**CI-WATER: Cyberinfrastructure to Advance High Performance Water Resource Modeling**

**Introduction:** Population growth, shifting land uses, and climate variability are altering the magnitude and timing of water fluxes, stores, and availability in the arid Intermountain Western U.S. These alterations are driven by coupled human-natural system interactions at spatial scales ranging from farm plots and buildings to entire river basins and temporal scales from seconds to centuries. These pressures produce interconnected responses in atmospheric, surface, and subsurface processes, threatening the sustainability of natural water systems supporting fragile ecosystems and the resiliency of constructed water systems on which tens of millions of people depend. Numerous researchers have investigated the individual atmospheric, hydrological, geological, environmental, economic, and sociological components of this complex human-natural water system. However, components are only infrequently integrated to characterize the overall system sustainability. Furthermore, it is rare for comprehensive evaluation of integrated system behavior to inform or guide land use or water system planning or management by individual users, cities, water conservancy districts, or states.

This project, which we call **CI-WATER**, will allow a consortium of Utah and Wyoming researchers to acquire and develop hardware and software cyberinfrastructure (CI) to support the development and use of large-scale, high-resolution computational water resources models to enable comprehensive examination of integrated system behavior through physically-based, data-driven simulation. Successful integration requires data, software, hardware, simulation models, tools to visualize and disseminate results, and outreach to engage stakeholders and impart science into policy, management, and decisions. The computational requirements of stochastic methods to consider uncertainties, fine spatial and temporal resolutions to improve accuracy, and representation of dynamic processes that include feedbacks among system components demand use of state-of-the-art high-performance computing (HPC). We propose a robust and distributed CI consisting of integrated data services, modeling and visualization tools, and a comprehensive education and outreach program that will revolutionize how computer models are used to support water resources research in the Intermountain West and beyond.

Our proposed CI developments leverage and extend the shared expertise in Utah and Wyoming and align with the focus areas presented in both the current Wyoming Science and Technology plan and the draft Utah plan.

**Project Goal and Objectives:** The scientific problem that this project will address is*: How are the quality and availability of water resources sensitive to climate variability, watershed alterations, and management activities*? The CI challenge that we will address is: *How can we best structure data and computer models to address this scientific problem through the use of high-performance and data-intensive computing by discipline scientists coming to this problem without extensive computational and algorithmic knowledge and experience*? The project thus aims to broaden the application of CI and HPC techniques into the domain of integrated water resources modeling. To meet these goals, we propose four primary components:

**1. Enhance cyberinfrastructure facilities.** The demands of the proposed data-intensive modeling require additional hardware in the form of data systems and compute clusters to support the work proposed and enhance the research competitiveness of the Consortium states. This CI will include servers and disk farms connected to the four participating institutions via an ultra-high-speed network. The servers will host the data services, regional models, and computing clusters used to access and run simulations. It will also include a new 100+ TeraFLOP class computer system and a complementary data storage system.

**2. Enhance access to data- and computationally-intensive modeling.** We will develop easy-to-use model and data interfaces that link integrated system models running within an HPC environment to multiple data sources to enhance the use of computational simulation and data-intensive modeling to better understand water resources. We will establish a cybercollaboratory based on tools developed from NSF-funded projects and blend hydrologic data and information system capability with HPC gateway functionality into a platform for scientific discovery. These tools will reduce the time and expertise required to define, populate, and execute regional models on HPC. This will include new data services to provide hydrologic, geophysical, demographic, socio-economic, and legal water rights data needed to inform and interpret output from large-scale models run in stochastic predictive form.

**3. Advance high-resolution multi-physics watershed modeling.** We will revolutionize water resources modeling by integrating new physical process descriptions and linking with existing widely-used codes to enable long-term simulations with high spatial resolution to answer location-specific questions related to water availability in the face of growing demands, uncertain future meteorological forcings, and existing prior-appropriations water rights. The model will include engineered watershed features and water transfers, enabling water management and economic analyses.

**4. Promote STEM learning and water science engagement.** We will foster scientific and cyber-literacy and improve educational and research capacity within the Consortium through dissemination and communication activities reaching four audiences across the STEM learning pipeline: 1) the CI-WATER partners and other EPSCoR jurisdictions; 2) Utah and Wyoming K-12 students and their teachers; 3) higher education faculty, students, and water agency professionals; and 4) adult learners. Using water resource issues as the basis for educational and diversity-building activities, the Consortium will reach all levels of the STEM pipeline.

**Management, Coordination, and Evaluation:** We will manage the project in a manner that will result in cross-disciplinary and cross-jurisdictional scientific integration. We have identified metrics that will be used throughout the project to **evaluate and assess** the adoption and effectiveness of our cyberinfrastructure at enabling cyber-related discovery through the use of high-performance water resources models. This information will be used by the state committees and EPSCoR offices, an external evaluator, and an advisory committee to inform project direction following best industry practices.

**Comprehensive Diversity Plan:** Our project is ideally suited for engaging under-represented groups in STEM learning and bringing to them the excitement of cyber-related discovery and innovation that is important for retention. We will hold annual summer workshops for underrepresented students. The proposed web user interface to our system aids in **broad dissemination**, draws upon the capabilities in the Utah and Wyoming university systems, and will be integrated into curricula at the respective universities to provide a tight coupling between education and research components.

**Intellectual Merit:** The integrated data-intensive modeling enabled by the proposed CI will lead to better understanding of coupled natural and human water resources systems and their response and sensitivity to alterations across space-time scales. Advances in data and modeling systems that enhance HPC usability and access by non HPC specialists will transform the way hydrologic knowledge is created and provide broader informatics applicability beyond the field of water resources.

**Broader Impacts:** This project provides CI that improves access to data and sophisticated models, combines models and model components from different sources, enables scientists to populate models with readily accessible data, harnesses high-performance computing resources to perform multi-decadal simulations over large spatial areas with high space-time resolution, and transforms the way hydrologic knowledge is created and used in water resource planning and management. The CI enhancements in this project will be integrated into a robust education program focused on improving cyber-literacy throughout the region. Outcomes will be disseminated broadly to water users, scientists, planners, managers, regulators, industries, municipalities, engineers, state and federal agencies, non-profit entities, and the public. The measure of our success will be a transformational change in how students, researchers, practitioners, and citizens in our states use data and models to make meaningful predictions regarding influencing factors, choices, and future availability of ground and surface water. The adjacency of Utah and Wyoming provide compelling case studies related to water, energy, urban growth, climate, and ecosystems that will foster natural collaboration at all levels of education and across disciplines. Open access to the data and models combined with enhanced usability and active outreach will extend capability to those groups currently underrepresented in water resources.