Water Power Technologies Office Energy-Water Resilience White Paper

Building Resilient Energy–Water Systems: Integrated Modeling, Scenario Selection, and Near-Term Decision Support

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Focal Areas: Energy for water (managing electricity demand in water systems); Water for energy (water management supporting grid reliability); Energy-water intersections (agriculture/industrial, including AI data centers).

Existing Challenge: U.S. energy and water systems are increasingly interdependent, often leading to cascading and compounding system failures when faced with acute and chronic hazards, including droughts, wildfires, hurricanes, earthquakes, and pandemic disruptions. Such stressors propagate across multiple spatial scales, typically starting with changing earth system dynamics (for example, droughts) that interact with the regional natural environment (for example, streamflow and temperatures), and affect the local built environment (for example, cities, reservoirs, hydropower generators, and conveyance pumps). Emerging water-intensive industries (e.g., advanced manufacturing, artificial-intelligence (AI) data centers, geothermal power, and hydraulic fracturing) further concentrate risk where water availability/quality, energy reliability, and compound hazards intersect. Finally, adaptation measures to these resource stresses, like water shortages, also have tradeoffs because alternative water supplies are often energy-intensive. These compounding effects require explicit modeling of feedback loops between energy supply and demand and water availability and demand, rather than in isolation.

Current modeling architectures rarely support this level of cross-sectoral coupling in large part because of institutional and, therefore, modeling siloes, with limited unifying and integrated tools for the joint planning and co-optimized operations of the sectors, or standardized selection of scenarios to stress test future conditions. While many modeling tools exist, they are typically focused on specific scales, time horizons, single hazard classes, and sectors in isolation, making it difficult to quickly identify joint vulnerabilities. Further, such models are often not actionable for decision-makers, such as at water and electric utilities or Independent System Operators (ISOs). The absence of standardized interfaces and scenario protocols also makes it difficult to align global, regional, and local modeling outputs in support of real-world decisions.

There is therefore a need for integrated modeling frameworks, co-produced between scientists and resource managers, that (i) include common scenario selection across sectors, (ii) connect existing water and energy system sector models, and global earth system and economic models, (iii) enable quick, practical risk screening to find the biggest vulnerabilities and early opportunities for action, before investing in deeper, more complex modeling, and (iv) provide tools for decision-support under deep uncertainty (DMDU).

Near-Term Opportunities:

There is a near-term opportunity to invest in model connection or "wrapper" tools that link data, scenarios, and assumptions between existing global and regional energy, water, and hazards models that were built for single sectors/hazards/time frames. Such connection tools, building on the advances in AI, can facilitate better communication between models across multiple scales and sectors, both vertical (global → regional → local) and horizontal (between energy and water sectors). Practical triage tools are also needed so utilities can anticipate threats and prioritize actions without relying solely on heavy modeling, with deeper analyses available as needed. Strategic investments in automated modules that link inputs and outputs across existing earth systems, integrated assessment, regional hydrology, water management, and grid models can enhance interoperability without requiring the development of new platforms from scratch.

For example, in the Colorado River Basin, drought is a stressor that affects hydropower generation and water availability for cooling power plants, irrigation, and drinking water. An example of the smallest functional chain of existing models needed to screen and prioritize risks, inform early decisions, and guide where deeper modeling is actually needed may include (as in Figure 1):

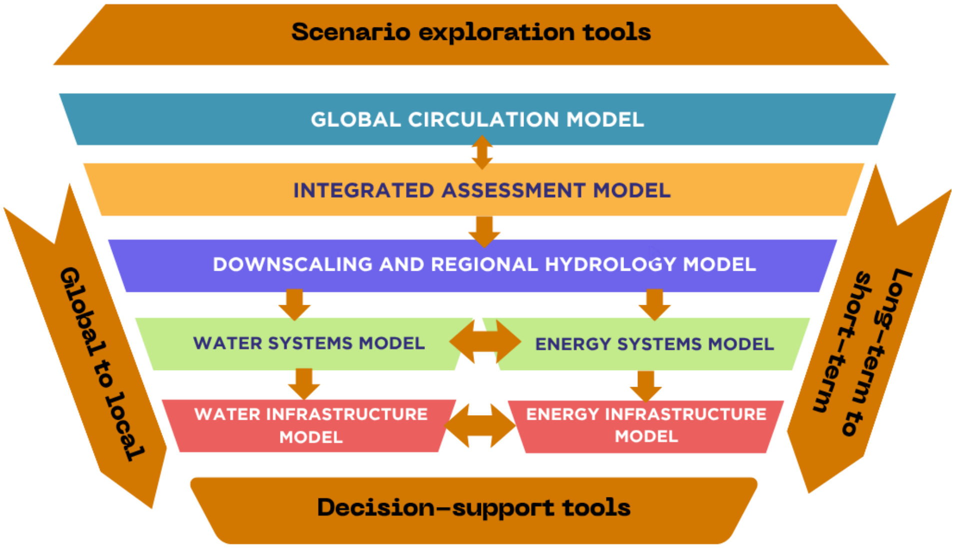

Figure 1: Conceptual diagram of model linkages in integrated energy-water modeling framework.

- Global Circulation Models (GCM) provide precipitation and temperature scenarios that can impact water supply and demand.

- Integrated Assessment models provide sectoral demand signals (e.g., irrigation and other water demand, energy demand).
- Downscaling tools translate global precipitation and temperature information to basin conditions.
- Hydrology models simulate inflows, evapotranspiration, and reservoir storage.
- Water management models apply allocation rules, water rights, and shortage tiers.
- Asset-level models estimate the impacts on hydropower production and plant cooling.
- DMDU methods evaluate different operational or investment strategies under uncertainty.

Similar model chains can support other contexts, such as linking downscaled projections of future extreme weather events with urban-water and grid models for heat-event planning or assessing the water-energy footprint of AI data centers.

There is an opportunity to build the “wrapper” tools, represented by the arrows linking models in Figure 1, to automatically identify and link them together efficiently by deciding which models/tools to connect to answer a question. In this case, pulling integrated assessment model demand outputs, feeding them into hydrology models, using downscaled earth system data, passing results to water management and asset models and electricity grid models, and running DMDU stress tests.

Success Measures (examples)

- Reliability & recovery: reduction in service interruptions; restoration time.
- Risk reduction: decreased exposure to cascading failures (quantified).
- Cost: lower lifecycle energy/operations and maintenance (O&M); avoided outage costs
- Interoperability: measurable improvements in data/standards across agencies; practitioner‑ready decision‑support and threat‑triage tools, plus hazard‑aware siting/operations playbooks for utilities, operators, planners, and regulators.

These metrics are intended to be measurable across both energy and water sectors, enabling shared performance targets.

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