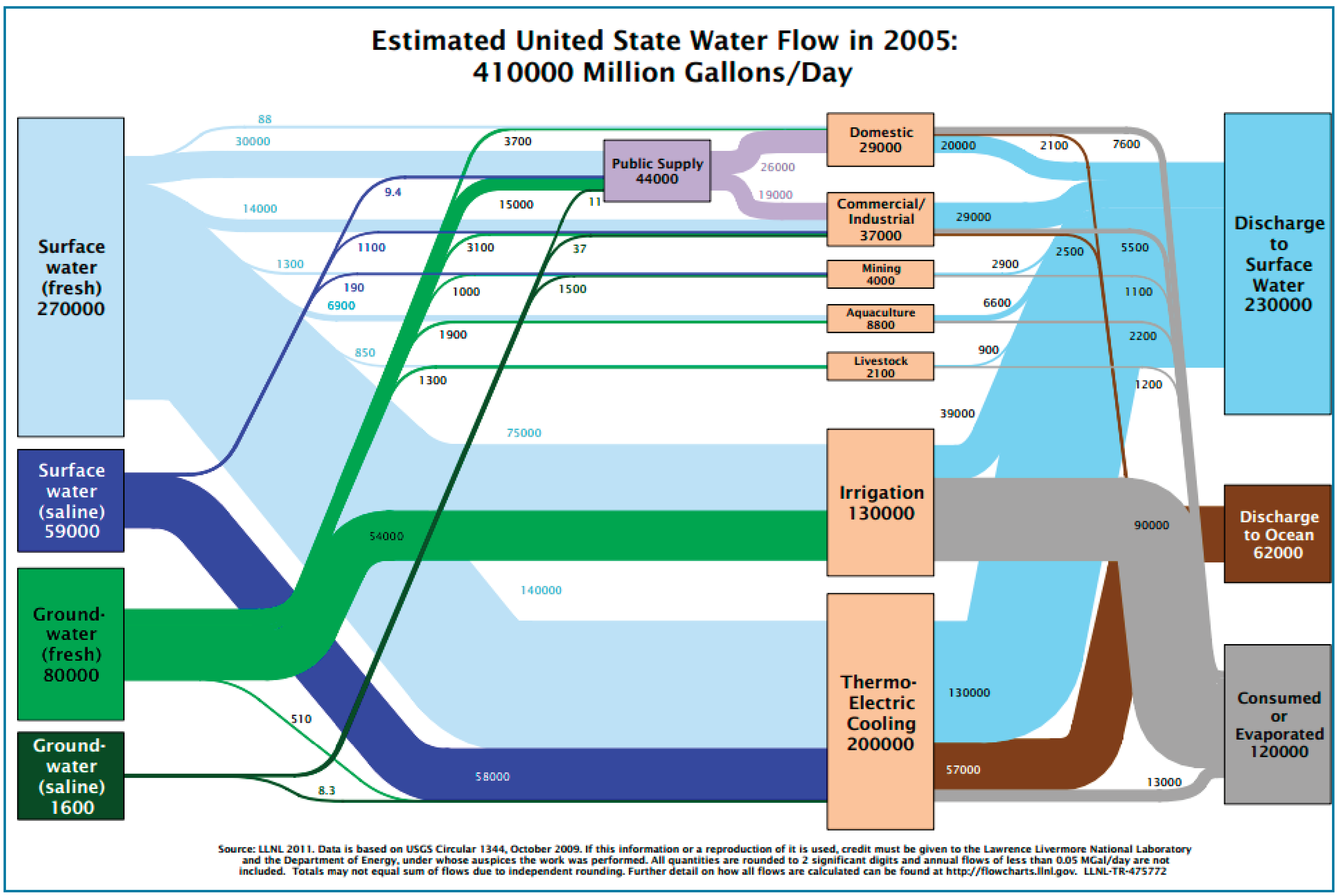


Figure 2. Estimated U.S. water use in 2005 [12]

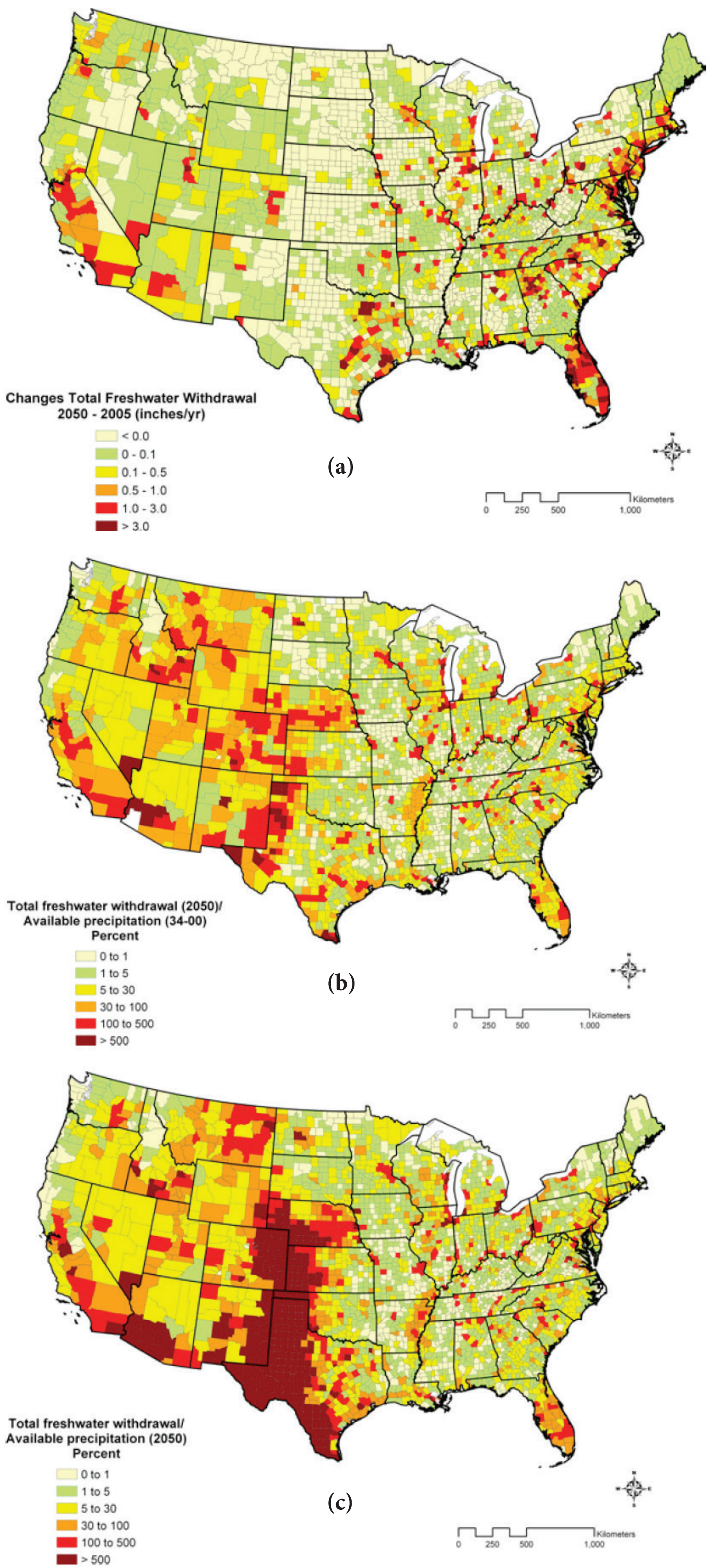


Figure 3. (a) Changes in total freshwater withdrawal (inches/yr) from 2005 to 2050 at the county level; (b) Projected total freshwater withdrawal in 2050 as percent of historical (1934-2000) total available precipitation; (c) Projected total water withdrawal as percent of available precipitation in 2050 [1]

almost remained constant (Figure 1). Total freshwater withdrawal in 2005 was about 410,000 Mgal/d, with thermoelectric power sector having the highest withdrawal rate (41% of the total), followed by irrigation (~37% of the total and about 62% of the nation's surface water withdrawals, excluding thermoelectric power withdrawals) [11]. California had the largest surface-water withdrawals to meet its irrigation demands. The largest rates of fresh surface water withdrawal for thermoelectric power were in Illinois, Texas, and Michigan. Sources of water supply for different uses in the U.S. and where the wastewater is discharged are shown in Figure 2. Although thermoelectric generation has the highest water withdrawal rate, it only consumes 6% of the total withdrawal, while irrigation accounts for 80% of total consumptive water use in the U.S.

By 2050, the highest increase in total freshwater withdrawal will be expected in the western and eastern parts of the U.S., mostly in California and Florida. The Midwest will maintain about the same freshwater withdrawal rate, and there will be a low-to-moderate increase) in the rest of the U.S. (Figure 3a) [1]. However, when compared with the available precipitation, higher water scarcity and stress will be imposed to the western U.S. even if climate change effects are ignored (Figure 3b). It is anticipated that climate change effects will intensify water scarcities, especially in the Midwest (Figure 3c).

1.4. Energy in the U.S.

Fossil fuels are currently the main source of energy in most parts of the world. It is anticipated that the global energy demand will grow about 40% by 2030 [5] and biofuel demands could grow by 100% by 2030 [13]. This 40% increase in energy demand could result in a 165% increase in freshwater demand in the energy sector [14]. However, by effective demand management, these growth rates can be significantly reduced [15]. Substantial reduction of carbon emissions from the burning of fossil fuels over the coming decades is essential to the mitigation of climate change. Renewable sources presently supply about 13% of global energy use [16], and in the U.S. the main renewable is hydropower . The global use of renewables is projected to grow significantly [17], mainly through expanding solar and wind energy resources. For example, the European Union, through its Renewable Energy Directive, has planned to supply at least 20% of its total energy from renewables by 2020 [5].

The U.S., with about 5% of the total world population, consumes 21.8% of the total energy supply [18] and more than 80% of this demand is supplied from fossil fuels (Figure 4). Energy development plans that do

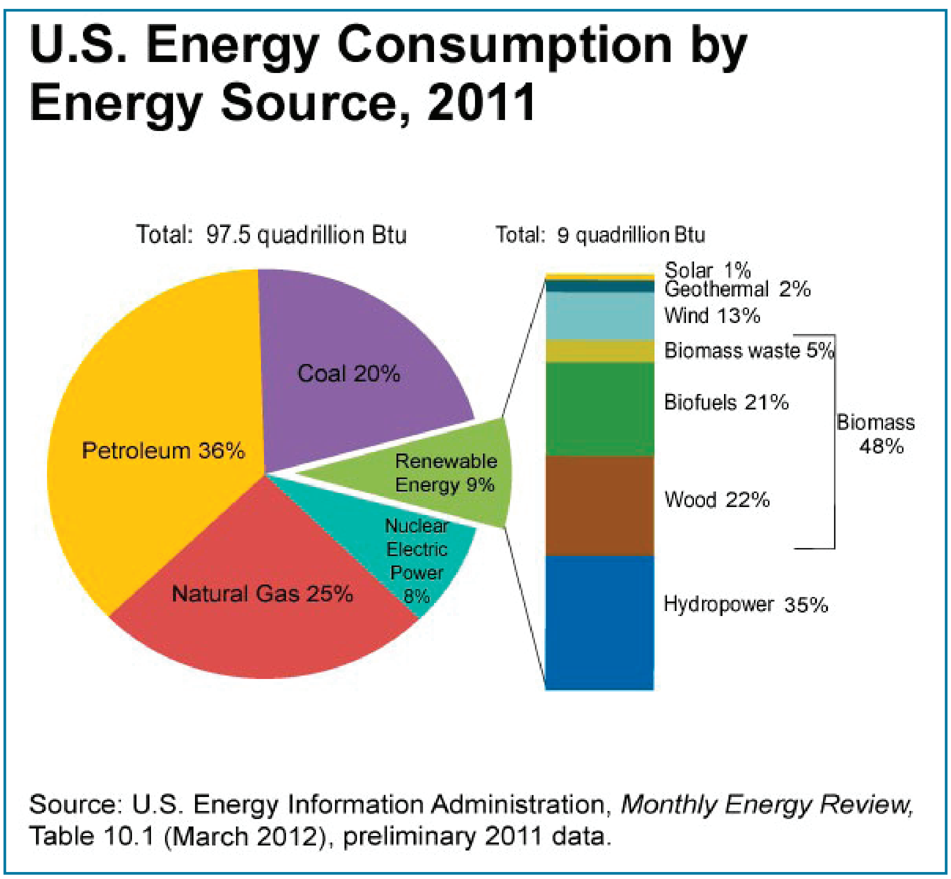


Figure 4. U.S. energy consumption by energy source in 2011 [21]

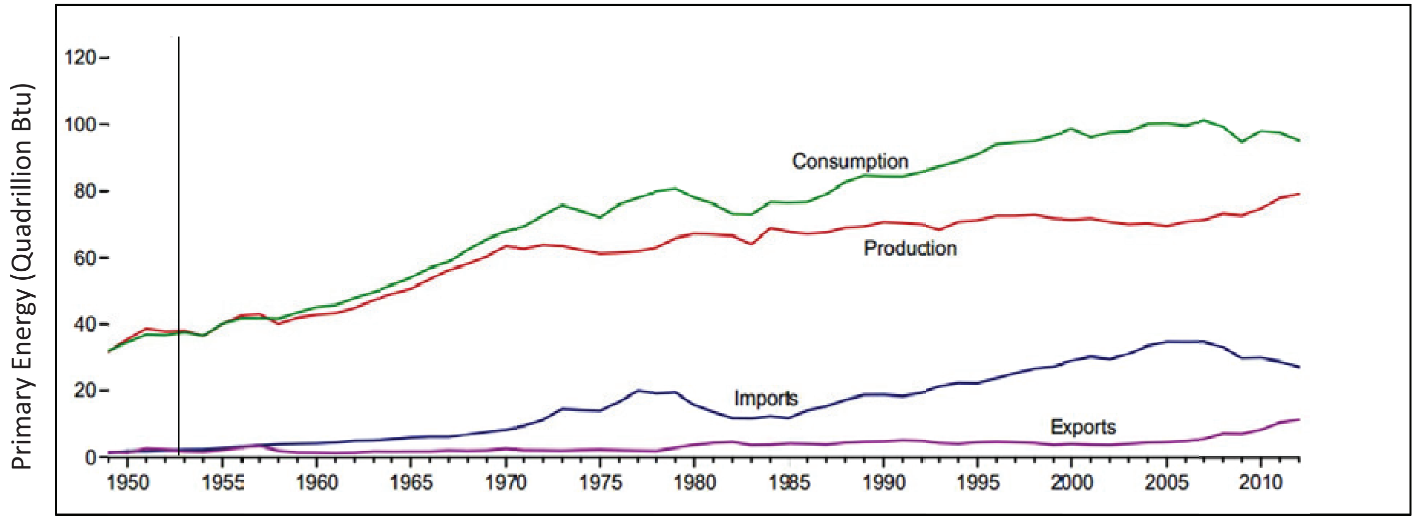


Figure 5. Primary energy overview, 1949-2012 [22]

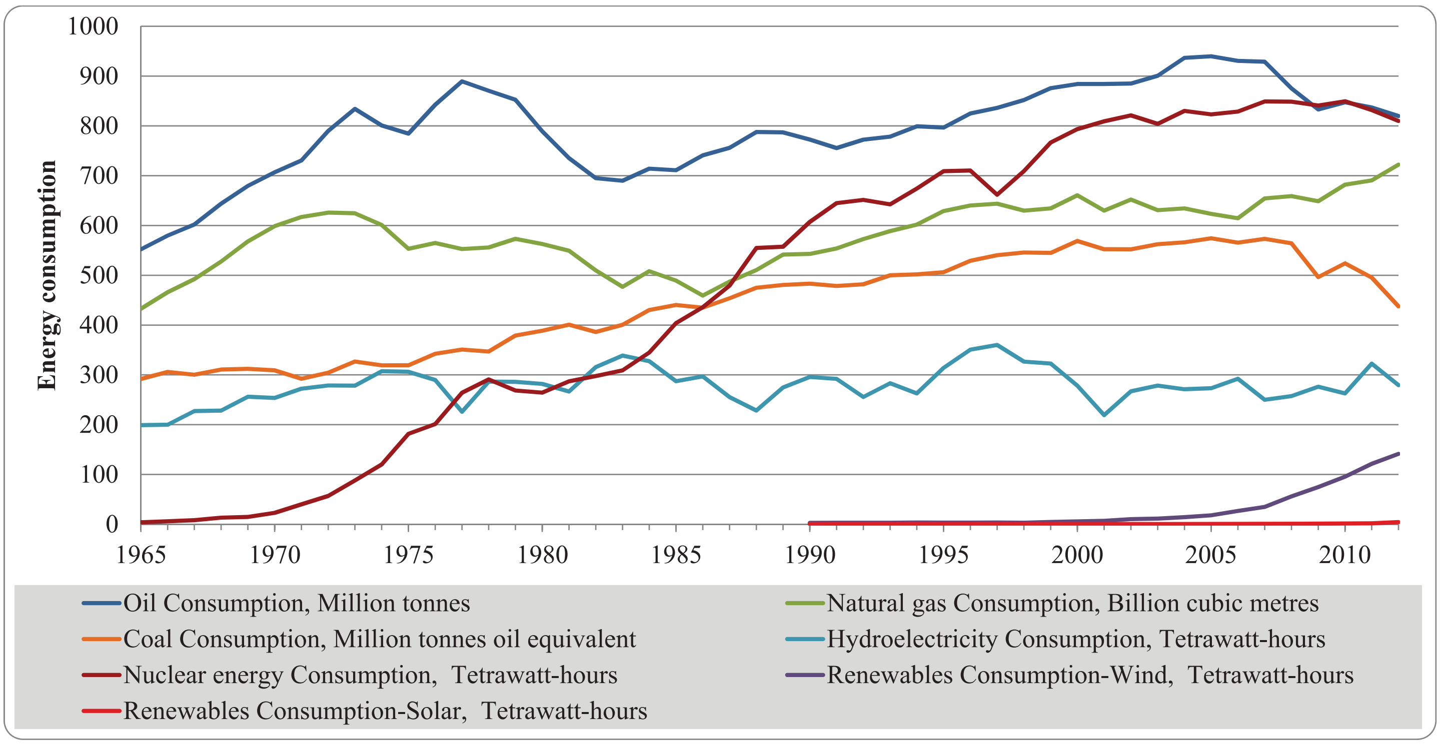


Figure 6. U.S. historical energy consumption from different sources [23]

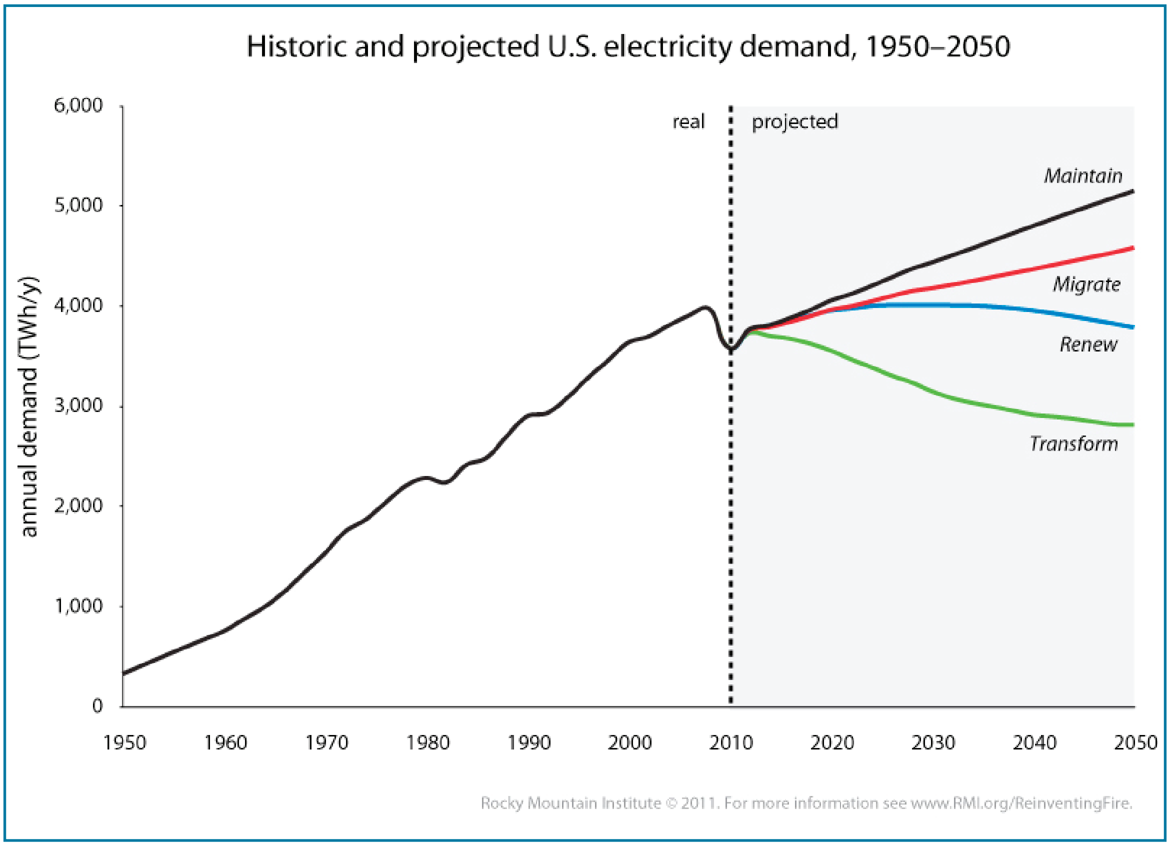


Figure 7. Historical and projected U.S. electricity demand, 1950-2050 [20]

not increase carbon emissions and that minimize extra water demands are needed [4]. To satisfy this, although the total primary energy production has risen (Figure 5), there is a declining trend in fossil fuel consumption in the U.S. since 2007, which is mainly due to increased energy efficiency in automobiles and energy use at home. Increase in generation of renewables (wind and solar energy) has also supplied a portion of the demand (Figure 6).

The U.S. Energy Information Administration has anticipated about a one percent annual growth rate in energy use up to the year 2030 [19]. The Rocky Mountain Institute extrapolated the energy growth rates through 2050 and defined four scenarios for the future electricity system in the U.S. with the same energy services but with different end-use efficiencies (Figure 7) [20]. The Maintain scenario is a "business-as-usual" projection of the future based on the 2010 reference case; the Migrate scenario imagines coal plants equipped with carbon capture and sequestration (CCS), and new nuclear plants; Renew assumes renewables—mostly at utility scale— provide at least 80% of 2050 electricity; and Transform considers aggressive energy efficiency adoption on the demand side and substantial growth in renewables. Details of each scenario can be found at http://www.rmi.org/RFGraph-Electricity_scenarios. Depending on which scenario is implemented, the nationwide energy demand could be cut by up to 1% annually.

1.5. Food in the U.S.

Agriculture is the world's largest and the U.S.'s second largest water withdrawer. In the U.S., it has the largest consumptive use and many agricultural water use practices are not sustainable. Food production has impacts on water quality and biodiversity, and it depends on non-renewable external inputs. Energy use, land use change, methane emissions from livestock and rice cultivation, and nitrous oxide emissions from fertilized soils produce about one third of total greenhouse gas emissions [24], making the food sector a large contributor to these emissions. To meet food demands of increasing global populations, agricultural growth has focused mostly on intensification on existing agricultural land [25], and agricultural intensification and efficiency has concentrated on food production rather than the types of food produced, resulting in excessive inputs of water, fertilizers, and energy without enhancing food security [4]. In planning for development in the food sector and agricultural activities, minimization of further pressures on water, energy, and carbon emissions has to be considered [4].

In 2005, about 37% of the total U.S. freshwater withdrawal was for irrigation purposes. This accounted

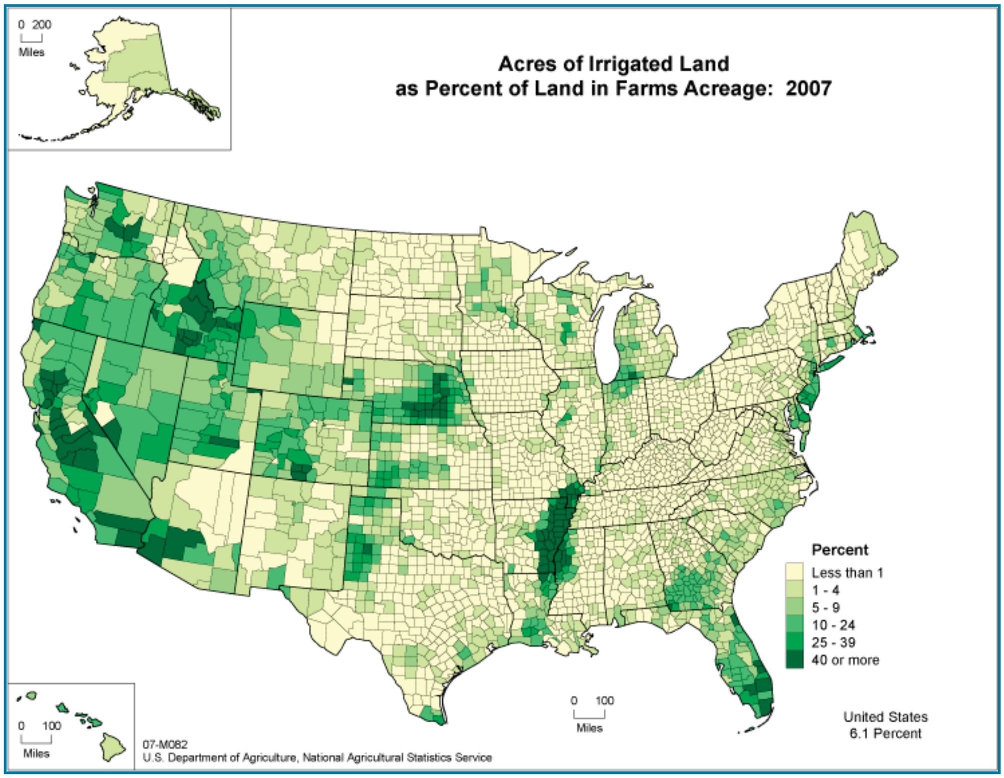


Figure 8. Acres of Irrigated Land as Percent of Land in Farms Acreage in 2007 [27]

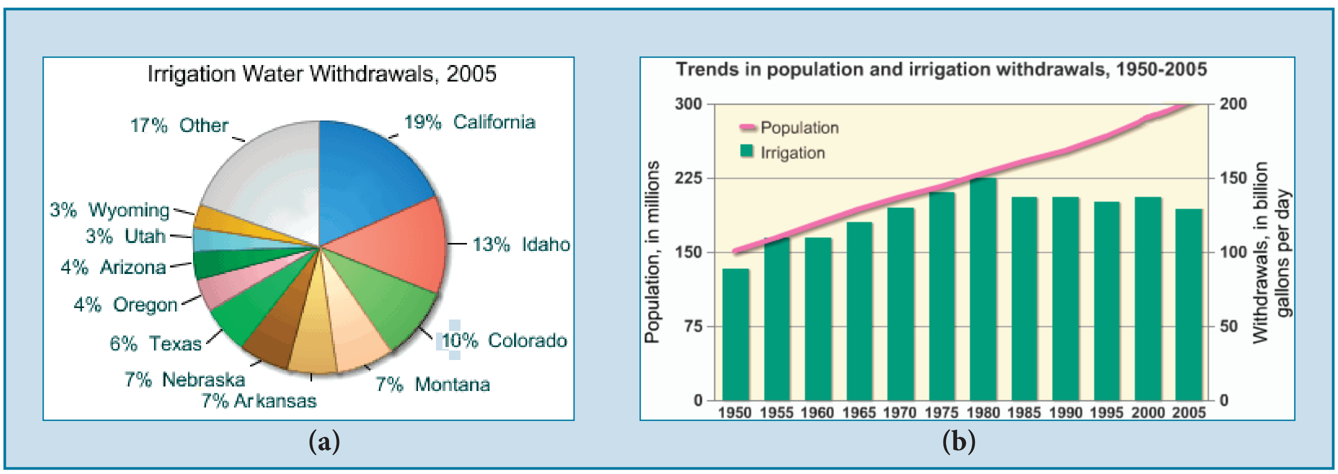


Figure 9. (a) Irrigation water withdrawals in 2005; (b) Trends in population and irrigation withdrawals from 1950 to 2005 [11]

for 28% of total surface water and 67% of total groundwater withdrawals. Approximately 85% of the total irrigation water withdrawals supplied agricultural water demands of the 17 western states [11], which contained 74% of irrigated acres in the U.S. in 2007 (Figure 8). The first three largest agricultural water users, California, Idaho, and Colorado, withdrew 19%, 13%, and 10% of the total U.S. irrigation water, respectively (Figure 9a). Half of the groundwater withdrawal for irrigation was to supply demands in California, Nebraska, Arkansas, and Texas [11]. Despite population growth, overall irrigation withdrawals have stabilized since 1985 due to substitutions, advances in irrigation efficiency, and higher energy costs (Figure 9b). Conversion of agricultural lands to urban or developed areas was another factor affecting agricultural water withdrawals. There has been a 12% decline in agricultural lands from 1949 to 2007 [26].

1.6. Climate Change

Global climate change is projected to decrease annual precipitation and gradually increase temperature, especially in much of the western

U.S. [28, 29]. On a sub-annual scale, more frequent and intense early spring rain as well as less winter snowpack are expected in many parts of the western U.S., resulting in less snowmelt in warmer seasons, altered quantity and timing of associated streamflow, and reduced late-season reservoir storage. Climate change may also lower mountain recharge rates in the West, reducing water-table levels [30, 31]. For example, if air temperature increases by 4.5° F, the Ogallala Aquifer's recharge rate will be reduced by more than 20% [28]. In the eastern U.S., where precipitation usually supports rainfed crop production, climate-induced changes may shift normal growing-season rainfall, increase the frequency and severity of droughts, and force relative returns to irrigated and dryland production [32]. Climate change is also expected to cause greater crop ET for the southern-tier western states, increasing irrigation water demands in the region. All of these effects will reduce water supplies for traditional peak irrigation water demands during the summer and fall growing seasons [32]. To address the challenges that the changing climate is imposing, an integrated approach is required which reflects a complex set of ecodynamics, considers all potential players from different levels of government and other sectors, and identifies mechanisms affecting change (Figure 10).

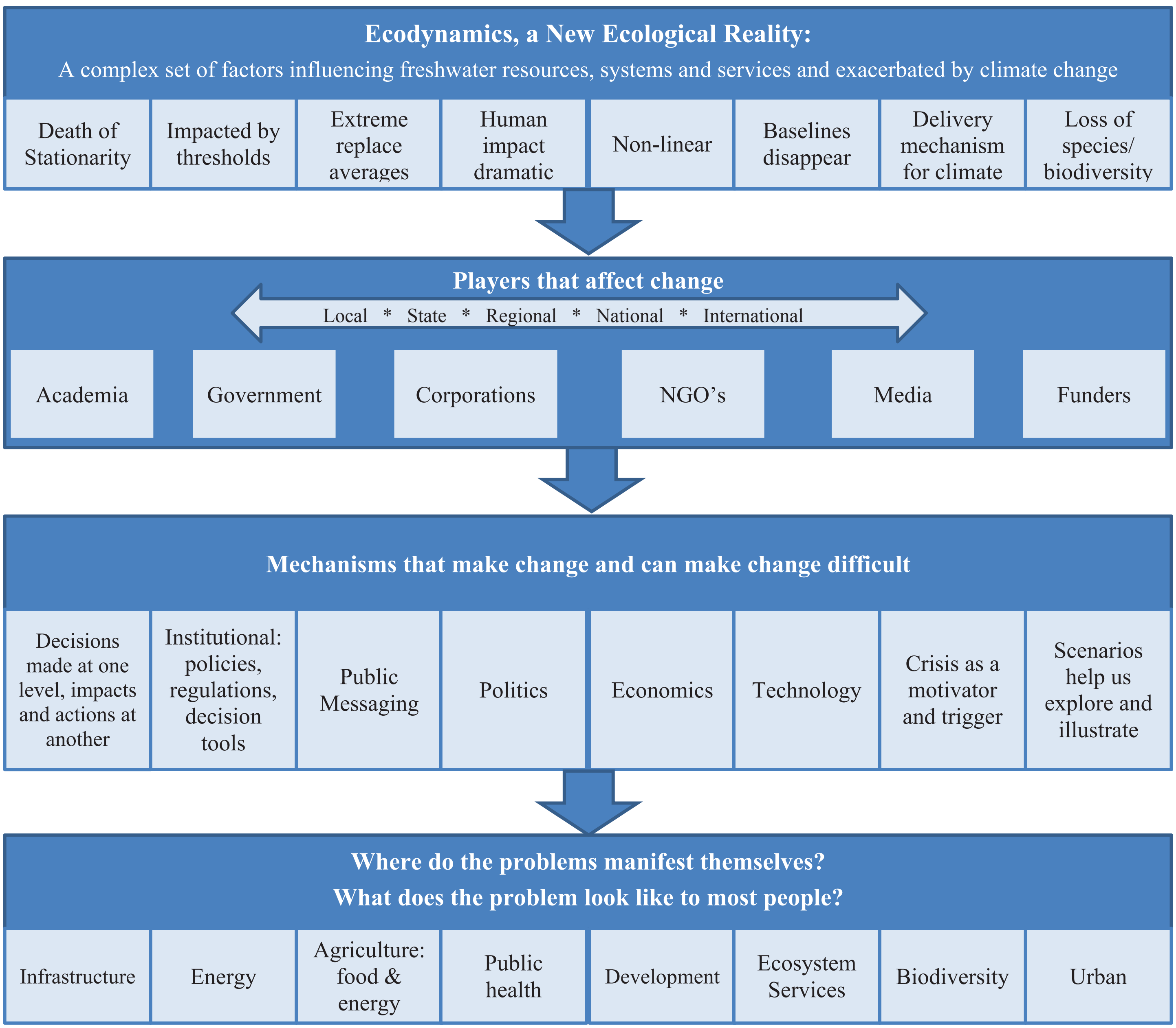


Figure 10. An integrated approach to address climate change problems [33]

2. Water-Energy Nexus

Water and energy are closely bound in consumption and production patterns. Water is largely used for cooling and other purposes in many forms of energy production. Figure 11 shows the flowchart of embedded water in energy. Only a small portion of water that is used for energy production is usually consumed. For example, the thermoelectric power sector, which uses 41% of the U.S. total water withdrawals, consumes only 6% the total water withdrawal [34]. However, hydropower reservoirs, another important energy source, can have significant evaporative losses. Instream hydropower plants have much lower losses than those fed by reservoirs [5]. Return flow from energy production facilities can have negative externalities on the availability of clean water, environment, and ecosystems, since it affects water quality.

On the other hand, large quantities of energy are usually used in water supply and sanitation services for pumping, desalination, water and wastewater treatment, water distribution and transfers, heating and cooling, sewage disposal and sanitation, etc. [4]. Irrigation, especially drip and sprinkler irrigation, is energy intensive [35]. Groundwater withdrawal is more energy intensive than surface water, with exponential energy demand depending on the water depth. Other highly energy intensive water sources are non-conventional sources, e.g., reclaimed wastewater or desalinated seawater.

Thermoelectric and hydropower facilities generate approximately 80% and 8% of the total U.S. net electricity, respectively [34]. Fuel production has mostly grown in areas where there is intensifying water competition, preexisting water concerns, or regions with ecologically sensitive surface water resources. To choose sources in order to increase energy production, complex tradeoffs exist between water use and wastewater byproducts, as well as low-cost reliable energy, energy independence and security, climate change mitigation, public health, and job creation. Private entities, subject to a myriad of local, federal and state regulations that constrain unfettered energy and water exploitation, make the majority of the U.S. energy sector water decisions, but water use and allocation policies and decisions are mostly authorized through state entities, while federal entities often lack the authority over water allocation decisions [34], except in watercourses that are navigable or rivers which flow across state boundaries. Policy-makers' main challenge at the federal, state, and local levels currently is whether and how to respond to satisfy the energy sector's increasing water demand. After all, demand is generated by consumer needs – both for water, and energy. Maximum efficiency in the use of water and maximum carbon efficiency in the energy supply need further consideration [4] , and that is

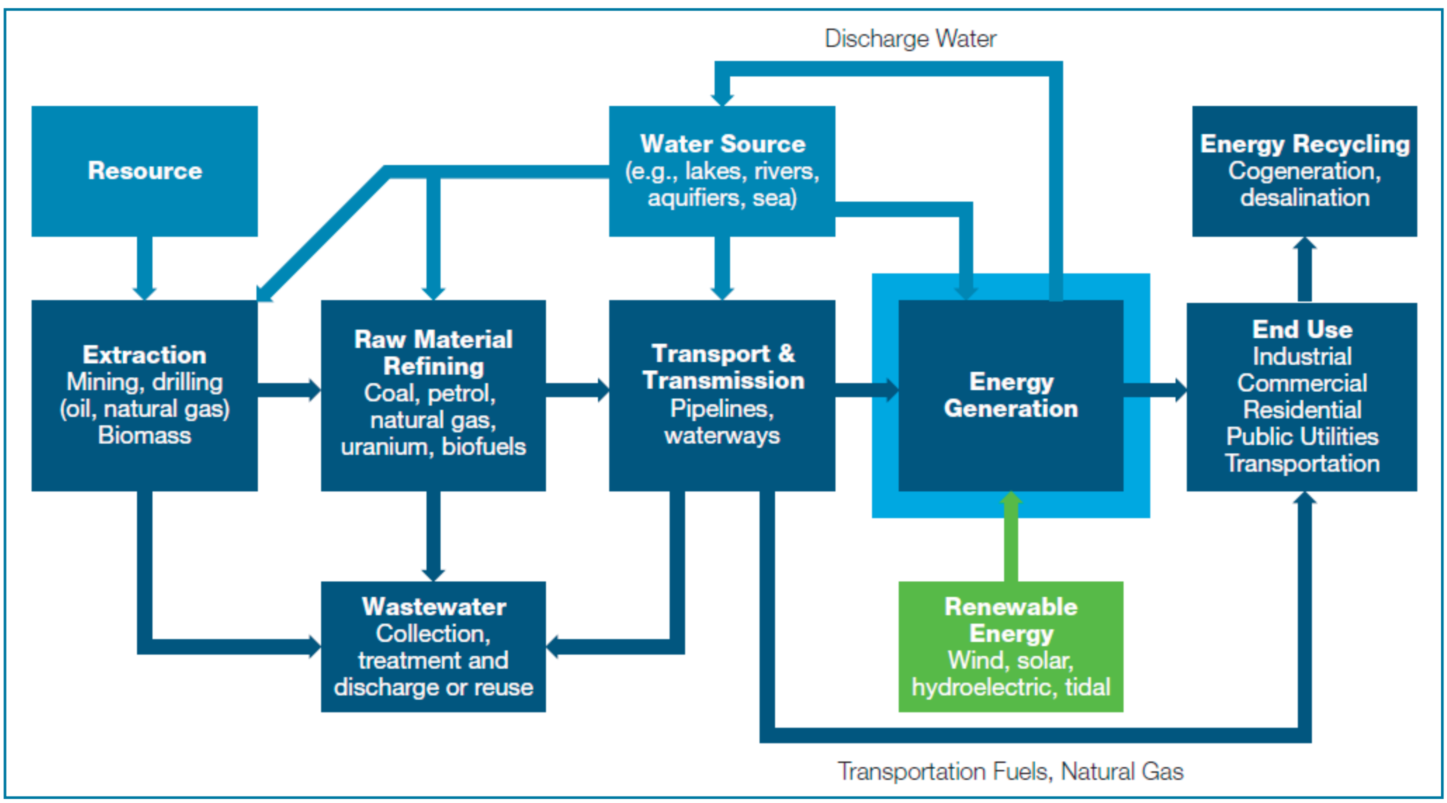


Figure 11. Flowchart of embedded water in energy [38]

one of the key criteria of most public utility regulation commissions.

One of the reliable ways to sustainably develop energy sources is to expand renewables as a supplement to current energy sources. The U.S. has significantly expanded its wind power generation as a renewable source of energy since 2007 (Figure 6). Contribution of renewables to total energy provisioning should rely on both supply-side enhancement and effective demand management [5]. A key factor to consider while developing renewables is that although they seem not to be over-exploited or depleted, they may have negative externalities on other nexus sectors. For instance, biofuels and hydropower have higher water demands per unit of energy produced than fossil fuels; or energy production from corn in the U.S. may require more input calories than it eventually produces – this is controversial between different studies, though [36, 37]. Additionally, wind and solar are intermittent power sources and need to be subsidized to be profitable.

2.1. Energy Use for Groundwater Withdrawal and Desalination

Generally, relatively little energy is required to supply water demand from surface water resources [39]. In comparison with surface water, more energy is consumed to pump or transfer groundwater, but its treatment requires less energy since it is typically cleaner than surface water [40, 41]. Public supply systems are estimated to consume about 1,800 kilowatt-hours (kWh) per million gallons (MG) of water to supply from groundwater resources [42]. However, the amount of energy consumption is highly dependent on depth of water and the type of pumps, ranging from solar-powered pumps to electric or diesel-powered pumps. The energy price influences the use of these pumps. For example, high diesel prices have forced the move to electric and natural gas powered pumps on the Ogallala aquifer [43, 44].

Desalination is the most energy-intensive water option for utilities, and is done by thermal or membrane processes. Depending on the volume and saltiness of water being desalted as well as the technology used to desalt the water, the energy intensity varies [45]. The majority of desalination facilities in the U.S. have been designed for brackish water, which has much lower total dissolved solids (TDS) concentration than the seawater and takes much less energy to desalt. Only 7% of installed capacity desalts seawater [38]. In 2005, about 2,000 desalination plants larger than 0.3 MGD, with the total capacity of 1,600 MGD, were operated to provide less than 0.4% of total water use in the U.S. [46]. Energy intensities to desalt brackish water range from 1,400 to 2,000 kWh/MG [39] while it takes 9,500 to 38,000 kWh/MG to desalt seawater [47, 48]. However, the cost of desalting a cubic meter of water (~ 30 cubic foot, or about 225 gal of water) has decreased to less than $1 per cubic meter, including energy, operations, maintenance, and capital costs over the life of a desalting plant. This is far less than the equivalent costs of building a storage reservoir.

2.2. Energy Use for Water Conveyance

Water conveyance is one of the main challenges where local water resources cannot satisfy the growing population water demands such as the western U.S. For example, 75% of Californians live in the south, while 75% of precipitation falls in the north. To meet water demands in Southern California, water is pumped up and over hilly terrain through 4,800 kilometers of pipelines, tunnels and canals [49] of the Central Valley Project (CVP), the State Water Project (SWP), the Colorado River Aqueduct, and others. Assuming 100% pump efficiency, about 1.5 MW of energy is required to raise 100 cubic meters of water per minute by 100 meters [43]. The terminal city for the SWP is San Diego, which has an energy intensity of 6,900 kWh/AF (2040 kWh/AF for source and conveyance, 20 kWh/AF for water treatment, 330 kWh/AF for distribution, 3900 kWh/AF for end use, and 540 kWh/AF for wastewater treatment) [50, 51]. The energy intensity for farmers in the Central Valley is about 1,300 to 3,100 kWh/AF [52].

2.3. Water Treatment and Distribution

Approximately 170,000 water treatment plants supply potable water to about 90 percent of Americans, while the remainder use private groundwater wells [40]. Treating and distributing potable water to end-users is highly energy intensive. . Supplying treated water and wastewater management consume 3% of the total energy use by cities in the USA [53], but in some states such as California it can be as high as 20% [54].Size, elevation, system age, and configuration of the system affect energy intensity. Distribution of treated water is much more energy intensive than its conveyance [55]. Using high-pressure pumps to distribute potable water to end-users is the most energy intensive step in water distribution, consuming about 83 percent to 85 percent of the electricity embedded in potable water in California [45, 56]. About 80 kWh/MG to 150 kWh/MG of energy may be used by water treatment facilities depending on their size, with larger facilities consuming less energy [42]. However, the total energy intensity for water treatment and distribution may be around 1,400 to 1,800 kWh per MG, consuming about 0.8% of the nation's energy [42, 45, 57]. Newer regulations requiring higher levels of water and wastewater treatment are likely to increase the energy intensity of treatment plants [38]. Electricity consumption for water supply, treatment, and distribution is projected to increase by approximately 50% from 2000 to 2050 [58].

2.4. Energy Use for Wastewater Treatment

Energy is consumed for both wastewater collection and treatment. Wastewater pumps are generally less efficient, as they pump both liquids and solids. Aged wastewater collection systems have higher pumping and treatment costs. Based on U.S. Environmental Protection Agency (EPA) estimates, $54.1 billion was needed in the early 2000s to improve sewer and wastewater collection and conveyance systems [59]. To treat wastewater, there are approximately 16,000 Publicly Owned Treatment Works [60] and 23,000 privately operated treatment facilities in the U.S. [58].

Wastewater is discharged to surface or groundwater sources after treatment. More than 50% of treated effluents receive advanced treatment. If the effluent receives tertiary treatment, it can be used for irrigation, residential and commercial use, groundwater recharge, thermoelectric generation, direct or indirect potable water, or may be discharged to surface water [38]. However, advanced and tertiary treatments are often very energy intensive. It is possible to reduce the energy intensity by optimizing aeration and pumping, which may help wastewater treatment plants save 500 million to 1,000 million kWh annually.

2.5. Energy Intensity of Water Recycling

Depending on the quality of the wastewater being recycled and the use of it, energy intensity of recycled water may vary. In California, recycled water is the least energy-intensive source [56]. Low TDS concentrations and high nutrient levels are acceptable for agriculture. To be used for drinking water supply, recycled water should meet high standards. Industry can use recycled water that is very pure to less pure, depending on the application. Energy intensity is directly related to the amount of treatment. However, distribution of recycled water requires more energy cost than potable water, since wastewater facilities are often located at lower elevations to take advantage of gravity and, thus, the recycled water often must be pumped to higher elevations. On average, it can take up to 1,130 kWh/AF or 3,460 kWh/MG to recycle water [39], which, in comparison with costs related to collecting, treating, disinfecting, and distributing drinking water for non-potable uses, saves energy. Net energy savings of recycled water have been estimated by the U.S. EPA at 3,000 to 5,000 kWh/MG [61].

2.6. Water for Energy

Water use for extraction, processing, and generation of different types of energy sources including coal, natural gas, oil, uranium, hydropower, thermoelectric, and biofuel is discussed in this section.

2.6.1. Coal

The U.S. has the world's largest reserves of coal [62] and can produce it at the current rate for the next 214 years. During the 19th and 20th centuries, coal played a major role in the economic success of the U.S. by fueling trains, factories, and power plants. In 2011, coal accounted for 21% of the U.S. primary energy consumption and 45% of the electricity generation [63]. In 2005, an estimated 50% increase in coal extraction by 2025 was projected, mostly for electricity generation [64]. However, climate change, air emission rules, and increased sources of natural gas may mitigate this increase.

Coal extraction and processing may have substantial impacts on the quantity and quality of water resources. However, there is no accurate estimation of water use for coal extraction, as coal mines are not required to report water usage. Water is used during mining, processing, and electricity generation. Mining requires large water inputs, and it consumptively uses approximately 30% of the total withdrawn [38]. Both underground and surface mining, with 30% and 70% of the U.S. production, respectively, require water to cool and lubricate equipment and manage dust [65]. During processing, western coals are seldom washed, but approximately 80% of Appalachian coal needs to be washed [66], which is a water intensive process [43]. Coal washing degrades the quality of the wastewater discharged, which is a major concern of coal mining. Coal mining tailings are exposed to wind and rain and may threat air quality, leach into water bodies, or impact groundwater quality [67].

2.6.2. Natural Gas

The U.S., as the world's largest producer and consumer of natural gas, has 272.5 trillion cubic feet (TCF) of proven natural gas reserves and a reserves-to-production ratio of 12.6 years [62]. The Energy Information Administration, however, has estimated that the U.S. possesses the potential of 2,500 TCF [63], which allows it to produce natural gas at current rates for the next 100 years. Twenty four percent of U.S. electricity is generated from natural gas. Natural gas demand has been projected to increase about 12% by 2035 [63].

Water is used during drilling and extraction of natural gas, and water intensity is relatively low in comparison with other energy sources. Therefore, there are fewer concerns about the impacts of natural gas production on water quantity, but it may degrade water quality. Extraction from conventional reservoirs requires relatively modest amounts of water, but the drilling and development of unconventional reservoirs (such as shale and sand gas reservoirs), which is done by hydraulic fracturing, may demand up to millions of gallons of water per well. About 11,000 new wells are hydraulically fractured every year (U.S. EPA, 2012). Besides high water intensity of the fracking practices, it may degrade water quality if fracking chemicals reach water resources. Debates about the overall impacts of fracking continue across the U.S.

2.6.3. Oil

The U.S., as the world's first consumer and third producer of oil [62], meets a quarter of its energy demand by oil, mostly consumed in transportation and industrial use. One-fourth of the world's oil production (twice as much as China) is used in the U.S. [62]. There are about 500,000 active oil wells in the U.S. [38] and Gulf of Mexico, California, and Alaska are main oil-producing areas in the U.S. The U.S. has the largest reserves of oil shale in the world (about 77% of the world's total reserves), mostly located in Colorado, Utah, and Wyoming. These oil shale resources can supply U.S. demand for the next 500 years at current levels of consumption [70]. As a result of increased domestic production, the oil imported to the U.S. has been reduced by 11% since 2005 and is projected to be reduced by about 24% by 2035 (Figure 12). However, shale resources are mostly located in the driest and already water-stressed parts of the country, and supplying water is one of the challenges facing this industry.

In comparison with natural gas, coal, and uranium, oil drilling and processing from conventional resources uses more water and generates more produced waters, which affects surface and groundwater quality and quantity. Drilling does not use a lot of water, but drilling wastes may contain chemicals that can impact water quality [66]. Extraction, however, is a water intensive practice, and this water use is entirely consumptive

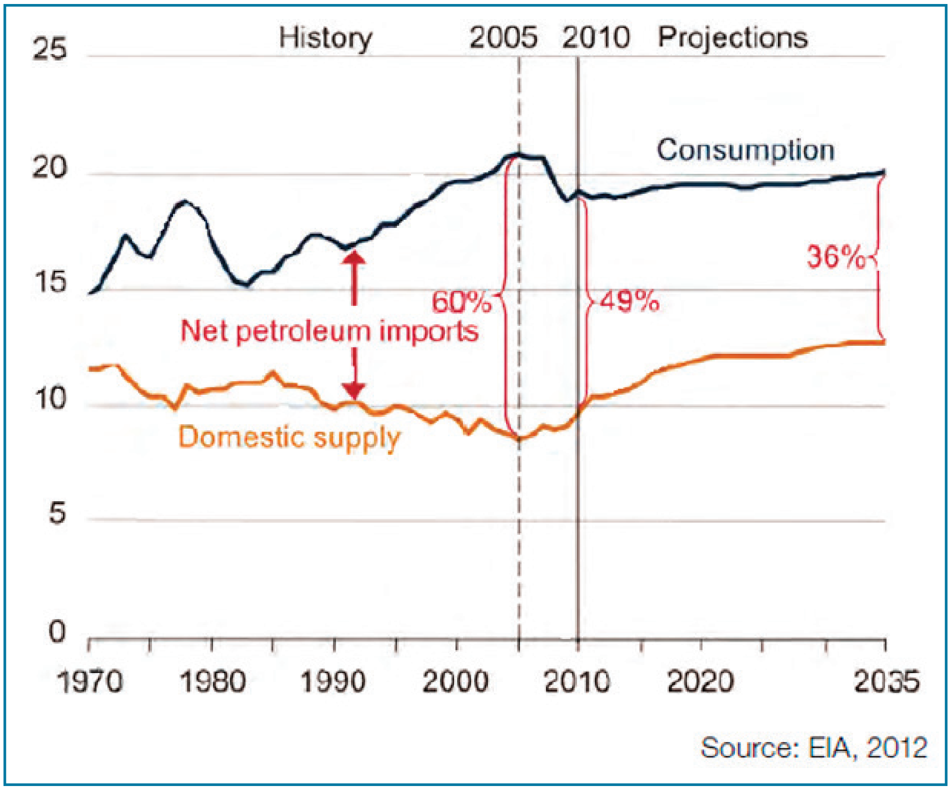


Figure 12. U.S. liquid fuel supply from 1970 to 2035 (million barrels per day) [63]

[38]. In addition, the water that is extracted with oil from oil reservoirs, produced water, may contain hydrocarbon residues, heavy metals, hydrogen sulfide and boron, and have high salinity [38]. In some cases, produced water is discharged into the environment, but now is mostly re-injected back to the oil reservoir or other underground formations.

2.6.4. Uranium

In nuclear electric generation large quantities of water are used to cool the power plant, besides impacting the quantity and quality of water resources in the extraction and processing of uranium. In 2011, about 800 billion kWh of nuclear energy was produced in U.S., the world's largest producer of nuclear energy [65]. Approximately, 1,660 tons of uranium per year is produced in the U.S., providing 9% of demand [63]. About 80% of uranium reserves are located in New Mexico and Wyoming. All uranium mining operations are located in water-scarce regions of the West, and securing a reliable water source is a big challenge, especially in the future. Since the ore has very low uranium concentrations (0.06% to 2.71% [71]), massive stockpiles of radioactive and toxic waste rock and sand-like tailings are left behind, threatening water quality of surface and groundwater resources in the vicinity of uranium mines. Uranium mines may also generate 3 to 5 MGD of polluted wastewater [66].

2.6.5. Hydropower

The U.S. is the fourth largest hydroelectricity producer after China, Canada, and Brazil [72]. Despite many advantages of hydroelectric generation, it can be curtailed by water availability issues, such as regional drought, low flow, endangered species, or intense competition for water. It might also be vulnerable to seasonal, annual, and multi-year drought conditions, with the latter being the most harmful to generations in large reservoirs [34]. The Pacific Northwest is the most vulnerable region in the U.S. to drought due to its heavy reliance on hydroelectric generation [73].

"Qualified energy resources," including some hydroelectric, received a 1.1 cent per kWh tax credit through Dec. 31, 2013. This provided incentives to finance over 120 facility upgrades, resulting in an average of 10% generation increase since 2005 [74]. Expiration of this law raised concerns about upgrading hydropower facilities. In April 2014, the Senate approved a bill, called the Expiring Provisions Improvement Reform and Efficiency Act (EXPIRE), which extends the production and investment tax credits for hydropower and other renewable energy technologies for two years [74].

2.6.6. Thermoelectric

In thermoelectric generation, high-pressure steam drives a turbine generator to produce electricity. Heat is required to boil water into steam, which should be cooled at the turbine exhaust. A variety of sources such as coal, natural gas and oil, nuclear energy, biomass, concentrated solar energy, and geothermal energy provide heat [38]. The water requirement for extraction and processing of these fuels was explained above. During thermoelectric generation, water is used and consumed for cooling. Three main thermoelectric generation technologies include: open-loop (once-through), closed-loop (recirculation) and dry cooling. Hybrid cooling is another technology, combining closed-loop and dry cooling.

As mentioned earlier, the thermoelectric power sector has the highest withdrawal rate among all water users. This sector is also the largest discharger of thermal pollution, which in consequence reduces dissolved oxygen and elevates metabolic rates, resulting in higher oxygen and food demands [38].

Table 1. Water intensities of different steam turbine thermoelectric facilities (gal/kWh) [38]

	Open-Loop	Closed-Loop	Dry
Coal, Gas, Biomass			
Withdrawal	34.98	0.64	0.01
Consumption	0.25	0.56	0.01
Nuclear			
Withdrawal	41.97	1.25	0.03
Consumption	0.31	0.86	0.02

Return flow of the once-through (open-loop) cooling technique is 10oC to 20oC warmer. Their water consumption rate is very low, and they return about 99 percent of the water to the source. These systems, which account for about 31% of U.S. generating capacity, are highly dependent on water availability and extremely vulnerable to droughts and high temperature [75]. Closed-loop cooling systems use much less water but consume much more. The operation costs in these systems are 50% higher than open-loop cooling systems [75]. Dry cooling systems use air to cool the circulating cooling fluid and use and consume much less water compared to the other techniques. However, plant efficiency is much lower, especially in the peak of summer when demand is highest (U.S. DOE, 2006) and their capital cost is about 10 times more that of an open-loop system [75]. Table 1 presents water intensities of different thermoelectric facilities.

2.6.7. Biofuels

With about 60% of worldwide biofuel production, the U.S is the largest producer of biofuel, followed by Brazil (30%) [38]. Any fuel produced from biological materials is called biofuel. It is mostly used in transportation and produced from food crops (e.g., corn, sorghum, sugar cane, soybean), crops for energy (e.g., switchgrass or prairie perennials), crop residues, wood waste and by-products, and animal manure [38]. As an oxygenate fuel additive, bioethanol has replaced methyl tertiary butyl ether (MTBE) in gasoline to reduce harmful tailpipe emissions from motor vehicles [76]. This replacement was forced by the Renewable Fuel Standard (RFS) mandated by the 2005 Energy Policy Act and the 2007 Energy Independence and Security Act [38]. Bioethanol production increased tenfold in a decade to achieve the E-10 (10% ethanol, 90% gasoline) goal. The increased bioethanol production has depleted water quality due to nutrient runoff and erosion and increased water demands for crop irrigation. In addition, bioethanol production is highly energy intensive with the energy intensity (the ratio of produced energy over energy investment) of 43% to 53% [77].

Almost all biofuel currently produced in the U.S. is from corn. A gallon of ethanol requires almost 20 pounds of corn [78, 79]. Forty percent of all corn grown in the U.S. is used to produce bioethanol [78], and the waste is used for feeding livestock, which moderates the de facto amount of corn used by the industry to 25% of produced corn. Approximately 95% of the corn used in ethanol production is produced in the Corn Belt (USDA zones 5, 6 and 7, Table 2). Water use for corn ethanol production may vary depending on climate conditions and related annual rainfall (Table 2) [80, 81]. While most of the corn grown is rainfed, much of the irrigation water in these three regions is withdrawn from groundwater aquifers.

Table 2. Water consumption rate for corn ethanol production in USDA Regions 5, 6, and 7 (adopted from [82])

USDA Regions	Corresponding States	Water consumption
Regions 5	Iowa, Indiana, Illinois, Ohio, Missouri	0.76 (gal/bushel)
Regions 6	Minnesota, Wisconsin, Michigan	1.48 (gal/bushel)
Regions 7	North Dakota, South Dakota, Nebraska, Kansas	34.45 (gal/bushel)

Under irrigated conditions, 250 to 1,600 gallons of water is required to produce one gallon of ethanol [80], and almost 3% of irrigation water in the U.S. is used for the bioethanol industry's corn production [11], of which 71% is consumed [82]. However, irrigation water use for corn has declined by 27% over recent years despite consistent corn yield increase over the past 20 year [82].

Biodiesel is another biofuel, which is biodegradable with very low quantity of sulfur and aromatics, while providing fuel economy, horsepower, and torque similar to conventional diesel [79]. It is a substitute for traditional diesel fuel and is mostly produced from vegetable oil from soybeans in the U.S. About 50% of the U.S. feedstock for biodiesel is provided from soybean [83]. With a national average of 0.8 AF/A of water use, soybean production may take 0.2 acre-feet/acre (Pennsylvania) to 1.4 acre-feet/ acre (Colorado) [66]. A gallon of biodiesel needs almost 7.5 pounds of vegetable oil [78, 79]. Currently, 1.1% of all irrigation in the U.S. is used for soybean production. This could be increased to 18% of 2005 irrigation in the U.S. if production of soy biodiesel reached the 1.5 billion-gallon limit [38].

3. Water-Food Nexus

Food production processes have the largest global water consumption of any sector [84]. Water availability with proper quantity and quality at the right time, on the other hand, significantly affects food production rate. More than 75% of the Earth's ice-free land surface has been altered by humans for food production [85]. To meet the 70% higher food demands of the increasing global population, agricultural land has to expand by 10% by 2050 [86]. Even the most optimistic scenarios of improvements in productivity through technological development anticipate at least 20% increase in global agricultural water demand by 2050 [5]. Therefore, significant changes toward more sustainable production and consumption patterns are inevitably required.

3.1. Agriculture in the U.S.

Agriculture accounts for 80% of total consumptive water use in the U.S. This water is consumed either by crops or through water lost to the environment by evaporation. Irrigated agriculture is mostly practiced in the West; while in the more humid East, irrigation usually complements growing-season precipitation as necessary. The share of irrigated crops in the eastern U.S. has increased by almost 20% from 1998 to 2008 and by 15% since 2003 [87]. This increase is mainly due to increases in commodity prices and yields, increased risk aversion due to recurring drought conditions, and access to cheap groundwater supplies due to shallow aquifer pumping depths [88-91].

In the U.S., population growth and climate change are expected to increase current agricultural water demands. In addition, the switch to growing feedstock as first-generation biofuels increases pressure on water resources [92]. On the other hand, Native American water rights, instream (environmental) flow requirements, and an expanding energy sector are imposing more limitations on agricultural water supply. Native American reservation water rights, confirmed by the U.S. Supreme Court in 1908, reserves Native Americans' water rights based on the amount of water necessary to maintain and survive on the land granted to their reservation. These water rights are quantified as the water needed to irrigate all "practicably irrigable acreage," and since the priority date of these rights is equivalent to the date the reservation was established, they are generally superior to the other rights [93, 94]. Native American water-right claims are estimated to be approximately 46 MAF per year [95], affecting water resources availability for competing uses in the future.

3.2. Irrigated Agriculture in the U.S.

Irrigated agriculture, accounting for about 40% of U.S market sales, makes a great contribution to the value of the nation's agricultural production. In 2007, it contributed $118.5 billion to the total of $297.2 billion of the market value of all agricultural products. The average per farm value of irrigated farms products was nearly 2.5 times higher than that of all farms ($344,413 vs. $143,835) and 3.3 times the average value for non-irrigated (dryland) farms [32]. Out of 56.6 million acres irrigated lands across the U.S., about 75% were in the 17 western states in 2007 [32]. Twelve leading irrigation states that contained 77.3% of all irrigated acres in 2007 are shown in Figure 13, and an illustration of the spatial distribution of irrigated acres in the U.S. in 2007 is shown in Figure 14.

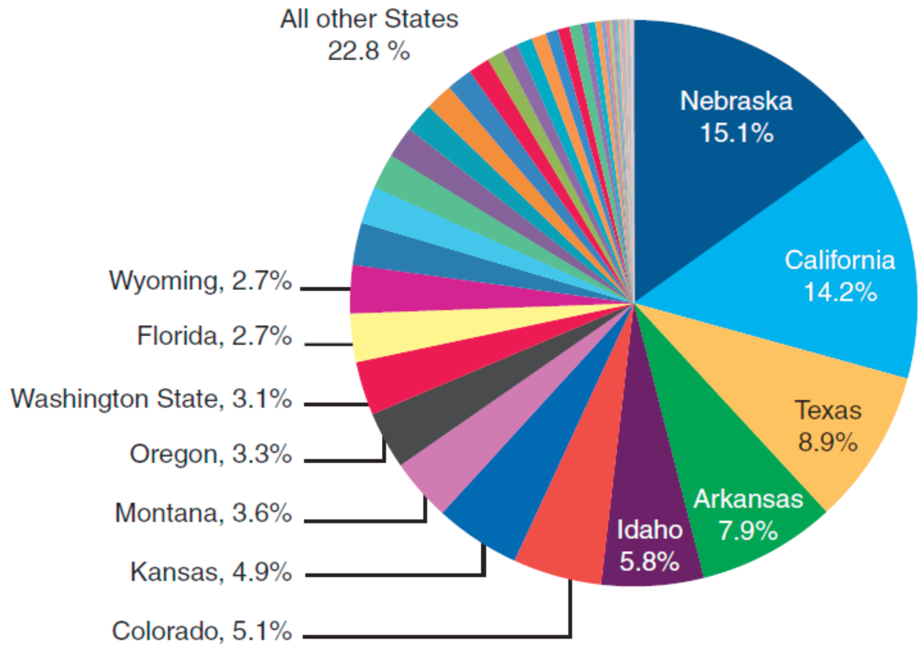


Figure 13. State shares of total U.S. irrigated acres, 2007 [96]

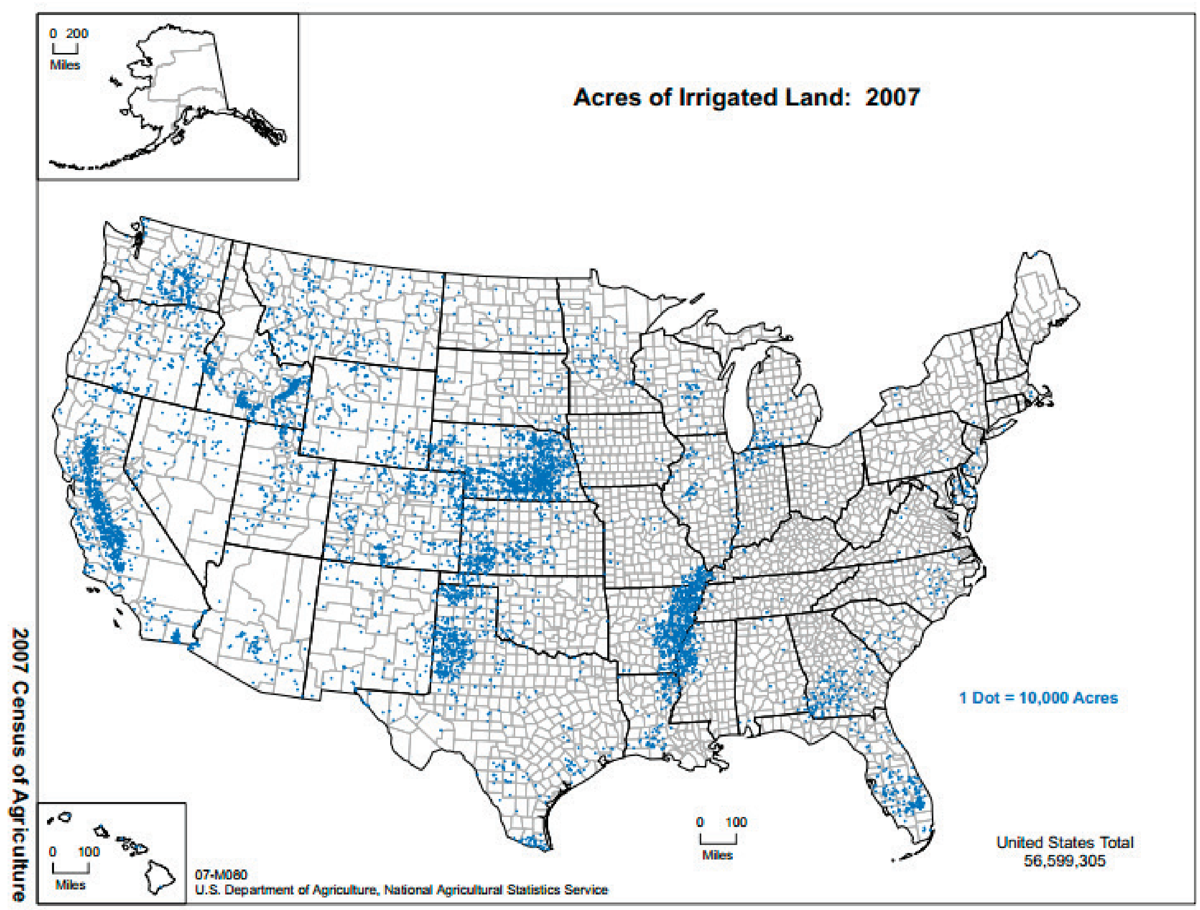
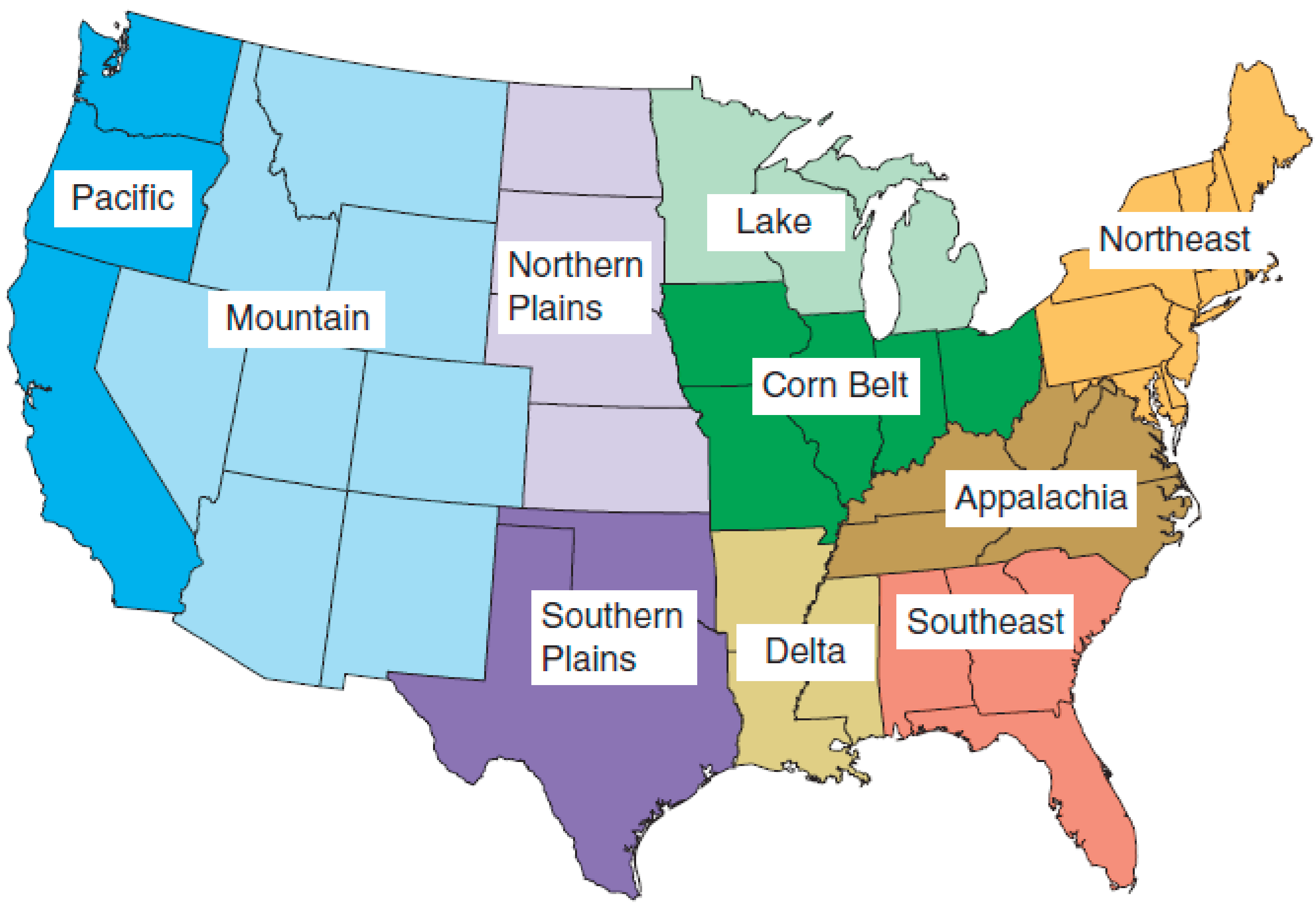


Figure 14. Acres of irrigated land, 2007 [97]

Irrigated acres in the U.S. increased from 1982 to 1997 and started a decline afterwards. Since 1997, irrigated acres expanded mostly in the Northern Plains, Delta, and Corn Belt regions, with more moderate expansion across the eastern U.S., except Florida (USDA's farm production regions are illustrated in Figure 15). There was a net increase of nearly 1.3 million irrigated acres across the U.S. from 2002 to 2007. About one million of these acres were added in Nebraska, followed by Arkansas, Colorado, Mississippi, Missouri, and Georgia. Availability of water supplies, improved irrigation economics, increased demand for corn, recurring regional drought conditions, and the prospect of future restrictions on new irrigation development were the main drivers of the expansion in the irrigated acreage [32]. In 2007, irrigated acreage accounted for 36% and 22% of cropland in the warmer Delta and Southeast regions, respectively. Less than 4% of cropland acreage in the middle- and northern-tier regions was irrigated. The Pacific and Mountain States together accounted for 65% of total agricultural water applied across the U.S. [32].

3.3. Agricultural Water, Its Source, and Cost

Based on the 2008 Farm and Ranch Irrigation Survey [98], 74.2 MAF water was applied to the irrigated agricultural lands across the western U.S.. Approximately 52.4% of this water was supplied from surface water sources and the rest from local and regional aquifers. Surface water originates from on-farm or off-farm sources. These sources account for about 15% and 38% of total agricultural water applied in the West, respectively. In eastern states, almost 79% of irrigated water was pumped from shallow aquifers, and less than 4% came from off-farm water sources. Off-farm sources might have higher water loss and demand more energy to be transferred into the farms, and they are usually used to supply the



[1]The 17 Western States include those within the Northern Plains, Southern Plains, Mountain, and Pacific regions. The 31 Eastern States include those within the Lake, Corn Belt, Northeast, Appalachia, Delta, and Southeast regions.

Figure 15. USDA farm production regions [32]

demand for higher valued, more water-intensive crops. Based on 2008 data, variable irrigation costs across the West averaged about $91 per acre for on-farm surface water, $129 per acre for pumping groundwater, and $144 per acre for pumping purchased surface water and using contract labor [98]. Average variable irrigation costs in the 31 eastern states ranged from $65 to $75 per acre – lower costs are because groundwater pumping depths are generally shallower, and purchased water from off-farm sources costs averaged less than $10 per acre, compared with $66 per acre in the West.

3.4. Irrigation Water Efficiency

Prior to early 1980s, gravity irrigation was practiced in the U.S. as the traditional irrigation system. Between 1984 and 2008, there was a substantial shift from the traditional to pressurized irrigation systems across the western states, resulting in a decline in use of gravity irrigation systems from 71% in 1984 to 48% in 2008 and an increase of 23% in using pressurized irrigation systems [32]. Over the period of 1984 to 2008, although the irrigated lands in the West increased by 2.1 million acres, the total agricultural water applied declined by almost 100,000 acre-feet. This was mainly due to the use of more efficient pressure irrigation systems including drip, low-pressure sprinkler, or low-energy precision application systems. Table 3 presents irrigation system improvements from 2003 to 2008 and key barriers to making system improvements. In 1998, more efficient irrigation accounted for approximately 49% of irrigation in the West. Traditional gravity or less efficient pressure-sprinkler systems still comprise more than 50% of irrigated acres, leaving significant room for improvement in farm irrigation efficiency in the West. Almost similar conditions exist in the eastern U.S., where more efficient pressure systems embrace only 52% of total farm irrigated acres. Therefore, there is a substantial potential in the entire country to improve agricultural irrigation and adopt more efficient systems, which is necessary for the sustainability of irrigated agriculture [99-101].

Achieving a more sustainable future for irrigated agriculture through

Table 3. Irrigation system improvements and key barriers to making system improvements, 2003-08 [32]

	17 Western States	31 Eastern States	U.S.
Number of farms implementing irrigation system improvements (since 2003)	**62,189**	**11,926**	**74,846**
Effect of system improvements:	*Percent of Responses*		
Improved crop yield/quality	58.7	67.6	60.2
Reduced energy costs	43.6	56.5	45.6
Reduced water applied	60.6	54.1	59.4
Reduced labor costs	42.6	34.7	41.2
Reduced fertilizer/pesticide loss	18.3	16.1	17.9
Reduced soil erosion	29.8	25.9	29.1
Reduced tailwater runoff	23.6	11.5	21.5
Farms identifying barriers to energy and/or water conservation improvements (since 2003)	**107,796**	**22,626**	**131,988**
Barriers to making irrigation system improvements:	*Percent of Responses*		
Investigating improvements was not a priority	34.6	39.6	35.5
Risk of reduced yield or poorer crop quality	14.2	13.5	14.1
Physical field/crop conditions limit system improvements	17	10.4	15.8
Improvements will not reduce costs enough to cover installation costs	26.3	2.2	25.6
Cannot finance improvements	29.6	23.1	28.4
Landlord will not share costs of improvements	4.5	8	5.2
Uncertainty about future availability of water	17	4.8	14.8
Will not be farming long enough to justify new improvements	13.4	11.3	13.1

agricultural water conservation requires three elements [102, 103]: continue promotion of adopting high-efficiency irrigation application systems; place greater emphasis on adoption of the systems that decrease water use at the field level, while improving farm profits; and integrate on-farm water conservation with watershed-scale water management mechanisms to optimize allocation of limited water supplies among competing demands. However, based on a holistic view, on-farm water conservation through improving irrigation efficiency may or may not conserve water within the watershed or river basin [99-101, 104-106], as it might be consumed somewhere else or by other sectors. Water conservation programs at the watershed or river basin level may emphasize on-farm irrigation efficiency enhancing the viability and sustainability of the regional agricultural economy, improving the quality and availability of water supplies locally, improving the quality of return flows, providing water supply for other sectors, e.g., urban, and reducing environmental degradation of existing regional supplies [32].

3.5. Sources of On-farm Irrigation Investment Funding

In the U.S., on-farm irrigation investment is generally financed privately, with public financial assistance only accounting for 6% of investment [98]. This may reduce challenges associated with participation in public funding programs, such as limited funding allocations, administrative requirements for program enrollment, and payment limits to farm operators. Many farmers, however, rely on public programs as an important source of funding to support adoption of more efficient irrigation systems.

As the nation's primary agricultural conservation program for working farms and ranches, the Environmental Quality Incentives Program (EQIP), administered by USDA's NRCS, provides technical and financial assistance for eligible conservation practices under short-term contracts (typically 1-10 years). This program provides financial support to cover 50 to 75% of installation of structural and vegetative practices costs. It also provides annual payments for the adoption of conservation-compatible management practices. EQIP provided financial support to 58% and 54% of farms reporting public financial assistance for irrigation investments across western and eastern states, respectively [32]. Other USDA financial assistance programs, including Conservation Stewardship Program and Wetlands Reserve Program, accounted for 25% of farms reporting assistance, with the remaining funding provided by non-USDA programs, such as U.S. Environmental Protection Agency, Bureau of Reclamation, and state and local water management and supply district programs [32].

3.6. Resilient Water Systems for Food Production

About 40% of food production is typically wasted. Part of this food is wasted when harvested crops spoil during transport, storage, processing, and packaging. Another part is wasted when retailers, food companies, and customers throw food away [107]. To reduce these losses in the food chain, a combination of policy measures should be employed, including: science-based regulation of crop-protection products, investment in postharvest technologies, investigation into the role of the food processing industry and retail stores, and pricing mechanisms to educate the public on reducing food waste [108].

In September 2009, the Johnson Foundation convened a group of eminent scientists, policy makers, and practitioners of diverse perspectives at an Environmental Forum Working Session to discuss "Examining U.S. Freshwater Systems and Services – Agriculture and Food Production." The group focused on defining a resilient freshwater system that addresses our needs for food production and considered different elements of the system including governance, institutions, technology, agricultural practices, environmental impacts, and ecosystem services. Based on their conclusions, a resilient freshwater agriculture system should [109]:

- Be able to adapt to an unpredictable and complex set of circumstances
- Support the nation's ability to reliably and securely supply food and assist other nations to do the same
- Protect and restore critical natural infrastructure and sustain a drinkable, fishable, and swimmable water supply
- Provide a variety of ecosystem services that balance agricultural production and environmental conservation
- Sustain terrestrial and aquatic wildlife and their habitats
- Consider groundwater and surface water interactions
- Sustain the economic and cultural viability of rural agricultural communities
- Acknowledge the compatibility of agricultural production and environmental outcomes

4. Energy-Food Nexus

Mechanization and application of new technologies have helped increase yields and ease agricultural labor. Applications of these practices are, however, usually energy intensive, especially for land preparation, fertilizer application, and irrigation. Energy is used in growing, processing, preparing, packaging, storing, distributing, serving, and disposing of food. About 30% of the global energy demand is used for the full food production and supply chain [5]. In the U.S., use of energy along the food chain has increased more than six times higher than the rate of increase in total domestic energy use between 1997 and 2002 [110]. This accounts for over 80% of energy flow increases nationwide over the same period. Half of this increase in energy consumption is due to the use of more energy-intensive technologies throughout the U.S. [110]. Food production, on the other hand, can also be impacted by the energy sector. For example, mining for fossil fuels reduces agricultural land or production of oil and gas can result in temporary disruption of agricultural activities [5].

4.1. Energy Use in U.S. Food Production

Although there was a 1.8% decline in per capita energy use in the U.S. from 1997 to 2002, per capita food-related energy use increased by 16.4% [110]. About half of this increase was associated with a shift from human labor toward a greater reliance on energy services. The highest food related energy use was in household operations, while food processing had the largest growth in energy use. Both of these stages of the U.S. food supply chain increasingly outsourced manual food preparation activities to the manufacturing sector, which relied on energy-intensive technologies [110].

Fossil fuels are consumed in agricultural activities for fertilizer production, irrigation, farm equipment, as well as processing, packaging, and transportation. Huge quantities of synthetic fertilizers, requiring significant energy inputs for production, are used in industrial farms. Other types of fertilizers such as potassium and phosphorus are obtained through mining, requiring even more energy [111]. Crop irrigation accounts for about 37% of all water withdrawals in the U.S. [11], which also has implications in the energy sector as pumping, treating, and moving such large volumes of water require a great deal of energy. Modern agriculture also uses tractors, combines, etc. that uses gasoline and diesel fuel as well as equipment that uses electricity, such as lights, pumps, fans, etc. Due to consolidation and centralization of production, agricultural products often have to be packed and transported long distances, requiring more energy consumption [111].

Industrial scale livestock operations produce most meat, eggs, and dairy products in the U.S. At these operations, thousands of animals are grown in confined conditions without access to pasture and grazing, requiring the operations to use substantial quantities of feed produced by energy-intensive industrial crop farms. Confined livestock production has in the past contributed pollution to ground and surface water resources, imposing more treatment requirements at municipalities, which consume additional energy [111].

Current agricultural schemes, however, have significant potentials toward energy sustainability. Energy efficiency of food production can be improved by shifting from energy-intensive industrial agricultural activities to less intensive methods, such as pasture-raised livestock, non-synthetic fertilizers, no-till crop management; utilizing more efficient machinery, equipment, and transportation methods; lowering food processing and packaging, decentralizing food production, and improving the efficiency of transportation. In addition, farms can also produce their own clean energy by installing solar systems, biogas generation, or wind turbines [111].

4.2. Food-Related Household Operational Energy Use

In addition to food production processes, household food-related operations also consume energy. These operations may include [110]:

- Electricity for cooking (electric range, oven, microwave, toaster oven, and coffee makers), cleaning, and food storage
- Natural gas, or liquid petroleum gas for cooking
- Auto fuel for grocery shopping
- Energy embodied in purchases of equipment for food storage, preparation, and serving
- A portion of energy embodied in purchases of automobiles, parts, and auto services

Based on the Residential Energy Consumption Surveys [112], cooking accounted for 6.6% and 6.5% of total household electricity consumption in 1997 and 2001, respectively. Assuming households require similar amount of energy for cooking regardless of energy source, 2.1% and 3% natural gas as well as 1% and 1.6% petroleum were spent on cooking in these years. In the same years, refrigeration was responsible for 13% and 14%; freezing, 3.6% and 3.4%; dishwashers, 2% and 2.5%. Together, these sources consumed 25% and 26% of the total energy use of households in 1997 and 2001, respectively.

4.3. Changes in Food System Energy Technologies

Population change, per capita food budget increases, and product mix changes accounted for about half of total increase in energy use from 1997 to 2002. These increases were mainly in five categories: frozen, canned, and snack foods; food-related household operations; poultry; fresh vegetables; and baking products. Fresh vegetables, eggs, and poultry products were responsible for the largest increases in food-related

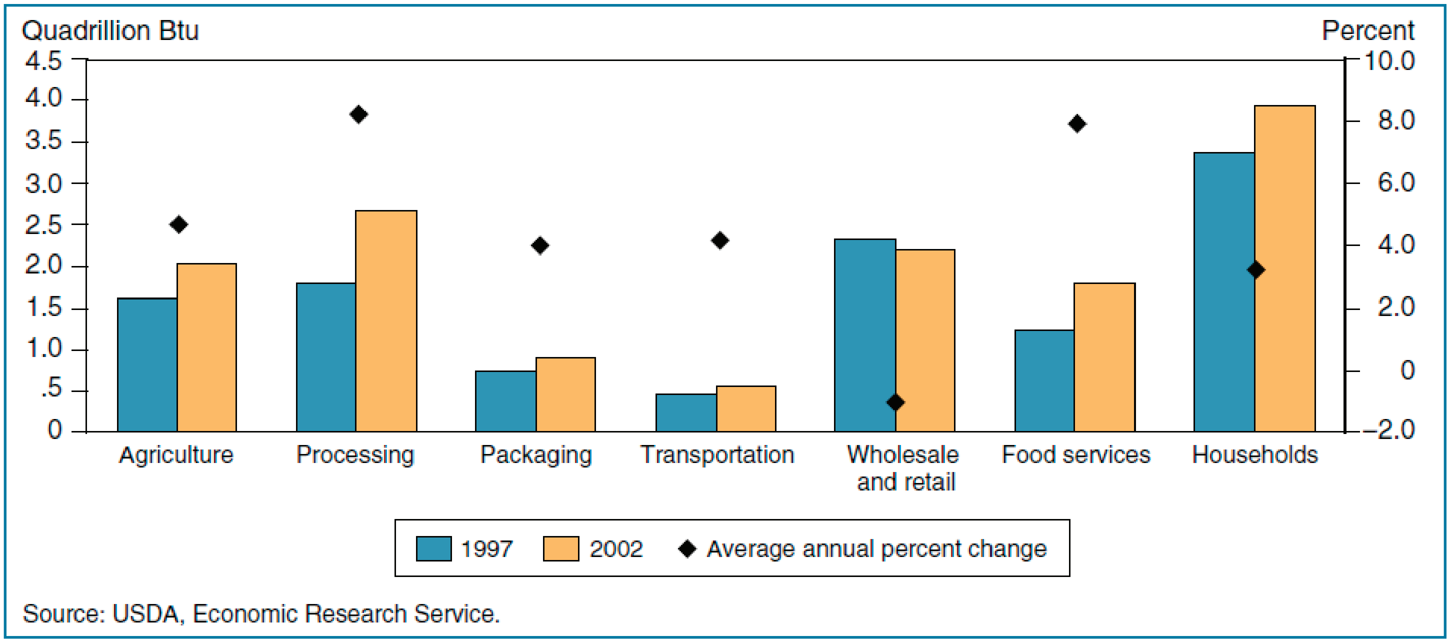


Figure 16. Change in U.S. energy consumption by stage of production from 1997 to 2002

energy flows [110]. The average time per day spent on cooking and cleaning at home by adults between ages 18 and 64 was reduced from 65 minutes to 31 minutes between 1965 and 1995 [113]. This reduction in food preparation time is concurrent with a substantial growth in demand for convenience foods, which require more energy-intensive processing, preparation, and packaging services than household prepared food.

In agriculture, there is an ongoing trend of replacing manual labor with the use of technology, resulting in a 30% decrease in farm labor inputs and a 10% increase in services from durable farm equipment from 1996 to 2006. Although the use of technology significantly increases energy consumption, there has been a significant decrease in agricultural energy use from 2002 to 2006, which is mainly a response to increases in energy prices [110].

Another energy-intensive food system process in the U.S. is freight services. Domestic food is mostly shipped by trucks and to a lesser extent by rail. Over the past decade, the intensity of freight service used by the U.S. food system has considerably increased. From 1997 to 2002, food commodities shipment distances increased about 5 to 15 miles annually and for some commodities, the shipment distance increase was about 10 to 16 miles between 2002 and 2007. Due to the large volume of food related freight services, these distance increases result in significant growth in energy use [114].

4.4. Change in U.S. Energy Consumption

The USDA Economic Research Service performed a supply chain analysis on the entire food system [110] and indicated the changes in energy consumption in different stages of food preparation, including production, processing, packaging, transportation, wholesale, food services, and households. Among these stages, food processing, food services, and households had the highest rate of increase from 1997 to 2002 (Figure 16). These three stages accounted for 55% and 60% of total 1997 and 2002 food-related energy flows, respectively.

4.5. Factors Affecting Future Energy Use in the U.S. Food System

U.S. DOE's Energy Information Administration has projected changes in energy use through 2030 [115]. Based on their projections, energy use for refrigerators, freezers, cooking, and dishwashers will increase by 12% between 2009 and 2030. With 22% projected increase in the U.S. population over this same period [116], the rate of increase in energy use indicates significant efficiency gains for household food related operations. However, the 12% increase is still substantial. Energy use by food retailers and foodservices is also projected to increase by about 20% from 2009 to 2030. Therefore, per capita energy use of these industries will stay the same. In the food processing and agriculture stages, energy use is projected to increase by 27% and 7%, respectively.

Among several factors that could influence the outlook of energy flows in the U.S. food system, three are considered key to reduce the rates of growth in food-related energy flows [110]:

- Adoption of energy-efficient food system technologies
- Food expenditure trends (the quantity of food-related purchases)
- Food and energy prices

5. Water Footprint Accounts in the U.S.

In a report prepared for the UNESCO-IHE Institute for Water Education [117], national water footprint accounts were studied in the period 1996-2005. This section summarizes the U.S. related discussions in this report. The water footprint of an individual is defined as “the total volume of freshwater used to produce the goods and services consumed by the individual,” and the national water footprint is the water footprint of all inhabitants of a nation [118].

China, India, and the U.S. jointly have about 38% of the global water footprint. China, with a total footprint of 1,368 Gm3/yr, is the largest, followed by India and the U.S. with 1,145 and 821 Gm3/yr, respectively. With the focus on water footprints related to industrial production, China and the U.S. are the top two countries, with 22% and 18% of the global water footprint related to industrial production, respectively. The total population of the U.S. is about 23% and 25% of the total population of China and India, respectively (based on 2012 statistics). Therefore, when the total footprint of these countries are averaged over their total population, U.S. citizens have the largest water footprint per capita—2,842 m3/yr—followed by Chinese, 1,071 m3/yr, and Indians, 1,089 m3/yr.

In terms of virtual water, or water embedded in food or other products [119], the major gross exporters of virtual water are the U.S., China, India, Brazil, Argentina, Canada, Australia, Indonesia, France, and Germany. These countries together account for more than half of the global virtual water exports. The major gross virtual water importers are the US, Japan, Germany, China, Italy, Mexico, France, the UK, and the Netherlands. In both virtual water exports and imports, the U.S. is the leading country, with 314 Gm3/yr of virtual water export and 234 Gm3/yr of import. Therefore, U.S. has a negative virtual water balance, which means that it has net virtual water export (Figure 17).

Figure 18 shows the global water footprint of U.S. citizens related to the consumption of crop and animal products and industrial products in the period 1996-2005. An important issue to consider while planning to increase dependency on imported virtual water is the fact that three of the world’s top ten food exporters are water scarce, and three of the world’s top ten water importers are water rich. Due to the groundwater overdraft as well as salinity and water quality problems in developing countries, the world could face annual losses in grain crops production equivalent to 30% of global cereal consumption by 2025; while the global demand is projected to increase by about 42% in the same period [92]. Therefore, increasing dependency on supplying demands through international trades requires planning for water supply. In addition, current international arrangements do not take account of water issues in international trades. “It is unclear under the rules and rulings of the World Trade Organization when, and to what extent, water itself can become a product, a commodity of subject to the rules of trade… if a price or a label must be placed in water to improve global water use… what are the implications under WTO rules?” [92]

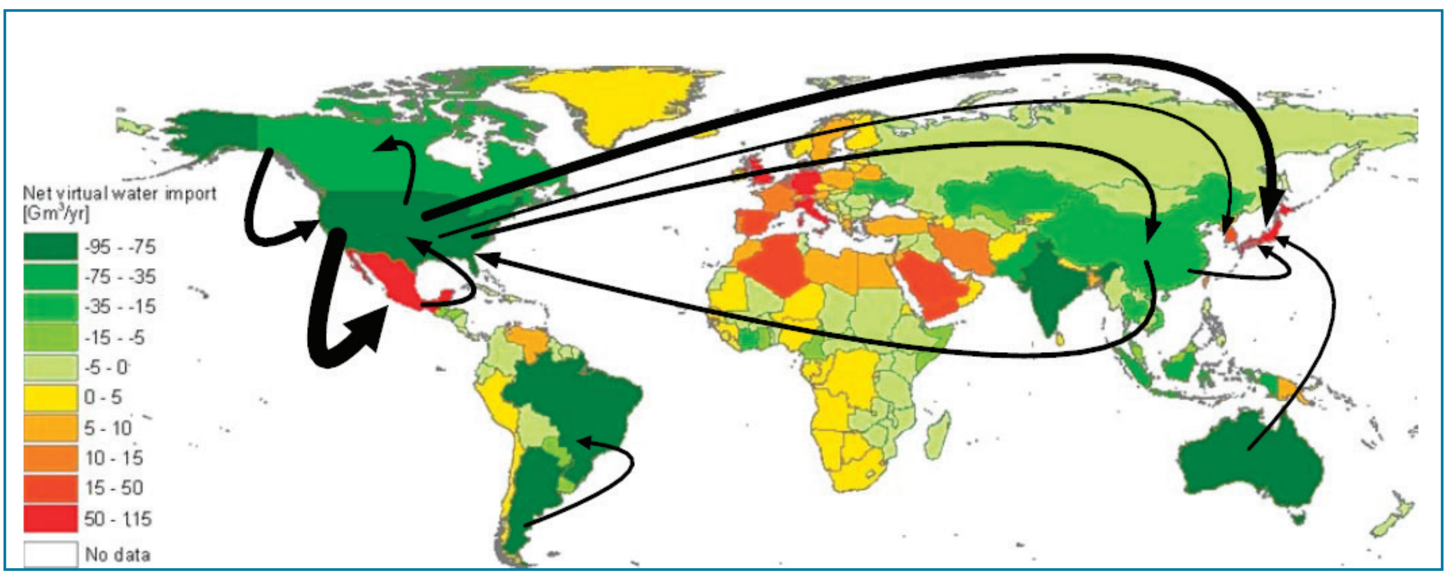
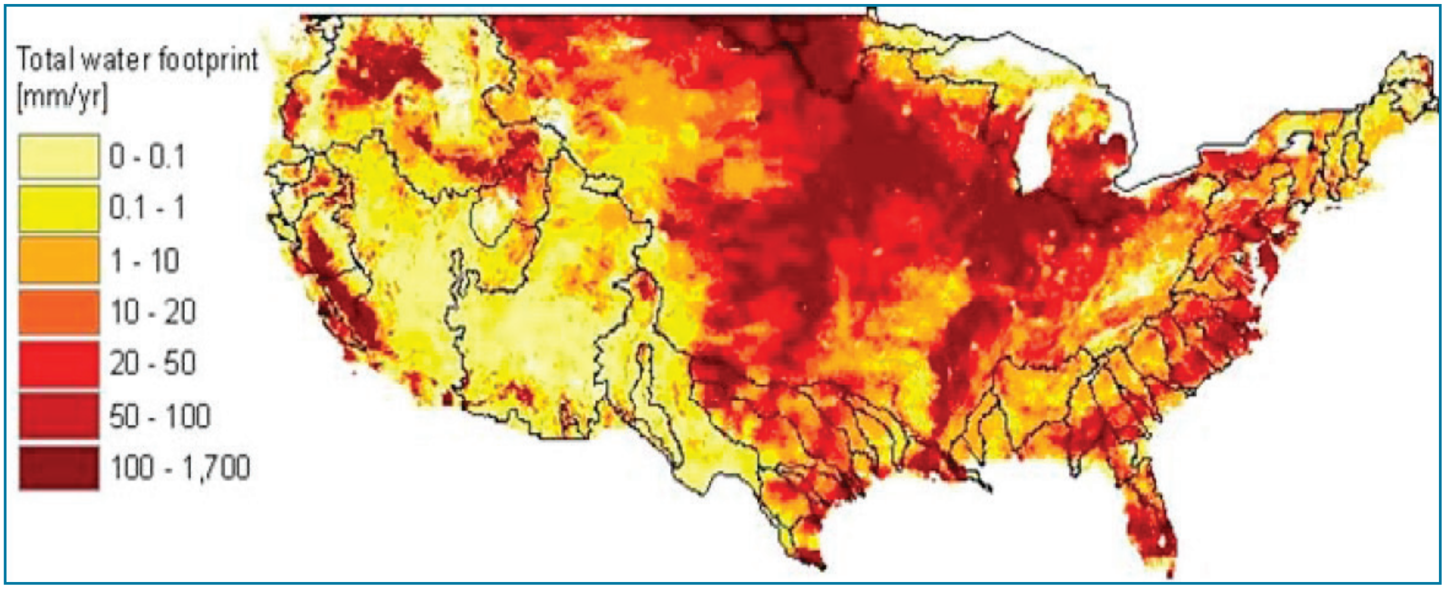


Figure 17. Virtual water balance per country and direction of gross virtual water flows (>15 Gm3/yr) related to trade in agricultural and industrial products (1996-2005). The thickness of arrows is relevant to the amount of virtual water flow [118]



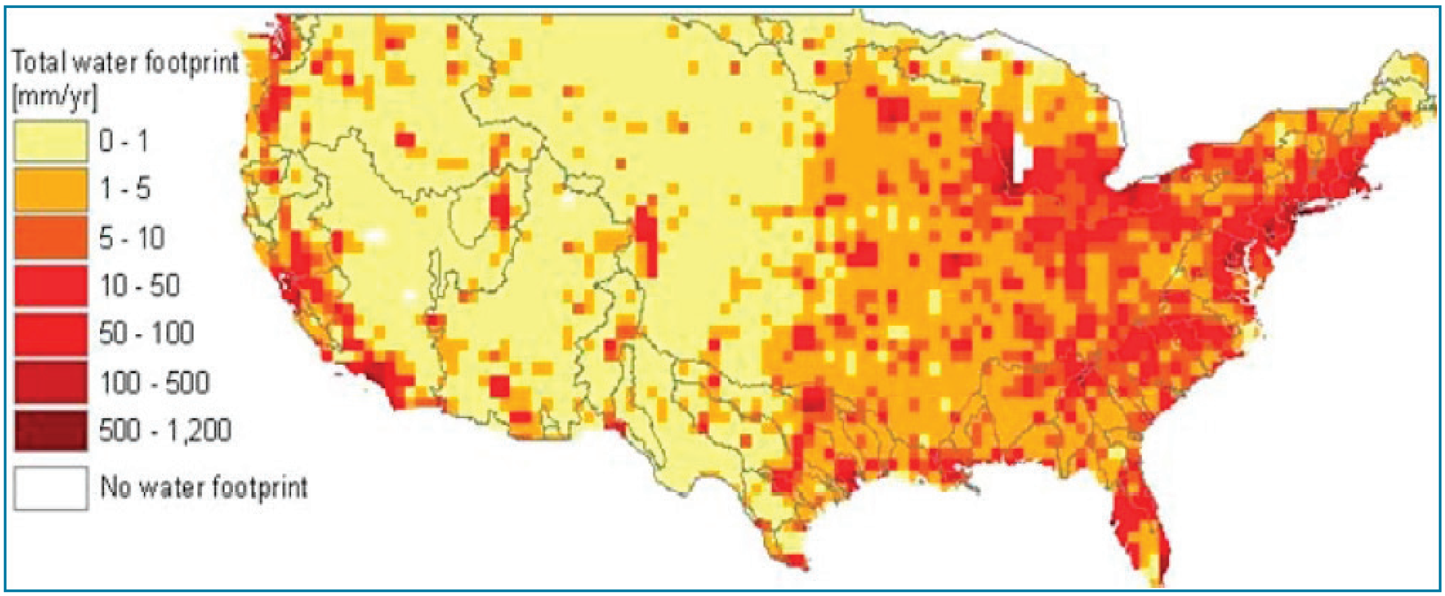


Figure 18. The global water footprint of U.S. citizens related to the consumption of crop and animal products (Top); industrial products (Bottom) (1996-2005) [118]

6. The Water, Energy, and Food Security Nexus

The inter-connected reciprocal interactions between all sectors of the nexus implies the importance of developing nexus-based approaches and policies, increasing understanding of the nexus, developing nexus-based decision support tools, and enhancing partnerships to involve all different stakeholders and sectors in problem solving [3]. It is also important to identify the barriers and obstacles to optimization of solutions for water, energy, and food security and to find practical ways to overcome these obstacles [120].

Water, as a non-substitutable substance, is a control variable centrally located in the nexus (Figure 19). Global trends toward urbanization, population growth, and climate change are forcing the implication of a nexus-based approach. Society, economy, and environment are the main action fields in the nexus, but finance, governance, and innovation are the main incentives and create opportunities to improve water, energy, and food security.

A nexus approach fosters system efficiency, rather than segregated focus on the productivity of individual sectors [5]. Therefore, all nexus sectors must be evaluated simultaneously to avoid enhancement in one sector at the cost of other(s). For example, energy intensive development solutions or the ones that require large amounts of water may be inappropriate in certain settings, and energy/water efficient scenarios should be desired. To increase total resource use efficiency, opportunities and synergies need to be promoted, and co-optimization is a key. A top-down theoretical analysis may not appropriately lead to the integration of objectives. Instead, a broadly-based dialogue and engagement of all stakeholders is demanded [4]. Civil societies and business leaders can support governments in a comprehensive nexus reform through [92]:

- Sharing and developing knowledge among stakeholders
- Creating innovative new business models that address challenges
- Engaging in policy dialogue with other stakeholders
- Increasing collaboration with other stakeholders
- Establishing leadership commitment to create market-based solutions

7. Infrastructure

A diverse group of experts representing municipal, federal, NGO, private sector, and academic perspectives from all regions of the country convened in a meeting at the Johnson Foundation in May 2009 and outlined the specific problems associated with water infrastructure and the built environment as following [121]:

- Surface runoff is the primary root of freshwater pollution in many parts of the country. From failing sanitary sewer infrastructure, untreated sanitary sewage leaks storm sewers cause public health concerns tied to storm events.
- There are significant infiltration and exfiltration challenges associated with aging water infrastructure.

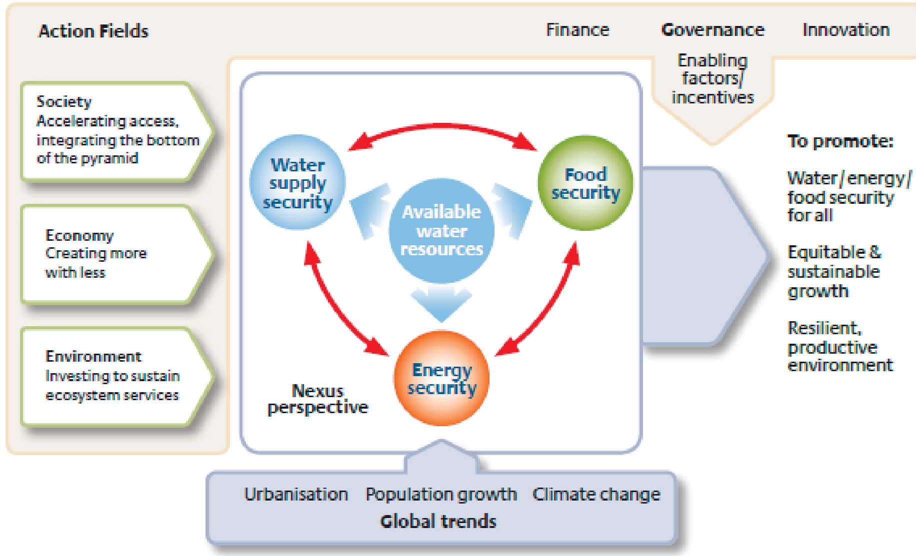


Figure 19. The water, energy, and food security nexus [5]

- Local hydrologic and ecologic regimes have been altered by stream and channel modification efforts (e.g., channel lining), and public access to surface waters in most urban settings has been eliminated.
- The capacity of existing systems (such as combined sewer overflows) is exceeded by more frequent and intense floods, potentially due to climate change.
- Long-term financial plans are compromised by short-term financial concerns.
- Institutional barriers usually block innovative solutions.
- Old standards are still used in many cities and towns to design renovation and expansion of their water infrastructure. An example is large-scale centralization of sewage treatment facilities, which is energy intensive, capital intensive, and frequently transfers water downstream or into saltwater estuaries, destabilizing the local hydrologic regime.
- There are inadequate source controls at the manufacturing level to prevent potential harmful compounds that threat the environment and human health.
- Climate change is adding complexity to decision-making about water systems as it is associated with high levels of uncertainty.
- Water-intensive power generation is a big issue in many parts of the country.

In the following, infrastructure issues specifically related to aging dams, drinking water and wastewater, energy, and levees are discussed followed by suggested paths to move towards sustainable communities.

7.1. Dams and Problems with Aging

There are approximately 84,000 dams in the U.S., with the average age of 52 years. By 2020, 70% of the total dams in the U.S. will be at least 50 years old [122]. In 2012, there were 4,000 deficient dams including 2,000 deficient high-hazard dams (dams in which failure or mismanagement is expected to result in loss of life and may also cause significant economic losses). The total number of high-hazard dams was about 14,000, which has increased from 10,118 over the course of ten years [122]. Population increase and development downstream of dams re-categorizes more dams as high-hazard dams and increase their numbers. A U.S. population increase of 130 million people has been estimated by the U.S. Census Bureau by 2050, which may result in more development in areas below aging dams.

An estimate by the Association of State Dam Safety Officials claims that the total rehabilitation cost for the nation's federal and non-federal dams is more than $57 billion and if only the high-hazard dams are to be rehabilitated, it would cost the about $21 billion. These costs will increase by delaying the maintenance, repair, and rehabilitation [123]. The U.S. Army Corps of Engineers, which owns a total of 694 dams in the U.S., estimates that over $25 billion is required to address dam deficiencies for its dams and would take more than 50 years to complete these repairs if the rehabilitation is done with current investment rates [123].

The Federal Energy Regulatory Commission regulates only 2,600 dams in the U.S. The remaining dams are inspected through state dam safety programs, which have primary responsibility and permitting, inspection, and enforcement authority for 80% of dams in the U.S. However, many of these programs have been found to be ineffective due to the lack of sufficient resources, and occasionally lack of enough regulatory authority. Alabama is the only state without a dam safety regulatory program.

The federal government provides grants to states through the National Dam Safety Program, administered by the Federal Emergency Management Agency (FEMA), to improve programs through training, technical assistance, and research. This program, however, expired in September 2011. The U.S. also lacks a national dam rehabilitation and repair program, which would fund the repair, removal, or rehabilitation of the nation's publicly owned, nonfederal, and high-hazard dams [123]. Additionally, the criteria for prioritizing dam rehabilitation funding across agencies and the extent to which the federal government should fund inspection and rehabilitation activities at nonfederal dams are still unclear [124]. Further, Congress is yet to establish criteria for prioritizing funding among nonfederal projects [124].

To improve dam safety, the following solutions have been suggested by ASCE [125]:

- Reauthorize the National Dam Safety Program (expired in 2011)
- Establish a national dam rehabilitation and repair funding program
- Develop emergency action plans for every high-hazard dam
- Implement a national public awareness campaign to educate individuals on the location and condition of dams in their area
- Encourage incentives for governors and state legislatures to provide sufficient resources and regulatory authorities to their dam safety programs
- Require federal agencies that own, operate or regulate dams to meet the standards

7.2. Aging Agricultural Infrastructure and Inland Waterways

Aging agricultural infrastructure can affect both water quality and availability. High volumes of water can be lost in irrigation systems due to aging infrastructure and antiquated technologies. Infrastructure maintenance has not been paid enough attention for decades in many regions. In addition to aging problems associated with on-farm and off-farm infrastructure, some USDA research facilities also suffer from aging infrastructure.

USDA's Agricultural Research Service (ARS) operates an extensive network of 122 federally-owned major research facilities. These facilities require regular maintenance and periodic upgrades during their 35 to 40 year lifetime. Major renovation, modernization or replacement is also eventually required. Twenty one of ARS research facilities are currently in greatest need of improvement and require recapitalization over the next decade. As these facilities are upgraded and improved, other facilities in need will move to a higher priority position for improvement. To maintain and upgrade these facilities in order to support agricultural science, approximately $150 million is annually demanded in capital investments [126].

Additionally, over 44% of the inland waterway facilities are at least 50 years old. Many of them are undersized for modern commercial barge tows [127]. By 2020, more than 80% of the U.S. locks will be functionally obsolete [128]. Approximately 95% of U.S. agricultural exports and imports are transported through these waterways and these activities support more than 400,000 jobs [128]. The undersized facilities need to be dissembled and reassembled at each lock, which prolongs transit time, increases operating costs, and decreased efficiency. It also advances operational energy demand and may result in wastage of at least a portion of the food by the time it is transported. Nationwide, a total of 550,000 hours queuing delays are responsible for an estimated annual $385 million in increased operating costs imposed to shippers, carriers, and consumers [127].

7.3. Drinking Water and Wastewater Infrastructure

After the adoption of Clean Water Act in 1972 and over the last four decades, several hundred billion dollars were invested by federal, state, and local governments to improve water and wastewater infrastructure [60]. Now, almost similar levels of investment as 1972 are again needed and the nation faces as significant funding gap for public water and wastewater infrastructure to store, transport, treat, and distribute water supplies to growing cities [129]. This is mostly because of population growth, urbanization, increasing percentage of the nation's population served by municipal treatment systems (from 71% in 1968 to 88% in 2025), stricter water quality requirements, and infrastructure aging. Climate change will also significantly alter regional patterns of water supply and demand and exacerbate our demand for water and wastewater infrastructure, while these infrastructures also contributes to climate change due to their significant rate of energy use [49]. Failure in meeting improvement demands of water supply and treatment systems and wastewater infrastructure may result in serious public water shortages, public health concerns, and water quality problems as severe as it experienced before the 1972 Act [130]. According to EPA estimations, ultimate biochemical oxygen demand discharge levels in 2016 will resemble those existing in the mid-1970s and will be similar to those existing before the 1972 Act in 2025 [129].

To invest on water and wastewater infrastructure, pipes represent the largest capital need (more than 75% of total needs). Treatment plants account for 15%-20% of total capital needs, which is subjected to increase due to new regulatory requirements. By estimation, over 1,000,000 miles of water mains and about 700,000 to 800,000 miles of public sewer mains are in place in the U.S. [131, 132]. As these pipes are buried underground out of sight, and owned and operated by various local entities, their conditions are unknown. Many of these pipes are approaching the end of their useful life. The U.S. annually faces about 240,000 water main breaks, forcing the utilities to replace 4,000 to 5,000 miles of drinking water mains annually, which is projected to increase to replacement rate of 16,000 to 20,000 miles of pipes in 2035 [131]. One of the main concerns associated with aging pipes is directed toward combined sewer overflows (CSOs), which may affect more than 700 American cities and towns by discharging a mixture of storm-water and sanitary wastewater to rivers and streams. As a national priority since 2007, the federal government has required cities to invest more than $15 billion in new pipes, plants, and equipment to eliminate combined sewer overflows [132].

EPA has recently estimated the costs for publically owned treatment works (POTW), CSOs corrections, and stormwater management facilities and programs to be $298.1 billion over the next 20 years [60]. In a parallel report, EPA estimated drinking water infrastructure needs, which summed up to about $334.8 billion in capital improvements from 2007 to 2026, with the highest capital needs for distribution and transmission pipes and treatment and storage facilities [133]. According to these two EPA reports, capital needs for both water and wastewater infrastructure improvements total $632.9 billion over the next two decades (about $32 billion annually). However, both of these reports underestimate the required financial investments, because: 1. They do not account for climate change, which increases drinking water, wastewater, and stormwater collection and treatment demands; 2. Only those portions of the public water supply system eligible for Drinking Water State Revolving Fund (DWSRF) were considered in the EPA's drinking water supply and treatment cost estimates and additional costs were ignored, such as the ones associated with dams and raw water reservoirs [133] as well as long-distance conveyance systems and construction of new dams or reservoirs [129]; 3. Based on the American Water Works Association estimations, national costs for replacing, restoring, and expanding only buried water delivery mains (and excluding water supply and storage infrastructure, treatment facilities, and local delivery pipes), over $1 trillion is needed in capital costs over the next 25 years, exceeding $1.75 trillion by 2050 [134].

Significant progress in reducing municipal pollution has been achieved through Title II of the Clean Water Act over the past forty years. There are, however, critics arguing subsidies for municipal sewage treatment systems promoted urban development, as they provided incentives increase capacity without sufficient consideration of efficiency [129]. The massive secondary wastewater treatment infrastructure has been built without an explicit legislative mandate to consider energy demand [129]. As an alternative remedy, there was a shift from a federal grants program to a revolving loan program in 1987. Although Congress has adopted several provisions to the Title II program to require states and cities to pay for their own water and wastewater infrastructure costs [135], these provisions have not been adequately effective and failed to promote sufficient public investment in water and wastewater infrastructure [57].

It can be learned from the Clean Water Act construction grant program that: 1) federal infrastructure subsidies are likely to have unintended effects on fiscal and energy costs; 2) providing federal funding to encourage recycling and reuse of sewage effluent and the elimination of surface water discharges appear to have been unsuccessful. One or a combination of several reasons may have caused the latter, including a) the incentive-based, rather than mandatory, nature of provisions; b) the pressure to immediately address severe water quality problems; c) lack of public acceptance and concerns associated with the health and environmental effects of wastewater recycling and reuse; d) the desire of short-term cost-effectiveness over long-term sustainability [129]. Therefore, although technologies are currently available to construct a more sustainable infrastructure path for the next forty years, finding the legal, policy, and financing tools needed to support and promote them is essential.

The aforementioned lessons and their potential reasons must be considered in new federal water and wastewater infrastructure funding programs. We need to switch to clean water-energy nexus from the current approach of transferring substantial amounts of water over long distances, treating all of it to drinking water quality regardless of end use, and collecting and treating resulting wastewater to meet receiving water standards. Learning from these lessons, one strategy would be to return to a former set of mandates requiring more sustainable infrastructure alternatives, as envisioned by Congress. This strategy would require significant and controversial federal rulemaking and likely result in legal challenges. Another approach is to renew federal financial commitments, with fixed conditions, to help communities meet their infrastructure needs. The federal government would only subsidize investments that move away from the energy-intensive, water-intensive, and water quality-risking policies of the past [129].

Delay in initiating change to our approach will result in more adverse effects associated with energy use and climate change. However, changing the approach and implementing it is a time consuming process. In a comprehensive study on water and wastewater infrastructure in the U.S., Adler has suggested the following principles to guide future infrastructure policy [129]:

1. Reduce the use of energy-intensive, fiscally expensive, and inefficient water conveyance systems and avoid long distance water transfers unless that water is necessary for potable uses as opposed to outside watering and other non-potable uses [136].
2. Abate treating all public water to drinking water standards whether or not it is intended for potable end use.
3. Avoid discharging wastewater to surface waters if it can receive alternative end uses in the community, e.g. groundwater recharge.
4. Principle of cascading water use can be adopted to use each gallon as many times as possible, with water quality requirements and descending costs for accompanying treatment according to the end use [137].
5. System users should be charged based on full costs of construction, financing, and O&M, as well as environmental costs to promote efficient water use. Strategies such as differential fees, lifeline rates, or ascending block pricing can be employed in this approach.

In addition, the ASCE has suggested the following solutions to improve water and wastewater infrastructure through its 2013 Report Card for America's Infrastructure [138, 139]:

- Raise awareness of the true cost of water
- Reinvigorate the State Revolving Loan Fund (SRF) under the Clean Water Act
- Eliminate state caps on private activity bonds for water infrastructure
- Explore the potential for a Water Infrastructure Finance Innovations Authority (WIFIA)
- Establish a federal Water Infrastructure Trust Fund
- Separate potable and nonpotable water

7.4. Energy

To meet increasing electric power demands in the U.S., new transmission lines have to be added to the almost 400,000 miles of existing lines, which suffer from aging problems. Aging equipment causes increasing numbers of intermittent power disruptions and increases system vulnerability to cyber-attacks. There has been an increasing trend in significant power outages from 76 in 2007 to 307 in 2011 [140]. These congestions increase concerns about distribution, reliability and cost of service, may lead to system-wide failures and unplanned outages, and put public safety at risk [141].

In addition to electricity transmission lines, the 150,000 miles of crude oil and product pipelines and over 1,500,000 miles of natural gas transmission and distribution pipelines, mostly buried underground, are responsible to supply energy demands in the U.S.. This energy infrastructure, which is typically owned by private industry, has experienced a series of failures leading to deaths, injuries, significant property damage, and environmental impacts since 2008. Therefore, greater pipeline management and maintenance programs are increasingly needed. In 2011, new federal safety requirements were adopted to address the problems and concerns relative to aging infrastructure in energy sector.

In the 2000s, capital investment in electricity infrastructure averaged $63 billion per year. This includes more than $35 billion in generation, $8 billion in transmission, and almost $20 billion in local distribution lines. These investments were funded by government agencies, regulated utilities, private companies and developers, and nonprofit cooperatives [142]. Despite these investments, there will still be an investment gap of $57 billion for distribution infrastructure and of $37 billion for transmission infrastructure by 2020. Further, adoption of new technologies, (e.g., smart grid technologies, computer-based, automated systems) has increased investment demands in recent years. Modernizing and automating the energy infrastructure may increase system vulnerability to cyber-attacks, which can demand extra funding for system security.

The U.S. Energy Information Administration predicted an 8% to 9% increase in electricity demand from 2011 to 2020. It was also projected that electricity supply capacity will increase about 10% by 2016. This increase is mostly to be accomplished through new natural gas-fired and renewables generation to meet enhanced environmental regulations. For this purpose, an additional 17,000 circuit miles of high-voltage transmission lines will be added to the system [143]. Due to capacity constraints in refineries and oil and gas transmission systems, the main challenge in capacity expansion will begin after 2020, when the sufficiency of energy pipelines and related operations becomes an additional concern [141].

Suggested solutions to improve energy infrastructure and alleviate concerns about capacity and aging issues include [144]:

- Adopt a national energy policy that accounts for adaptation to future energy demands and sustainable energy sources and energy conservation
- Minimize the timing of planning to operation by timely approval of transmission lines
- Identify and prioritize risks to energy security
- Design and construct additional transmission grid infrastructure
- Create incentives to promote energy conservation
- Find innovative ways to enhance the nation's transmission and generation infrastructure

7.5. Levees

U.S. has approximately 100,000 miles of levees mostly built in the mid to late 19th century as critical infrastructures that reduce the risk to public safety from floods and protect farmland. For examples, levees protected the Midwest from more than $141 billion in flood damages in 2011. The federal government only funds levees maintained and operated by the USACE through the Civil Works budget and therefore, almost 85% of the nation's levees, which are locally owned, operated, and maintained, rely on state and local governments for investment. USACE operates the National Levee Database (NLD), which is an inventory of most of the levees it has designed, maintained, and inspected. The average age of levees in the NLD is more than 55 years and on average each levee protects approximately 14 million people who live or work behind the structures. Only 8% of levees in this database are in acceptable condition, while approximately 69% are minimally acceptable, and 22% are in unacceptable conditions [145].

The U.S. levees system currently needs more than $100 billion for repair and rehabilitation [146]. These costs are subjected to increase as more floods occur. Only the USACE's levee and flood control facility damages average $4.2 billion per year, and annual damage to the entire nation's levees system is estimated to be approximately $15 billion [146].

Several aspects associated with the levees system increase the risk of people and property damage from flooding, including: the lack of formal federal, state, and local government oversight; adequate technical standards; and lack of effective understanding about the risks of living behind a levee [145]. Although Congress has created the National Levee Inventory in 2007, legislation which creates a National Levee Safety Program is still missing [145]. In order to increase awareness of people living and working around levees, the USACE and Federal Emergency Management Agency (FEMA) have invested in coordinated efforts and work collaboratively while involving local, state, and other federal agencies. The ASCE has suggested the following solutions to improve the U.S. levees system:

- Establish a National Levee Safety Program
- Complete the National Levee Inventory
- Adopt a levee hazard potential classification system
- Complete levee mapping as outlined in the National Flood Insurance Program reform bill
- Increase funding at all levels of government and leverage private funds
- Require insurance where appropriate
- Ensure that operation and maintenance plans cover all aspects of a complex levee system

- Evaluated the effects of urbanization and climate change on levees

7.6. Water Infrastructure to Guard against Drought and Crop Damage

Climate change may have some positive aspects, such as longer growing seasons; however, more flooding and extreme events are expected. These events have associated impacts on infrastructure, buildings, and public health. Therefore, more communities are expected to be placed at risk of property damage, regulatory liabilities, and uncertain access to drinking water. As an extreme event, drought has considerable economic, environmental, social, and political impacts. An extensive system of water supply infrastructure, including reservoirs, managed groundwater basins, and inter-regional conveyance facilities, helps mitigate the effect of short-term (single year) dry periods. However, managing longer-term events is more complicated. So far, we have developed our water resources plans based on the observed historical hydrological data recorded over a little more than a century. However, paleoclimatologists have recently shown that the last century does not represent the full range of the climate system's natural variability, which can be far greater than that observed in the historical record. According to their findings, the last 150 years have been among the wettest hydrological periods, and droughts prior to the historical record were far more severe than today's water institutions and infrastructure were designed to manage [147].

To minimize adverse impacts of drought, investments in infrastructure and using existing natural and built infrastructure and institutions can increase the options for adaptive behavior. Some adaptation options include: water banking, conjunctive use of groundwater and surface water, storage for instream flow maintenance, and regional interdependence [148]. American Water Resources Association (AWRA) comprehensively researched successful cases in the U.S. where proactive flood and drought management were implemented. Their major findings in evaluating these cases were [149]:

Driven by Disaster: In all cases, drastic floods or droughts of record were among the driving forces, which increased public and institutional willingness to design and implement proactive approaches in order to mitigate future impacts.

Comprehensive Approaches: Although all cases used conventional approaches, such as dams and levees for flood control and water-use restrictions for drought mitigation, they included science and best practices in hydrology, geomorphology, and land-use management to increase effectiveness.

Creativity and Innovation in Institutions: Instead of seeking a single solution, they extended their efforts beyond existing, conventional institutions and regulatory authority. As an example, the City of Easton extended the national minimum building and land-use restrictions beyond the 100-year flood plain.

Multiple Benefits, Multiple Funding Sources: They considered many related water and environmental objectives in effective flood and drought mitigation. Clearly, more costs are associated with a multiple objectives project, but the benefits regarding the elimination of financial demands for separate projects that would otherwise be needed justifies those costs.

Regional Coordination: Regional partnerships was a key as managing flood and drought are significantly more challenging if management efforts are to be implemented in an isolated portion of a basin or aquifer system.

Ecosystem-Based Efforts: A successful strategy in these cases studies was the integration of noninfrastructural, ecosystem-based approaches in planning and management.

Multi-Stakeholder Engagement: Another critically important approach that was taken in these studies was coordination of local, state, and federal agencies, as well as the input of often competing interest groups.

Based on the aforementioned lessons learned from the case studies, AWRA has recommended strategies to mitigate flood and drought effects. These recommendations, which have been categorized into enabling proactive management, organizing stakeholder feedback and outreach, designing strategies, and continuing efforts, include [149]:

Enabling proactive management: Solicit support from politicians; engage the local business community; partner with state, federal, and regional entities; seek assistance and ideas from research centers; use third-party facilitators; if needed, create new authorities; dedicate staff; pursue diverse and alternative funding sources.

Organizing stakeholder feedback and outreach: Assemble a representative body; communicate with local, state, and federal partners early and often; create online tools for public education and outreach; station staff in the field.

Designing strategies: Base management strategies on data; integrate spatial analysis; manage through local ordinances; plan for the unexpected.

Continuing efforts: Evaluate and update your strategy regularly; monitor climate and precipitation; share information regularly.

7.7. Paths to Accelerate the Pace of Change toward More Sustainable Communities

To move towards more sustainable communities, change in legal and regulatory policies, institutional and governance structures, financial structure, business innovation, natural systems, communities, education, as well as monitoring and assessment mechanism are inevitably required. The following is a synopsis of the Johnson Foundation meeting on "Examining U.S. Freshwater Systems and Services: Infrastructure and the Built Environment," which summarized these suggested changes [121]:

Legal and Regulatory Policy: Basin level, area-wide and facility level planning and decision-making should be promoted. A new Sustainable Cities Act is under consideration which may provide agencies with the legal opportunity to function in a more integrated fashion. Green infrastructure is now more supported by EPA and environmental advocates. However, more needs to be accomplished at the local level. Local codes and zoning ordinances should be revised to allow implementation of green infrastructure. Water reuse strategies are facing significant barriers in some states, where water capture and reuse is considered illegal. Many different federal agencies are currently moving toward integrated water and energy policy decision-making; however, a central coordinating body is required to facilitate coordination and integration across agencies.

Reforming institutional and governance structures: Government agencies, universities and professional associations are still leaning toward fragmentation between disciplines, hindering implementation of innovative approaches to freshwater management. However, an integrated approach is required to sustainably design and plan for urban and water systems development. Water resource engineering needs to practice updated and integrated multi-disciplinary approaches. Federal agencies should also mitigate barriers among the disciplines of flood management, water supply, and pollution control that are currently operated independently. Integrated strategies have the potential to embrace significant co-benefits for transportation, public health, energy, and open space and environmental quality, housing, and public works departments. However, funding barriers need to be removed.

Financial structures, pricing, and economic factors: Current water pricing structures do not incentivize water conservation as they do not employ full-cost pricing, which is accounted for the cost of infrastructure maintenance and upgrades, water processing, environmental externalities, as well as social equity, access, and affordability issues, the value of ecosystem services, and the cost of their degradation.

Business Innovation: New business opportunities, such as outsourcing non-core activities of utilities, can be practiced. Encouraging companies to set up their own water systems could also alleviate some of the capital strain on municipalities.

Natural Systems: In designing or redesigning freshwater infrastructure, a principal goal should be to mimic the pre-development condition of natural hydrologic systems to the greatest extent possible. This can be incentivized through tax credits to landowners, so that they conserve ecosystem on their property.

Regionalism and Community: Watershed-based planning in community and/or regional planning processes face local constraints and challenges. Capacity building is required at the community level in areas such as adaptive management, revising local codes, and understanding the land use-water use connection, the water and energy connection, etc. Leaders should help citizens explicitly understand the impacts of land use decisions on water resources so that they can cross traditional boundaries and envision a better future for their communities. If citizens are involved in establishing and evolving the vision for their communities' future, their engagement in achieving that vision is more likely.

Monitoring and Assessment: Monitoring and assessment can help specify effective strategies, techniques and technologies. It is also required for policy and regulatory reform. The obtained data can also be used to increase public awareness and promote behavior change.

Education and Communication: Scalable models of success stories in pricing, governance, green infrastructure, etc. should be identified and disseminated. The message should cover main concerns that people may have, such as health, clean air, and climate, and help them understand what source water is and how it can be polluted or protected. Existing social networks and communications channels, such as schools, churches, master gardeners, and community radio, can be used as different alternative ways to transport the message.

8. Nexus Challenges

To focus on potential achievements through the nexus approach, it is important to differentiate between what is or is not the nexus. A nexus framework is only efficient when there is a strong linkage between sectors and may not work for independent sectoral analysis. The linkages must be understood clearly, and their interactions should be managed. In addition, it must be assured that the nexus dialog is science-based, so that clear definitions, well-tested methodologies, and well-designed integrated models are created [4]. Other nexus challenges can be categorized as lack of scientific data, information, and literature; policy; finance; public perception; water rights; and urbanization. These are discussed next.

8.1. Lack of scientific data, information, and literature

The main data gaps in the water sector relate to groundwater and recycled water. There is an absence of enough data about actual groundwater use, which has led to inaccurate energy requirement data for groundwater extractions [38]. In addition, the end uses and volumes of recycled water are not well documented nationally, and there is no inventory of water recycling plants and their capacity [38]. Among all states, California and Florida are the only ones that publish reports on their reclaimed water use. The U.S. Geological Survey's 1995 report is the last comprehensive survey of reclaimed water reuse [150].

In comparison with data availability on water resources per se, the lack of data about the effects of the energy sector on water resources is more substantial. Some of the main gaps in data availability include [38]:

- The long term effects of coal mining, especially on groundwater, are not yet fully understood;
- There is not enough peer-reviewed literature analyzing effects of natural gas extraction on water and environment;
- There is little understanding about the impacts of new technologies and the exploration of new energy deposits;
- The majority of documents evaluating the impacts of oil and natural gas extraction and processing are now outdated due to the development of unconventional oil and natural gas sources and rapid change in technologies;
- Uranium mining, especially in-situ leaching, has not received enough academic attention
- There is a need for federal quantitative data on biofuel production water consumption;
- There are high uncertainties associated with the precision of historical data on average annual rate of water withdrawals for thermoelectric generation [151];
- There is no comprehensive data on nuclear power plants water use as they were exempted from reporting their water use to the EIA since 2002 [41];
- False water use reporting from water-cooled natural gas and coal power plants and no data about nuclear plants water use has left 27% of all freshwater withdrawals and 24% of all freshwater consumption unaccounted for [152].

Most information about the water intensity of oil and natural gas extraction and processing are reported by industry, and federal regulation exempts declaration of some chemicals used in the process. Gleick's work in 1994 [43], which is based on data from the 1970s and 1980s, is the main source of data for the majority of the literature discussing the effects of coal, natural gas, oil, and uranium on water [66, 71, 153]. The lack of comprehensive information on the energy sector's water use has created an incomplete picture of the impacts this sector has on water resources. The policymakers need more accurate data to regulate operations and development of these resources.

8.2. Policy and Governance

Policy barriers are among the main challenges to moving toward a nexus approach. National water policy choices have to find the tradeoff between environmental sustainability and economic affordability. For this purpose, governments and policy designers should find ways to encourage synergies among different sectors and implement innovations that accelerate nexus security. Some existing policy gaps and shortcomings are discussed below.

Federal and state supports, such as state revolving funds for wastewater treatment, loan and grant programs of the USDA's Rural Utilities Service, and the Community Development Block Grants from the Department of Housing and Urban Development, undermine incentives for water and wastewater services to make cost-effective decisions [154]; the lack of regulatory requirements and government funding has resulted in the fact that utilities wait until direct and indirect costs become unbearable before they rehabilitate water pipeline; the lack of federal legislation for wastewater recycling has substantially slowed its development down, even though the development of recycled water is very promising; promotion of water-recycling projects is affected by water rights laws; specific requirements for treatment or monitoring for recycling have not been stated in the Safe Drinking Water Act [155]; the only guideline on non-potable water reuse, documented by the U.S. EPA [40], is partially based on a review and evaluation of current state regulations, not on rigorous risk assessment methodology [40, 155]; hydraulic fracturing was exempted under the federal Safe Drinking Water Act, creating substantial uncertainties associated with the type of chemicals used in the process and therefore their impact on water and the environment.

A set of regulations for the oil and natural gas industries was issued by the U.S. EPA in 2012. These regulations were under the Clean Air Act and addressed emissions, leaks and spills [40]. However, more regulations are demanded under the Safe Drinking Water Act to address pumping chemicals underground [38]. For the fracking industry, a Fracturing Responsibility and Awareness of Chemical Act was proposed in Congress twice in 2009 and 2011, but it was never passed.

8.3. Finance

Finance is one of the main drivers of the nexus. Future funding should maximize funding tradeoffs between different sectors [4]. Over the next 20 years, a gap of $534 billion, about $27 billion annually, has been projected by the U.S. EPA to meet required clean water and drinking water capital needs and to satisfy operations and maintenance costs [156]. Climate change effects may escalate these costs, and adaptation strategies need to be developed to mitigate these effects.

Most of the wastewater treatment plants were built 40 to 50 years ago [59, 60, 154]. To install secondary and advanced wastewater treatment, $105.2 billion should be invested [60]. It has also been estimated that for water infrastructure, between $13.0 billion and $20.9 billion should annually be invested for wastewater systems and between $11.6 billion and $20.1 billion should be invested for drinking water systems from 2000 to 2019 [154]. In addition, significant capital investments are required for development and use of recycled water, as the current rates do not usually return the full treatment and distribution costs [155].

Federal and state subsidies for energy and water in large water transfers, especially for irrigation in the West, have created resource inefficiency in the water-energy nexus. These subsidies have promoted inefficient and energy-intensive water use by hiding the true resource costs [52]. Government funding for energy and water projects should target sustainable development and efficient use of financial resources.

8.4. Water Pricing

Prices of a majority of agricultural inputs are typically influenced by the demand and scarcity of the commodity. Clearly, high demand and short supply increase the costs, encouraging more efficient use. However, among agricultural inputs, irrigation water prices often reflect only the cost of supplying water and are not set in a market. Irrigation water costs generally reflect different combinations of type of water sources (surface water or groundwater), distance to water source, suppliers, distribution systems, and other factors, such as topography, underlying aquifer conditions, energy source, etc. [157]. In addition to full costs of construction, financing, and O&M, pricing mechanism should be refined to reflect environmental costs, social equity, access, and affordability issues [121, 129].

Water pricing in the U.S. is often based on acreage served rather than volume of water delivered. This is mainly because there are lower administrative costs for a land-based charge. Users pay a fixed cost per acre to receive a specified water allotment. This pricing structure, which charges regardless of the amount of the water allotment used, reduces the financial incentive to conserve water [157]. Due to the increasing urban and environmental water demands, water pricing reform can be consider as a potential means of reducing agricultural water demand. Volumetric pricing may somehow promote water conservation. Other strategies such as differential fees, lifeline rates, or ascending block pricing can be employed in this approach can also be employed to promote environmental conservation [129]. Refined pricing mechanisms can also target educating the public on reducing food waste [108]. However, significant barriers exist and have to be overcome in developing a comprehensive pricing policy. These barriers include [157]:

- Existing water costs have a nonmarket nature
- State laws governing withdrawals and instream uses vary among different states
- Water management institutions and delivery organizations vary across the U.S.
- Institutional and administrative restrictions to water market development

The Bureau of Reclamation has developed new legislation in the Central Valley Project, California, that requires increase in water prices as contracts are renewed and water delivery charges are collected on a per-acre-foot basis. This reforming legislation could be used as a model for future pricing adjustments to promote water conservation and also be implemented in other basins where competition for limited water supplies exists [157].

8.5. Climate Change and Energy

During droughts and warm summer months, when energy demands and water deficits are high, water-energy conflicts may be exacerbated [158]. Climate change may increase the intensity and frequency of these extreme weather conditions [159]. These hot weather conditions not only negatively affect power plant efficiencies and increase energy demand for cooling purposes, they might also force thermoelectric power plants to shut down in order to supply water to the other demands with higher priorities, i.e., domestic and environmental, which would cause major blackouts [41, 152, 159].

8.6. Climate Change and Food Production

Climate change is expected to increase water demand even in northern-tier states. The timing of irrigation is expected to become a more critical on-farm water management issue. In the eastern U.S., where adequate precipitation usually occurs to support rainfed crop production, changes in precipitation patterns may shift the normal growing-season. Increases in the frequency and severity of drought may force shifts in irrigated and dryland production. In addition, rising temperatures cause greater evaporation rates, making high-pressure sprinkler and traditional gravity irrigation systems even less efficient. Reduced water supply will also expand groundwater use for irrigated agriculture, depleting aquifer water levels, and increasing pumping costs (and saltwater intrusion near coastal regions) [32]. The situation is exacerbated in the West, which is likely hit harder by climate change and where water resources are already over-allocated and water demands are highly increasing. Therefore, increased agricultural competition across the country may underscore the importance of managing irrigation applications. However, a more sustainable future requires widespread adaptation of more efficient irrigation systems, coupled with intensive field-level water management practices across the U.S. and especially in the West [32].

Besides climate-induced challenges imposed on agricultural activities, other challenges associated with freshwater use and management in the U.S. agricultural sector include [109]:

- Incomplete and unreliable water data
- Artificial distinction between groundwater and surface water
- The actual price of water is not reflected in the cost to consumers
- Deficiency of an integrated national legal framework for water rights
- Lack of robust institutional frameworks
- Absence of an integrated water management strategy for rural/agricultural and urban areas
- Overlapping water management and regulatory jurisdictions
- Incompatibility in political boundaries and watershed boundaries
- Willingness of existing economic, political and market-based forces in keeping the status quo
- Absence of political will on the issue

8.7. Public Perception

Change causes resistance. One of the environmentally sound methods for stretching limited water supplies is through the use of recycled water. However, concerns associated with the risks to public health, consequences of using reclaimed water, the chance of failure of the system and combination of potable and reclaimed water may create public resistance to accept the use of recycled water. An extensive public education and involvement program can help to gain public trust and acceptance of water reuse.

In addition, in implementation of agricultural conservation practices, there are concerns that conservation agreements open a way towards reallocating agricultural water to other users, transferring agricultural water rights to the others, and it is perceived that farmers may lose their water rights over time. Coming to these agreements is hard, especially when it involves farmers giving up water, regardless of whether this water is demanded or not. It requires conversations, clarifications, strategizing, trust, and collaboration.

8.8. Water Rights and Energy Production

The western U.S. has some of the most fertile soils in the nation. California, as the nation's largest agricultural producer , produces half of its fruit and vegetable crops. Arizona's Yuma Valley, known as "America's Winter Vegetable Capital," produces 90% of all leafy vegetables produced from November through March in the U.S. [160]. On the other hand, the biggest U.S. oil fields are also located in the West (Southern California, western Texas, Utah, Colorado, Wyoming) [38]. The agricultural practices and production of crude oil in these areas require large quantities of water. However, these areas are some of the driest places of the nation, making water unavailable in desirable volumes to meet all demands. Complicated water rights provisions exist in the West, and obtaining water rights, which is essential for production, can be seen as one of the biggest challenges for energy and agricultural development.

8.9. Urbanization

Another important nexus challenge is urbanization, which concentrates energy and water use while producing more waste [5]. In 2010, 80.7% of Americans lived in urban areas, which was 12.1% higher than 2000, while the nation's overall growth rate was 9.7% for the same period [161]. The global ratio of urban population over the total population is just over half. Sustainable urbanization requires a strong management between urban and rural development, which engages both urban and rural communities to configure future settlements and living patterns in a sustainable way. However, in the current paradigm, jurisdictions compete between urban and rural areas and among urban areas, which increases inefficiencies in land, water and energy use [4].

8.10. Public Health

The World Health Organization (WHO) defines health as being "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" [162]. An example of water-related physical health is the fact that human fecal matter still gets into the U.S. water supply through leaking sewers. Another emerging threat to physical health is the introduction of pharmaceuticals and endocrine disrupting chemicals through wastewater discharges to receiving waters and potentially to downstream drinking water supplies. A healthy environment capable of satisfying one's basic human needs is required for human mental health. Stress associated with human inability to access a sufficient amount of clean water for drinking, cooking, bathing and/or recreating can affect mental health. As water stress could create water supply conflicts or migration in extreme cases, it will affect social health [163].

Audrey Levine, National Program Director of the U.S. EPA Drinking Water Research Program, summarized threats to the quality of freshwater supplies at the Johnson Foundation Freshwater Forum on Public Health Threats and Solutions as [163]: inadequate or inappropriate stormwater management, water reclamation and reuse, groundwater pumping and recharge practices, climate-induced stressors, and outdated and inadequate water infrastructure. In addition, insufficient water supply, which affects the reliability of supply, is an emerging public health concern in many parts of the U.S.

Current public health protection efforts lack a holistic view of what is important for human health. They are typically based on a contaminant-by-contaminant approach or illness-centric conceptions and do not consider the synthesizing effects of multiple contaminants. In addition, although contaminations of water supplies are recognized threats to public health, the public health risks associated with freshwater supplies are not as fully understood. There is a demand for developing better tools that evaluate and measure water-related variables impacting human health among other variables. It is also required to develop tools to analyze the effectiveness of new water treatment technologies [163]. Developing these tools demands epidemiological research and adequate funding to support it. Public education about the relation between water and public health needs to be improved, as public unawareness about risks or rewards related to water quality or quantity may reduce political will to address them. A more holistic view of freshwater and public health that considers physical, mental, and social health and integrates water availability and quality, environmental relations, and social science needs to be established. The country also needs more robust water quality monitoring, modeling, and mapping systems, continued improvement of treatment technologies, and enforcement of and compliance with policies and regulations [163].

9. Examples and Case Studies

Given the broad nature of the nexus, examples can be cited from the policy level through operating programs and at scales from local to trans-national. The following examples include two planning examples at the regional and urban scales and a few policy and programmatic initiatives that focus on nexus activities.

9.1. Infrastructure Sustainability Policy

To promote sustainable infrastructure within the water sector, the U.S. EPA has issued its Clean Water and Drinking Water Infrastructure Sustainability Policy [164]. Guided by this policy, EPA has developed the Water Infrastructure: Moving toward Sustainability program, which provides technical support and financial resources to states to increase water and energy efficiency in water, wastewater, and stormwater infrastructure. The agency works with partners across the water sector and a broad group of stakeholders to help implement practices on three levels [165]:

- Sustainable Water Infrastructure: To sustain infrastructure that is used for the collection and distribution systems, and treatment plants in water-related services
- Sustainable Water Sector Systems: To sustain any aspect of the utilities and systems that provide water-related services
- Sustainable Communities: To promote the role of water services in extending the broader goals of the community

EPA has identified the following four key areas of action to assure sustainability of water infrastructure: asset management, water and energy efficiency, infrastructure financing and the price of water services, as well as alternative technologies and assessment. To promote and maintain sustainable water systems, EPA has two management frameworks: Effective Utility Management Initiative and the Safe Drinking Water Act's Capacity Development Program. In addition, to advance community sustainability, EPA is collaborating with the states of New York, Maryland, and California to identify ways in which projects that promote smart growth and other sustainable practices can be incentivized [165].

9.2. Critical Infrastructure Partnership Advisory Council

The U.S. Department of Homeland Security (DHS) is responsible to protect the Nation's diverse and complex critical infrastructure. In 2006, DHS issued the National Infrastructure Protection Plan (NIPP), which was updated in 2009, as a unifying framework to integrate efforts that improve the protection of the Nation's critical infrastructure. In February 2013, Presidential Policy Directive 21: Critical Infrastructure Security and Resilience (PPD-21) was declared as: "proactive and coordinated efforts are necessary to strengthen and maintain secure, functioning, and resilient critical infrastructure—including assets, networks, and systems—that are vital to public confidence and the Nation's safety, prosperity, and well-being." NIPP is currently under revision as part of implementation of PPD-21.

The Critical Infrastructure Partnership Advisory Council (CIPAC), established by the DHS Secretary, and national critical infrastructure partnership structures aim to enable the collaboration and trusted information sharing required to enhance the protection of the Nation's critical infrastructure. CIPAC is an advisory council which promotes coordinating, communicating, and sharing effective practices across critical infrastructure sectors, jurisdictions, or specifically defined geographical areas. It values the private-sector participation in the critical infrastructure mission as an essential planning strategy. As an effective entity that has increasingly enabled cross-government and public-private partnerships, CIPAC's general achievements include [166]:

- Member institutions increased from 962 in 2012 to 1,130 in 2013.
- In 2012, 60 working groups held a total of 199 meetings and in the first half of 2013, 42 working groups held a total of 100 meetings under CIPAC. These meetings aimed for information sharing, training and exercises, research and development, program evaluation, strategic planning, risk management, and sector-specific metrics development.
- For the third year in a row, through the Regional Partnership Engagement effort, CIPAC convened more than 300 participants, representing 257 critical infrastructure owners and operators from almost all sectors. The participants discussed steps that DHS can take to better satisfy owner/operator security and resilience goals and to strengthen the value of the public-private partnership.

9.3. Agricultural Water Conservation

To secure water supplies in stressed river basins, especially in the West, water conservation agreements have been gaining attention over the last decade. In 2008, the Western Governors' Association in their publication, Water Needs and Strategies for a Sustainable Future: Next Steps, identified that "…states, working with interested stakeholders, should identify innovative ways to allow water transfers from agriculture to urban use while avoiding or mitigating damages to agricultural economies and environmental values." In Southern California, municipalities partner with irrigation districts and pay for agricultural water conservations to use the conserved water. The conservation methods typically practiced are enhancements in irrigation delivery system, on-farm irrigation efficiency improvements, land fallowing programs, and environmental conservation [167].

Among different water conservation methods, fallowing agreements have largely been practiced in Southern California [160]. Although there are concerns that these types of agreements may ultimately result in redirecting agricultural water to the other users, in several cases, the parties have successfully become to an agreement to leave agricultural lands for fallowing and transfer the corresponding water to the municipal sector. Examples include the consensus between the Imperial Irrigation District and San Diego County Water Authority in 2003, where they agreed to transfer 200,000 acre-feet of water per year from the irrigation district for a 45-year period subject to be renewed for another 35-year period. The district must fallow agricultural lands for the first 15 years and then implement efficiency-based conservation practices [168]. Another example is the agreement between the Palo Verde Irrigation District and the Metropolitan Water District in 2004. They agreed to transfer 25,000 to 118,000 AF/year from agricultural water to urban Southern California for 35 years. This water is saved by fallowing 7% to 28% of each agricultural land [169, 170]. Yuma Mesa Irrigation and Drainage District and the Central Arizona Groundwater Replenishment District (CAGRD) have also signed a 3-year pilot agreement, effective as of January 2014, to save about 9,000 acre-feet per year water, through fallowing 1,500 acres of agricultural lands. This water will initially be used to conserve water in the Colorado River system to be maintained in Lake Mead. It is also seen as a supply acquisition strategy for groundwater replenishment by CAGRD [160]. However, while planning for agricultural water conservations, it is important to assure that these practices will not reduce crop yield, as food deficit is going to be a problem for the growing population.

9.4. CALFED Program

California has been dealing with serious conflicts over its water resources management for decades. Debates over whether or not to transfer water from the Delta region to users elsewhere, and how to transport the water, have been the root causes of the conflicts in this state [171]. The conflicts became more complex after more limitations were imposed to the supplying system due to new environmental regulations enacted to protect the region's ecosystem.

To find a solution, a variety of innovative ideas have been developed. However, they lacked an overall framework. California Bay-Delta Program (CALFED) was initiated in 1995 as the most comprehensive effort to resolve water resources conflicts in the region and to address three main areas: ecosystem health, water quality, and water supply reliability. The "problem area" was defined as the Delta, and the "solution area" as all areas hydraulically connected to the Delta or relying on its water supplies, mainly Sacramento and San Joaquin Rivers [172]. CALFED intended to respond to the conflicts through a series of agreements and revisions that have involved federal and state legislation, and stakeholder accords [173]. Early in the program, the CALFED agencies decided the program needed to engage the public, particularly from identified interest groups or NGOs. One of the best and earliest achievements of CALFED was public awareness and their participation in water conservation activities [171]. CALFED has not been able to eliminate the zero-sum aspect of the game through collaborations, negotiations, and collective decision-making by stakeholders [171]. A review by the Little Hoover Commission found CALFED to be "costly, underperforming, unfocused, and unaccountable" [174]. Elimination of the strong support from the political leadership in Washington and Sacramento, after President Bush was elected, caused the situation at CALFED to begin a slow decline [175]. New leadership who was less supportive of CALFED, creation of the California Bay-Delta Authority (CBDA) without enough authority, and depletion in external funding secured earlier from Congress and the state taxpayers were other reasons for the decline of CALFED [176].

9.5. Energy Conservation

Energy conservation can be effectively practiced in water supply and treatment. Due to their high energy demand, enhancing and updating the technology of pumps is one of the most straightforward energy conservation options [41, 56]. In early '90s, it was estimated that 880 million kWh (30% of total use) can be saved in treatment plants by load shifting, variable frequency drives, high-efficiency motors and pumps, equipment modifications, and process optimization [56]. The energy crises in 2000 and 2001 forced a number of California water agencies to join an energy and conservation campaign. In one year, they reduced their energy use by up to 15% by employing some techniques such as: adjusting operation schedules, increasing water storage, utilizing generators, optimizing cogeneration and installing efficient water system equipment, variable frequency drives, and advanced equipment controls [56].

A range of approaches for energy savings are also emerging in the water sector. These include [177]:

- A holistic water and energy management approach to: develop local water sources instead of transferring water great distances; use advanced transport and treatment management systems; employ energy efficient water system products (e.g. premium efficiency pumps and motor systems, new types of low pressure membrane filtration, more energy efficient ultra-violet disinfection technology, advanced aeration equipment, and energy recovery systems for desalination)
- Research and development on innovative and energy efficient water treatment technologies such as: membranes to desalt at much lower pressures, with higher yields; ultraviolet disinfection with less energy demand; real-time monitoring systems for raw water quality to control and optimize instantaneous treatment process; and decentralized treatment systems to improve the water and energy use efficiency
- Behavioral changes through the incorporation of sustainability considerations and new design, management and operational philosophies
- Identify and address energy implications of water policy decisions through better coordination among resource management agencies
- Using lessons learned from other industries, such as the oil industry, in terms of exploring alternative ways of operating

9.6. Recycled Water

Water recycling has numerous benefits. It can create dependable, locally-controlled water supply, decrease the diversion of water from sensitive ecosystems, decrease wastewater discharges, reduce pollutions, enhance wetlands and riparian habitats, and save energy [178]. As the leader of other countries in terms of volume of recycled water, U.S. reuses 7% to 8% of its treated municipal effluent [40]. Some countries, however, have set vigorous targets to reuse their treated effluents. For example, Australia has planned to increase its water reuse to 30% by 2015. Israel currently reuses 70 percent of its municipal wastewater effluent [40]. Water reuse is rapidly growing in California [59], especially for large users in industry (refineries, agriculture), commercial irrigation facilities (golf courses), groundwater recharge, and landscaping [38]. With current recycling rate of about 500,000 AFY, the 2020 and 2030 targets of using recycled water are 1.5 and 2.5 million AFY, respectively [179]. To meet these goals, numerous projects are being funded at the federal (Bureau of Reclamation), state ($1.25 billion through the Safe, Clean and Reliable Drinking Water Act of 2010) and local (Metropolitan Water District and others) levels. The State Water Resources Control Board issued a mandate to increase wastewater reuse levels from 2009 by 200,000 AFY in 2020 and by an additional 300,000 AFY in 2030.

9.7. Recycling Materials

In 2009, 34% of waste generated in the U.S. was recovered. It included recycling 25% of all electronics at the end of their useful lives, 25% of all produced glass, 7.1% of all plastics, 28% of all plastic bottles, and 66.2% of all steel containers produced. With the highest recycling rate, more than 50% of the steel produced in this country over the past 50 years has been recycled [180]. In addition, in 2010, 58.1% of all aluminum beverage cans and 63.5% of U.S. papers (89% increase since 1990) were recycled [180].

Recycling aluminum also creates 97% less water pollution than making new metal from ore [181]. The energy that is saved by not producing one aluminum can be used to recycle twenty cans. In 2010, an energy equivalent of 17 million barrels of crude oil was saved in the U.S. just from recycling cans [180]. Forty percent less energy is consumed by producing recycled paper rather than producing new paper, and 84% energy can be saved by manufacturing recycled PET instead of making it from raw material. Recycling steel may also consume 60% to 74% less energy than producing it from virgin materials [180].

9.8. Green Infrastructure

Natural ecosystems have the capability of cleaning water without using any energy. These systems can be seen as an energy-efficient treatment option. For this purpose, protected areas need to be maintained and used to help avoid significant costs and associated energy demands of traditional treatment works [182, 183]. New York City (Catskills region), San Francisco (Hetch Hetchy) and Portland, Oregon (Bull Run) currently take advantage of these systems and rely on watershed protection and management for their potable supply treatment [38, 184].

9.9. Constructed Wetland Treatment

As natural water filtration systems, wetlands play an important role in removing water pollutants such as nutrients and sediments. The pollutant removal capability of wetlands would save a considerable amount of energy that would otherwise be used to treat water. Wetlands can also help flood control and groundwater recharge. The "no net loss" wetland policy in the U.S. requires rebuilding of wetlands destroyed for development in the same size and watershed. However, artificial wetlands require more energy.

9.10. Increasing the Quality of Drinking Water

Out of 16,000 Publically Owned Treatment Works providing drinking water for Americans, about 5,000 plants perform advanced treatment to remove some nonconventional pollutants, such as nutrients [59]. These efforts are beyond federal requirements. In addition, in 2000, there were only 47 facilities providing less than secondary treatment, declined from 4,800 in 1972 (ICF International, 2008).

9.11. Enhancement in Data Collection from Power Plants

The average annual rate of the energy sector's water withdrawals used to be reported by the power plants to the Department of Energy via Form 767, which was the principal source of information for federal agencies [185]. These withdrawal rates were typically under- or overestimated by the utilities [151]. In addition, this form did not require certain power plants to declare their withdrawal rates and did not account for new technologies such as hybrid cooling or solar thermoelectric [151]. In 2008, the Energy Information Administration replaced this form and five other forms with Forms 860 (environmental aspects) and 923 (electricity generation and fuel use) to resolve most of these issues. Nuclear, geothermal, solar, and hybrid cooling power plants were mandated to fill out these forms and all plant operators must report their water use on a monthly basis.

9.12. Thermoelectricity Generation

As mentioned in section 2.6.5, open-loop cooling facilities use substantially more water than close-loop or dry cooling facilities. In 1972, the Federal Water Pollution Control Act and Section 316(a) of the Clean Water Act, which regulate intake structures and thermal pollution discharges, established restrictions on open-loop cooling systems. It resulted in a declining trend in the construction of open-loop cooling power plants and only 10 of these plants have been built since 1980 [66]. Closed-loop cooling plants, with less water requirements, lower discharges, and less vulnerability to water shortages, have been the main substitute of

Table 4. Key areas in the CEO Water Mandate and actions in each area that companies should pledge to undertake [189]

Area	Actions
Direct Operations	Comprehensive water-use assessment to specify the company's water use in the direct production of goods and services.
	Set targets for water conservation and waste-water treatment.
	Investment in and utilization of new technologies to achieve these goals.
	Raise awareness of water sustainability within the corporate.
	Make business decisions based on water sustainability considerations.
Supply Chain & Watershed Management	Promote improvements in water conservation, quality monitoring, waste-water treatment, and recycling practices for suppliers.
	Build capacities to analyze and respond to watershed risk.
	Promote and facilitate assessments of water usage and impacts for suppliers.
	Share established and emerging water sustainability practices with suppliers.
	Encourage major suppliers to report regularly on progress achieved related to goals.
Collective Action	Enhance connections with civil society organizations, especially at the regional and local levels.
	Address water sustainability issues and policies through collaboration with national, regional and local governments, public authorities, and relevant international institutions.
	Promote development and use of new technologies
	Involvement in the UN Global Compact's Country Networks.
	Support the existing water initiatives involving the private sector
	Collaborate with other relevant UN bodies and intergovernmental organizations.
Public Policy	Provide water sustainable inputs and recommendations in government regulations and market mechanisms.
	As a "business statesmanship," advocate water sustainability in global and local policy discussions
	Collaborate with governments, businesses, civil society and other stakeholders to improve the body of knowledge, intelligence, and tools.
	Join and/or support special policy-oriented bodies and associated frameworks.
Community Engagement	Try to understand the water and sanitation challenges in the adjacent communities and how our businesses affect those challenges.
	Be active members of the local community, and promote or support local government, groups, and initiatives that improve the water and sanitation agendas.
	Partner with local stakeholders and undertake water-resource education and awareness campaigns.
	Collaborate with public authorities to support the development of sufficient water infrastructure.
Transparency	Describe actions and investments undertaken regarding to the CEO Water Mandate in the annual Communications on Progress for the UN Global Compact.
	Publish and share water strategies, targets, results, and areas for improvement in the corresponding corporate reports.
	Be transparent in communications and correspondences with governments and other public authorities on water issues.

open-loop system since then. Hybrid cooling technology, which uses both wet and dry cooling components that can be used either separately or simultaneously are is in its early phases of development. These systems may reduce water requirements of wet systems by up to 80%, while they do not have the disadvantages of dry cooling systems. Therefore hybrid cooling technology can be seen as a promising way to secure energy generation in the future while imposing less stress on water resources.

9.13. Facing the Challenges: Water-Energy Nexus in Austin, Texas

Austin, located near the center of energy-rich and water-stressed Texas, is one of the fastest growing cities in the U.S., with 80% population growth from 1990 to 2011 [186]. This rapid growth has made it challenging for the public electricity and water suppliers to provide reliable and affordable services while promoting environmental sustainability. However, Austin suppliers have successfully integrated and strategized programs and policies to sustainably meet the public demands. Austin Energy, as the 8th largest public electricity utility in the U.S., serves more than 400,000 customers and Austin Water, as its 5th largest consumer, which uses 210,000 MWh electricity to pump and treat 200 million m3 water and 100 million m3 wastewater [187].

Energy and water conservation initiatives are important aspects of the city. Austin Energy initiated the Green Building Program in 1990. A citizen driven effort terminated a substantial development over a local aquifer the same year. This effort was followed by the adoption of the city's Save Our Springs ordinance in 1992 to ensure sustainable use of water resources [53]. Austin Water and Austin Energy continuously measure the amount of energy used in providing water services, water use in thermoelectric generation, and the average water use in water and energy services to use these data in optimizing water and energy use and keeping costs down.

Austin Energy has conserved 700 MW in demand-side and targeted an additional conservation of 800 MW peak-day demand by 2020. Meanwhile, Austin Water is making comprehensive water conservation efforts, such as a tiered rate structure and weekly watering schedules for landscaped areas, which has reduced peak seasonal demand. In addition, the two utilities collaborate in generating renewable energy and reducing greenhouse gas emissions [53]. Additional demand-side energy savings are practiced in the city by distribution of high-efficiency kitchen and bathroom aerators and showerheads, as well as rebates to buying high-efficiency dishwashers, washing machines, auxiliary water and irrigation system upgrades [188]. In addition, Austin Water employed Green Choice, Austin Energy's 100% wind energy program, in 2011 resulting in an 85% reduction in the water utility's greenhouse gas emissions. The utility has also reduced its surface water withdrawals through its reclaimed water program and supplies low cost water to energy generation facilities operated by Austin Energy and the University of Texas [53].

10. Opportunities for Improving the Water, Energy, Food Security through a Nexus Approach

10.1. Role of Businesses in the Nexus

The private sector plays an important role in addressing the resource challenges faced by the world today. For example, companies can directly impact resource management within their own business and indirectly help it by encouraging their product users. Through a collaborative partnership between the United Nations Global Compact and the Government of Sweden, the CEO Water Mandate was created and launched at the Leaders Summit in July 2007. As a private-public initiative, it concentrates on creating strategies and solutions to contribute positively to the emerging global water crisis [189]. It is open to all UN Global Compact participating companies, and the ones that join the CEO Water Mandate commit to implement the framework's six key areas for water management (Table 4) and publicly report progress on an annual basis.

Table 5. U.S. historical total water productivity [192]

Year	U.S. total water productivity*
1982	11.52
1987	-
1992	18.41
1997	21.67
2002	25.09
2007	28.61
2011	28.94

* Values are in constant 2005 US$ GDP per cubic meter of total freshwater withdrawal

There are currently 530 UN Global Compact participants from the U.S. (http://www.unglobalcompact.org), out of which 19 companies have endorsed the CEO Water Mandate, including CH2M HILL, Inc., the Coca-Cola Company, Coca-Cola Enterprises Inc., PepsiCo, Inc., Molson Coors Brewing Company, Nike, Inc., etc. [190]. As a successful example of companies endorsing the CEO Water Mandate, SABMiller Plc, an international brewer with operations in over 70 countries across six continents, has reduced its absolute water use by 16% since 2008, despite an increase in production volumes, and is on track to meet its efficiency target of using 3.5 liters of water per liter of beer by 2015 [6].

10.2. Water and Energy Productivity

One measure of water productivity is defined as Gross Domestic Product (GDP) in constant prices divided by annual total water withdrawal. Over the past decades, intensification and new technologies have escalated water productivity (Table 5). Energy productivity, however, has not improved as much. For example, over the last 60 years, the U.S. energy intensity of corn production has only improved from 2.7 to 2.2 GJ per ton of product [191]. To decrease the energy intensity of regional water supplies, some recommendations exist, such as conveying less water and substituting more local sources through recycling and getting maximum use from local water supplies [52]. More research is required to find ways of increasing energy productivity for all uses and energy sources.

10.3. Recycled Water

Recycled water, as a drought-resistant and stable source of local water, is one of the cheapest ways of water supply. It also decreases energy consumption per unit of water and reduce discharge of nutrient loads to water bodies through reduction of effluent discharge. Wastewater treatment effluent discharge in the U.S. is about 32 billion gallons per day [40, 155], out of which, 38% is discharged to an ocean or estuary. Reusing the treated wastewater may increase available water resources by about 6% of total U.S. water use or 27% of public supply [155]. Currently, recycled water is mostly supplied in only four states: Florida, California, Texas and Arizona, which account for 90% of national water reuse [40].

10.4. Using Produced Water for Irrigation and Stream Augmentation

Produced water is a byproduct of the process of developing, extracting, or disposing energy-related products. It is produced in large volumes during the extraction of hydrocarbon energy resources. Current estimation of produced water volumes across the U.S. is about 14 billion bbl/yr (1 bbl=42 gallons) [193]. Produced waters can be extremely saline, with greater salinity than seawater, or they can be at potable. Using produced water to secure water and energy resources has recently gained attention. Some researchers in the U.S. Geological Survey (USGS) Energy Resources Program (ERP) are studying characterization, use, and impact of produced waters in three focused area [193]:

- *Assessing Impacts of Coalbed Methane Produced Waters:* To produce coalbed methane, an increasingly important source of energy in the U.S., coal beds are de-watered and the produced water is either discharged into surface waters or re-injected back into ground. The USGS is studying the environmental impacts of use and disposal of these produced waters.
- *Characterization and Sources of Appalachian Basin Produced Waters:* Due to the lack of adequate data about produced waters from oil and gas development in the eastern U.S., USGS is researching the source and chemistry of current and future produced waters from the Appalachian Basin.
- *Water Balances for Energy Resource Production:* Scientists at USGS are developing water budget methods to explore inputs and outputs from regional oil and gas resources.

Treating and using produced water for other purposes, not only may reduce energy companies' costs associated with re-injecting it into the ground (as the benefit from selling that water covers treatment costs), it also diminishes environmental concerns, augment streamflow, and secure agricultural water supply. Therefore, it is a three way nexus strategy. In February 2007, legislation, S. 1116, the More Water, More Energy, and Less Waste Act of 2007 was introduced to House "to facilitate the use of water produced in connection with development of energy resources for irrigation and other beneficial uses in ways that will not adversely affect water quality or the environment [194]." The bill directs the Secretary of the Interior, acting through the Commissioner of Reclamation, the Director of the U.S. Geological Survey, and the Director of the Bureau of Land Management (BLM), to conduct research to identify [195]:

1. The obstacles to decrease the volume of produced water and to advance the extent to which produced water can be used for irrigation or other purposes without adversely affecting quality of water or the environment
2. The actions that help reduce or eliminate such obstacles along with the associated costs and benefits. The Secretary is directed to provide financial assistance for the development of facilities, technologies, and processes to indicate the feasibility, effectiveness, and safety of:
    a. Optimizing energy resource production, while reducing the volume of produced water; or
    b. Advancing the extent to which produced water may be treated to a level that is suitable for specified purposes.

The aforementioned assistance should be provided for at least one project in:

1. Each of the Upper Basin States (Colorado, New Mexico, Utah, and Wyoming)

2. Each of the Lower Basin States (Arizona, California, and Nevada).

10.5. Energy Production

There is a pressing need to develop lower water intensive technologies for energy production. In thermoelectric generation, technologies such as dry and hybrid cooling are promising ways to reduce water intensity. Attention also needs to be paid to new and more sustainable water resources for plant operations, such as recycled water and non-potable brackish water. For this purpose, the technology already exists. We just need to fill data gaps and remove regional policy and financial barriers to implement these technologies. The U.S. can also increase collaboration with nations that are researching reduction in costs and operational challenges of water desalination, such as Australia, Singapore, Persian Gulf States, and Israel [196].

There is a significant potential to increase water use efficiency and conservation in the energy sector, and research should be focused on enhanced efficiency potential and reduce costs. Four major strategies that are currently researched or being employed at thermoelectric energy generation plants [177]:

- Implementing dry/hybrid cooling
- Using degraded/reclaimed water for cooling
- Recycling water within plant by:
    - o Increasing closed cooling cycles
    - o Treating and reusing blowdown water
    - o Capturing vapor in wet cooling tower and stacks
- Increasing thermal conversion efficiency

Solar energy is one of the least water intensive ways of producing electricity. The Pacific Gas and Electric Company (PG&E), which is the largest utility in the U.S. and provides electricity and natural gas to almost 40% of Californians, would like to offer all its bundled electric customers an opportunity to support new small and mid-sized solar projects, 100% renewable energy, located in PG&E's service area. The company has proposed this project (called Green Option) to the California Public Utilities Commission and if it is approved by mid-2014, PG&E expects to offer the program to customers in the first half of 2015 [197].

In addition to high water demand, corn-based ethanol has high energy intensity (43 to 53%). Comparatively, cellulosic ethanol has much less energy intensity (10% to 22%) [198, 199]. Therefore, cellulosic ethanol is a sustainable substitute to secure biofuel energy production, but this method is at an early development stage. The Renewable Fuel Standard has mandated that the annual production of cellulosic ethanol should be at least 16 billion barrels by 2022. Besides reduction in energy intensity, this mandate will decrease the water demand for production as it uses crop and forestry waste and crops that do not require much irrigation, such as switchgrass [66]. Switchgrass is one of the most promising perennial crops since it is rather drought-tolerant and does not need irrigation in its native habitat [66, 82].

10.6. Energy Savings Potentials

In water conveyance systems, pumps are the main consumer of energy, accounting for 95 percent of the energy used to distribute drinking water [41, 56]. Updating older water conveyance and groundwater pumps can substantially improve pump performance (by 5-50%) [41, 52], accruing energy savings. Regular required repairs and maintenance can also improve energy efficiency. Other energy efficiency improvements options include: installing parallel pipe systems, reducing pipe friction losses by increasing pipe diameter, lining pipes, and changing pump impellers [56].

Renewing old piping can also be an energy saving strategy in the U.S. as the average pipe is more than 40 years old [38]. However, about one-third of water utilities in the U.S. are not appropriately maintaining their distribution assets, most likely due to the lack of funding [38]. Old pipes were from iron, which corrodes and degrades over time, leading to leaks and ruptures resulting in significant losses—i.e., there is on average 8 to 20% unaccounted water in the U.S. distribution systems [154]. The energy embedded in water (energy for water conveyance and treatment) is also lost with water leakage [200]. The most efficient water and energy savings programs are those focused on leak management (detection and repair) [201]. Installation of dual distribution systems to separate water supply for potable and non-potable uses is another energy saving option as less energy would be required for water treatment.

In-conduit hydropower is a way to generate energy from water distribution systems. Micro-hydro technologies can also be installed in large pipes to convert the pressure and flow into electricity [202, 203]. This technology is already being used in major water transfer projects, such as the Hetch Hetchy and the Central Valley Project in California. There is also potential to provide substantial additional generation [56]. However, regulations often prevent development of in-conduit hydropower. Most states self-generation is not allowed and the produced power cannot be directly connected to an existing load and has to be sold into the wholesale bulk power market [38]. However, these regulations are likely to change as some Congress members support small (1.5 MW or less) and nonfederal hydropower at federal sites [204]. One of the results has been the Bureau of Reclamation Small Conduit Hydropower Development and Rural Jobs Act passed by the House of Representatives in 2012 (H.R. 2842), which amend the Reclamation Power Act of 1939. It authorizes the Secretary of the Interior to permit the development of small conduit hydropower at Reclamation facilities and exempt small conduit hydropower development from NEPA [204].

10.7. Energy Generation from Wastewater Treatment Plants

Biogas and biosolids can be seen as potential energy sources to supply a portion of energy demand. As solid waste produced from wastewater treatment plants, biosolids can be used as fuel in incinerators. Sewerage can also be converted to bioplastics or rocket fuel [205]. However, high capital investments are required for these facilities [206]. California, uses approximately 50% of its sewage sludge, 2% of dairy manure and less than 1% of food processing wastes and wastewater to produce biogas [56]. The rate of energy production from biogas and biosolids may meet energy demands of an entire plant. For example, the WWTPs in San Diego and Carson in California are energy self-sufficient utilities occasionally produce even more power than their demand [38]. Energy production from biosolids generated in WWTPs has the potential to save 600 million to 5,000 million kWh per year in the U.S. [206].

10.8. Energy Sector's Water Policy Options

As policy makers confront the growing water demands of the energy sector, the challenge is which policy levers to use. While water decisions of the energy sector in the U.S. are mostly made by private entities, states and federal entities set the regulatory framework for these decisions. The public sector may indirectly influence private water decisions through routes such as tax incentives, loan guarantees, permits, regulations, planning, and education [34]. In a report prepared by the Congressional Research Service for members and committees of congress in 2013, a range of policy options were presented to minimize water use,

Table 6. Policy options for water demands of the energy sector in the U.S. [34]

Water Demand Management Options	Water Supply Management Options	Options for Knowledge Development and Use
Minimize Energy Sector's Growth in Water Use	**Improve Energy Sector's Access to Water**	**Support Informed Decision-Making**
Promote water-efficient energy sources through standards, regulations, or incentives (e.g., rebates, water pricing)	Allocate sustainably available water, not otherwise allocated	Data and assessments; information sharing (e.g., data and research warehousing)
Promote water conservation and efficiency in the energy sector through standards, incentives, regulations, or pricing	Facilitate transfer of water from nonenergy sectors (e.g., purchase of water from municipalities, or land owners; water markets)	Education, training, and dissemination of knowledge and information
Promote energy conservation and efficiency to reduce demand for energy and the embedded water		Integrated energy-water planning; coordination of research, decisions, and investments
Support research, development, scaling up, or adoption of technologies to reduce energy sector water use (e.g., public-private research collaborations)		Decision-support research and technical assistance; development of standard protocols and codes

facilitate access to water, or improve decisions and data (Table 6).

10.9. Public Awareness and Education

The media can play a major role in the public perception of water conservation. For example, in the states with the highest water reuse rates, survey results show that two-thirds of people knew what recycled water is [40]. Ambiguity about the potential harms and consequences of using recycle water could restrain public acceptance, and the more familiar a community is with a water reuse project, the more favorable attitude it may have [38]. Media's education and public awareness programs made it possible to implement water reuse projects.

Other important fields that need intensive public awareness are the concepts of virtual water, virtual energy, as well as water and energy footprints. To conserve water and energy, people usually think it is adequate to fix a leaking faucet or use energy efficient appliances. While these are effective practices, thousands of gallons of water per family and a considerable amount of energy can annually be saved by reducing waste. U.S. citizens on average waste 40% of their food, which means more than 30% of the total water consumption in the U.S. goes to trash [7]. Besides increasing postharvest crop protection and infrastructure, reducing food waste and supporting sustainable farms can substantially reduce water consumption. It is also important to educate people that they can save energy by saving water, as it results in less wastewater to be treated. Other ways to promote energy saving is to encourage people to use water filters instead of bottled water as the production of water bottles is an energy intensive process accounting for the equivalent of more than 17 million barrels of oil in the U.S. in 2006 [7].

10.10. Public Health

In December 2009, the Johnson Foundation convened a group of scientists, policy makers, and practitioners of diverse perspectives at a Freshwater Forum Working Session to discuss about "Examining U.S. Freshwater Systems and Services: Public Health Threats and Solutions." The group believed that high-level opportunities or strategies to address freshwater and public health issues exist in the U.S. These opportunities include [163]:

- Connect freshwater and public health issues to other prominent public policy issues (such as health care, economy, etc.) to obtain public and decision-maker attention
- Take advantage of social networking technology to educate public and build political will
- Increase public awareness and build political will through highlighting examples of real human health impacts of freshwater problems
- Raise public knowledge about new approaches and technologies by establishing demonstration projects
- Tie wellness to public health and relate them to freshwater
- Encourage public dialogue about the actual value of water
- Develop ways to separate contents of wastewater from sewer system (such as nutrients) for beneficial uses (e.g., local agriculture)
- Enhance monitoring technologies and extend monitoring network
- Practice water re-use and recycling

In addition, water conservation and use efficiency should be promoted to mitigate the social health impacts of water scarcity. Researchers should seek models to set new research paradigms, which assess public health, as well as environmental and social justice impacts of new technologies. For this purpose, an example model is environmental impact statement studies. Incentives should be provided to support implementation of technologies proven to be effective in terms of cost, water savings and public health outcomes. Equitable access to water for low-income or remote communities should become a priority in all parts of the nation. Utilities should investigate models to find innovative structure rates that allow vulnerable individuals and low-income communities to afford a sufficient water supply. An example of these models can be the Low Income Home Energy Assistance Program (LIHEAP) [163].

10.11. Water Banking

Water banking has been used as a valuable tool to enhance water supply reliability in the western U.S.. It can be defined as "an institutional mechanism designed to facilitate transfers of water on a temporary, intermittent, or permanent basis through voluntary exchange" [207]. Long-term strategic policy and established standards for daily operations, which reflect the underlying goals and vision, are required for water banks [208]. A mechanism of conflict resolution should also be developed to quickly, equitably, and efficiently deal with potential disputes and minimize the potential associated costs. Water banks typically seek one or more of the following objectives [209]:

a) A more reliable water supply during dry years

b) Assured water supply for various water demands in the future

c) Promote water conservation

d) Facilitate and promote water market activities

e) Reduce conflicts between groundwater and surface-water users

f) Facilitate compliance with intrastate agreements regarding instream flows and with interstate compacts

Water banks are generally operated through four key ways [207]: surface storage in a reservoir, underground storage in an aquifer, facilitating transactions among entitlement holders, and institutional banking (i.e., water trusts). Surface storage banking has great level of security, but it may require high capital investments and is associated with losses of the bank water. As a method of surface storage banking, top water banking is practiced where an annual allocation of surface water is not diverted but left in reservoir storage for future use. Groundwater banking can be done through either in-lieu (or indirect) recharge or direct recharge. In-lieu recharge allows groundwater to stay in the aquifer and surface water might be substituted for groundwater that would otherwise have been pumped. This method may considerably decrease energy demand for pumping. One issue with groundwater banking is associated with the lack of sufficient legislative or judicial intervention and well-defined groundwater rights [210], which may result in unexpected use of the banked water by other users. Facilitating arrangements may involve water transaction or brokerage activities that secure water for future use. In this method, buyers and sellers, as well as lessors and lessees, might be brought together by a bank to facilitate trades. Institutional banking usually aims to augment instream flow and is designated as the transfer of legal documents that delineate access to a specific water quantity during a specific time period [209]. Examples of existing water banks in the U.S. include:

- Arizona Water Bank
- California's Drought Water Bank
- California's Dry-Year Purchasing Program
- Colorado's Arkansas River Basin Bank
- Colorado West Slope Bank
- Truckee Meadows Groundwater Bank
- New Mexico's Pecos River Basin Water Bank
- Waterbank.com and other private sector banks
- Pecos River Acquisition Program
- Oregon-California Klamath River Basin Pilot Water Bank
- Oregon's Deschutes River Conservancy
- Idaho Rental Pools Water Bank(s)
- Texas Water Bank

10.12. Agricultural Water Conservation, Challenges and Opportunities

Through the Agricultural Water Enhancement Program (AWEP), USDA has established federal, State, and local partnership agreements to participate in watershed-scale agricultural water conservation and water-management activities. This program provides financial and technical assistance to agricultural producers to implement agricultural water enhancement activities in order to conserve surface and groundwater and enhance water quality. Food, Conservation, and Energy Act's establishment of AWEP in 2008 expanded USDA's water conservation program to include on-farm as well as watershed/ regional/institutional conservation. Therefore, AWEP can improve water conservation objectives

Table 7. Challenges and opportunities for freshwater use and management in the U.S. agricultural sector [109]

CHALLENGE	OPPORTUNITY
Current water allocations (and over-allocations) are based on outdated supply scenarios.	Establish more rational allocations based on updated water availability scenarios that reflect current conditions.
Better decision-making about and management of instream and return flows is needed	Involve stakeholders and/or independent peer review processes as part of planning to enhance ecosystem services
Broaden the definition of "beneficial use" in water law to include nonhuman uses.	Create flexibility to adapt water use to emerging needs such as ecosystem services and recreation.
Major gaps exist in data on water use (on farm practices, groundwater withdrawal rates, usage for different crops), and water availability (groundwater levels and recharge rates, snowpack levels, snowmelt rates), while the best monitoring technology is not being used widely.	Maintain and/or increase funding for monitoring programs, and build public private partnerships to support expanded and improved monitoring and data collection.

CHALLENGE	OPPORTUNITY
Selection of appropriate water efficiency, conservation or supply enhancement strategies depends on good data.	Data-driven selection of efficiency and conservation measures from a suite of available strategies to optimize impact (desalination, water re-use, groundwater banking, rainwater capture, flood water capture).
Aging irrigation supply and distribution infrastructure hinders understanding of water availability for agriculture.	Assess and upgrade infrastructure and update availability assumptions in the process; where possible, link upgrades to environmental benefits to create access to more funds.
There is a lack of political will to generate better data.	Build coalitions and partnerships to encourage and support collection and sharing of better data, especially site/basin-specific on-farm data.
Cost of investment in efficient irrigation technologies is prohibitive for many farmers.	Ramp up financial and technical assistance for implementation of water efficiency technologies to enhance on-farm conservation efforts and increase overall water supply.
The public has a negative perception of water re-use.	Better educate the public about the process and benefits of water re-use.
Link water supply management with urban growth management.	Create mechanisms for integrated planning to balance and meet urban and agricultural water supply needs, while protecting and enhancing existing rural economic and environmental values.
Recognize and account for links between water quantity and water quality challenges.	Anticipate and avoid unintended impacts of management decisions.
Need to manage and/or capture surplus flood waters in certain regions such as the Midwest.	Develop innovative management plans to balance storage and drainage needs (Iowa plan).
Though pesticides are regulated under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), many agricultural activities are exempt from Clean Water Act regulations. Meanwhile implementation of existing Federal regulations by states has been ineffective and has not significantly reduced a wide array of non-point source pollutants and associated impacts (nutrients, sediment, pathogens, antibiotics and hormones, temperature, salinity).	Soften the point source and nonpoint source dichotomy, recognize legitimate agricultural point sources (confined animal feeding operations), and streamline and improve enforcement of existing Federal water quality regulations (nutrient management plans and numeric nutrient standards), while emphasizing those incentives as a means of meeting regulations. Explore innovative tools for achieving water quality goals including watershed permitting and water quality trading.
Cost of investment in new monitoring technologies and other on-farm technologies is hindering collection of adequate water quality data on point source and non-point source pollution in both surface waters and groundwater.	Ramp up financial and technical assistance for farmers to obtain new mitigation and monitoring technology and help collect baseline water quality data.
USDA conservation programs (e.g. EQIP) have not achieved widespread improvements in water quality because they are not adequately funded and funds are not targeted at the highest priority problem areas.	Adequately fund USDA programs (Farm Bill) and base award of conservation funds on potential environmental improvements and/or maximal number of agricultural participants in target watersheds with acute water quality problems rather than politics, and hold the agency accountable for environmental outcomes.
Approximately 50% of agricultural land in the U.S. is leased, making responsibility for environmental conservation unclear in many cases, which reduces the incentive for farmers to enact conservation measures and/or apply for conservation funds from USDA and other programs.	Landlords establish agreements with tenants regarding responsibility and permissions for environmental and water conservation measures.

CHALLENGE	OPPORTUNITY
There is a disconnect between the large number of actors involved in agricultural activities on individual plots of land and the downstream impacts they cause (ex. Gulf of Mexico dead zone).	Create incentives for farmers to coordinate on water quality management at the watershed scale by incorporating criteria into conservation programs (Federal and otherwise) that reward collaborative planning efforts.

at a landscape scale, while gaining financial support from other Federal, State, and local organizations. Some examples of policy approaches being used to promote agricultural water conservation include [32]:

- Environmental Quality Incentive Program (EQIP) financial assistance provisions
- Groundwater management
- Environmental flow regulations
- Incentive pricing for surface water
- Water markets
- USDA's Conservation Reserve Enhancement Program (CREP) land retirement

The opportunities that exist to address concerns associated with challenges for freshwater use and management in the U.S. agricultural sector were summarized by a group of scientists, policy makers, and practitioners of diverse perspectives at an Environmental Forum Working Session on "Examining U.S. Freshwater Systems and Services – Agriculture and Food Production." These challenges and opportunities are listed in Table 7.

10.13. Federal Government and Water-Energy Nexus

Subsidies and appropriations that have been set in federal energy and water policies, such as Federal Power Act and Farm Bill, respectively, should be revised to incentivize water and energy conservation as well as application of new technologies that increase efficiency [177]. Water efficiency standards, such as the Energy Star program, can be established by the federal government to promote efficiency and conservation to the public. An existing example is WaterSense, an EPA sponsored partnership program, which convenes local water utilities and governments, product manufacturers, retailers, consumers, and other stakeholders to develop water efficiency performance criteria and help consumers recognize water-efficient products and programs [177]. It can be used as a model to develop national standards. Federal Housing Administration loan conditions can also be established to require certain water and energy retrofits for home resale. The federal government should also promote the use of low-carbon energy sources, and the forthcoming carbon management regulations that Congress passes should incorporate water considerations. An example that can be used as a model for these regulations is California Assembly Bill 32 [177]. In integrating federal water and energy policy, the following should highly be considered [177]:

- Low carbon energy choices with severe water impacts should be avoided;
- Water choices with severe energy or GHG impacts should be avoided;
- The knowledge of water-energy tradeoffs should be enhanced;
- Public should participate in problem definition and decision-making; and
- Sustainability measures that assess water and energy efficiency should be developed and employed.

The interdependence of the energy and water industries prompted introduction of the Nexus of Energy and Water for Sustainability Act 2014 (The NEWA Act) by Sen. Lisa Murkowski (R-Alaska) and Sen. Ron Wyden (D-Ore.) in January 2014. The bill promotes the establishment of interagency coordination between the Department of Energy, the Department of the Interior, and other federal agencies to ensure sustainability of water and energy resources [196]. "It features a set of policy improvements. It directs the office of science and technology policy to establish a committee or subcommittee under the national science and technology council to coordinate and to streamline the Water and Energy Nexus activities of all federal departments and agencies. This new panel, which will be co-chaired by the Secretary of Energy and Secretary of Interior and populated by the secretaries of other federal agencies will identify all the Water and Energy Nexus activities across the federal government, they will work to enhance the coordination of effective research and development activities, they work together and disseminate data to enable better practices and explore relevant public-private collaboration," Murkowski said at the Webcast: The Nexus of Energy and Water for U.S. Sustainability and National Security at the Atlantic Council [211].

11. U.S. International Programs and Commitments

International policies and programs are focused on three key mechanisms to address and support goals in water, food, and energy security in developing counties: Investment, South-South partnerships, and improving policy environments for enabling investment. In addition to providing financial mechanisms for infrastructure investment, the U.S. largely seeks to build public-private partnerships and attract the private sector to bring their technical skills and capital to bear in addressing the challenges. As a means of developing and sharing technological achievements, South-South collaboration is promoted. Legal, regulatory, and political mechanisms as well as physical infrastructure that might attract investors need to be improved to encourage private-sector investment as a key strategy. While water is a cross-cutting theme between the sectors, initiatives largely address each sector individually, and there is no program that addresses all three sectors together. They usually focus on water and food security, energy and food security, or water-energy nexus.

11.1. Commitments

The U.S. has made water a foreign policy priority, and the government is building capacity for international water projects at the local, national, and regional levels to mobilize resources inside developing countries [212]. In 2001, more than 20 U.S. government agencies joined together and created the Inter-Agency Water Working Group (IWWG), led by U.S. Department of State (DOS), to share their knowledge and expertise in addressing international water challenges [213]. On behalf of 17 agencies, in March 2011, the Secretary of State signed a Memorandum of Understanding (MOU) on water cooperation with the World Bank. The main goal of this memorandum is to expand joint efforts to create a more water-secure future for the world [213]. Potential activities include: promotion of new technologies to advance access to safe drinking water and sanitation, rehabilitation of watersheds and wetlands, promoting water efficiency through improved irrigation practices, using remote sensing data to improve water resources management, mobilizing public-private partnerships and private capital to support water infrastructure and development projects, identifying areas for potential regional cooperation, and knowledge sharing [214].

The U.S. also provides financing support for investors and exporters. These are in the forms of project financing through direct loans and loan guarantees as well as political risk insurance for investors, and working capital loan guarantees, other export loan guarantees, project and structured finance direct loan, and export credit insurance for exporters [212].

In FY 2009, the U.S. invested about $774 million for water and sanitation related activities in developing countries. This budget was increased to more than $953 million in FY 2010 [213]. With an increase of $109.1 million from FY 2008, the U.S. Agency for International Development (USAID) committed $598.7 million for water and sanitation-related activities in more than 62 countries in FY 2009. As a result, approximately 5.8 million people received improved access to safe drinking water, and over 1.33 million received improved access to sanitation in at least 57 countries [215]. In addition, the Millennium Challenge Corporation (MCC) invested $121.3 million for these types of activities while the U.S. Army Corps of Engineers committed approximately $54 million for water and sanitation projects in Iraq [215].

The U.S. DOS has also specified Principles for Advancing Food Security [216] to comprehensively address the underlying causes of hunger and under-nutrition, invest in country-led plans, strengthen strategic coordination, and leverage the benefits of multilateral institutions. Through the DOS, the U.S. is also the largest bilateral country donor to international humanitarian organizations, contributing more than $1.74 billion in FY 2009 for protection and assistance, including water, sanitation, and hygiene-related services. In addition, U.S. is one of the largest donors to several multilateral development banks (such as the World Bank, the African Development Bank, and the Inter-American Development Bank), contributing about $9.22 billion in water sector and sanitation-related financing in FY 2009, which was over twice as much as in FY 2008 [215].

11.2. Programs and Partnerships

In order to achieve a water-secure world, the U.S. DOS works through partnerships to build political will and support national-level planning processes; leverage expertise, knowledge technology and resources; and promote water security [217]. The U.S. DOS programs and partnerships for water security include: National Planning for Results Initiative [218], African Minister's Council on Water [219], U.S. Water Partnership [220], Shared Waters Partnership [221], UN-Water Country Briefs Project [222], Agricultural Water Management Partnership for Africa (AgWA) [223], Ambassador's Water, Sanitation, and Hygiene in Schools Initiative (a-wash) [www.a-wash.org], Middle East Network of Water Centers, and Nexus Dialogue on Water Infrastructure.

In addition to the U.S. DOS, USAID is also actively involved in water resources management efforts that focus on sustaining watersheds and aquatic ecosystem services. It uses science to inform decision-makers and helps strengthen governance frameworks [224]. The Water and Development Strategy steers programs toward themes consistent with water for health and water for food programs. Integrating the focus on water across agriculture, health, and climate, are under the USAID's Water and Development Strategy [224]. USAID develops and implements energy-related programs to support the construction and rehabilitation of infrastructure to improve enabling environments, including policy legal, regulatory, and increase private sector participation and investment [224]. They provide an Energy Toolkit [225] as a diagnostic framework to identify a country's potential energy sector challenges, which illuminates the linkages between challenges and potential interventions that should be considered.

Feed the Future Initiative [226] is another U.S. government commitment to achieving food security. This initiative seeks to increase agricultural production and incomes in rural areas. Through this initiative, the U.S. is partnering with developing countries, such as Brazil, India, and South Africa to leverage their expertise, resources, and leadership. Feed the Future Initiative also invests in "creating enabling policy environments and physical infrastructure that facilitate private sector investment by individual agricultural producers, small and medium enterprises, and larger businesses."

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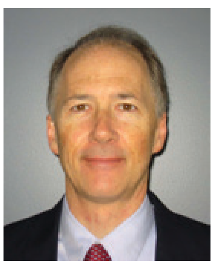

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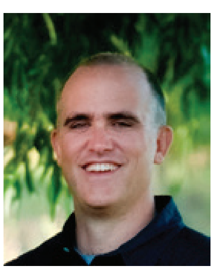

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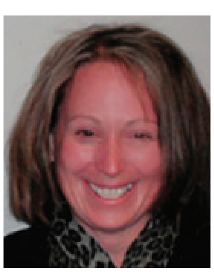

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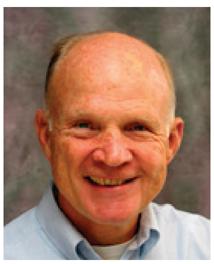

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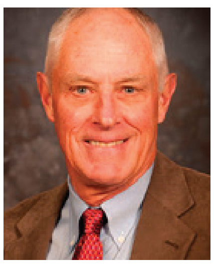

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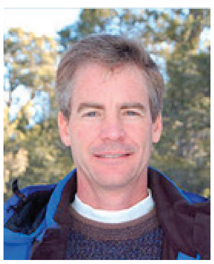

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