Optimizing Hydropower Operations through Basin-Scale Coordination for Energy–Water Resilience

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Focal Area

This work addresses the water for energy focal area, focusing on how bottom-up basin-scale coordination of water resources can enhance hydropower generation efficiency and operational flexibility within the broader energy-water system, leading to greater resilience for both energy and water systems and economic opportunities for water users across the basin.

Existing Challenge

Hydropower lies at the center of the energy–water intersection, yet its performance and flexibility are often limited by fragmented decision-making and unclear coordination pathways among water users, regulators, and energy markets. DOE's Water–Energy Nexus reports (2014, 2020) and Stanford's ongoing Uncommon Dialogue on Hydropower, River Restoration, and Public Safety (Hydro Reform Coalition, 2022) have advanced strategic and technological collaboration, yet practical frameworks for integrating hydropower operations into local water management remain scarce. As a result, hydropower facilities prioritize electric grid reliability and regulatory compliance over adaptive flexibility, even though local users hold critical contextual knowledge that supports more dynamic management that could yield economic, environmental, and social benefits (Wang, 2019).

Water-intensive economic systems involve interactions among stakeholders using common-pool resources at multiple scales. Top-down operation of these systems can entail social trade-offs and can exacerbate food–energy–water tensions. Conversely, implementing bottom-up collaborative approaches to design and operate such systems can improve their sustained economic performance (Ostrom, 1990). A system-scale planning approach that builds from local values and considers multi-scale stakeholder decisions can ease policy and project adoption, reducing delays associated with opposition. Further, this approach contributes to efficient and sustained water use while optimizing value-oriented services (Opperman et al., 2017). Therefore, basin-scale coordination among water users presents a compelling opportunity to enhance regional economies and stakeholder value.

Most hydropower coordination research and management practice remain top-down, led by sectoral authorities or utilities focusing on compliance, infrastructure upgrades, or policy reform. These efforts, while valuable, often occur with isolated jurisdictions and are not designed to reflect how operation decisions propagate through a basin as in interconnected system. Hydropower performance and basin health, however, depend on relationships among upstream release, midstream regulation, and basin-wide use. Interventions such as infrastructure upgrades or policy reforms may be implemented sequentially along a river beginning with upstream storage and release, and extending to downstream delivery without coordination mechanisms. Studies using stakeholder network analysis demonstrate that mapping such relationships improves coordination and decision outcomes in complex water systems (Maya-Jariego, 2024). These relationships can reduce transaction costs, improve trust in public agencies, and produce actionable knowledge that informs decision-making (Ananda & Proctor, 2013; Veisi & Kirchhoff, 2025).

Near-Term Opportunity (3–5 Years)

The near-term opportunity to improve economic opportunity and resilience across a watershed can be met with a novel Hydropower Operations Toolkit that includes a bottom-up Stakeholder Mapping Framework and an innovative Regional Economic Model (**Error! Reference source not found.**). Together, these

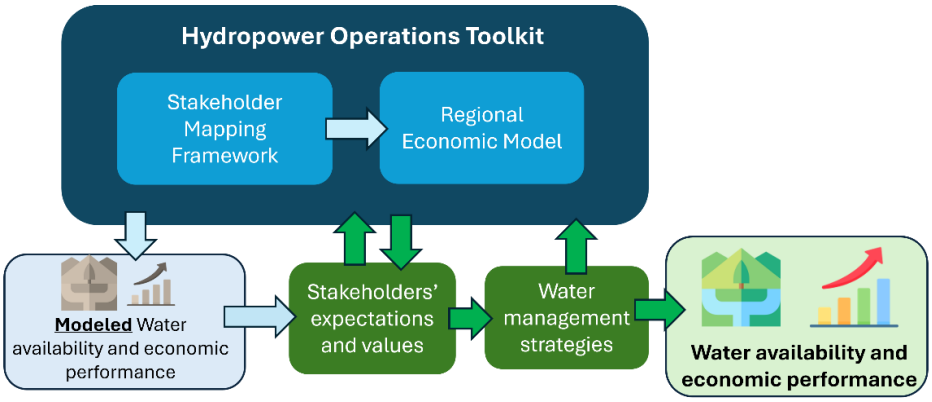


Figure 1. Conceptual map of the Hydropower Operation Toolkit.

frameworks help hydropower operators identify coordination touchpoints, strengthen information pathways supporting efficient basin-scale operations, and make visible economic gains from a bottom-up approach. The combined approach links stakeholder decisions and economic outcomes, offering a system-level view of basin interdependencies that enhances flexibility and long-term value.

The Toolkit has the potential to standardize good practices, streamline communication pathways, and ensure scalability across diverse hydrologic and operational settings. Serving as a boundary object (Cash et al., 2003) to guide a knowledge system, the toolkit can incorporate communication, translation, and mediation strategies that provide salient, credible, and legitimate information to all interested parties.

1. Stakeholder Mapping Framework

Effective collaboration depends on context; not all collaborative efforts yield favorable outcomes. Clearly defining the purpose and desired results before engagement begins is essential (Ananda & Proctor, 2013; Pahl-Wostl et al., 2007; Veisi & Kirchhoff, 2025; Rogéliz et al. 2018). Selecting participants with an understanding informed by the basin's social and institutional context ensures decision coverage and supports durable coordination (del Aguila & del Sagrado, 2023; Pahl-Wostl et al., 2007).

The Stakeholder Mapping Framework operates as a structured process rather than a static map, beginning with the identification of existing communication pathways, information exchanges, and decision dependencies across the basin. Users can apply network-analysis methods (e.g., Maya-Jariego, 2024) and stakeholder selection principles (del Aguila & del Sagrado, 2023) to visualize these relationships and identify where added coordination can provide greatest efficiency gains. This innovative approach begins with the local water and energy users and traces dependencies through utilities and governance entities to hydropower operations, revealing how operational decisions such as minimum flow requirements and release schedules affect hydropower scheduling, flow management, and grid performance.

The framework defines who to engage (interested parties from end users to operators), when to engage (key points in data collection, planning, and adaptive management); and how to engage (structured data sharing and planning methods for transparency and efficiency). By clarifying how operational decisions influence and are influenced by basin participants, the mapping framework improves visibility, enabling faster, more transparent decisions, reducing uncertainty and fostering flexible, coordinated operations. Ultimately, it

transforms coordination into a performance advantage that improves efficiency, minimizes downtime, and strengthens relationships that enhance long-term system resilience and value.

2. Regional Economic Model to Assess Benefits of Coordinated Basin Management

Bottom-up coordination strategies are expected to bring about economic and environmental gains. Such strategies can contribute to basin conservation and ecosystem protection, which in turn enhances long-term water availability (Opperman et al. 2017). While such coordination requires initial investments in stakeholder mapping, engagement, and governance frameworks, these costs are typically offset by the economic gains realized through improved water resource management (e.g., optimizing operation costs, maximizing benefits from watershed investments, and reducing long-term water scarcity risks). In the hydropower sector, even modest improvements in flow synchronization and diversion timing can yield measurable operational cost reductions (DOE, 2016; Reclamation, 2018; Jeuland et al., 2014) and reduce redundant investments. Moreover, such bottom-up approaches can contribute to protection of key ecosystems and social values synergistically with economic gains.

A regional economic modeling framework can be developed to identify and assess the societal effects of alternative business models and operation rules, revealing economic benefits and congruence with stakeholder expectations. Modeling a basin's water-related economic activities within a regional economic framework, makes it possible to quantify the direct, indirect, and induced effects of coordinated water use. Because hydrologic flows and economic streams in water-intensive industries depend on stakeholders interactions, incorporating decision processes (which reflect local values and stakeholder expectations) can better inform operation policies. This approach enables comparison of business-as-usual conditions with various coordination strategies, including collaborative business models, optimized cases, and stakeholder-informed alternatives. For example, improved water availability for agriculture may increase crop yields and farm income, stimulating local service sectors through induced demand. Reduced water-related production risks for industrial users can stabilize regional supply chains and energy demand, contributing to broader energy, water, and economic resilience. The framework can support evaluation of the performance and resilience of alternative business models for coordinated water systems operation, revealing trade-offs and synergies, and guiding the development of cost-effective water management strategies.

Success Measures

Success will be evaluated through quantitative and qualitative indicators aligned with DOE's Energy–Water Resilience objectives, focusing on hydropower performance, coordination efficiency, and usability. The Stakeholder Mapping Framework helps operators identify coordination pathways, understand basin interdependencies, and support adaptive planning. The regional model evaluates economic performance using insights from the mapping framework to simulate stakeholder decisions and interactions. Stakeholder mapping informs modeling scenarios that identify strategies yielding economic and resilience benefits. Success is achieved when stakeholders validate that projected benefits are realized.

Validation could occur through pilot applications of the Hydropower Operations Toolkit will test the framework in real coordination scenarios such as flow adjustments during grid congestion or low-demand periods. Modeling results will highlight opportunities for improved basin-wide economic performance. Reduced curtailment, better synchronization of water releases, and greater operational confidence will demonstrate value and guide toolkit refinement for replication across diverse basins. Together, these frameworks demonstrate a scalable approach to improving coordination, resilience, and value creation across the nation's hydropower systems.

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