Energy and Water in the Western and Texas Interconnects

A proposal prepared by:

Sandia National Laboratories

With support from:

Argonne National Laboratory
Electric Power Research Institute
Idaho National Laboratory
National Renewable Energy Laboratory
Pacific Northwest National Laboratory
University of Texas

In response to DOE Call:

Technical Support for Interconnection-Level Electric Infrastructure Planning
RC-BM-2010
Area of Interest 3: Water/Energy Nexus

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List of Acronyms

Argonne	Argonne National Laboratory
BCSD	Bias Correction – Statistical Downscaling
BGD	Billion gallons per day
CCS	Carbon Capture and Sequestration
CCSM	Community Climate System Model
CMT	Collaborative Modeling Team
DEM	Digital Elevation Model
DOE	Department of Energy
DSS	Decision Support System
EIS	Environmental Impact Statement
EPRI	Electric Power Research Institute
EPWSim	Energy-Water-Power Simulation
ERCOT	Electric Reliability Council of Texas
ESA	Endangered Species Act
ET	Evapotranspiration
GFDL-CM	Geophysical Fluid Dynamics Laboratory Climate Model
GUI	Graphical User Interface
HadCM	Hadley Centre Climate Model
HRU	Hydrologic Response Unit
Idaho	Idaho National Laboratory
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
LCA	Lifecycle Analysis
NARCCAP	North American Regional Climate Change Assessment Program
NCDC	National Climate Data Center
NETL	National Energy Technology Laboratory
NGO	Non-Government Organization
NHD	National Hydrographic Dataset
NLCD	National Land Cover Database
NREL	National Renewable Energy Laboratory
PI	Principal Investigator
PNNL	Pacific Northwest National Laboratory
SWAT	Soil and Water Assessment Tool
USGS	U.S. Geological Survey
UT	University of Texas
VHP	Virtual Hydropower Prospector
WF	Water Footprint
WGA	Western Electricity Coordinating Council
WRR	Water Resources Regions

Technical Content

Background

Since 1950 water use has grown by 230% while electric power production has increased 12 fold (EIA 2003), stimulating a 43-fold increase in the nation's economy as measured by gross domestic product (BEA 2007). The linkage between electricity, water and the economy is further demonstrated when one considers that on average droughts costs the U.S. $6-8B/yr, while the 1988 drought cost $40B (NDMC 2008), and similarly the 2003 blackout in the Northeast U.S. incurred damages of $6-10B (NextGen Energy Council, 2008). These facts point to our nation's need for secure and reliable sources of water and electricity. Unbridled demand for these resources represents a very real internal threat to our nation's security. Further intensifying this issue is the fact that electricity and water are inextricably linked; that is, considerable quantities of water are required in thermoelectric power production while a sizeable fraction of that power is required to lift, convey, treat, store and distribute water.

In 1995, the last year the U.S. Geological Survey conducted a comprehensive analysis of water consumption (USGS 1995), total freshwater withdrawals in the U.S. were 342 billion gallons per day (BGD), while consumption measured 100 BGD. Of this, thermoelectric freshwater withdrawals accounted for 132 BGD or 39% of the total, while consumption (3.3 BGD) for thermoelectric power accounted for 3.3% of the national total. Water withdrawals by thermoelectric power generation was second only to irrigated agriculture (134 BGD at 39%); however, when considering total water withdrawal (potable and non-potable sources) the thermoelectric sector led all others accounting for 48% of all water withdrawals. In terms of consumption, thermoelectric power production was roughly equivalent to all other industrial uses in the U.S. combined. Conversely, significant energy is expended to extract, convey, treat and deliver water and wastewater. While the total energy requirement by water utilities is highly location-specific, on average 3% of all electrical power generated in the U.S. is used in the water sector (EIA 2003). According to the California Energy Commission (2005) this fraction is much more significant if water heating is considered, where it is estimated that almost 20 percent of California's electricity demand, and more than 30 percent of California's natural gas demand, are associated with water use.

The lack of integrated electric power and water planning has already impacted electricity production in many basins and regions across the U.S. In three of the fastest growing regions, the Southeast, Southwest, and Northwest, new power plants have been opposed because of potential negative impacts on water supplies (Tucson Citizen 2002; Reno-Gazette Journal 2005; U.S. Water News Online 2002 and 2003; Curlee and Sale 2003). For similar reasons, Idaho recently placed a 2-year moratorium on construction of coal-fired power plants (Reuters 2006). Concerns over falling water levels in Lake Norman, Lake Mead, and reservoirs all along the Apalachicola River have water managers and utility operators perplexed over how to supply water to cool thermoelectric power plants and/or generating hydroelectric power while maintaining adequate flows for environmental and human needs (Webber 2008).

The nexus between electric power production and water use is likely to face more challenges in the future. The Energy Information Administration projects the U.S. population will grow to 364 million people by the year 2030, increasing electric power demand by 30 percent between 2008 and 2035 (EIA 2010). Depending on the type and number of power plants built, cooling technologies used, and emission requirements water withdrawals in the thermoelectric industry are projected to decrease between 0.5 and 30% while consumption is projected to rise between 21 and 48% (Reeley et al. 2007). Increasing population will likewise put pressure on the municipal, industrial and agricultural water sectors. This growth in water demand will occur at a time when the nation's fresh water supplies are seeing increasing stress from limitations of surface-water storage capacity, increasing depletion and degradation of ground water supplies, increasing demands for the use of surface water for in-stream ecological and environmental uses, and the uncertainty about the impact of climate variability on future surface and ground water resources. Based on a survey of water managers, the Congressional General Accounting Office (2003) reports that 36 states anticipate water shortages in the next 10 years, even under normal water conditions, and 46 expect water shortages under drought.

To address this emerging energy and water interdependency challenge, Congress directed the Department of Energy (DOE) in 2005 to "initiate planning and creation of a water-for-energy roadmap." This road mapping process relied heavily on stakeholder input gathered through three regional needs workshops and two technology identification workshops. Almost 500 stakeholders from over 40 states participated in the five Energy-Water workshops representing a broad range of energy and water agencies, developers, regulators, users, managers, utilities, industry, and academia. Participant input and suggestions were used to define the future research, development, demonstration, and commercialization efforts needed to adequately address emerging water-related challenges to future, cost-effective, reliable, and sustainable energy generation and production (http://www.sandia.gov/energy-water/).

While results from the road mapping exercise identified the need for technology innovation, such solutions alone were recognized as insufficient. Specifically voiced was the need for long-term and integrated resource planning supported with scientifically credible models. Similarly, the National Research Council (2004) recognized that although a number of resource planning tools and models exist, additional efforts are needed in the development, integration, and dissemination of decision support tools and system analysis approaches to help communities and regions better address emerging natural resource - energy, water, land, and environment - demand and availability challenges.

Project Objectives

This proposal is in response to the Research Call to DOE/Federal Laboratories for "Technical Support for Interconnection-Level Electric Infrastructure Planning, RC-BM-2010" Area of Interest 3: Water/Energy Nexus. According to the stated needs in the Research Call, three overarching objects are identified:

1. Develop an integrated Energy-Water Decision Support System (DSS) that will enable planners in the Western and Texas Interconnections to analyze the potential implications of water stress for transmission and resource planning.
2. Pursue the formulation and development of the Energy-Water DSS through a strongly collaborative process between members of this proposal team and the Western Electricity Coordinating Council (WECC), Western Governors' Association (WGA), the Electric Reliability Council of Texas (ERCOT) and their associated stakeholder teams.
3. Exercise the Energy-Water DSS to investigate water stress implications of the transmission planning scenarios put forward by WECC, WGA, and ERCOT.

Project Team

The lead laboratory for this project is Sandia National Laboratories (Sandia) supported by other national laboratories, a university, and an industrial research institute. Specific participants include Argonne National Laboratory (Argonne), Idaho National Laboratory (INL), the National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), the University of Texas (UT), and the Electric Power Research Institute (EPRI). Each institution brings a rich portfolio of experience with respect to water, energy, and the environment. To take advantage of this experience, our proposal strongly leverages past and present investment by DOE across multiple program offices, Laboratory Directed Research and Develop programs at each of the national labs, academic research, and industrial contributions. This multi-institutional portfolio of research has yielded a wide range of models, data, and analyses that will be key to developing a comprehensive Energy-Water DSS. The proposed project team also benefits from a healthy professional relationship stemming from prior collaboration on the Energy-Water Nexus National Laboratory Team (e.g., www.sandia.gov/energy-water/lab_team.htm).

Technical Objectives

As noted above the overarching objective of this work is the development of an integrated Energy-Water DSS that will enable planners in the Western and Texas Interconnections to analyze the potential implications of water stress for transmission and resource planning. The DSS will be comprised of a series of dynamic and interacting models controlled through a graphical user interface (GUI). Each model will address a specific physical or social system pertinent to water resource sustainability and potentially impacted by electrical transmission planning. Consistent with the specifications in Interest Area 3 of the Research Call, these models will include a water withdrawal and consumption calculator for current and planned electric power generation; a water demand projection model; a water availability model; an environmental controls model; a climate change calculator; a water cost model; an energy for water calculator, and; an accompanying GUI for scenario control and visualization of simulation results.

The foundation for the Energy-Water DSS will be Sandia's Energy-Power-Water Simulation (EPWSim) model (Tidwell et al. 2009). The modeling framework targets the shared needs of energy and water producers, resource managers, regulators, and decision makers at the federal, state and local levels. Specifically, the framework provides an interactive environment to explore trade-offs, and "best" alternatives among a broad list of energy/water options and objectives. The decision support framework is formulated in a modular architecture, facilitating tailored analyses over different geographical regions and scales (e.g., national, state, county, watershed, interconnection region). An interactive interface allows direct control of the model and access to real-time results displayed as charts, graphs and maps. The framework currently supports modules for calculating thermoelectric power demand and related water use; water demand from competing use sectors; surface and groundwater availability; and an energy for water calculator.

Ultimately this framework will be merged with the various models and datasets contributed by our project partners. In addition, numerous new and extended modeling elements are planned. The complete integrated package of process models will be operated by a universal interface. The interface will facilitate interactive scenario development, simulation operation and analysis of results.

Below we describe the proposed work according to eleven project tasks. These tasks largely correspond to the key DSS model elements noted above. Additional tasks are included for Project Management, Transmission Scenario Analysis, and Project Reporting. Beyond the task descriptions we address the four "Merit Review Criteria" and then conclude with "Project Deliverables" and "Relevance, Outcomes and Impacts." Additional project detail can be found in the Qualifications and Resources section as well as in the attached appendices.

Task 1: Project Management

Appropriate attention to project management is paramount to project success. This task addresses necessary efforts toward project coordination, communication, contracting, resource tracking, and reporting. ***Subtask 1.1: Scope of Work and Management Plan.*** The fist activity will include the preparation of a project Scope of Work and Project Management Plan according to the instructions in Attachments A and B, respectively of this RFP. The approach to project management will follow the basic principles set forth in the Project Managements Institute's "A Guide to the Project Management Book of Knowledge." In assembling the Project Management Plan we will work with our project partners to address issues of intellectual property, quality assurance, configuration management, etc. to facilitate communication and coordination of efforts throughout the duration of the project.

Subtask 1.2: Project Coordination. Vincent Tidwell of Sandia will serve as overall Contact Principal Investigator/Project Coordinator for research under this proposal; however, multiple principal investigators (PIs) will collaborate to plan and conduct the proposed research. This collaboration will include Argonne PI John Gasper, EPRI PI Robert Goldstein, NREL PI Jordan Macknick, INL PI Gerald Sehlke, PNNL PI Mark Wigmosta and UT PI Michael Webber. Project Coordinator and PI responsibilities include directing, coordinating and conducting research for specific projects under this proposal, jointly reporting to the DOE program manager, and assuring administrative requirements are met. Specific responsibilities for the work tasks spelled out below are contained in the Qualifications and Resources section. Project coordination across this team will be pursued through periodic (at a minimum monthly) web conferences among all project participants augmented by periodic face-to-face meetings. Communication outside the project team will be required and achieved through active representation at pertinent DOE, WECC, WGA, ERCOT, and stakeholder meetings.

To enhance project coordination a Collaborative Modeling Team (CMT) will be assembled to oversee development of the Energy-Water DSS. Team membership will involve a self-selection process of participants from the WECC, WGA, and ERCOT planning teams. The CMT will meet on a periodic basis with our project modelers to define: 1) key metrics and decision variable for inclusion in the DSS; 2) vet process models; 3) vet data, water use factors, etc; 4) jointly review the models and conduct calibration analyses; and 5) conduct desired scenario analyses. Meetings will largely be handled through web conferencing with occasional face-to-face meetings coordinated with other project events. Sandia has significant experience in developing models within the context of a CMT, which improves model transparency and consensus in the model and the results rendered (Cockerill et al. 2009, 2007, 2006, Tidwell and van den Brink 2008, Tidwell et al. 2004, www.iwr.usace.army.mil/cadre/)

Subtask 1.3: Financial Management: Sandia Corporation's Finance policy is to conduct its financial and accounting operations using sound business principles that comply with contractual requirements, including Cost Accounting Standards. All Members of the Workforce are responsible and accountable for managing and safeguarding customer-entrusted assets and demonstrating competent financial stewardship in all activities. Managers are responsible to ensure that all costs are permissible and allowable. Accordingly, Sandia will maintain an accounting system that is integrated with DOE's books of account and will ensure that all work performed is consistent with DOE's Approved Funding Program. Further, Sandia will comply with all appropriate DOE financial requirements, including:

- Maintaining an effective system of internal controls.
- Developing and maintaining resource-management systems.
- Providing efficient financial services.
- Providing accurate, timely, reliable, and useful reporting to customers, senior management, and Lockheed Martin Corporation, as required.

UT will contract with Sandia, while all other participants will contract directly with DOE. Each participant will be individually responsible for a similar level of financial tracking and reporting (except UT which will work through their contract with Sandia).

Subtask 1.4: American Recovery and Reinvestment Act (ARRA). Sandia acknowledges the modification of its prime contract to incorporate ARRA-specific requirements, specifically:

- DOE Clause H-999, *Special Provisions Relating to Work Funded under the American Recovery and Reinvestment Act of 2009* (APR 2009)
- DOE Clause B-9999, *American Recovery and Reinvestment Act Work Values*
- FAR 52.203-15, *Whistleblower Protections under the American Recovery and Reinvestment Act of 2009* (MAR 2009)
- FAR 52.204-11, *American Recovery and Reinvestment Act – Reporting Requirements* (MAR 2009)
- FAR 52.215-2, *Audit and Records – Negotiation* (Alt I) (MAR 2009)
- FAR 52.225-21, *Required Use of American Iron, Steel, and Manufactured Goods – Buy American Act – Construction Materials* (MAR 2009).

In addition to the foregoing requirements, Sandia receives periodic ARRA reporting guidance updates from the DOE, posted at http://www.energy.gov/recovery/ARRA_Reporting_Requirements.htm. Quarterly reporting is filed by Sandia using Recipient DUNS Number 007113228. Sandia will be responsible for ARRA reporting except in terms of financials, which will be the responsibility of each project participant under separate contract to DOE.

Task 2: Water Withdrawal and Consumption Calculator for Current and Planned Electric Power Generation

The purpose of this model is to calculate water withdrawal and consumption at the power plant level across the Western and Texas Interconnections. Input to the water use calculator will be the output of WECC's and ERCOT's transmission planning models; specifically, the transmission planning models will define the full operational characteristics of both existing and future power plants, including capacity, production, type of plant, type of cooling, and type of emissions controls. The hourly level data from the transmission planning models along with local climate information will be used by this calculator to determine the hourly water withdrawal and consumption as well as parasitic energy demands imposed by emission controls and water-conserving cooling technologies. While the hourly power plant-level data will be available for use, calculator output will also be aggregated to an appropriate spatial and temporal resolution and passed to the Water Demand Projection Model (Task 3). Calculated parasitic energy loads will be passed back to the transmission models.

Subtask 2.1: Water Withdrawal and Consumption and Parasitic Energy Factors. The first activity under this task involves the development of a model to calculate water withdrawal and consumption at the power plant level. Estimates will leverage work identifying the water use requirements of power plants for a variety of fuel types, generation technology, and cooling types. Both emerging and mature technologies will be considered. The primary focus of this effort will be to develop water use factors associated with individual power plant specifications that are projected to be built. This work will build on NREL's initial work identifying water consumption and withdrawal factors for power plants. Further refinement of water use factors will be needed to address the variation in power plant efficiencies associated with differences in microclimates.

Working through the CMT, efforts will be made to vet the calculated water demands for existing power plants with data available from regional water managers and utility operators.

Another factor affecting power plant efficiencies relates to the cooling system employed. Dry cooling and hybrid cooling systems can impose additional energy requirements. The focus of this particular activity will be to identify and evaluate these parasitic energy requirements and associated reduced efficiencies related to choice of cooling technology. This effort will leverage existing work on renewables being conducted by NREL and will also require collaboration with the National Energy Technology Laboratory (NETL) and other institutions to develop parasitic requirements for conventional technologies.

Subtask 2.2: Impacts of Carbon Capture and Sequestration. The second activity will focus on the impacts of Carbon Capture and Sequestration (CCS) on thermoelectric water withdrawal and consumption rates. CCS induces direct impacts on water use through increased cooling water requirements for capture and compression, as well as indirect water use through related parasitic energy losses. Establishing water withdrawal and consumption and parasitic energy loss factors associated with CCS will be the focus of this effort. Factors will vary with the capacity of the plant, manner of sequestration, and the type of power plant; particularly, subcritical and supercritical pulverized coal plants and Integrated Gasification Combined Cycle (IGCC) plants. Efforts will also be made to identify which plants are likely to be retrofitted for CCS under different carbon capture policies, which plants are likely to close, and which might operate without capture. Water withdrawal and consumption factors as well as parasitic energy loss factors will be developed from the best and most up-to-date data available. This effort will leverage ongoing collaboration between Sandia, NETL and the DOE Office of Policy and International Affairs.

Task 3: Water Demand Projection Model

The water demand projection model provides a basis for estimating future water demand for sectors competing with thermoelectric power generation. Using information on population growth, Gross State Product (GSP) and historical water use trends, future water demands in terms of withdrawals and consumption are calculated. The source of the withdrawal (surface water, groundwater, non-potable) is tracked as well as the disposition of return flows. The competing demand projections are then combined with that for thermoelectric power (Task 2) to provide a complete view of water demand. Model output is routed to the DSS interface where it can be viewed directly or can be combined with other measures in the Regional Water Stress Calculator (Subtask 9.3). The calculated growth in water consumption is also used in the Water Availability Model (Task 4) to estimate impacts on future water supply.

This task will build on component elements found in Sandia's EPWSim model (Tidwell et al., 2009). Within EPWSim water demand is individually calculated according to six different use sectors: municipal (including domestic, public supply, and commercial), industrial, agriculture, mining and livestock (thermoelectric demands are calculated in Task 2 and passed here). Water use and consumption are tracked separately as are the resulting return flows. Also modeled is the source of the withdrawal, whether that be surface water, groundwater, or a non-potable source.

Water use statistics published by the U.S. Geological Survey (USGS) serve as the primary data source for the EPWSim analyses. Every five years since 1950 the nation’s water-use data have been compiled and published by the USGS. Collection of this data is a collaborative effort between the USGS, state and local water agencies, and utilities. However, the level of detail at which these data are reported varies from year to year. Data from the 1985, 1990, and 1995 campaigns provide the most comprehensive picture of water use in the U.S., and hence form the basis of this analysis (USGS 1985, 1990, 1995). Specifically, the 1995 data provide the initial conditions, while all three data sets are used to estimate trends in water use rates. These rates are further modified by changes in population and economic activity (as measured by gross state product) where quantifiable correlations exist. In this way water use projections are a function of population change, economic growth and trends in historical water use rates (i.e., reflecting changing use/conservation practices). Historical trends alone are used to project the source mix for future water withdrawals.

Demands are calculated as daily averages. Calculations are made at the county level but can be aggregated to the watershed, state, or interconnection level. The user can accept the default growth rates and/or source of diversion in the model or specify their own.

Three activities are planned for this task. ***Subtask 3.1: Updating the EPWSim Water Demand Model.*** The first activity involves the broad vetting of the water demand model with the CMT and as needed with stakeholders convened by WECC, WGA, and ERCOT. We envision that in many cases, state water managers will want to see specific future water use scenarios integrated into the model, which reflect individual state planning efforts. Additionally, we will work to update the initial conditions in the model to reflect that recently published in the 2005 USGS Water Use Report (augmented with state input).

Subtask 3.2: Biofuel Water Use. The second activity will expand the agricultural water withdrawal and consumption module in EPWSim to consider irrigation demands for biofuels. We will augment the model’s current simulation of trends toward improved conveyance and irrigation efficiency. Specifically, we will integrate a biofuels water use model developed previously through collaboration between Sandia and General Motors (West et al., 2009). The model calculates annual water withdrawal and consumption for both irrigation and feedstock conversion. Feedstocks currently modeled include corn, switch grass, short rotation woody crops, forest residue, and agricultural residues.

Energy crops require different amounts of water depending on the location's soil and climatic conditions. These conditions contribute to determining whether or not energy crops require irrigation, how much irrigation, and when it will be needed. Climatic- and geographic-specific water requirements for energy crops will draw from water footprint tools being developed at INL and NREL (Heath et al. 2009) that assess the total water demand (in terms of rainwater and irrigation water) of crops based on crop attributes, soil type, and climatic conditions. INL and NREL will develop a GIS-coverage map for known and projected locations of biofuel crops in the U.S. This assessment will be based on: 1) national/west-wide data collected/currently being collected by DOE, U.S. Department of Agriculture (USDA) and other researchers, 2) an assessment of preferred crop types versus historical western agricultural records, and 3) an assessment of general western crop growth factors (e.g., growing season, temperature, precipitation and soil data). UT also has developed geographically-resolved maps of the potential for algae-based biofuels production in the ERCOT based on water resources (Wogan, 2009) that can be used for this study. These data will be used to estimate the anticipated seasonal/annual water withdrawals and water consumption necessary to meet current and projected biofuel crop demands.

Subtask 3.3: Water Use for Energy Extraction. We will expand the EPWSim water use module to consider potential growth in the use and consumption of water for energy resource extraction and processing. Argonne staff have investigated the energy-water relationships for components and lifecycles of energy resource extraction and processing. Investigations have included development of primary source data, modeling approaches and analysis, addressing oil and gas, coal (including coal bed methane), oil and gas shales, tar sands, and biomass (e.g., Veil 2003, Argonne 2007, Veil 2007, and Wu et al. 2008). These investigations have been sponsored by organizations such as the DOE's Offices of Fossil Energy and Energy Efficiency and Renewable Energy and the Ground Water Protection Agency. Similarly, Sandia working with NETL have investigated the potential of deep saline formations (Ciferano 2009, Kobos et al. 2008), particularly for CCS applications. Data, analysis and expertise from these works will be used to assist in development and verification of data, algorithms and other components for the DSS.

Task 4: Water Availability Model

The water availability model provides a regional measure of water supply for surface water, groundwater, and non-potable resources. The model has two principle components, "wet" and "paper" water. Wet water provides a measure of the physical water available in a basin for use, while paper water addresses the institutional controls (policies) that define access to the water. The model combines historical gauge data and other information to project surface and groundwater availability. These supplies are adjusted by growing water consumption as calculated in Tasks 2 and 3. Model output is routed to the DSS interface where it can be viewed directly or can be combined with other measures in the Regional Water Stress Calculator (Subtask 9.3).

Stream gauge statistics based on extended sampling periods provide one of the best measures of surface water availability. As these gauged flows are affected by activities upstream of the gauge, the measured statistics account for upstream reservoir operations, evaporative losses, groundwater-stream interaction, withdrawals, etc. In this way, the mean daily flow provides a good measure of the average surface water supply available at the gauge location, while the accompanying exceedance flows provide a measure of the variability in supply at that point. Likewise, the gauged average daily baseflow index (that portion of the stream flow contributed by groundwater discharge) provides a good measure of the sustainable groundwater recharge available for use.

For this task we will again make use of modeling components found in EPWSim; specifically, the modeling of surface and groundwater availability compiled at the accounting unit (6-digit Hydrologic Unit Code [HUC]) level (Figure 1). The basis of this modeling is the USGS National Hydrographic Dataset (NHD). Specifically, the USGS has stream flow data from 23,000 gages in which the available sampling record has been statistically analyzed to give the minimum and maximum daily flows, mean daily flow, key percentiles (1, 5, 10, 20, 25, 50, 75, 80, 90, 95, 99) of daily flow, and the base flow index (Stewart et al. 2006). For each watershed we have identified the NHD gauge with the longest record and which is the closest to the point of discharge. As activities upstream of the gauge will affect the measured flow, the NHD long term statistics are constantly adjusted in the model for changes in consumptive use upstream of the gauge (projections of water consumption from Task 3). Specifically, changes in water consumption (post 2004) are sequentially aggregated across watersheds from headwater to the gauge. The aggregated consumption is then subtracted from the long term gauge statistics to yield an adjusted measure of water availability.

Several upgrades to the water availability model are planned. ***Subtask 4.1: Update EPWSim Water Availability Model.*** We will vet the water availability model with the CMT, and as needed with

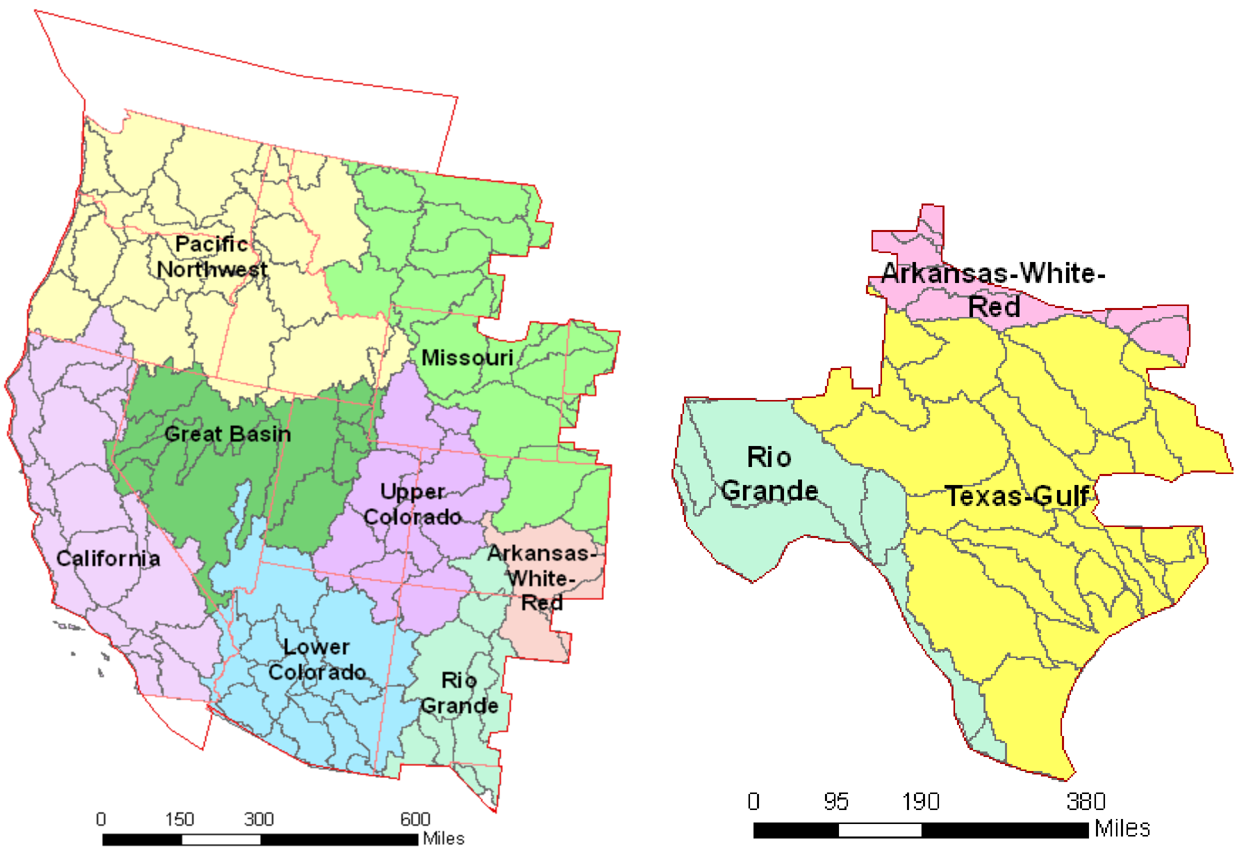

Figure 1 Water resources regions (WRRs) in the Western (left) and Texas (right) Interconnections. There are 5 full and 3 partial WRRs in the Western Interconnection and 3 partial WRRs in the Texas Interconnection. Each WRR has 10-20 sub-basins (USGS 6-digit basins).

stakeholders convened by WECC, WGA, and ERCOT. In this vetting process we will work to reflect region specific knowledge in our current water supply measures. ***Subtask 4.2: Expand Water Availability Model.*** We will also work to improve the spatial resolution of water availability model by linking to

INL's Virtual Hydropower Prospector (VHP) (DOE 2004). The VHP operates on small synthetic watersheds to collect precipitation data and to route runoff into synthetic streams. INL will consolidate the 3 to 5 mi^2 synthetic watershed and stream data contained within the VHP to provide a synthetic representation of watershed hydrology in the West at the USGS HUC 8-digit level. Synthetic data within the prospector currently supports mean annual flows. INL will add seasonal flows and exceedence flows if sufficient data are readily available from regional/national databases (e.g., PRISM data).

Subtask 4.3: Expand Groundwater Availability Model. Mapping of groundwater availability will be expanded through collaboration between INL and Sandia aimed at consolidating existing groundwater information within a standardized GIS coverage. The USGS base map of aquifers in the western U.S. will be used to collect and consolidate available information on general aquifer type (e.g., freshwater, brackish water, saltwater), and more specific information on the classification and use of economically viable aquifers (e.g., sole source and drinking water aquifers). Additional groundwater availability information will include EPA's wellhead protection/sole source aquifer programs and USGS and/or state saltwater intrusion maps. We will also use the CMT along with WECC, WGA, and ERCOT stakeholder teams, to gather and incorporate regional specific groundwater data. All combined, this information will be used to estimate the potential for groundwater depletions in a given basin.

Subtask 4.4: Non-Potable Resources. Analysis of water availability in EPWSim will be expanded to include non-potable resources. Here we will make use of extensive analyses by EPRI (2003a and 2008a). EPRI analyzed availability, quality, transport, acquisition and regulation of sewage treatment plant effluent, agricultural runoff, produced water and saline groundwater. It examined how quality of source water can require additional intake and discharge treatment, the compatibility of source water quality with both cooling system and transport materials, how to cost transport, and strengths and limitations of treatment technologies. At present, EPRI is finishing an analysis of the potential for recycling storm water runoff for use within a generation station. EPRI also examined treatment and reuse of power plant discharge streams (EPRI 2008b). Expanding on this work, INL will conduct a search for other federal and state GIS coverages and databases on brackish, produced, and waste water, and assess their viability and, where appropriate, incorporate that information into the Energy-Water DSS.

Subtask 4.5: Water Institutions Tool. Physical availability of (wet) water alone is insufficient to assure that water will be available for power production needs. In general, a water right or permit issued by the state is required to use water in the western U.S. In many basins in the west, especially in arid regions with large and growing populations, water is already fully allocated (and in some cases over-allocated) to existing uses, requiring that water for new uses must be transferred from existing uses. The price of water rights is also increasing rapidly in some of these areas.

The laws and processes governing water rights, permits, and transfers are complex and vary widely by state (NRC 1992). In many areas, additional local or basin-specific rules apply as well (Thompson 1993). Native American tribes often hold the largest most-senior water rights with their own sets of rules. Unless a tribe has received U.S. congressional approval, tribal water rights may generally not be used outside tribal lands (Colby et al 2005). Environmental issues may also be a factor, as endangered species act issues may restrict water use in many situations (Task 5).

In many basins in the west, water rights have not been adjudicated, leaving large uncertainties in the validity or certainty of rights (Thorson et al 2005). Legal protests by other rights holders are also increasing in some basins. Navigating the various processes to acquiring water for a new use can be an expensive and time consuming process, and particularly where transfers are involved there are no guarantees that the investment of time and money will result in success (Richards 2008).

The varied and complex web of laws and rules governing water allocation and use can pose formidable financial and legal challenges to the implementation of new energy facilities and in some cases to the operation of existing facilities. This task will provide for the development of a Water Institutions Tool that will enable an initial assessment of the institutional hurdles a potential project is likely to encounter as a function of location.

The team will assess and map the major institutional controls that govern state water rights in the west. For any given location, the mapping tool will identify what state-level water rights regimes are in place for surface water and groundwater, the extent to which the water rights have been adjudicated, and what additional controls may apply, such as those that existing Tribal lands, acequias, irrigation districts, or special water districts. The tool will identify which basins are closed to future appropriation and indicate what rules are in place for water transfers. To the extent possible, the current price of water rights will be included, or a suitable proxy (Task 7). Similarly, if feasible, the tool may incorporate information about water conflict in the basin, using the number of water-related lawsuits or other suitable metric. The tool will also identify basins were some or all water use is subject to interstate compact limitations.

The Water Institutions Tool will be integrated with the water availability model so that the user can determine which locations might be best suited for a project from both a wet water and paper water perspective. It will also be used to assess prospective locations to determine whether there are likely hurdles to particular projects and will provide an initial assessment regarding locations to be avoided.

Task 5: Environmental Controls Model

Argonne will develop the Environmental Controls Model for identification and assessment of potential environmental risks associated with growing water use (thermoelectric and other) and climate change. The proposed work will include compilation of relevant and available environmental data, development of analytical risk assessment tools, and development of GIS-based tools for visualization of risk impact. The risk assessment tool will utilized data generated by the Water Demand, Water Availability, and Climate Change models. Model output will be routed to the DSS interface where it can be viewed directly or can be combined with other measures in the Regional Water Stress Calculator (Subtask 9.3).

Subtask 5.1: Compilation of Relevant and Available Environmental Data. Argonne's existing GIS data inventories, extensive experience in characterizing environmental impacts of energy technologies and development scenarios and familiarity with applicable regulatory requirements will be the basis for analytical tool development identified below. Due to the extent of information available in Argonne's existing data bases, it is anticipated that the amount of additional data compilation required will be minimal.

Subtask 5.2: Environmental Risk Tool. In this portion of the proposed project, a tool will be developed for quantifying environmental risks associated with specific environmental resources and for estimating an overall risk level of a proposed energy scenario. The tool would focus initially on identification and visualization of environmental risk based on single indicators such as presence of selected endangered species. The initial tool will then be enhanced to incorporate a framework for identification and visualization of more comprehensive measures of environmental risk.

Environmental risk will be directly related to the types of environmental resources occurring in a river basin, the relative significance of those resources in terms of regulatory requirement and the impact on those resources from changes in water availability. An algorithm will be developed for assigning a numerical weighting factor of relative importance to each environmental resource within in a scenario-impacted river basin. The value of this weighting factor will be a function of the regulatory requirements associated with the resource (e.g., Endangered Species Act [ESA] protection), the nature of the effect that an energy scenario may have on the resource (e.g., temporary habitat disruption, long-term displacement of biota, injury or mortality) and the sensitivity of the resource to changes in water availability. To provide an overall relative risk level for a proposed scenario, the algorithm will combine the importance values (on the basis of overlap of GIS data layers for each ecological resource at that location) to generate a single numerical risk level. For equally important resources, the more resources overlapped at a specific project location, the higher the relative environmental risk level.

Subtask 5.3: GIS Risk Visualization Tool. This component of the proposed project will consist of a GIS tool for identifying the environmental risk from coincidence of ecological resources within a specific river basin. To the extent available, GIS data will be made available for standard base map features (such as boundaries, roads, and cities), water resources (such as water availability data from Task 4), environmental features (such as topography and surface waters), and key ecological resources. In the initial phase environmental risk for single indicators of risk (e.g., endangered species) will be included in the tool. Subsequent development of the tool will include more comprehensive risk measures developed under the previous component of this task.

The GIS tool will display an interactive GIS map that can be zoomed to view more detailed data, or interrogated for information about features of interest. Map content (such as the particular GIS data displayed) will be able to be turned on and off to show information of interest to the user. Layers depicting environmental risk such as surfaces or isopleths will be available as a means to visually identify and compare scenario impacts.

Task 6: Climate Change Calculator

Argonne and PNNL will develop a climate change calculator that will allow for estimation of potential changes in water availability due to climate change within study area river basins. This will include two components – a climate downscaling model to provide future climate forcing data for the watershed model, (PNNL), and a dynamic large-scale watershed model to project related changes to water availability (Argonne). The Climate Change Calculator will utilize water demand data generated in Tasks 2 and 3 (updated for climate change affects). Results will be integrated with that from the Water Availability Model (Task 4), which will be routed to the DSS interface where it can be viewed directly or can be combined with other measures in the Regional Water Stress Calculator (Subtask 9.3).

Subtask 6.1: Downscale Model. A multi-model ensemble of regional climate change scenarios developed by the North American Regional Climate Change Assessment Program (NARCCAP) (Mearns et al. 2009) will be used to help assess future changes in sustainable water supply. This multi-model ensemble includes a total of 12 regional climate simulations produced by 6 different regional climate models downscaling global climate simulations from 4 different global climate models including the Community Climate System Model (CCSM), Geophysical Fluid Dynamics Laboratory Climate Model (GFDL-CM), Canadian Global Climate Model (CGCM), and Hadley Centre Climate Model (HadCM) (http://www.narccap.ucar.edu/). These simulations are available at 50 km horizontal resolution for the current (1970 – 2000) and future (2040 – 2070) climate conditions over North America under the Intergovernmental Panel on Climate Change (IPCC) A2 emission scenario. In addition to the climate change simulations, each regional climate model has already generated a 25-year simulation (1979 – 2004) driven by the NCEP/DOE global reanalysis. The NARCCAP investigators are applying statistical methods to assess the uncertainty in projecting climate change due to various factors, including uncertainty in the large-scale circulation (e.g., global climate simulations versus global reanalysis), uncertainty in the downscaling models, and natural climate variability.

These simulations will be utilized to provide a multi-model ensemble of regional climate change scenarios to assess climate change impacts on the magnitude and timing of water supply. As described in the NARCCAP website (http://ww.narccap.ucar.edu), 3-hourly surface temperature, precipitation, surface radiation, surface winds, surface humidity, and a suite of other variables are archived by each model in netCDF format and accessible from the Earth System Grid. Since 50 km resolution is not sufficient to resolve temperature and precipitation variations across the complex terrain in the western U.S., we will apply the Bias Correction – Statistical Downscaling (BCSD) method described by Wood et al. (2004) to produce gridded daily maximum and minimum temperature and precipitation scenarios at a 1/8 degree grid resolution.

Besides using the NARCCAP model outputs to drive the hydrologic models, analysis of the current climate and regional changes simulated by the suite of regional/global climate models will be performed. These include changes in the precipitation regimes such as precipitation frequency and intensity, floods and droughts frequency, and changes in temperature and surface radiation. This will provide the context for interpreting the hydrologic changes simulated by the models and provide guidance and planning tools for diverse hydrologic changes occurring across the western U.S.

Subtask 6.2: Large-scale watershed model. The large-scale watershed model will provide a dynamic tool to explore the water availability at basin level in the Western and Texas Interconnections. The model will adopt the Soil and Water Assessment Tool (SWAT) (Neitsch et al., 2005) as a main modeling tool coupled with a set of assisting development tools built at Argonne. The Western and Texas Interconnections involve 9 water resources regions (WRRs, USGS 2-digit basins) and ~125 sub-basins (USGS 6-digit basins) (Figure 1). Argonne will construct watershed models at selected water resources regions to cover the majority of the two Interconnections.

The model will incorporate physically-based hydrologic processes, plant growth processes, and water use management. It is a semi-distributed, continuous watershed simulator that computes long-term water flows over large basins. The model treats the watershed system by taking two scale levels of the spatial heterogeneity into account. The first level (subbasins) supports the spatial heterogeneity associated with hydrology, and the second level (hydrologic response units or HRUs) incorporates the spatial heterogeneity associated with land use, soil type and slope class. Within a subbasin, the model does not retain the spatial location of each HRU. The outputs from all HRUs in a subbasin are aggregated to the subbasin level, which is computationally efficient for large-scale modeling.

For each model of one water resource region, the watershed will be divided into a number of subbasins (USGS 6-digit basins), which are further subdivided into smaller groups (HRUs) with each HRU possessing unique land use, soil type, and management attributes. The water balance of each HRU is calculated through four water storage bodies: snow, soil profile, shallow aquifer, and deep aquifer. Many physical processes involved in these water storage bodies are formulated through submodels, such as snow pack/melt (Fontaine et al., 2002), surface runoff (USDA-NRCS, 2004), evaporation on bare soils and evapotranspiration on vegetated canopy (Priestley and Taylor, 1972; Hargreaves and Samani, 1985; and Allen et al., 1989), layered soil water routing, lateral subsurface flow, shallow groundwater recharge/discharge, and percolation to deep aquifer (Arnold et al., 1993). Flows generated from all HRUs are summed for each subbasin and routed through the channel network, ponds and/or reservoirs to watershed outlet using several variations of the kinematic wave approach. The simulation results will provide a spatial and temporal distribution of water in surface runoff, shallow groundwater, deep groundwater, soil profiles, and various storage reservoirs at sub-basin level.

Water use management accounts for various competing water uses, which include water withdrawal for thermoelectric generation, public and domestic supply, industry and commercial water usage, agricultural irrigation, mining, and livestock. Application of irrigation and/or all other water uses is flexible using either for specific date or with an auto-irrigation/withdrawal routine, which triggers irrigation/withdrawal events according a water stress threshold. The water withdrawal can be simulated at the subbasin level from five alternative sources through either water transfer function or consumptive use with no return based on daily or monthly rate.

Simulation of water availability for the future scenarios will be performed by integrating this watershed model with the water demand simulator (Tasks 2 and 3 and adjusted for climate affects, Subtask 6.3) and climate downscaling model (Subtask 6.1). The outputs from these two models will be used as model inputs for the watershed model to project the future water availability for all sub-basins.

The model will use the datasets collected through this study including: USGS Digital Elevation Model (DEM) at resolution of 60 m or 90 m, USGS stream network (RF1), latest National Land Cover Database (NLCD), weather station data from the National Climatic Data Center (NCDC), and major water features such as reservoirs. Watershed models will be calibrated for the period of 1990-2000 against stream flow data at 2-3 USGS gauge locations along the main channel for each WRR. The model validation will be performed for the period of 2001-2005 for the flow data observed at same gauge locations. The USGS gauge stations for calibration and validation will be selected based on data quality and coverage of drainage area within each WRR.

The calibrated model will provide water availability data under the current conditions and future scenarios of climate impacts and water usage. The simulation results include distributions of all water components for each sub-basin (USGS 6-digit basin) at daily, monthly, and annual time intervals. The typical water components are evapotranspiration (ET), surface runoff contribution, groundwater contribution (base flow), and total water yield from each sub-basin and stream flow at each sub-basin outlet.

Subtask 6.3: Climate Impact on Water Demand. Estimating impacts on water demands related to changes in power demand and irrigation requires utilizing metrics associated with climate-specific water and energy use factors, climate specific water requirements of crops, and regional-specific climate change projections. Also necessary to include are expected demographic changes, energy requirements associated with these changes, changes in power plant efficiencies, changes in expected evapotranspiration rates, and changes in crop locations. This work will be lead by NREL and will be contingent upon successful integration of the results of Task 2, Task 3, and climate change projections.

Task 7: Water Cost Calculator

Beyond the scarcity of water, information concerning the potential cost of water for a new withdrawal is of interest. Such costs might simply involve construction of a groundwater pumping system or surface water diversion works. Alternatively, costs could be associated with the purchase of a water right or costs associated with the treatment and conveyance of water from a non-potable source (e.g., brackish or waste water).In this task a new water cost calculator will be developed by Sandia. Here we will not worry with basic infrastructure costs at a power plant (i.e., wells, pumps) but will rather focus on the cost of the water itself. Model output will be routed to the DSS interface where it can be viewed directly or can be combined with other measures in the Regional Water Stress Calculator (Subtask 9.3).

Subtask 7.1: Water Rights Payments. The first component of the cost calculator will project historic payments for water rights. Data on historic payments was compiled in the Water Transfer Level Dataset by the Bren School at the University of California Santa Barbara. The data were drawn from water transactions reported in the monthly trade journals the *Water Strategist* and its predecessor the *Water Intelligence Monthly* from 1987 through October 2007. The database lists, by state, water transfers including: the year of a water transfer; the acquirer of the water; the supplier; the amount of water transferred; the proposed use of the water; the price of the trade; and the terms of the contract.

This data set will be synthesized and organized into a set of data layers that can then be integrated into the DSS. Information such as the average price paid, and the range of prices will be available by state and by type of transfer (e.g., agriculture to urban). Additional efforts will be made to review the available literature for other water rights transfer data.

Subtask 7.2: Surrogate Water Payments. Unfortunately, the purchase price for water rights often goes unreported, as this information is viewed as proprietary among the involved parties and the broker. Thus, the purchase price database only provides a limited picture of the potential monetary value of water. For this reason an alternative measure for the monetary value of water will be developed; specifically, the water intensity associated with each of the principle industrial activities in a basin. Water intensity is simply the ratio of the total economic activity (gross output) associated with a particular industry (measured in dollars) to its total water use. For example, irrigated alfalfa would have low water intensity (low crop value but high water use); while a service oriented industry will have high water intensity (high economic value but low water use).

The purpose of this analysis is to provide an idea of what it might cost to transfer water from one use to another. It is likely to be easier to move water from a low water intensity use (e.g., irrigated pasture) to one of higher intensity (e.g., computer chip manufacturing). Toward this end, the model will display both the economic activity (gross output in dollars) and the total water used by each principle industry. Industrial class will include feed crops, food crops, specialty food crops, biofuels, livestock, general industrial/commercial, mining and electrical power generation. Analyses will be conducted at the county level but can be aggregated to watershed, state or interconnection levels. Primary data for the cost calculator model will be taken from the U.S. Agriculture Census and the Bureau of Economic Analysis, Industry Economic Accounts.

Subtask 7.3: Water Treatment Costs. Where there is no access to unappropriated water and water rights are expensive, non-potable water represents an option for new water development. Associated costs might include the purchase of a right to use the water, along with associated treatment and conveyance capital, operating and maintenance expenses. Under this subtask, estimated costs for utilizing non-potable water will be developed and available for comparison to the estimated costs for traditional water sources derived in subtasks 7.1 and 7.2 above. The option to use non-potable water and its ultimate cost will be linked to its availability, as determined in subtask 4.4.

Rough estimates of the potential cost to utilize non-potable water will be derived. Cost functions will be based on considerable work which has been performed by Sandia, the Bureau of Reclamation and others (Kobos et al. 2008, Zammit and DiFillipo 2004, and USBR 2003). The cost functions will consider such features as the type of treatment, water source, distance to the source, gross chemical characteristics of the source and system through put. In this way, non-potable water use costs will vary regionally according to the demand and the non-potable water source.

Task 8: Energy for Water Calculator

As water use expands, so to does the demand for electricity to pump, convey, treat (both primary and waste water), and distribute the water (e.g., EPRI 2008c). Models developed under the previous tasks address the growing demand for water, here the associate energy use is determined. Water withdrawals and waste water return flows (Task 3) form the primary input to this model, while output in terms of electric power demand will be returned to the WECC and ERCOT transmission planning models. Model output will also be routed to the DSS interface where it can be viewed directly.

The basis for the analysis is the energy for water module in the EPWSim model. Electricity demand for primary water supply is modeled at the county level according to an empirical relation developed by

AWWArf (2007) based on a regression of municipal water use versus energy consumption for a wide range of U.S. cities. The relation explains 76% of the measured correlation. For municipalities dependent on groundwater, energy demand is increased by 30% to account for the increased energy burden for pumping the water (EPRI 2002). In the case of the waste water system, electrical demand was modeled as a function of the water discharged to the waste treatment system, the type of treatment (trickling filter, activated sludge, advanced, advanced with nitrification), and the design capacity of the plant (EPRI 2002). Waste water plant specific data are available from EPA's Clean Watersheds Need Survey database (2004). These calculate power demand versus water use relations developed at the plant level are subsequently aggregated to the county level, weighting the influence of each plant by its through put relative to that of the other plants in that county.

Subtask 8.1: Updating the EPWSim Energy for Water Calculator. Improvements to the energy for water model will begin by vetting the current models and energy use rates through the CMT and with our partners at WECC, WGA, and ERCOTT. Of particular value will be interactions with the California Energy Commission that has performed considerable analyses toward this issue. ***Subtask 8.2: Energy for Large Projects.*** A particularly important aspect missing from the above analysis is the energy use by large scale conveyance projects. Working with our interconnection partners we will strive to acquire data on large scale conveyance projects such as the Central Arizona Project, San Juan-Chama Project, California Aqueduct, etc. ***Subtask 8.3: Energy for Agriculture.*** Energy use for agricultural irrigation is consistently tracked in the Census of Agriculture performed by the National Agricultural Statistics Service. This data will be used to extend the coverage of energy use for water to include agriculture.

Task 9: Decision Support System Interface

The work described here builds on years of experience by Sandia, EPRI, NREL, INL and UT in the development of user friendly modeling tools and DSS interfaces (e.g., EPRI 2009, 2007, 2005, 2003c, DOE 2004, Roach and Tidwell 2009, Tidwell et al. 2004, http://ficp.engr.utexas.edu/tipsv2/index.html). The DSS interface is the "dashboard" that controls scenario makeup, simulation operations, and the rendering of results. The first step in this task is the integration of EPWSim with all the other models and GIS coverages developed in the preceding seven tasks. An interface that fully encompasses all the inputs and outputs across these disparate modeling platforms will then be developed to control operations and view results.

An operational interface currently accompanies the EPWSim model and provides the foundation for future interface development for this project. The current dashboard provides an interactive, real-time environment comprised of slider bars, buttons and switches for changing key input variables, and real-time output graphs, tables, and geospatial maps for displaying results. Specifically, one set of hyperlinked interface pages provide user control of scenario makeup, allowing choices on fuel mix for the future fleet of power plants; mix of corresponding cooling technologies employed; criteria for siting future plants; population and gross state product growth rates; growth in non-potable water use; and many others. These scenario controls can be implemented at the county, state, watershed, or interconnection level.

The user likewise has control over the rendering of scenario results. Results can be displayed in terms of data tables, graphs, bar charts, or geospatial maps displayed interactively through Google Earth™. Results can be displayed at their native resolution (county/watershed) or aggregated to the state or interconnection level. A few of the metrics currently supported in the interface include total water use, total water consumption, available surface water supply, change in groundwater demand, ratio of water supply to water demand, and municipal water use.

The dashboard is designed to make the DSS accessible to the professional and lay public alike, requiring no specialized software (Excel is the only requirement). The model operates on a laptop computer taking only few seconds to accomplish a simulation. Currently the model can be distributed to users on CD or via download from the internet. To give a sense of the "look and feel' for the model interface a few selected screenshots are provided (Figure 2 and 3).

Subtask 9.1: Model Integration. The Energy-Water DSS will be comprised of a wide variety of tools and data sets contributed by a number of different institutions. Some elements currently exist while others remain to be developed. A challenging issue facing this team is the fact that all the existing models are formulated on different software platforms. EPWSim is constructed on a commercial system dynamics platform (Powersim Studio Expert), the climate change watershed model uses SWAT, while the VHP and climate downscaling models utilize specialty applications. Additionally there are a wide range of data sets that must be assembled from various GIS coverages.

The first order of business of this team will be the development of an overarching modeling architecture for integrating these models and data sets as well as those remaining to be created. Options include porting all existing applications to a uniform platform, developing APIs and protocols to link the disparate applications, or some hybrid between these two approaches.

Subtask 9.2: Interface Design. Working through the CMT we will develop an interface that meets the needs of WECC, WGA, and ERCOT. This effort is likely to require the addition of new interface options to control scenario makeup, for example, policy options controlling CCS implementation, or policies concerning environmental or institutional controls on new water withdrawals. Changes in display will also be necessary to address new metrics added to the EPWSim model.

Subtask 9.3: Water Stress Calculator. A review of the preceding tasks reveals the numerous metrics that contribute to the concept of water stress (e.g., water demand, water availability, institutional controls, water cost, environmental factors), for which there is no universally accepted measure. For this reason, flexibility will need to be built into the way water stress is calculated. An interface feature will be constructed that allows a given user to define what measures will be used and their relative weighting in constructing a personal measure of water stress. Of course, the user can always view each metric individually. In this way the DSS interface will facilitate the development of water stress metrics that appeal to a particular stakeholder and that can be subsequently vetted with the broader community.

Task 10: Scenario Analysis

Sandia will lead the scenario analysis task for WECC and WGA, while the University of Texas will lead analyses for ERCOT. The entire project team will participate in scenario exercises for both interconnections. The purpose of this task is to support the Western and Texas Interconnections in their responsibilities for identifying potential implications of water stress related to transmission and resource planning. This effort will proceed by utilizing the Energy-Water DSS to evaluate alternative future scenarios developed by WECC, WGA and ERCOT.

Subtask 10.1: Scenario Development. Development of scenarios to be evaluated with the Energy-Water DSS will be the responsibility of WECC, WGA, ERCOT and their associated stakeholder teams. However, our project team will work with our interconnection partners through the CMT to formulate scenarios that can be comprehensively addressed. In particular, this will involve communicating the limitations of the model, as well as negotiating modifications to the model (within the scope of this proposal) to facilitate the desired range of analyses. Scenarios will largely be defined by the output of the interconnection wide transmission planning process; specifically, the distribution of power production over the entire interconnection. This includes operations of existing facilities as well as new capacity necessary to meet growing demand.

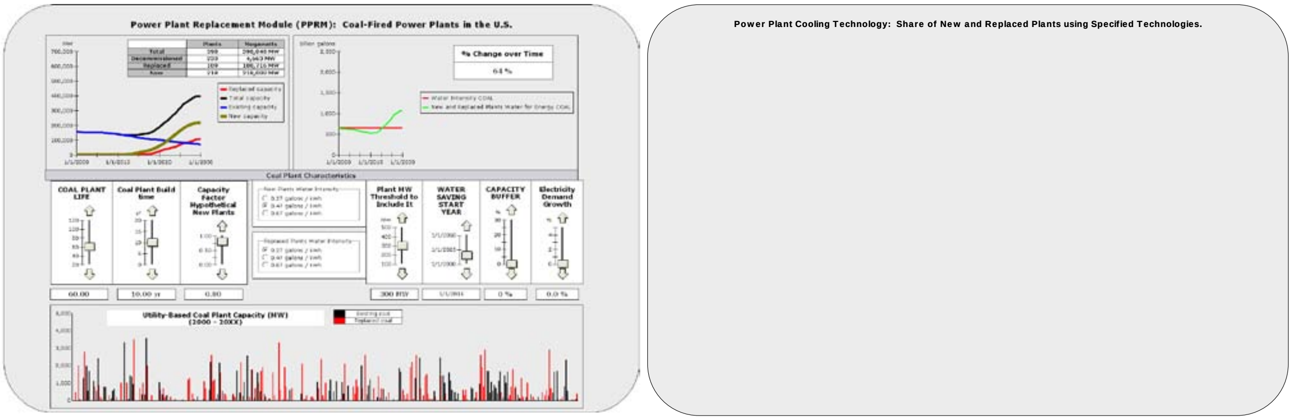

Figure 2 Example of EPWSim interface control pages. Control of power plant characteristics (left) and control of cooling system makeup (right).

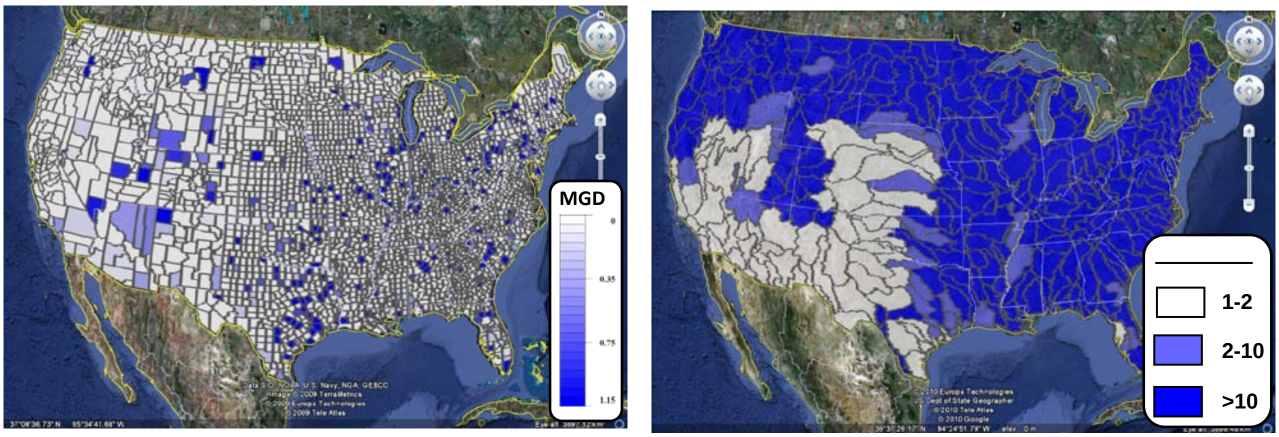

Figure 3. Example of EPWSim interface output pages. Water consumption for thermoelectric power generation in 2004 (left) and ratio of surface water supply to water demand in 2004 (right).

Subtask 10.2: Scenario Analysis. Scenarios developed by WECC, WGA, and ERCOT will be submitted to the project team for analysis. Simulations with the Energy-Water DSS will be performed and the results reported back to our interconnection partners. Scenario analysis will provide insight on such factors as: water withdrawal and consumption for thermoelectric power production (locally and interconnection wide); increased demand across other water use sectors; impact of increased water use on water availability; alternative water supply options; potential water policy constraints; water related environmental impacts; increased energy demand due to water use; identification of areas susceptible to climate impacts; as well as many other metrics and or combination of metrics.

In most cases, scenario development and analysis will proceed in an iterative fashion. That is feedback on water availability will influence transmission planning conditions, which when adjusted will change the water stress landscape. The interactive nature of the DSS will allow scenario analysis to be conducted directly with the planning teams. That is the DSS interface will facilitate direct adjustment of scenario conditions, model simulation, and reporting of results in real-time in a workshop or focus group setting.

WECC, WGA, and ERCOT will be engaged in transmission planning exercises throughout the entire three year project period. In fact, early stages of scenario development are currently in progress in the WECC. These early stage analyses will be accommodated with EPWSim in its current state of development. As EPWSim and the broader Energy-Water DSS matures so to will our capacity to comment on the broader aspects of the scenario analysis. But the positive aspect is that we can accommodate a basic level of scenario analysis from the very beginning of the project.

Subtask 10.3: Training. Our goal is to develop a DSS that is easily accessible to project partners, in terms of both computer platform and the interface with which the user interacts with the tool. As such, we will provide our partners with the option of conducting scenario analysis on their own. This will potentially allow a wide range of stakeholders to test their personal scenarios and learn from the exercise. To facilitate this exchange, training workshops will be offered to provide interested stakeholders the DSS operational skills they will need to perform scenario analysis. The UT Austin team is already engaged in training hundreds of professionals annually through executive education and CEU coursework for professional engineers, policymakers, entrepreneurs, lawyers, accountants and analysts; it should be straightforward to include the DSS training in future short courses.

Task 11: Reporting

Sandia will be responsible for all reporting requirements with input from our project participants. Reporting will occur at a variety of levels. ***Subtask 11.1: DOE Reporting.*** Reporting on project budget, schedule and milestones will be performed as requested. Other communications will be provided as requested by the DOE Project Office. ***Subtask 11.2: Scenario Reporting.*** Letter reports will be issued to our interconnection partners on results from the requested scenario analyses. ***Subtask 11.3: Final Report***. A final report will be issued that fully documents the Energy-Water DSS, user instructions, and results from 3 years of scenario analysis. ***Subtask 11.4. Professional Reporting***. Efforts will also be made to broaden the impact of this research through publications in professional and trade journals. Presentations at regional, national and international conferences will also be pursued as deemed appropriate.

Merit Review Criteria

Needs Assessment: The project team was assembled based on the professional connections, experience, data, and models they can contribute toward the development of the Energy-Water DSS. For each of the modeling tasks listed above project participants are leveraging past and/or current research to accomplish the stated goals. According to this first-hand experience, our team members have demonstrable understanding of the techniques, models, data needs, analytical approaches and challenges in meeting the demands of this project. This strength in experience is further demonstrated in the papers, reports, data sets and models generated through their past research.

Technical Approach and Project Management: Adequacy and completeness of this proposal to meet DOE and our interconnection partner’s goals is demonstrated by the proposed set of project tasks that carefully address each element in the research call. Tasks are organized according to the structure of the research call with each task meeting or exceeding the stated expectations.

Feasibility and validity of the approach is demonstrated by the past productivity of the project team. Extensive data sets, reports and models speak to the team’s ability to deliver. In this way, prototypes for most of the Energy-Water DSS elements have been developed calibrated and tested. Here we will be vetting, extending and integrating these disparate elements. Thus, chances of success are very high.

Project responsibilities have been distributed across project participants according to proven performance by way of reports, data sets and models. Budget has been distributed according to the level of effort required to extend and integrate the individual elements into the Energy-Water DSS.

Elements of a project management plan are clearly evident in the body of this proposal. A clear and comprehensive set of project tasks is articulated, while a schedule for deliverables is provided below. The tasks and deliverables are crafted to meet the specific needs and desires stated in the research call. In terms of experience, Sandia along with all the project participants have significant project management experience, both in terms of leading projects and supporting them. Sandia also has demonstrated capacity to track and manage the financial and American Recovery and Reinvestment Act aspects of the project.

The purpose of establishing a Collaborative Modeling Team (CMT) is to pursue transparency and consensus building (Subtask 1.2). By engaging stakeholders directly in the development of the Energy-Water DSS, they better understand the capabilities and limitation of the model—it is no longer viewed as a black box. This transparency improves consensus in the developed model and the results rendered. Broad access to the tool also expands the number of stakeholders who can experience the model first-hand, further increasing transparency and consensus.

Outreach and Impact: Sandia has a good working relationship with WECC and WGA, which grew out of our original teaming on DE-FOA0000068. At that time we worked to develop the water-energy nexus related articles of their proposal. Upon WECC and WGA receiving the grant award, we continued to work with these institutions at their request. We attended several meetings and assisted in the project planning. As such, Sandia is very familiar with the needs of WECC and WGA along with the tools and approaches they will employ in this project. The work proposed here reflects that understanding. Please note that all communications between WECC, WGA and Sandia were discontinued upon the issuance of this call.

The University of Texas has an ongoing and strong working relationship with ERCOT and has an extensive record of research relevant to the energy-water nexus in ERCOT. For example, two of the co-PIs from UT Austin (Webber and King) are co-PIs on ongoing or recent projects specific to Texas and ERCOT. One of these is a two-year study that began in February 2010 and is funded by the Department of Energy titled "Techno-economic modeling of integration of 20% Wind and large-scale energy storage in ERCOT grid by 2030." The second study funded by the National Science Foundation Emerging Frontiers in Research and Innovation program titled "Resilient Infrastructures: The Interface of Infrastructures, Markets, and Natural Cycles - Innovative modeling and control mechanisms for managing electricity, water and air quality in Texas," closely examines the relationship of energy and water for the grid in ERCOT. In both cases UT and ERCOT are working closely to coordinate efforts, share data, and develop transmission scenarios.

A key aspect of WECC, WGA and ERCOT's project activities is the engagement of an extended set of stakeholders; particularly, the involvement of Non-Government Organizations (NGOs). In each case our interconnection partners have assembled special working groups with the purpose of expanding stakeholder participation in transmission planning. Rather than convening yet an additional stakeholder group we will utilize the teams already assembled. In this way we will work closely with WECC, WGA and ERCOT to actively participate in both project and stakeholder meetings. In addition, we will establish a CMT, comprised of a subset of WECC, WGA, and ERCOT members and stakeholders, who will oversee development of the Energy-Water DSS and its application in scenario analysis.

A variety of publication and presentation venues will be pursued to expand the impact of this project beyond the bounds of the entities immediately involved with the project. Publications in trade and professional journals will be pursued as well as presentations at local, national, and international conferences. Members of this project team are also actively engaged in making invited presentations on energy-water issues, which is fully expected to continue and grow. In addition, Dr. Webbers' team at UT Austin has expertise developing podcasts and interactive websites dedicated to the energy-water nexus as a way to take technical findings to broader audiences comprised of policymakers and the general public. These avenues will also be pursued to reach a bigger audience of non-experts.

Relevant Experience and Capabilities: The credentials, capabilities and experience of our project team members are clearly articulated in their proven accomplishments to date. These capabilities are further documented in the Qualifications and Resources section. Project coordination and its focus on WECC, WGA, and ERCOT needs will be facilitated through the CMT. Commitment of project participants is demonstrated in the attached Letters of Commitment (Appendix B). Compliance with American Recovery and Reinvestment Act requirements is addressed in Subtask 1.4.

Deliverables

Table 1 Project Deliverables

Task	Deliverable	Delivery Date*
1	Management Plan and Scope of Work	Quarter 1
1	Establish Cooperative Modeling Team	Quarter 1
9	Design integrating platform for the DSS	Quarter 2
2	Electricity Water Withdrawal and consumption Calculator	Quarter 2 and 6
3	Water Demand Projection Model	Quarter 4 and 8
4	Water Availability Model	Quarter 3 and 7
4	Water Policy Model	Quarter 4 and 10
5	Environmental Flows Model	Quarter 4 and 10
6	Climate Change Calculator	Quarter 6 and 10
7	Water Cost Calculator	Quarter 8
8	Energy for Water Calculator	Quarter 6
9	DSS and Interface	Constantly Evolving
10	Scenario Analysis	Annual
11	Project Management Reports to DOE	As Required
11	Scenario Letter Reports	Annual
11	Final Report	Quarter 12

* Multiple delivery dates indicate tasks where a preliminary operational model is developed (first date) and then updated at a later time (second date).

Relevance, Outcomes and Impacts

While timely accomplishment of the deliverables set out above is important and necessary, we are striving for broader impact. Currently there are no long-range, interconnection-wide transmission plans for the Western and Texas Interconnections. Consequently, the ability to assess how various infrastructure options balance reliability, cost, and the environment from an interconnection-wide perspective does not exist. This project coordinated with the efforts of WECC, WGA, ERCOT and their partners will create a comprehensive package of stakeholder-vetted, regional planning models, data, and conclusions that are coordinated at the interconnection-wide level. Cumulatively, this information will substantially improve the quality and quantity of information available to industry planners, state and federal policymakers and regulators. Specifically, this project will supplement interconnection-wide transmission planning studies with information on water availability, which is critical in shaping electricity generation options.

This proposed project represents the first comprehensive, regional analysis of the energy-water nexus. This is also the first coordinated analysis undertaken by federal and state agencies, the power industry, NGOs and other interested stakeholders. In this way, the data, models, scenario analyses, and insights derived from this effort will provide a significantly improved body of information for policy making on issues pertaining to the energy-water nexus.

Qualification and Resources

A very capable and experienced team of national laboratories, a university, and an industrial research institute has been assembled to address the issue of water and energy in the Western and Texas Interconnections. Team membership is based on a proven record of research in areas pertaining to the energy-water nexus. In each case team members bring data, models, and experience necessary in the development of an Energy-Water DSS. Specifically, these team members include Sandia National Laboratories, Argonne National Laboratory, Idaho National Laboratory, the National Renewable Energy Laboratory, Pacific Northwest National Laboratory, the University of Texas, and the Electric Power Research Institute. Below is provided a brief introduction to the capabilities of each project participant along with the specific role they will fill in this project. Roles of specific personnel within the project can be found in the Resume File (Appendix B).

Technical work addressed in this proposal involves data analysis, computer model development, and database management. All of these tasks are computer-based and will be performed in existing office environments at the participant's institution. As such, there is no need for specialized facilities or equipment to accomplish the goals of this work.

Sandia National Laboratories has a long history in system engineering and analysis beginning with its role in nuclear weapon systems integration. Since this time our systems analysis heritage has evolved to address a broad range of issues related to safety/security, energy, nuclear non-proliferation, and environmental management. Over the last 11 years Sandia's Earth Systems Department has developed system models embodied in Decision Support Systems to assist in water resource planning and management from the local to international level. A few examples of our work include regional water planning studies for the Upper Rio Grande; development of a water leasing market in the Mimbres Basin in southern New Mexico; reservoir operations study to manage flows and water temperature for endangered species recovery in the Willamette Basin; utilization of "new water" made available through the Arizona Water Settlements Act in the Gila River Basin in southwestern New Mexico; development of groundwater safe-yield limits for the Barton Springs Aquifer in central Texas; and transboundary water resource management for the Tigris and Euphrates Rivers in Iraq. In each case, these studies worked to develop decision aiding tools in an open and participatory environment with interested stakeholders. Through these efforts we have embarked on a collaborative effort to establish a multi-agency, multi-university center devoted to the creation and application of computer-aided decision support tools and stakeholder mediated decision processes (www.iwr.usace.army.mil/cadre/).

More recently the Earth Systems Department has become increasingly involved in studies pertaining to the nexus between water and energy. In 2008 Sandia teamed with General Motors to develop a "seed to station" model investigating the full supply chain for cellulosic ethanol, including a strong linkage to water. A wide variety of systems models are in development to support DOE's Solar America Cities program and the Geothermal program. Finally, the Energy-Power-Water Simulation (EPWSim) model was developed to investigate issues associated with the energy-water nexus. This model is currently being utilized in studies funded by the Great Lakes Commission, the National Energy Technology Laboratory, and DOE's Office of Policy and International Affairs.

Sandia National Laboratories will function as the lead lab on this project, responsible for project management, coordination, tracking and communications. Sandia will be responsible for development of the Energy-Water DSS. The foundation of the DSS will be EPWSim, which will subsequently be extended through the integration of new process models, modules and data developed by Sandia and other project participants. Specifically, Sandia will take responsibility for construction of the Water Institutions Tool and the Water Cost Calculator. Throughout the development of the DSS, Sandia will take the lead in coordinating interactions with the CMT, our interconnection partners and engagement with the stakeholder committees convened by our partners. Sandia will also manage the scenario analysis aspects of the project and project reporting.

Argonne National Laboratory staff have extensive experience in environmental assessment, modeling and field studies related to energy technology development and deployment and climate change. They have conducted environmental, economic and regulatory studies to determine feasibility of a wide range of electric power and energy resource extraction and processing technologies. They have modeled and analyzed numerous power systems focusing on economic and environmental issues associated with the operation of hydropower systems in the western United States, including analysis of the energy-water nexus relationships in the region. They have developed extensive knowledge and data related to the environmental risks and impacts of energy system development and management in the southwestern U.S. through preparation of Environmental Impact Statements (EIS) including: the BLM Wind Energy Development Programmatic EIS, the BLM Oil Shale and Tar Sands PEIS, the DOE/BLM West-wide Energy Corridor, and the Colorado River Basin Water Shortage Criteria EIS. As part of this work, they have also developed and applied GIS technologies to evaluate spatial relationships among energy resources, environmental resources, land use designations and restrictions, and infrastructure. Additionally, they have developed and co-developed a number of regional and global-scale atmospheric chemistry, aerosol, and climate change models. These models have been applied in the conduct of watershed modeling for large-scale watersheds in the U.S. to address regional climate impacts on water availability and energy development under expected biofuel growth and land use change. The methods, computation tools, data and techniques developed and applied by Argonne through these studies will benefit the proposed work for the Western and Texas Interconnection regions.

Argonne will assist Sandia in development and verification of data, algorithms and other components of the DSS Model related to water use by selected electric power generation technologies and plants and for energy resource extraction and processing. Argonne will also develop analytical tools to be incorporated into the DSS, for identification and assessment of the potential environmental risk associated with water availability and use under DSS-generated scenarios of energy development. The proposed work will include compilation of relevant and available environmental data, development of analytical risk assessment tools, and development of GIS-based tools for visualization of risk impact. Finally, Argonne, with assistance from PNNL, will develop a climate change calculator that will allow for estimation of potential changes in water availability due to climate change within the study area river basins. This will include two components – a climate downscaling model to provide a future climate forcing data for the watershed model, (PNNL), and a dynamic large-scale watershed model to project related changes to water availability (Argonne).

Electric Power Research Institute has been managing research on the issue of the energy/water sustainability for the last decade. This work has resulted in numerous publications, most recently, Managing Water Resource Requirements for Growing Electric Generation Demands, EPRI 1017946, 2009. EPRI has also organized several conferences and workshops on the subject, co-authored several journal papers, and made technical presentations at numerous national conferences sponsored by professional, government and stakeholder organizations. The scope of EPRI's research includes advanced cooling technologies, energy use by the water sector, utilization of non-traditional water sources, assessments of water availability, and decision support systems for managing water resources.

EPRI will support the project by making available to the entire research team its research results (publications and data sets), experience and expertise. It will do so through providing written materials, team conference calls and team in-person meeting. It will also participate, as requested, in team presentations to DOE project managers and team technical transfer activities.

Since 1949, the ***Idaho National Laboratory*** (INL) has been actively engaged in energy and natural resources research and management. INL is DOE's lead laboratory for Hydropower, biofuel feedstocks and Nuclear Energy programs. Through its work as landlord for an 890 mi^2 and extensive work with numerous federal, state and regional agencies and the private sector, INL has long history in energy, geosciences, ecological, hydrological and other research, development and deployment. INL has worked collaboratively with other DOE laboratories and agencies (e.g., NASA, USDA and DOD) conducting environmental assessments, environmental impact mitigation projects, hydrologic assessments and modeling studies. Recent remote sensing and geospatial analysis projects include analyses in the Columbia River and Snake River Basins, and on the Olympic Peninsula in Washington State. INL has also conducted extensive systems modeling of energy systems, and basin-wide systems modeling including in the Bear River Basin, in Idaho, Utah and Wyoming, and the Upper Snake River Basin in Idaho and Wyoming.

The INL will be providing support to the team in the realms of data collection, aggregation and analysis, and in geospatial analysis and visualization. INL primarily focus on assessing/projecting the location and water demands associated with biofuels, improving the spatial resolution of water availability information in the west, mapping groundwater availability in the west, and assessing potential institutional controls and/or impediments to energy-related water use in the west.

The National Renewable Energy Laboratory (NREL) is the only U.S. Department of Energy (DOE) National Laboratory dedicated solely to advancing renewable energy and energy efficiency technologies from concept to commercial application. NREL has primary expertise in individual renewable energy technologies and their cooling systems as well as extensive analysis expertise (sustainability, techno-economic), for energy technologies such as biofuels, geothermal, hydrogen, solar (PV, CSP), wind, ocean energy and hydropower. In addition, NREL has a leading national role in the development of individual building and community-level understanding of energy and water flows, and the integration of renewable energy technologies (wind, solar) with conventional energy systems and storage (e.g., wind/hydro). A few of the activities that NREL is undertaking that will contribute to this project include the development of a methodology to collect and synthesize water consumption and withdrawal values resulting from electricity production, an assessment of literature to develop energy use values associated with water infrastructure, a Lifecycle Analysis (LCA) Harmonization project that has conducted a literature review of over 1500 papers and identified water requirements for individual lifecycle phases of electricity-generating technologies, a survey of water use by existing geothermal facilities, lifecycle assessments of water use for energy crops, a water footprint (WF) system dynamics model designed to determine total water requirements of energy crops based on climatic conditions, and extensive experience in developing tools and software systems, many of them online, for use by the general public and groups with specific, complex needs. NREL also has deep expertise in market, policy and impacts analysis.

NREL's role in this project will be to support Sandia National Laboratories in its efforts as lead lab. Specifically, NREL will provide expertise and technical support on a number of subtasks, including the development of power plant-specific water use factors and parasitic energy requirements for alternative cooling systems for the Water Withdrawal and consumption Calculator, development of water requirements for crops under different climatic conditions for the Water Demand Projections Model, contributions to the energy crop and power plant demand variations due to climate change in the Climate Change Calculator, contributions to the Energy for Water Calculator, and a role in the design and development in the Decision Support System Interface.

Pacific Northwest National Laboratory staff have worked closely with industry, government, and private stakeholders to develop balanced environmental, sociocultural, and economic needs assessments for energy production. They have developed integrated environmental assessments, evaluate the effects of global climate change on water and biological resources, and conduct environmental assessments and studies under NEPA. Related expertise includes ensemble streamflow forecasting, analysis of water resource constraints on traditional and alternative energy production, the interaction of climate and land use on land surface hydrologic processes, distributed watershed hydrology, land use management, hydroclimatology, and snow processes.

Under this proposal, PNNL will assist Argonne in developing a climate change calculator that will allow for estimation of potential changes in water availability due to climate change within the study area river basins. This will include two components – a climate downscaling model to provide a future climate forcing data for the watershed model, (PNNL), and a dynamic large-scale watershed model to project related changes to water availability (Argonne).

The University of Texas at Austin is particularly well-suited for this project because it has conducted extensive prior relevant work with ERCOT that will serve as the foundation for the tasks specific to this project in the Texas interconnect. For this project, the UT Austin team will focus on all aspects relevant to ERCOT. The University of Texas has an ongoing and strong working relationship with ERCOT and has an extensive record of research relevant to the energy-water nexus in ERCOT. For example, two of the co-PIs from UT Austin (Webber and King) are co-PIs on ongoing or recent projects specific to Texas and ERCOT. One of these is a two-year study that began in February 2010 and is funded by the Department of Energy titled "Techno-economic modeling of integration of 20% Wind and large-scale energy storage in ERCOT grid by 2030." This project includes a series of workshops to engage stakeholder input, and the outcomes of those workshops will be available for the grid -planning project proposed herein. The stakeholders include ERCOT system planners and grid operators, electric generators, retail electric providers, transmission and distribution utilities, municipal utilities, cooperative utilities, government agencies (e.g. Public Utility Commission of Texas), and the academic community. ERCOT signed a letter of support for that project's proposal, pledging to participate in the workshop, make data available, and act as an expert resource for the research team. Webber is also co-PI on a 4-year $2 million study funded by the National Science Foundation Emerging Frontiers in Research and Innovation program titled "Resilient Infrastructures: The Interface of Infrastructures, Markets, and Natural Cycles - Innovative modeling and control mechanisms for managing electricity, water and air quality in Texas," that closely examines the relationship of energy and water for the grid in ERCOT. That project will examine the tensions between water and air quality for dispatching decisions. Webber of the UT team is also co-PI of a five-year $10.4 million smart-grid demonstration project in Austin, TX, which is funded by the DOE and also began in February 2010. That project will include the demonstration of integrated smart-grid and smart-water systems to 1000 homes and 75 businesses partly to determine what the effects of those combined energy-water systems might be for grid reliability, decision, and planning decisions relevant to transmission and power plant siting. The UT team has also done several statewide energy and water assessments relevant to grid-planning within the last two years for the Texas Water Development Board, Texas Commission on Environmental Quality, and the Texas State Energy Conservation Office. Moreover, professionals from ERCOT, Texas Water Development Board, TCEQ, SECO, Texas Workforce Commission, and the Public Utilities Commission of Texas attend Dr. Webber's professional short courses titled "Energy Technology and Policy" and gave input to his development of online interactive websites that teach the tradeoffs for power production in Texas. Dr. Webber's research team has published dozens of peer-reviewed journal papers, books, book chapters, conference articles and technical commentary related to the energy-water nexus, with a particular emphasis on Texas.

UT's role on the project will be to leverage more than $13 million in prior federal and state funding on related topics to develop scenarios for future energy mixes, effects of energy conservation, water conservation and re-use, likely power plant locations, novel power plant cooling technologies as a mitigant for water strain, and other aspects that affect grid planning in Texas.

Appendix A: Project Summary

Project Title: Energy and Water in the Western and Texas Interconnects

Lead Laboratory: Sandia National Laboratories
Principal Investigator: Dr. Vincent Tidwell (email: vctidwe@sandia.gov)

Supporting Partners: Argonne National Laboratory
Electric Power Research Institute
Idaho National Laboratory
National Renewable Energy Laboratory
Pacific Northwest National Laboratory
University of Texas

Project Objectives: This proposal is in response to the Research Call to DOE/Federal Laboratories for "Technical Support for Interconnection-Level Electric Infrastructure Planning, RC-BM-2010" Area of Interest 3: Water/Energy Nexus. According to the stated needs of the Research Call, three overarching objects are identified:

1. Develop an integrated Energy-Water Decision Support System (DSS) that will enable planners in the Western and Texas Interconnections to analyze the potential implications of water stress for transmission and resource planning.
2. Pursue the formulation and development of the Energy-Water DSS through a strongly collaborative process between members of this proposal team and the Western Electricity Coordinating Council (WECC), Western Governors' Association (WGA), the Electric Reliability Council of Texas (ERCOT) and their associated stakeholder teams.
3. Exercise the Energy-Water DSS to investigate water stress implications of the transmission planning scenarios put forward by WECC, WGA, and ERCOT.

Project Methods: Beyond efforts toward project management and reporting, eight additional project tasks are focused on the development of the Energy-Water DSS. The initial foundation for this tool is Sandia National Laboratories (Sandia) Energy-Power-Water Simulation (EPWSim) model. This existing framework provides an interactive environment for exploring trade-offs, and "best" alternatives among a broad list of energy/water options and objectives. The framework currently supports prototype modules for calculating thermoelectric power demand and related water use; water demand from competing use sectors; surface and groundwater availability, and; an energy for water calculator. Each of these modules will be updated and expanded, while additional process modules will be added.

Development of the DSS will be conducted in close cooperation with WECC, WGA, ERCOT and their stakeholder teams. To enhance transparency and consensus a Collaborative Modeling Team (CMT) will be assembled to oversee development of the Energy-Water DSS. Team membership will include a subgroup of our interconnection partners. The CMT will meet on a periodic basis with our project modelers to define: 1) key metrics and decision variable for inclusion in the DSS; 2) vet process models; 3) vet data, water use factors, etc; 4) jointly review the models and conduct calibration analyses; and 5) conduct desired scenario analyses.

The first module of the DSS calculates water withdrawals and consumption for current and projected thermoelectric power generation. Input to the model are WECC and ERCOT's transmission planning results. Water demands are calculated according to power plant capacity, production, type of plant, type of cooling, and type of emissions control. Accompanying parasitic energy loads imposed by emission controls and water-conserving cooling technologies are also calculated. Using information on population growth, Gross State Product and historical water use trends, future water demands are calculated for competing water use sectors (municipal, industrial, agriculture, mining and livestock). The source of the withdrawal (surface water, groundwater, or non-potable water) is tracked as well as the return flows.

The DSS is also fitted with a water availability model that provides a regional measure of water supply for surface water, groundwater, and non-potable resources. The model has two principle components, “wet” and “paper” water. Wet water provides a measure of the physical water available in a basin for use, while paper water addresses the institutional controls (policies) that define access to the water. The model combines historical gauge data and other information to project surface and groundwater availability.

The water demand and availability modules are accompanied by additional process models to further resolve water availability. The first of these is an environmental controls model for identification and assessment of potential environmental risks associated with growing water use. A climate change calculator is included for estimating potential changes in water availability. This will include two components – a climate downscaling model to provide future climate forcing data for the watershed model and a dynamic large-scale watershed model to project related changes to water availability. Beyond the scarcity of water, information concerning the potential cost of water for a new withdrawal is calculated including water rights purchase, value of goods and their water intensity, and cost of treating non-potable water. Finally, an energy for water calculator is included to calculate electricity demand to pump, convey, treat (both primary and waste water), and distribute water.

The DSS is fitted with an interface that serves as the “dashboard” controlling scenario makeup, simulation operations, and the rendering of results. This dashboard provides an interactive, real-time environment comprised of slider bars, buttons and switches for changing key input variables, and real-time output graphs, tables, and geospatial maps for displaying results. The DSS operates on a laptop computer taking only few seconds to accomplish a simulation. The DSS can be distributed to users on CD or via download from the internet.

Project Benefits and Outcomes: A key deliverable from this project is an integrated Energy-Water DSS that will enable planners in the Western and Texas Interconnections to analyze the potential implications of water stress for transmission and resource planning. Working with WECC, WGA, and ERCOT and utilizing this Energy-Water DSS a wide range of transmission planning scenarios will be simulated and evaluated.

While timely accomplishment of these tasks is important and necessary, we are striving for broader impact. Currently there are no long-range, interconnection-wide transmission plans for the Western and Texas Interconnections. Consequently, the ability to assess how various infrastructure options balance reliability, cost, and the environment from an interconnection-wide perspective does not exist. This project coordinated with the efforts of WECC, WGA, ERCOT and their partners will create a comprehensive package of stakeholder-vetted, regional planning models, data, and conclusions that are coordinated at the interconnection-wide level. Cumulatively, this information will substantially improve the quality and quantity of information available to industry planners, state and federal policymakers and regulators. Specifically, this project will supplement interconnection-wide transmission planning studies with information on water availability, which is critical in shaping electricity generation options.

This proposed project represents the first comprehensive, regional analysis of the energy-water nexus. This is also the first coordinated analysis undertaken by federal and state agencies, the power industry, NGOs and other interested stakeholders. In this way, the data, models, scenario analyses, and insights derived from this effort will provide a significantly improved body of evidence for policy making at local, state and federal levels.

Appendix B Letter of Commitment

Rick Stevens
Associate Laboratory Director

Computing, Environment and Life Sciences
Argonne National Laboratory
9700 South Cass Avenue, Bldg. 240
Argonne, IL 60439-4832

1-630-252-3378 phone
1-630-252-6333 fax
stevens@anl.gov

April 23, 2010

Mr. Brian Mullohan
Project Manager
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

Dear Mr. Mullohan:

SUBJECT: ARGONNE NATIONAL LABORATORY - AUTHORIZATION TO PARTICIPATE IN RESEARCH FUNDED UNDER THE NATIONAL ENERGY TECHNOLOGY LABORATORY "RESEARCH CALL TO DOE/FEDERAL LABORATATORIES *Technical Support for Interconnection-Level Electric Infrastructure Planning, RC-BM-2010"*

In accordance with the subject solicitation, approval is hereby granted for Argonne National Laboratory Staff to participate in any research that may be funded under Area of Interest 3: Energy/Water Nexus.

The work proposed for the Laboratory is consistent with or complementary to the missions of the laboratory and will not adversely impact execution of other DOE assigned programs at the Laboratory.

If there are any questions regarding this matter, they can be discussed with John Gasper of Argonne's Environmental Science Division at 202-488-2420.

Sincerely,

Rick Stevens
Associate Laboratory Director
Computing, Environment and Life Sciences

RS/JG:lmg

ELECTRIC POWER RESEARCH INSTITUTE

BRYAN HANNEGAN, Ph.D.
Vice President
Environment and Renewables

April 28, 2010

Dr. Vince Tidwell Principal Member
of Technical Staff Sandia National
Laboratories
P.O. Box 5800, MS 1137
Albuquerque, NM 87185-1137

Subject: Letter of Support for Sandia Response to DOE Call: Technical Support for Interconnection-Level Electric Infrastructure Planning, RC-BM-2010, Area of Interest 3: Water/Energy Nexus

Dear Dr. Tidwell,

The Electric Power Research Institute, Inc. (EPRI) is pleased to offer this letter of support for Sandia's response to the subject DOE Research Call RC-BM-2010. EPRI appreciates the invitation from Sandia to become part of the research team being assembled to respond to the energy-water nexus component of the research call on Technical Support for Interconnection-Level Electric Infrastructure Planning. EPRI has been actively engaged in energy-water nexus research for the last decade. EPRI would support the Sandia research team by sharing the results of that research, our experience, and our expertise to the team effort. Please note that any support assumes successful negotiation among the parties of a mutually acceptable agreement between the parties. Such support would also be subject to EPRI's continued interest in the project as ultimately structured. For the avoidance of doubt, this letter may not be construed by Sandia, EPRI or any third party as creating legally binding obligations.

EPRI is a nonprofit corporation organized under the laws of the District of Columbia Nonprofit Corporation Act and recognized as a tax exempt organization under Section 501(c)(3) of the U.S. Internal Revenue Code of 1986, as amended, and whose mission is to conduct research and development in energy and related fields for the benefit of the public. EPRI supports your proposed project in furtherance of its public purpose mission.

Sincerely,

Bryan Hannegan Vice President, Environment
and Renewables Electric Power Research
Institute

Together . . . Shaping the Future of Electricity

3420 Hillview Avenue, Palo Alto, CA 94304-1338 USA • 650.855.2459 • Fax 650.855.1042 • bhannegan@epri.com

Idaho National Laboratory INL

April 30, 2010 CCN 220843

Mr. Brian Mollohan, Project Manager
U.S. Department of Energy
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

SUBJECT: Letter of Commitment to Support the Joint Proposal by Sandia National Laboratory, *et al.* in Response to DOE Lab Call, "Technical Support for Interconnection-Level Electric Infrastructure Planning" (RC-BM-2010)

Dear Mr. Mollohan:

The U.S. Department of Energy's Idaho National Laboratory (INL), operated by the Battelle Energy Alliance, fully supports conducting the research described in the above-referenced proposal submittal. If the proposal is granted to our team, the INL has the capacity to perform the geospatial and other analytical tasks assigned to INL, and we fully commit to providing the INL services as described in the proposal response.

Please contact me at 208-526-1707 if you have any questions or need further clarification.

Sincerely,

J.W. Rogers, Jr., Ph.D., Associate Laboratory Director
Energy & Environment, Science & Technology

JJ:CS

cc: J. J. Grossenbacher, INL, MS 3695
D. J. Hill, INL, MS 3695
A. Clark, INL, MS 3695
L. Schlke, INL, MS 3810

P.O. Box 1625 • 2525 North Fremont Ave. • Idaho Falls, Idaho 83415 • 208-526-0111 • www.inl.gov
Battelle Energy Alliance, LLC

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

April 23, 2010

Brian Mollohan, PE
DOE/NETL
Energy Delivery Technologies Division
3610 Collins Ferry Rd.
Morgantown, WV 26507-0880

Re: Organizational letter of Commitment-National Renewable Energy Laboratory
Technical Support for Interconnection-Level Electric Infrastructure Planning
RC-BM-2010 – Area of Interest 3

Dear Mr. Mollohan,

National Renewable Energy Laboratory's (NREL) Strategic Energy Analysis Center, along with partners within NREL, are committed and will provide our full support under Sandia National Laboratory's lead in Area of Interest 3: Water/Energy Nexus.

NREL will be able to meet the needs over a multi-year performance period. A more detailed cost estimate will be prepared with a successful award and with concurrence of our DOE sponsors.

Please contact me at 303-275-3070 or bobi.garrett@nrel.gov if you require any further information.

Sincerely,

Bobi Garrett

Bobi Garrett, Sr. Vice President
Outreach, Planning and Analysis

c: Robin Newmark

1617 Cole Boulevard
Golden, CO 80401-3305
Phone: 303-275-3000

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

Pacific Northwest
NATIONAL LABORATORY

Tel: (509) 375-6535
Fax: (509) 371-7061
MSIN: K6-83
steve.schlahta@pnl.gov

April 30, 2010

Mr. Brian Mullohan
Project Manager
National Energy Technology Laboratory
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

Dear Mr. Mullohan.

SUBJECT: DE-FOA-0000068, Topic Area 3, Scope 59639 – WATER/ENERGY NEXUS

This letter is written on behalf of Dr. Mark S. Wigmosta, of the Pacific Northwest National Laboratory (PNNL). We are pleased to support the above mentioned proposal in response to the Department of Energy (DOE), National Energy Technology Laboratory, "Technical Support for Interconnection-Level Electrical Infrastructure Planning RC-BM-2010".

The work proposed for the Laboratory is consistent with or complementary to the missions of the laboratory and will not adversely impact execution of other DOE assigned programs at the Laboratory.

PNNL proposes to undertake the technical services described in the enclosed Statement of Work at an estimated funding level of:

Fiscal Year 2011	$50,000
Fiscal Year 2012	$50,000
Fiscal Year 2013	$50,000
Total	$150,000

All work will be performed under a separate contract awarded directly from DOE.

OFFICE OF SPONSORED PROJECTS
THE UNIVERSITY OF TEXAS AT AUSTIN

P.O. Box 7726 • Austin, Texas 78713-7726 • (512) 471-6424 • FAX (512) 471-6564 • (mc A9000)

April 30, 2010

ATTN:

Mr. Vincent Tidwell
vctidwe@sandia.gov

Re: "Energy-Water Nexus for Grid Planning"; OSP # 201001419 - 001

Dear Mr. Vincent Tidwell:

The University of Texas at Austin is pleased to submit the above referenced proposal prepared by Michael Webber of our Department of Mechanical Engineering. This proposal has the approval of cognizant officials at The University.

For information relating to the technical portions of this project, you may contact Michael Webber at webber@mail.utexas.edu or 512-475-6867. Administrative and budgetary matters should be referred to Ms. Michelle Taylor, Contracts and Grants specialist, Office of Sponsored Projects at m.taylor@austin.utexas.edu or 512-475-8074.

Award and post-award matters should be referred to the Office of Sponsored Projects, ATTN: Awards Department at osp@austin.utexas.edu or 512-471-6424.

Sincerely,

Courtney Frazier Swaney

Courtney Frazier Swaney
Assistant Director
Office of Sponsored Projects

CDF: mdt

Enclosure

XC: Development Office

Appendix C: REFERENCES

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