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SHORT COMMUNICATION

RE-THINKING ENVIRONMENTAL FLOWS: FROM ALLOCATIONS AND RESERVES TO SUSTAINABILITY BOUNDARIES

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ABSTRACT

Attempts to implement environmental flows have encountered many obstacles. Many water allocation systems include a system of prioritization among water uses that generally does not favor environmental flow protection, or do not allow for protection of high flow events for ecological purposes. It has proven very difficult to implement complicated environmental flow prescriptions that attempt to mimic natural flow variability within water allocation systems. Additionally, many water allocation systems do not adequately address interconnections between surface water and groundwater, or releases from dams. It is time to re-think our approaches to protecting environmental flows. As with water quality protection, environmental flows should be viewed not as an ''allocation'' of water, but rather as a desirable outcome of integrated management of water and land resources for long-term sustainability. In this sense, environmental flows should be managed in a manner similar to water quality protection, in which the influences of diverse land and water use activities are regulated to ensure that the ecological and social values of water are optimized. Both water quality and environmental flow management protect a vast array of important social benefits that are sustained by managing for healthy freshwater ecosystems. In this paper I offer a definition of sustainable water management that explicitly recognizes the fact that society derives substantial benefits both from out-of-stream extractions of water as well as by maintaining adequate flows of water within freshwater ecosystems. To help facilitate sustainable water management, a ''Sustainability Boundary Approach'' is described for use in setting quantitative water management goals. When the cumulative hydrologic impacts of water and land uses are managed within these sustainability boundaries, the full array of values associated with water can be more fully realized.

KEY WORDS: environmental flow; sustainability; Sustainability Boundary Approach; river management; water management; integrated water resource management

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A strong consensus now exists within the scientific community around the need to maintain some semblance of natural flow variability to sustain the ecological health of river ecosystems and the array of goods and services they provide to society (Poff *et al*., 1997; Postel and Richter, 2003). It is widely recognized that in addition to maintaining appropriate low-flow conditions, higher flows and even floods are also essential to the ecological health and dynamism of river, floodplain and estuarine ecosystems (Bunn and Arthington, 2002). Abundant evidence from developed rivers around the world documents the fact that when natural hydrologic variability is heavily controlled by impoundments or diminished by water withdrawals, many of the benefits that humans derive from river ecosystems, including river-based food sources such as fisheries and flood-recession agriculture, can be severely disrupted (Postel and Richter, 2003; Millennium Ecosystem Assessment, 2005).

In contrast with marked recent advances in environmental flow science, water policy and management have been slow to progress. Environmental flows are being implemented in only a tiny fraction of the world's rivers; in the vast majority of these cases, environmental flow management is focused only on low flows. The protection of higher

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flows from water withdrawals or provision of high-flow releases from dams for environmental flow purposes remains extremely limited, even though the linkages between higher-flow events and important ecological functions and human benefits are now routinely documented in environmental flow assessments (Dyson *et al*., 2008; IWMI, 2009).

In this paper, I offer a critical analysis of some implementation obstacles that need to be addressed by environmental flow advocates seeking to foster fuller implementation of environmental flows. My proposal for resolving these issues is based upon a premise that the protection of environmental flows—along with maintaining proper water quality—must be viewed as central pillars of sustainable water management. Both water quality and environmental flow protection are necessary to secure the vast array of socially-valued goods and services provided by healthy river ecosystems (Table I). The protection of environmental flows must become an integral aspect of water governance that ensures that the full spectrum of values and benefits associated with water—*including those that require extracting water from rivers for purposes such as irrigating farms or providing drinking water supplies, as well as those such as fisheries that require that water remain in the river*—is given its due consideration in water plans and regulations.

Rather than treating environmental flow protection simply as one of many competing uses or allocations of water, the maintenance of environmental flows capable of sustaining healthy river ecosystems should instead be viewed as both a goal and a primary measure of sustainability in water resources management. In other words, the existence of adequate environmental flows in a river basin indicates that all water allocations and dam licenses within the basin are being managed in a sustainable manner. Akin to water quality management, governments must begin setting quantifiable targets that reflect broad stakeholder input for environmental flow management in all rivers and regulate other uses of water in a manner that ensures the attainment of these targets (Poff *et al*., 2009).

Implementing the management approach I suggest in this paper will require fundamental changes in water governance in virtually all geopolitical settings. I do not attempt the design of a blueprint for such sweeping policy reform in this paper. However, I believe that all reform movements benefit from a clear vision statement, and from tangible, quantifiable measures of success.

In this paper I offer a definition of sustainable water management that is based on the concept of constraining human-induced alterations of water flows and water quality within 'sustainability boundaries'. I propose that sustainability boundaries, as illustrated in Figure 1, be used to express the desired environmental flow conditions in a river.

This 'Sustainability Boundary Approach' (SBA) serves to set limits on the extent to which water withdrawals and discharges, water infrastructure operations and land uses can alter natural variability in water flows and water chemistry, thereby sustaining the social benefits and biodiversity of freshwater ecosystems. In addition to protecting the dynamism of river systems, these boundaries should themselves be dynamic, reflecting changing societal needs and values over time as well as new scientific understanding of flow-ecology relationships.

Some of the basic steps necessary to define and implement the SBA are outlined in this paper. Both the definition of sustainable water management and the SBA are designed to ensure that the full array of human benefits of water is better addressed through integrated, sustainable water management.

OBSTACLES TO ENVIRONMENTAL FLOW MANAGEMENT

There are many plausible explanations for the laggard performance in implementing environmental flow management, and the reasons vary considerably with differing cultures, economies and historical levels of water development. Some of the most common maladies are summarized here.

Issue #1: lack of understanding of environmental flow benefits

Environmental flows are perceived by many as serving only those who like to fish or biodiversity advocates. The misperception that environmental flows are intended to benefit primarily non-human species can be at least partially attributed to the fact that public exposure to environmental flow issues in many countries has been limited to regulatory actions involving endangered species. The connections between healthy river ecosystems and human

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Table I. Human benefits supported by environmental flows (adapted from E-Flow Network at www.eflownet.org)

Service category	Service provided	Key flow related function	Key environmental flow component or indicator
Production	Water for people—subsistence/rural and piped/urban	Water supply	Floodplain inundation
	Fish/shrimp/crabs (non-recreational)	Habitat availability and connectivity, food supply	Instream flow regime, floodplain inundation, flows sustaining riparian vegetation
	Fertile land for flood-recession agriculture and grazing	Supply of nutrients and organic matter, moisture conditions in soils	Floodplain inundation
	Wildlife for hunting (non-recreational)	Habitat availability and connectivity, food supply	Floodplain inundation, flows sustaining riparian vegetation
	Vegetables and fruits	Supply of nutrients and organic matter, seasonality of moisture conditions in soils	Floodplain inundation, flows sustaining riparian vegetation
	Fiber/organic raw material for building/firewood/handicraft	Supply of nutrients and organic matter, seasonality of moisture conditions in soils	Floodplain inundation, flows sustaining riparian vegetation
	Medicine plants	Supply of nutrients and organic matter, seasonality of moisture conditions in soils	Floodplain inundation, flows sustaining riparian vegetation
	Inorganic raw material for construction and industry (gravel, sand, clay)	Sediment supply, transportation and deposition (fluvial geomorphology)	Instream flow magnitude and variability
Regulation	Chemical water quality control (purification capacity)	Denitrification, immobilization, dilution, flushing	Floodplain inundation, instream flow regime
	Physical water quality control	Flushing of solid waste, flushing/retention of sediment, shading	Floodplain inundation, instream flow regime, flows sustaining riparian vegetation
	Flood mitigation	Water retention capacity	Floodplain inundation, flows sustaining riparian vegetation
	Groundwater replenishment (low flow maintenance)	Groundwater (aquifer) replenishment	Floodplain inundation
	Health control	Flushing of disease vectors	Instream flow regime, water quality
	Pest control	Habitat diversity, disturbance and stress	Instream flow regime
	Erosion control (riverbank/bed and delta dynamics)	Healthy riparian vegetation, erosion, transportation and deposition of sediments	Flows sustaining riparian vegetation
	Prevention of saltwater intrusion (salinity control)	Freshwater flow, groundwater replenishment	Instream flow regime
	Prevention of acid sulfate soils development	Groundwater replenishment	Floodplain inundation
	Carbon 'trapping' (sequestration)	Accumulation of organic material in peat soils	Floodplain inundation
	Microclimate stabilization	Healthy ecosystems	Floodplain inundation, flows sustaining riparian vegetation

(*Continues*)

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Table I. (Continued)

Service category	Service provided	Key flow related function	Key environmental flow component or indicator
Information	Recreation and tourism (incl. fishing and hunting)	Presence of wildlife, aesthetic significance, good water quality	Site specific
	Biodiversity conservation	Sustaining ecosystem integrity (habitat diversity and connectivity)	Natural flow regime
	Cultural/religious/historical/symbolic activities	Site specific	Site specific
Life support	The prior existence of healthy ecosystems	All	Natural flow regime

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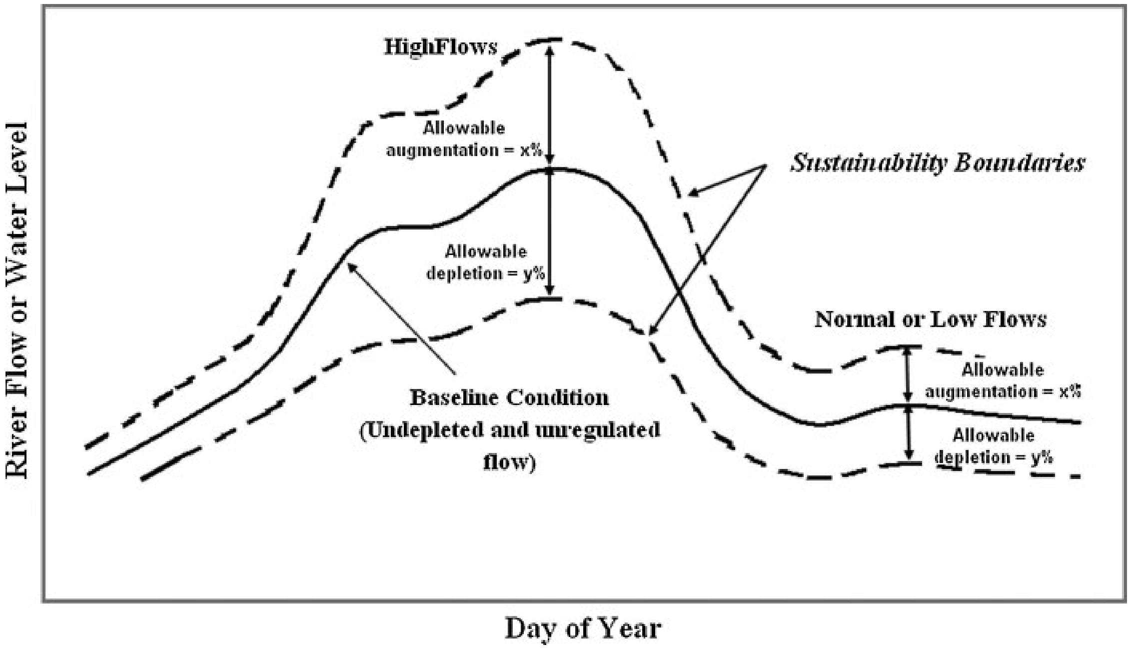

Figure 1. Illustration of the Sustainability Boundary Approach (SBA) to setting goals for sustainable water management. Uses of water and land are managed such that hydrologic regimes are not altered beyond agreed-upon sustainability boundaries. The degree of allowable augmentation or depletion will differ depending upon social objectives for water management in the particular water body (river, lake, aquifer) in which the SBA will be applied. As implied by this illustration, different levels of allowable modification may be applied to different flow or water levels, and could differ by season

well being are seldom explained in public forums and are conspicuously absent in the public media. The critical importance of environmental flows in sustaining ecosystem services, local economies and subsistence and other river-dependent lifestyles is still largely unrecognized and grossly under-appreciated (for examples see Governor Sonny Perdue, 2007: Apalachicola River, Florida; Barbier and Thompson, 1998: Hadejia and Jama' are rivers, Nigeria). As long as communications about environmental flows remain centred on non-human benefits, these misperceptions of environmental flow benefits will persist and it will be difficult to make the case for environmental flow protection to those who do not fish recreationally or value biodiversity conservation.

Issue #2: uncoordinated management of water resources

Many existing water management approaches conflict with environmental flow implementation, but one issue is of particular significance. Regulatory authorities for managing water are often conflicting, overlapping or uncoordinated. Most pertinent to environmental flow management is the fact that in many jurisdictions, the regulation of surface water, groundwater and dams is not coordinated. This problem becomes particularly severe for trans-boundary rivers that cross multiple states or nations. As a result, unregulated and unsustainable use of groundwater can compromise efforts to protect environmental flows by reducing surface water flows, and dam operations can both artificially reduce or augment flows, in conflict with environmental flow objectives (for examples see Martínez-Santos *et al*., 2008: Guadiana River, Spain Beilfuss *et al*., 2000: Zambezi River, Mozambique).

Issue #3: low priority given to environmental flows in allocation systems

Many water allocation systems include a prioritization scheme that comes into play during times of water shortages. Such prioritization can take the form of priorities among different types of use, such as giving priority to domestic needs or industry over agricultural or environmental flow needs, or a temporal prioritization that gives earliest users of the water the highest-priority rights during times of shortage. When water is in short supply,

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environmental flow allocations with lesser seniority or priority are among the first to be sacrificed, and complete drying of rivers by water extractions, particularly in arid and semi-arid regions, is not uncommon.

Issue #4: environmental flow allocations are usually limited to low flows

The rationale for limiting environmental flow allocations to relatively small volumes of water is fairly obvious, i.e. water managers and regulators are reluctant to commit large volumes of water associated with high flows or floods to environmental flow purposes, particularly in water scarce regions, and particularly when such allocations are perceived as limiting other uses of the water for human purposes. While it is true that setting an environmental flow requirement or allocation for a particular segment of a river can limit upstream uses of water to some degree, this constraint on upstream uses is commonly overstated. Such overstatement results from an implicit assumption that water dedicated to environmental flows is unavailable for any other human uses, upstream or downstream. This is simply not true. To use a simple example, virtually 100 per cent of the water passing through a river segment to meet environmental flow requirements could be used for hydropower generation upstream. Additionally, much of the water withdrawn upstream for other purposes (i.e. irrigation, urban water supply) returns to the river after use. In the US overall, an average of 70 per cent of all water withdrawn from freshwater sources is returned to those sources after use (Solley *et al*., 1998). The water that returns to rivers after use is available for meeting environmental flow needs, provided that it is in appropriate quality and returns to the same river near the point of withdrawal. And the same water that is designated for environmental flow purposes in a particular river reach could be fully available for other human uses downstream.

Issue #5: too much water can be damaging as well

Water allocation and dam licensing systems do not address the problem of unnatural augmentation of river flows. This commonly results from inter-basin transfers of water or from dam operations, such as when hydropower is being generated or stored water is released for downstream irrigation uses. Unnatural increases in flows can cause problems for plant and animal reproduction or feeding, and allow certain species to proliferate to the detriment of other species (for examples see Postel and Richter, 2003: Green River, Kentucky; Pearsall *et al*., 2005: Roanoke River, North Carolina; Rivers-Moore *et al*., 2007: Great Fish River, South Africa).

Issue #6: difficulty of implementing complex environmental flow specifications

It has proven exceedingly difficult to specify and implement complex environmental flow specifications intended to mimic elements of natural flow variability (i.e. by including both intra- and inter-annual variations in flow). Due to uncertainties in water availability during coming weeks or months, water managers are also hesitant to release high flows for environmental purposes when other human uses could be jeopardized (for example see Wilson and Berney, 2009: Gwydir River, Australia).

These problems are tenacious, and progress in resolving them has been slow and incremental. Given the reality that water withdrawals could increase by as much as 50 per cent or more in the next half-century (Shen *et al*., 2008), and the already rapidly deteriorating condition of the world's freshwater ecosystems (Millennium Ecosystem Assessment, 2005), rapid policy changes will be needed to prevent further widespread damage to freshwater ecosystems and the goods and services they provide to people. It is time to re-think our approaches to environmental flow protection.

A VISION OF SUSTAINABILITY

Similar to water quality protection, the beneficiaries of environmental flow protection are numerous, arguably extending to the whole of society. The benefits of environmental flows should, therefore, be viewed as common social goods and services and protected as communal rights or the public trust. As with water quality, the social benefits associated with environmental flows can be impacted by many different types of water and land uses within a river basin. Therefore, I suggest that environmental flow protection should be viewed not as a 'use' or allocation of water but instead as a necessary and desirable outcome of sustainable water management. In other words, the

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existence of adequate environmental flows is an indicator that water resources are being managed for long-term sustainability.

At the same time, there is no (scientifically credible) rule-of-thumb for defining the amount of water that should remain in a river to satisfy environmental flow needs. While scientists have advanced greatly in their ability to predict likely ecological and even social consequences of hydrologic alterations, decisions about which of these consequences are acceptable, and how much water should remain as environmental flow in a river, are societal decisions, involving complex trade-offs among human values and benefits. The degree of 'sustainability' achieved is directly proportional to degree to which water stakeholders are satisfied with the way that water is being allocated and managed. The only way to realize a high degree of satisfaction, and therefore sustainability, in water management is to foster an inclusive, transparent and fair stakeholder dialogue that allows all water interests to be heard, and results in water allocation decisions that are regarded by those stakeholders as being fair and equitable. Importantly, such stakeholder dialogue must be informed by natural, physical and social science, so that options and trade-offs are very clearly understood.

In this context, *sustainable water management* involves managing water in a manner that ensures that the full array of benefits associated with water, including benefits that derive from adequate water flows and quality remaining within freshwater ecosystems as well as those that require withdrawals of water from freshwater sources, are protected over the long-term, while meeting the basic water needs of all people. Sustainability in water management will require that human impacts on the natural variability of water chemistry and hydrologic processes are constrained within specified limits, as agreed to by water managers and stakeholders. Implementation of sustainable water management requires proper governance systems that ensure an adequate understanding of water availability and the influences of human uses of water and land within the river basin, as well as decision-making and priority-setting based on transparent, inclusive, and well-informed stakeholder engagement.

This definition of sustainable water management is fully consistent with the philosophy of 'integrated water resources management' (IWRM), with respect to the need to consider perspectives and needs of all stakeholders and the interdependencies among different water uses, and the importance of understanding the physical interactions between all parts of the hydrologic cycle (Lenton and Muller, 2009). However, the definition of sustainable water management offered above addresses Issue #1 (lack of understanding of environmental flow benefits) and Issue #3 (low priority given to environmental flows in allocation systems) highlighted previously, by giving much-needed, explicit recognition to water benefits that depend upon adequate flows and water quality remaining in freshwater ecosystems, and makes clear the importance of maintaining water quality and quantity patterns (amount, timing) within specific, quantifiable boundaries.

MANAGING WITHIN SUSTAINABILITY BOUNDARIES

Successful implementation of sustainable water management will require the adoption of specific, measurable goals that can guide water managers and stakeholders (Rogers and Bestbier, 1997; Richter *et al*., 2003). As emphasized above, those goals must be developed through stakeholder dialogue. Measurable goals help to translate idyllic concepts such as 'sustainability' into something operational. These measurable goals must address the water quality and environmental flows required to support water-dependent ecosystem benefits. With respect to environmental flow protection, goals should reflect the scientific consensus around the need to protect some semblance of natural flow variability. At the same time, goals should explicitly acknowledge the fact that water-related benefits requiring consumptive extractions of water from freshwater ecosystems will necessarily alter natural flow variability.

Here I offer a 'Sustainability Boundary Approach' (SBA) as a means for setting measurable goals relevant to environmental flow protection. As illustrated in Figure 1, sustainability boundaries define the degree to which human uses of water and land within a river or lake basin can alter natural or baseline hydrologic conditions without impairing flow-dependent ecosystem benefits valued by stakeholders. The SBA builds on the 'sustainability boundary concept' introduced by Postel and Richter (2003), by translating the concept into operational targets for sustainable water management.

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While the SBA is offered here as a new way to express desired environmental flow conditions, this approach should not be construed as a new environmental flow method. Sustainability boundaries will need to be determined using one or more of the available environmental flow methods (Tharme, 2003). These sustainability boundaries could be applied to the flow regime of a river or segment of river, to the water level regime of a lake or aquifer or to water quality characteristics that vary over time.

In determining appropriate sustainability boundaries, the basic scientific challenge remains the same: determining the water flows and quality necessary to maintain the freshwater ecosystem at a targeted level of health. However, instead of expressing environmental flow requirements as a certain volume of flow to be maintained in the river at specified times of the year, the SBA is used to translate those flow requirements into allowable percentages of deviation from the natural condition.

This can be illustrated as follows. Let's say that it has been scientifically determined (using the environmental flow method of choice) that a flood of at least 1000 cubic meters per second ($m^3 s^{-1}$) needs to be released from an upstream dam every year during the months of April and May. By reviewing the historical flow record (or model simulations), scientists or other technical experts could identify a targeted percentage reduction (e.g. 30 per cent) of high flows that would ensure that a $1000 m^3 s^{-1}$ flood would be released from the dam in every year. This 30 per cent reduction becomes the lower boundary in the SBA. To ensure that the dam never releases a higher flow than is safe or desirable, an upper boundary can be imposed as well (see Figure 1).

Once the sustainability boundaries are determined on the basis of environmental flow requirements, water managers then need to evaluate whether they can meet all other objectives and needs for water withdrawals or dam operations, both upstream and downstream of the point at which the SBA will be applied, while staying within the sustainability boundaries. This feasibility analysis should be based on a well-defined set of water management objectives, agreed to by water managers and stakeholders. Reaching agreement on these objectives will necessarily require trade-offs among instream and out-of-stream benefits. A description of appropriate social processes for facilitating such trade-off decisions is beyond the scope of this paper, but it is acknowledged that the design of the 'right' social process for this purpose will vary greatly across differences in culture, laws, economies and political systems.

When the Sustainable Boundary Approach is used as a basis for quantifying desired environmental flow outcomes, it will foster sustainable water management in a number of important ways, many of which are directly or indirectly responsive to the obstacles to environmental flow management highlighted earlier:

- The SBA explicitly links sustainable water management to maintaining some semblance of natural (baseline) hydrologic conditions. The SBA preserves much of the natural hydrologic variability known to be essential for healthy freshwater ecosystems by protecting greater environmental flows during high water periods and lower flows during dry periods.
- The SBA explicitly recognizes the fact that human activities can cause water flows to be decreased by water extractions as well as increased, i.e. by accentuating watershed runoff, inter-basin transfers, or by dam operations. This addresses Issues #4 and #5 highlighted previously (environmental flow allocations are usually limited to low flows; and too much water can be damaging as well).
- Rather than relying on current scientific knowledge to define every aspect of the flow regime and the associated characteristics of magnitude, timing, duration, frequency and rate of change necessary for ecological maintenance, the SBA fosters a precautionary approach that requires only the determination of the magnitude of flow (expressed as the allowable alteration from natural), thereby greatly reducing scientific uncertainties.
- The SBA is easier for water managers to implement (as compared to complex, multi-parameter, seasonally-varying environmental flow prescriptions), because they understand and appreciate the simplicity of protecting a portion of the available water in the river from withdrawals, or releasing a portion of the water inflowing to a storage reservoir. The allowable degree of alteration may vary by season, or water level, but the structural and operational elements of water infrastructure can be readily designed to meet these requirements. This addresses Issue #6 highlighted previously (difficulty of implementing complex environmental flow specifications)
- The spread of the sustainability boundaries—representing the degree of allowable alteration—is intentionally flexible, to be set by water managers in collaboration with stakeholders to achieve mutual benefits through a

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negotiated balance between benefits derived from water extractions with benefits derived from keeping water in the freshwater ecosystem.

- Successfully managing within sustainability boundaries requires integrated water resource management; for example, when applied to rivers, it requires the coordinated management of hydrologic influences from surface water extractions, infrastructure operations, groundwater pumping and land uses that affect hydrologic processes. This addresses Issue #2 highlighted previously (uncoordinated management of water resources). The SBA clarifies the intended limits of cumulative impacts from water and land uses in the basin on freshwater sources.
- The approach is robust in the context of climate change; as water flows change in response to climate change influences, the SBA boundaries (allowable per cent departures) continue to apply. However, climate change must be taken into consideration when setting the sustainability boundaries, to ensure that water-related values and benefits as well as flood management objectives will continue to be satisfied as the climate changes.
- The SBA provides a relatively simple, clear vision of success for sustainable water management.

Approaches similar to the SBA have been applied with considerable success. For instance, a ‘per cent-of-flow’ approach has been used in the Southwest Florida Water Management District in the United States that limits water withdrawals to a percentage of natural streamflow at the time of withdrawal (Flannery *et al*., 2002). These withdrawal percentages have been set at 10 per cent of natural flow in the Peace and Alafia Rivers, but range up to 47 per cent during high flows in the Little Manatee River to provide cooling water for an electrical power plant. An important difference between per cent-of-flow-approach and the SBA proposed here is the explicit recognition that higher-than-natural flows can also damage freshwater ecosystems and associated benefits.

Similarly, in formulating a 50-year water supply plan for the City of Charlottesville and Albemarle County in Virginia (United States), the Rivanna Water and Sewer Authority developed a formula based on natural inflows to determine how much water could be stored for water supply and how much of the natural inflows to its reservoirs needs to be released to maintain adequate environmental flows downstream (Richter, 2007). As a result, under the plan approved by state regulators, at least 90 per cent of natural flow will be maintained below one reservoir, and 30–100 per cent will be released from another reservoir (see Figure 2).

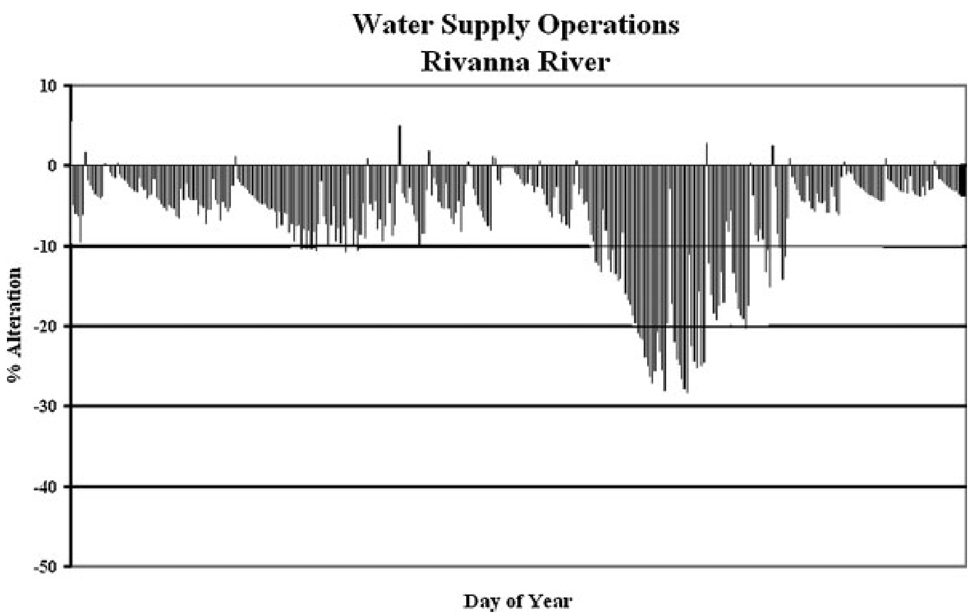

Figure 2. This graph illustrates the degree to which natural flows in the Rivanna River in Virginia (US) will be altered by water supply operations under a recently-adopted 50-year water supply plan. The Rivanna Water and Sewer Authority plans to mimic natural river flows by releasing a percentage of natural daily inflows from its reservoirs for environmental flow purposes. This graph portrays computer-simulated results for one typical year under the proposed operations, which will provide water for a population of 160 000 in 2050

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IMPLEMENTATION OF SUSTAINABILITY BOUNDARIES IN WATER MANAGEMENT

While successful implementation of the SBA will require coordination of many different water- and land-use activities in a lake or river basin, the two most important management challenges will involve permitting of water withdrawals from both surface water and groundwater, and dam licensing. In river basins with many different

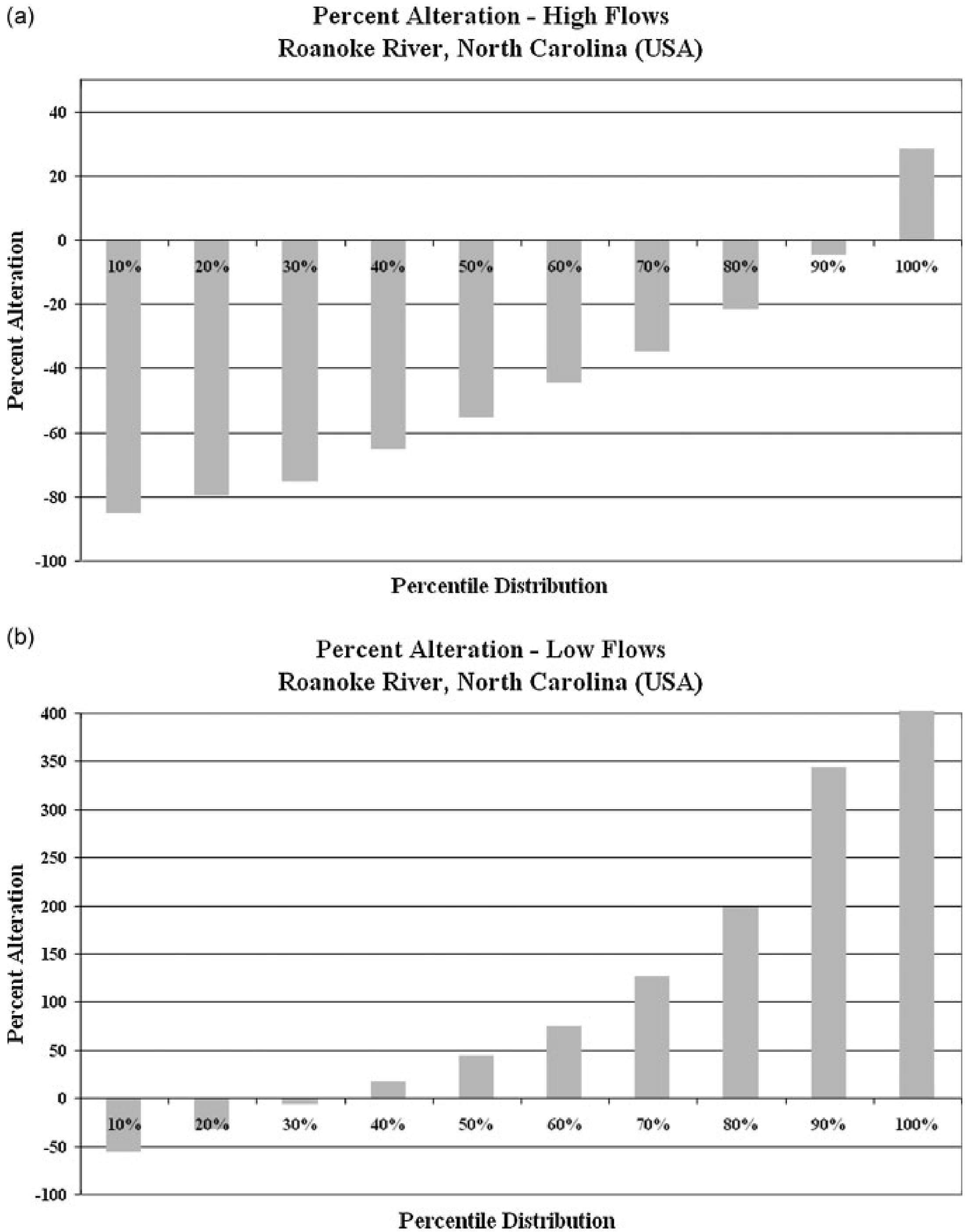

Figure 3. Analysis of percentage alteration of both high flows (a) and low flows (b) for the Roanoke River, North Carolina (USA). These results indicate that dam operations on the Roanoke have generally augmented low flows and decreased high flows

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human influences on flow regimes, it will be extremely helpful to develop a computerized hydrologic simulation model that can facilitate understanding of complicated spatial and temporal interactions among water and land uses, such as surface water extractions, groundwater pumping, dam operations and watershed runoff.

Hydrologic models will also be very useful in developing estimates of the baseline hydrologic conditions within freshwater ecosystems, which form the basis around which sustainability boundaries can be applied (Poff *et al*., 2009). Hydrologic models can also facilitate water permitting or dam licensing decisions. For instance, using a hydrologic model, water managers will be able to evaluate whether a proposed water withdrawal or the operations of a proposed dam will likely cause river flows to fluctuate outside of sustainability boundaries at various times of the year, or during critical periods such as droughts. Such model-based assessment of water withdrawals and dam operations will require that these water uses are described in sufficient detail—in terms of location, timing and volume of extraction, storage and return flows or dam releases—such that the influences of these water uses can be properly evaluated for their compatibility with sustainability boundaries. Additionally, monitoring of river flows in locations proximate to these water uses will be of great benefit in verifying model projections.

Partial or hybrid implementation schemes

Understandably, many jurisdictions will find it daunting to migrate their current water management approaches into an SBA-based management system immediately. However, by conducting an analysis of the current state of flow alteration within their jurisdiction, a range of conditions is likely to be revealed (Figure 3). Some rivers will likely remain relatively unaltered, and others may have been heavily altered. Some rivers may have experienced considerable alteration of low flows but not high flows. By gaining an understanding of the current state of flow alteration, water managers will be better able to assess the prospects for moving into an SBA-based management system.

Many jurisdictions will likely want to begin with a partial or hybrid implementation strategy. For instance, regulators may want to begin applying the SBA to water withdrawal permitting, but use other mechanisms for implementing environmental flow releases from existing dams. Rather than requiring dam managers to immediately begin operating continuously within sustainability boundaries, regulators may instead require that dam operators make carefully prescribed environmental flow releases—such as high pulse releases during certain critical times of the year—to alleviate flow alterations below the dam over time.

However, it is critically important to begin moving toward integrated, coordinated implementation of water and land management activities as early as possible. Regulators can immediately begin requiring SBA-compatible dam operations in all new licenses or re-licensing activities, thereby helping advance the transition into full SBA implementation over time.

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