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White Paper

Integrated Vulnerability and Impacts Assessment for Natural and Engineered Water-Energy Systems in the Southwest and Southern Rocky Mountain Region

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Problem Description – Grand Challenge

In the Southwest and Southern Rocky Mountains (SWSRM), energy production, energy resource extraction, and other high volume uses depend on water supply from systems that are highly vulnerable to extreme, coupled hydro-ecosystem-climate events including prolonged drought, flooding, degrading snow cover, forest die off, and wildfire. These vulnerabilities, which increase under climate change, present a challenge for energy and resource planners in the region with the highest population growth rate in the nation. Currently, analytical tools are designed to address individual aspects of these regional energy and water vulnerabilities. Further, these tools are not linked, severely limiting the effectiveness of each individual tool. Linking established tools, which have varying degrees of spatial and temporal resolution as well as modeling objectives, and developing next-generation capabilities where needed would provide a unique and replicable platform for regional analyses of climate-water-ecosystem-energy interactions, while leveraging prior investments and current expertise (both within DOE and across other Federal agencies).

Background Information

The US Bureau of Reclamation projects that Lake Mead's hydropower capacity of 2,074 megawatts will decline to as low as 1,120 MW in June 2016. With diminished and over-subscribed regional surface water resources, thermoelectric power plants are now contributing to the depletion of regional aquifers. Groundwater depletion in the Colorado River basin buffers short-term surface water impacts, but masks a potential long-term crisis in freshwater supply.

In the other extreme, flooding over a 7 day period in September 2013 caused substantial and expensive damage to oil and gas extraction systems, primarily in Colorado. This also resulted in environmental spills of oil and gas materials from equipment hit by debris or upset by flood waters (about 1150 barrels of oil and condensate). Drought and floods are interrelated extreme events in this region that substantially impact water and energy systems.

Effectively planning for energy production, designing energy infrastructure, and optimizing adaptation strategies for the future in the Southwest and Southern Rocky Mountains will require understanding the complex processes governing responses in natural and engineered water systems. This requires the organized development and coupling of modeling and data systems that can represent the complexities associated with extreme events and non-linear, interacting, dynamic processes and then synthesizing uncertainties and potential outcomes appropriate for long-term decision support in water and energy infrastructure and systems.

Predicting water supply for energy development in the future is a core concern for DOE, energy utilities, and resource extraction companies as well as numerous other stakeholders. However, we cannot understand future impacts and develop appropriate adaptation and mitigation strategies without a significantly improved understanding of how rare and extreme events, operating at multiple temporal scales, interact with the nonlinear feedbacks in ecohydrological systems that can lead to irreversible changes. The scientific community is currently unable to estimate water supply—quantity, quality, and timing—under novel climate conditions ("no analog futures"). Increasing temperatures and changes in precipitation patterns will likely lead to significant changes in the composition of many watersheds, and the effect of these changes on vegetation root uptake and evapotranspiration are not quantified in existing watershed models. This omission is particularly striking because transpiration is the predominant control on the water balance in many critical watersheds. Further, we do not understand the long-term coupled impacts of intense fire on hydrology and erosion, vegetation succession, and watershed resiliency. Thus, it is not possible to evaluate whether watershed conditions after major fires or vegetation mortality events (e.g. beetle infestations) will yield reliable or sufficient water to reservoirs and aquifers to meet current plans and expectations. A better understanding of the governing processes is essential: this will substantially improve understanding about uncertainties in natural system behaviors that need to be captured in engineered system assessments.

With uncertainty in natural system water supply to engineered systems for energy production, adaptation strategies must balance risks, costs, and performance when considering infrastructure design and alternative sources of water. Further, the priority, intensity, timing, and locality of water demand by energy production must be put in the full context of competing demands by agriculture, industry, municipalities, recreation, and the environment. Adaptation strategies and policies relevant to the energy sector must also consider the traditional, cultural, legal and institutional constraints on the delivery and allocation of scarce water resources. These additional constraints are unique to the region, and national analyses often cannot capture the subtleties that dictate how water resources are managed in the region. Moreover, this nexus of uncertainty, options, competing demands, and disparate values often requires water planning and management decisions to be conducted in transparent and public forums.

Opportunities

The Southwest and Southern Rocky Mountain region is highly sensitive to water-related challenges for future energy production and energy resource development. Uncertainty in natural and engineered system performance is a key issue when considering future vulnerability to reliable water supply or impacts on energy infrastructure from extreme events. The current opportunity is to develop and use modern, integrated information and assessment tools to better understand governing and sensitive processes in the natural and engineered energy-water systems, understand how the systems interact, and then to improve the integration of those systems to reduce vulnerabilities and increase resilience.

This region is ideal for developing, testing, and integrating water and energy system analysis and assessment tools at a regional or basin-level of detail. This region, which is highly susceptible to climate change, variability, and extreme events is experiencing rapid population growth; supports a variety of electric power production systems spanning thermoelectric plants, hydropower, and renewables; and has extensive oil, gas, and other energy resource extraction operations. These issues, which are affecting the region now, will almost certainly impact the rest of the country in the coming decades.

An effort to improve regional watershed models with emphasis on climate-related changes, upgrade engineered system (infrastructure) models to address adaptation strategy optimization, and integrate the two would fill a critical gap in quantitative assessment. Such an effort would leverage heavily existing and ongoing projects and capabilities, including current DOE programs and others sponsored by collaborating agencies with vested interest in this topic.

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Key Features and Elements of Approach

Two key features a Southwest and Southern Rocky Mountains Total Water Management system will be (1) building a watershed vulnerability assessment model to properly propagate and quantify hydrologic response to dynamic, interdependent processes that affect the quantity, quality, and timing of flows, and (2) integrating energy and water sector models in a basin-scale tool to quantify downstream impacts on engineered infrastructure and energy systems enabling robust assessment and adaptation planning . Using process assessments that the watershed model will provide, including consideration of climate mean trends as well as extreme event scenarios, the integrated energy-water system model will be properly parameterized to support decisions in design and policy at the regional level while also providing improved data to feed back into national level analyses.

The starting point for watershed assessment modeling will be the output from global climate models which are the focus of considerable investment by DOE. The climate project results will be coupled with process-level simulation capability for watersheds to enable accurate assessment of flow from the natural system to the engineered system, while propagating true uncertainty (e.g. climate drivers) and better capturing processes currently not found in regional simulations tools. Processes of importance include: 1) forest die off and ecosystem shifts through mean temperature and precipitation changes 2) abrupt and disruptive changes by drought, fire, wind, floods, landslides, and 3) human land-use change. Each of these can result in tipping points that permanently change the watershed from its current state, thus requiring dynamic parameterization for the integrating systems level model.

Output from the watershed assessment model (streamflows and groundwater recharge) must then be routed through the engineered system to evaluate climate related impacts to water deliveries and the potential for damage to critical human and environmental assets. Considerable investment in river/reservoir routing and groundwater operations/management modeling has been made by the U.S. Army Corps of Engineers, U.S. Geological Survey, U.S. Bureau of Reclamation, and the U.S. Environmental Protection Agency. In a majority of the basins around the U.S., high-quality water resource models already exist. Rather than recreating these established and vetted tools, we will leverage this considerable investment. Additionally, current assessment capabilities will be enhanced by coupling these water resource models with related energy operations and management tools (e.g., electric transmission and dispatch, hydropower operations, energy resource assessment). Resulting impacts to the economy and the full suite of the Nation's Critical Infrastructure will be possible by leveraging the extensive suite of models developed through the National Infrastructure Simulation and Analysis Center (NISAC).

Leveraging Capabilities Within and Across Agencies

Issues of energy and water reside within many DOE offices and numerous other federal agencies. They also cross many federal, state, and local institutional boundaries. DOE's expertise in climate and energy-related modeling can help other agencies with their specific missions, ongoing projects, and studies, while DOE will benefit from the expanded context brought by additional stakeholders with overlapping missions and by the additional data sets which will improve and constrain the climate and energy models. In this sense DOE and other agencies would leverage ongoing studies, each benefitting from a broader integration of tools. Networking, integration of tools, and leveraging experience within DOE and across agencies will ultimately lead to greater efficiency and improved quality and assessments of energy-water system impacts, vulnerabilities, and adaptations strategies.

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