Adaptive water resources management in a changing climate

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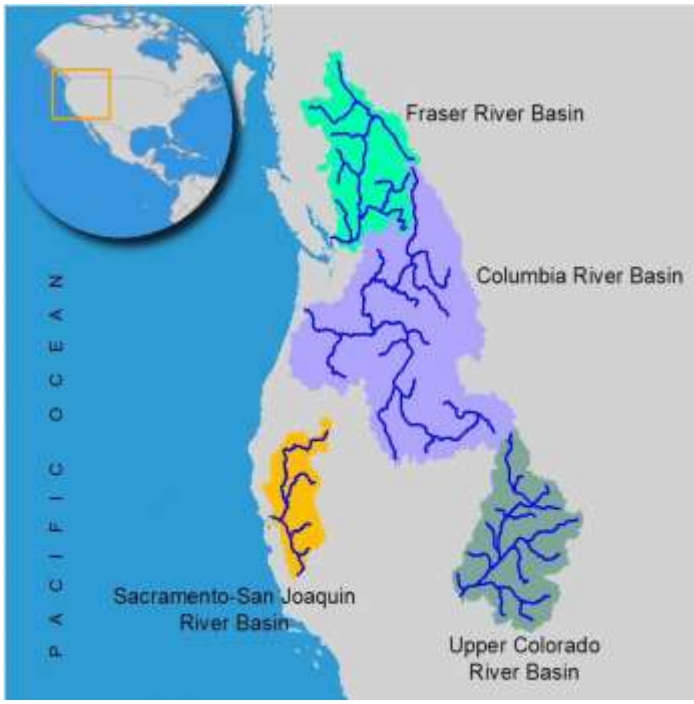
Across the world, managing water resources is becoming an increasingly contentious issue. Numerous natural and human-induced forces continue to reshape floodplains at an unprecedented rate—the regional expression of climate variability and change, land-use changes, and water needs stemming from rapid development are some of the key drivers in this regard. While the ability to provide reliable water supplies is constrained by the quality and quantity of available water, developmental trajectories that stymie ecosystem services are on a path that is not only unsustainable but in some cases irreversible.

Through a variety of biogeochemical cycles, ecosystems services support a habitable environment. In river systems, hydrologic alteration limits the natural range of seasonal and longer-term variations in river flow, thus disrupting the natural rhythms of river and riparian ecosystems. Regulation of river flows for human use is primarily accomplished by dams, reservoir operations, hydraulic structures that divert or withhold water. From the standpoint of adapting and possibly determining a sustainable path toward the management of water resources, a first step involves understanding the climate-induced changes in water supplies and clarifying the linkages between weather and climate variations and river flows, especially ones that sensitively impact ecosystems health.

Western North American river systems exemplify a unique blend of complexity—highly managed and dammed, heavy reliance on water supplies, climatic influences, increasing water demand, and at-risk ecosystems. Two examples from ongoing research are discussed briefly. In both cases, questions are derived from the analysis of the past and current adaptive management efforts in these basins. Adaptation to climate variability and change is being examined with a goal to understand the multiple time scales of hydroclimatic variability. As noted above, the identification of climate precursors and characterization of their potential predictability (and associated uncertainty) is likely to facilitate development of illustrative models (with a few variables) that are amenable to quick decision-analysis and promote an effective, iterative dialogue between decision-makers and scientists.

Western North American River Basins

A late-twentieth century emergent trend toward increasing year-to-year variance (decreasing reliability) of stream flow across the major river basins in western North America—Fraser, Columbia, Sacramento-San Joaquin, and Upper Colorado—have been noted in recent studies. Simultaneously, a disproportionate increase in the incidence of synchronous high and low flows across these basins has resulted in expansive water resources stress. The observed trends have analogues in wintertime atmospheric circulation regimes and ocean temperatures, raising new questions on the detection, attribution, and projection of regional hydrologic change induced by climate.



Increased variability is accompanied by a tendency toward synchronous extremes, wherein the four river basins simultaneously experience excesses or deficits in water supply. Statistical analysis of streamflow records reveals sensitivity to tropical oceanic temperatures, and a correspondence between the trends in these two disparate regions.

One implication for water resources management is that increased year-to-year variability in flows implies a larger reservoir volume to meet the water demand. Thus, a reassessment of the adequacy of the water resources infrastructure will be an important step in determining the systemic reliability. Furthermore, more frequent hydrologic extremes, especially over the entire region highlight the changing reality for resources allocation and response for disaster relief.

Adaptive environmental management in the Grand Canyon region of the Colorado River Basin

Climatic drivers of episodic to multi-decadal variations to the observed changes in the flood magnitude, timing and spatial scales affect the sediment inputs to the Colorado River ecosystem. Since the 1963 closure of Glen Canyon Dam, the dominant sole major supplier of sand to the Colorado River in the upper portion of Grand Canyon is the Paria River, which supplies about 6% of the pre-dam supply of sand at the upstream boundary of Grand Canyon National Park. Sand is delivered by the Paria River during short-duration (< 24 hours), large magnitude (up to 300 m^3/s) floods that occur primarily during the warm season (July-October).

The planning and decision processes in the Glen Canyon Dam Adaptive Management Program (GCD-AMP) strive to balance numerous, often competing, objectives, such as, water supply, hydropower generation, low flow maintenance, maximizing conservation of the tributary supplied sediment, endangered species recovery, and cultural resources. A key concern identified by the AMP, related to the timing and volume of sediment input into Grand Canyon. Adequate sediment inputs into the river ecosystem in the Canyon combined with active flow management (in the form of strategically timed bypass releases from Glen Canyon Dam) support the restoration and maintenance of sand bars, habitat and in stream ecology. An improved understanding of the relative role of eastern North Pacific tropical storms, tropical Pacific sea surface temperatures, and subtropical moisture sources is allowing development of predictive tools for flood forecasting (and related sediment supplies) to support the AMP efforts.

On longer time scales, structured variations in the sediment supply imply a changing baseline for mean ecological and geomorphological conditions in the Canyon, counter to the static view taken in the current environmental impact assessments. Better understanding of the coupled climate-hydrologic variations on multiple time scales is increasingly recognized as critical input for adaptive management (both passive and active). In collaboration with the Glen Canyon Dam Adaptive Management Program (GCD-AMP), a deliberate effort is made to identify the entry-points for predictive hydroclimatic information at appropriate lead times.

For the active adaptive management program, lead climate information allows scientists and managers to anticipate geomorphic response from critical tributaries, in turn triggering large-scale, experimental releases from Glen Canyon Dam. Current studies are attempting to understand the ecosystem's sand supply and the spawning success and recruitment of endangered humpback chub. This is a collaborative work with scientists at the U.S. Geological Survey's Grand Canyon Monitoring and Research Center in Flagstaff, Arizona and National Oceanic and Atmospheric Administration's Earth System Research Laboratory in Boulder, Colorado.

Towards integrative approaches with involvement of the users of scientific information

Resource management and planning concerns can be systematically studied within the context of users, institutions, retrospective assessments of management and programmatic actions, and adaptive management programs. From such work, identified knowledge gaps and translated research questions have a disproportionately higher potential to hit the mark. Furthermore, user-inspired applied and basic research on problems such as hydroclimatic change, water and ecosystems management is most likely to benefit from illustrative models and tools that allow users to explore and pursue "virtual" experiments with generated scientific information. This allows users to assess incremental benefits, develop a revised set of questions and knowledge gaps, and in the process impart native knowledge from the trenches of resource management, ordinarily unavailable in the applied science realm.

Shaleen Jain is an Assistant Professor of Civil and Environmental Engineering and a Cooperating Assistant Professor at the Climate Change Institute at the University of Maine. He completed undergraduate work at the Indian Institute of Technology and graduate work at Utah State University. His current research is broadly focused in the following area: Hydroclimatology, Environmental Flows, Climate Variability and Change, Hydrosystems Modeling, Adaptive Management and Decision Analysis.

Shaleen Jain gave a poster presentation on the similar topic at the National Academies during its Sackler Colloquia. The Arthur Sackler Colloquia of the National Academy of Sciences addresses scientific topics of broad and current interest, cutting across the boundaries of traditional disciplines.