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Title: Synergistic Pathways for Water Security in Emerging Sectors: Data Centers and Modern Nuclear Facilities

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Focal Area(s): Stand-alone data centers, nuclear-powered data centers, and novel nuclear facilities such as fusion plant and small modular reactors (SMRs) are water-intensive sectors poised to rapidly expand, presenting a significant challenge to the water-for-energy nexus. The potential for large-scale water consumption for cooling could reduce downstream water quantity and degrade quality, demanding an integrated approach by stakeholders to understand and address these impacts through infrastructure planning.

Existing Challenge: Adequate water supply is an increasingly complex challenge, complicated by evolving demands from emerging and expanding highly water-intensive sectors such as data centers and modern nuclear facilities. Nuclear-powered data centers have been proposed as a pathway to meet growing energy demand in the United States (Hanna et al. 2024). However, existing nuclear facilities require substantial water resources, putting them in direct competition with data centers and other water-intensive industries. Nearly half of data center servers are powered by power plants located within water-stressed regions (Siddik et al. 2021), underscoring the vulnerability of this energy-water nexus. Expanding technologies threaten not only water supply but also quality. Data centers and most advanced nuclear reactor designs depend on high-quality, reliable water resources for cooling and maintaining uninterrupted operations (You et al. 2025). Heated effluent from cooling systems can contribute to thermal pollution, while radionuclides (nuclear fission byproducts) and treatment chemicals used for water purification can negatively impact surface and groundwater quality long-term.

Intensifying hydrologic variability in droughts, extreme precipitation events, and snowmelt patterns provides additional complexity to changing water demands. Such changes demand coordinated resilience planning that integrates variability into energy operations. Yet, coordination across sectors remains limited, resulting in competing claims that exacerbate stress during shortages. This impacts not only facility operators, but also downstream water-reliant entities including agriculture, fisheries, and municipalities. Also, regulatory frameworks designed for legacy energy infrastructure have not kept pace with evolving technologies. Current practices in energy-water management often rely on site-specific assessments, regulatory compliance with water rights and permits, and localized engineering solutions such as efficiency upgrades, water recycling, or dry-cooling technologies. While valuable, these approaches are fragmented, uneven across regions, and often reactive rather than anticipatory. Addressing the increasing strain on water availability requires proactive and integrated management strategies.

Near-Term Opportunity: As novel nuclear technologies and data centers expand rapidly, there is both urgency and opportunity to integrate meaningful water-energy resilience strategies into the early stages of planning, design, and operations. Operationalizing an innovative, synergistic approach to energy-water management that encompasses comprehensive data collection, cross-sector collaboration, and assimilation of emerging technologies is essential to bolster water security in an evolving hydrologic landscape.

Advancements in nuclear technology and data center facilities provide rich datasets that can inform energy-water resilience planning. Recent studies of U.S. data centers explored water consumption by connecting sites to sourcing power plants, water utilities, and wastewater treatment plants based on location and energy usage (Siddik et al. 2021). However, as the data center landscape is rapidly evolving, utilizing water quality and quantity data directly from facilities would more accurately reflect water security. Planned development of data centers and modern nuclear facilities offers an opportunity to collect new, more comprehensive data regarding water consumption, thermal effluent, and chemical discharge to develop effective resilience measures. DOE's 2024 *United States Data Center Energy Usage Report* further emphasizes the need for additional data on water and energy consumption such as cooling system types, as technological differences among sites lead to varying resource usage. The established frameworks nuclear facilities follow for conducting environmental impact assessments and monitoring water intake and discharge temperatures offer proven methodologies that could be leveraged to standardize data collection across emerging sectors.

Access to larger datasets for energy-water nexus research and decision-making necessitates broader data sharing and coordination among stakeholders, including utility providers and sector operators. For example, many data centers are managed by technology companies providing cloud services, so a holistic plan for data reporting requires collaboration with these companies for frequent and robust assessments of water security. Data access and collaboration are fundamental to a synergistic water-energy security approach in emerging sectors. Executive Order (EO) 14239 *Achieving Efficiency Through State and Local Preparedness* reinforces the need for a risk-informed approach to enhance infrastructure resilience. Near-term, collaborative EWR efforts across all levels of government can meet this directive by integrating hydrologic risk, water availability, and water quality into comprehensive siting and planning. Siting analyses can offer insights into potential colocation of data centers with nuclear plants for shared cooling systems and integrated water management strategies. Under EO 14318 *Accelerating Federal Permitting of Data Center Infrastructure*, Department of Defense installations have emerged as another stakeholder in siting, underscoring the importance of immediate development and adoption of a synergistic approach to resilient infrastructure planning.

Technological innovation in infrastructure creates unprecedented opportunities for holistic, system-level planning at the water-energy nexus. Advances in nuclear reactor technologies, including small modular reactors, hybrid reactor designs, and enhanced safety and efficiency features, expand feasible energy options for siting and planning. Innovations in data center thermal management, including liquid cooling, hybrid air-liquid systems, and energy-reuse approaches, provide a range of options to address water constraints. A synergistic approach to energy-water management enables flexible deployment configurations of emerging technologies. Through a systematical evaluation of the costs and benefits of the latest technologies, stakeholders can determine site-specific suitability based on water availability. Results will inform infrastructure solutions that maximize system-wide performance, resilience, and efficiency, which was previously infeasible under traditional, fragmented planning approaches.

Integrated approaches to address water security in the energy landscape through stakeholder engagement and collaboration must also consider weather variability. Potential shifts in atmospheric rivers and monsoon dynamics in the Southwest, for example, will alter seasonal water availability (Gershunov et al. 2017; Dominguez et al. 2009) and must be accounted for by energy and water planners. Exploring hydrological dynamics surrounding emerging sectors can support water management and operations.

Together, these opportunities highlight a pathway to embed water security into the innovation trajectory of emerging energy suppliers and consumers. Through a synergistic approach that facilitates collaboration and development of more comprehensive datasets, stakeholders can make measurable progress on innovative energy-water resilience planning within the next five years, building foundations for long-term adaptation.

Success Measure: Success in advancing near-term opportunities for EWR will be measured by both cross-sector coordination and the generation of actionable, science-based insights. Effective data collection, multi-criteria siting, and implementation of synergistic pathways for water security will foster collaboration among utilities, regulators, municipalities, and industry operators, leading to more comprehensive planning and fewer conflicts over water allocation and quality. Equally important will be the availability of transparent, data-driven insights that improve understanding of energy-water systems and more easily facilitate or accelerate permitting, water-use planning, and decision-making across stakeholders.

System outcomes can be assessed through a tiered framework. At Tier 1, new deployments should avoid adding stress to water supply, quality, or grid reliability, demonstrated through quantitative measures and compliance with EPA and NRC standards. At Tier 2, deployments should generate net benefits, such as improving grid reliability, reducing withdrawals with improved re-use of water, or enhancing water quality by reducing thermal, chemical, or radioactive discharges. Together, successful outcomes can meet emerging and expanding sector needs while strengthening the resilience and security of energy-water systems.

References:

Dominguez, F., Villegas, J.C. and Breshears, D.D., 2009. Spatial extent of the North American Monsoon: Increased cross-regional linkages via atmospheric pathways. *Geophysical Research Letters*, 36(7).

Gershunov, A., Shulgina, T., Ralph, F. M., Lavers, D. A. and Rutz, J. J., 2017. Assessing the climate-scale variability of atmospheric rivers affecting western North America. *Geophysical Research Letters*, 44(15), pp.7900-7908.

Hanna, B. N., Abou-Jaoude, A., Guaita, N., Talbot, P. and Lohse, C., 2024. Navigating Economies of Scale and Multiples for Nuclear-Powered Data Centers and Other Applications with High Service Availability Needs. *Energies*, 17(20), p.5073.

Shehabi, A., Smith, S. J., Masanet, E. and Koomey, J., 2018. Data center growth in the United States: decoupling the demand for services from electricity use. *Environmental Research Letters*, 13(12), p.124030.

Siddik, M. A. B., Shehabi, A. and Marston, L., 2021. The environmental footprint of data centers in the United States. *Environmental Research Letters*, 16(6), p.064017.

You, Z., Wu, Y., Wang, J., Wei, Z. and Ling, J., 2025. Dynamic Equilibrium Mechanism: Integrating Small Modular Reactors and Optimized Cooling for Sustainable Data Centers. *Available at SSRN 5193510*.

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