# *A Review of Benefits to People and Nature from Environmental Flow Management*

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## Summary

Globally, many dams are now managed for environmental objectives in addition to their original purposes such as water supply, flood control, power generation, or navigation. The rationale for managing dams for flows to achieve environmental objectives is based on sound scientific and socioeconomic understanding of the importance of natural flow regimes to river ecosystem health and services to society. A range of environmental and socioeconomic benefits have been documented in response to different types and examples of managed environmental flow components.  While environmental flow management can be remarkably beneficial, its effectiveness in improving ecosystem health and services is limited where structural constraints or conflicting operational demands prevent reestablishment of critical components of natural flow, or where other threats limit ecosystem responses to flow management. This document summarizes types and degrees of benefits that have been documented from monitoring impacts of environmental flow management, providing empirical evidence to draw from for developing impact goals and objectives, informing monitoring and measures approaches, selecting project sites that have greater potential for success, and leveraging this activity more broadly.

## Introduction

"Water managers and stakeholders are now demanding from scientists more than just a strong conceptual understanding of the likely ecological responses of river biota to managed flows"
(King et al. 2010)

The Nature Conservancy and others are working with dam owners and operators to define and implement environmental flows. While the literature is teaming with summaries of the detrimental impacts of dams on ecosystem health and services, what has been missing is a summary of the documented benefits to freshwater ecosystem health and services resulting from implementing environmental flows. There are numerous examples where environmental flow management has been implemented and impacts documented. This body of knowledge can serve as the basis to communicate the types and degrees of benefits that result to inform future projects, and to leverage support to greatly expand the scope of its implementation.

A working group at the *National Center for Ecological Analysis and Synthesis* recently completed a global review of experimental approaches to dam management for environmental and socioeconomic objectives: (http://knb.ecoinformatics.org/knb/metacat?action=read&qformat=knb&sessionid=0&docid=FlowExp.3.2) and Konrad et al., (2011). This review identified over 100 sites comprised of rivers from 23 countries where the results of environmental flow management were published in peer review journals or as formal peer reviewed reports.

Many of these reports provide clear and well documented evidence that environmental flow management can improve river ecosystem health through benefiting habitats and water quality, fish, waterfowl, invertebrates, riparian vegetation, and commercial and subsistence resources and ecosystem services for people. These demonstrated benefits illustrate the possibilities for recovering and sustaining the health and services of river ecosystems through environmental flow management. The summary of these benefits in this document is limited to what has been studied and clearly demonstrated. There are probably many environmental and socioeconomic benefits that were not evaluated. Absence of certain benefits in the summary does not preclude their existence.

### What are natural flow regimes and why are they important?

Natural flow regimes – the natural patterns of the magnitude, timing, duration, and variability of flows - drive the dynamics of sediment, temperature, nutrient, and connectivity regimes of rivers, floodplains, and estuaries. They control the characteristics of habitat, environmental conditions and cues for plants and animals that have evolved in response to them, such as fish and bird migration and reproduction, and plant seed dispersal and establishment, all which are also critical for many ecosystem-dependent socioeconomic benefits. Many rivers have altered flow regimes from dams that result in significant detrimental impacts to the patterns and processes that support ecosystem health and services, causing declines in plant and animal populations, fisheries, cattle grazing, and agriculture, to name a few.

### What is environmental flow management?

Environmental flow management is the process of defining and managing the outflow of dams and other infrastructure to maintain and/or re-establish important components of natural flow regimes in order to sustain and/or restore the health and services of freshwater ecosystems that depend upon them. Environmental flow management at dams has typically focused on re-establishing individual flow characteristics (such as low flows or high flows), though in some cases, (and the focus of The Nature Conservancy's efforts), dams are managed to re-establish multiple characteristics of natural flow regimes that have been lost as a result of historic dam operations.

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## Types of Environmental Flow Management and their Responses

### 1. Re-establishing higher minimum flows

Dam operations often hold back water to fill reservoirs for water use later in the year, or bypass flows around a river reach. These operations can result in low flows and base-flows that are much lower than those that occur naturally at certain times of year, resulting in higher water temperatures, lower oxygen concentrations, less freshwater habitat or even the complete loss of freshwater habitat.

Re-establishing higher minimum flows have been documented to benefit fishes, aquatic invertebrates, riparian vegetation, and estuaries. These benefits occur through increase the area, volume, stability and diversity of aquatic habitats during natural low flow periods. Higher minimum flows also improve aspects of water quality, such as temperature, oxygen and salinity:

- Increase in number of native fish species that are river habitat specialists and their abundance (Travnichek et al. 1995; Layzer and Scott 2006; Lamouroux et al. 2006);
- Increase in weight and growth rate of native and recreational fish species (Weisberg and Burton 1993; Korman et al. 2010);
- Increase in spawning and juvenile survival of native fish species (Sabaton et al 2008; Platania and Dudley 2009; Rolls and Wilson 2010).
- Shift toward or maintenance of natural diversity of invertebrate assemblages (Weisberg 1990; Bednarek and Hart 2005; Lind et al 2007).
- Increase in early-establishing wet-meadow native vegetation species (Hill and Platts, 1998)
- Increase in sea grass density in estuaries (South Florida Environmental Report 2010)
- Increase in abundance of aquatic habitat availability during drought (Victoria Gov 2008, 2009, 2010)
- Increase in fish migration and survival though dam structures (Ploskey et al.2007, Tiffan et al.2009; Tiffan et al. 2005. Johnson et al.2007; Bisson et al.2000; Arnekleiv et al. 2007; Kraabol et al 2008; Connor et al. 2003;

As an example from above, restoration of minimum flows and aeration to the dam outflow resulted in restoration of the number of native fish species from 42 to 82 of the original 100 native fish species known to occur in the French Broad River, North Carolina and Tennessee, USA (Layzer and Scott 2000).

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## 2. Re-establishing stable daily flows

Dam releases can fluctuate over a very large range of flows during a single day in response to hydropower generation demands – where water is collected in the reservoir during the evening (low power generation), and released during the day (high power generation). Dams are often managed in such ways on a daily basis for decades. Such changes result in highly unstable freshwater habitats, daily flooding and drying of riparian habitats causing limiting vegetation growth and reproduction, and stranding organisms in habitats that are unsuitable for survival.

Efforts to re-establish more stable daily flows, for example - by limiting the daily range and rate of change in dam releases – have been successful in stabilizing critical habitat characteristics and improving conditions for vegetation, fish and invertebrates such that fish spawning habitats are not dewatered and organisms do not have to expend energy during high-flow periods seeking preferred habitat conditions, or risk being stranded in dry habitats on a daily basis:

- Decrease in redd (spawning bed) de-watering and stranding rates, increase in returning adult spawning fish (Connor and Pflug 2004);
- Increased abundance and diversity of invertebrates, shift in trophic structure toward more scrapers and grazers (Marty et al. 2009, Patterson and Smokorowski 2011).
- Increase in water temperatures along river margins to mitigate cold-water releases (Ralston 2011)

As an example from above, dam reoperations to limit the range and abruptness of flow declines (down ramping) in order to allow salmon eggs to mature in their gravel nests in the Sakagit River, Washington, USA, resulted in an increase in pink salmon spawning, juvenile recruitment, and return “spawners” that achieved densities as high as 1,817% at sampling sites below the Gorge Powerhouse facility (Connor and Pflug 2004).

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## 3. Re-establishing high flow characteristics

Dam operations to store water during naturally high flow periods (e.g. for flood control or to create water storage for hydropower or water supply) reduce the natural magnitude, duration, frequency, and gradual recession of post-high flows in rivers. These flow characteristics are cues for many migratory animals, and re-set the morphology, habitat availability and water quality of rivers by moving wood, gravel, sediment and nutrients that create and maintain critical habitats. They connect and inundate floodplains to rivers to provide habitats for fishes, birds and vegetation reproduction, and move nutrients and sediment to estuary and coastal marine habitats to support marine biota. In many large rivers, particularly those receiving spring snowmelt, stream flows naturally recede gradually after high flows. Dam operations often abruptly lower flows after high flow periods, stranding biota in unconnected and inhospitable habitats, and dewatering soils that must maintain moisture for riparian vegetation reproduction and growth.

Re-establishing high flows provides important ecological cues for aquatic organisms, connect rivers and off-channel habitats such as side channels and floodplains, and mobilizes and transports water, sediment and organic materials among connected habitats. Numerous benefits have been observed in response to re-establishing high flows in rivers. Re-establishing gradual recession after high flows has resulted in more natural patterns of aquatic habitat connectivity, water level changes, and soil moisture, and beneficial responses from riparian plant and animal communities and the services they provide to people:

- Increase in native or recreational fish spawning (Cambray 1991; Ortlepp and Murle 2003; King et al. (2010); Korman et al. 2011);
- Increase in area of native wetland and riparian vegetation (Hamerlynch and Duvail 2003; Hamerlynch et al 2005; Rood et al. 2003; Rood et al. 2005; Shafroth et al. 2010);
- Increase in native water fowl breeding (Hamerlynch and Duvail 2003);
- Decrease in density of non-native riparian plant species (Shafroth et al. 2010);
- Decrease in density of non-native fish species (Propst and Gido 2004);
- Decrease in non-native fish spawning (Kleinschmidt 2008);
- Decrease in number of beaver dams (Andersen and Shafroth 2011);
- Decrease in nuisance algae (Uehlinger et al. 2003; Arscott 2008);
- Increase in area and diversity of aquatic and riparian habitats (Murle et al. 2003; Shang 2009; Hazel et al. 2010; Erwin et al. 2010); and
- Shift toward natural diversity of invertebrate assemblages (Robinson and Uehlinger 2008)
- Increased zooplankton production in floodplain and nutrient dynamics between river and floodplain (Mackay et al. 2009)
- Increased riparian native tree germination (Rood et al. 2005)

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- Increase in fisheries production (Hamerlynch and Duvail 2003; Hamerlynch et al 2005);
- Increase in river -dependent agricultural practices (Hamerlynch and Duvail 2003; Hamerlynch et al 2005);
- Increase in collection of floodplain materials for weaving mats, basket and roofs (Hamerlynch and Duvial 2003; Hamerlynch et al 2005)

As an example from the above, dam reoperations to re-establish high flow events in the Senegal River in Mauritania to rehabilitate the floodplain delta plants and animals resulted in a 118 fold increased in daily fish catches, a 15 fold increase in the number of water birds, and a 30 fold increase in the number of women gathering reeds for weaving mats (Hamerlynch and Duvail 2003; Hamerlynch et al 2005).

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## 4. Re-establishing multiple environmental flow components

Dam operations often alter many characteristics of natural flow regimes, resulting in multiple constraints to ecosystem processes, biotic life histories, and ecosystem services. Re-establishing multiple aspects of natural flows regenerates and maintains a variety of diverse habitats; environmental processes such as sediment and nutrient transport; seasonal patterns of connectivity and inundation of floodplain habitats, and appropriate patterns of environmental conditions, all contributing to the environmental needs of multiple life-stages of many plants and animals and the ecosystem services they provide:

- Decrease in elevated salinity (Victoria Gov 2009, 2010);
- Maintenance of diversity, structure and quality of fish habitats (Victoria Gov 2009, 2010);
- Increase in native perennial floodplain vegetation (Scholte et al. 2000; Rood et al 2003);

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- Increase in recreational salmon populations available for fisheries (Connor and Pflug 2004)
- Increase in fisheries production (Loth 2002);
- Increase in traditional floating rice and flood-dependent sorghum cultivation (Loth 2002);
- Increase in livestock grazing on floodplain vegetation (Scholte et al. 2006).

As an example from above, dam reoperations to re-establish a variety of critical components of natural flow regimes, the natural flow regime was restored to the floodplain delta on the Lagone River in Cameroon, Africa (Scholte et al 2000; Loth 2002). The components of flow that were lost due to dam and levee development and re-established through management were floods and post-flood recession. Two pilot management flow releases and levee openings resulted in the re-establishment of flooding of 180 $km^2$ and increased water levels to more natural levels to an area of 400 $km^2$. These pilot management re-operations resulted in a 7% annual increase in the area of natural perennial grasses, and a direct response of grazing intensity from 27 to 69 cattle per $km^2$. Herd sizes grew an average of 4.5% per year, resulting in a 30% increase in cattle herd size from 1993-1999. There was 48% increase in the number of fishing households and a 93% increase in fish catch per household. There were increases in the harvesting of reeds and the weaving of fish baskets and thatched roofs, bee keeping and production, river transportation, water points for retrieving water, food security, and diversity of livelihoods. Models for a range of alternative flow management scenarios evaluated costs and benefits of a variety of sectors illustrating the multiple sector benefits and overall socioeconomic benefits of alternative environmental flow management scenarios.

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## General trends and implications for environmental flow management and monitoring

The types and degrees of benefits from environmental flow management vary longitudinally. Benefits are often minimal immediately downstream of dams because of significant alterations to habitat from dam infrastructure and discharges, and alterations to transport of sediment and organic matter, temperature and dissolved oxygen, dominance of tolerant and/or non-native species, and barriers to dispersal and migration. Benefits increase downstream of areas proximal to dams, but attenuate further downstream with distance from dams. The decrease in the degree of changes with distance from dams were often attributed to decreased impacts of flow management with distance, and the differences in baseline conditions downstream associated with flows, temperature and sediment effects of surface run off and tributaries ameliorating the negative impacts of dams.

Dam re-operations on segments of rivers that had unregulated and connected tributaries downstream from dams reflected benefits from these, as they are often source of sediment, warm water, natural flow patterns, provide seasonal habitats for biota, and source populations for re-colonization of biota.

Lateral benefits (e.g. establishment and growth of floodplain vegetation, connectivity to floodplain and other off-channel habitats for fish and bird reproduction and rearing, and nutrient dynamics) were affected by the magnitude and duration of high flows.

Greater benefits of environmental flow management were associated with larger differences from historic dam operations that had resulted in significant flow alteration, including a larger percentage in change in minimum flows, larger high-peak flows, and larger volume releases to estuaries. Benefits were more evident, greater in scope and less limited in degree when there were fewer anthropogenic impacts to the system other than flow alteration (e.g. alterations to connectivity, water quality, or habitat structure).

The benefits of single flow events were not as great or as long-lasting in shifting species composition and abundance towards desired outcomes as repeated or long-term flow management. Broader and longer-term changes in dam operations provided the flows needed for the generation and maintenance of a variety of critical processes, habitats, and requirements of many flow-dependent life-history stages of plants and animals.