SANDIA REPORT
SAND2016-9984
Unlimited Release
Printed October 2016

A History of Sandia's Water Decision Modeling and Analysis Program

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Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185-1137

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Abstract

This document provides a brief narrative, and selected project descriptions, that represent Sandia's history involving data, modeling, and analysis related to water, energy-water nexus, and energy-water-agriculture nexus within the context of climate change. Sandia National Laboratories has been engaged since the early-1990s with program development involving data, modeling, and analysis projects that address the interdependent issues, risks, and technology-based mitigations associated with increasing demands and stresses being placed on energy, water, and agricultural/food resources, and the related impacts on their security and sustainability in the face of both domestic and global population growth, expanding economic development, and climate change.

Acknowledgments

The authors thank Laura Connolly, Mark Rigali and Stephanie Kuzio for their helpful comments and input to this document.

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Nomenclature

A2E	Ag2Energy
ASU	Arizona State University
ATS	Algae Turf Scrubber®
AwwaRF	American Water Works Association Research Foundation
ATP^3	Algae Testbed Public-Private Partnership
BETO	Bioenergy Technologies Office
BLM	Bureau of Land Management
CADRe	Computer Assisted Disputer Resolution
CCS	CO_2 capture, transportation, and storage
CEA	Controlled Environment Agriculture
CUFA	Consumptive Use and Forbearance Agreement
DARPA	Defense Advanced Research Projects Agency
DOE	Department of Energy
EERE	Energy Efficiency Renewable Energy
EPA	Environmental Protection Agency
ERCOT	Electric Reliability Council of Texas
EWL	Energy-Water-Land
FEMA	Federal Emergency Management Agency
FY	Fiscal Year
GDP	Gross Domestic Product
GGE	Gallons of Gasoline Equivalent
GHG	Greenhouse Gas
GIS	Geographic Information System
GM	General Motors
HLB	Huanglongbing
HTL	Hydrothermal Liquefaction
HUC-8	8-digit Hydraulic Unit Code
LCOE	Levelized Cost of Electricity
LDRD	Laboratory Directed Research and Development
MGD	Millions of Gallons per Day
NA	Nuclear and Arms
NASS	National Agricultural Statistics Service
NCA	National Climate Assessment
NM	New Mexico
NMSBA	New Mexico Small Business Assistance
NMSU	New Mexico State University

NREL	National Renewable Energy Laboratory
PVBC	Pecos Valley Biomass Consortium
SD	System Dynamics
SWaRMS	Southwest and Rocky Mountains South
SWRI	Southwest Research Institute
TEA	Technoeconomic Assessment
TMDL	Total Maximum Daily Load
TRC	Technology Research Consortium
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNM	University of New Mexico
URGWOM	Upper Rio Grande Water Operations Model
URGWOPS	Upper Rio Grande Water Operations
US	United States
USDA	US Department of Agriculture
WECSSim	Water, Energy, and Carbon Sequestration Simulation Model

Executive Summary

This document provides a brief narrative, and selected project descriptions, that represent Sandia National Laboratories' history involving data, modeling, and analysis related to water, energy-water nexus, and energy-water-agriculture nexus within the context of climate change. Sandia National Laboratories has been engaged since the early-1990s with program development involving data, modeling, and analysis projects that address the interdependent issues, risks, and technology-based mitigations associated with increasing demands and stresses being placed on energy, water, and agricultural/food resources, and the related impacts on their security and sustainability in the face of both domestic and global population growth, expanding economic development, and climate change.

Sandia's Water Initiative program was developed in the early-to-mid 2000s around the three pillars of Security, Safety, Sustainability. The data, modeling, and analysis projects highlighted in this document fall under these broad Water Initiative categories, which include topic areas focused on water modeling and management, energy-water nexus assessment, modeling and analysis and related decision-support, water monitoring and resource assessment, water and energy security, international projects, and New Mexico Small Business Assistance projects.

Project funding sources include Congressional Directives, Program Development, Sandia Laboratory Directed Research and Development, United States Department of Energy, Department of Defense, Environmental Protection Agency, Department of Homeland Security, New Mexico Small Business Assistance, Cooperative Research and Development Agreements, and other state agency, industry, and non-governmental organization sources.

Sandia, along with other DOE labs and industry associations, such as Electric Power Research Institute, began raising concerns in the early-2000s about the critical relationship between energy and water, and the fact that their critical interdependencies were not being properly addressed to assure the security and sustainability of the nation's water and energy supplies. This led, in part, to the emergence of the Energy-Water Nexus as a key area of investigation for Sandia National Laboratories, in collaboration with others, with the first major funded efforts beginning in 2004-2005 with the Energy Water Report to Congress, and the Energy Water Roadmap, both mandated by Congress and funded through Congressional Directives.

The following pages provide a selected summary of water and energy-water related projects at Sandia National Laboratories beginning in the 1990s through the present.

1 Water Quality Monitoring and Trans-National Collaborations in Central Asia

Following the breakup of the former Soviet Union, several countries were formed in the Caucasus and Central Asian regions. These countries, formerly held together by the power of the central government, now find themselves negotiating with their neighbors over shared resources such as water. The United States Department of Energy (US DOE), as part of its nonproliferation program has engaged scientists and engineers from these Central Asian countries in non-weapon-related areas of research important to the stability and well-being of those countries. One such area of collaborative research is in water-quality monitoring and transnational collaborative model development in which Sandia is acting as a technical trainer and intermediary between the various participants. Although this project is not currently funded (it was funded for several years through DOE-Nuclear and Arms (NA), the collaborations remain ongoing, a testament to the power of this approach to resolving trans-boundary water resource management issues (Figure 1-1).

Figure 1-1. Sandia Howard Passell demonstrates the details of a regional collaborative water monitoring project to Central Asian partners. The countries involved in the partnership effort are highlighted on the underlying map of Central Asia.

Impact: This ongoing collaborative project brings water-resources professionals from the neighboring countries of Kazakhstan, Uzbekistan, Tajikistan, and Turkmenistan together over their shared water resources. It is focused on developing and sharing much needed water quality and quantity information that is useful for regional water-resource planning. The project creates a collaborative environment in a region where little cooperation exists between the countries and leads to enhanced mutual understanding and cooperation.

2 Evaluation of the Spread of Contaminants in Rivers After a Radionuclide Contamination Event

Contamination is ubiquitous in many US rivers. While knowledge of these contaminants is important, it is equally important to understand and predict how these contaminants are transported in the environment before, during, and after cleanup operations, and how contaminants act that result from unexpected events such as a radionuclide dispersal event. To address this problem, Sandia has developed tools to measure the dynamic soil properties in riverine environments and to accurately predict contaminant transport (Figure 2-1).

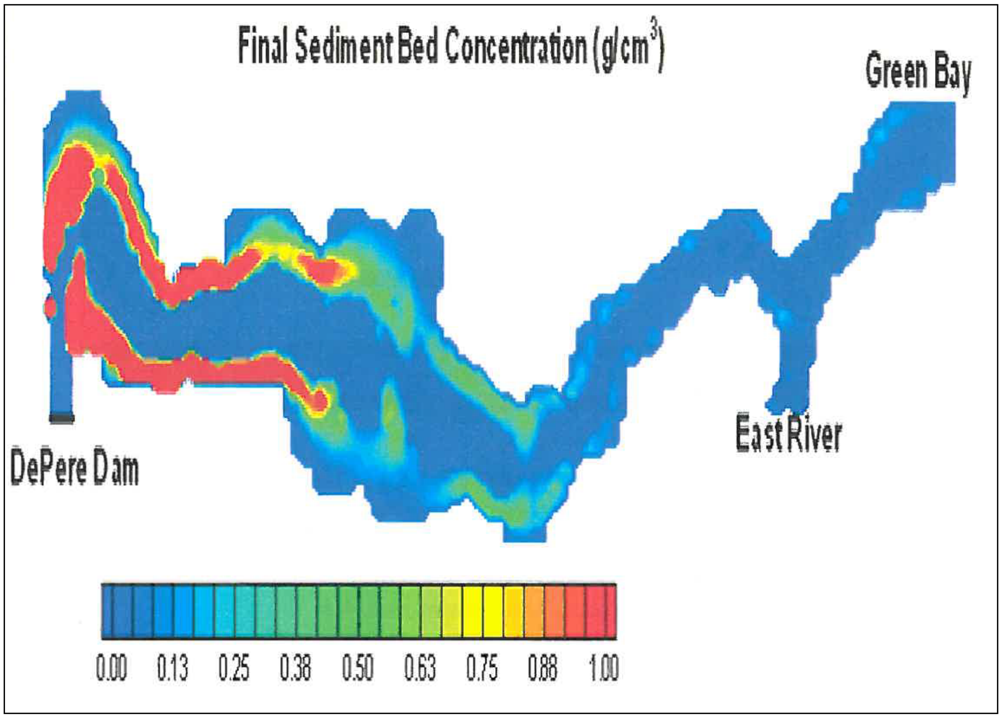


Figure 2-1. Graphical results from a numerical simulation of the spread of a potential cesium contamination event in the Lower Fox Fiver, Wisconsin.

Impact: Contamination is ubiquitous in many river systems in the US. A better understanding of the potential spread of contaminants is required to (1) understand the spread and (2) develop a cost-effective clean-up program that will not result in greater spread of the contaminants. Although mush research has been conducted to evaluate the initial spread of contaminants after a radiological dispersion event, there has been little attention to the potential for subsequent wind and water-borne transport of radionuclides following an initial release. This project has resulted in tools that will enable agencies and planners to better deal with the after-effects of a radioactive material dispersal in riverine environments.

3 Global Water Futures

In September 2005, after a year of extensive background research, two conferences hosted in February and March 2005, and collaboration with several experts, the Center for Strategic and International Studies and Sandia National Laboratories released a white paper outlining the major conclusions of the Global Water Futures project.

The goal of the project was to generate fresh thinking and concrete policy recommendations on how the US can (1) better address future global water challenges and (2) more efficiently leverage and deploy available technologies. The white paper, *Addressing Our Global Water Future*, facilitates meeting these goals by exploring four themes supported by fourteen main "Findings" that together highlight the core tenets of an integrated, comprehensive US foreign policy toward global water challenges (Figure 3-1.

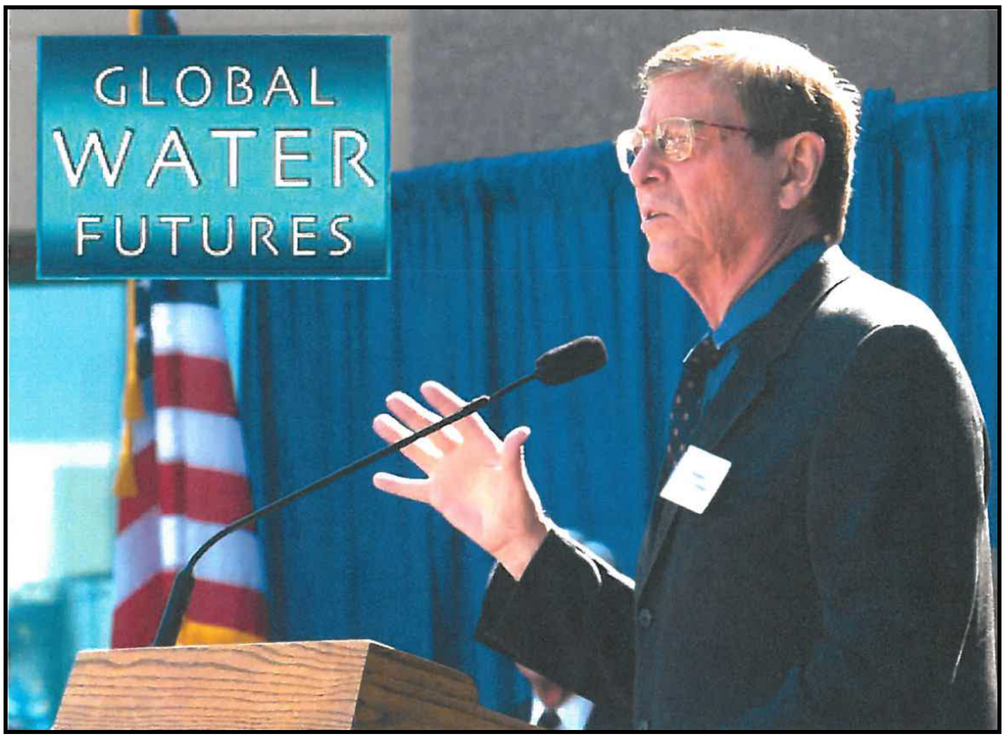


Figure 3-1. Senator Pete Domenici giving a briefing at a press release in conjunction with the September 2005 release of the Center for Strategic International Studies/Sandia Global Water Futures white paper report.

Impact: The Global Water Futures effort resulted in a widely distributed report that addresses major issues in US foreign policy related to water-resources management and technology. Fresh ideas and concrete policy recommendations were developed and communicated to the broadest audience possible in government, NGOs, private companies, and other stakeholders on how the US can (1) better address future global water challenges and (2) more efficiently leverage and deploy available technologies. The success of this initial Global Water Futures project has led to development of region-specific workshops for the Middle East, Sub-Saharan Africa, Asia, and India to be conducted over the next two years.

4 Cyber Security for Drinking Water Systems

Following the 9/11 attacks, there was an increased interest in improving the security of the water infrastructure from various forms of attack, and hackers and other cyber-attacks are perceived threats. Vulnerability assessments were conducted using Sandia's Risk Assessment Methodology. As a result, Sandia undertook an internally funded Laboratory Directed Research and Development (LDRD) effort to develop a framework to assess water utility vulnerabilities to cyber-attacks and to recommend cost-effective upgrades to their systems. The research described here is intended to be used as a toll by the water sector to assess and improve their security to cyber-attacks of any kind (Figure 4-1).

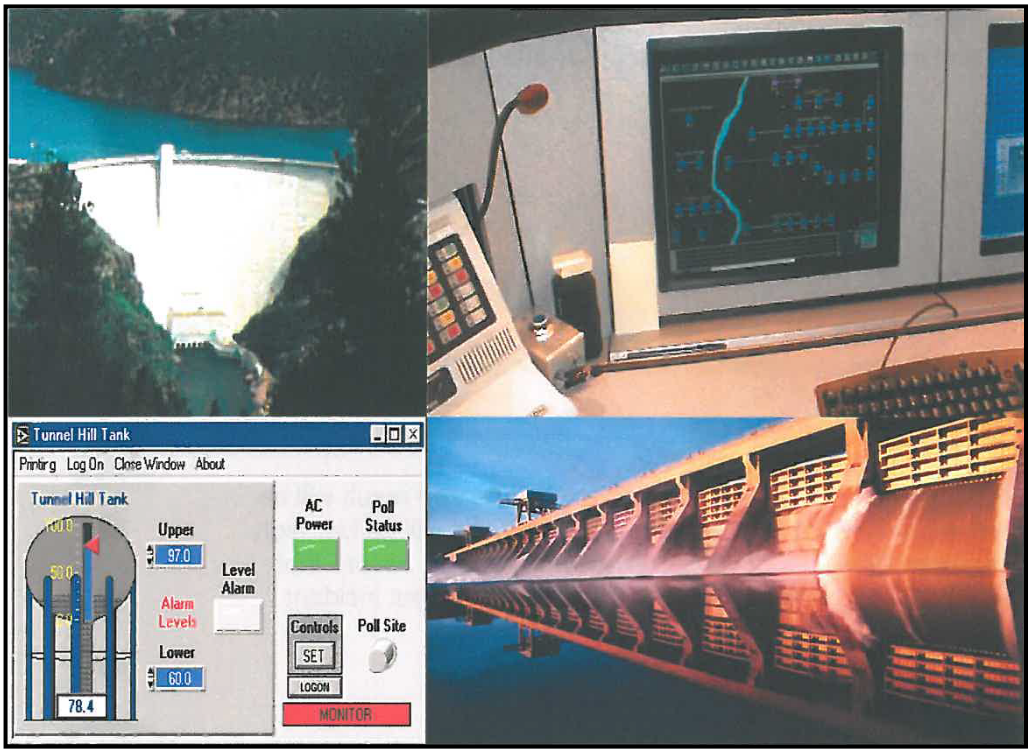


Figure 4-1. Examples of water infrastructures susceptible to cyber-attack include dams, hydro, control centers, and all control features within water distribution systems.

Impact: Security of cyber (Supervisory Control and Data Acquisition, electronic controls, etc.) for the water infrastructure will result in greater security and improved water quality for the water sector. Upgrading of cyber systems will result in greater control of water quality and more cost-effective operations.

5 Development of a System Dynamics Decision Model Toolbox for Water Resources Management

Based on Sandia's experience in developing the Middle Rio Grande model for the Middle Rio Grande water resource allocation planning exercise, we recognized that an effective water resources management and decision tool must be easily changed to meet site- and region-specific needs and conditions. To address this need, we embarked on an internally funded LDRD project to develop a series of portable modules that contain the necessary model framework and information for site- and basin-specific models to be developed easily and quickly. The result is the System Dynamics (SD) Water Management Model Toolbox, which contains most of the likely scenarios to be encountered during water planning exercises (Figure 5-1).

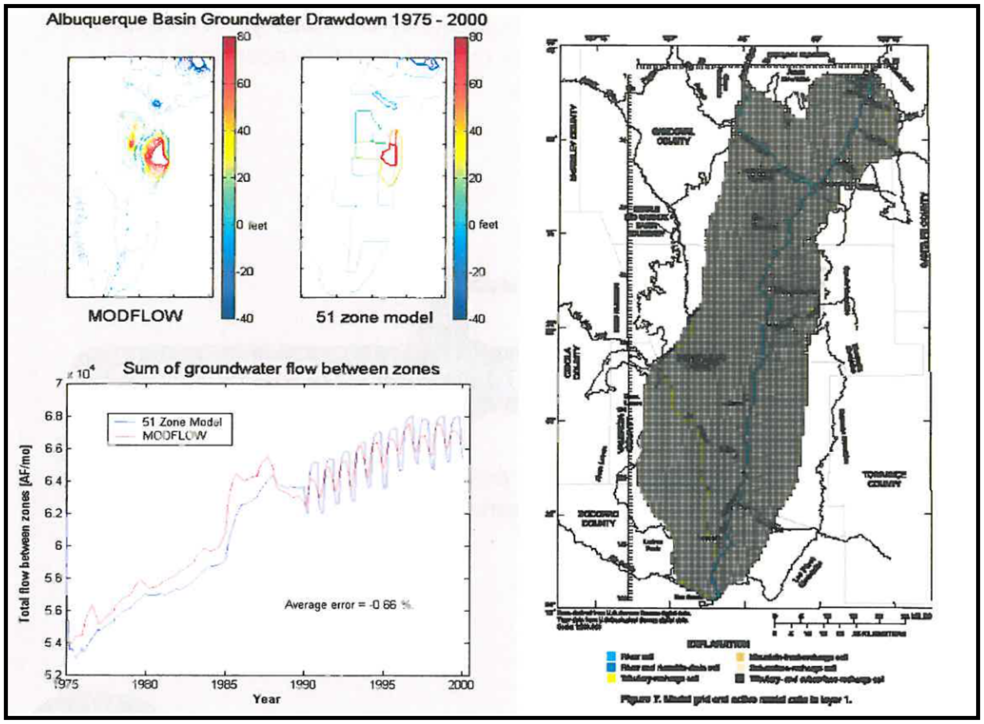


Figure 5-1. Graphical examples of a model conceptualization of the linkage between modeled groundwater flow for the Albuquerque basin and a zone-specific system dynamics model. This is one of many model subroutines that can be used from the SD Toolbox.

Impact: The SD Decision Model Toolbox is an important addition to the resources available for enhanced management of water resources. The SD Toolbox creates modules (essentially subroutines) for various common water resource management issues (e.g., aquatic species, water quality, sedimentation, water consumptive uses, energy-water uses, etc.) that can be easily transported from a "toolbox" into a site specific model with only minor modifications and specifications. The SD toolbox allows for more effective training of users so that they can create their own region-specific water resource management models that meet their own specifications.

6 Decontamination and Cleanup in Drinking Water Distribution

Much effort has been expended in the US and worldwide in an attempt to develop early warning systems for early detection of contamination in drinking water systems. What is known, however, is that sensors to detect the wide array of contaminants possible do not yet exist, and water distribution systems represent a potentially infinite array of contaminant introduction locations (depending on the contaminant). What has not yet received much attention however, is what to do in the event of a contamination event. How do you clean a system after contamination? How clean is clean? When are you through decontaminating the system? How uniform is the treatment? All of these (and more) questions need to be answered so that our nation is prepared for effective consequence management following a contamination event. The research described here is addressing these questions and will develop tools for water system managers to use for prediction and preparation of contingency plans (Figure 6-1).

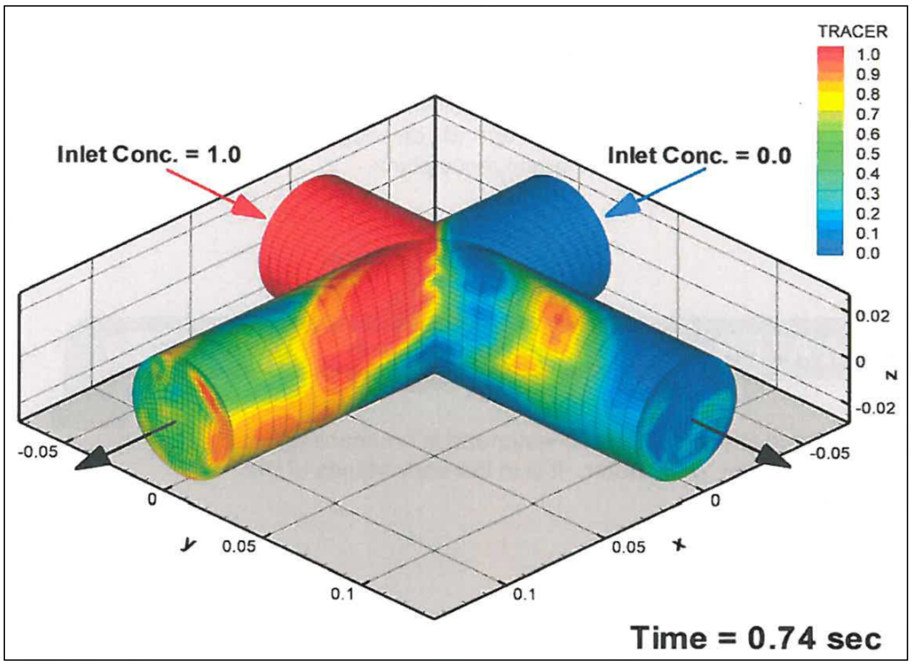


Figure 6-1. Results of a detailed analysis of contaminant transport through a cross-joint pipe connection in a water distribution system. Research results suggest that very "imperfect" mixing occurs at these junctions – a feature not predicted with current hydraulic models.

Impact: This project developed knowledge and technology to aid in planning and conducting decontamination of contaminated water distribution systems. It evaluated the relationships between contaminants, biofilms, system hydraulics, and decontamination in the laboratory and numerically. The knowledge gained improved the cost effectiveness and adequacy of contingency planning for contamination events in water distribution systems, and real-time decision making required during post-event consequence management.

7 Development of Early Warning System Sensor Optimization, Threat Evaluation, and Water Quality Analysis for Drinking Water Distribution Systems

Drinking water systems are critical to the security of the US. Sandia is collaborating with the Environmental Protection Agency (EPA) National Homeland Security Research Center and others within the EPA's Threat Assessment Vulnerability Program to develop contaminant warning systems that can protect our nation's potable water distribution systems. These systems use real-time water sensors to monitor water quality and provide early detection of chemical or biological contaminants. Three central challenges for the design of an operational warning system is to determine optimal locations for sensors to minimize costs and potential casualties, define where the contaminant was introduced to effectively mobilize response measures, and to understand the natural water quality variability to better understand when an alarm is truly an alarm (Figure 7-1).

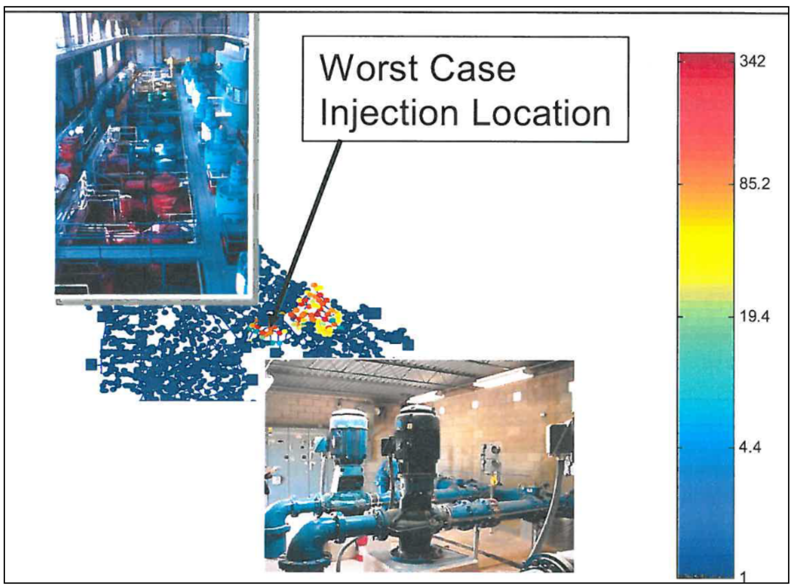


Figure 7-1. Example of analysis of a water distribution system allowing the "worst-case" contamination location as a prelude to identifying Early Warning System sensor locations to minimize public health consequences.

Impact: Sandia teamed with the US EPA's National Homeland Security Research Center and Water Sentinel Program, the University of Cincinnati, Argonne National Laboratory, and others to develop and implement the Threat Ensemble Vulnerability Assessment program to evaluate contamination threats to water distribution system security and an early warning system development to protect the nation's drinking water systems from terrorist attacks. We developed computational algorithms that can reliably find optimal early warning· system sensor placements for real-world water distribution systems containing 10,000s of pipes and pipe junctions. Our evaluation of natural water quality variability provided baseline information for early warning system analyses to identify normal and off-normal operating conditions for alarm triggering of contamination events and water-quality issues. Our contaminant source location software aids in forward analyses of the likely spread of a contaminant in the distribution system and will allow for effective contingency planning for water system managers.

8 Technical Assistance - Supporting the New Mexico Office of the State Engineer - Gila Basin Settlement

Sandia collaborated with the New Mexico Office of the State Engineer and Interstate Stream Commission to assist in developing System Dynamics (SD) based water resources management models of the Gila River basin in southwestern New Mexico. These models create various water use scenarios that the stakeholder group used to evaluate and optimize options for management of this water resource in conjunction with legal obligations with the state of Arizona. The model framework is based on modules developed for the Middle Rio Grande planning effort and other SD Toolbox projects, and its execution allows for stakeholder participation and decision making. The scenarios were evaluated and options selected to create a "scenario" that best satisfies stakeholder requirements (Figure 8-1).

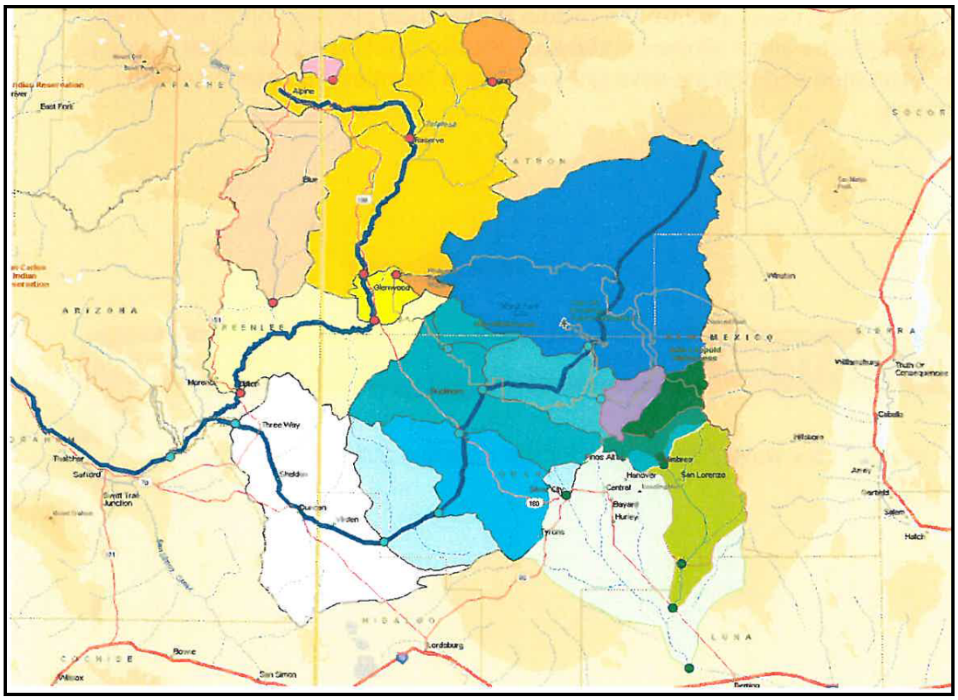


Figure 8-1. A map showing the outline of the Gila River basin (including the tributaries of the San Francisco and Mimbres) for the decision support model development.

Impact: This water management modeling project assisted the New Mexico Office of the State Engineer and Interstate Stream Commission to develop water resource management options and scenarios for management of the Gila River basin. Numerous stakeholders have participated in development of the planning options (see Partners) and a draft Consumptive Use model has been completed. Cooperation among the partners will aid in development of the basin water-sharing plan with Arizona.

9 Water Security & Water Quality Monitoring Collaborations with Israel

Interactions were initiated between Israel and the EPA in a 2002 visit by the Israeli water commissioner to the EPA. An Israeli and EPA delegation visited Sandia in July 2003 to learn more about Sandia's water-security technologies. This visit was followed up by a meeting between an Israeli delegation and the EPA National Homeland Security Research Center and Sandia in Cincinnati in March, 2004. Numerous discussions were held with EPA/Department of Homeland Security/Sandia regarding US/Israel interactions prior to an October 2004 visit to Israel by Sandia personnel to better understand their unique water issues and their technologies and approaches for achieving water independence. We have continued to discuss possible collaborative projects with Israeli water experts and are seeking financial resources to achieve these goals. Recently, we have begun interactions with KIWA (the Dutch water resources research institute) to consider a multiple-partner collaborative program (Figure 9-1).

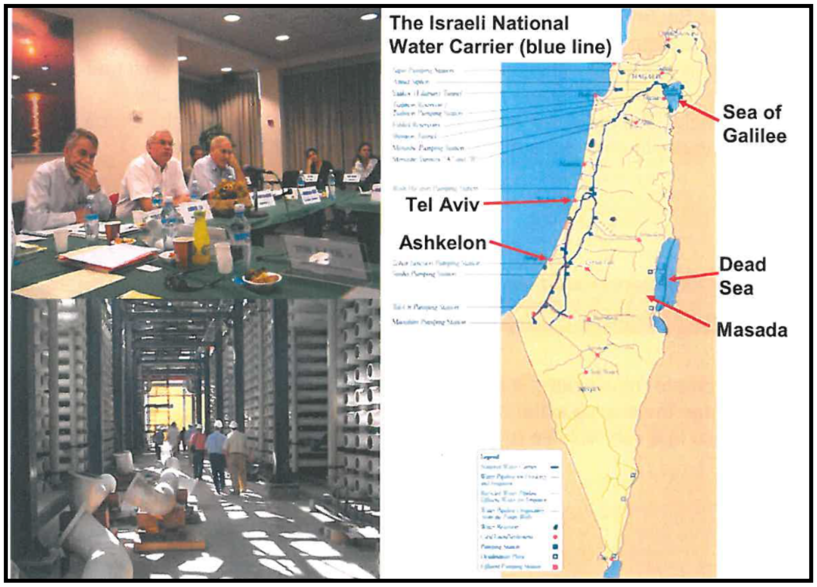


Figure 9-1. A map showing the location of the Israeli National Water Carrier (right), a meeting between Sandia technical staff and Israeli water experts (top left), and the Ashkelon 100 MGD desalination plant under construction on the Mediterranean coast.

Impact

- Israel has a very well-developed water infrastructure and water treatment, desalination, and reuse infrastructure. Through this collaboration, Sandia is able to share the Israeli-water management technologies with the US water community.
- Israel believes they have an urgent need to protect their vulnerable water supplies. Therefore, they have a keen interest in collaborating with Sandia, a recognized leader in water-security technology development.
- As a result of the above considerations, Israel, acting as a test bed location, represents a potential strong partner in the development of US water security technologies (e.g., sensors, early warning systems, and risk assessment models).

10 A Collaboration with Jordanian Scientists on Water Quality Monitoring and Modeling of the Jordan River Valley

Water resources are extremely scarce in the Middle East. Jordan is a key strategic ally of the US in this region and in the war on terrorism. Aiding Jordanian scientists and engineers to more effectively manage these water resources will serve to stabilize the region. Sandia and the US. DOE have established a Cooperative Monitoring Center in Amman, Jordan. This facility and charter allows Sandia to easily engage with Jordanian and regional scientists and engineers to assist in stabilizing the region and promoting nonproliferation of nuclear materials. Sandia has developed useful tools for decision making in water-resource management that apply to specific problems faced by Jordan in the upper Jordan River Valley. Sandia has met with Royal Scientific Society personnel and initiated training on these advanced tools and we have jointly developed proposals to implement these water resources management models in managing water-quality issues in the Zarqa and upper Jordan River valleys (Figure 10-1).

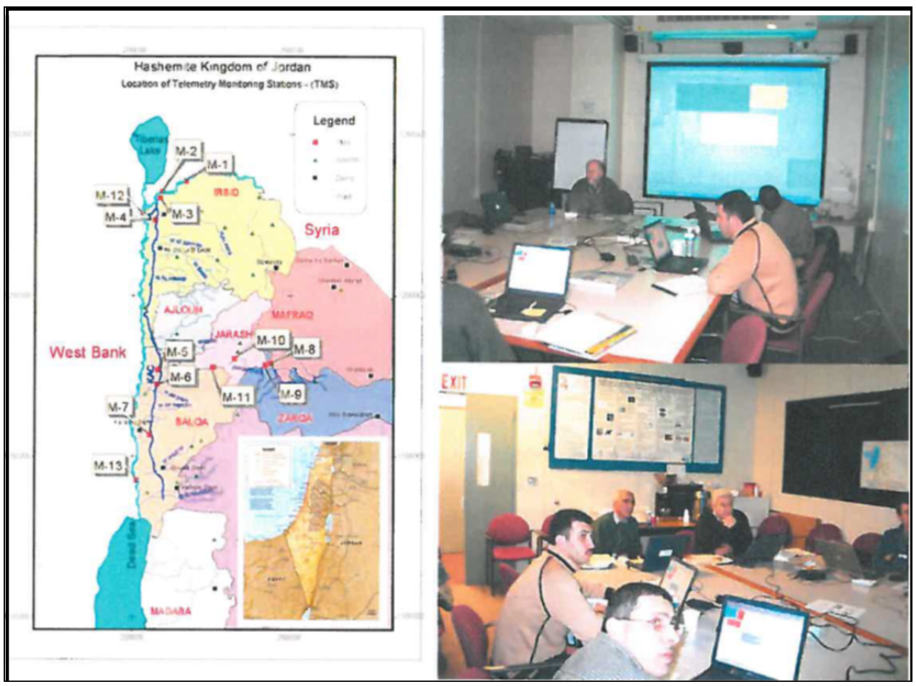


Figure 10-1. A map showing water quality monitoring stations in the northern Jordan River Valley (left). Members of Jordanian Royal Scientific Society attending a two-week, Sandia-led training session in Albuquerque on water management models and tools (right).

Impact: Jordan is a key ally of the US in the strategically important and volatile Middle East. Interactions and collaborations with the Royal Scientific Society (Jordan's national laboratory) in water resources management, which is a key strategic interest for Jordan, aided in the US strategic vision for increased stability this region. Collaboration with the Jordanian scientists and training provided by Sandia aided in Jordan technical self-sufficiency and will create a regional partner for expanding US technical influence in this region. Water resource management tools developed at Sandia (for example, SD models for water management decision making) aided in conflict resolution over scarce resources and will train the Jordanian technical and management staff to better allocate financial resources.

11 Lower Rio Grande Trans-Boundary Water Resources Management Decision Model

The US/Mexico border region is the fastest growing population in North America with > 3% annual growth, doubling every 20 years. The Rio Grande forms the border in this arid region, where water scarcity is creating increasing international tensions. Sandia has teamed with partners in New Mexico, Arizona, and the Mexican states of Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas to develop a first-order system-dynamics model of the Rio Grande along the border using the approach and technology developed for the Middle Rio Grande water plan. This model considers many of the factors of interest in managing this shared water resource, including the interplay between surface and groundwater, surface water quality degradation, demand in excess of supply, groundwater mining, economic development, agriculture, industry, ecology, and community needs. This model has been developed at a fairly high level and integrates information in simple ways. It may be revised or refined in future projects to further investigate trans-boundary water-resources management (Figure 11-1).

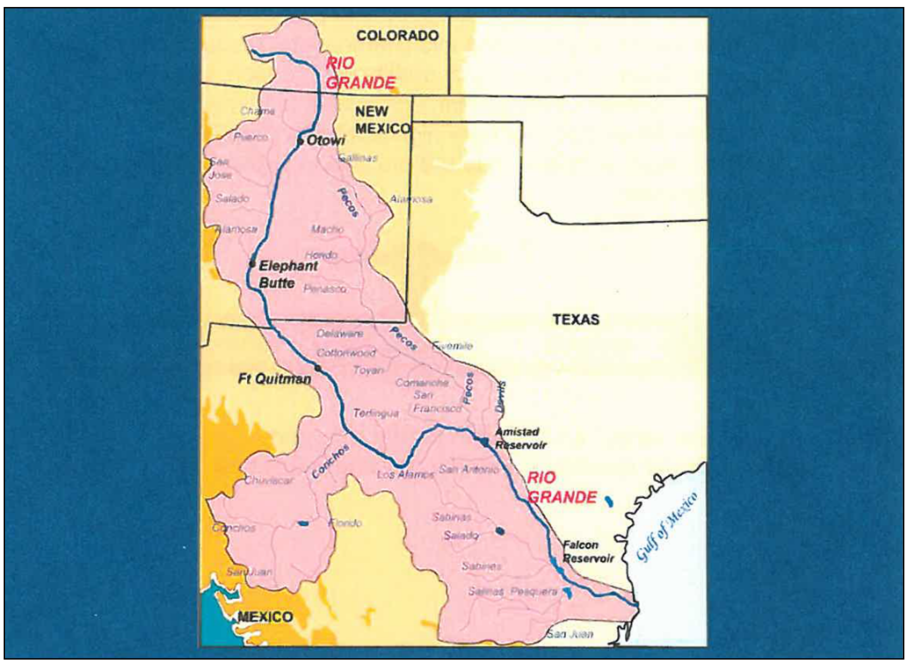


Figure 11-1. An image of the entire Rio Grande basin and the US-Mexico border from Texas to the Gulf of Mexico.

Impact: A collaborative project between Sandia, the Institute Mexicano de Tecnologia del Agua, and the University of Arizona produced a system-dynamics water resources management model of the Rio Grande from Ft. Quitman (near El Paso, Texas, to the Gulf of Mexico). This model could act as a centerpiece for international trans-boundary river management on the Rio Grande, allowing resource managers and policy makers on both sides of the border to simulate the impact of competing management strategies in real time. The model includes "AguaNet," a data-sharing system between US and Mexico that facilitates model development and that is accessible through the internet.

12 Middle Rio Grande Cooperative Water Resources Management Model

The Middle Rio Grande Regional Water Planning Project developed a system-dynamics, decision- support model for improving water resources management in the Middle Rio Grande basin of central New Mexico. The project included strong stakeholder involvement. The project represents a collaboration between the Middle Rio Grande Water Assembly, the Utton Transboundary Resources Center, Sandia, and numerous local, state, and federal agencies in the region. The project took place over three years from 2002 to 2004 and was funded by the New Mexico Small Business Assistance Program (NMSBA). A web version of the model resulting from the project is ready for publication so that users all over the world can use the model to experiment with water management strategies and outcomes (Figure 12-1).

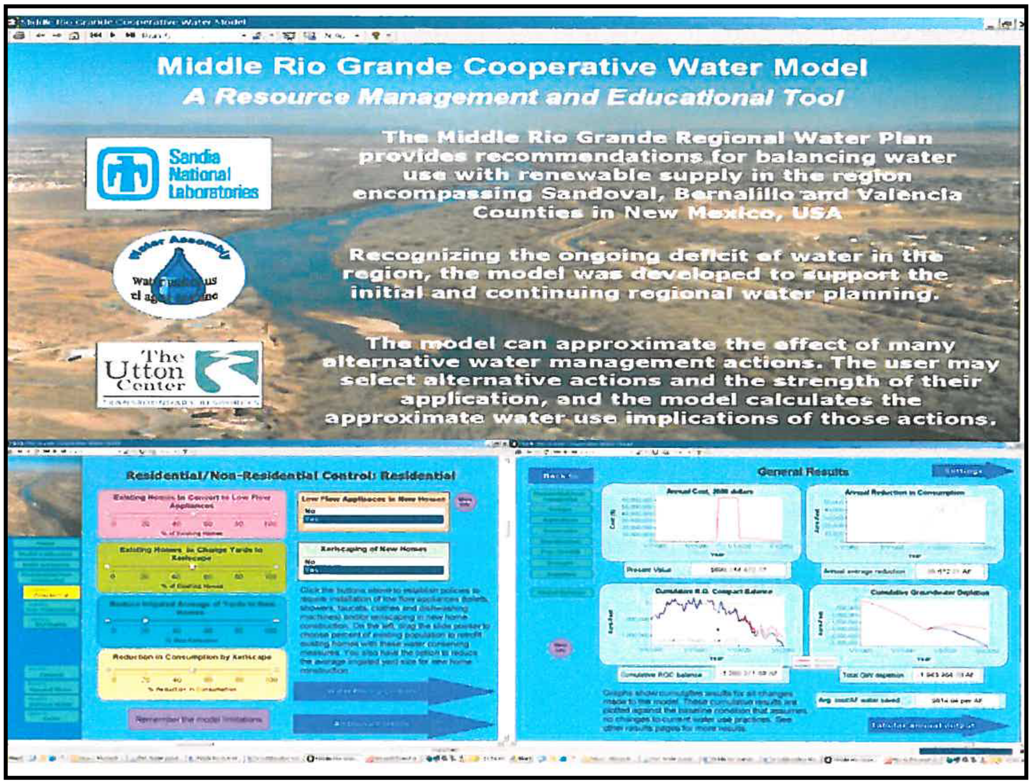


Figure 12-1. A screen capture of the Middle Rio Grande Cooperative Management model used in development of the Middle Rio Grande water plan for New Mexico. The model includes outputs for management aspects such as cost, New Mexico-Texas Compact delivery predictions, regional groundwater resources, and others.

Impact: The Middle Rio Grande Cooperative Water Model was used to create possible future water-use scenarios and ultimately resulted in the collaborative development of a water plan for the Middle Rio Grande Region. Collaborative model development demonstrated the utility of this type of water planning process. Interactive tools such as this are particularly important because of the numerous sources of conflict and distrust that existed and emerged between stakeholders during the process. The collaborative nature of the planning exercise, enlightened by the model, proved the utility of this type of process for decision-making in conflicted groups with divergent goals and agendas.

13 Upper Rio Grande Water Operations Model

The Upper Rio Grande Operations was previously based on a simple river routing model (water quantity on a short time step). We have integrated this model (which functions well for managing quantities of water) to include features necessary for collaborative stakeholder-driven management of the total upper Rio Grande basin water resource. This combined tool will allow the agencies responsible for management of this resource to better consider various stakeholder interests in future water resource management decisions (Figure 13-1).

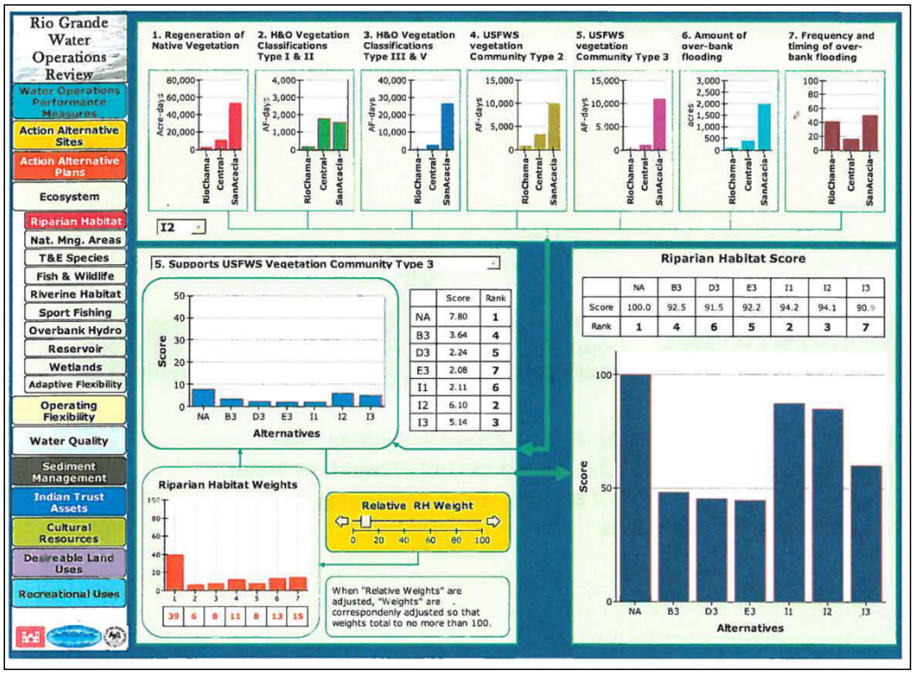


Figure 13-1. A screen capture from the Upper Rio Grande Water Operations model showing the criteria and weights used to compute the riparian habitat score. This illustrates just one of numerous screens and options that have been incorporated into the model to enhance water resources management decision making.

Impact: The Upper Rio Grande Water Operations Model (URGWOM) was developed by a consortium of federal and state agencies with a focus on the development of a numerical computer model capable of simulating water storage and delivery operations in the Rio Grande from its headwaters in Colorado to below Caballo Dam in New Mexico and for flood-control modeling from Caballo Dam to Fort Quitman, Texas. The model is used in flood control operations, water accounting, and evaluating water operations alternatives. The Upper Rio Grande Water Operations Model (URGWOM) represents a significant upgrade to the existing Upper Rio Grande Water Operations (URGWOPS) tools, which is based only on water routing (quantity only). Numerous features have been added, including various management options for ecosystems, water quality, sediment management, Indian Trust assets, cultural resources, and desirable and recreational uses. The resulting new model adds much greater flexibility for water resource managers to consider stakeholder interests in the management of the Upper Rio Grande water resource.

14 Summary of Water-Related Projects Supported Through the New Mexico Small Business Assistance Program

The NMSBA has provided in excess of several hundred thousand dollars per year of technical support to New Mexico business associated with water and energy-water issues and technology needs since 2001. These have included decision-support modeling, exemplified by the Middle Rio Grande effort, as well as a broad range of research, technology development, modeling, and assessment projects involving water and the interdependencies of energy, water, agriculture, and climate. These have included energy and water savings through innovations with controlled environment agriculture (CEA – greenhouse ag) technologies, exploration of biofuel production from algae grown with municipal and agricultural wastewater, and numerous others Figure 14-1).

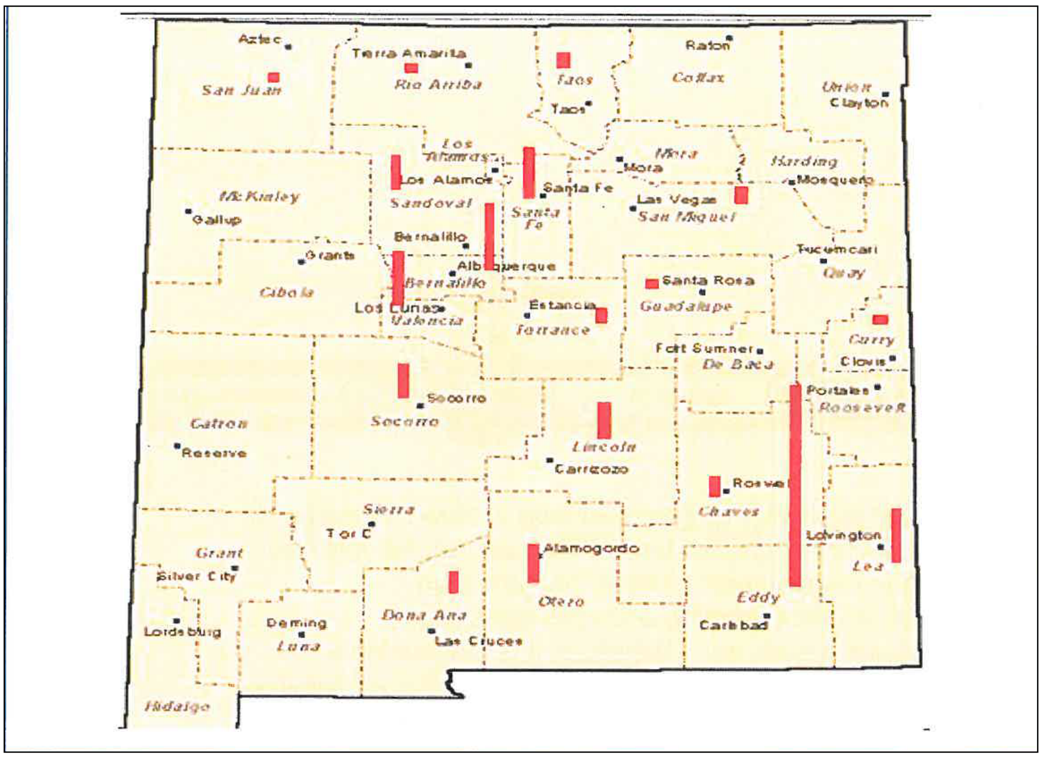


Figure 14-1. A map showing the relative number of New Mexico Small Business Assistance water related projects allocated by county from 2001-2005.

Impact: The impact of NMSBA projects in the water sector is largely measured through the feedback from the small businesses that have been helped by this funding and through the number of repeat and renewal projects in water. Water-sector projects represent one of the largest technical need areas for the Sandia NMSBA program.

15 Rainey River (US-Canada) Trans-Boundary Water Resources Management Decision Model

The Rainey River forms part of the border between the US and Canada (in portions of Minnesota). Recently, severe rainfall events have had a deleterious effect on stakeholder belief that the water system is being adequately managed. Sandia teamed with the International Joint Commission to develop a simplified system-dynamics water-resources management model for the region as a possible tool that can be used by the stakeholders to better understand the consequences of various water-management options on the water resources in the region. This tool is based on the successful Middle Rio Grande model framework used for water-resources management planning in New Mexico. Although this tool has not been used by the stakeholders, the International Joint Commission plans to develop stakeholder briefings centered around the model as a means of regaining public trust (Figure 15-1).

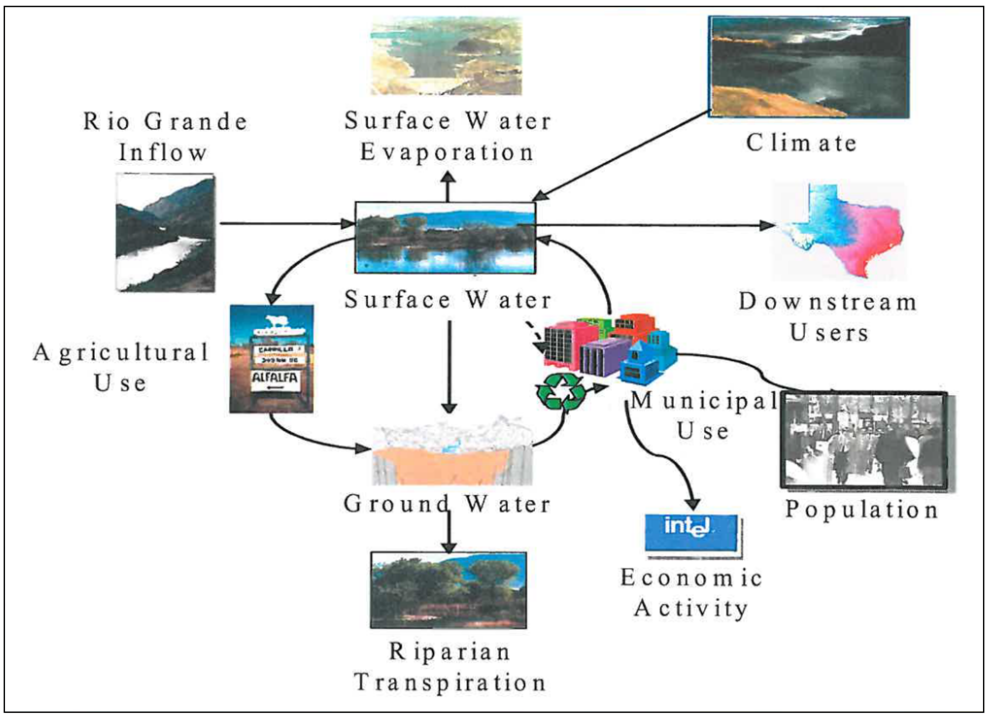


Figure 15-1. A logic diagram for a generic system-dynamics water-resources management model similar to that to be developed for the Rainey River basin on the US-Canada border.

Impact: A decision-support model for the Rainey River basin (which includes parts of Minnesota) has been developed that can be used to evaluate the consequences of various alternative water-resources management decisions. The system-dynamics model that Sandia developed can be used by water managers in the region to engage stakeholders, to assist in making informed decisions, with a greater "buy-in" by all the stakeholders in the region.

16 Development and Implementation of a Security Risk Assessment Methodology for Potable Drinking Water Systems in the US

Presidential Decision Directive 63 and Homeland Security Presidential Directive 7 established a national policy for federal departments and agencies to identify and prioritize US critical infrastructure and key resources and to protect them from terrorist attack. The US Environmental Protection Agency was assigned responsibility for the water infrastructure, which includes both drinking water and wastewater systems. Furthermore, the Bioterrorism Preparedness and Response Act of 2002 required large utilities to conduct their vulnerability assessments and submit a report to the EPA. Sandia, in response to the events of 9/11, acted quickly in collaboration with the American Water Works Association Research Foundation (AwwaRF) and EPA and developed a risk- based, consequence-driven methodology (RAM-W) methodology, developed training programs, and enabled the industry to meet the demands of the Bioterrorism Act. The results of these assessments have led to other research to support the security of the US water sector (Figure 16-1).

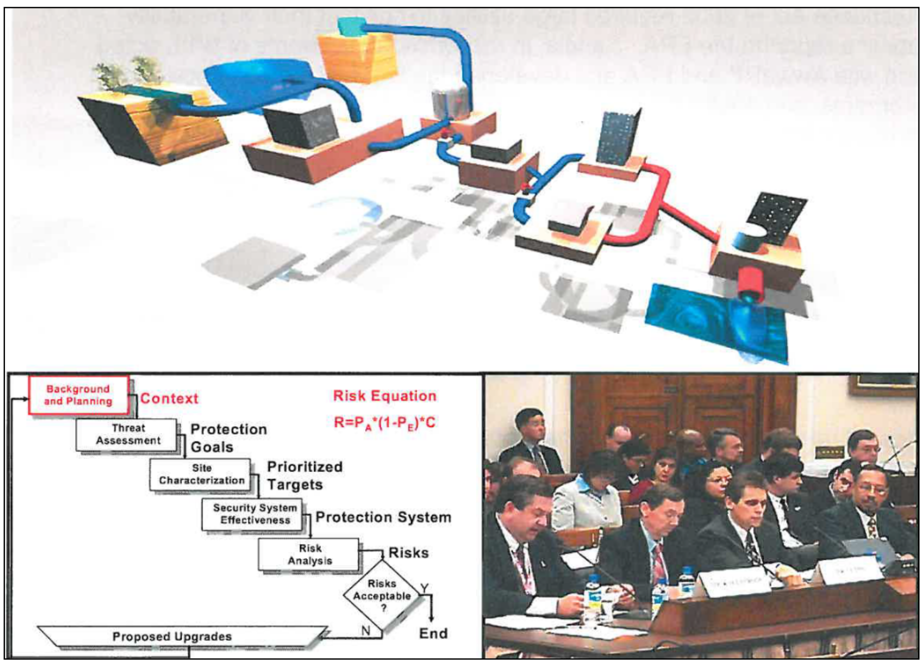


Figure 16-1. A conceptual layout of a "typical" drinking water system in the US (top), testimony on water security to Congress by Sandia manager Jeffrey Danneels, and a process flow diagram of the RAM-W methodology.

Impact: Sandia, in collaboration with AwwaRF and the US EPA, developed RAM-W to evaluate the security risks of the nation's water infrastructure. The methodology was applicable to both large- and medium-sized water utilities. RAM-W has been used at a majority of the large water utilities in the US to evaluate security risks. Thousands of consulting and utility personnel representing over 95% of the largest US water utilities have been trained in the use of the RAM-W methodologies. The Bioterrorism Act passed by the US Congress required risk assessments to be completed and submitted to the EPA. RAM-W and the training provided by Sandia allowed utilities to complete this requirement on time, define security and/or operational upgrades, and develop realistic contingency plans.

17 A Small-Scale Water Distribution System Network for Risk Assessments and Early Warning System Evaluation

Analysis results from collaborations with the EPA National Homeland Security Research Center have identified weaknesses in currently used hydraulic models that predict the fate and transport of contaminants in these complex nodal networks. All of this has led to the realization that new models are needed that predict the behavior of the system hydraulics in water distribution systems and can predict the concentration and location of contaminants. To accomplish these goals, a scaled-water distribution system that can be modularized is needed to conduct controlled experiments to provide data for both model development and model validation (Figure 17-1).

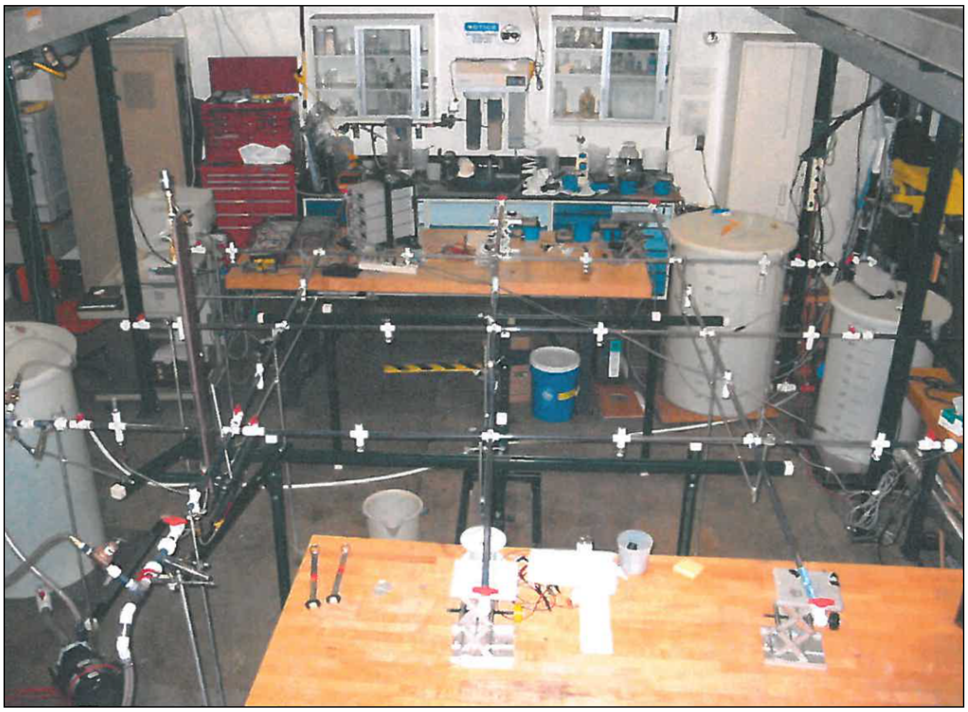


Figure 17-1. Experimental layout for the sealed-water distribution system that will validate hydraulic model hypotheses and early warning system sensors and components.

Impact: Models used to predict the movement of contaminants in drinking water distribution systems have not been "validated" for accuracy, nor have models that can be used for locating early warning system components. This scale-model water distribution system and the associated software serves as a water industry resource for evaluating models, hypotheses, system components, sensors, etc., at a scale reasonable for multiple experiments and configurations. This capability improves confidence about network designs and operations and will result in fundamentally more secure water distribution system infrastructures.

18 Energy-Water Report to Congress

Energy and water are closely linked. Water is important in all aspects of energy production and generation-from hydropower and cooling of thermoelectric power plants to oil and gas refining to growing and processing biomass for liquid fuels. Growing shortages and competing demands for limited fresh water supplies could significantly impact energy production and generation in the future.

The report to Congress was directed by Congress and provided $500K to the DOE to evaluate the emerging energy-water interdependencies. The report was developed to help identify the emerging issues and needs nationally and regionally, and help identify the primary water concerns for energy production and generation that will need to be addressed to insure future energy and economic security and reliability (Figure 18-1).

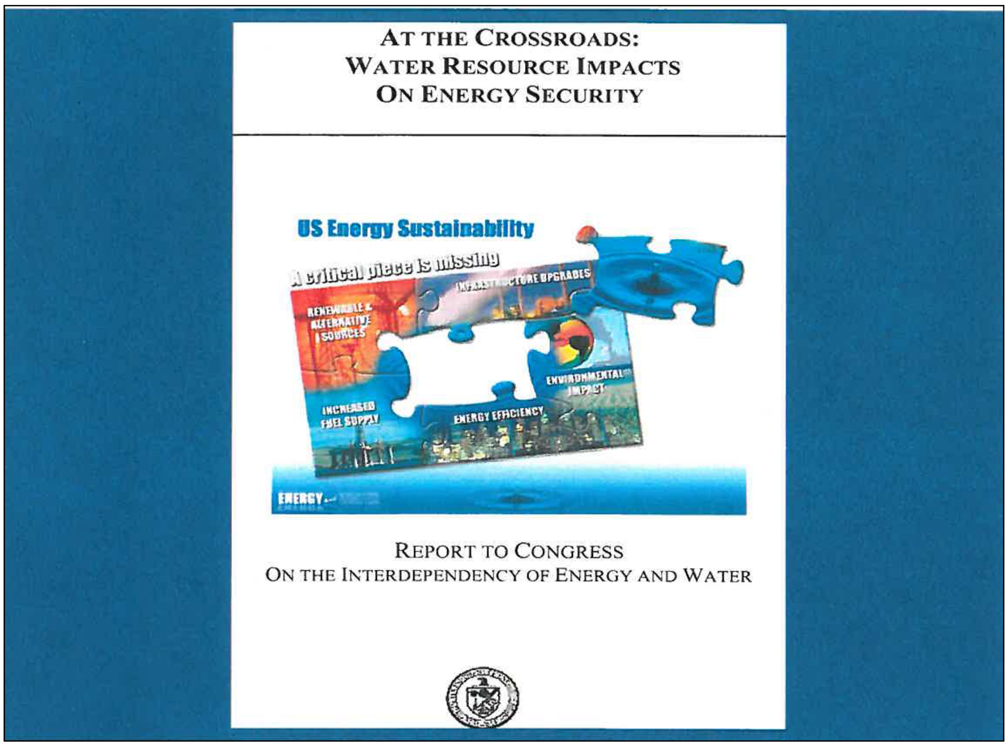


Figure 18-1. *At the Crossroads*, a report to Congress on the impact of fresh water resource availability on the future security and reliability of energy supplies, was developed in 2006.

Impact: Thermoelectric power generation accounts for the largest withdrawal of water in the US. A report to Congress schedule for release in March 2006 provides an overview of the major issues and concerns over growing demands on water supplies from different sectors, and the impacts of these water demands on regional and national energy availability and energy security. The report provides a summary of the improvements in water-use efficiency in energy production and generation and improvements in energy-use efficiency in water supply and treatment needed to ensure cost-effective energy and economic growth in the future. The report was published in March of 2006 and provides the basis for discussions of energy and water interdependencies, research and development needs, and future directions.

19 The Energy-Water Research Roadmap

Congress requested that the DOE prepare a National Energy-Water Roadmap in the Energy Policy Act of 2005. Congress provided approximately $2M in funding to Sandia through DOE to develop an Energy Water Research Roadmap. The purpose of the Roadmap was to identify the regional and national issues associated with emerging water-resource impacts on energy development, and to establish research priorities needed to address these issues such that energy development is not negatively impacted. The Roadmap set the foundations for a research program that addresses technological solutions to increasing water demand issues. New technologies enabled by this Roadmap allow the US to better utilize limited water resources and insure that competing demands for water from other sectors do not negatively impact energy production and generation. The Roadmap addressed water-use efficiency in energy generation as well as the energy-use efficiency in water treatment and distribution (Figure 19-1).

Figure 19-1. Images from a recent Energy-Water Roadmap, Western Region Needs Assessment Workshop in Salt Lake City, Utah. Three workshops have been held to identify key regional issues in the Energy-Water problem.

Impact: The Energy-Water Research Roadmap development effort focused on identification of the emerging science and technology needs associated with the growing competition by the energy- producing, agricultural, and other sectors for limited fresh water resources. Identification of the research needed to appropriately address and minimize potential impacts on energy reliability and economic growth and security is an important component of the effort. The Roadmap provided the US with research and development directions and priorities to meet future energy demands with improved water-use efficiency. This included providing research directions for major elements of energy production and generation, such as oil and gas production, biofuels production, and hydroelectric and thermoelectric power generation, to insure that water resources do not limit energy supplies. The Roadmap also provided information on where additional research efforts should be focused. For example, improved climate modeling capabilities and more extensive water-resource data collection can further support improved future energy reliability and economic growth.

20 Development of a New Tool to Evaluate Sediment Transport in Western Streams and Rivers

The Time Domain Reflectometer project was developed to address a need for better quality data collected in real-time for the specific conditions particular to western US streams and rivers. Current practice involves limited "spot measurements" of stream stage with little or no information on water quality. Because ephemeral streams often "meander" across channels, this means that much of the information necessary for accurate reporting is not collected, and erroneous information is used to make decisions regarding water resources management. This new technology resolves these deficiencies. Although this technology requires some additional testing, results are promising, and future trials will resolve data and equipment uncertainties (Figure 20-1).

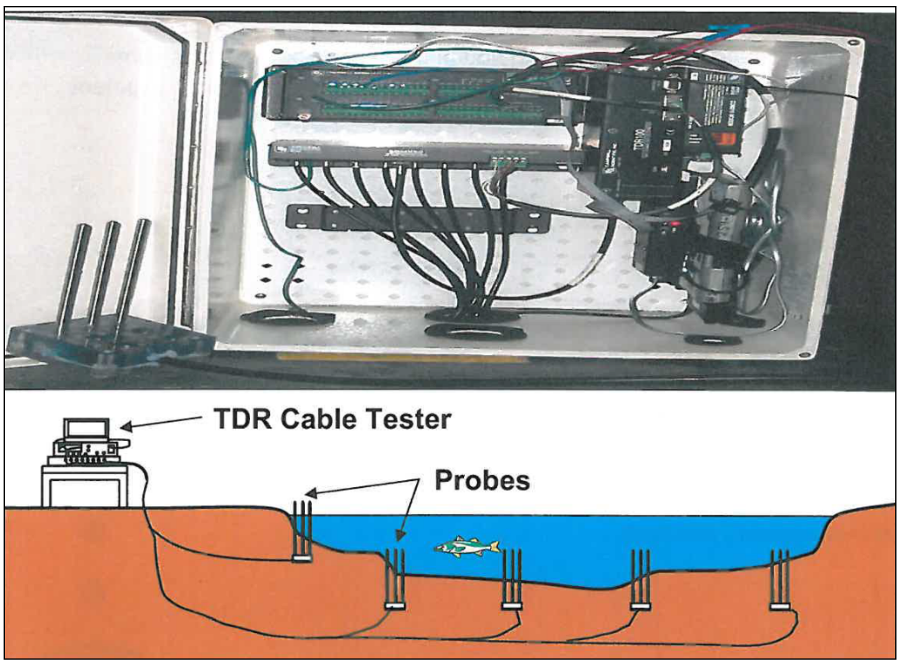


Figure 20-1. A photo of the time domain reflectometry cable tester and probe (top) and a conceptual sketch of time domain reflectometry probes installed in a stream (bottom). This technology can be used to measure the water level and sediment load in Western US ephemeral streams and rivers.

Impact: Time Domain Reflectometer technology can be used to measure stream stage, channel profile, salinity, and sediment concentration in ephemeral streams in the western US. The technology is potentially able to gather data in real time, allowing continuous data collection rather than "spot" measurements. The collected data can be used to better understand water management information necessary for decisions related to endangered species, water quality, erosion control for watershed management (e.g., forest fires), and sedimentation behind dams This technology has been tested and demonstrated in the Rio Grande near the Albuquerque Central Avenue bridge, Paria River near Lee's Ferry, Arizona, and New Mexico State University's Santa Fe Ranch Watershed Research Facility.

21 Technical Assistance – Development of a Water Web Portal for Enhancing Water Management Interactions

Sandia's Water Portal (https://waterportal.sandia.gov/) provides a web-based, interactive environment for collaborative regional and international water monitoring and data sharing, modeling, and management. The Water Portal allows multiple scientists, policy makers, water managers, and stakeholders at multiple institutions around the globe to work together on regional water issues in real time. It provides a data sharing repository so that all partners can upload and download data and other information Figure 21-1).

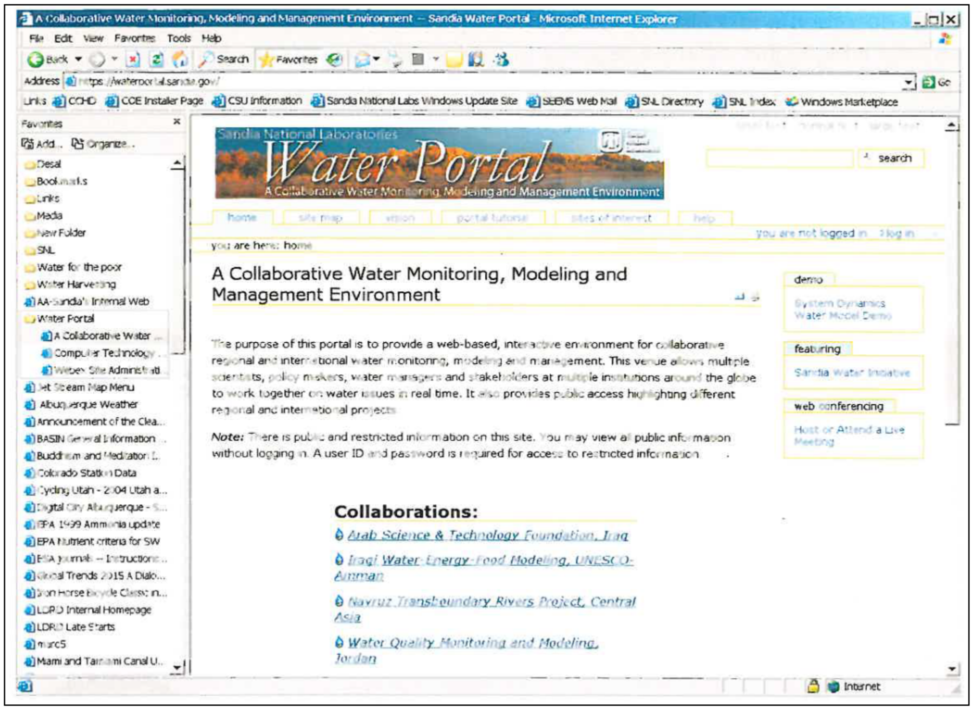


Figure 21-1. A screen shot of the SNL Water Web Portal describing collaborative water monitoring, modeling, and management activities. Active collaborations are in place with a number of international partners.

Impact: The Sandia Water Web Portal is a user-friendly environment that enhances collaborative water management. The Water Web Portal has created an environment for data and idea sharing. The Water Web Portal has been used successfully in collaborative projects in New Mexico, Texas, and the country of Jordan. The Water Web Portal enhances efficiencies across long distances and over ranges of technical and equipment capabilities. The Water Web Portal can serve as a repository for data and information categorized any way a user-group desires (e.g., basin-to-basin, technology, general information, water rights, water banking, etc.).

22 Optimization and Scaling of Models for Water-Resources Decision Making

This project takes advantage and leverages other efforts in the development of SD models for conflict resolution and water resources management by teaming with the University of Texas at Austin to develop optimization tools for economic, environmental, and demographic sustainability along with tools to incorporate spatially distributed physics-based models (e.g., MODFLOW) into a systems-dynamics framework. The test case for this complex problem is the Barton Springs Aquifer of the Edwards Formation near Austin, Texas, an area that is well understood by our partners, the UT Jackson School of Geoscience (Figure 22-1).

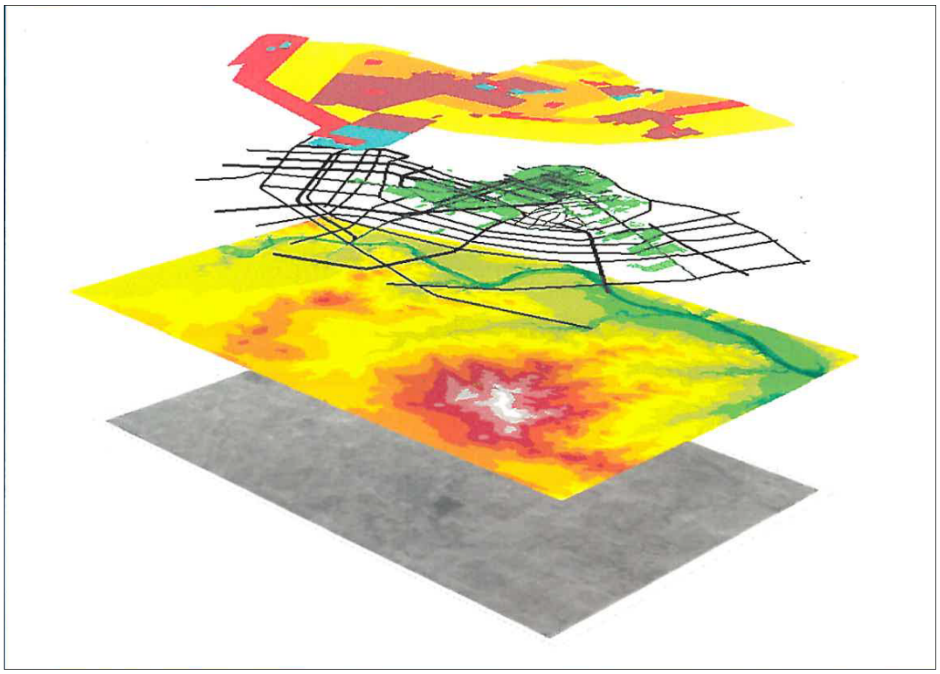


Figure 22-1. A conceptual cutaway showing model framework for combinations of land-use, topography, urbanization, and hydrologic conditions near Austin, Texas.

Impact: Optimization algorithms allow greater speed and flexibility when analyzing complex suites of variables and model interfaces. Such algorithms will create a subset of possible optimized scenarios to aid in group decision making based on stakeholder preferences and metrics. The development of automated linkage between spatially distributed physics-based models and systems dynamics models allows for the real-time connection of high-fidelity models of physical processes with user-friendly, fast-decision models. In addition, the development of a custom, graphical user interface that enables various levels of interaction with the models enhances the ease of understanding and use for a range of user-groups. The Framework is built as a generic tool that can be applied to other types of problems (e.g., surface water, water quality, etc.) and to address the specific problems faced in the Austin, Texas area.

23 Water Use Optimization Toolkit: Hydropower Optimization

A major challenge facing conventional hydropower plants is to operate more efficiently while dealing with an increasingly uncertain water-constrained environment and complex electricity markets. The goal of this project, was funded by the DOE, was to improve water management simultaneously increase the energy, revenue, grid services, and environmental benefits from available water while maintaining institutional water delivery requirements. The toolkit is to be used by environmental analysts and deployed by hydropower schedulers and operators to assist in market, dispatch, and operational decisions as well as long-term planning and forecasting (Figure 23-1).

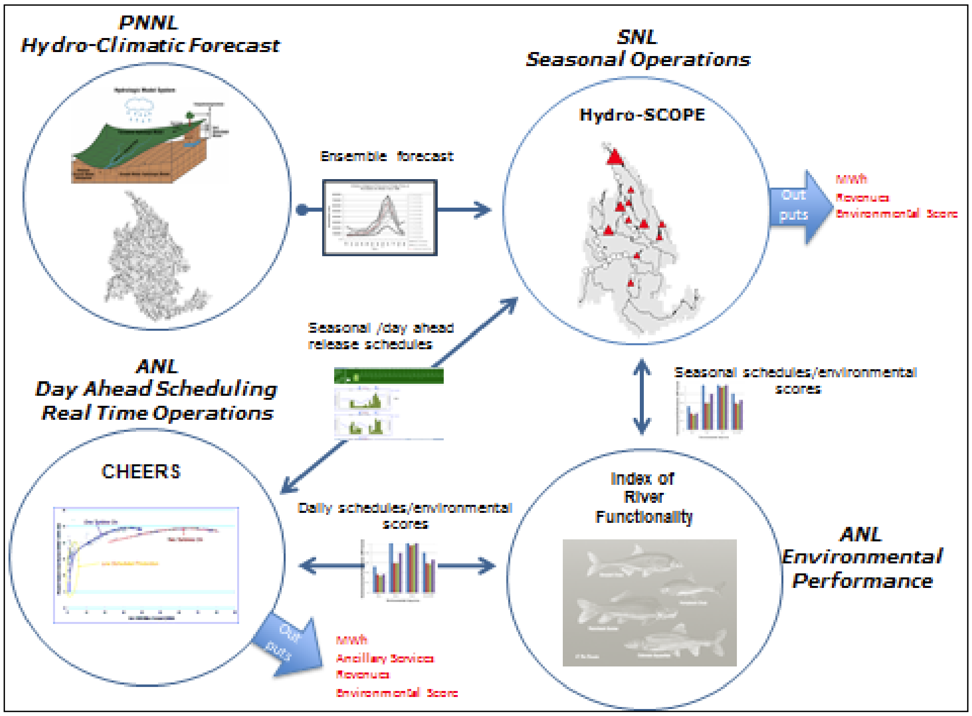


Figure 23-1. The water use optimization toolkit is a set of advanced analytical tools that are designed to work together through a common database to help hydropower operators and planners manage the economic and environmental performance of their systems.

Impact: Sandia created and demonstrated an integrated toolset of advanced analytical tools that allows hydropower operators and planners to optimize power generation, economics, water management, and environmental performance. The Multi-laboratory project was done in collaboration with Argonne and Pacific Northwest National Labs. Demonstrations completed at three different sites show a potential for a 3-5% increase in revenue from power sales with equal or better environmental performance.

24 Water Sustainability for Resource Extraction in the Permian Basin Region of New Mexico

Advancements in directional drilling and well completion technologies have resulted in an exponential growth in the use of hydraulic fracturing for oil and gas extraction. Within the New Mexico Permian Basin, water demand to complete each hydraulically fractured well is estimated to average 7.3 acre-feet (2.4 million gallons), resulting in an increase to the regional water demand of over 5000 acre-feet per year. The rise in demand along with proposed rule changes that govern the regulation and management of hydraulic fracturing on Federal and Indian lands (40 CFS 3160) has created concern as to the regions ability to meet future demands in a manner that fulfills the Bureau of Land Management's (BLM's) role of protecting human health and the environment while sustainably meeting the needs of the variety of water users in the region. This project uses a multi-disciplinary approach that synthesizes data collection, field verification, and SD modeling to better understand the dynamics of the regional water supply and demand under different management, policy, and growth scenarios to identify risks to water sustainability and develop alternatives to mitigate those risks (Figure 24-1).

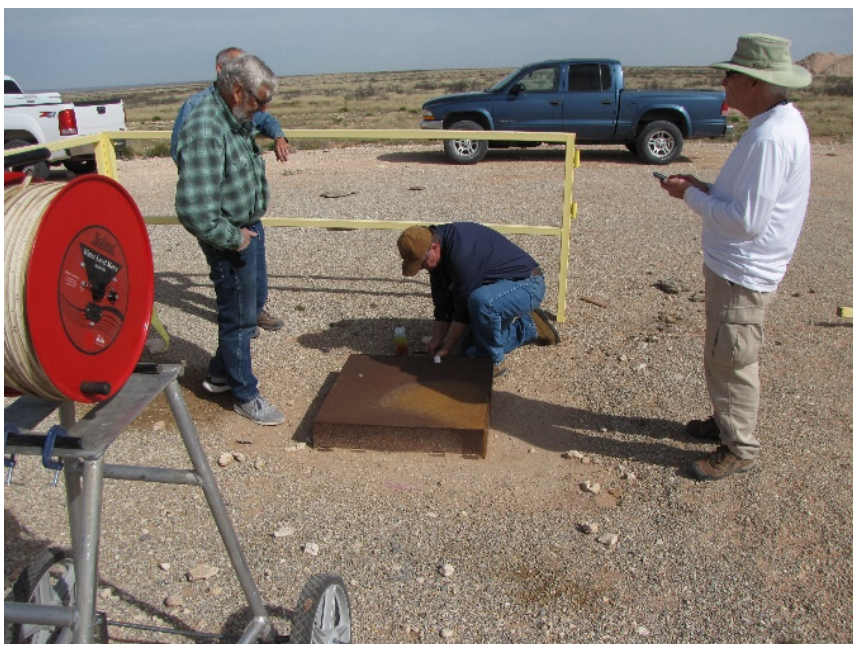


Figure 24-1. Dave Herrell of the Bureau of Land Management oversees field data collection and monitoring activities being conducted by Sandia personnel and contractors.

Impact: Sandia is creating a decision support tool to help the BLM, the funding agency for this project) better manage water resources in Southeast New Mexico. The tool uses a multi-disciplinary approach that combines hydrologic field testing and monitoring with SD modeling. The goal is to insure that the long-term use of the regions water reserves are sustainable under projected increases in demand.

25 GT-Mod: A System Dynamics Model for Uncertainty Analysis and Integrated Risk Assessment in Geothermal Energy Development

Geothermal energy development requires accurate assessments of the quality and accessibility of a geothermal resource, the costs associated with drilling and power plant construction, and the long-term thermal and hydrological performance of the system. Geothermal energy is unique in that each of these systems are dynamically linked such that the full suite of systems and sub-systems result in a set of multi-tiered dependency structures with multiple feedback loops that propagate uncertainties in the inputs in non-linear and unintuitive ways. Understanding the propagation of these uncertainties in the context of economic risk of development is paramount if geothermal energy production is to become cost competitive. This project is developing a SD model that aids decision makers by placing uncertainties in knowledge and understanding into a risk-based framework. GT-Mod simulates the economic and thermal performance of a given geothermal energy site to calculate the levelized cost of electricity (LCOE) as a function of known and unknown (i.e., uncertain) physical and economic conditions. The tool identifies the key areas of uncertainty that if better understood, would provide the largest gain in understanding and predictability and hence, the largest reduction in risk. Furthermore, the tool is able to identify and assess the set of physical, technological, and economic hurdles that are preventing a geothermal project from becoming market competitive (Figure 25-1).

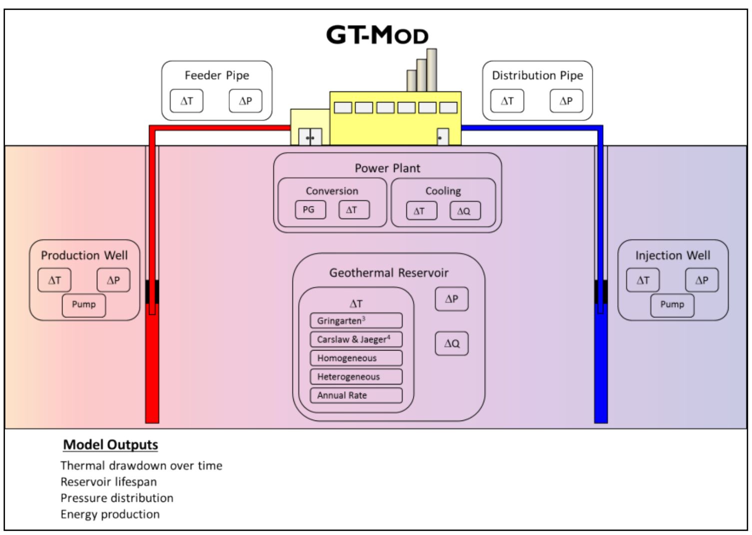


Figure 25-1. Conceptual model of the GT-Mod SD model for simulating geothermal energy production.

Impact: The model Simulates the dynamic linkages between system performance (heat extraction) and economics (LCOE). Uncertainties in the inputs are represented a probabilistic density functions to produce probabilistic output of a geothermal projects' long-term performance. Uncertainties are also used for integrated risk assessment that communicates the risk to the developer of a projects ability to meet performance targets. It models both flash-type and binary-type power plant performance coupled with reservoir thermal performance and pumping requirements.

26 Water Atlas in Support of Long-Term Electric Transmission Planning

The objective of this study was to estimate the availability, projected future use, and cost for water in support of long-term electric transmission planning. Water metrics were mapped in two separate studies for 31 eastern and 17 western states. The compiled set of water metrics is unique in four important ways. First, multiple sources of water were considered, including fresh surface water, fresh groundwater, municipal wastewater, and brackish groundwater. Second, water availability metrics accommodate institutional controls (e.g., water permitting, administrative controls, interstate compacts) to the extent available data permitted. Third, water availability estimates were accompanied by cost estimates to access, treat and convey each unique source of water. Fourth, water metrics were developed with the direct assistance of state water managers in framing, identifying, understanding and vetting the resultant metrics. This work in the Eastern US is matched with complimentary data collected for the 17 Western states (Figure 26-1).

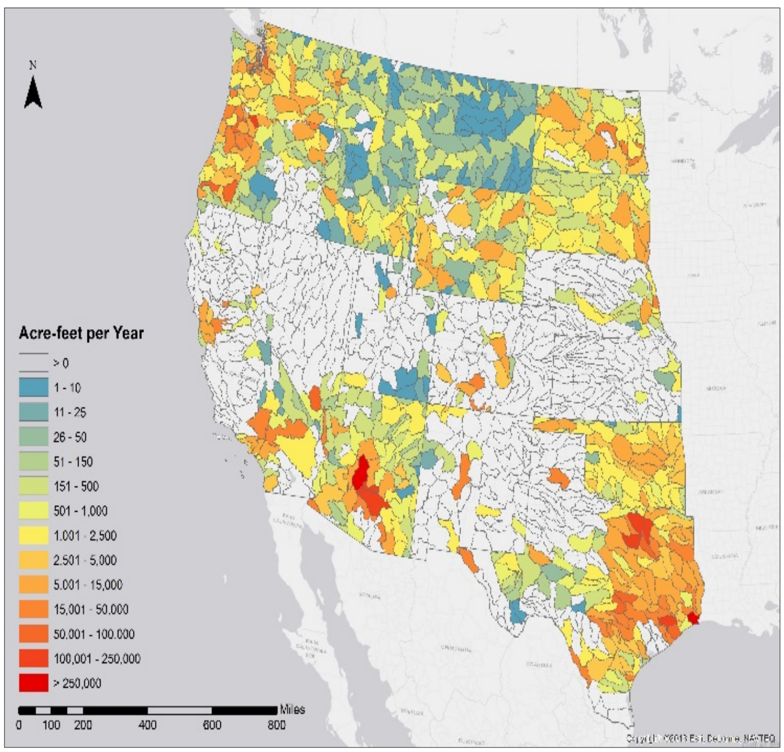


Figure 26-1. Forecasted consumptive water use for the period from 2010-2030 across 17 western states. This map is combined with other maps of water availability by source to identify regions of high water stress.

Impact: This study accounts for multiple sources of water and institutional controls and limits, estimates costs to access, treat, and convey each water source**.**

27 Analysis of High Plains Resource Risk and Economic Impacts

The area overlying the High Plains Aquifer is one of the most prolific agricultural regions in the Nation, covering 111.8 million acres (175,000 square miles) in parts of eight states—Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. As of 2007, there were 50 million acres of cropland in the High Plains, of which 15.4 million acres were irrigated supplying approximately one-fourth of the Nation's agricultural production. The aquifer also provides drinking water to 2.3 million people who live within its boundaries. Pumping has been exceeding recharge since the onset of substantial irrigation around 1950 and by 1980 had resulted in water-level declines of more than 100 feet in parts of Texas, Oklahoma, and southwestern Kansas.

The study explores how continued depletions of the High Plains Aquifer in 140 counties in Kansas and Nebraska might impact both critical infrastructure and the economy at the local, regional, and national scale. The analysis utilizes climate projections to estimate crop production, water use, and management practices to explore their related impact on the High Plains Aquifer barring any changes in water management practices, regulation, or policy. Finally, the impact of declining water levels and even exhaustion of groundwater resources are projected for specific sectors of the economy as well as particular elements of the region's critical infrastructure (Figure 27-1).

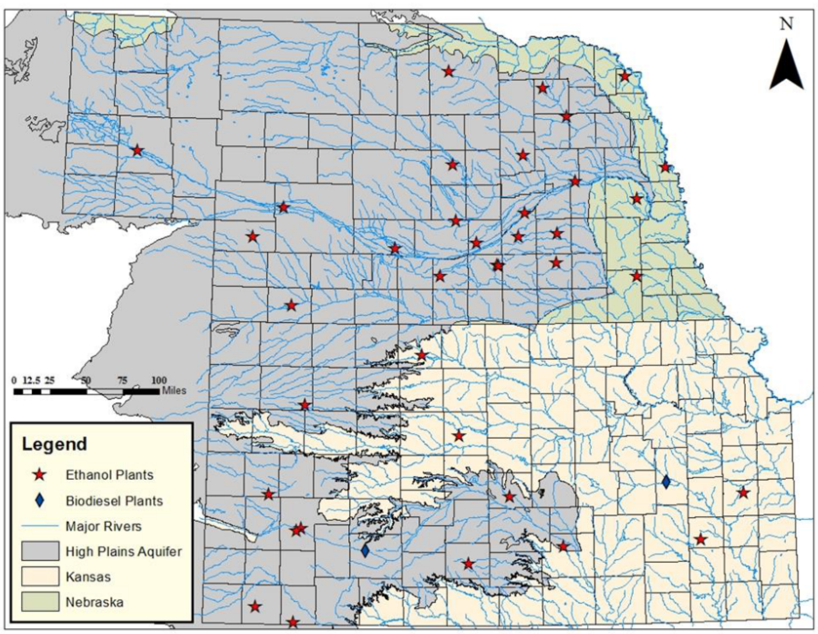


Figure 27-1. The spatial distribution of ethanol and biofuel plant locations within the study area. Changes in crop yield for corn due to climate change and water scarcity translate into economic impacts in the ethanol and biofuels industry.

Impact: This study predicts future crop yields for different climate projections to estimate the impacts to water availability in the High Plains Aquifer as well as to the economy at local, regional, and national scales. We show that declining water levels increase utility costs to the farmer, with each $1000 increase in expenditure resulting in a 2.6% increase in the probability that a farm will fail. Outside of agriculture, other impacted infrastructures include water and wastewater, chemical (ethanol production), and energy (ethanol as a transportation fuel).

28 Integrated Energy-Water Planning in the Western Texas Interconnections

While long-term regional electricity transmission planning has traditionally focused on cost, infrastructure utilization, environmental impact, and reliability, the availability of water is an emerging issue. Toward this growing need, the DOE Office of Electricity Delivery and Energy Reliability supported an integrated planning project with funding through the American Reinvestment and Recovery Act (2009) to perform to explore the potential implications of water availability and cost for long-term transmission planning. The project brought together electric transmission planners (e.g., Western Electricity Coordinating Council and the Electric Reliability Council of Texas (ERCOT)) with western water planners (e.g., Western Governors' Association and the Western States Water Council). Water use factors were developed for a range of unit processes that allowed projection of future water demands related to electric generation expansion planning as well as current and future water use for other purposes at the 8-digit Hydraulic Unit Code (HUC-8) level over 1200 watersheds. Power plants at greatest risk to the impacts of drought were identified and the electricity used to provide water-related services was mapped at a county level throughout the Western US. The data, modeling and reports generated by this project have been made publicly available through the project website: http://energy.sandia.gov/climate-earth-systems/water-security-program/water-energy-and-natural-resource-systems/energy- and-water-in-the-western-and-texas-interconnects (Figure 28-1).

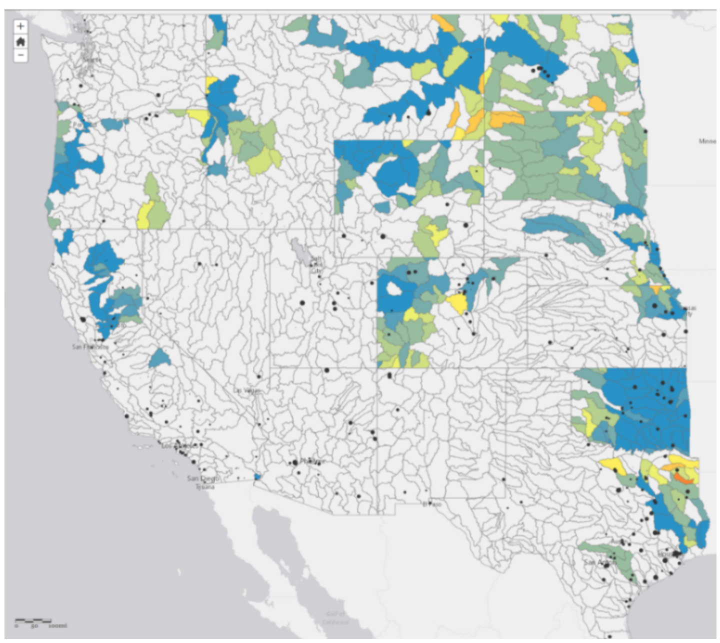


Figure 28-1. Map showing the estimated water consumption for power plants in the project area. Blue shows areas of high water usage (>250,000 AF/yr).

Impact: Sandia created a decision support tool that includes water availability to aid decision makers in electric transmission planning. The tool includes climate projections and its effect on reservoir levels and thermal effluent discharges and the resulting changes in water availability and plant efficiency**.** The tool also factors in five different sources of water that includes unappropriated surface water, unappropriated groundwater, appropriated water, municipal wastewater, and brackish groundwater

29 Upper Rio Hondo Water Availability Model

Lincoln County is located in south/central New Mexico and includes the towns of Ruidoso, Carrizozo, Alto, Ruidoso Downs, and Capitan. At an increasing rate, the area is enjoying vibrant growth and development (8% average increase in the tax base for the 10 years ending in 2007) that has begun to put stress on the area's water resources. During drought years, constrictive emergency water management options have been implemented that have had a negative impact on development and growth. Concern that predicted changes in local weather patterns due to climate change could result in further restrictions have arisen to the point where the community has become active in addressing this problem. Through the NMSBA program, Sandia constructed a SD based decision support model for water planning in the region. The model was being transparently developed through a Shared Vision Planning process, with the stakeholders actively guiding and informing the model building process. The model simulates the gross water balance within the legal framework of current water allocations and water rights to examine and analyze various conservation measures and management strategies within the municipal, agricultural, and commercial sectors. Climate impacts are modeled by hindcasting local conditions to various types of agency forecasting data and global climate indices and establishing short-term (1 to 6 months) and long-term (5 to 50 years) correlations from which future predictions can be made (Figure 29-1).

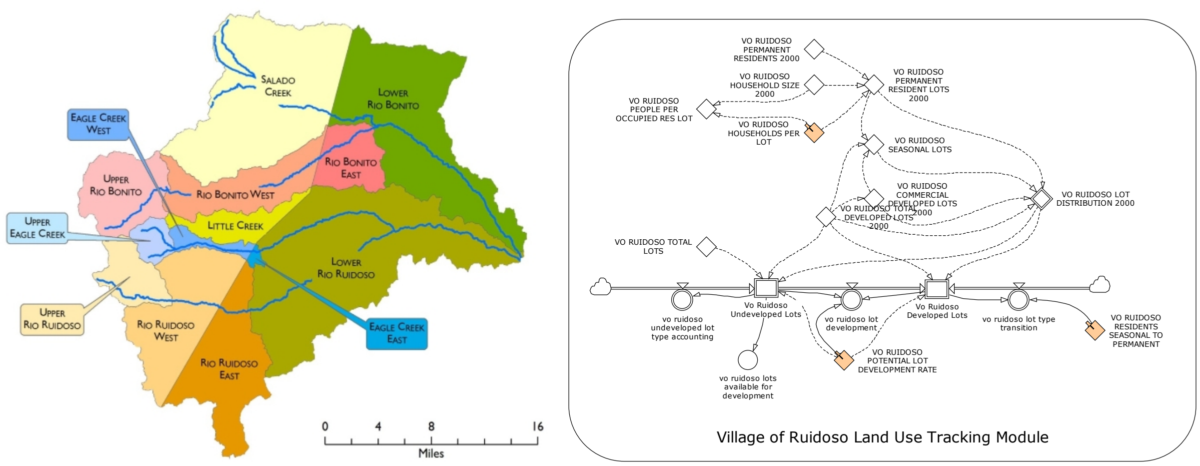


Figure 29-1. Map showing the study area in south central New Mexico (left) and the representation of the land use tracking module for the Village of Ruidoso from the SD model.

Impact: Sandia developed a SD model to examine uncertainty in water availability in the context of rapid local growth rates. It provides a means to test drought contingency and water conservation plans and uses a shared vision planning approach whereby stakeholders actively engage in guiding and informing the model building process

30 Evaluating Reservoir Operations and Other Remediation Strategies to Meet Temperature TMDL's in the Willamette Basin, Oregon

Water managers in the Willamette River Basin face a number of difficult and closely interrelated challenges associated with the Endangered Species Act, the Clean Water Act, and other associated concerns including Total Maximum Daily Load (TMDL) requirements for temperature in the Willamette Basin. Some of the major factors impacting temperature in the Willamette include operation of the multiple reservoirs, permitted industrial and municipal discharges, land-use types, and irrigation practices. Possible mitigation strategies include changes in land-use to increase shading along streams, installations to cool or store point-source discharges, changes in how and when water is released from the reservoirs, installation of multi-port withdrawal structures on the reservoirs, and remediation of riparian and hyporheic zones. Each of these strategies comes with ecological, economic, and/or social tradeoff's that must be weighed and understood before meaningful decisions can be made. This project worked with stakeholders in the basin to design and develop an integrated SD model of the basin to examine the linkages between the various strategies and their tradeoffs. Model outputs include changes in temperature at key monitoring points and costs per kcal of energy saved due to different remediation strategies, impacts on recreational opportunities and the economic impacts of those changes, and salmonid habitat suitability as it relates to temperature (Figure 30-1).

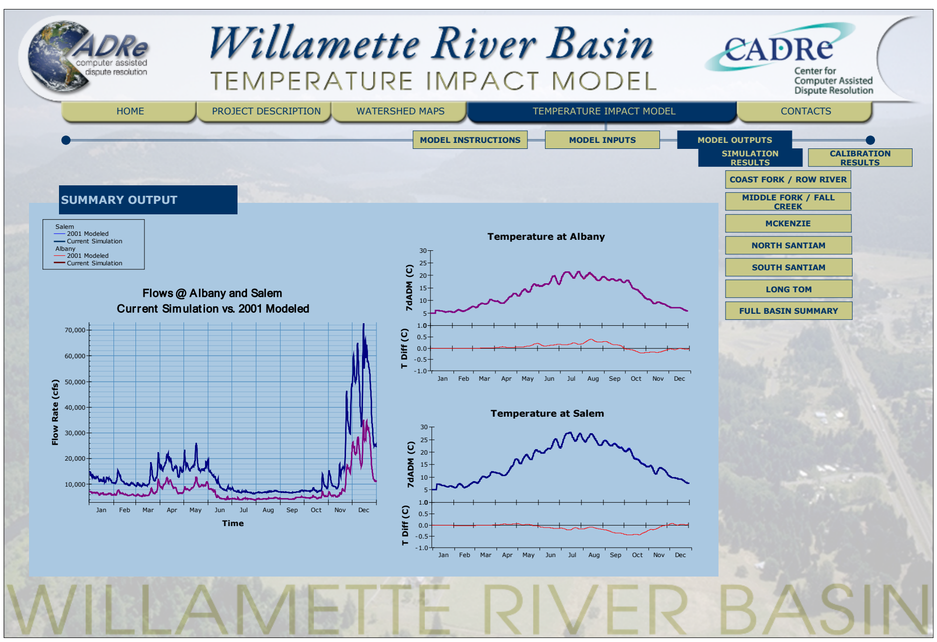


Figure 30-1. Screen shot of a model output page that shows temperature variations at key points in the basin and deviations from a 'business as usual' simulation.

Impact: Sandia created a SD model to look at the ecological, economic, and/or social tradeoffs of various strategies for meeting temperature requirements in the Willamette River**.** The model simulates temperature changes at key points in the basin, costs of remediation, changes in recreation visitation and spending, and impacts to salmonid habitat.

31 Climate Uncertainty and Implications for US State-Level Risk Assessment Through 2050

Decisions for climate policy need to take place in advance of climate science resolving all relevant uncertainties. Further, if the concern of policy is to reduce risk, then the best-estimate of climate change impacts may not be as important as the currently understood uncertainty associated with realizable conditions having high consequence. This study focuses on one of the most uncertain aspects of future climate change – precipitation – to understand the implications of uncertainty on risk and the near-term justification for interventions to mitigate the course of climate change. Ensemble climate forecasts from the Intergovernmental Panel on Climate Change's Fourth Assessment Report 4 are used as the referent for climate uncertainty over the next 40 years. A SD model is created that examines the changes in water availability, power generation, and crop yields under each instance of the ensemble. These changes are mapped to the county level to perform a detailed, seventy-industry, analysis of economic impact among the interacting lower-48 states. Industry Gross Domestic Product (GDP) and employment impacts at the state level, as well as interstate population migration, effect on personal income, and the consequences for the US trade balance are also estimated (Figure 31-1).

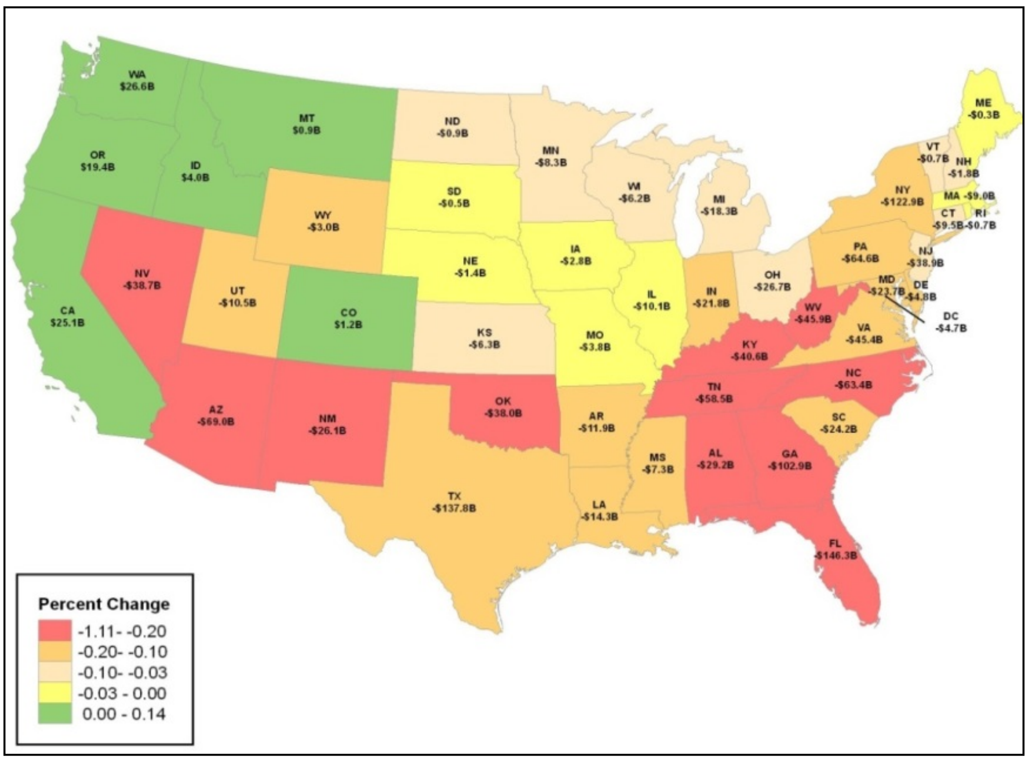


Figure 31-1. Map showing the risk to GDP ($B) from 2010-2050 by state.

Impact This project was LDRD funded at the direct request of DOE Secretary Steven Chu**.** Sandia created an integrated SD model that provides input to an economic input-output model to examine the effects of forecasted climate extremes on risk to state and national GDP's**.** The results show that the mean risk of damage to the economy from climate change is on the order of on trillion dollars with employment impacts of nearly 7 million labor-years.

32 Designing a Water Leasing Market for the Mimbres River, New Mexico

This study developed a conceptual framework for establishing water leasing markets in New Mexico using the Mimbres River as a test case. Given the past and growing stress over water in New Mexico and the Mimbres River in particular, this work developed a mechanism for the short term, efficient, temporary transfer of water from one user to another that avoids adverse effects on users not directly involved in the transaction (i.e., third party effects). Five basic tasks were performed, (1) a series of stakeholder meetings were conducted to identify and address concerns and interests of basin residents, (2) several gauges were installed on irrigation ditches to aid in the monitoring and management of water resources in the basin, (3) the hydrologic/market model and decision support interface was extended to include the Middle and Lower reaches of the Mimbres River, (4) experiments were conducted to aid in design of the water leasing market, and (5) a set of rules governing a water leasing market was drafted for future adoption by basin residents and the New Mexico Office of the State Engineer (Figure 32-1).

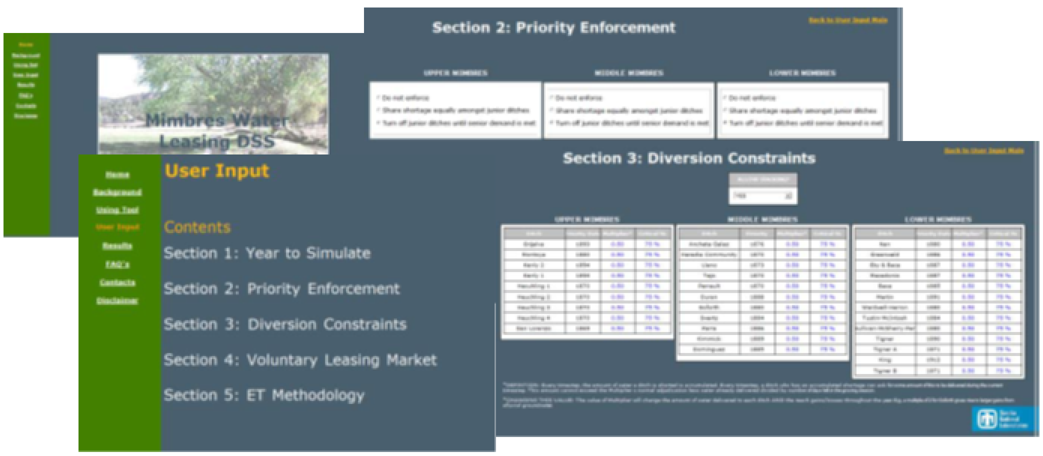


Figure 32-1. Example screen shots from the Mimbres Water Leasing Decision Support System.

Impact: Sandia created a water leasing decision support system for short term water transfers within the Mimbres River Basin**.** The tool includes stakeholder input to insure basin concerns are being met and establishes a set of rules governing a water leasing market.

33 Climate Variability and Potential Impacts on ERCOT Electricity Generation

As the availability of water becomes limited due to increased demand or reductions in supply through drought, the potential for reducing or curtailing power generation increases. Climate change within Texas is projected to increase the frequency and magnitude of drought, which complicates the decision making process with regards to long-range transmission planning. This project evaluates the impacts of future climate variability, drought scenarios, and water demand to the Electric Reliability Council of Texas' (ERCOT) grid to estimate the impacts on water availability and the corresponding reductions of power generation due to low lake levels and/or thermal effluent limitations. Includes future scenarios of varying amounts of wind production to estimate the impacts on water and power sustainability of adding renewable energy to the system (Figure 33-1).

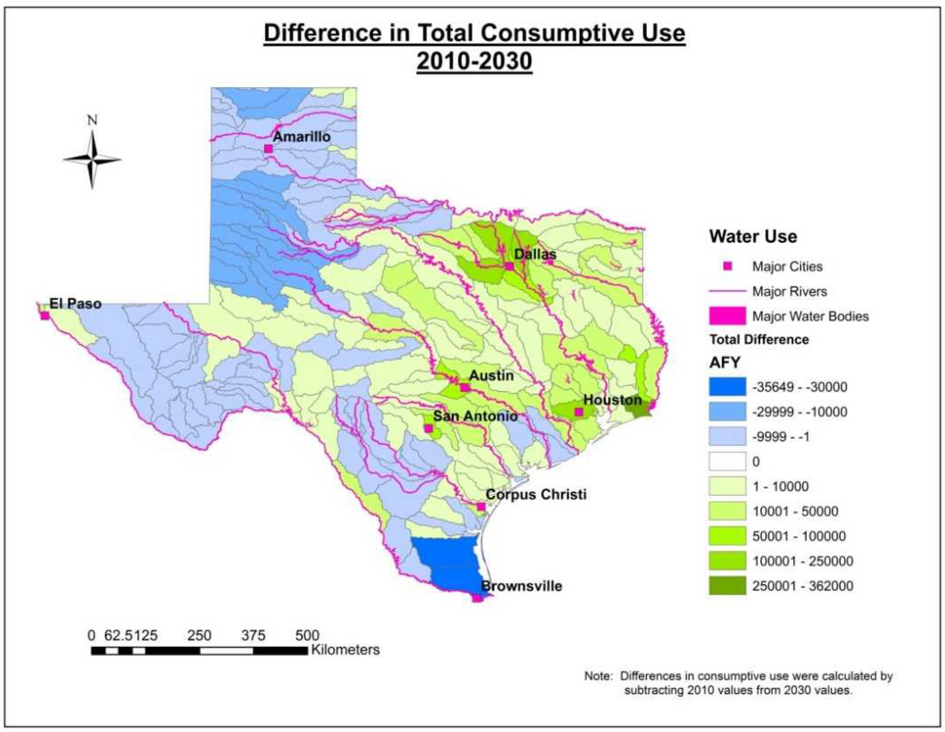


Figure 33-1. Map showing the difference in the consumptive use of water from 2010 to 2030 at the HUC-8 watershed scale. Blue indicates consumptive water use is higher in 2030 than 2010.

Impact: The study utilizes climate projections at the HUC-8 watershed level to identify the basins with the strongest potential for loss of electricity generation under different drought scenarios. A majority of generation capacity within ERCOT uses surface water cooling, which is more sensitive to climate change than other types of cooling The project was done in collaboration with Argonne and Pacific Northwest National Laboratories and the University of Texas.

34 Modeling the Gila-San Francisco Basin using System Dynamics in support of the 2004 Arizona Water Settlement Act

This work developed a computer-based simulation tool to assess the impact of additional water allocation from the Gila River and the San Francisco River prescribed in the 2004 Arizona Water Settlements Act. Between 2005 and 2010, Sandia National Laboratories engaged concerned citizens, local water stakeholders, and key federal and state agencies to collaboratively create the Gila-San Francisco Decision Support Tool. Based on principles of SD, the tool is founded on a hydrologic balance of surface water, groundwater, and their associated coupling between water resources and demands. The tool is fitted with a user interface to facilitate sensitivity studies of various water supply and demand scenarios. The model also projects the consumptive use of water in the region as well as the potential CUFA (Consumptive Use and Forbearance Agreement which stipulates when and where Arizona Water Settlements Act diversions can be made) diversion over a 26-year horizon. Scenarios are selected to enhance our understanding of the potential human impacts on the rivers' ecological health in New Mexico; in particular, different case studies thematic to water conservation, water rights, and minimum flow are tested using the model. The impact on potential CUFA diversions, agricultural consumptive use, and surface water availability are assessed relative to the changes imposed in the scenarios (Figure 34-1).

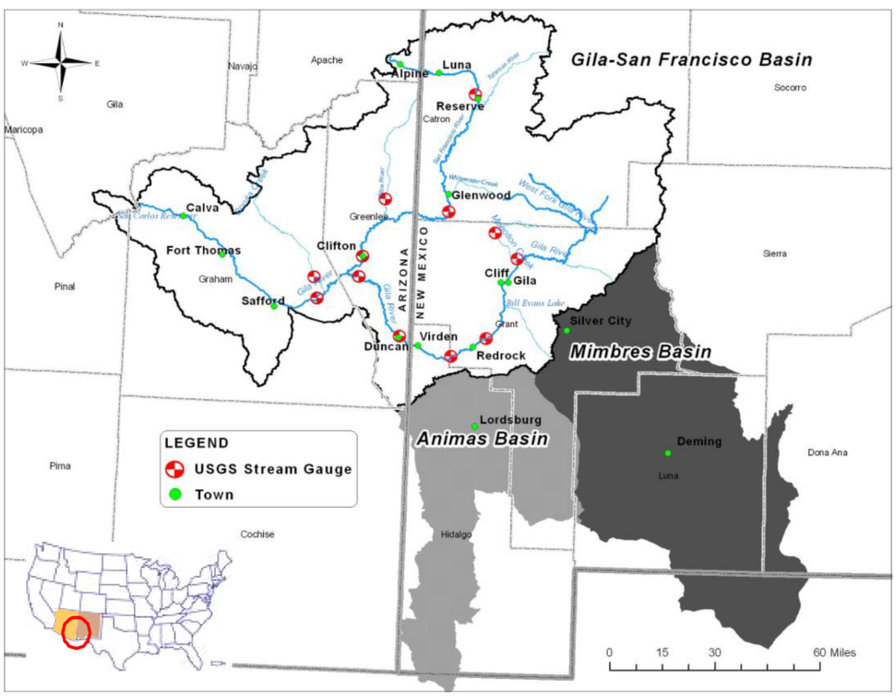


Figure 34-1. Map of the Gila-San Francisco Basin showing the primary waterways and associated gaging stations that were modeled in this project.

Impact: Sandia developed the Gila-San Francisco Decision Support tool to assess the impact of newly available water allocations to the Basins. The tool utilizes a SD framework that simulates the balance between surface water and groundwater and the respective supplies and demands and uses a collaborative modeling approach that engages stakeholders and key federal and state agencies that insures transparency and facilitates dialogue.

35 Southwest and Rocky Mountains South (SWaRMS) – Water/Energy Nexus Partnership

Energy production, resource extraction, and other high-volume water uses depend on sources that are vulnerable to extreme, coupled hydro-ecosystem-climate events such as drought, flooding, changes in snow pack, forest die off, and wildfire. The Southwest and Rocky Mountains South (SWaRMS) partnership seeks to link established modeling tools and develop next-generation capabilities to produce a unique and transferrable platform for assessing regional climate-water-ecosystem-energy issues. Supported by the DOE, this effort is engaging in a broad range of science and technology research including the development of decision support tools to aid in planning and research and development in technologies to reduce fresh water use. The objective is to improve planning, management, and conservation of fresh water among all sectors where the appropriate water is used for the appropriate application in the most efficient way possible (Figure 35-1).

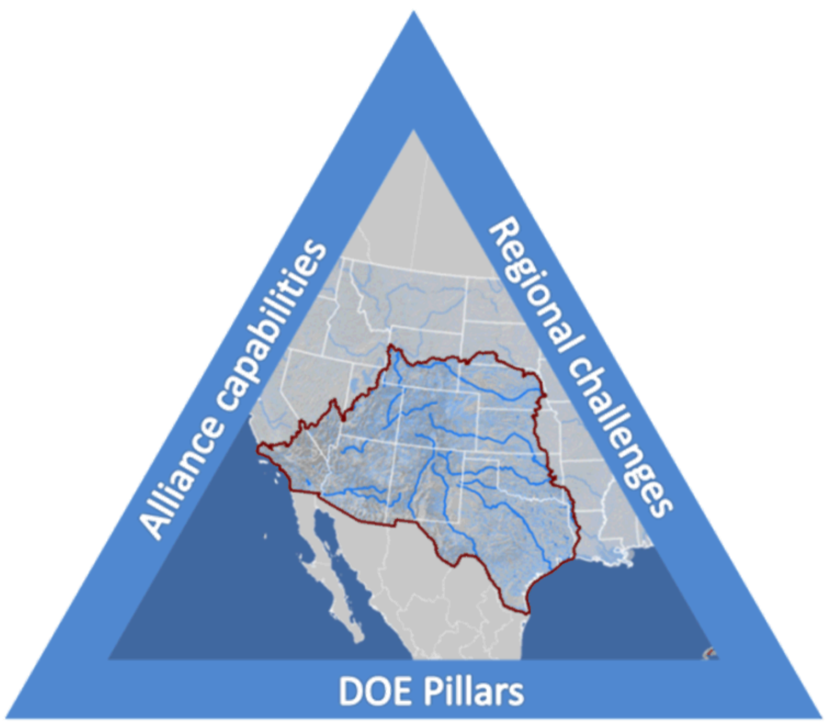


Figure 35-1. The SWaRMS partnership brings together the vast and unique capabilities of the DOE national labs to address critical regional challenges involving energy and water.

Impact: SWaRMS is a national laboratory-led consortium of regional stakeholders working together to address water-energy challenges. The focus is to insure that there is enough water for energy and enough energy for water. It is led by Sandia National Laboratories, Los Alamos National Laboratory, and the National Renewable Energy Laboratory.

36 Merging Spatially Variant Physical Process Models Under an Optimized System Dynamics Framework

The complexity of water resource issues, its interconnectedness to other systems, and the involvement of competing stakeholders often overwhelm decision-makers and inhibit the creation of clear management strategies. While a range of modeling tools and procedures exist to address these problems, they tend to be case specific and generally emphasize either a quantitative and overly analytic approach or present a qualitative dialogue-based approach lacking the ability to fully explore consequences of different policy decisions. This project developed the Computer Assisted Disputer Resolution system (CADRe) to aid in stakeholder inclusive resource planning. CADRe uniquely addresses resource concerns by developing a spatially varying SD model coupled with innovative global optimization search techniques to maximize outcomes from participatory dialogues. Ultimately, the core system architecture of CADRe serves as the cornerstone upon which key scientific innovation and challenges can be addressed Figure 36-1).

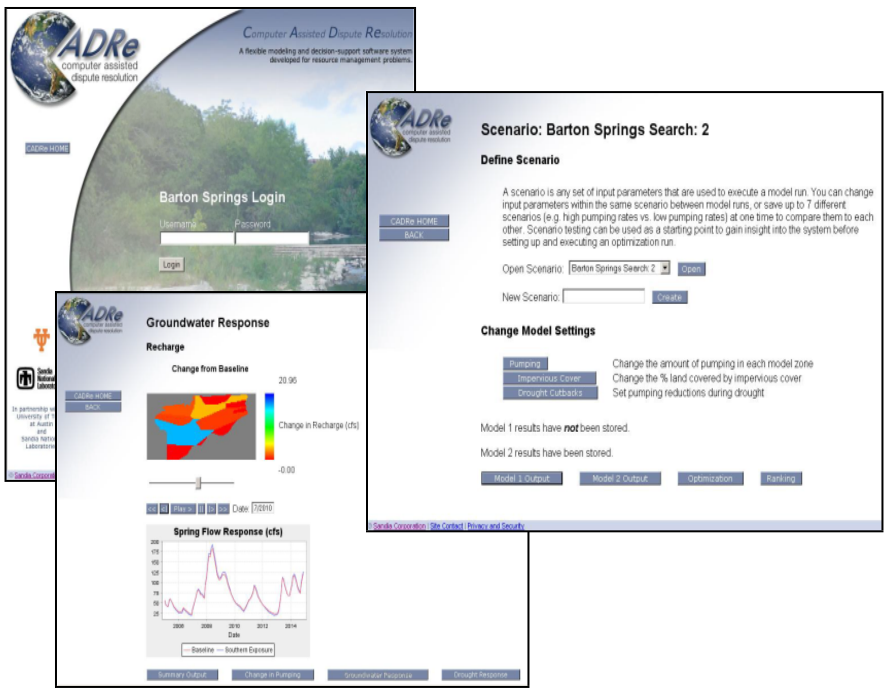


Figure 36-1. Example screen shots from the Computer Aided Dispute Resolution Decision Support System interface.

Impact: This decision support system brings together physics-based SD modeling and advanced optimization to aid decision makers and stakeholders in exploring the consequences of different policy decisions. The web based approach provides a graphical user interface the facilitates user input and provides immediate visualization of the results. It has been applied and tested with stakeholders and decision makers in the Barton Springs region of Austin, Texas.

37 Regional Water Infrastructure Model of Canterbury, New Zealand

The project developed a SD model to aid the Canterbury Regional Council in their analyses of a range of water demand, storage, distribution, and use scenarios in terms of their ability to deliver on relevant Canterbury Water Management Strategy goals and objectives. The model simulates annual and long term climate variability while assuming that the trend of future climate changes will be small relative to the historic climate variability for the 39-year simulation period (June 1972 through May 2011). The model accounts for soil types, on-farm efficiencies, the addition of supplemental storage, and aquifer recharge and discharge to and from local river systems. Outputs show the reliability of the water supply by month, delivery and pumping costs, and environmental flows at key points in the rivers (Figure 37-1).

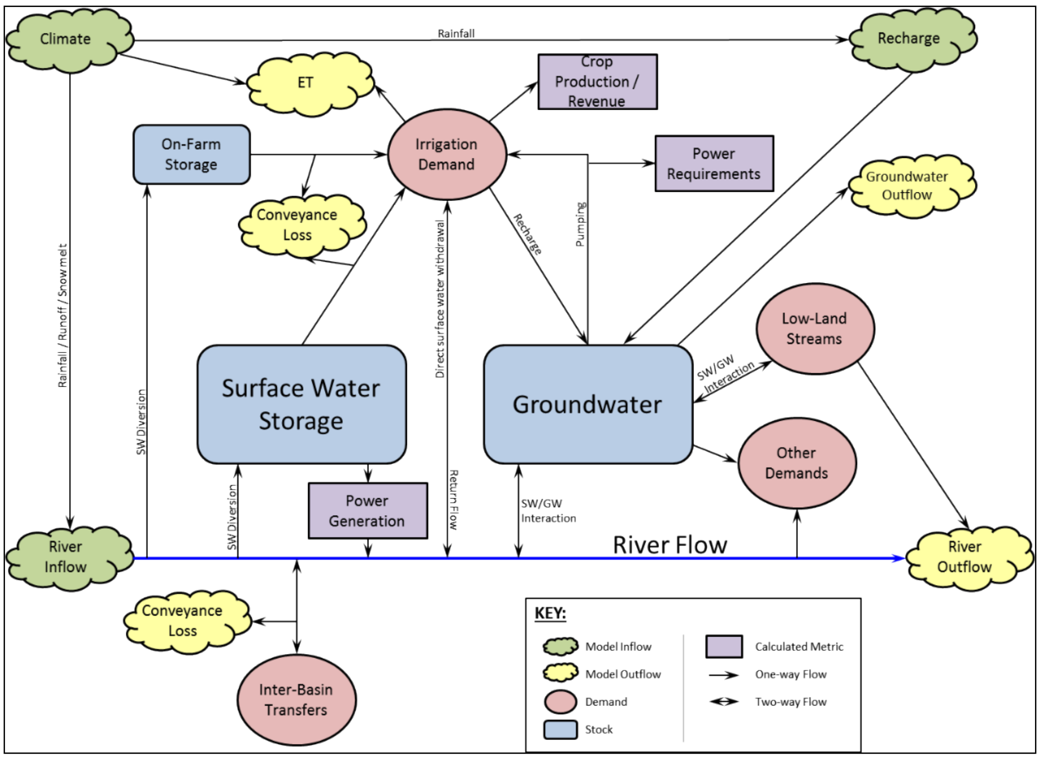


Figure 37-1. Conceptualization of the Regional Water Infrastructure Model for the Canterbury Region of New Zealand.

Impact: This coupled groundwater, surface water, irrigation model is designed to aid decision makers in long-term planning of future infrastructure investments. It is a SD-based model with a graphical user interface that provides real-time feedback to the user and includes water allocation blocks and the ability to transfer water to downstream users as well as inter-basin.

38 Systems Assessment of Water Savings Potential of Controlled Environment Agriculture (CEA) Using Wirelessly Networked Sensors

Reducing agricultural water use in arid regions while maintaining or improving economic productivity of the agriculture sector is a major challenge. CEA affords advantages in direct resource use (less land and water required) and productivity (i.e., much higher product yield and quality per unit of resources used) relative to conventional open-field practices. These advantages come at the price of higher operating complexity and costs per acre. The challenge is to implement and apply CEA such that the productivity and resource use advantages will sufficiently outweigh the higher operating costs to provide for overall benefit and viability. This project undertook an investigation of CEA for livestock forage production as a water-saving alternative to open-field forage production in arid regions. Forage production is a large consumer of fresh water in many arid regions of the world, including the southwestern US and northern Mexico. With increasing competition among uses (agriculture, municipalities, industry, recreation, ecosystems, etc.) for limited fresh water supplies, agricultural practice alternatives that can potentially maintain or enhance productivity while reducing water use warrant consideration.

The project established a pilot forage production greenhouse facility in southern New Mexico based on a relatively modest and passive (no active heating or cooling) system design pioneered in Chihuahua, Mexico. Experimental operations were initiated in August 2004 and carried over into early-FY05 to collect data and make initial assessments of operational and technical system performance, assess forage nutrition content and suitability for livestock, identify areas needing improvement, and make initial assessment of overall feasibility. The effort was supported through the joint leveraging of late-start fiscal year 2004 (FY04) LDRD funds and bundled calendar year 2004 project funding from the NMSBA program at Sandia. Collection of greenhouse environmental data in this project was uniquely facilitated through the implementation and use of a self-organizing, wirelessly networked, multi-modal sensor system array with remote cell phone data link capability. Despite lack of optimization with the project system, initial results show the dramatic water savings potential of hydroponic forage production compared with traditional irrigated open field practice. Applications of wirelessly networked sensing with improved modeling/simulation and other Sandia technologies (e.g., advanced sensing and control, embedded reasoning, modeling and simulation, materials, robotics, etc.) can potentially contribute to significant improvement in higher-value CEA applications (Figure 38-1).

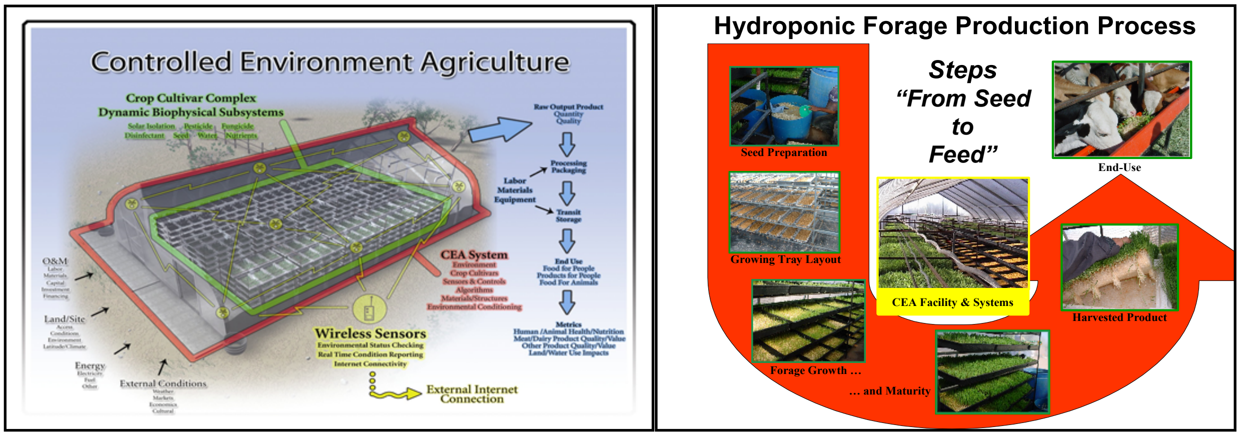


Figure 38-1. CEA Schematic (left) and Hydroponic Forage Production Process (right).

Impact: This evaluation demonstrated significant water-savings potential of CEA vs. open field ag in Southern New Mexico using hydroponic forage as an exemplar crop. The freshly harvested hydroponic forage evaluated in this project had good nutrition content, with the exception of calcium content, and compared well with more traditional forms of forage on a dry weight equivalent basis. The cost-effectiveness of forage production will depend strongly on the availability and cost of seed, labor, and water, while the water savings potential demonstrated by this project was large, with room for improvement. The viability of CEA for production of relatively low-value livestock forage is more problematic than for higher-value vegetable, fruit, and flower crops. The project demonstrated the potential for emerging wirelessly networked sensor and control technologies to potentially provide improved and higher-resolution monitoring, environmental control, and enhanced operational performance in CEA systems.

39 Integrated Bioenergy Processing System for Productive Use of New Mexico Dairy Industry Waste Streams

The State of New Mexico funded Sandia to lead a Technology Research Consortium (TRC) project during 2007-2008 to explore the potential for biofuels production in New Mexico from algae grown using dairy effluent. Sandia's partners on the project included the University of New Mexico (UNM), New Mexico State University (NMSU), and the small company Ag2Energy (A2E), who was also working closely at that time with NM dairy industry project stakeholders organized as the Pecos Valley Biomass Consortium (PVBC). The PVBC was a dairy industry group located in Roswell, NM. As a stakeholder group, the PVBC was concerned about energy, but also had an environmental awareness that the regulations being imposed on NM dairy operators would subsequently increase production costs. Thus, they also recognized the positive benefits that bioconversion of dairy wastes could offer that would enable them to be better "environmental stewards." The PVBC has had a long-term commercial interest in the possible creation of a centralized biomass processing facility to convert the wastes provided by a localized cluster of dairies into energy and other value-added products to provide additional revenue and also serve as a means of improved manure management in the region. The Sandia-led TRC project team was focused on exploring with A2E how algae biofuel production could be coupled with a proposed PVBC Dairy Waste-to-Energy project in the Roswell area to utilize the effluent from the bioprocessing (e.g., anaerobic digestion) of manure to grow algae biomass, recycle N and P nutrients, and help clean the effluent water in the process. Team partner UNM applied their algae biology expertise to help address algae cultivation and productivity, while NMSU brought chemical engineering expertise to evaluate both a conventional catalytic process as well as a supercritical methanol or CO_2 process for processing and converting microalgae to biodiesel (Figure 39-1).

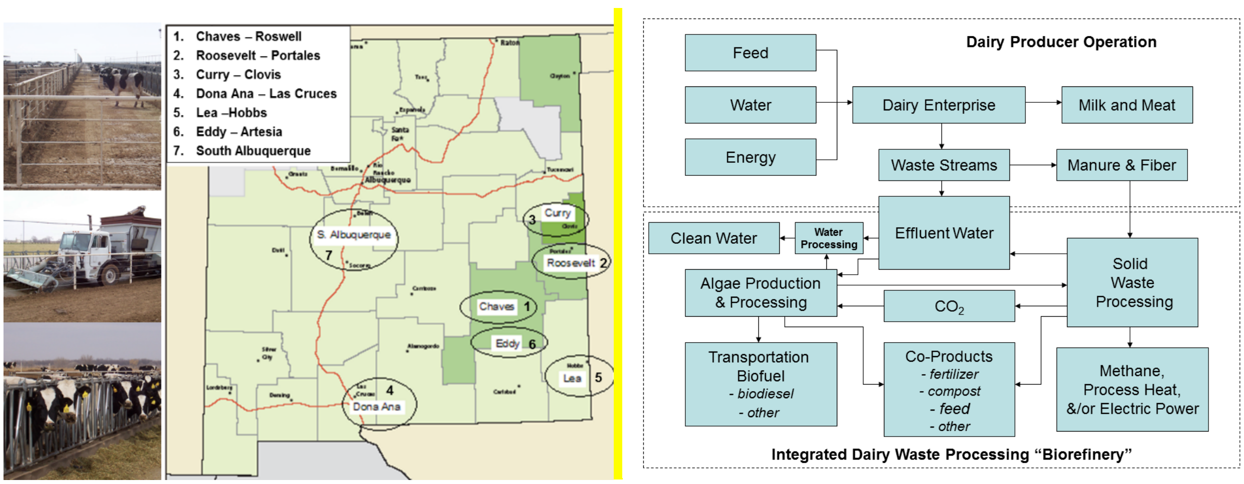


Figure 39-1. New Mexico Dairy Waste Steams and Dairy Producer Operation Schematic.

Impact: Potential for the production of energy and revenue from NM dairy industry waste streams. Improved environmental management of agricultural wastes in NM. Potential for environmentally beneficial nutrient recycling and cleaning and reclaiming dairy effluent water for other downstream uses. Potential for production of biofuels or other bio-products from algae biomass.

40 Algae Biofuels Resource Demand Assessment and Techno-Economic Modeling and Feasibility Analysis Project

From 2008 through 2011, Sandia conducted combined systems modeling and geographic information system (GIS) analysis to assess resource demand and preliminary techno-economics of algae cultivation, processing, and conversion to fuels and co-products in support of the DOE/Energy Efficiency Renewable Energy (EERE) Office of Biomass Program. Selected results from this work were included in the National Algae Biofuels Technology Roadmap Report publically released by DOE in June 2010 (Figure 40-1).

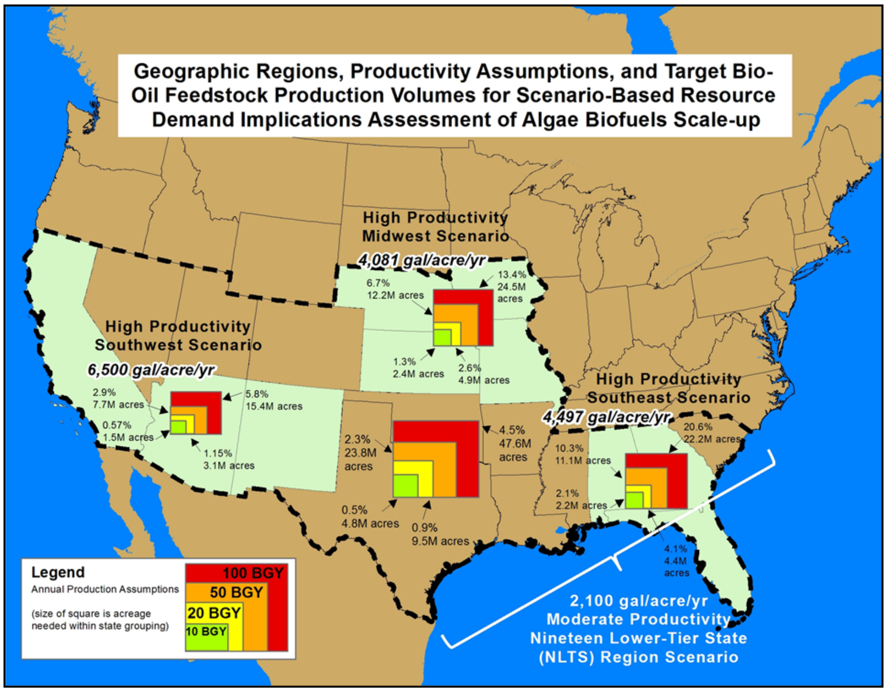


Figure 40-1. Geographic Regions, Productivity Assumptions and Target Bio-Oil Feedstock Production Volumes for Scenario-Based Resource Demand Implications Assessment of Algae Biofuels Scale-Up.

Impact: This assessment provided a high-level scenario-based assessment of the demands that can be expected on land, water, major nutrients (N, P), and CO_2 as a consequence of large volume national scale-up of algae biofuels production. We showed land requirements for algae production scale-up are likely to be the most manageable of the resource demands considered. Meanwhile, water requirements for algae production scale-up under evaporative loss conditions represent a significant challenge with limited fresh-water resources, depending on the geographical region. In addition, the demand for Nutrients (N & P) represent a very significant challenge for algae biofuels production scale-up that would seriously compete with agriculture for commercial fertilizer use, unless nutrient recycling is implemented. Finally, carbon dioxide requirements appear to be the most significant challenge to algae biofuels scale-up, and can be expected to severely constrain the extent to which CO_2-enhanced algae biomass and oil feedstock production can be affordably scaled in the US. Our conclusions, based on SNL's first-order analysis, are that CO_2 and nutrient (N, P) requirements, in particular, will likely emerge as constraints for autotrophic algae biofuels scale-up in the US as nationally aggregated oil feedstock production levels approach 5 to 10 billion gallons per year (BGY).

41 Algae Biofuels Technology Roadmap

Sandia National Laboratories and the National Renewable Energy Laboratory (NREL) were specifically tasked by the DOE/EERE Bioenergy Program Office to help lead the organization and execution of a DOE-sponsored workshop to assess the opportunities and challenges for the production of biofuels from algae. As a family of rapidly growing aquatic species, the use of algae and cyanobacteria for biofuels falls under the umbrella of energy-water nexus, where they have been viewed for many years as promising feedstock for fuels that could use impaired and non-fresh water sources and lower quality land resources. DOE funded the $25M Aquatic Species Program from the late-1970s to the early-1990s to explore the potential of algae for biofuels, but ended the program in 1996 due to the low price of petroleum, significant technical challenges, and other higher priorities for funding at DOE at that time. Beginning in the early-to-mid 2000s, significant renewed interest in algae biofuels emerged domestically and internationally, driven by high petroleum prices, concern about US dependence on oil imports, growing concern about the climate change impacts of fossil fuel combustion, and the availability of new biotechnology tools and capabilities to better address the challenges encountered during the Aquatic Species Program. DOE determined in 2008 that they should take a renewed look at algae by convening a National Roadmap Workshop. The three-day workshop was held in the Washington, DC area in December 2008. The event brought together approximately 200 experts from around the country to explore the current state of technology and the key needs, gaps, opportunities, and challenges for algae cultivation and conversion to fuels. This led to the development of DOE's National Algal Biofuels Technology Roadmap Report that was publically released in June 2010. SNL played a major role in the writing of several sections of the report, and has subsequently played a significant role in DOE's renewed research and development program in algae biofuels which began in FY2009 and has been substantially guided by the Algae Roadmap Report. DOE investments in algae biofuels during the 2009-2015 period are on the order of $350M. An update to the original 2010 Algae Roadmap, also contributed to by Sandia National Laboratories, is scheduled for publication in 2016 (Figure 41-1).

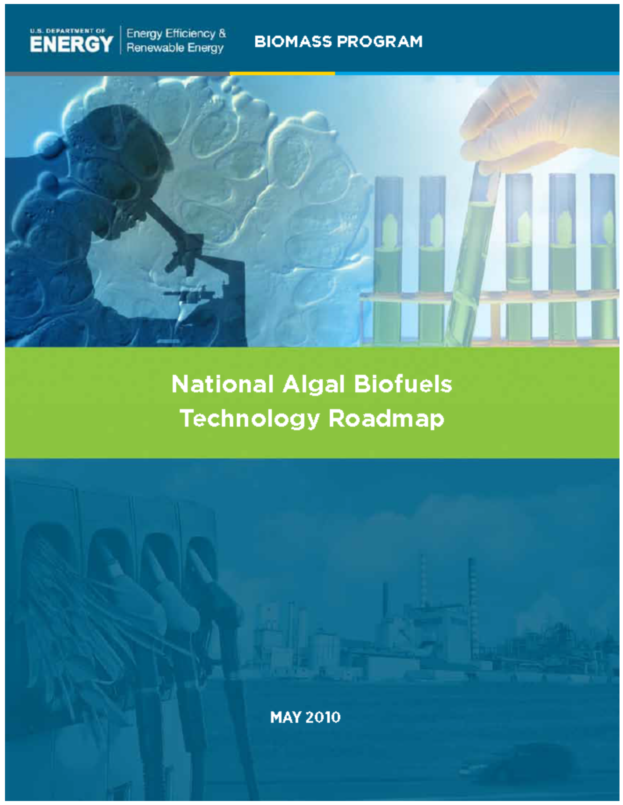
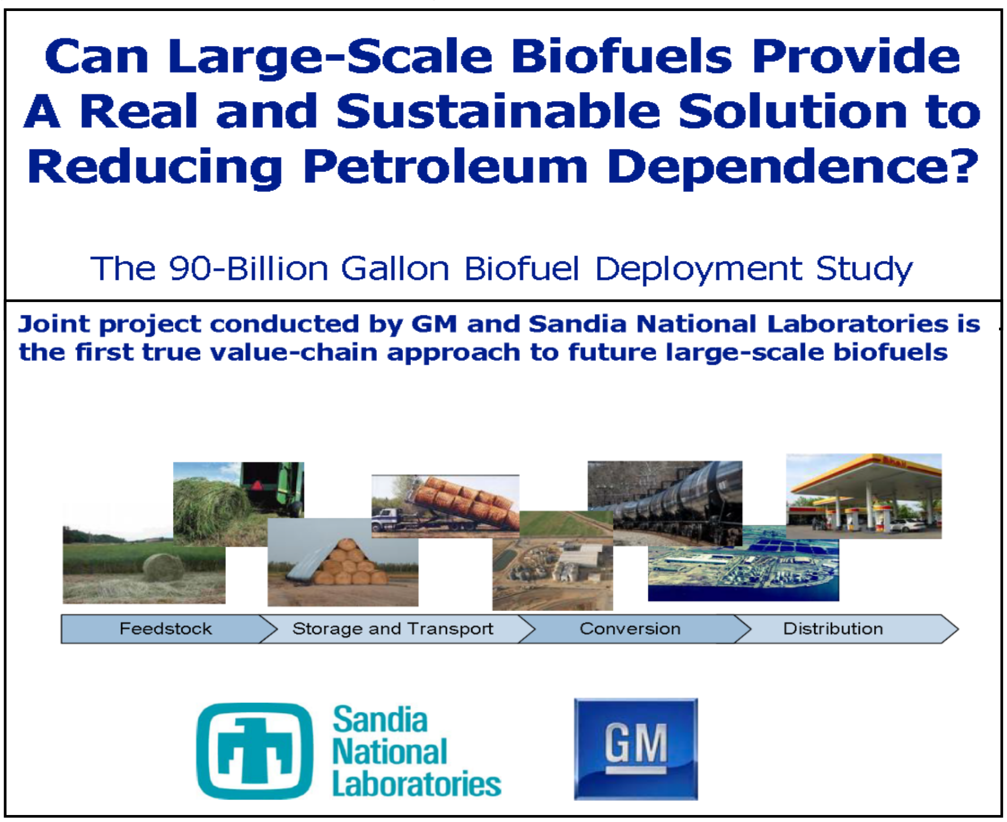


Figure 41-1. National Algal Biofuels Technology Roadmap Cover.

Impact: The roadmap established an updated assessment of the state-of-technology and key needs, gaps, opportunities, and challenges for creating nationally significant volumes of advanced liquid transportation biofuels from algae. It initiated and helped to guide a new national research and development program for algae biofuels in the DOE/EERE Bioenergy Technologies Office, which succeeded the earlier DOE-funded Aquatic Species Program. Ultimately, there has been over $350M in DOE research and development funding through Bioenergy Technologies Office for algae biofuels related projects from 2009-2016, as well as other support for the advanced biofuels industry.

42 Sandia-GM Biofuel Deployment Model

General Motors (GM) and Sandia entered into a joint 8-month project in 2008 to employ SD modeling and analysis to determine whether biofuels can be scaled to a level on the order of 90 billion gallons per year to provide a sustainable solution to reducing US dependence on petroleum-based fuels. The study took a value-chain system approach from feedstock production through conversion to distribution of finished fuel product. Direct input of information and data for the project also came from other labs (Argonne National Laboratories, Idaho National Energy Laboratory, National Renewable Energy Laboratory, Oak Ridge National Laboratory), universities (Purdue), federal agencies (DOE, US Department of Agriculture (USDA)), and private industry (Ceres, Mendel Biotechnology, John Deere, Poet, Coskata, Mascoma, Kinder-Morgan, and Union Pacific). The study sought answers to the four key questions: 1) What must happen to grow ethanol production to 90B gal by 2030?; 2) What is required for cellulosic ethanol to be cost competitive with gasoline?; 3) What are the greenhouse gas, energy, and water footprints associated with this level of ethanol production?; and 4) What risks could impact cellulosic ethanol's production and competitiveness goals and how can we mitigate these? The SNL-GM team built a "seed to station" SD model to explore the feasibility of scaling up to the production of 90 billion gallons of ethanol fuel per year in the US using a range of assumptions for price of petroleum, yield and cost of cellulosic biomass feedstock and production of ethanol. The time from for the study was out to 2030, with a state-level geographic granularity. The model was used to understand how key variables affect the cost and volume of ethanol production from biomass sources and how these variables may interact. It also allowed a study of variable sensitivity to provide a better understanding of the forces at work in the development of a national



bioethanol production capability (Figure 42-1).

Figure 42-1. Sustainability of Large Scale Biofuels.

Impact: The study found that Feedstocks for 60B gallons of cellulosic ethanol can be grown in states requiring little or no irrigation. In addition, we determined that 90B gal of biofuels would require only 7% of total 2030 water consumption, while US food and feed production requires 70%. Large-scale cellulosic biofuel production can be achieved at/below current water consumption levels of petroleum fuels from on-shore oil production and refining. Using cellulosic ethanol in transportation consumes only one-fourth of the fossil fuels as gasoline, on a well-to-wheels basis (numbers based, in part, on assumptions in Argonne National Laboratory's GREET model). 90B gallons of ethanol provide annual Greenhouse Gas (GHG) savings of 400 million tonnes of CO_2e per year (excluding GHG emissions from land use change) equivalent to 87 coal-fired power plants. There are no fundamental barriers to large-scale production of biofuels (e.g., supply chain or water constraints), assuming the technology matures as projected. There are supportive policies needed, including well-planned market incentives and carbon pricing, to minimize investment risks in light of oil price volatility and periodic economic dislocations. Finally, enhanced research and development and commercialization-associated funding is needed, despite current declining/low oil prices.

43 DARPA Biofuels Project

The Department of Defense, Defense Advanced Research Projects Agency (DARPA) initiated a competitive research and development program in 2006 focused on the production of military fuel from renewable biological (plant and animal based) sources of oil feedstock. Several winning teams were each funded at multi-million dollar levels for 18-month duration projects to explore different pathways for potentially achieving affordable and sustainable scale-up of fuels capable of meeting the volume and quality demands of the US military. Sandia was partnered on a winning team led by the refining technology company UOP that included the additional partner organizations Cargill, Southwest Research Institute, Honeywell Aerospace, Arizona State University (ASU), and several others. ASU, Cargill, and Sandia were specifically tasked to evaluate the technical, economic, and environmental interdependencies of supplying bio-oil feedstock from plant and animal sources, including various oil seed crops and algae. Sandia National Laboratories was tasked with conducting comparative technical and economic analyses and tradeoff assessments, and assessing the scale-up feasibility, of achieving high-volume bio-oil feedstock and JP-8 fuel production from oil-rich microalgae and other suitable oil crops and waste oil streams. Sandia worked with Cargill to specifically address issues and options for the necessary expansion of reliable and cost-competitive oil crop production and oil feedstock processing. This include evaluation of promising oil crops that will not directly compete with food and feed markets, can avoid the use of higher-quality agricultural land, and may also allow for reduced demand for energy, fresh water, and other inputs. Sandia also worked closely with ASU on algae production system and process engineering performance and cost analyses. The goal of this effort was to provide an objective evaluation of the performance, costs, and feasibility of scale-up of algal biomass and oil feedstock production systems using selected alga strains that can potentially provide reliable and competitively priced algal oil suitable for conversion into military jet fuel. The project team lead, UOP, and other down-stream testing partners at Honeywell and Southwest Research Institute (SWRI), were more specifically focused on the development and testing of the processing, conversion processes, and technologies to demonstrate the ability to cost-effectively produce drop-in equivalent renewable jet and diesel fuels capable of meeting military specifications (Figure 43-1).

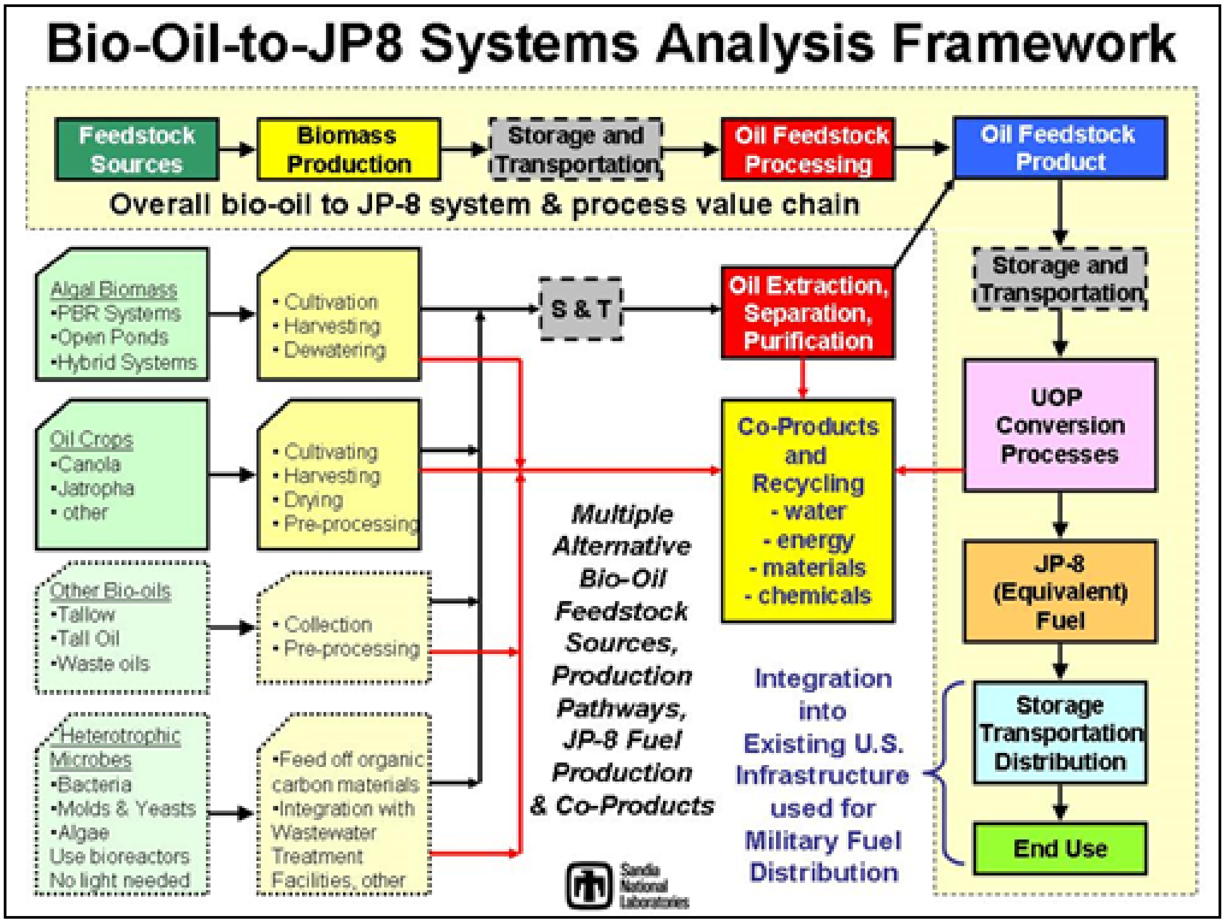


Figure 43-1. Bio-Oil to JP* Systems Analysis Framework.

Impact: The project achieved the successful development and testing of UOP's "Eco-Fining" technology and processes for converting plant and animal based oil feedstocks into renewable jet and diesel fuels capable of meeting military specifications. The analyses performed on renewable bio-oil feedstock scale-up potential demonstrated that sufficient volumes of fuel production to meet military needs can potentially be provided in a sustainable way from a combination of various non-food oil crops, animal fats, and other waste oil streams. Finally, the initial technoeconomic assessment suggesting that renewable military grade biofuels from bio-oil sources can be relatively affordable, depending on the feedstock source and the cost of conventional petroleum fuels.

44 Algae Testbed Public-Private Partnership (ATP^3) Project

The Algae Testbed Public-Private Partnership (ATP^3) project was made possible by a $15 million DOE competitive grant from its Bioenergy Technologies Office (BETO). The project was initiated in FY13 as a five-year effort led by the Arizona Center for Algae Technology and Innovation at ASU in partnership with the National Renewable Energy Laboratory, Sandia National Laboratories, Cellana, Florida Algae, Valicor Renewables, California Polytechnic University at San Luis Obispo, Georgia Institute of Technology, University of Texas at Austin, and Commercial Algae Management. The mutual goals of the partners were to facilitate innovation, empower knowledge creation, and accelerate growth of the emergent algal energy industry via a high-level collaboration among the partners to provide access to testing facilities, laboratory capabilities and expertise, and resulting test data to the broader algae research and development community. The DOE funding allowed ATP3 to support the operation of existing outdoor algae cultivation systems and produce algae that can be used for real-world solutions such as biofuels and bio-products. Sandia personnel held key positions on the ATP3 Executive Team (e.g., Ron Pate as Deputy Director and Liaison with the ATP3 Technical Advisory Board) and Technical Task Leads (e.g. Todd Land for Metagenomics and Cultivation Crash Forensics, Jeri Timlin and Tom Reichardt for Spectroradiometric Monitoring of Algae Cultivation Performance, and Tricia Gharagozloo for Dynamic Modeling of Algae Cultivation Systems and Operations Performance) (Figure 44-1).

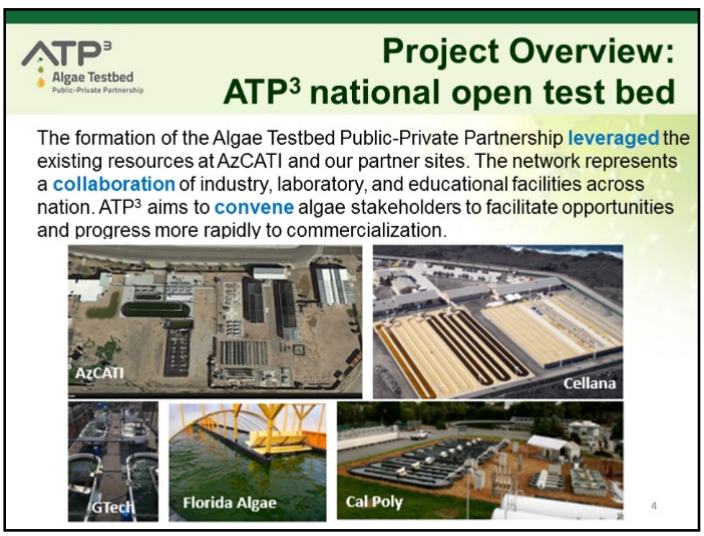


Figure 44-1. ATP^3 National Open Test Bed.

Impact: This project established DOE/EERE BETO's first national testbed for algae biofuels and bioproducts research and development using existing closed and outdoor test facilities in different geographical and climate regions of the US. In addition, it (1) established standardized testing and data analysis procedures, protocols, and operational practices coordinated across multiple test sites; (2) conducted harmonized algal cultivation and analysis experiments to provide algae biomass productivity and quality data for selected species from the ATP3 testbed consortium sites; (3) established a high-quality professional algae education and training workshop curriculum and held quarterly technical workshops to both paying and subsidized customers; and (4) Provided unique test facilities and support capabilities, through the ATP3 partnership, to support algae biofuels and bioproducts related research, technology development, and testing with interested industry and university users on both a pay-for-service and subsidized basis.

45 Polyculture Algae Productivity Project

Beginning in late-FY2013, SNL received funding from the DOE/EERE BETO to explore the potential of polyculture algae as an alternative approach for algae biofuels. The goal was to take advantage of the superior resilience of polyculture, relative to monoculture, to provide resistance to cultivation crashes and loss of productivity due to predators, pathogens, and seasonal variations in growing conditions. From a practical point of view, the polyculture algae cultivation approach of growing benthic algal turf in engineered systems like the Algae Turf Scrubber®, which are scalable and have been commercialized for cleaning surface water bodies, seemed to be a preferred approach. During FY14-FY15, Sandia began investigating the potential for polyculture algal turf biomass to be processed and converted to fuel intermediates using biochemical and thermochemical hydrothermal liquefaction (HTL) approaches. Testing at bench scale confirmed that the whole algal biomass could be converted by HTL to biocrude product with relatively high efficiency, and that the protein and carbohydrate fractions of the biomass, which make up the majority of the polyculture algal turf, could be converted to fuel alcohols with high efficiency using SNL-developed biochemical processing steps. Sandia technoeconomic assessment (TEA) and resource assessment analyses also identified the potential path for the cost-effective scale-up of fuel production in the US to the billion gallons of gasoline equivalent (GGE) per year level. Beginning in FY16 and continuing in FY17, Sandia's project emphasis has moved upstream to establish, monitor, and assess the performance of pilot-scale algal turf cultivation systems with partners in Texas (Texas A&M AgriLife in Corpus Chrisi) and California (Imperial Valley Conservation Research Center in Brawley, California and the Imperial Irrigation District). Of particular environmental remediation interest in California is the potential for Algae Turf Scrubber® (ATS) technology to remove selenium from the river inflow to the Salton Sea (Figure 45-1).

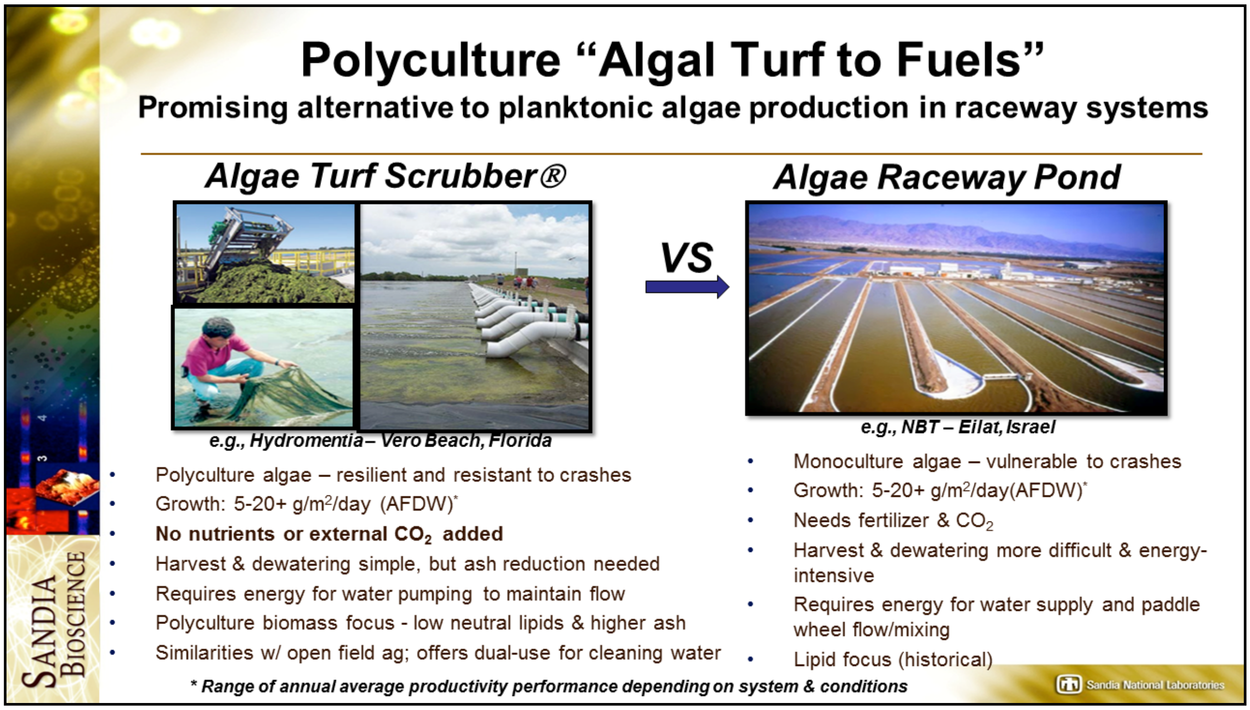


Figure 45-1. Polyculture Algal Turf to Fuels.

Impact: This alternative approach to monoculture algae biofuels production can potentially avoid several of the major logistical, performance, and cost challenges facing the affordable scale-up of algae biofuels. It utilizes robust polyculture algae biomass production using established, commercialized, and scalable ATSTM systems technology that offers the dual-use capability of cleaning surface waters from fresh, estuarine, or saline/marine sources that are contaminated with excess nutrients (N, P, C, etc.). Further it has the potential to cost-effectively produce large volumes of algae biomass that can be used as feedstock for biofuels and bioproducts while providing the environmental service benefit of cleaning surface waters from rivers, lakes, estuaries, coastal marine bays, as well as municipal and agricultural waste water. SNL has demonstrated: (1) at laboratory bench scale, the potential for efficient biochemical and/or thermochemical (hydrothermal liquefaction: HTL) conversion of the entire algae biomass to fuel intermediates and (2) through initial TEA and GIS resource assessment the potential for economically-viable "algal turf to fuels" scale-up to one or more billion GGE fuel per year from the Southeastern US region of the Gulf Coast and Mississippi River watershed. SNL is currently (FY16-FY17) monitoring and assessing the algae biomass productivity and water cleaning contaminate-removal performance of pilot-scale ATS systems operating with marine water in Corpus Christi, Texas and relatively fresh agricultural runoff river water in the Imperial Valley of California.

46 Climate Change Impacts on Agriculture and Ecosystems in SE US

Sandia's National Infrastructure Systems Analysis Center conducted a survey assessment funded by the US Department of Homeland Security on the possible impacts of climate change and extreme weather events on agriculture, ecosystems, and key related infrastructure in the Southeastern US (Federal Emergency Management Agency (FEMA) Region IV). This region consists of the eight (8) states of Alabama, Georgia, Florida, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee. Several of these states are among the nation's leaders in the production of agricultural products that include poultry and eggs, hogs and pigs, nursery and greenhouse floriculture, cotton and cotton seed, vegetables, melons, potatoes and sweet potatoes, and hay and other crops. The purpose and scope focused on five key questions: 1) How might climate in Region IV vary in the future?; 2) How will variations in climate potentially affect agriculture and ecosystems in the future? ; 3) What are the existing plans for dealing with the potential impacts of climate? ; 4) When is climate variability likely to begin affecting the regional economy and critical infrastructure? ; 5) How could a climate-related threat in the form of a disease/pest potentially affect agricultural production and ecosystems ? Additional and more detailed assessment was also done for the State of Florida using a case study example driven by interest in the impacts of Citrus Greening Disease on Florida Citrus Industry. The case study consisted of an initial economic analysis of farm exits in Florida using data from USDA/ National Agricultural Statistics Service (NASS) Census of Agriculture from 1982 – 2012 (Figure 46-1).

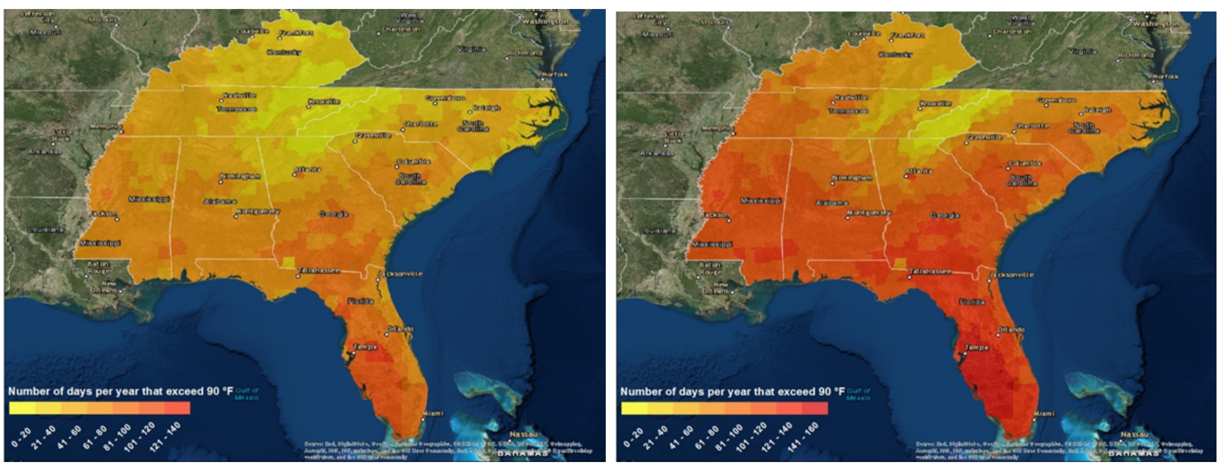


Figure 46-1. Annual Average Days w/ Temperatures ≥ 90°F projected change for 2030-2040 vs. 1980-1990.

Impact: Over the next two to five decades, portions of FEMA Region IV—Alabama, Georgia, Mississippi, and North Carolina —will likely experience significant increases in the number of days above 90°F with high humidity (extreme heat index). The region will also see increases in extreme weather events such as floods, droughts, severe storms, and rising sea levels for coastal states due to climate change. Extended periods of extreme heat will likely increase heat-related mortality in agricultural animals, electricity demand, water demand, and energy system efficiency. Labor productivity will be reduced in outdoor operations such as agriculture and forestry. These changes will likely impact agricultural operations through higher production and cold storage costs. In all FEMA Region IV states, an increased frequency of extreme heat events will likely decrease crop yields and outdoor agricultural labor productivity. Extreme heat will impact poultry production, which requires air-conditioned poultry houses, and contribute significantly to an overall increase in energy demand for cooling. Coastal ecosystem and infrastructure damage is projected from extreme storm surges and sea level rise. Further, the composition of the agriculture industry in Florida may change significantly in response to extreme weather events and increased risk from the spread of invasive species, such as huanglongbing (HLB), to specialized crops such as citrus. Net farm exit rates have historically been lower in Florida than other areas of the US. Many factors influence exit rates, and preliminary analysis of Florida farm exits indicate farm specialization and socioeconomic factors play major roles in the likelihood of exit. Hog production, field crops, and dairy production are ag categories with the lowest exit rates in Florida, indicating they may have greater resilience to stresses related to extreme weather events and may be a logical shift for agricultural production with the possible decline of specialty crops such as citrus.

47 Carbon Sequestration Source-Sink Matching and Cost Model

A team of collaborators within DOE's Southwest Regional Partnership on Carbon Sequestration developed an interactive software tool to help facilitate discussions involving the science, engineering, economic and policy considerations for a carbon sequestration pilot project. This project created the Integrated Assessment model, and highlights the 'String of Pearls' network algorithm used to develop a potential carbon dioxide (CO_2) transportation network in sequence with existing infrastructure. The model assesses geological sink choices according to their distance from the point source (e.g., power plants), relative size (to maintain a useful fill lifetime for a project under consideration), relative distance from existing CO_2 transportation infrastructure such as pipelines, and other salient project attributes. It includes the cost to capture CO_2 at point sources and the transportation and storage system's costs to help planners when deciding where to develop future carbon sequestration projects or power plants (Figure 47-1).

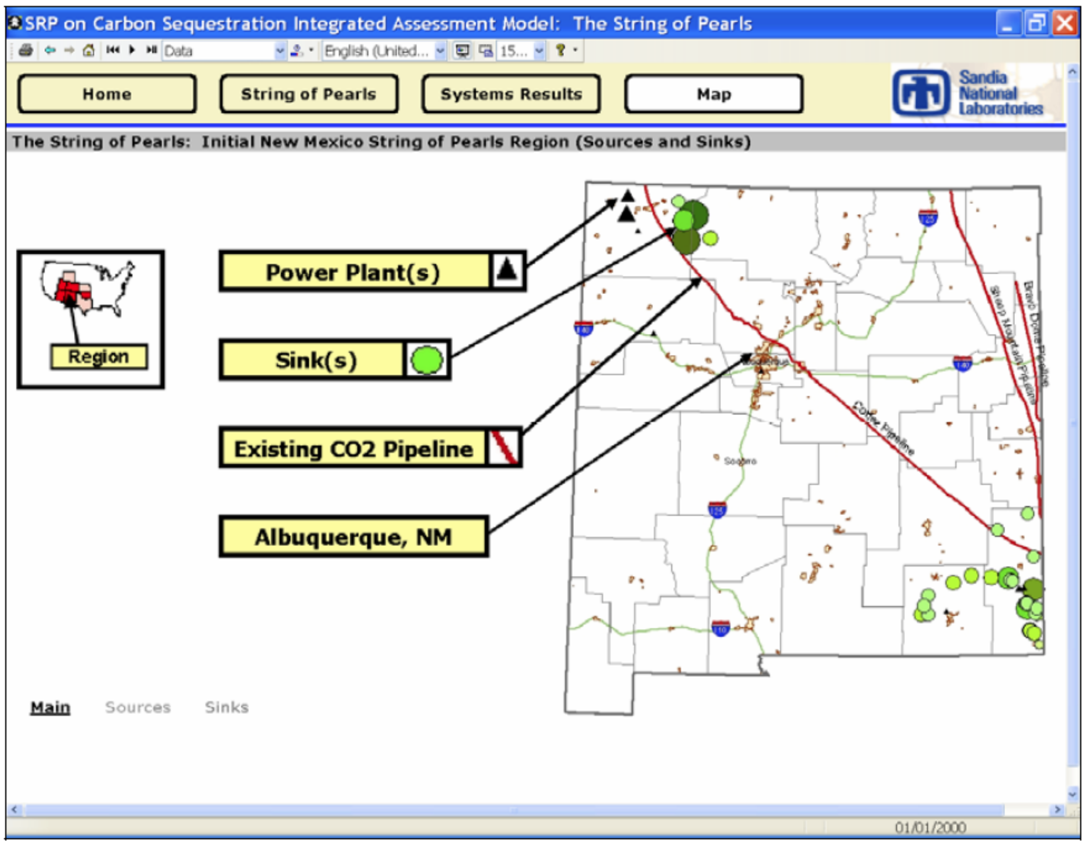


Figure 47-1. Map of the CO2 sources (power plants) and geological sinks considered in the New Mexico prototype of the Integrated Assessment 'String of Pearls' model.

Impact: This model uses a SD framework with a user friendly interface. It supports decision makers, policy analysts, and interested parties with power plant and carbon sequestration siting decisions by considering current plant locations, sink availability, existing pipeline infrastructure and right-of-ways.

48 Strategy for Water and Land Resources in Iraq Model

This model was built in collaboration with the US Department of State, United Nations Educational, Scientific and Cultural Organization (UNESCO), and Iraqi engineers and scientists to assist the Government of Iraq in long range national planning for investments into water and agriculture-related infrastructure for water. The model simulates monthly flows from the upper watershed in Turkey and Syria into and through Iraq. The model uses historic data sets from 1930-2007 and projects historic discharge data into the future for future simulation. The model was especially helpful in simulating the potential impact of various reservoir project in Iraq (Figure 48-1).

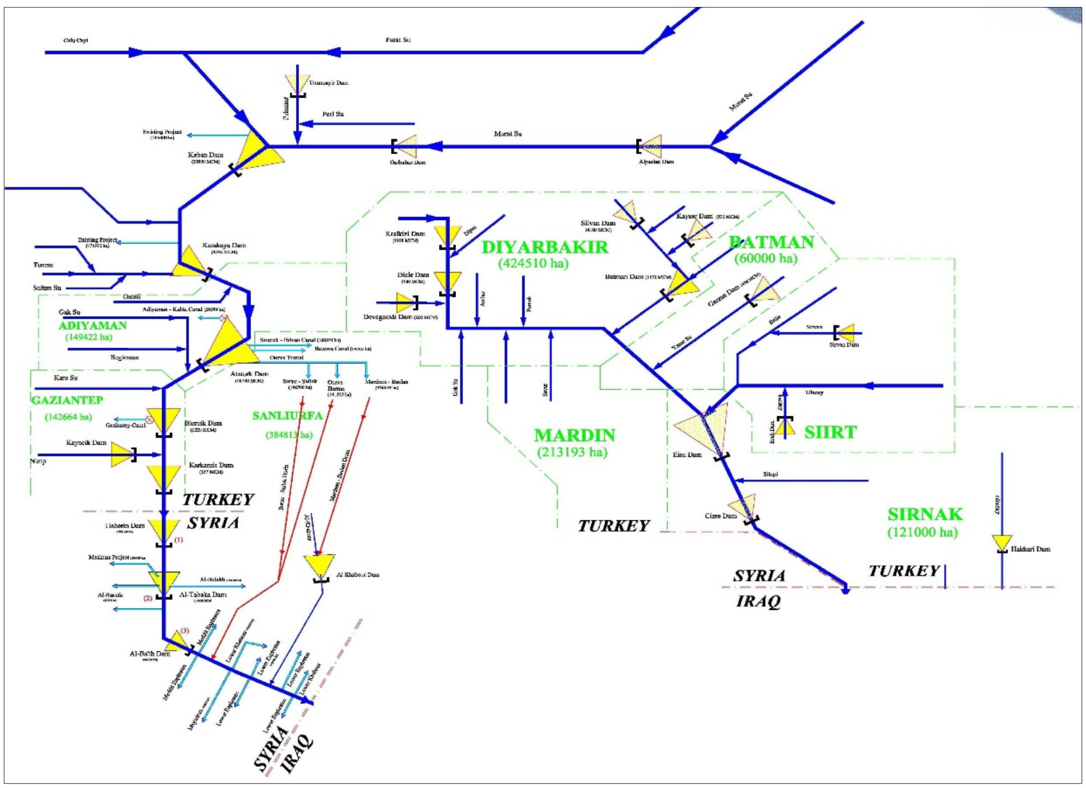


Figure 48-1. Schematic of the Tigris-Euphrates watershed in Syria and Turkey

Impact: This model integrated groundwater, surface water, salinity, population growth, agriculture, municipal and industrial uses, hydropower, and the southern Mesopotamian Marshes. Further it helped Iraqi planners better understand regional water SD and provided foundational model for future regional development.

49 Libyan Water-Energy-Food Modeling Workshop

In 2007, in collaboration with the US Department of State, this workshop introduced Libyan experts from the General Water Authority, the Libyan Petroleum Institute, and the Libyan Information Technology and Programming Center to modeling approaches intended to help them better plan water, agriculture and energy projects in Libya. With instruction and assistance from a team of Sandia modelers, the participants used historic and current Libyan data to build a model showing the tradeoffs required for Libya to achieve self-sufficiency. The water supply provided by the Great Manmade River and the energy required to pump that water were key variables. The workshop and the model itself provided a foundation on which Libyan engineers and scientists could build future modeling projects (Figure 49-1).

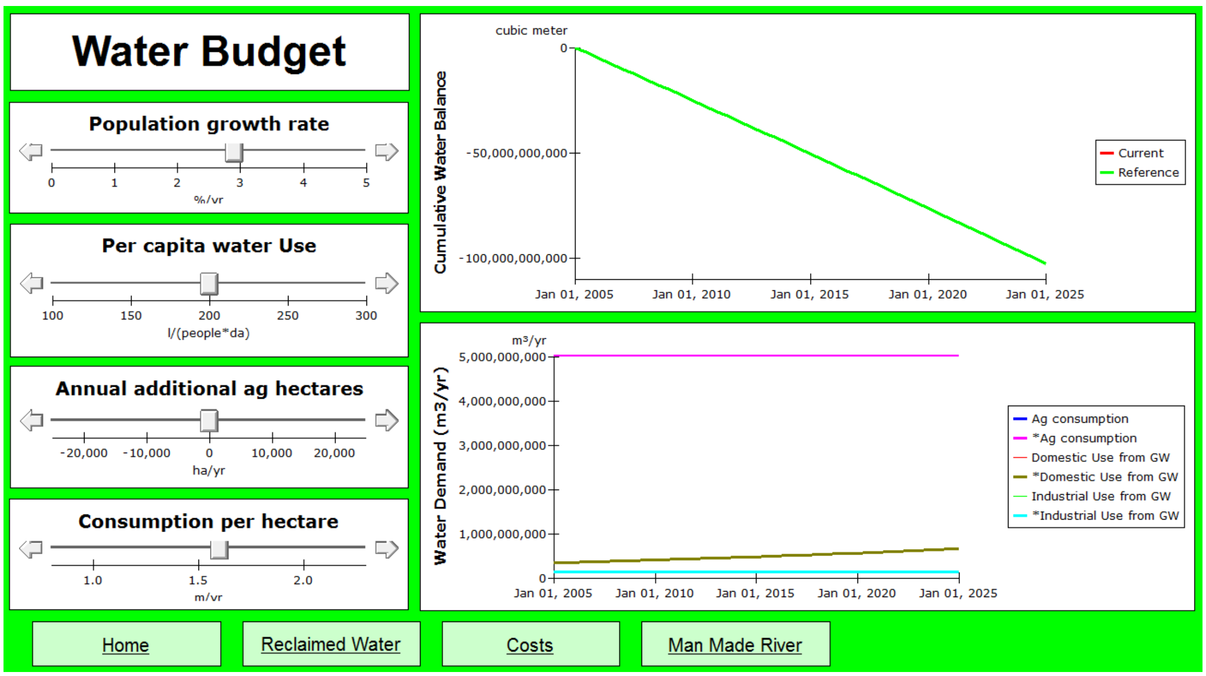


Figure 49-1. User interface page from the Libyan Water-Energy-Food Modeling workshop held in Tripoli, Libya, 2007.

Impact: The three-day workshop in Tripoli to introduced SD modeling to Libyan water, energy, and computer science experts. We engaged 26 engineers from Libyan General Water Authority and other agencies to build a preliminary model of Libyan water resources, agriculture, and energy.

50 Borders as Membranes: Metaphors and Models for Improved Policy in Border Regions

This project applies the metaphor of a membrane to look at how people, ideas, and things "move" through a border to develop a SD model to assess legal and illegal migration on the US-Mexico border. The work relies on a multi-disciplinary team and an array of methods to gather data including traditional literature reviews, subject matter experts, focus groups, and interviews. The membrane metaphor assumes gradient based transfers where transfer rates are determined by the gradient of various commodities and socio-economic metrics on either side of the border (Figure 50-1).

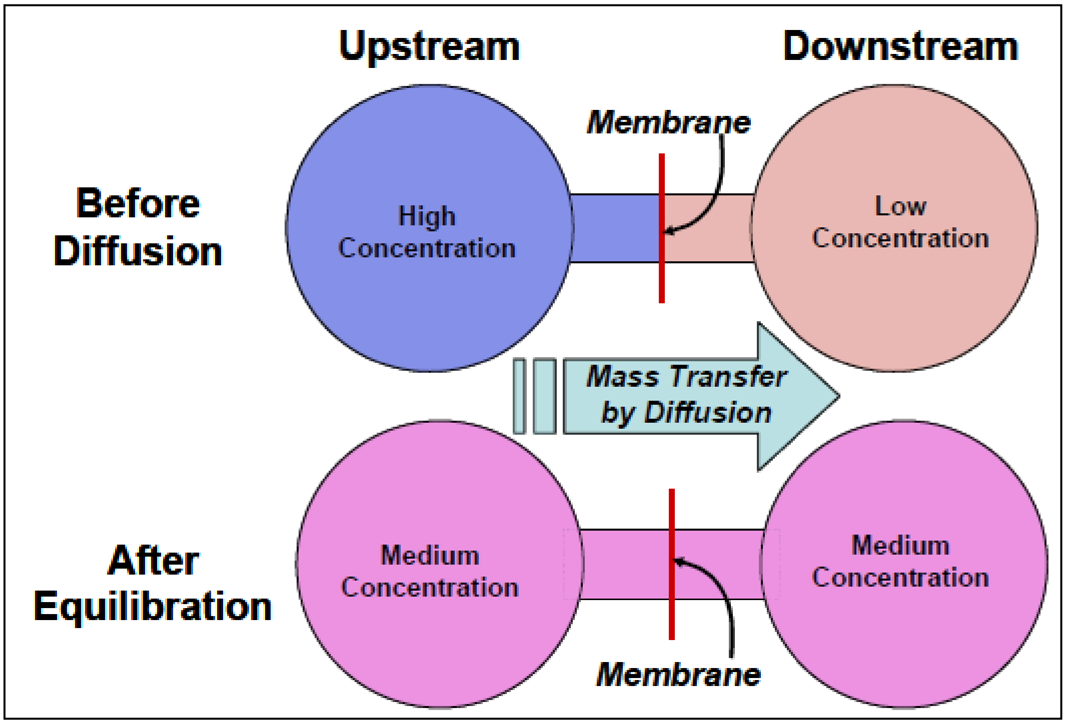


Figure 50-1. Schematic of the membrane concept applied to the transfer of people, ideas, and commodities across the US-Mexico border.

Impact: This model uses the metaphor of a membrane to describes transfer rates of people, ideas, and commodities across the US-Mexico border. It shows that current US policies based on neo-classic economic theory and enforcement policies are not effective at curbing illegal migration.

51 The Water, Energy, and Carbon Dioxide Sequestration Simulation Model (WECSsim)

The Water, Energy, and Carbon Sequestration Simulation Model (WECSsim) is a national dynamic simulation model that calculates and assesses capturing, transporting, and storing CO_2 in deep saline formations from all coal and natural gas-fired power plants in the US. WECSsim simultaneously accounts for CO_2 injection and water extraction within the same geological saline formation. Extracting, treating, and using these saline waters to cool a power plant is one way to develop more value from using saline formations as CO_2 storage locations. WECSsim allows for both one-to-one comparisons of a single power plant to a single saline formation along with the ability to develop a national CO_2 storage supply curve and related national assessments for these formations (Figure 51-1).

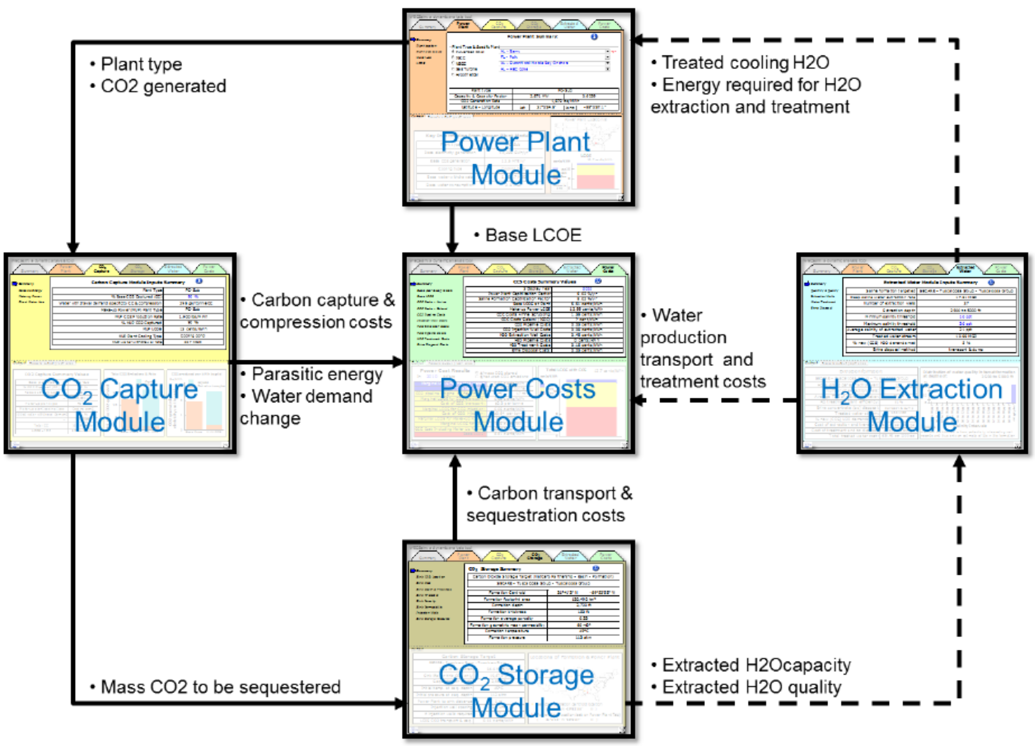


Figure 51-1. Schematic diagram of the WECSsim water,energy, and CO_2 sequestration simulation model.

Impact: The model allows users to run power plant and formation-specific scenarios to assess their cost and performance variability relative to other pairings throughout the lower 48 states. It identifies which plants are most economically viable for CO_2 capture, transportation, and storage (CCS) and which saline water-bearing formations candidates to support large-scale, multi-decadal CCS and finally it provides scenario based analysis to address questions regarding geologic parameters, power plant make-up power, water treatment costs, and efficiencies.

52 Nambe Pueblo Water Budget and Forecasting Model

The Nambe Pueblo Water Budget and Water Forecasting model is a SD-based software package designed to investigate the various aspects of the Nambe Pueblo's current and future water use. The model forecasts water demand for domestic, industrial, livestock, and irrigation uses using population growth, per capita water use, diversion rates, and irrigation efficiency. Irrigation scheduling is calculated based on the irrigation demand, precipitation, and availability of reservoir water. Reservoir water is tracked over time by balancing inflows against releases and diversions. The model water forecast and reservoir models run for a 60-year period from 2001 through 2061 using a 7-day timestep while the irrigation scheduling is done on a user defined 3-year segment at 0.5 day timesteps (Figure 52-1).

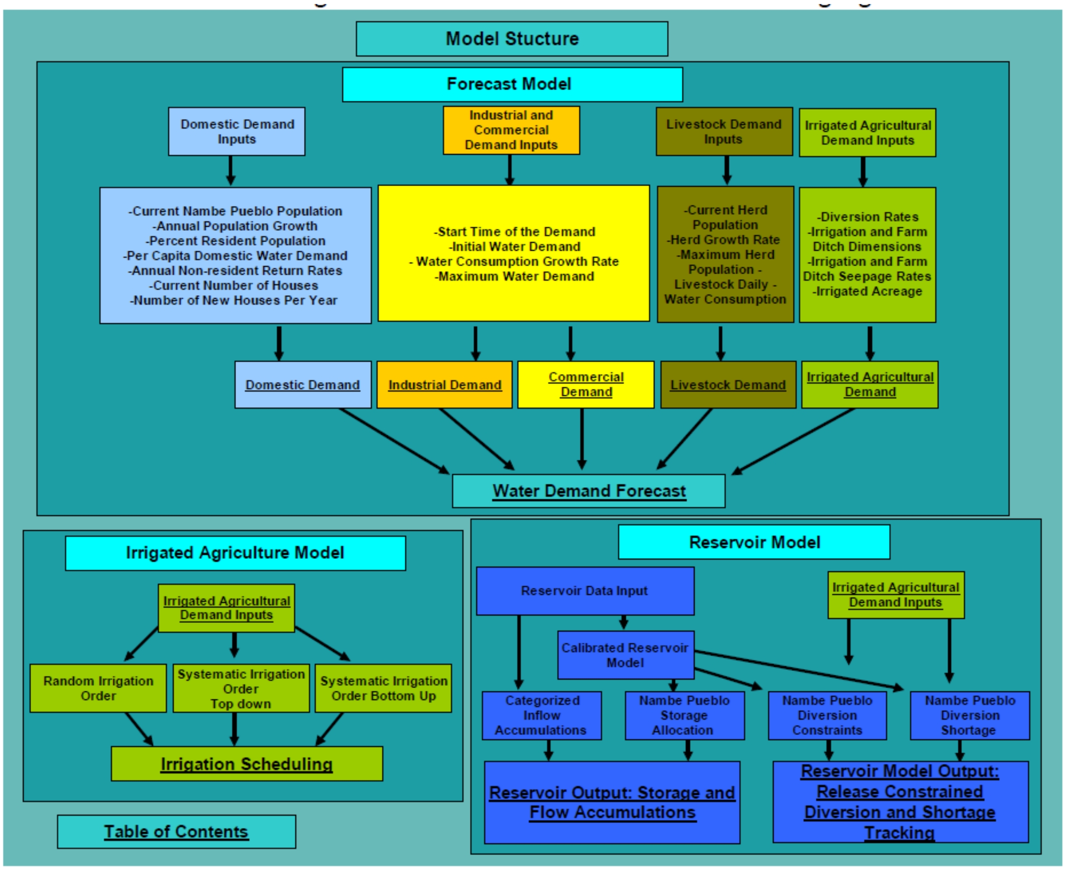


Figure 52-1. Schematic diagram of the Nambe Pueblo Water Budget and Forecasting model.

Impact: This model quantifies current and future water supply and use on Nambe Pueblo lands. Users can test assumptions of water use efficiency, population growth, irrigated acreage, and future climate. Finally, it provides scenario based analysis to address questions regarding geologic parameters, power plant make-up power, water treatment costs, and efficiencies.

53 National Climate Assessment Project

This technical assessment and report on Climate and Energy-Water-Land (EWL) system interactions was prepared for the DOE in support of the US National Climate Assessment (NCA). This work was conducted under the project leadership of Pacific Northwest National Laboratory, and along with SNL, included team partners and contributors from USDA's Agriculture Research Service, the Electric Power Research Institute, Los Alamos National Laboratory, the Union of Concerned Scientists, and the University of Colorado. The technical input report was prepared on an accelerated schedule in early-FY12 to fit the NCA's timeline. The report provided a summary of existing information and understanding of this broad topic. The report also provided a framework to characterize and understand the important elements of climate and EWL system interactions. It identified many of the important issues, discussed our understanding of those issues, and identified the research needs to address the priority scientific challenges and gaps in our understanding. Much of the discussion was organized around two discrete case studies with the broad themes of (1) extreme events and (2) regional differences. These case studies help demonstrate unique ways in which energy-water-land interactions can occur and be influenced by climate. In addition, a series of "illustrations" portray representative decision-making considerations relevant to climate-EWL interfaces (Figure 53-1).

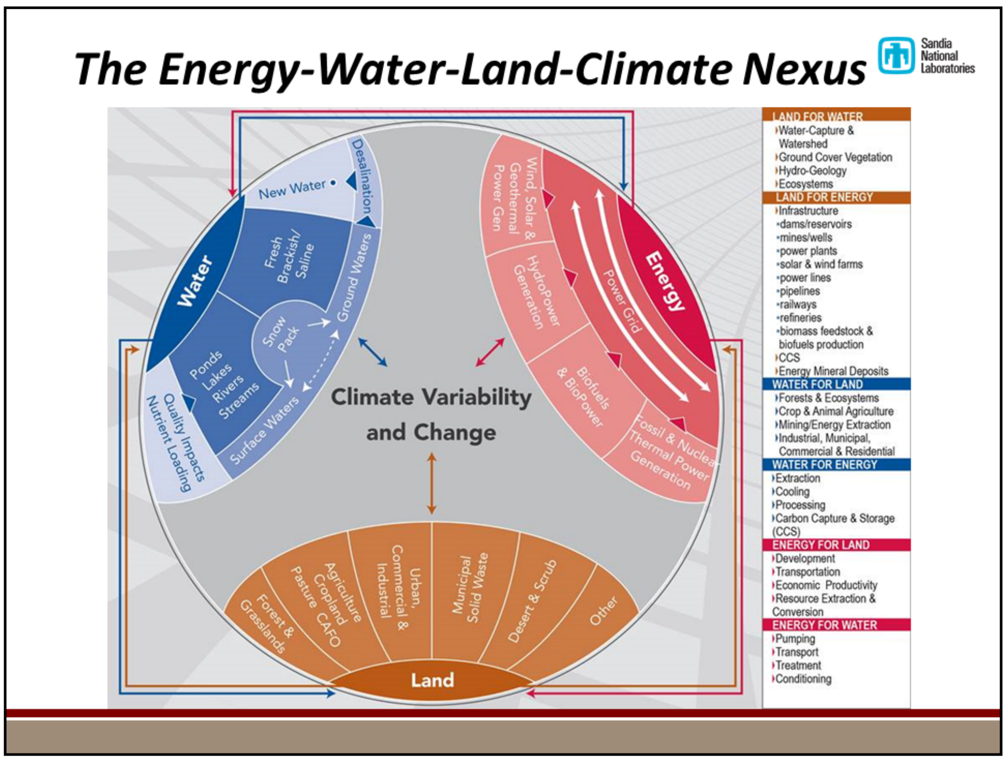


Figure 53-1. Schematic of the Energy-Water-Land Nexus.

Impact: This study characterized Climate and Energy-Water-Land (EWL) system interactions and described and discussed EWL-Land Interfaces and associated resource interdependencies and interactions with Climate as well as risk, uncertainty, and vulnerability associated with climate impacts on energy-water-land interfaces. In addition, it described and discussed climate mitigation and adaptation at the energy-water-land interfaces. Finally, it identified research needs associated with climate impacts on energy-water-land interfaces.

54 Summary

Sandia, along with other Department of Energy labs and industry associations began raising concerns in the early-2000s about the critical relationship between energy and water. These concerns centered around the observation critical energy-water interdependencies were not being properly addressed to assure the security and sustainability of the nation's water and energy supplies. This led to the emergence of the Energy-Water Nexus as a key area of investigation for Sandia National Laboratories with the first major funded efforts beginning in 2004-2005 with the Energy Water Report to Congress, and the Energy Water Roadmap, both mandated by Congress and funded through Congressional Directives. The data, modeling, and analysis projects highlighted in this document focus on water modeling and management, energy-water nexus assessment, modeling and analysis and related decision-support, water monitoring and resource assessment, water and energy security, international projects, and New Mexico Small Business Assistance projects. Together these projects address the interdependent issues, risks, and technology-based mitigations associated with increasing demands and stresses being placed on energy, water, and agricultural/food resources, and the related impacts on their security and sustainability in the face of both domestic and global population growth, expanding economic development, and climate change.

The projects all have a common goal in that they focused on tool development and utilization to both assess and provide understanding of energy-water interdependencies and in some cases with the inclusion of land, food and agricultural resources. Further they have had impact at numerous scales from the local (Nambe Pueblo and the Gila River) to regional (SWaRMs and the US-Mexico border) as well as to the national (across the United States) and international (Libya and Iraq).

Project funding sources include Congressional Directives, Program Development, Sandia Laboratory Directed Research and Development, United States Department of Energy, Department of Defense, Environmental Protection Agency, Department of Homeland Security, New Mexico Small Business Assistance, Cooperative Research and Development Agreements, and other state agency, industry, and non-governmental organization sources.

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