Ecological Limits of Hydrologic Alteration

Environmental Flows for Regional Water Management

Worldwide, water conflicts are escalating as cities, industries, agriculture, and energy producers compete for limited freshwater supplies. At the same time, there is a growing awareness of the need to maintain adequate freshwater flows in rivers, lakes, floodplains, aquifers, and estuaries to sustain biodiversity and the many benefits derived from the healthy, functioning ecosystems upon which local communities and economies depend. Efficient, integrated water resource management systems help governments provide for growing human populations while protecting and restoring healthy freshwater ecosystems.

The integration of ecological considerations into water management has been hampered by the difficulty, cost, and time required for determining **environmental flows** -- the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems.[1] Environmental flow assessments scientifically evaluate tradeoffs between alteration of natural water flow patterns by humans and consequent changes in ecological health.

Despite the hundreds of methods available for assessing environmental flow needs, many are not based on sound ecological principles or are simply impractical for application at the broad regional scales at which governments manage water resources. Simple "rules of thumb" lack scientific credibility, while more sophisticated, data-intensive methods are too expensive and time consuming to apply to every freshwater system within a large jurisdiction.

The **Ecological Limits of Hydrologic Alteration (ELOHA)** is a new framework offering a flexible, scientifically defensible compromise for broadly assessing environmental flow needs when in-depth studies cannot be performed for all rivers in a region. ELOHA builds upon the wealth of knowledge gained from decades of river-specific studies, and applies that knowledge to geographic areas as large as a state, province, nation, or large river basin.

An international group of river scientists published the scientific basis for this regional approach (Arthington, Bunn, Poff and Naiman, 2006, *Ecological Applications* 16: 1311-1318). Based on many years of experience in working with water managers on environmental flows, these authors and other leading international scientists then developed practical guidelines for its application (Poff et al., 2008, submitted to *Freshwater Biology*).

ELOHA synthesizes existing hydrologic and ecological databases from many rivers within a region to generate **flow alteration-ecological response relationships** for rivers with different types of hydrological regimes. These relationships correlate measures of ecological condition, which can be difficult to manage directly, to streamflow conditions, which can be managed through water-use strategies and policies. Detailed site-specific data need not be obtained for each individual river.

Several jurisdictions within the United States are already applying elements of the ELOHA framework to accelerate the integration of environmental flow into regional water resource planning and management. ELOHA also has been trialed in Australia and China.

Photo: Yellowstone River, USA (© Dennis Frates)

Concurrent scientific and social processes define the ELOHA framework.

The Scientific Process

Developing Flow Alteration-Ecological Response Relationships

Step 1. Build a hydrologic foundation, a regional database of daily or monthly streamflow hydrographs representing both baseline (pre-development) and developed conditions for river segments throughout a region, for a selected time period long enough to represent climate variability. Include sites where water managers may want to make allocation or other water management decisions, as well as sites where biological data have been collected. Use hydrologic modeling to extend the periods of streamflow data for gauged sites and to synthesize data for ungauged sites as needed. Alternatively, ELOHA can be integrated into existing hydrologic models or decision support systems for water management.

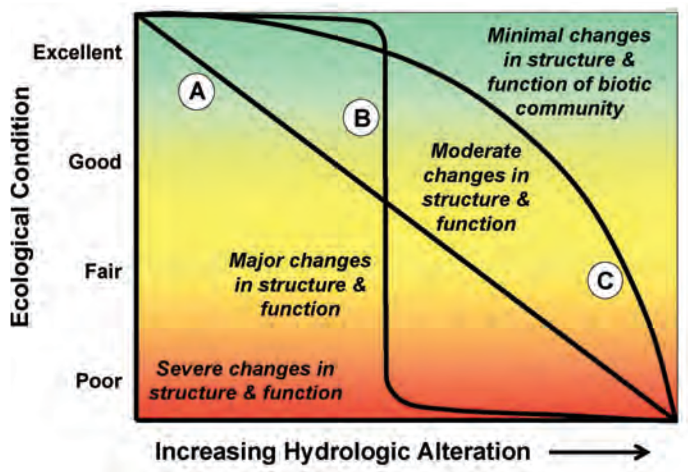
COMPUTING FLOW STATISTICS AND HYDROLOGIC ALTERATION

Hundreds of flow statistics that are already being used in hydro-ecological research and environmental flow assessments can also be used in ELOHA. Hydrologic metrics that are intuitive to hydrologists, ecologists, and water managers alike facilitate communication and understanding between stakeholders regarding environmental flow assessment and implementation.

The U.S. Geological Survey's Hydroecological Integrity Assessment Process (HIP) software *(free download at www.fort.usgs.gov/Resources/research_briefs/HIP.asp)* analyzes 171 hydrologic metrics derived from daily hydrologic data, which are useful for establishing links between flow processes and ecological response.

Similarly, The Nature Conservancy's Indicators of Hydrologic Alteration (IHA) software *(free download at nature.org/freshwater)* assesses 67 flow statistics, including 34 "Environmental Flow Components" which describe the magnitude, frequency, duration, timing, and rate of change of ecologically important flow events such as pulses, floods, and low flows.

Both HIP and IHA can calculate the degree of hydrologic alteration between baseline and developed conditions. ELOHA uses statistical methods to select a small, manageable subset of non-redundant flow statistics for analysis of hydrologic alteration.



Conceptual flow alteration-ecological response relationships. Possible forms include: linear (A), threshold (B), and curvilinear (C). The form of the relationship depends on the specific ecological and flow statistics analyzed.[2]

Step 2. Classify river segments based on similarity of flow regimes, using ecologically relevant flow statistics computed from the baseline streamflow hydrographs developed in Step 1. Subclassify each segment based on key geomorphic characteristics that define physical habitat features, such as meandering versus canyon rivers. The number of river types in a region depends on the region's inherent heterogeneity and size.

Step 3. Compute hydrologic alteration for each river segment, expressed as the percentage deviation of developed-condition flows from baseline-condition flows, using a small set of flow statistics that are strongly linked to ecological conditions and are amenable for use as water management targets.

Step 4. Develop flow alteration-ecological response relationships by associating the extent of hydrologic alteration with consequent changes in ecological condition. A family of such relationships is developed for each river type, using a variety of flow statistics and ecological variables. Ecological data used to develop the flow-ecology relationships – for example, aquatic invertebrate species richness, riparian vegetation recruitment, or larval fish abundance – ideally are sensitive to existing or proposed flow alterations, can be validated with monitoring data, and are valued by society.

The Social Process

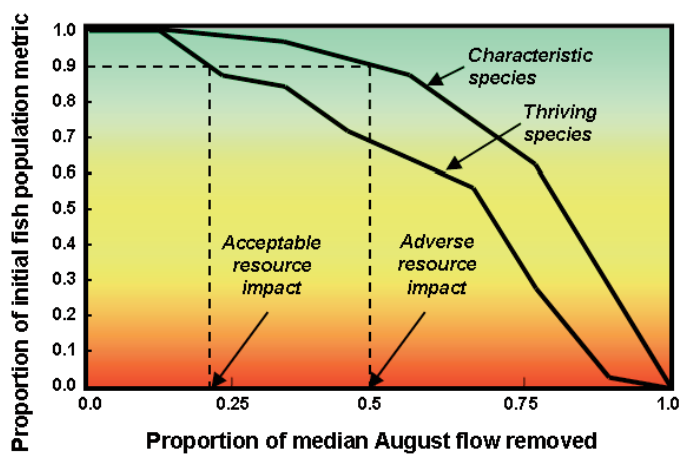
Using Flow Alteration-Ecological Response Relationships for Environmental Flow Management

Step 1. Determine acceptable ecological conditions for each river segment or river type, according to societal values. This is accomplished through a well-vetted stakeholder process of identifying and agreeing on the ecological and cultural values to be protected or restored through river management. The goal of ELOHA is not to maintain or attempt to restore pristine conditions in all rivers; rather, it is to understand the tradeoffs between human uses of water and ecological degradation. Stakeholders might decide that some rivers should be protected from development, but other rivers could be managed for fair to good, rather than excellent, ecological condition. This gradational approach lends flexibility to governments overseeing variable levels of water development within their jurisdictions. ELOHA establishes a scientifically credible, legally defensible basis for this public discussion. Once the ecological goals are decided, scientists can develop flow alteration - ecological response relationships based on flow statistics that are relevant to those goals. All stakeholders need to understand the process and uncertainties involved in developing these flow alteration-ecological response relationships.

Step 2. Develop environmental flow targets by using flow alteration – ecological response relationships to associate the desired ecological condition with the corresponding degree of flow alteration for the appropriate river type. The allowable degree of flow alteration becomes the environmental flow "target."

Step 3. Implement environmental flow management by incorporating environmental flow targets into the broader water planning process. Because the hydrologic model developed in Step 1 of the Scientific Process accounts for the cumulative effects of all water uses, it can be used to assess the practical limitations to, and opportunities for, implementing environmental flow targets at any site within the project area, or for every site simultaneously. It can be used, for example, to prioritize restoration projects, optimize water supply efficiency, or account for cumulative upstream and downstream effects in permitting decisions. For basins in which water is already over-allocated, the hydrologic model can help to identify and prioritize flow restoration options such as dam re-operation, conjunctive management of ground water and surface water, demand management (conservation), and water transactions.

The hydrologic model used to build the hydrologic foundation is, in essence, a comprehensive regional water management tool into which environmental flow targets can be integrated. Thus, ELOHA's hydrologic foundation anchors decisions about water management to the availability, location, and timing of the flows needed to maintain or restore the overall health of a region's river ecosystems.



Actual flow alteration-ecological response relationships. Using existing fish population data across a gradient of hydrologic alteration, scientists determined two flow-ecology relationships between populations of "thriving" and "characteristic" fish species versus proportion of median August flow reduction for 11 stream types in Michigan, USA. A diverse stakeholder committee then proposed a ten percent decline in the thriving fish population index as a socially acceptable resource impact, and a ten percent decline in the characteristic fish population index as an adverse impact. The corresponding flow alteration (X-axis) would trigger environmental flow management actions associated with each of these ecological conditions. The "ten-percent rule" applies to each of the 11 stream types, but the shapes of the curves – and therefore the allowable degree of hydrologic alteration – vary with stream type.[3]

[1] Brisbane Declaration, http://www.riversymposium.com/index.php?element=2007BrisbaneDeclaration241007

[2] Inspired by Arthington AH et al, 2006. The challenge of providing environmental flow rules to sustain river ecosystems. Ecological Applications 16: 1311-1318, *and* Davies SP, Jackson SK, 2006. The biological condition gradient: a descriptive model for interpreting change in aquatic ecosystems. Ecological Applications 16:1251-1266.

[3] Michigan Groundwater Conservation Advisory Council (2007) Report to the Michigan Legislature in response to Public Act 34, 37 p., http://www.michigan.gov/documents/deq/Groundwater_report_206809_7.pdf.

Monitoring and Evaluation

Continually Improving Outcomes

The development and implementation of regional environmental flow targets is an ongoing, iterative process in which data collection, monitoring, evaluation, and evolving social values continually refine the targets and the flow-ecology relationships upon which they are based. Environmental flow monitoring also helps discern the relative roles of compliance, infrastructure, flow restoration, and other ecological improvements such as channel restoration, pollution abatement, and fishery management in successfully achieving agreed-upon environmental outcomes.

Summary

ELOHA offers a robust regional environmental flows framework grounded in scientifically-defined flow-ecology linkages that are subject to empirical testing and validation. It is intended for use anywhere in the world, across a spectrum of social, political and governance contexts, and to be useful regardless of the stage of water resource development, the historical status of environmental flow protection, and the cause of flow alteration, from modified land use, to surface- and ground-water diversions, to river regulation by dams. Because of its flexible design, the ELOHA framework may be adapted across a wide range of available data and scientific capacity.

While ELOHA is a necessary new advance in environmental flow determination, it does not supplant river-specific approaches for certain rivers that require more in-depth analysis, where political, socio-economic, or conservation issues are of such magnitude that only a river-specific treatment will suffice. But at a time when population increases, land-use changes, economic development, and climate change are amplifying demands for sound science to inform decision making in water management, ELOHA offers the potential to greatly accelerate the broad-scale, comprehensive management of river flows to support sustainable goods and services, biodiversity, and human well-being.

WHO DOES ELOHA?

Because environmental flows sustain ecosystem processes critical to river health and human livelihoods, successful implementation of ELOHA necessarily involves many people, from water managers to scientists to citizen stakeholders.

Engaging an interdisciplinary team of hydrologists, geologists, biologists, and ecologists from government agencies and universities broadens and strengthens the scientific basis of ELOHA applications.

Both funding and expertise can come from a variety of sources. In the United States, for example, state agencies and The Nature Conservancy have collaborated with U.S. Geological Survey scientists to lead ELOHA's scientific process. Similar collaborations are employed in Australia.

For more information about ELOHA, visit **nature.org/ELOHA.**