



# Securing Water for Ecosystems and Human Well-being: The Importance of Environmental Flows



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Securing Water for  
Ecosystems and Human  
Well-being: The Importance  
of Environmental Flows

## Note to the Reader:

This report highlights the service role played by healthy ecosystems in helping water managers meet their goal of maximising the economic and social welfare of all water users in an equitable manner. Healthy ecosystems simultaneously serve multiple aspects of human well-being, especially among poor communities living close to the land-water interface. Ecosystem services have real economic value today and special importance in mitigating future problems and economic losses related to climate change. To preserve and benefit from these services, the water manager must ensure that an environmental flow regime is maintained in rivers and wetlands. Environmental flows describe the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on them (Brisbane Declaration 2007).

Our goal is to illuminate the role of environmental flows to simultaneously improve human well-being and sustain vital ecosystems. We hope that the reader will come to

understand environmental flows as essential to meeting the water management challenges we face today and into the future, including adaptation to climate change.

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Photo: Mattias Granberg

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### How to Cite

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## Summary

- 21<sup>st</sup> Century water resource managers are called upon to maximise the economic and social welfare of water users in an equitable manner without compromising the sustainability of vital ecosystems. This requires managers to view human well-being in a broader context and to recognise the multiple ways that people, especially the poor, depend on ecosystems and the services they provide. This includes basic elements of survival, improved community health, enhanced security, and better social relations. The services maintained by ecosystems have real economic values that are generally neglected in project cost-benefit analyses. These values are linked to the products provided by ecosystems as well as the avoidance of costs related to declining profits, remedial measures, damage repair, and health care. Healthy aquatic ecosystems are also to be valued for their adaptability and greater resilience in the face of climate change.
- The quantity, quality and timing of water flows required to sustain ecosystems and the valuable services they provide are referred to as Environmental Flows. For river and wetland ecosystems, the flow regime is the most important determinant of ecosystem function and services provided by these functions. Flow features are determined by river size, geology, climate variation, topography and vegetation cover. The different components of an environmental flow regime contribute to different ecological processes. For example, base flows help maintain water table levels in the floodplain and soil moisture for plants, high pulse flows shape the character of river channels and large floods recharge floodplain aquifers.
- Human well-being, in its broadest sense, refers to everything important to peoples' lives, ranging from basic elements required for human survival (food, water, shelter) to the highest level achievement of personal goals and spiritual fulfilment. Human well-being is dependent upon multiple and often interrelated ecosystem services. Environmental flows support a particular range of provisioning services such as clean water, plants, building materials and food. The most important products derived from inland waters in terms of human nutrition are fish and fishery products. Environmental flows also support regulating ecosystem services, such as erosion, pollution, flood, and pest control. Moreover, rivers have aesthetic, religious, historical, and archaeological values central to a nation's heritage.
- The marginalisation of ecosystems in water resources management, and the associated degradation or loss of ecosystem services, have resulted in economic costs, in terms of declining profits, remedial measures, damage repair, cost of healthcare and in sick days missed at work due to poor health or the need to take care of a family member in poor health, and lost opportunities. The highest cost is typically borne by the rural poor, who often depend on nature's services directly for their livelihoods. Therefore, recognising the values of ecosystems, and investing in them

accordingly, is key to achieving the Millennium Development Goals (MDG) and poverty alleviation.

- Economic valuation of ecosystem services is one way of quantifying and justifying the benefits of ecosystem services and placing ecosystems on the water agenda. The global economic value of water for drinking, washing, to grow food and for energy and industry, has been estimated at USD 7.5 trillion a year. Other important services, such as food supply, flood control, purification of waste, and delivery of nutrient rich sediments to floodplains are more difficult to estimate. While economic valuation of ecosystem services can help identify costs and benefits, economic valuation cannot be the sole factor when it comes to negotiating trade-offs and water resource management options. Economic valuation must be placed in a broader decision-making context that can include non-commensurate values and societal priorities.
- When the value of ecosystem services (and thus environmental flows) for human well-being has been recognised, the concept of Payment for Ecosystem Services (PES) provides a promising opportunity to mobilise resources. PES is a mechanism through which beneficiaries pay for the ecosystem services they receive. It combines the approaches for valuing services with a mechanism for providing incentives to people for the protection of that service.
- Climate change will alter the magnitude, timing, frequency, duration, and variability of the different components of flow regimes in every populated river basin in the world. Stream flow modifications will affect water availability, determine ecosystem fragmentation, wetland infilling and drainage, and increase sediment transport to coasts. Lowering groundwater levels will entail drying of shallow wells, land subsidence, and saline water intrusion. The combination of the different categories of impacts erodes the self-repairing capacity of ecosystems until they cease to cope with sudden changes. Environmental flows enhance the resilience of ecosystems to climate change and should be considered in national adaptation and mitigation plans.
- Climate change will also present new opportunities for operating dams and power stations in those areas where run-off is expected to increase. More water could be released to reaches that presently have reduced discharge, creating opportunities to better match managed flows with important aspects of natural flow variability. More water could also be allocated to by-pass channels to enhance organism migration, or spillways could be left open more frequently to enhance downstream transport of organisms and matter. This would improve the ecological status of rivers used for hydro-power production.
- Calls for maintaining environmental flows are implicit in international agreements ranging from Agenda 21 of the 1992 Rio Earth Summit to the Ramsar Convention, and specific requirements for maintaining environmental flows are beginning to appear in national water laws. However, with so few countries having developed environmental flow policies, it remains important to consider global mechanisms and systems through which countries will commit to addressing the health of their freshwater systems and specifically environmental flows. The UN Convention on the Law of Non-navigational Uses of International Watercourses is of particular interest when it comes to environmental flows. It is the only global treaty that addresses rivers for purposes other than navigation, and it applies to transboundary freshwater systems.
- Goal 7 of the MDGs commits nations to ensure “environmental sustainability” and includes three global targets and eight official global indicators. Specifically, it calls on nations “to integrate the principle of sustainable development into country policies and programmes and reverse the loss of environmental resources”. One major problem with the current MDG framework, with a separate environmental target, is that it does not reflect that maintaining the integrity of ecosystem services underpins and is of central importance to all eight MDGs. Similarly, many Poverty Reduction Strategy Papers (PRSP’s) fail to make water a priority and often do not clearly define water objectives.
- The goods and services sustained by environmental flows play a central role in achieving the MDGs. The fundamental social and economic role of fisheries to people across the globe and especially the rural poor makes the health and productivity of aquatic ecosystems, as well as environmental flows, important indicators and poverty – environment linkages in MDGs and PRSPs.



*Photo: Digital Archive Japan Inc.*

## **Key messages and recommendations**

### **Recognise the importance of environmental flows and their link to freshwater ecosystem services**

Providing for environmental flows is a key to achieving the MDGs and alleviating poverty: ecosystems will remain a vital lifeline for the poorest until these goals are met. Failing to do this may lead to social and ecological costs or benefits of water allocations remaining hidden or unappreciated.

### **Ensure environmental flows to help mitigate some of the negative impacts from climate change**

The limitations to energy and food production as well as navigation forecasted under climate change will entail reconsidering water allocations. Environmental flows management as part of a broader climate change adaptation strategy can help mitigate some of the negative impacts. Examples of adaptation measures include recharging of aquifers, refilling of wetlands, and reconnecting floodplains to buffer against the damage of floods. Flow management would also help reserve ecological refugia and spawning waters for fisheries during periodical flooding. As such, EFAs become an opportunity for reducing vulnerabilities among people directly dependent on freshwater resources in a changing climate.

### **Address gaps in water resources management. This is critical for maintaining healthy freshwater ecosystems**

The water sector is plagued by institutional fragmentation that may result in governmental agencies working against each other to achieve their specific goals (e.g., water supply, wastewater management, water resources management). The result is that the overarching need for maintaining healthy freshwater ecosystems is overlooked, with the poor suffering even more due to their dependency on freshwater ecosystem

goods, such as fish, and services. The policy links between water management and poverty reduction require greater attention if the poverty-reducing potential of reversing the loss of ecosystem services is to be realised.

### **Valuation systems for ecosystem services, such as Payment for Ecosystem Schemes, can play an important role in highlighting the values of ecosystem services – and the environmental flows that sustain them for human well-being**

Establishing critical factors in PES requires sufficient data to value services, the existence of legislation and implementing agencies to administer and track payments, and a full understanding of the relationship between upstream activities and downstream impacts. Incentives are needed for behaviours upstream that will positively impact service flows downstream. PES must be placed in a broader context of IWRM, poverty reduction and sustainable development, especially in the face of climate change.

### **Environmental flows can serve as an important link between environmental conservation and poverty alleviation**

Environmental flows offer an effective means for countries to mainstream the environment – especially freshwater ecosystems – into national development planning. This includes PRSPs as well as strategies to address the MDGs. Environmental Flow Assessments provide the tools to assess the effect of changes in flow on various users and make the important trade-off between development and securing vital ecosystem services. Moreover these indicators will improve and support the monitoring processes of the MDGs.



Photo: WWF-Canon/Zeb Hogan

## Introduction

The goals and objectives of water resource management have become increasingly complex over recent decades, as managers face new challenges above and beyond simply meeting the water demands of prominent water users. The scope of new challenges is reflected in the Global Water Partnership's definition of Integrated Water Resources Management (IWRM) and the call for managers to maximise the economic and social welfare of water users in an equitable manner without compromising the sustainability of vital ecosystems. Social welfare, equity, and ecosystem sustainability are new and interrelated challenges for the water manager that have emerged in response to failures of the past. Economic gains at the expense of social welfare characterised many large water projects during the last century, and the benefits of projects were rarely shared in an equitable manner (World Commission on Dams 2000). The parallel impacts on aquatic and riparian ecosystems are manifest in an alarming decline in freshwater biodiversity and the more ubiquitous and insidious degradation of ecosystem functions (WWF, 2008).

The motivation for these expanded goals partially grew out of a recognition that people depend on aquatic ecosystems for far more than water, energy, and transportation.

Healthy aquatic ecosystems provide other basic elements of survival, improve community health, enhance security, and support good social relations. This generally underappreciated suite of ecosystem services has only recently been featured in the international water community through the efforts of the 2005 Millennium Ecosystem Assessment (MEA). Moreover, these services have real economic values that are often neglected in cost-benefit analyses, including costs linked to declining profits, remedial measures, damage repairs, and health care. Thus, efforts to sustain ecosystems also contributes to social welfare and reduces economic costs. In the face of climate change, healthy aquatic ecosystems have value for their adaptability and greater resilience.

This report examines each of these topics in turn and links them to the most fundamental variable in water science and management, flow. One of the first and most critical decisions a water manager makes is how much water to leave flowing in a river and how much to allocate to extractive uses, hydropower generation, or storage in reservoirs. This is not a static or one-time decision. It is a dynamic input to management planning that varies across space in river



basins and across times of the year. It varies with changing development priorities and societal choices about nature conservation and delivery of ecosystem services.

The unallocated flow intentionally preserved in a river is most commonly termed the Environmental Flow. Although strict definitions of environmental flows vary, the most recent and widely held definition was developed during the second international conference on environmental flows and released as The Brisbane Declaration (2007): *“Environmental flows describe the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems”*. This definition acknowledges the linked variables of quantity, quality, and timing that together constitute an environmental flow regime of sufficient quality to meet management goals. Emphasis is also placed squarely on flows to improve human livelihoods and well-being, recognising that biodiversity conservation and other more traditional environmental motivations are an integral part of human well-being. The target environmental flow is not necessarily the natural flow, but rather a negotiated flow, set by either objectives (deciding what you want to achieve and setting flows to achieve it) or by scenarios (negotiating between different users) – (Acreman and Dunbar, 2004).

Environmental flows fit well into multiple levels of the hierarchy of water management, ranging from international policy to river-scale flow management. For example, environmental flows, in their broad definition, encompass the objectives of international agreements such as the Ramsar Convention and regional frameworks such as the European Water Framework Directive. Similarly, the implementation of specific environmental flow prescriptions achieves quantifiable results within river-scale water management plans. Consequently there is considerable momentum around the world to incorporate environmental flows into policy making and river-scale management plans. Each of these trends is explored in the sections that follow.

This report represents a joint effort between a number of organisations and individuals working at the forefront of research, training, and implementation of environmental flows. Our collective goal is to illuminate the role of environmental flows in simultaneously improving human well-being and sustaining vital ecosystems. We hope that the reader will come to understand environmental flows as essential to meeting the water management challenges we face today and into the future, including adaptation to climate change.

Photo: WWF/Zig Koch



# The Links between Ecosystems, the Flow Regime and Human Well-being

Water for public supply, irrigation and industry is water directly for people, whilst water for ecosystems is water indirectly for people (Acreman, 1998). There are trade-off between allocating water to direct and in-direct human uses. The impact on the hydrological cycle of allocation of water to natural ecosystems, which in turn provide valuable goods, is frequently positive, as, for example, ecosystems improve water quality. Direct use of water through the development of highly managed systems, including reservoirs, intensive irrigation schemes, dams, river embankments and water purification plants frequently has a negative impact on the hydrological cycle.

## Freshwater ecosystem services and human well-being

Ecosystem services refer to the tangible benefits people obtain from ecosystems; including human use of products from forests, wetlands and oceans (timber, medicinal plants, food products, etc) and the functions ecosystems perform that are used and valued by human societies, such as the provision of clean water, pollination of crops, and maintenance of livable climates and atmospheric conditions (carbon sequestration). Materials provided 'free of charge'

by ecosystems are important for local livelihoods and for the manufacturing of products that people in other communities like to purchase.

The MEA categorised ecosystem services as provisioning, regulating, cultural, and supporting (which sustains the other three types) (Fig. 1). Freshwater ecosystems (rivers and wetlands), and associated flows in particular, provide a broad range of services: clean drinking water, protein (fish/shrimp, crabs), fertile land for flood-recession agriculture and grazing, populations of wildlife for harvest, growing vegetables and fruit, fibre/organic raw material, medicinal plants, inorganic raw material, flood mitigation, and disease control (see Values chapter, Table. 4 for more examples). Provisioning services are the most clearly recognisable of all the types of services, because they provide direct products people can use. Regulation services, by contrast, are more easily overlooked, but are equally vital: natural purification processes in wetlands and river ecosystems contribute to maintenance of clean water; evaporating and infiltrating water are part of the natural patterns of rainfall and discharge. Cultural services, including sites of scenic beauty valued for recreation or sites for traditional ceremonies, are also important, although they are less tangible by comparison.



Photo: Jakob Gramit, STWI

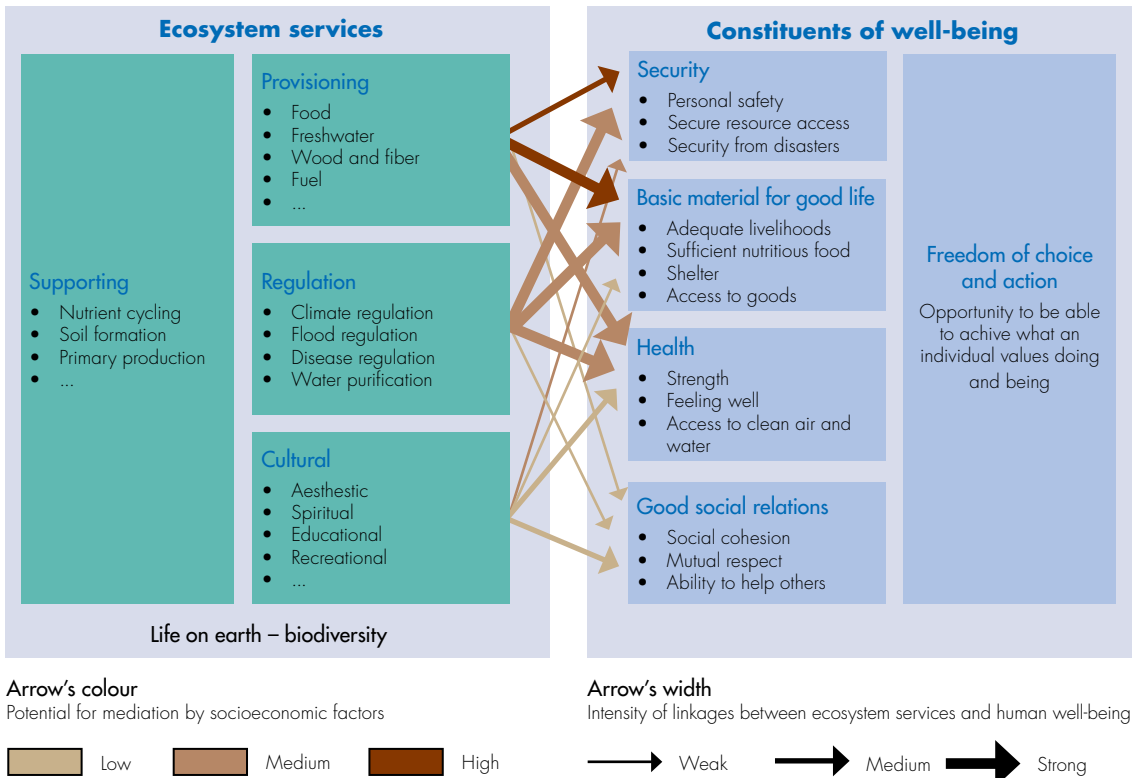


Figure 1. Links between ecosystem services and various constituents of human well-being. Adapted from Millennium Ecosystem Assessment, 2005.

Human well-being is a somewhat ambiguous term. It encompasses “everything important in a person’s life” ranging from basic elements required for human survival (food, water, shelter), to the highest level achievement of personal goals and spiritual fulfilment (Maslow, 1954). The MEA defines the links between human well-being and ecosystem services in terms of security, basic material for a good life, health and good social relations. These four constituents contribute to an ultimate human well-being benefit of “freedom of choice and action”. The width of arrows in the MEA diagram indicate the relative importance of provisioning, regulating and cultural ecosystem services to the four well-being groups (Fig.1). For example, provision of water, flood and disease regulation are most connected to ensuring basic materials for a good life, health and security.

Human well-being is dependent upon not one, but multiple and often interrelated, ecosystem services. For example, the basic material for a good life is largely based on provisioning services – yet other types of income generation, such as recession agriculture (cultivation in floodplain areas after flood recession), depend more on soil moisture and

the sediments deposited during flooding – which are part of both regulating and provisioning services. Security from natural hazards has a strong link with regulation services. In addition, human health can relate to the purification and waste processing that are part of the regulation services, but health also links to provisioning services for drinking water and food, and to the cultural services that are important for mental well-being. Income and food are required to maintain health and to buy medicines, while at the same time health is required to generate an income and to collect, grow or buy food products. Income may also be required to participate in social activities, without which families may become isolated, leading to mental well-being problems. The interconnectedness of the well-being components stresses the importance of sustaining all of the ecosystem services.

The connections between well-being components may be especially relevant for the poor, who often depend more directly on ecosystem products for their subsistence and employment, without health-insurance. For those most dependent on ecosystem services, the loss of those services triggers a vicious cycle of impoverishment. Poverty is defined

by the World Development Report (World Bank 2001) as the pronounced deprivation of well-being and has many different dimensions. How poverty is experienced and expressed depends on the situation (e.g. physical, social and personal) and factors such as geography, environment, age and gender. Ecosystems and the services they provide play an important role in helping to supply what is needed by those who are impoverished (MEA 2005). Poor communities depend most on services provided by ecosystems and may therefore be hit hardest when ecosystems degrade (Silvius *et al.*, 2000; Mainka *et al.*, 2005).

**Ecosystem services and human well-being components depend on the flow regime**

Given that ecosystem services are critical for human well-being, we need to understand the components and characteristics of ecosystems that determine how, where and when services are provided and sustained over time. For river and

wetland ecosystems, the flow regime is the most important determinant, referring to the magnitude, frequency, duration, timing, and rate of change of river flows (Poff *et al.*, 1997). Various flow features can be linked to different responses in ecosystem components and overall ecosystem function, which help us understand how to manage flow. Flow features manifest largely as regional patterns that are determined by river size, geology, climate variation, topography and vegetation cover. Seasonality may influence flow pattern fluctuations – minimal seasonality in precipitation produces streams that are relatively stable, while high seasonal precipitation can result in large flow fluctuations. Bunn and Arthington (2002) highlighted four different principles that demonstrate how the flow regime is the key driver of processes that sustain river and floodplain biodiversity (Fig. 2).

The different components of an environmental flow regime contribute to different ecological processes (Postel & Richter 2003, Tab. 1). For example, the low base flow maintains

**Aquatic biodiversity and natural flow regimes**

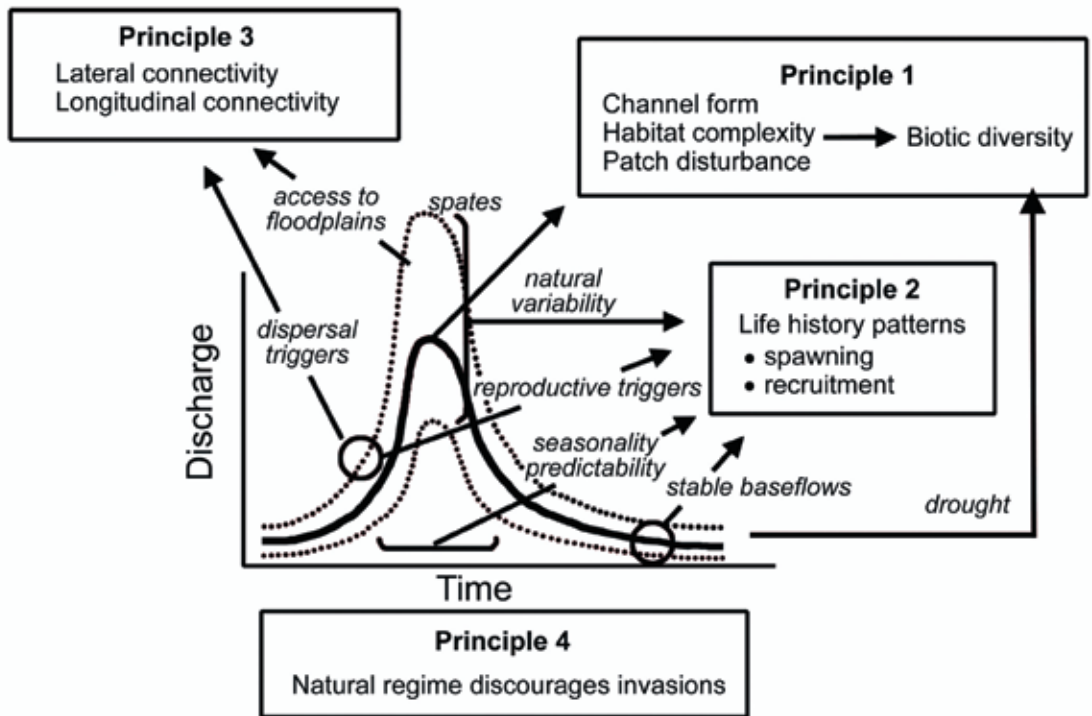


Figure 2. The four principles of how the flow regime is the key driver of river and floodplain ecosystems: 1) the flow regime is the dominant factor to determine the habitats in a river and surrounding freshwater ecosystems which in turn will determine the composition of species; 2) aquatic species have developed life history strategies in response to the natural flow regime; 3) maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species; 4) the invasion and successes of exotic and introduced species in rivers is facilitated by the alteration of flow regime. Source: Bunn and Arthington, 2002.

**Table 1: Ecological functions supported by different river flow levels**

<b>Low (base) flows</b>	<p><b>Normal level:</b></p> <ul style="list-style-type: none"> <li>• Provide adequate habitat for aquatic organisms</li> <li>• Maintain suitable water temperatures, dissolved oxygen, and water chemistry</li> <li>• Maintain water table levels in the floodplain and soil moisture for plants</li> <li>• Provide drinking water for terrestrial animals</li> <li>• Keep fish and amphibian eggs suspended</li> <li>• Enable fish to move to feeding and spawning areas</li> <li>• Support hyporheic organisms (those living in saturated sediments)</li> </ul> <p><b>Drought level:</b></p> <ul style="list-style-type: none"> <li>• Enable recruitment of certain floodplain plants</li> <li>• Purge invasive introduced species from aquatic and riparian communities</li> <li>• Concentrate prey into limited areas to benefit predators</li> </ul>
<b>High pulse flows</b>	<ul style="list-style-type: none"> <li>• Shape physical character of river channel, including pools and riffles</li> <li>• Determine size of stream bed substrates (sand, gravel, and cobble)</li> <li>• Prevent riparian vegetation from encroaching into channel</li> <li>• Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants</li> <li>• Aerate eggs in spawning gravels and prevent siltation</li> <li>• Maintain suitable salinity conditions in estuaries</li> </ul>
<b>Large floods</b>	<ul style="list-style-type: none"> <li>• Provide migration and spawning cues for fish</li> <li>• Trigger new phase in life cycle (e.g. in insects)</li> <li>• Enable fish to spawn on floodplain, provide nursery area for juvenile fish</li> <li>• Provide new feeding opportunities for fish and waterfowl</li> <li>• Recharge floodplain water table</li> <li>• Maintain diversity in floodplain forest types through prolonged inundation (different plant species have different tolerance)</li> <li>• Control distribution and abundance of plants on floodplains</li> <li>• Deposit nutrients on floodplain</li> <li>• Deposit gravel and cobbles in spawning areas</li> <li>• Flush organic materials (food) and woody debris (habitat structures) into channel</li> <li>• Purge invasive introduced species from aquatic riparian communities</li> <li>• Disperse seeds and fruits of riparian plant</li> <li>• Drive lateral movement of river channel, forming new habitats (secondary channels and oxbow lakes)</li> <li>• Provide plant seedlings with prolonged access to soil moisture</li> </ul>

*Modified from Postel & Richter, 2003.*

water table levels in the floodplain and soil moisture for plants. It also provides drinking water for terrestrial animals. High pulse flows will shape the character of river channels and large floods will recharge floodplain aquifers.

### **Flows, provisioning services and basic materials for good life**

An environmental flow regime supports a particular range of provisioning services such as clean water, plants, build-

ing materials and food (Tab. 2, case study 1). The most important product derived from inland waters in terms of human nutrition are fish and fishery products. Inland fisheries in developing countries may provide the only source of animal protein for rural people (Welcomme *et al.* 2006). The life cycle of many fish species is heavily dependent on the natural variability in river flows, e.g. large floods are important for fish migration and spawning in floodplain rivers. Recession agriculture is also heavily dependent on the

**Table 2. Links between ecosystem services, ecological processes supported by the flow regime and human well-being**

<b>Ecosystem services</b>	<b>Human well-being</b>	<b>Environmental flow component and ecological processes</b>
<b>Provisioning</b>		
The flow regime supports the delivery of a range of different provisioning services such as clean water, plants, building materials and food	Basic material for good life	Fish supply: the life cycle of many fish species heavily depends on the natural variability in river flows e.g. large floods are important for fishes being able to migrate as well as spawn.  Medical plants, fruits: drought level enables recruitment of certain floodplain plants. Large floods disburse seeds and fruits of riparian plants.  Water supply: large floods recharge floodplain water tables.
<b>Regulating</b>		
The environmental flow regime helps controlling, pollution, pests and floods	Security, Health	Flood control: riparian vegetation stabilises river banks. Flows that maintain soil-moister levels in the banks as well as high flows to deposit nutrients and seeds on the bank will maintain riparian vegetation.  Pollution control: high pulse flows restores normal water quality conditions after prolonged low flows, flushing away waste products and pollutants  Pest control: a river with environmental flows is more resistant against the intrusion of exotic species. Damned, diverted and modified rivers that create permanent standing water and more constant flow regimes provide favorable environment for exotic species
<b>Cultural</b>		
Spiritual, recreational, aesthetic services	Good social relations	Sufficient flows to maximise aesthetics values and contribute to cultural services are an important component of the environmental flow regime.
<b>Supporting</b>		
Biodiversity, nutrient and sediment cycling	Basic material for good life, Security, Health, Good social relations	Large floods can maintain balance of species in aquatic and riparian communities. They can also maintain diversity in floodplain forest types through prolonged inundation (different plant species have different tolerance)

flow regime. Alterations of natural flow disrupt normal cycles of flooding in many areas and thus disrupt nutrient laden sediment influxes to floodplain agricultural areas (Postel & Richter 2003). Other crops, such as reeds, are becoming important sources for building materials. Reed-growing is undergoing a revival as a source of roofing materials and is a growing industry in countries such as the Netherlands (Ramsar 2001). Thatched roofs are superior insulators to conventional tile roofs, and they have a lifespan of 25-40

years. Reed is also being investigated as a possible source of renewable energy (Komulainen *et al.* 2008).

### **Flow, regulating services and human health and security**

An environmental flow regime also supports regulating ecosystem services, such as erosion, pollution, and flood and pest control. Riparian vegetation stabilises river banks, but riparian vegetation is dependent on different flow regimes

## Case study 1: Pangani

By Katharine Cross, International Union for the Conservation of Nature (IUCN)

The Pangani River Basin (PRB) covers an area of 43,650 km<sup>2</sup>, with a 5 percent of this area in Kenya and the remainder in Tanzania in the administrative regions of Arusha, Manyara, Kilimanjaro and Tanga (Figure 1).

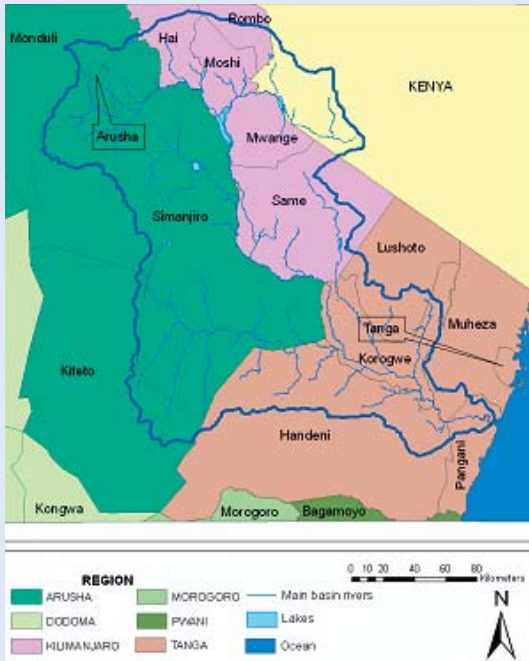


Figure 1. The Pangani River Basin in relation to administrative boundaries in north-eastern Tanzania.

### Description

The Pangani River Basin Flow Assessment Initiative (FA) is an IUCN-Pangani Basin Water Office (PBWO) initiative that brings together a national team of specialists from a range of river-related, water-allocation and policy-making disciplines, and an international team of flow-assessment specialists from Southern Waters Ecological Research and Consulting and Anchor Environmental Consultants. Their task is to develop an understanding of the hydrology of the Pangani River Basin, the nature and functioning of the river system and the links between the river and the social and economic value of its resources.

Mount Kilimanjaro is the most important hydrological feature within the PRB. Rainfall on the mountain provides a large portion of inflow to the Numba ya Munga Reservoir and surface water. Rainfall is unevenly distributed; the high-

lands receive a larger amount (1200-2000 mm annually) than the lowlands (as little as 500 mm annually). Additional sources of water are springs and groundwater.

Most of the communities within the PRB depend on agriculture for subsistence and employment. Forestry, wildlife and fisheries are relatively minor activities within the basin in terms of their economic contribution, although fisheries are an important source of income and food locally. Mining and hydropower production are important outputs of the basin.

The largest user of surface water is irrigated agriculture, but urban and industrial uses and hydropower are also major users. Water that remains in the environment generates aquatic ecosystem goods and services. Households living near aquatic ecosystems harvest a variety of resources, the most important being fish.

### Ecosystem services

Ecological processes that support ecosystem services include floods that improve water quality, upstream migration of fish and germination of plants. There are also floods that inundate wetlands and floodplains, deposit sediment to improve soil fertility, and flush sediment and debris from the channel. Changes in flow variability create conditions where exotic plants proliferate, fish populations decrease and natural vegetation is lost. The flow regime is also important to maintain ecological processes in the estuary. A reduction in mean annual run-off, floods and the seasonality of freshwater flows has impacted sediment transport to the estuary and has resulted in a reduction in water quality due to a decrease in dissolved oxygen and an increase in inorganic nutrients. Changes in flows have had a serious negative impact on the abundance and diversity of fauna and flora in the system, including aquatic resources that are used for livelihoods. The aquatic resources in the PRB also provide non-consumptive use value such as recreation and tourism. In addition, the aquatic ecosystems have option and existence value, which affect the present and future well-being of society in general.

Many households across the Basin depend on river systems for washing their clothes. Over 20 percent of households interviewed stated that river systems were

also significantly important for recreational activities such as swimming, resting and socialising. Spiritual and religious use of the river system was especially important for Muslim households as rivers and lakes were essential for washing before attending mosque. Thus water quality would be expected to be of particular significance to these households.

The Pangani River Basin Flow Assessment Initiative concentrated only on the direct value of water and aquatic natural resources to rural households in the basin. An estimate of the value of aquatic ecosystems to rural households living within a few kilometres of the Pangani River system was determined. A total of 75 percent of rural households in the basin are within 10 km of major rivers, and 47 percent are within 5 km. The total direct consumptive use value of

the basin's aquatic ecosystem resources was estimated to be between Tshs 8.7 billion and 11.9 billion (USD 7–10 million) per year. The study found that the value provided by aquatic resources had already decreased due to changes in the river system. About 58 percent of this value (Tshs 5.0 billion – 7.3 billion) was attributed to fishing.

Aquatic resources, such as fisheries, act as a safety net by providing a means of survival for households during times of economic vulnerability such as loss of employment or death of a breadwinner. Natural resources also provide a risk buffer for poor households that are vulnerable to crop failures due to rainfall variation, or other risks such as food shortages before the main harvests. The study noted that the income from aquatic ecosystems actually exceeded the social welfare that is received in the form of pensions.

**Table 1. Household income from aquatic resources in different parts of the Pangani Basin**

Zone	Household income (Tsh/y)	Income from river resources	% from river resources
Northern Highlands	2 718 901	20 363	0.7%
Eastern Highlands	2 189 378	70 485	3.2%
Lake areas	2 728 343	563 966	20.7%
Pangani-Kirua	2 593 301	43 584	1.7%
Mesic Lowlands	1 878 795	46 309	2.5%
Estuary	2 965 828	233 574	7.9%

Source: PBWO/IUCN, 2007b



Photo: Manfred Matz





such as large floods for dispersal of seeds and fruits. The construction of dams stabilises flows and captures sediment, thereby threatening many estuaries and coastal wetlands. The loss and degradation of freshwater ecosystems reduce the natural ability to buffer the impacts of floods and threaten the security of individuals and communities. The loss of mangroves and other natural barriers played a key role in the devastating effects of Hurricane Katarina and the tsunami in southern Asia in December 2004 (Costanza & Farley 2007). Coastal wetlands, marshes and islands in the Mississippi delta previously provide protection from storms. The sea has steadily eroded and now these features have been lost during the last decades, mainly because large dams in the Missouri and Mississippi Rivers have altered the flow regime and reduced sediment input to the delta. Efforts to replant the mangrove forest, through community planting programmes, and timber donations for rebuilding Aceh, one of the areas worst hit by the southern Asia tsunami, help rebuild that storm buffer. The magnitude and severity of storm surges are expected to grow with climate change, further emphasising the need for natural buffers to protect coastal zones (IPCC 2007a).

Moreover, an environmental flow regime may control pests and the invasion of exotic species (Bunn & Arthington 2002). For example, flows can be set to prevent or treat nuisance algal blooms (Maier *et al.* 2001). About one third of the world's population lives in areas where biodiversity and diversity and magnitude of ecosystem services tend to be concentrated (Turner *et al.* 2007). In spite of the value of these areas for people in terms of services, they also are tropical and sub-tropical, where disease risk due to vector-borne diseases is high. An altered flow regime changes the biodiversity and can favour species being vectors for diseases such as malaria and schistosomiasis (case study 2). Change of flow regime that has caused favourable conditions for species introductions is also one of the largest drivers of species extinctions (Postel & Richter 2003).

The presence of water also regulates the local climate and prevents dust. Almost 17 tons per hectare per year of dust polluted with pesticides are blown off the dried portions of the Aral Sea in Eastern Turkmenistan (O'Hara *et al.*, 2000, Bennion *et al.*, 2007). In the Sistan Inland Delta of Iran people reportedly suffer from both physical and mental health problems due to the hot dusty climate and the constant sandstorms that took place when the wetland area was dry for almost seven years. When the wetland area was inundated, the same winds brought comfort in the form of refreshing water droplets blown over the villages (Meijer & Hajjiamiri, 2007).

### Flows, cultural services and good social relations

*"What makes a river so restful to people is that it doesn't have any doubt – it is sure to get where it is going, and it doesn't want to go anywhere else."*

Hal Boyle, Pulitzer prize-winning columnist

Rivers are often iconic, having not only aesthetic values but also religious, historical or archaeological values central to a nation's heritage. There are numerous examples from around the world where tribal people and local communities live in close relationship with their river. In India, the flow of the River Ganges has an important place in Hindu mythology and river communities have a close link to the river. In the Sistan Inland Delta of Eastern Iran, the Hirmand River provides water to flood 500,000 ha of land, and establishes an oasis in a desert region (case study 3). Local people enjoy their New Year ceremonies along the shores of the wetland. The presence of large reed areas and birds is highly valued by the local population as a background to their festivities (Meijer & Hajjiamiri, 2007). Bird watching, salmon fishing and white water rafting are some of the many recreational activities linked to rivers, streams and lakes.



Photo: Anton Earl, SIWI

## Case study 2. Environmental flows and disease prevention: Snail borne diseases as an example

By Thomas Krogsgaard Kristensen, University of Copenhagen

### Background

For the last 50 years dam construction has been a major cause of environmental degradation, including biodiversity loss and an increase in infectious diseases throughout the world. In many parts of the world dam-building promotes the propagation of pulmonate snails, the intermediate hosts for schistosomiasis, a debilitating disease more than 200 million people suffer from.

Dam construction often reduce flow variability. A more constant flow results in reduced habitat diversity and consequently reduced and/or altered biodiversity along the river. Some downstream habitats may depend on seasonal flooding, and there is little or no specific information on how lack of flooding would affect the diversity of snail communities, let alone the potential impact on human health.

### Examples

*Akasombo Dam, Lake Volta and Kpong Dam Volta River*  
Akasombo Dam was one of the first large dams in Africa, which was finished in 1964. After filling, which was finalised in 1966, the schistosome intermediate host snail *Bulinus truncatus* flourished and a heavy increase in schistosomiasis prevalence occurred in the local human population.

Before construction of the dam, schistosomiasis was present to some extent in the northern part of the lake, as *S. haematobium* is borne by the local *Bulinus* snail species *B. globosus*. After the filling of the lake, the fishermen from the south in the delta of the river Volta were attracted by the numerous fish in the lake and moved there. They were naturally infected with another *S. haematobium* borne by *Bulinus truncatus*. Humans and their fishing gear transported both parasite and snail by accident to the lake. The snail became well established and the parasite attacked the original inhabitants, causing a severe outbreak of schistosomiasis during the next decades. Prevalence went from 1-2 percent to 80-90 percent. One of the reasons for the success of *Bulinus truncatus* in establishing in Lake Volta is its capacity to tolerate the high water level differences in the lake (Rosenfield, 1979).

Thirty miles down the River Volta from the Akasombo Dam, the Kpong Dam was constructed, which is much smaller than the Volta Dam. The same thing happened in this dam, but even worse, because here no water level change took place and another schistosomiasis snail, *Biomphalaria pfeifferi*, had good conditions for becoming established. This species is the intermediate host for

intestinal schistosomiasis. Thus construction of the dams, disturbing the natural biodiversity, led to a severe outbreak of a serious disease.

#### *The Three Gorges Dam, China.*

The construction of the Three Gorges Dam in the upper reaches of the Yangtze River is a major project aimed at speeding economic development in China, amongst other benefits through better use of water sources and reduction in flood damage during the wet season. This project was initiated in 1993, began to generate electricity in 2003, and is scheduled for completion in 2009.

The development of the Three Gorges Dam will also increase the extent of marshlands and irrigation in areas currently free of schistosomiasis. In studies carried out in the Three Gorges Reservoir region, He *et al.* (1999) confirmed that no *Oncomelania* snail existed in the reservoir region. However, this region is similar to the snail's endemic region in terms of climate regime, soil type and identical plants to serve as food. It is difficult to explain why no snails have existed in the region previously. Yang *et al.* (1998) explained this as due to arid soil and lack of irrigation systems. Yang also proposed that along with economic development, improvement of water conservancy facilities, transformation of cultivated farmland and management of soil erosion during construction of the Three Gorges Reservoir, snail habitats would be inevitably extended. The potential for the spread of schistosomiasis into these new areas is a major concern, and there is a continuing need to develop new ways to monitor the situation in the Three Gorges Reservoir region and downstream of the Yangtze River during and after the construction of the Three Gorges Dam. The Department of Water Conservancy predicts that after the Three Gorges project is built the sedimentation of silts will cause some back-water islets of the reservoir to form after 10 to 14 years. 60 islets will be formed after 30 years, and 27 large islets with an area of 34 square kilometers will appear at the end of 100 years. The three types of snail habitats that will be formed after the dam is built will consist of 1) sedimentation areas near the highest water-level, 2) sedimentation areas above the designed water level and under the flooding level and 3) the areas created by soil modification projects and poorly executed irrigation projects.

Implementation of a GIS model system to manage spatial data on the drainage network, land use, infection sources and population centres may provide a practical

way of predicting future problem areas. Hydrological models can be of particular importance in assessing future environmental risk. Zhou *et al.* (1998) have demonstrated that the potential snail areas after flooding can be predicted by analysis of time-difference satellite images using snail distribution models. Thus scientists are keen to apply GIS and remote sensing technologies to the monitoring process owing to the easier and faster approach of GIS.

#### **Biodiversity and health considerations in irrigation schemes Sudan**

Owing to the continuing increase in human population and the ensuing demands on energy and food, construction of hydroelectric dams and large irrigation schemes, is likely to increase. Obviously, these schemes have beneficial effects in increasing food and energy security, but there are numerous examples that they also have resulted in an increased transmission of schistosomiasis and other water-related diseases.

Strictly speaking, biodiversity changes induced by the establishment of irrigation schemes are difficult to describe, because this leads to conversion of arid land into a sys-



*Melanoides sp.*



*Biomphalaria* shedding parasite larvae.



tem of irrigation canals suitable as habitats for freshwater gastropods. Comparisons with the existing snail fauna in the river systems feeding irrigation schemes are also not valid because the physical characteristics are so different. However, anthropogenic influences in the scheme makes the canals appear to have rather low species diversity with a few highly dominant species (usually the schistosome intermediate hosts). The anthropogenic influences that are important in irrigation schemes are related to canal maintenance, such as desilting and removal of aquatic macrophytes, and to agricultural activities, such as use of fertilisers and pesticides. Other features that make irrigation canals excellent habitats for schistosome intermediate hosts are related to design and management of the system. In addition to the storage of water at the dam, most if not all irrigation systems require a system of water storage within the scheme, either in the form of storage ponds or by over-dimensioning of canals. Health problems are often related to this water storage within the irrigation system, as these water bodies constitute excellent habitats for the intermediate host snails.

#### **Example: Gezira-Managil scheme, Sudan**

The Gezira irrigation scheme started in 1924 and the Managil extension opened in 1963 (Gaddal 1985). The prevalence of intestinal schistosomiasis is high in the Gezira Agricultural Scheme, while that of urinary

schistosomiasis is variable but generally low (Gaddal 1985). *Biomphalaria pfeifferi* and *Bulinus truncatus* are very abundant and all types of canals in these irrigation schemes may harbour populations of the intermediate hosts of schistosomes (Madsen *et al.* 1988). Minor canals are the most important transmission sites as snail densities are generally high and most of the human water contact takes place in these canals. Minor canals are used for water storage within the scheme and this makes these canals very suitable as snail habitats. Snail density varies greatly among sites and is highly dependent upon specific conditions in the site, especially composition and density of the aquatic macrophyte flora and activities related to agriculture and canal maintenance. There is no clear association between occurrence of snails and human water contact activity. However, there is such an association between occurrence of infected snails and human water contact (Babiker *et al.* 1985). The gastropod fauna is highly dominated by the two species of intermediate hosts. These species are more strategic than the prosobranch snails in the scheme. Hence they are likely to recover quickly from the various influences resulting from canal maintenance or agriculture. There are indications that snail distribution patterns now are changing in the scheme. The reasons for this could be related to changed pattern of water usage and possibly introduction of new pesticides or schemes for their application.

### Case study 3: Hamoun wetlands Iran

By Karen Meijer, *Deltares*

The description of this case study is based on Meijer & Hajiamiri (2007).

#### Summary

The Sistan Inland Delta is the Iranian part of the Hirmand River Basin, and represents the downstream 5 percent of the total catchment area of 150,000 km<sup>2</sup>. The Sistan Inland Delta is bordered by the Hamoun wetlands, which can extend up to 500,000 ha in wet conditions.



Figure 1. Location of Sistan Inland Delta and Hamoun wetlands (source: Meijer & Hajiamiri, 2007).

#### Description

The Sistan inland Delta has low local precipitation (60 mm/year) and depends largely on inflows from Afghanistan (5,000 Mm<sup>3</sup>/year from the Hirmand rivers, and another 2,500 Mm<sup>3</sup>/year from other rivers). Water from the Hirmand river is stored in the Chahmimneh reservoirs (total capacity 800 Mm<sup>3</sup>), and is used to irrigate 120,000 ha of land. What is left enters the Hamoun wetland system, consisting of three separate wetlands: Hamoun-e-Puzak, Hamoun-e-Saberi and Hamoun-e-Hirmand, which are connected at high water levels. High discharges causes

the Hamouns to spill over into a small river that ends up in a salt lake. Due to this regular spilling the Hamoun wetlands system remains a freshwater system. When in a healthy state, the wetlands contain vast areas of reeds, and provide habitat for large amounts of birds and fish. 60,000 ha of the area is designated as Ramsar sites, but are currently included in the Montreux Record of threatened wetlands.

The area holds around 70,000 households. Around 20 percent depends for a large part (>70 percent) of their income on services provided by the Hamoun wetlands (fishing, bird catching, reed harvesting and livestock herding). Of the other 80 percent of the population depends around 50 percent depends on irrigation and the other 50 percent has a not-water-related profession in the city.

The Sistan Inland Delta is located in a very hot and dry part of Iran. Without the wetland system, the area would be a desert. In fact, during a seven year drought (1998-2005), the wetlands dried out and strong winds caused dust and sand to be blown into the inhabited area of the delta. Moreover, the air cooling service, that had resulted from lake evaporation and the spread of water droplets over the area, was lost.

#### Ecosystem services:

The wetlands provide provisioning, regulating and cultural services for the people living in the area. The main provisioning services are fish, birds and reeds. The wetlands provide a regulation function through the protection against sand storms and the cooling and moisturising of the air, which is in the opinion of the population important for their physical and mental health. Cultural services consist of providing the site for New-Year picnics, and people mainly enjoy the sight of water, reeds and birds.

The main processes that sustain the ecosystem services relate to flooding of the wetland area, of which a number of parameters were identified as important:

- The frequency of 'spilling' of the wetland into a downstream salt lake in order to maintain a freshwater system, which is important to sustain fish species and reed vegetation

- The timing and extent of spring floods, to support the growing/breeding season of birds, fish and reeds
- The inundated area available in fall, mainly to support migratory birds
- The inundated area available from May till September in Hamoun-e-Saberi, this does not have an ecological function, but is meant to reduce the risk of sandstorms in the season with strong winds and moisturise and cool the hot, dry air.

#### Human well-being:

Based on the above mentioned parameters and a model of the water resources system, the change in availability of ecosystem services assessed. This change was further translated into changes in three constituents of well-being: 1) income & food, 2) (physical) health, and 3) perception & experience of the surrounding environment, for various population groups, based on group discussion and interviews with these groups.

This change in human well-being was assessed for various water management options, such as a change in irrigated area and provided and additional criteria for decision-making in water resources management in the area. The results of the water resources modelling and

the assessment of the various strategies can be found in Meijer & Hajiamiri (2007).

Because of their dependence on ecosystem services, the livelihood of the bird catchers, fisherman, reed harvesters and pastoralists is expected to improve when a smaller area is irrigated. Consequently, the income of farmers will decrease. All people in the area will benefit from the reduced sandstorms and cooling of the air when more water is available in the wetlands, and will enjoy the natural area for recreation and festivities.

The assessment discussed above was based on an initial study and contains uncertainties in the relationship between the condition of ecosystems flows and human well-being. This should be further investigated to find the most suitable management options. This initial assessment shows the importance of the Hamoun wetlands for the local population and demonstrates that changes in management will affect stakeholder groups differently.

#### References

Meijer, K. S.& S. Hajiamiri, 2007. Quantifying Well-Being Values of Environmental Flows for Equitable Decision-Making: A case study of the Hamoun wetlands in Iran, *Journal of River Basin Management*.



*Photo: Christina Ritzi*

# Economic Valuation of Environmental Flows

Modifications of natural systems cause a continuous decrease in the indirect benefits that they provide (e.g. hydrological functions, products and biodiversity are lost). At the same time, benefits from the highly managed system can increase (e.g. improved food production). The benefits from the highly managed systems can reach a plateau, but the benefits of the natural system will decline to zero at some point (Acreman 2001, fig 3). The total long term overall benefits can be calculated by adding the benefits of the natural and highly managed systems. The total rises to a maximum before declining. It is at this point that the balance between naturalness and level of management is optimised. The value that society places on various goods

and services and ethical considerations will determine the exact form of the curves. The perceived benefits will also vary between different groups and individuals. It is essential therefore that the costs and benefits to society of allocating water alternatively to maintain ecosystems and to support direct use in the form of agricultural, industrial and domestic uses are quantified.

As described in the previous section, ecosystems sustained by environmental flows underpin many aspects of human well-being. Nevertheless, ecosystems and the water needed to sustain them are often not considered in the management of water resources. This marginalisation of ecosystems in water resources management and the as-

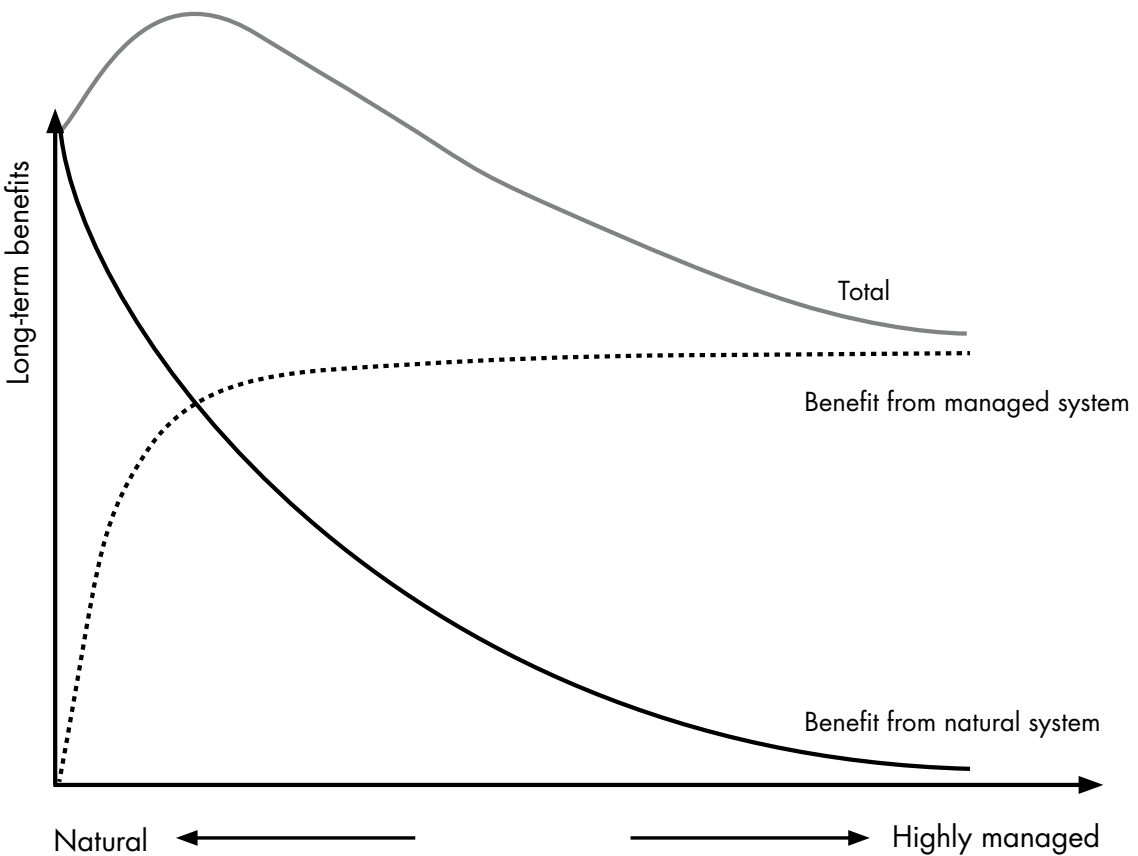


Figure 3. Modifications of natural systems continuously decrease the indirect benefits of the natural system (solid line). At the same time, benefits from the highly managed system increase (dashed line). It is suggested that the benefits from the highly managed systems reach a plateau, whilst the benefits of the natural system will decline to zero at some point. The total long term benefits can be calculated by adding the benefits of the natural and highly managed systems. The total rises to a maximum before declining. It is at this point that the balance between naturalness and level of management is optimised. Source: Acreman 2001.



Photo: Getty Images

sociated degradation or loss of ecosystem services, have resulted in economic costs, in terms of declining profits, remedial measures, damage repairs, cost of healthcare and in sick days missed at work due to poor health or the need to take care of a family member in poor health, and lost opportunities. The highest cost, however, is typically borne by the rural poor, who often depend on nature's services directly for their livelihoods (Emerton & Bos, 2005; MEA, 2005; Pearce *et al.*, 2006). Therefore, recognising the values of ecosystems, and investing in them accordingly, is central to achieving the MDGs and poverty alleviation as ecosystems will remain a vital lifeline for the poorest until these goals are met (Emerton & Bos, 2005).

Water users such as industry and agriculture can put a monetary value on their water use with relative ease and have well-developed methods to quantify and defend their dependence on these uses. These same users also often receive heavy subsidies or otherwise lower prices for water, to offset other costs of expansion and development. For example, in member countries of the Organisation for Economic Co-operation and Development (OECD), water pricing generally does not cover capital expenditures; in particular, irrigation can be subsidised by as much as 80 percent. The National Center for Environmental Economics within the US EPA reports that estimated irrigation water subsidies provided by the U.S. Bureau of Reclamation in selected areas ranged from 57 percent to 97 percent of the Bureau's full cost for water delivery. Excessive irrigation has been associated with a number of environmental problems, including water shortages and the contamination of water with natural pollutants and agricultural inputs (US EPA, 2008). The costs of maintaining ecosystem services and flows even

if known are rarely incorporated directly into water pricing. Nonetheless, water pricing could provide incentives for greater efficiency of use and protection of flows through policy and market reform to include ecosystem function and service protection.

As it is harder to quantify the value of ecosystem services and justify the need to provide water for environmental flows, ecosystems and people that depend on them for subsistence (particularly the rural poor) become a voiceless and often neglected group of water users. There is a need to identify and recognise the various services provided by ecosystems, and find ways to value these services so that actors representing environmental water needs can effectively negotiate investments and trade-offs with other water users.

Economic valuation of ecosystem services is one way of quantifying and justifying the benefits of ecosystem services and placing ecosystems on the water agenda (giving a voice to the voiceless). One study estimated the global economic value of water for drinking, washing, to grow food and for energy and industry, at USD 7.5 trillion a year (in 2008 dollars) – or around 15 percent of the total estimated value of the world's ecosystem services (Costanza *et al.* 1997). Other important services, such as food supply, flood control, purification of waste, and delivery of nutrient rich sediments to floodplains have been much more difficult to estimate (Baron *et al.* 2002; Postel & Richter 2003; Wallace *et al.* 2003). These figures are meant to be estimates, and have been hotly contested based on ethical, social and methodological issues, yet their importance lies in stimulating discussion about how ecosystem services and the environmental flows that sustain them can be compared to other water needs and incorporated into water, land use and development decision-making.



Such approaches are also appealing because they help reveal social and ecological costs or benefits that otherwise would remain hidden or unappreciated in assessing nonmarket ecosystem goods and services (Dorfman & Dorfman 1993; Freeman 1993; Costanza *et al.* 1997; Daily 1997; Turner *et al.* 2003; National Research Council 2005).

It is also necessary to consider how the benefits of water use are distributed in a society. Distributional effects are often hidden from gross economic values and national wealth statistics. For example, hydropower generation at the

Manantali dam in Mali has led to better electricity supplies to urban areas in Senegal, Mali and Mauritania; which has mostly benefited the urban elite. However, there has been little rural electrification and rural people have suffered loss of ecosystem services. This includes loss of fisheries, due to alterations to the river flow regime downstream from hydropower generation (Acreman, 1996). If these effects are not considered, economic development and attempts to reduce poverty may result in increasing inequalities and vulnerability among the poorest people (case study 4).

#### **Case study 4: Cambodia**

*By Tracy Farrell, Conservation International (CI)*

Watershed management in the Cardamom Mountains of Cambodia is creating opportunities for biodiversity conservation, drinking water and energy provision.

The Cardamom Mountains, found in the Southwestern corner of the Indo-Burma hotspot, are highly biodiverse, offer a range of forest and water-related services for people. Yet they are under significant threat from mining, deforestation and hydropower development. The network of rivers flowing through the Cardamoms is expected to supply up to 50 percent of Cambodia's energy needs by 2020, providing electricity to remote communities, through billions of dollars of investments which are already underway. In addition, the highlands provide drinking water to approximately 3,500 villages and towns located on the agricultural plains that surround the Greater Cardamom Highlands where tens of thousands of small farmers rely on surface water to irrigate crops.

CI is working with the Cambodian government and other partners to promote the adoption of an integrated watershed management plan for the region which will meet multiple needs of biodiversity conservation, energy generation and drinking water provision. One project is in the Areng Valley, which is home to a terrestrial ecosystem characterised by high biodiversity and a watershed with several endemic and endangered species. The Valley is also home to one of only two Khmer Daeum communities, an ethnic group that roughly translates as Ancestral Khmer. The residents of this valley were displaced during the Cambodian holocaust and had only recently returned to their ancestral home. Research of the valley's irreplaceable biodiversity, influenced the Japan International Cooperation Agency to give a proposed dam project a low environmental score,

which led to its exclusion from the priority list of hydropower facilities. CI is also helping the Khmer Daeum to reconstruct their traditional livelihoods based on paddy rice on the fertile soils of the valley bottom and the sustainable exploitation of forest products. If the Cambodian government continues to see success from this project over the next five years, the decision not to build the dam will likely be upheld.

CI is also demonstrating the link between forest conservation, sedimentation rates in rivers, and the economic lifespan of multi-billion dollar dam investments. This analysis is applied to seek payments for watershed conservation. Improved access to electricity brings settlement from non traditional groups. The resulting deforestation increases sedimentation rates and reduces water storage capacity in the six reservoirs that have been approved and the four additional facilities identified for fast track development. This reduced capacity will impact electricity generation during periodic droughts linked to the El Niño phenomenon. Eventually, the capacity of the reservoirs will be reduced to the point of unprofitability and the turbines will be shut down. The economic lifespan of a reservoir can vary greatly from as little as 50 years (2 percent sedimentation rate) to more than 1000 years (0.1 percent) – if watershed management is effective. Watershed management required to maintain sufficient energy yields from avoided sedimentation, was translated into hydropower company fees of USD 300,000-500,000 per year, over a thirty year period as part of a concession. This modest investment could be further leveraged with revenues from carbon credits generated by reducing emissions from deforestation and forest degradation to provide additional revenues for regional development.

Economic valuation of ecosystem services can help identify costs and benefits. But it cannot be the sole factor when it comes to negotiating trade-offs and management options in IWRM. Economic valuation must be placed in a broader decision-making context that can include non-commensurate values and societal priorities. Several multi-criteria decision support systems exist, and economic valuation is an important, although not exclusive, part of these water management trade-off tools. The various terms and methods to describe and quantify the value of environment goods and services are described below.

### Total economic value

The values associated with ecosystems can be divided into two types: use and non-use (or passive-use) values. Most of these values can be translated in to economic units to constitute the total economic value (TEV) of ecosystems. TEV of ecosystems can be divided into five categories (Fig. 4): Direct and indirect use, option, bequest (incl. altruism) and existence (Turner *et al.*, 1994). Direct use values are associated with direct use of ecosystem services, such as drinking water, transportation, electricity generation, pollution disposal, and irrigation, fishing, hunting and swimming. Indirect use values refer to services like flood mitigation and carbon sequestration, biodiversity, support for terrestrial and estuarine ecosystems, habitat for plant and animal life that are not directly consumed, but still create benefits to the current generation. The value of preserving an ecosystem for potential future use by the current generation is termed option value. Non-use values comprise bequest value and existence value. Bequest value is the value that the current

generation places on preserving ecosystems for coming generations. The current generation may appreciate the very existence of certain ecosystem assets, such as the blue whale, without any intentions of ever using it (e.g. for recreation). This non-use value is captured by existence value.

In many cases there are significant trade-offs between various human uses of ecosystem services, for example electricity generation and supporting habitat for valuable food sources. In environmental flow assessments, it is important to recognise the value of all ecosystem services and the various opportunity costs and trade-offs that exist between them.

### Economic valuation of ecosystem services

Economic valuation of ecosystem services aims at quantifying the contribution of ecosystem services to human well-being. This is done by measuring or inferring trade-offs and human preferences. A suite of methods exists to put a monetary value on ecosystem services that can be incorporated into methods for environmental flow assessments (Turner *et al.* 1994; Emerton & Bos 2005; Pearce *et al.* 2006). Table 3 gives a brief overview of the most commonly used methods. Data requirements and other shortcomings of the various approaches can appear daunting. However, each method has the potential to raise awareness about the roles and values of ecosystem services – and the environmental flows that sustain them for human well-being.

Various studies have attempted to value ecosystem services. Table 4 shows the results of a recent review of valuation of aquatic ecosystems. The values in Table 4 show a considerable scatter. This is to be expected as values

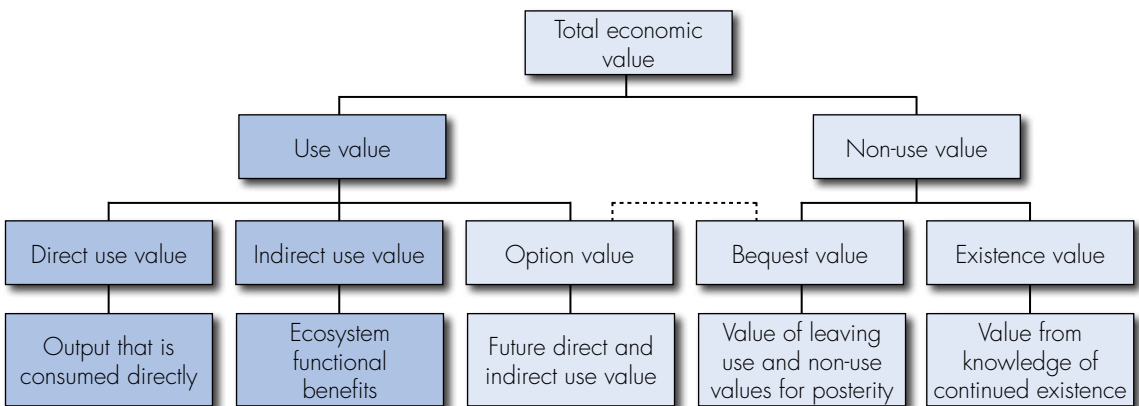


Figure 4. Total Economic Value (TEV) comprising several use and non-use values. Source: Turner *et al.*, 1994.

**Table 3 Summary of valuation methods. ES – Ecosystem Service.**

Method		Approach	Application	Data requirement	Main limitations
Revealed preference (actual behaviour)	Market prices (MP)	Market prices	Marketable products	Low	Imperfect and inaccessible markets
	Hedonic pricing (HP)	Effect of ES on price of other goods	Scenic beauty	High	Assumes freedom to select, difficult to isolate effect of ES
	Travel cost (TC)	Demand curve based on actual travel cost	Recreation	Medium	Multiple destinations, people in the vicinity may place high value
Stated preference (behavioural intentions)	Contingent valuation (CV)	Willingness to pay (WTP) or Willingness to accept (WTA)	Any ES	High	Many biases, difficult to use in a subsistence context
	Choice experiments	Preferred scenario	Any ES	High	Same as above
Non-demand curve approaches	Dose response (DR)	Effect of ES on production of other goods and services	Any ES	Medium	Lack of knowledge about relationship between ES and production
	Replacement cost (RC)	Cost of replacing lost ES	Any ES	Medium/ Low	Imperfect or unfeasible replacements
	Mitigative expenditure (ME)	Cost of mitigating effects of lost ES	Any ES	Medium/ Low	Imperfect or unfeasible mitigations
	Damage cost avoided (DC)	Damage cost avoided by maintaining ES	Any ES	Medium/ Low	Lack of knowledge about links between ES and damage avoided
	Opportunity cost (OC)	Value of development that has replaced ES	Any ES	Low	Doesn't yield the full value, doesn't allow for different scenarios
	Benefit transfer (BF)	Transfers results of existing valuation studies	Any ES	Very low	Gives poor results if contexts differ

are inherently method and context specific. The temporal, socio-economic and spatial scales of the studies affect the resulting value. Also, different ecosystems provide different services. The total values depend on the type of ecosystem being valued. Despite this dissimilarity, the total values in the reviewed literature only varied with a factor of 100, in the interval from 30 to 3,000 USD/ha/yr.

### Payment for ecosystem services

When the value of ecosystem services (and thus environmental flows) for human well-being has been recognised, the concept of Payment for Ecosystem Services (PES) provides a promising opportunity to mobilise resources for environmental flows. PES is a mechanism through which beneficiaries pay for the ecosystem services they receive (case study 5). It

**Table 4 Economic values of aquatic ecosystem services reported in recent literature.**

Type of Value	Service provided	Valuation method	Net Economic Values reported in literature*		
			Global estimate (USD/ha/year)	Developing countries (USD/ha/year)	Developing countries (USD/capita/year)
Direct use	Water for people	MP	45 <sup>13</sup> , 2000-7500 <sup>32</sup>	150 <sup>5</sup> , 50 <sup>20</sup> , 400 <sup>26</sup>	10 <sup>1</sup> , 21 <sup>5</sup> , 1 <sup>20</sup>
	Fish/shrimp/crabs (non-recreational)	MP	20013	95 <sup>1</sup> , 6 <sup>2</sup> , 150 <sup>3</sup> , 160 <sup>4</sup> , 17 <sup>5</sup> , 550 <sup>9</sup> , 50 <sup>14</sup> , 750 <sup>23</sup> , 90 <sup>24</sup> , 80 <sup>27</sup> , 50 <sup>31</sup>	95 <sup>1</sup> , 25 <sup>2</sup> , 65 <sup>3</sup> , 80 <sup>4</sup> , 40 <sup>5</sup> , 30 <sup>9</sup> , 50 <sup>14</sup> , 10 <sup>24</sup> , 160 <sup>27</sup> , 50 <sup>31</sup>
	Fertile land for flood-recession agriculture and grazing	DR, MP	40-520 <sup>32</sup>	110 <sup>1</sup> , 10 <sup>2</sup> , 150 <sup>3</sup> , 2 <sup>4</sup> , 170 <sup>5</sup> , 3 <sup>8</sup> , 180 <sup>9</sup> , 9 <sup>14</sup> , 40 <sup>20</sup> , 10 <sup>26</sup> , 10 <sup>27</sup> , 370 <sup>31</sup>	70 <sup>1</sup> , 40 <sup>2</sup> , 52 <sup>3</sup> , 10 <sup>4</sup> , 14 <sup>5</sup> , 15 <sup>8</sup> , 9 <sup>9</sup> , 9 <sup>14</sup> , 30 <sup>20</sup> , 30 <sup>27</sup> , 80 <sup>31</sup>
	Wildlife (for food)	MP	40-520 <sup>32</sup>	0.02 <sup>2</sup> , 12 <sup>5</sup> , 2 <sup>27</sup> , 320 <sup>31</sup>	0.1 <sup>2</sup> , 50 <sup>5</sup> , 10 <sup>27</sup> , 70 <sup>31</sup>
	Vegetables and fruits	MP	40-470 <sup>32</sup>	1 <sup>3</sup> , 200 <sup>9</sup>	4 <sup>3</sup> , 11 <sup>9</sup>
	Fibre/organic raw material	MP	4513	30 <sup>1</sup> , 1 <sup>2</sup> , 40 <sup>3</sup> , 1 <sup>4</sup> , 3 <sup>5</sup> , 7 <sup>14</sup> , 15 <sup>26</sup> , 20 <sup>31</sup>	20 <sup>1</sup> , 4 <sup>2</sup> , 25 <sup>3</sup> , 4 <sup>4</sup> , 20 <sup>14</sup> , 5 <sup>31</sup>
	Medicine plants	MP		63	23
	Inorganic raw material	MP	25-160 <sup>32</sup>	0.1 <sup>2</sup>	12
Indirect use	Chemical water quality control (purification capacity)	RC, ME	300 <sup>13</sup> , 60-6700 <sup>32</sup>	620 <sup>1</sup> , 20 <sup>2</sup> , 1400 <sup>7</sup> , 40 <sup>9</sup> , 140 <sup>26</sup>	20 <sup>1</sup> , 50 <sup>2</sup> , 8 <sup>7</sup> , 2 <sup>9</sup>
	Physical water quality control	RC, ME			
	Flood mitigation	RC, ME, AC	460 <sup>13</sup> , 15-5500 <sup>32</sup>	1700 <sup>1</sup> , 2 <sup>2</sup> , 30 <sup>3</sup> , 90 <sup>8</sup> , 1400 <sup>9</sup> , 340 <sup>26</sup>	20 <sup>1</sup> , 2 <sup>2</sup> , 2 <sup>3</sup> , 370 <sup>8</sup> , 75 <sup>9</sup>
	Groundwater replenishment	RC, ME, AC		10 <sup>2</sup> , 90 <sup>20</sup> , 70 <sup>26</sup>	25 <sup>2</sup> , 30 <sup>20</sup>
	Health control	DC, DR			
	Pest control	RC, ME, AC			
	Erosion control	RC, ME, AC		120 <sup>3</sup> , 20 <sup>26</sup>	73
	Salinity control	RC, ME, AC			
Prevention of acid soil development	RC, ME, AC				

	Carbon "trapping" (sequestration)	AC	130-270 <sup>32</sup>	50 <sup>2</sup> , 2 <sup>3</sup> , 1300 <sup>8</sup> , 2000 <sup>14</sup> , 15 <sup>26</sup>	120 <sup>2</sup> , 1 <sup>3</sup> , 9000 <sup>8</sup> , 2000 <sup>14</sup>
	Microclimate stabilisation	AC		1026	
Potentially all (direct and indi- rect use, option, bequest and existence)	Recreation and tourism (incl. fish- ing and hunting)	TC, CV	990 <sup>13</sup> , 230- 3000 <sup>32</sup>	20 <sup>1</sup> , 260 <sup>14</sup> , 30 <sup>26</sup>	20 <sup>1</sup> , 1100 <sup>14</sup>
	Biodiversity conservation	DR, CV, BT		0.6 <sup>8</sup> , 3600 <sup>14</sup> , 30 <sup>26</sup>	2 <sup>8</sup> , 2 <sup>14</sup>
	Cultural/religi- ous/historical/ symbolic activities	CV, BT	30-1800 <sup>32</sup>	8026	
'Total' economic values			120-370 <sup>13</sup>	2600 <sup>1</sup> , 100 <sup>2</sup> , 340 <sup>3</sup> , 30 <sup>6</sup> , 350 <sup>5</sup> , 2400 <sup>9</sup> , 2900 <sup>14</sup> , 500 <sup>18</sup> , 50 <sup>19</sup> , 2000 <sup>21</sup> , 1800 <sup>23</sup> , 110 <sup>24</sup> , 700 <sup>25</sup> , 1100 <sup>26</sup> , 90 <sup>27</sup> , 230 <sup>28</sup> , 1200 <sup>29</sup> , 500 <sup>30</sup> , 760 <sup>31</sup>	150 <sup>1</sup> , 50 <sup>2</sup> , 30 <sup>3</sup> , 41 <sup>5</sup> , 45-76 <sup>6</sup> , 125 <sup>9</sup> , 90 <sup>14</sup> , 70 <sup>18</sup> , 10 <sup>24</sup> , 10 <sup>25</sup> , 200 <sup>27</sup> , 230 <sup>30</sup> , 200 <sup>31</sup>

<sup>1</sup>Emerton & Kekulandala (2002), <sup>2</sup>Turpie *et al.* (1999), <sup>3</sup>Emerton *et al.* (2002), <sup>4</sup>Iflikhar (2002), <sup>5</sup>Emerton (1994), <sup>6</sup>IUCN (2001), <sup>7</sup>Emerton *et al.* (1999), <sup>8</sup>Rosales *et al.* (2003), <sup>9</sup>Gerrard (2004), <sup>10</sup>De Groot (1992), <sup>11</sup>Kirkland (1988), <sup>12</sup>Thibodeau & Ostro (1981), <sup>13</sup>Schuyt & Brander (2004), <sup>14</sup>Busk (2002), <sup>15</sup>Chowdhury (2003), <sup>16</sup>Rogers *et al.* (1998), <sup>17</sup>Sadoff *et al.* (2003), <sup>18</sup>Karanja *et al.* (2001), <sup>19</sup>Seyam *et al.* (2001), <sup>20</sup>Acharya (2000), <sup>21</sup>Woodward & Wui (2001), <sup>22</sup>Brown (1991), <sup>23</sup>MRCS (1998), <sup>24</sup>Ringler & Cai (2003), <sup>25</sup>Pyo (2002), 2002, <sup>26</sup>Seild & Moraes (2000), <sup>27</sup>Schuyt & Jansen (1999), <sup>28</sup>Christensen (1982), <sup>29</sup>Sathirathai (1998), <sup>30</sup>Bann (1997), <sup>31</sup>Drew *et al.* (2005), <sup>32</sup>Costanza *et al.* (1997).

\* Note that 'per hectare' refers to the area providing the service and 'per capita' refers to the people benefiting from that service. Only for some services this corresponds to total area or total population. Total value, therefore, may not be equal to the sum of the individual values.

combines the approaches for valuing services, as discussed above, with a mechanism for providing incentives to people for the protection of that service. Examples of how these payment schemes are developed and how they can provide incentive to protect ecosystems and environmental flows are presented below in a series of case studies.

### Case study examples of payment for ecosystem services projects

The Catskills and Delaware watersheds provide New York City with 90 percent of the drinking water supply through a payment for watershed protection programme combined

with restoration efforts in the catchment. Protection of the watershed negated the need for a 4-6 billion dollar investment in upgrading water purification infrastructure (Isakson 2002). In this case, leveraging cost savings made possible a comprehensive plan to restore watershed function to provide clean water for people. Through political leadership, many landholders and other stakeholders were involved in creating and implementing the plan.

A project in Madagascar examined the opportunity cost of protecting high biodiversity areas. An analysis of land values, carbon sequestration potential, and water provision for rice farming were done for high biodiversity areas. This study found

that people were heavily reliant upon clean water flowing from high biodiversity areas not yet protected that were also of low land value. Results included a prioritised list of areas with high service provision and biodiversity that were also less costly to protect (Wendland *et al.* 2007).

In Ecuador, USD 15-40 million in revenues was collected for the Paute hydroelectric scheme in the Andean Highlands. This was done through catchment management that minimises upstream erosion, prolongs reservoir storage capacity, dam lifespan and power generation (Southgate & Macke 1989). This example demonstrates the value of integrated energy/resource protection and management, collaboration among multiple government and community stakeholders, as well as the power of creating incentives and investment opportunities for utility companies.

At a popular visitor destination site in Lijiang, China, tourists' willingness to pay for waterfowl protection and scenic beauty, generated fees that were used to pay farmers to protect biodiversity and minimise their fertiliser use so as to maintain water flows and quality (Zhi *et al.* 2007). Strong government support was a key factor in the success of this example. Such support is vital to replicate and scale up PES work, which is seen as a desirable end result by the Chinese government, as is reducing conflicts between competing resource needs.

In the Lajeado São José micro-watershed in Brazil, environmentally sustainable upland management practices save almost USD 2,500 per month in downstream domestic water treatment costs – costs which need to be transferred to upland residents participating in protection (Bassi 2002). This example points out the need to understand the relationship between upstream activities and downstream impacts to devise an equitable payment system. Appropriate incentives for behaviours upstream will positively impact service flows downstream.

The Guayallabamba river basin, the Papallacta and Oyacachi River basins and the Antisana River basin in Ecuador are part of an economic trust fund to protect the waters in the area; Fondo Para la Protección del Agua (FONAG). The FONAG represents a payment for environmental services provided by ecosystems. This fund is a heritage fund that was set up in 2000 and has a useful life span of 80 years. It is operated as a private mercantile trust fund and is legally controlled by the Ecuador stock market laws. The revenues for this fund are used for co-financing environmental activities in favour of water conservation and maintenance of hydrographic basins that provide water to fulfil human and productive needs of the Quito Metropolitan District, and its areas of influence. Trust funds are good means of distributing payments to those responsible for protection efforts. (For

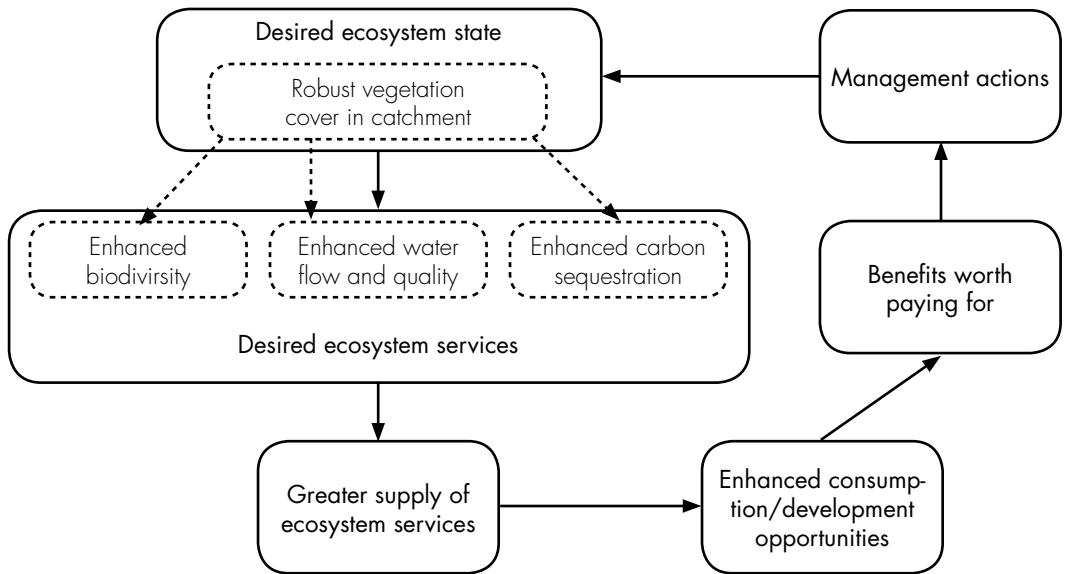


Figure 5. Conceptual model of a PES system. Boxes with broken lines show examples of desired ecosystem services mentioned in the Maloti Drakensberg Transfrontier Project. (Figure modified from the Maloti Drakensberg Transfrontier Project, 2007)

more information about the fund see: <http://www.fonag.org.ec/english/index.php>.)

PES has proven to be a viable option to enhance supply in the catchments of the Maloti Drakensberg Mountains on the border between Lesotho and South Africa. Land use in the surrounding grassland has reduced stream flow in the dry season and intensified flow in wet season. This has resulted in seasonal water shortage, reduced water quality, soil erosion, reduced productivity and increased water vulnerability. The Maloti Drakensberg Transfrontier Project showed that implementing a PES system (Fig. 5) would be an economically and institutionally feasible way to incorporate ecosystem services into water management. There are significant benefits to be gained by both local

ecosystem services producers (the mountain communities) and by the broader user or catchment community: less water vulnerability, more jobs in the region, and improved land quality that can stimulate the development of other economic options, such as tourism, game farming, improved grazing and natural products harvesting. The Transfrontier Project also showed that such a system is desirable from a rural development and social equity perspective, rewarding those who maintain a water supply engine but who are spatially and economically marginalised. There are several potential funding sources, but from the start, funding could be provided by the Department of Water Affairs and Forestry. Payments for carbon sequestration are also being negotiated with private sectors buyers.

### Case study 5. Creating the Bogota Water Fund for People and Nature

By Tracy Farrell, Conservation International (CI) and Sarah Davidson, The Nature Conservancy (TNC)

The high grassland páramo of the Andes mountain chain provides a variety of ecosystem services for human and natural communities in northern South America. In the centre of the Colombian Andes, Chingaza National Park provides habitat for a variety of threatened biodiversity and is crucial for the provision of water for downstream human populations. The area supplies drinking water for 8 million people in the Colombian capital of Bogotá, but the grassland páramo is threatened by human activities such as agriculture and cattle grazing in the Chingaza National Park buffer zones. The Bogotá Water and Sewerage Company (EAAB) has estimated that the water demand will increase significantly by 2020, which means that immediate measures are necessary to protect the watershed in order to be able to meet that anticipated demand.

TNC, EAAB, Sab Miller Bavaria brewery and National Protected Area Agency and Patrimonio Natural Foundation have created a conservation trust fund, launched in April 2008, to protect the watersheds of the Bogotá water supply system. The fund will attract voluntary contributions from Bogotá's water treatment facilities to subsidise conservation projects – from strengthening protected areas to creating incentives for ecologically sustainable cattle ranching – that will keep sedimentation and runoff out of the region's rivers. Without such projects, the facilities have to spend millions to remove those pollutants in order to provide clean drinking water for Bogotá's 8 million residents. A study undertaken by TNC and its partners found that water treatment facilities

in Bogotá could save USD 4 million per year by proactively investing in watershed protection so that trees do a large portion of their filtering work for them.

The water fund will support projects such as adding park rangers, strengthening protection in parks, and helping people who live in sensitive areas to switch to more ecologically sound livelihoods. For example, grants can enable ranching families to switch to ecologically sustainable operations by underwriting the purchase of higher quality cattle and other start-up costs if they commit to long-term conservation agreements to preserve their natural areas.



More milk from fewer cows means that ranchers will be less likely to clear forest land for additional grazing fields – resulting in less sedimentation in rivers.

The fund – based on a successful pilot programme in Quito, Ecuador – is projected to raise USD 60 million for conservation projects over the next 10 years. The Conservancy plans to implement six more such funds in South American countries in the next two years.



Photo: Mats Lannerstad

## Climate Change and Flow Regimes: The Value of Enhancing Adaptive Capacity in a Changing Climate

Climate change is projected to result in changes to sea level, rainfall distributions, flood and drought frequency and intensity, storm severity, and land-ice coverage. Annual average river runoff and water availability will decrease over some dry regions at mid-latitudes and in the dry tropics, while increasing at high latitudes and in some wet tropical areas. Changes in flood and drought frequency follow the new precipitation patterns in the different regions, with some drainage basins experiencing an increase of both floods and droughts. Changes in extreme rainfall and, thus, flow volumes affect the rate at which suspended material is flushed as well as the dilution of pollutant loads. As winter precipitation shifts from snow to rain due to rising temperatures, the spring snowmelt peak is brought forward, when not eliminated entirely, while winter flows increase (Kundzewicz *et al.* 2008).

The effects of these changes on flow regimes will change the magnitude, frequency, duration, and variability of the different components of a river flow regime. Stream flow modifications will affect water availability, determine ecosystem fragmentation, wetland infilling and drainage, and increase sediment transport to coasts. Changes in groundwater

levels will entail drying of shallow wells, land subsidence, and saline water intrusion (IPCC, 2007b). The magnitude of change in individual river systems is difficult to predict, but model projections forecast that every populated river catchment in the world will change, and some will experience large increases in water stress (Palmer *et al.*, 2008). Depending on the scenario and climate model, water stress may increase over about two-thirds to three-quarters of the total global river basin area (Alcamo *et al.*, 2007). Other regions, such as parts of Northern Europe, are forecast to experience increases in run-off (Andreasson *et al.*, 2004).

The impacts of climate change on freshwater resources and their management will be manifest at the global scale. However, such disturbances to the hydrological cycle will add up to other river basin-level pressures on natural flow regimes such as water diversions for hydropower and agricultural purposes (Framing Committee of the GWSP, 2005; UNEP GEO-4, 2007). The most important and pressing effects of climate change on freshwater run-off is decreasing water availability, stressing the need to find sustainable ways to utilise water resources in order to protect vital ecosystem



functions and people dependant on them. However, in some areas where run-off is projected to increase it also opens up a debate on how excess water shall be utilised, and a possibility to improve water management, for example dam operations.

### **Opportunities of climate change**

In areas where run-off is expected to increase it may open up a debate on how to utilise the “extra” water. Should it automatically be used to increase hydropower production? Or could it open up room for an ecologically better management of water resources? One example where climate change may provide an opportunity for this is rivers utilised for hydropower production in Northern Sweden. This area is expected to experience increases in river flows, as well as hydrographs better matching power demands. This gives new opportunities for operating dams and power stations to provide environmental benefits. Less precipitation coming as snow means there is less need for storage capacity, creating opportunities for flow regimes better matching natural hydrographs. Autumn floods are projected to become more frequent and of higher magnitude (Andreasson *et al.*, 2004). This calls for increases in dam security, but the installed capacity need not automatically be used to increase average storage. More water could be released to reaches that presently have reduced discharge, creating opportunities to better match flow with important aspects of natural flow variability (Arthington *et al.*, 2006). More water could also be allocated to by-pass channels across dams to enhance organism migration. Spillways could be left open more frequently to enhance downstream transport of organisms and matter. This would improve the ecological status of rivers used for hydro-power production.

### **Climate change effects on ecosystem services**

The resilience of an ecosystem is defined as “... the magnitude of disturbance that the system can experience before it shifts into a different state ...” (Holling, 1973). After the ecosystem has reorganised into a new structure, vital functions, such as provisioning and regulating ecosystem services, can change or be lost. A less desired state may be reached where less water is yielded, fewer fisheries are sustained, or less buffering capacity is provided in the event of floods or droughts. “The ability for reorganisation and renewal of a desired ecosystem state after disturbance and change will strongly depend on the influences from states and dynam-

ics at scales above and below. Such cross-scale aspects of resilience are captured in the notion of a panarchy, a set of dynamic systems nested across scales” (Peterson *et al.* 1998; Gunderson and Holling 2002).

Human actions can cause a loss of resilience through removal of functional groups of species such as apex predators or benthic feeders, bottom-up impacts via polluting emissions or excess nutrient influx, or the alteration of the magnitude, frequency, and duration of disturbance regimes. Climate-led modifications of the hydrological cycle, hydropower operations, and water withdrawals for irrigation are all examples of such disturbances to the natural flow regime. The combination of the different categories of impact erodes the self-repairing capacity of ecosystems until they cease to cope with change such as climate variability. Most importantly, though, the effects of climate change are exacerbated by each and every one of these impacts limiting water quality and quantity. For example, reducing biodiversity reduces the variability in responses of species to change. In the conditions of declining resilience, progressively smaller external events such as water withdrawals can cause irreversible flow regime shifts (Folke *et al.*, 2004).

A good example of how vulnerability to climate change can increase across different scales is offered by the Murray-Darling River Basin in southeastern Australia (Arthington and Pusey 2003). At the scale of ecosystem function, lack of the full suite of recommended environmental flow components may result in higher turbidity. When water is not sufficient and summer freshes are delivered in isolation, ‘blackwater’ events may translate into darkly discoloured water associated with low dissolved oxygen and high organic matter with consequences for aquatic species (Atkinson *et al.*, 2008). At the scale of biota, failure to deliver environmental flows to iconic river red gum forest (*Eucalyptus camaldulensis*) may result in irreversible loss of this vegetation type and associated riverine fauna and processes regulated by riparian vegetation (Pusey and Arthington 2003). Ecological impacts and loss of biodiversity have been documented in Australia when wetlands and floodplains are deprived of intermittent floods (Bond *et al.*, 2008). As opposed to such proactive management, in which artificial inundation maintain a healthy forest, reactive response will require widespread replanting and decades to recover (Palmer *et al.*, 2008). At the scale of the whole river basin, six different risks have been identified as a serious jeopardy to future water resources availability, among which climate change accounts for almost half of

the estimated reduction in water volumes. By 2023, over 2,500 gigalitres of system inflows could be lost not only as a result of climate change but also from plantation forestry, growth in groundwater use, bushfires, the construction of farm dams, and reduction in return flows from irrigation (Murray Darling Basin Commission, 2003).

### **The implications of climate-affected flows on human well-being**

Environmental flow regimes maintain or increase human well-being by maintaining or increasing provision of services from healthy ecosystems (case study 6). Climate change exacerbates degradation of ecosystems and thus increases the vulnerability of certain human groups, particularly the rural poor, whose livelihoods and safety depend upon the local ecosystem services. For example, increasingly dry conditions may affect human health by limiting the amount and thus the quality of downstream drinking water. Also irrigated agriculture and floodplain cultivation will need to cope with increasingly lower shares of water. A potential 30 percent decrease in rainfall over the Pangani River Basin in Tanzania is expected to entail losses for over USD 1,360 million in the scenario of a maximised irrigated area. By contrast, shifting the pattern of flows but retaining the present-

day volume can increase services. Flow management that supports ecosystem health first, then prioritises agriculture only after basic human needs, urban and industrial allocations are met to the extent possible, is estimated to yield the second highest value out the basin besides hydropower generation (case study 1).

Droughts felt in one region may also displace climate change impacts on the livelihoods of people from another region. For example, reductions in dry-season flows have urged Chinese dam operators to consider new developments in the upper mainstream of the Mekong River (Adamson, 2001). The barriers would have downstream consequences on the reproductive migration of inland fish, which the proteins uptake of some 60 million people is based on up to 44 percent on average (Hortle, 2007). In other as well as the very same areas, increasingly wet conditions may jeopardise the population due to higher floods and augment the spread of water-borne diseases in the same way water resources development does with impoundments (case study 2).

In summary, the combined effects of climate change and other human pressures on ecosystem structure and functions result in loss of resilience and, thus, in a downward shift of the services provided by ecosystems.

### **Case study 6. Climate change adaptation in the Central and lower Yangtze**

*By Li Lifeng and Anna Forslund, World Wide Fund for Nature (WWF)*

The Yangtze River is the third longest river in the world with a basin of 1.8 million km<sup>2</sup>. It drains a region of high economic importance with more than 400 million people, one third of China's total population. The Central Yangtze, the section of the river basin from Yichang in Hubei province to Hukou in Jiangxi province, has been listed by WWF as a priority ecoregion<sup>1</sup> for conservation. This is a region of floodplains and lakes, with high ecological value, and is known as China's home of rice and fish. Population pressure and rapid economic development has, however, severely degraded the environment. China's population has more than doubled and become heavily concentrated along the major river valleys. More than 100 lakes have been disconnected from the mainstream of the Yangtze River and

1/3 of the lakes have disappeared. More than 12,000 km<sup>2</sup> of wetlands have been converted into farmland and major dams have been built in the upper stream. Pollution from domestic sources, industry and agriculture has reduced the water quality, and the reduction in the extent of wetlands and lakes has altered the flow regime. Human intervention has dangerously reduced the capacity of the floodplain to mitigate the impact of seasonal flooding and also reduced the area's capacity to cope with impacts from climate change.

In 1998, WWF launched "The Central Yangtze: Partnerships for a Living River", a programme undertaken by WWF's China Programme Office (CPO). The project aimed to restore wetlands and lakes back to their 1950s size and

<sup>1</sup>The Global 200 is the list of ecoregions identified by the World Wide Fund for Nature (WWF) as priorities for conservation. According to the WWF, an ecoregion is defined as a "relatively large unit of land or water containing a characteristic set of natural communities that share a large majority of their species, dynamics, and environmental conditions (Dinerstein *et al.* 1995, TNC 1997)."

extension. The overall goal was to reverse the rapid decline of biodiversity and increase the resilience of the ecosystem to climate change. The project worked to promote ecological agriculture, e.g. fishery and livestock farming with a focus on the sustainable human interactions with ecosystems. WWF's intervention included reconnecting oxbows and lakes with the Yangtze main stem by opening the sluice gates of 17 lakes covering a total area of more than 1,200 km<sup>2</sup>.

### Climate change adaptation benefits gained from the project intervention

Securing environmental flows builds the capacity of the ecosystem to better adapt to impacts from climate change. The project took measures in different ways to secure environmental flows and to reduce the vulnerability of natural and human systems against climate change.

#### In summary the project:

- **Increased the flood retention capacity.** The restoration of the wetlands as well as reconnecting the lakes with the main stem of the Yangtze River increased natural processes such as storage and safe release of flood waters, including higher peak flood flows
- **Reduced pollution levels.** An important measure to reduce the impact from climate change will include cutting current pollution levels when impacts from pollution are expected to be exacerbated by higher temperatures. Project intervention for example improved water quality from IV to II (drinkable) in Hong Lake.
- **Improved livelihoods.** Diversified income generation strategies and increased incomes of many local communities increase their resilience to climatic events. The project supported the development of alternative livelihoods for the local communities and survey data show a higher diversification of income generation

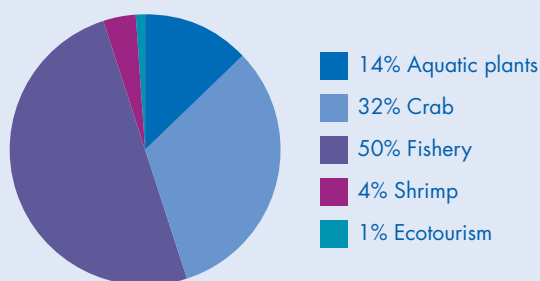


Figure 1. Income generation after the project intervention (from WWF 2005).

compared to before the project started (Figure 1). Also higher incomes were received due to e.g. increased fish production and better management practices (Table 1) (Shuyt, 2005).

- **Increased institutional capacity.** The Central & Lower Yangtze Wetlands Conservation Network was established as a way to improve and coordinate the management of the area. Strengthened local institutions can be an important measure to increase adaptive management capacities.
- **Restored connectivity.** Reconnecting the 17 lakes with the Yangtze increased hydrological and ecological connectivity. This enabled greater mobility and capacity for populations of species to colonise new habitats, which may be required in a warmer world.
- **Increased populations and habitats.** In Hong Lake fish diversity and productivity increased due to improved water quality and quantity. The Oriental White Stork, which had disappeared in the past 11 years, returned to the lake due to improved habitat. Lake Hong was designated as a Ramsar site in 2007. Restored populations of species and areas of habitat may better resist the impact of climate change.

Table 1. Household income comparisons in 2001 (unit: RMB, from WWF 2005)			
Item	Overall household income of project beneficiaries in Xipanshanzhou Polder	Non-project household income in Xipanshanzhou Polder	Non-project household income in other polders nearby
Household cash income	4456	3583	2456
Cash income per capita	1146	891	709

# Environmental Flows and Water Resource Management

The concept of environmental flows is an essential part of Integrated Water Resources Management (IWRM). IWRM is defined as 'a process, which promotes the co-ordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems' (GWP, 2000). In IWRM, there are three key strategic objectives:

- *Economic efficiency in water use:* Because of the increasing scarcity of water and financial resources, the finite and vulnerable nature of water as a resource, and the increasing demands upon it, water must be used with maximum possible efficiency;
- *Equity:* The basic rights for all people to have access to water of adequate quantity and quality for the sustenance of human well-being must be universally recognised;
- *Environmental and ecological sustainability:* The present use of the resource should be managed in a way that does not undermine the life-support system thereby compromising use by future generations.

Addressing environmental flows is indispensable to achieving all three IWRM objectives.

In the context of IWRM, the environmental flow requirement in a river system is a negotiated trade-off between water users (for example of EFA's in an IWRM context see case study 7). In this case, the resulting ecosystem condition is determined by that negotiated and 'desired' environmental flow. Alternatively, a desired ecosystem condition may be set (e.g. by legislation or international conventions), and the environmental flow requirement is the water regime needed to sustain the ecosystems in that desired condition. In any case, the required condition, in which freshwater and estuarine ecosystems and their services to humans are sustained, is essentially a socio-political decision. Incorporating EFAs in water management and the setting of objectives for a prescribed flow regime that includes negotiation between different stakeholders, with ecosystems recognised as legitimate users, allows for a more comprehensive, fair and sustainable utilisation of natural resources (Naiman *et al.* 2002).

Setting aside water to sustain various components in the ecosystem is nothing new; according to Tharme (2003), the practice of environmental flow provision has produced over 200 different methods. The methods used to assess environmental flows have developed from simple rule-of-thumb methods preserving commercially important fish species to holistic methods that encompass all important aspects of the ecosystem as well as socio-economic activities. Even



Photo: Anton Earl, SIWI

though many of the earlier methods, i.e. the Tennant model (Tennant 1973), were based on biological observations from a limited number of sites, the widespread use of these methods in other parts of the world has led to a lack in clear connection to ecological metrics and the values they were designed to protect. This led to the development of models that combine hydraulic ratings with ecological habitat metrics, with the most well know developed by the U.S. Fish and Wildlife Service in the late 1970s (Reiser *et al.* 1989). These methods, however, are data intensive and relatively expensive to use, and often focus on a limited part of the riverine ecosystem, typically commercially valuable fish. This limits their relevance to confined reaches of rivers and makes them difficult to apply in regions where ecological data are scarce. Holistic environmental flow methods encompass the whole range of flow variables and ecosystem components that need to be maintained, and additionally some (e.g. DRIFT –Downstream Response to Imposed Flow Transformation) focus also on sociological benefits of flow, such as maintenance of local freshwater

and estuarine fisheries for subsistence uses (Arthington *et al.*, 2003; King *et al.*, 2003).

Often, though, the integration of ecological considerations into water management on a wider scale has been hampered by the difficulty to properly assess flow-ecology relationships and the effects of flow modifications on a wider scale and also data deficiency (both flow and ecological data) in many rivers, especially in the developing world. This makes the more sophisticated data intensive methods that exist (i.e. IFIM, the Instream Flow Incremental Methodology, Reiser *et al.*, 1989) too expensive and time consuming to apply on broader scales. The recently developed Ecological Limits of Hydrologic Alteration (ELOHA) offers a flexible, scientifically defensible framework for a broad assessment of environmental flow needs, when in depth studies and more detailed assessments are not possible (Fig. 6). At present, several water jurisdictions within the US are applying components within the ELOHA framework into regional water recourse management. The framework has also been tried in Australia and China.

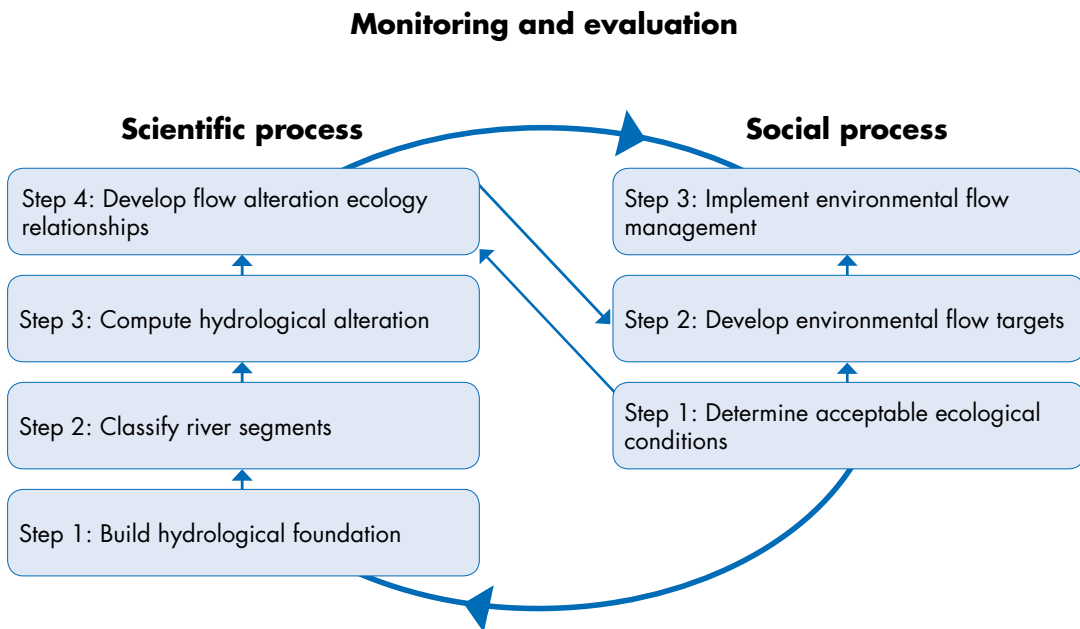


Figure 6. The ELOHA framework consists of two parallel scientific and social processes. Rivers/river segments are classified based on similarity of flow regime, hydrological alterations are computed and flow alteration-ecological response curves are developed. At the same time, acceptable ecological conditions are set through well-vetted stakeholder processes. Environmental flow targets are developed by using the flow alteration-ecological response curves and implemented in flow management. The development and implementation of flow management should be an ongoing iterative process based on monitoring and evaluation that is based on improved knowledge on flow alteration-ecological response curves and evolving social values. Figure based on the ELOHA fact sheet: [www.iwmi.cgiar.org/Publications/Other/PDF/ELOHA\\_FACT\\_SHEET.pdf](http://www.iwmi.cgiar.org/Publications/Other/PDF/ELOHA_FACT_SHEET.pdf)



## Case study 7. Zambezi River

By Bart Geenen, World Wide Fund for Nature (WWF)

The Zambezi is one of Africa's great rivers and is naturally divided into three sections: The Upper Zambezi from the source to Victoria Falls, the Middle Zambezi downstream from Victoria Falls to Cahora Bassa in Mozambique and the Lower Zambezi from Cahora Bassa to the Delta at the Indian Ocean in Mozambique. The Zambezi River's natural flood regime is the driving ecological process supporting pervasive wetland and riparian habitats important for wildlife and human well-being as the population is dependent mainly on agriculture and fisheries. Hydropower generation in the Zambezi River basin is considered to be essential for the development of Southern Africa. To meet the growing demand, several new dams are planned in the Zambezi river basin.

The Middle and Lower Zambezi have been largely modified by the creation of artificial reservoirs for hydropower generation like at Kariba, Kafue and Cahora Bassa gorges. These large dams have changed downstream ecology, largely by eliminating seasonal high and low flows and reduction of sediments trapped behind the dam wall. The dams created permanent artificial barriers and the resultant river fragmentation prohibits migration of fishes along the river channel (World Resources Institute 2003). The Kafue Lechwe population has fallen more than 50 percent in recent years. In addition, local communities blame the decline in fish yields and forage in riparian grazing areas on flow alterations by the dams. In the delta floodplain of the Zambezi River, reduced shrimp catches, declines in the productivity of artisanal fisheries, invasion of floodplains by upland vegetation, dying mangroves and decreased wildlife populations are some of the results of the altered hydrology.

WWF has been promoting and developing environmental flows in the Zambezi river basin for several years. A breakthrough was the modification of the Itzhi-Tezhi dam operating rules (2004) in the Kafue River – a main tributary to the Zambezi river – resulting in the release

of freshets (early 2007) and flooding of vast wetlands important to wildlife and small-holders in the area. Since 2006 environmental flows downstream of Cahora Bassa dam have been studied and promoted. A DRIFT analysis showed good potential for environmental flows in this river section crucial to maintain biological functions and enhance subsistence uses in the Zambezi delta. The development of multi-purpose dam operating rules and harmonisation of water management operations between riparian countries, in combination with water and dam managers taking control of water management, has taken environmental flow assessment and development to a whole new level.

Environmental flows have been recognised as a key-strategy for sustainable development in the Integrated Water Resources Management Strategy and Implementation Plan for the Zambezi River Basin (IWRM-ZRB, SADC-WD April 2008). WWF, with support of partners like UNESCO-IHE and TNC, has concrete plans to assess the potential of environmental flows in the Zambezi River downstream of Victoria falls in close cooperation with the water and dam managers in Zambia and Mozambique. To accommodate environmental flows it is envisaged that dam operations need to be modified to accommodate multi-purpose water use downstream. In addition, designated areas for flooding and retaining water in the Zambezi River system are crucial to the well functioning of the ecosystem and are therefore an integral part of the strategy. It is very exciting that strategic partners like water management authorities and dam operators of large dams like Kariba and Cahora Bassa are directly involved in the assessment process. In fact they will execute crucial modelling components to develop the prescribed flow regime. This is essential as it strengthens the capacity of these organisations to conduct environmental flow assessments in the context of the larger socio-political decision process.

# Policy and Legal Frameworks

Over the past two decades, global policies have begun to recognise the importance of freshwater ecosystem health. Chapter 18 of Agenda 21 of the Rio Conference of 1992 called upon governments to “make certain that adequate supplies of water of good quality are maintained for the entire population of this planet, while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature...” As part of an early movement toward IWRM, Chapter 18 also observed that “water resources have to be protected, taking into account the functioning of aquatic ecosystems...”

A decade later, the MEA concluded that: “Any progress achieved in addressing the MDGs of poverty and hunger eradication, human health, and environmental protection is unlikely to be sustained if most of the ecosystem services on which humanity relies continue to be degraded” (MEA, 2005). The Assessment went on to point out that freshwater systems are being lost at alarming rates, far faster than terrestrial and marine. The broad range of goods and services provided by environmental flows play a central role in achieving the MDGs.

Over the last decade, there has been greater recognition by the global community that a more holistic approach to water management is needed. The commitment by governments at the 2002 World Summit on Sustainable Development to develop IWRM and efficiency plans by 2005 was an encouraging commitment. IWRM is grounded on the

understanding that water resources are a part of a linked system, involving upstream and downstream users, terrestrial and aquatic systems, surface and groundwater sources, as well as the river basin and adjacent coastal and marine environments. It provides a framework in which the competing needs of multiple users and stakeholders can be explicitly analysed and addressed, in a transparent, systematic and participatory way.

To achieve the MDGs and the other targets agreed upon by governments on water over the last several decades, it is clear that freshwater ecosystem health must be integrated into national policies and that implementation of those policies needs to be a priority. Development strategies must include environmental protection in order for the ecosystem services upon which humans depend (i.e., provisioning, supporting, and regulating services) to continue.

The policy linkages between environmental flows and poverty do not have a long history. In recent years, two policy frameworks have gained special importance in the world’s struggle to reduce poverty: the MDGs and countries’ PRSPs (WRI, 2005). In addition, with increasing competition over limited water resources, governments have begun over the last few decades to accept the concept of integrated resource management as a fundamental approach to resource allocation issues. As noted, at the 2002 World Summit on Sustainable Development, countries committed to develop integrated water management plans by 2005. Moreover, a



Photo: Mattias Granberg



Photo: Mattias Granberg

handful of countries have developed environmental flow policies at the national level. South Africa stands out for enacting legislation to meet the needs of the poor for water.

### **The role of global systems in addressing environmental flows**

With so few countries having developed environmental flow policies, it remains important to consider global mechanisms and systems through which countries will commit to addressing the health of their freshwater systems and specifically environmental flows. International law and institutions can help push governments to develop the legal and regulatory systems to address environmental flows. The strategies of development banks and United Nations (UN) agencies can also spur action by countries. Declarations at global conventions and conferences can also help set the bar for how issues are regarded by the global community.

River treaties seldom have unique provisions that directly address environmental flows; however several international agreements have acknowledged the need to protect and restore freshwater ecosystems (Dyson et al 2003, Katz 2006). The United Nations convention on the Law of Non-navigational Uses of International Watercourses – (UN General Assembly 21 May 1997) is of particular interest when it comes to environmental flows. It is the only global treaty that

addresses rivers for purposes other than navigation (Scanlon 2003, Iza 2004), and it applies to transboundary freshwater systems, i.e. major watercourses, their tributaries, connected lakes and aquifers, accommodating competing users across international borders (Loures & Dellapenna 2007). It aims to open up a framework of cooperation for the contracting parties regarding shared water resources and to provide the means to prevent and resolve water conflicts, including considering environmental conservation in the allocation of transboundary waters (Katz 2006). The Convention still needs the ratification of 19 parties to enter into force (<http://untreaty.un.org>). Once ratified, it will constitute an important convention providing a forum for dialogue on international management of shared water resources. It could provide the appropriate and necessary legal response for implementation of environmental flows within the context of IWRM.

Several non-river treaties have recognised the need to protect freshwater ecosystems. The Convention on Wetlands of International Importance (referred to as the Ramsar Convention) is of special importance to environmental flows. Since it was drafted it has been developed to also include a range of species as well as broader aspects of water management (Dyson et al 2003). The Parties to the Convention have adopted guidelines on “the allocation and management of water for maintaining the ecological func-



tion of wetlands” and countries are encouraged to adopt measures in relation to policy and legislation, valuation of wetlands and the determination of environmental flows (Iza 2004). In addition, the 190 Parties to the Convention on Biological Diversity (CBD) adopted guidelines encouraging parties to address measures to manage environmental flows (Dyson et al 2003).

Furthermore, the Helsinki Rules of 1994 (adapted into the Berlin Rules of Water Resources) acknowledge the importance of environmental flows for ecological and other in-stream purposes (Articles 22 and 24) (Kratz 2006). Drafted by the International Law Association, these rules are not binding but are “instructive on emerging obligations” (Dyson 2007). Some countries are, however, attempting to apply these principles in specific international transboundary agreements.

Among development banks, the World Bank has made considerable progress in recognising the importance of environmental flows. Through its Water Resources Sector Strategy and its Environment Strategy, the World Bank notes the importance of integrating principles of environmental sustainability in Bank-supported projects. In addition, the World Bank has published a series of technical notes on environmental flows, and continues to do so to help build the capacity of its clients to adequately take into account environmental flow issues in projects, particularly in the development of multi-purpose and hydropower dams.

Within the UN system, the United Nations Environment Program (UNEP) developed a Water Policy and Strategy (WPS) in 2007 which aims: “to contribute substantively to environmental sustainability in the management of all water resources, utilising integrated ecosystems approaches, as a contribution to the internationally agreed targets and

goals relevant to water and socio-economic development.” Promotion of ecosystem based approaches is one of the key strategic principles of UNEP WPS. Environmental flows are seen as a major part of this strategic principle. Furthermore, environmental flows are explicitly mentioned as a thematic area for strategic action. The UNEP WPS will provide direction to the UNEP Secretariat in its drafting of the programme of work for the period 2007–2012. A focus on environmental flows has already been incorporated into several UNEP work plans and programmes, including that of UNEP-DHI Centre on Water and Environment.

### Millennium Development Goals

In the MDGs, the global community agreed on eight ambitious development goals to cut the world’s poverty in half by 2015. This constitutes an unprecedented commitment by countries and development institutions to reduce extreme poverty.

“To integrate the principle of sustainable development into country policies and programmes and reverse the loss of environmental resources,” Goal 7 of the MDGs (MDG 7) commits nations to ensure “environmental sustainability” and includes three global targets and eight official global indicators (Table 5). One major problem with the current MDG framework, with a separate environmental target, is that it does not reflect that maintaining the integrity of ecosystem services underpins and is of central importance to all eight MDGs. Table 6 summarises how freshwater ecosystem services and environmental flows are contributing to all 8 MDG goals.

Target 10 of MDG 7 is directly related to water and it commits governments to: “Halve by 2015 the proportion of people without sustainable access to safe drinking water

**Table 5. Global targets and indicators under MDG 7.\***

Targets	Indicators
9. Integrate the principal of sustainable development into country policies and programmes, and reverse the loss of environmental resources	25. Proportion of land area covered by forests
10. Halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation	26. Ratio of area protected to maintain biological diversity to surface area
11. Have achieved by 2020 a significant improvement in the lives of at least 100 million slum dwellers	27. Energy use per USD 1 GDP
	30. Proportion of population with sustainable access to an improved water source (urban and rural)
	31. Proportion of population with access to improved sanitation
	32. Proportion of households with access to secure tenure

\*MDG 7: Ensure environmental sustainability

**Table 6: Examples on links between Environmental Flows and the MDGs**

Millennium Development Goal	Example of Environmental Flow Linkages
1. Eradicating extreme poverty and hunger	Securing environmental flows will ensure healthy fish populations.
2. Achieve universal primary education	Water-related diseases such as diarrhea infections costs about 4423 million school days each year, and diminishing learning potential.
3. Promote gender equality and empower women	Woman and girls bear are often the ones responsible of collecting water, an assignment that gets more difficult when water gets degraded.
4. Reduce child mortality	Water-related diseases kill an estimated 3 million people/year in developing countries, the majority of whom are children under age five.
5. Improve maternal health	Provision of clean water reduces the incidences of disease that undermine maternal health and contribute to maternal mortality
6. Combat major diseases	Many amphibians have developed a variety of compounds that they release when stressed or injured. Many of them have or can have important medical use for humans. Amphibians are among the most threatened organisms on Earth; most of them have close ties with water and are threaten by the degradation of freshwater.
7. Ensure environmental sustainability	Current trends in freshwater degradation must be reversed in order to sustain the health and productivity of these ecosystems. According to the MEA, freshwater ecosystems are the worst off. About 50 percent of inland water systems have been lost during the twentieth century.
8. Develop a global partnership for development	Unfair globalisation practices export harmful side-effects. E.g. extensive trade of so called "virtual water" from water scarce areas that often lack effective governance, to regions with water abundance, are aggravating global water stress.

and basic sanitation". This target has a very direct bearing on all other MDGs, as water is the foundation upon which to meet other targets. However, in working to meet Target 10, governments are not adequately taking into account the amount of water needed to remain within systems to effectively provide long-term drinking water resources and to properly manage waste.

Among all the goals, MDG 7 is the least clearly articulated. Countries have faced many difficulties in monitoring the MDG 7 indicators, as well as the overall goal on making progress on environmental sustainability. This is in part due to the lack of measurable indicators related to securing freshwater ecosystem services. Moreover, there is currently insufficient availability of data to act as references to the indicators. Circumstances and priorities differ among countries, and thus many countries are encouraged to develop country specific MDG targets. As of 2005, only half of the 100 countries reporting in on the MDGs acknowledged development of targets to supplement MDG 7 (UNDP, 2005), such as expanding protected area systems.

In April 2008, the Global Monitoring report from the World Bank/IMF warned that most countries will fall short on the MDGs and stressed the need to strengthen the link between the environment and development to meet the MDG targets (World Bank, 2008). Although the MDG mid-term assessment showed some overall progress, most countries will fall short in meeting the MDGs. The Assessment also indicated that income inequities are rising in many parts of the developing world. The poorest group has a lesser share of national consumption. This is often the group most dependent on ecosystem goods and services. Many countries are seriously off track to meet Target 10 on water (See Figure 7).

As an example of the connection between freshwater ecosystems and human livelihoods, people across the globe depend on fish as their primary source of protein, with some regions particularly reliant on fish due to the fundamental social and economic role of fisheries. In a study of PRSPs by the World Bank, it was noted that fish consumption in Cambodia accounts for 30 percent of the population's intake of animal protein (Bojö & Reddy, 2003). In the Zambezi

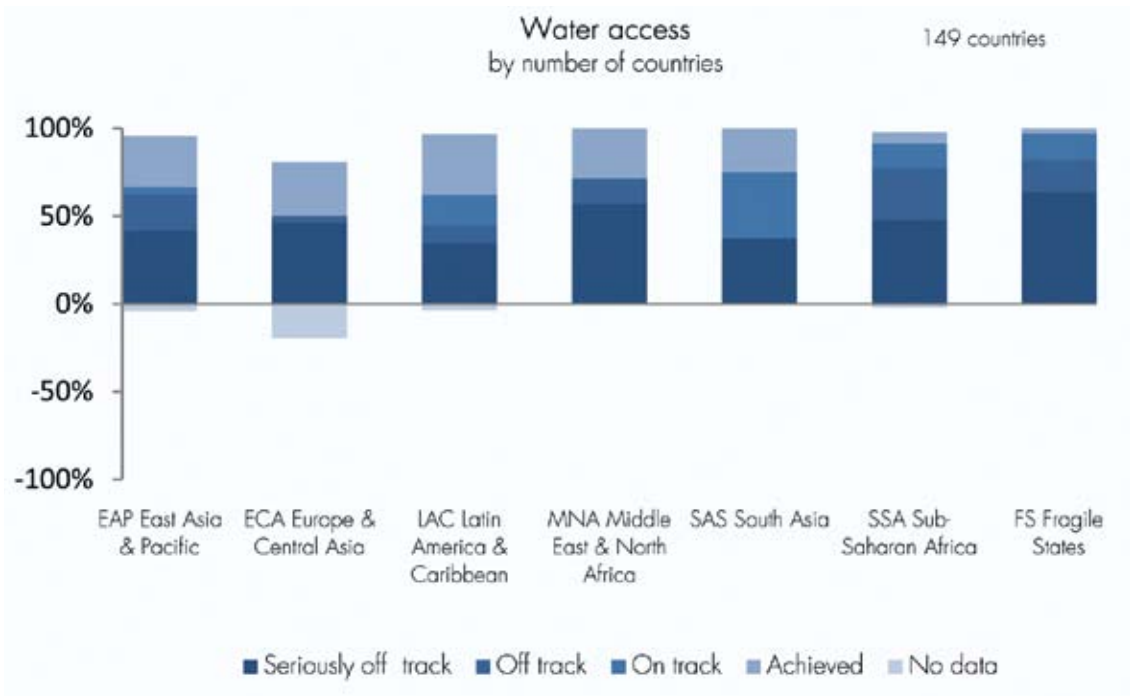
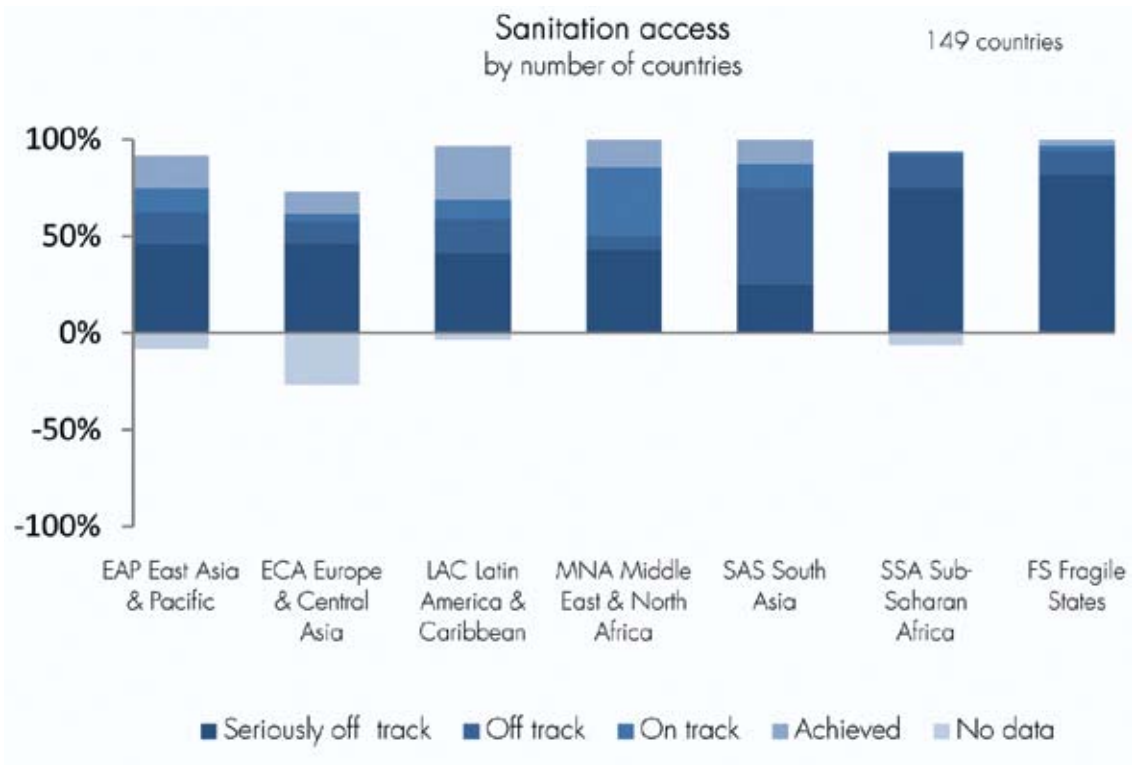


Figure 7. Proportions of countries on track to achieve the target 10 of MDG 7. "Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation". 57 percent of countries with available data in the Middle East, North Africa, Europe and Central Africa are seriously off track in improving access to safe drinking water. Source: World Bank 2001.

Basin, fish production is valued at USD 79 million per year and flood-recession agriculture is worth another USD 50 million per year (Schuyt, 2005). Degradation of freshwater ecosystems threatens the availability of fish protein. This is especially crucial for the poor who have few assets and rely on freely available natural resources for their survival. Wild fish are often their only source of protein. The loss of environmental flows thereby directly impacts the well-being of poor communities.

### **Poverty reduction strategy papers**

PRSPs are key instruments of national and sub-national planning within a country. Countries seeking debt relief and loans from the World Bank and the International Monetary Fund (IMF) must prepare a Poverty Reduction Strategy Paper – a document detailing the nation's plans for achieving substantive cuts in national poverty.

Many PRSPs fail to make water a priority. Those that do often do not clearly define the water objectives for the PRSP. Gambia's PRSP is the most comprehensive with its main objective as it relates to water resources "to meet national, regional and international development targets and indicative global water security targets through the provision of adequate and good quality water for domestic and industrial uses and for agricultural and livestock production purposes" (Gambia, 2006).

Some strategies call for developing a sound legislative and legal framework for water resources, forestry, land management and bio-diversity. Others focus on different priority actions including but not limited to: (i) conducting an ongoing public awareness and education programme on safeguarding the environment; (ii) defending natural forests; (iii) implementing the United Nations Framework Convention on Climate Change, (iv) maintaining environmental health, and, (vi) preventing natural disasters, among others.

Although PRSPs have changed lending to developing countries, with developing country governments playing a greater role in determining planning, policy and budget priorities, there are a range of criticisms of this approach to debt relief and concessional loans. The failure of PRSPs to mainstream environmental issues, in essence to make the link between improving environmental management and improving the lives of the poor, is a key critique (WRI, 2005). The World Bank review of environmental integration in PRSPs showed that many PRSPs note the same weaknesses on environmental integration as the MDG framework. Few

PRSPs contained realistic, time bound targets tied to sufficient relevant environmental indicators. Although it is encouraging that many countries are developing country specific targets on water, many still lack measurable indicators related to freshwater integrity. Furthermore, the World Bank study found that even in the case of those PRSPs that did do well in mainstreaming environmental issues, the countries have reported very little actual progress in implementing such measures (Bojö & Reddy, 2003).

The concept of environmental flows is not explicitly factored in poverty reduction strategies. Reviews of PRSPs have shown that Cambodia specifically calls for a national plan for water management that emphasises the importance of healthy aquatic ecosystems (Cambodia, 2002). Even with the greater global attention to the MDGs, PRSPs have also failed to address issues critical for achieving the MDGs, such as increasing access to safe water and sanitation. A study of the implementation of water supply and sanitation programmes as part of PRSPs in sub-Saharan Africa found that water supply and sanitation were not adequately taken into account (Slaymaker & Newborne, 2004). However, PRSPs address key elements of IWRM that could potentially help motivate policy makers and water sector practitioners to begin incorporating environmental flows in their decision-making and implementation processes.

### **National environmental flow policies**

Although many countries have developed drinking water quality standards, similar standards or guidelines for ecological uses of water are virtually non-existent. A few countries have started the process of legislating on the allocation of water resources to the environment. The most notable is South Africa which, in its National Water Act calls for the creation of two reserves of water: one for human needs and the other as an ecological reserve. The human reserve of 25 litres per person per day is for the purposes of drinking, food preparation, and hygiene. The ecological reserve focuses on the water needed to maintain ecosystem health, including aquatic species. The National Water Act also specifically links water for ecosystems to human well-being. The process of implementing the legislation involves the Minister designating the desired river health class and resource quality objectives which then become binding on all authorities and institutions.

Other countries, such as Mexico in its new Water Law of 2004, have taken the difficult steps to legislate for environ-



mental uses of water. Brazil's National Water Policy aims, through a river basin approach, to protect and restore freshwater ecosystems. Though ecological flows are taken into account to some degree in these policies, the assessments necessary to define the specific water requirements of rivers are seldom undertaken. Environmental considerations such as ecological flows and ecosystems protection are present in the Chilean Environmental Law and the Water Law (amended on June 16, 2005). Nevertheless, ecological flow is determined on a hydrological basis, not on biological criteria. And the connections between environmental flows and meeting the needs of the poor are overlooked. In the United States, Maine, Michigan and Florida have environmental flow standards in place. Other states in the USA are at various stages of developing standards and guidelines.

In order to achieve "good water status" in all waters of the European Union, the Water Framework Directive (WFD)

provides detailed instructions in relation to carrying out a characterisation of river basin districts, including an economic analysis. The assessment revolves around the effects of anthropogenic activity on the status of each surface and groundwater body. Based on this characterisation, environmental objectives are defined as "good chemical" and "good ecological" status for bodies of surface waters, and "good chemical" and "good quantitative" status for groundwaters. A river basin management plan (RBMP) should be then drawn up for each district and a programme of measures established, including the actions needed to protect or restore the aquatic ecosystems. Although the WFD does not explicitly mention environmental flows it is generally accepted that ecologically appropriate hydrological regimes are important to meet this status, and implementing environmental flows will be a key measure for restoring and managing river ecosystems (Acreman & Ferguson, in press).



Photo: WWF

## Conclusions and Recommendations

Healthy ecosystems help water managers maximise the economic and social welfare of all water users in an equitable manner. They provide for human well-being in multiple ways, especially among poor communities living close to the land-water interface. Ecosystem services have real economic value today and special importance in mitigating future problems and economic losses related to climate change. To preserve and benefit from these services, the water manager must ensure that an environmental flow regime is maintained in rivers and wetlands.

Environmental flows describe the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on them (Brisbane Declaration 2007). Precedent for preserving environmental flows are well represented in international agreements and are becoming more common in specific laws governing water resources management. The report concludes that environmental flows and the ecosystem services they support are critical to achieving all eight of the MDGs, even though they are not explicitly recognised as such in the PRSPs of most nations. The following are more specific recommendations.

1. Recognising the values of ecosystems, and investing in them accordingly, are key to achieving the MDGs and alleviating poverty: ecosystems will remain a vital lifeline for the poorest until these goals are met. The methods

that are used to estimate the values of ecosystems and their services, and the figures produced, have been hotly debated and contested for ethical, social and methodological reasons. Yet they help reveal social and ecological costs or benefits that otherwise would remain hidden or unappreciated in assessing nonmarket ecosystem goods and services. They provide a good foundation for discussions about how ecosystem services, and the environmental flows that sustain them can be compared to other water needs and incorporated into water, land use and development decision-making. Data requirements and other shortcomings of the various approaches of valuation of ecosystem services can appear daunting. However, each method has the potential for raising awareness about the roles and values of ecosystem services – and the environmental flows that sustain them for human well-being.

2. Critical factors in establishing PES schemes include ensuring sufficient data to value services as well as the existence of legislation and implementing agencies to administer and track payments. In determining the value of services and translating them into payment mechanisms, it is critical to understand the relationship between upstream activities and downstream impacts. There need to be appropriate incentives for behaviours upstream that will positively impact service flows downstream. Other

significant limitations and barriers exist to implementing PES mechanisms. In many developing countries, beneficiaries are poor and have no possibilities to pay for vital ecosystem services. PES must therefore be placed in a broader context of IWRM, poverty reduction and sustainable development, especially in the face of climate change. Paying for carbon sequestration may serve as an opportunity to bring in funding from private sources.

3. The limitations to energy and food production as well as navigation forecasted under climate change will necessarily entail reconsidering water allocations. Environmental flows management, as part of a broader climate change adaptation strategy, can help mitigate some of the negative impacts climate change will have on freshwater resources. It can ensure the recharging of aquifers, refill wetlands, and restore floodplain connectivity to buffer against the damage of floods. In particular, ensuring natural patterns of water flow would help preserve both ecological refugia against drought and spawning waters for fisheries during periodical flooding. As such, EFAs are opportunities for reducing vulnerabilities among people directly dependent on freshwater resources in a changing climate.
4. Both governments and donors have under-invested in improving water resource management. This significantly impacts the productive capacity of the economy and the lives of the people. Water management systems are also underdeveloped and require radical transformation. Poor water resource management is also attributed to an unnecessarily large number of authorities involved in

water resource management decisions. The water sector is plagued by institutional fragmentation that often results in governmental agencies working against each other to achieve their specific goals (e.g., water supply, wastewater management, water resources management). The result is that the overarching need for maintaining healthy freshwater ecosystems is overlooked, with the poor suffering even more due to their dependency on freshwater ecosystem goods such as fish, and services. While progress has been made in addressing gaps in water management and poverty reduction, the policy links between the two require greater attention if the poverty-reducing potential of reversing the loss of ecosystem services is to be realised.

5. Environmental flows can serve as an important link between environmental conservation and poverty alleviation in PRSPs as well as strategies to address the MDGs. Environmental flows offer an effective means for countries to mainstream the environment – especially freshwater ecosystems – in national development planning processes. For example the health and productivity of aquatic ecosystems can serve as an indicator for MDG 1 “Eradicate extreme poverty and hunger”. Sustaining environmental flows can be a useful indicator for MDG 7 on environmental sustainability. Environmental Flow Assessments provide the tools to assess the effect of changes in flow on various users and make the important trade-off between development and securing vital ecosystem service. Moreover these indicators will improve and support the monitoring processes of the MDGs.



Photo: WWF

# References

- Acreman, M.C. 2001. Ethical aspects of water and ecosystems. *Water Policy Journal* 3: 257-265.
- Acreman, M.C., Ferguson, A. *in press* Environmental flows and European Water Framework Directive. *Freshwater Biology*
- Acreman, M.C., Dunbar, M.J. 2004 Methods for defining environmental river flow requirements – a review. *Hydrology and Earth System Sciences*. 8, 5, 861-876.
- Acharya, G., 2000. Approaches to valuing the hidden hydrological services of wetland ecosystems. *Ecological Economics* 35: 63-74.
- Adamson, P. 2001. The potential impacts of hydropower developments in Yunnan on the hydrology of the lower Mekong. *International water power and dam construction*, 53: 16-21.
- Alcamo J., Flörke M, & Maerker M. 2007. Future long-term changes in global water resources driven by socio-economic and climatic changes. *Hydrological Science*, s 52: 247-75.
- Andreasson J., Bergström S., Carlsson B., Graham L. P. & Lindström G. 2004. Hydrological change: climate change impact simulations for Sweden. *Ambio* 33: 228-234.
- Arthington A.H., Bunn S.E., Poff N.L. & Naiman R.J. 2006. The challenge of providing environmental flow rules to sustain river ecosystems. *Ecological Applications*, 16: 1311-1318.
- Arthington, A.H. and Pusey, B.J. 2003. Flow restoration and protection in Australian rivers. *River Research and Application* 19: 377-395
- Arthington A.H., Rall J.L., Kennard M.J. & Pusey B.J. 2003. Environmental flow requirements of fish in Lesotho rivers using the DRIFT methodology. *River Research and Applications* 19: 641-666.
- Atkinson, B., Spooner, D. Treadwell, S., Bills, M. 2008. When environmental flows go wrong: A case study demonstrating the importance of understanding the inter-relationship between flow components in the Loddon River, Victoria. In. "Keeping aquatic ecosystems on Australia's water management agenda". Proceedings of the 47th ASL Congress, Mandurah Western Australia, 29 September – 3 October 2008.
- Bann, C., 1997. *An Economic Analysis of Alternative Mangrove Management Strategies in Koh Kong Province, Cambodia*. International Development Research Centre, Ottawa.
- Baron, J.S., Poff, N.L., Angermeier, P.L., Dahm, C.N., Gleick, P.H., Hairston, Jr., N.G., Jackson, R.B., Johnston, C.A., Richter, B.G. & Steinman, A.D. 2002. Meeting ecological and societal needs for freshwater. *Ecological Applications* 12: 1247-1260.
- Bassi, L. 2002. *Valuation of land use and management impacts on water resources in the Lajeado São José micro-watershed, Chapecó, Santa Catarina State, Brazil*. Land-Water Linkages in Rural Watersheds. Case Study Series. Food and agriculture organization of the United Nations. Rome, Italy
- Bennion, P., Hubbard, R., O'Hara, S., Wiggs, G., Wegerdt, J., Lewis, S., Small, I., van der Meer, J., Upsshur, R. on behalf of the Médecins sans Frontières/Aral Sea Respiratory Dust and Disease project team. 2007. The impact of airborne dust on respiratory health in children living in the Aral Sea region. *International journal of epidemiology*, 36: 1103-110
- Bojór, J. and Chandra Reddy, R. 2003. Poverty Reduction Strategies and the Millennium Development Goal on Environmental Sustainability. Opportunities for Alignment. *World Bank Environment Department Paper No. 92*. Washington DC, World Bank.
- Bond, N., Lake, P. S., Arthington, A. H. 2008. The impacts of drought on freshwater ecosystems: an Australian perspective. *Hydrobiologia*. 600: 3-16.
- Brisbane Declaration (2007) Available at [http://www.nature.org/initiatives/freshwater/files/brisbane\\_declaration\\_with\\_organizations\\_final.pdf](http://www.nature.org/initiatives/freshwater/files/brisbane_declaration_with_organizations_final.pdf).
- Brown, T. C., 2001. Water for wilderness areas: Instream flow needs, protection, and economic value. *Rivers* 2: 311-325.
- Bunn, S.E. & Arthington, A. H. 2002. Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. *Environmental Management* 30: 492-507
- Busk, R. J., 2002. *Which Way Okavango? A Critical Analysis of the Application of Cost-Benefit Analysis in the Regional Allocation of the Okavango Basin Water*. Institute of Geography, University of Copenhagen, Copenhagen, Denmark.
- Cambodia, Royal Government of (Cambodia PRSP). 2002. *National Poverty Reduction Strategy 2003-2005*.
- Chowdhury, N. T., 2003. The Economic Value of Water in the Ganges-Brahmaputra-Meghna (GBM) River Basin. Department of Economics, University of Gothenburg, Gothenburg, Sweden.
- Christensen, B., 1982. *Management and Utilization of Mangroves in Asia and the Pacific*. FAO, Rome, Italy.
- Costanza, R., d'Arge, R., De Groot, R., Farber, S, Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P. and Belt, M. van den, 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260.
- Costanza, R. and Farley, J. (2007) "Ecological economics of coastal disasters: Introduction to the special issue" *Ecological Economics*, 63: 249-253
- Daily, G. 1997. *Nature's services*. Island Press, Washington, D.C., USA.
- De Groot, R., 1992. *Functions of Nature: evaluation of nature in environmental planning management and decision making*. Woolters-Noordhoff, Groningen.
- Dorfman, R. & Dorfman, N.S. 1993. *Economics of the environment: selected readings*. W. W. Norton & Company, New York, New York, USA.
- Drew, W. M., Ewel, K. C., Naylor, R. L. and Sigrah, A., 2005. A tropical freshwater wetland: III. Direct use values and other goods and services. *Wetlands Ecology and Management* 13: 685-693.
- Dyson, M. 2007. *Legal and governance regimes for effective management of environmental flows in Australia's Murray-Darling basin*, Adelaide Australia
- Dyson M, Bergkamp G, Scanlon J (eds). 2003. *Flow. The Essential of Environmental Flows*. IUCN, Gland, Switzerland and Cambridge, UK. Xiv +118 pp
- Emerton, L. and Bos, E. 2004. *Value. Counting Ecosystems as an Economic Part of Water Infrastructure*. IUCN, Gland, Switzerland and Cambridge, UK.
- Emerton, L. and Kekulandala, B. 2002. *Assessment of the Economic Value of Muthurajawela Wetlands*. IUCN, Sri Lanka Country Office, Colombo, Sri Lanka.
- Emerton, L. 1994. *An Economic Valuation of the Costs and Benefits in the Lower Tana Catchment Resulting from Dam Construction*. Acropolis Kenya Ltd, Nairobi, Kenya.





- Emerton, L., Iyango, L., Luwum, P., and Malinga, A. 1999. *Economic Value of Nakivubo Urban Wetland, Uganda*. IUCN, Eastern Africa Regional Office, Nairobi, Kenya.
- Emerton, L., Seilava, R., and Pearith, H. 2002. *Bokor, Kiriom, Kep and Ream National Parks, Cambodia: Case studies of Economic and Development Linkages*. IUCN Regional Environmental Economics Programme, Karachi, Pakistan.
- Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., Holling, C. S. 2004. Regime Shifts, Resilience, and Biodiversity in Ecosystem Management. *Annual Reviews of Ecology, Evolution, and Systematics* 25: 557-581.
- Framing Committee of the GWSP. 2005. *The Global Water System Project: Science Framework and Implementation Activities*. Earth System Science Partnership.
- Freeman, M. 1993. *The measurement of environmental and resource values: theory and methods*. RFF, Washington, D.C., USA.
- Gerrard, P. 2004. *Integrating Wetland Ecosystem Values into Urban Planning: The Case of That Luang Marsh, Vientiane, Lao PDR*, IUCN – The World Conservation Union Asia Regional Environmental Economics Programme and WWF Lao Country Office, Vientiane
- Gunderson, L. H. & C. S. Holling, (eds). 2002. *Panarchy: understanding transformations in human and natural systems*. Island Press, Washington, D.C., USA
- Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4:1-23.
- Hortle, K.G. 2007. Consumption and the yield of fish and other aquatic animals from the Lower Mekong Basin. *MRC Technical Paper No. 16*, Mekong River Commission, Vientiane. 87 pp.
- Ifrikhar, U. 2002. *Valuing the economic costs of environmental degradation in the Indus Delta*. IUCN. *Sea Intrusion in the Coastal and Riverine Tracts of the Indus Delta – A Case Study*. IUCN Pakistan Country Office, Karachi.
- IPCC 2007b: Kundzewicz, Z.W., L.J. Mata, N.W. Arnell, P. Doll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen and I.A. Shiklomanov, 2007: Freshwater resources and their management. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 173-210.
- IPCC, 2007a: Parry, M.L., O.F. Canziani, J.P. Palutikof and Co-authors 2007: Technical Summary. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 23-78.
- Isakson, R. S. 2002. *Payments for Environmental Services in the Catskills: A Socio-Economic Analysis of the Agricultural Strategy in New York City's Watershed Management Plan*, Report was elaborated for the "Payment for Environmental Services in the Americas" Project, FORD Foundation and Fundación PRISMA, San Salvador.
- IUCN Eastern Africa Programme, 2003. *The Pangani River Basin: A Situation Analysis*.
- IUCN, 2001. *Economic Value of Reinundation of the Waza Logone Floodplain, Cameroon*. IUCN.
- Iza, Alejandro (Ed.) 2004. *International water Governance: Conservation of Freshwater Ecosystem. Vol.1 International Agreements-Compilation and Analysis*. IUCN, Gland, Switzerland and Cambridge, UK. Xiii + 324pp
- Karanja, F., Emerton, L., Mafumbo, J., and Kakuru, W., 2006. *Assessment of the Economic Value of Pallisa District Wetlands, Uganda*. IUCN, Uganda National Wetlands Programme, Kampala, Uganda.
- King J.M., Brown C.A. & Sabet H. 2003. A scenario-based holistic approach to environmental flow assessments for rivers. *River Research and Applications*. 19: 619-639.



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Kirkland, W. T., 1988. *Preserving the Whangamarino Wetland – and application of the contingent valuation method*. Massey University, New Zealand.

Komulainen, M., Simi, P., Hagelberg, E., Ikonen, I. & lytinen, S. 2008. *Reed Energy – Possibilities using the Common Reed for energy generation in Southern Finland*. Reports from Turku University of applied Sciences 67, Turku, Finland

Kratz D (2006) *Going with the Flow: Preserving and Restoring In-stream Water Allocation. The World's Water: 2006-2007*, Gleick, P (Ed.) Island press

Kundzewicz, Z. W. Mata, L. J., Arnell, N. W., Döll, P., Jimenez, B., Miller, K., Oki, T., Sen, Z. & Shiklomanov, I. 2008. The implications of projected climate change for freshwater resources and their management. *Hydrological Sciences Journal* 53: 3–10.

Lake, P. S., Bond, N. & Reich, P. 2007. Linking ecological theory with stream restoration. *Freshwater biology*, 52: 597-615.

Loures. F. & Dellapenna, J. W. (2007) Forthcoming developments in international law: proposal for a way a head. *Water Environment* 21

Maier, H.R., Burch, M.D., Bormans, M. 2001 Flow management strategies to control blooms of the cyanobacterium, *Anabaena circinalis*, in the River Murray at Morgan, South Australia *Regulated Rivers: Research & Management* 17: 637 – 650

Mainka, S., McNeely, J. & Jackson, B. 2005. Depend on Nature: Ecosystem Services Supporting Human Livelihoods. IUCN – The World Conservation Union, Gland, Switzerland.

Maloti Drakensberg Transfrontier Project. 2007. *Payment for Ecosystem Services: Developing an Ecosystem Services Trading Model for the Mnweni/Cathedral Peak and Eastern Cape Drakensberg Areas*. Mander (Ed) INR Report IR281. Development Bank of Southern Africa, Department of Water Affairs and Forestry, Department of Environment Affairs and Tourism, Ezemvelo KZN Wildlife, South Africa.

Maslow, A. 1954. *Motivation and Personality*. Harper & Row, New York.

Meijer, K.S. and Hajjmiri, S. 2007. Quantifying Well-Being Values of Environmental Flows for Equitable Decision-Making: A case study of the Hamoun wetlands in Iran. *Journal of River Basin*. 5:223-233.

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-Being: Wetlands and Water Synthesis*. World Resources Institute, Washington, DC.

MRCS (Mekong River Commission Secretariat). 1998. *Inventory and management of wetlands in the lower Mekong basin*. Review and assessment report for Phase I. MRCS Environmental Unit, Bangkok, Thailand.

Murray Darling Basin Commission. 2003. *Prospects for future deterioration in flow in the Murray Darling Basin*.

Naiman, R.J., Bunn, S.E., Nilsson, C., Petts, G.E., Pinay, G. & Thompson, L.C. 2002. Legitimizing fluvial ecosystems as users of water: an overview. *Environmental Management* 30: 455-467.

National Research Council. 2004. *Valuing Ecosystem Services: Towards Better Environmental Decision-Making*. The National Academies Press, Washington DC.

O'Hara, S. L.; Wiggs, G., Mamedov, B. 2000. Exposure to airborne dust contaminated with pesticide in the Aral Sea region. *Lancet*, 355:627-629

Palmer M.A., Reidy Liermann C.A., Nilsson C., Flörke M., Alcamo J., Lake P.S. & Bond N. 2008. Climate change and the world's river basins: anticipating management options. *Frontiers in Ecology and the Environment*. 6: 81–89.

PBWQ/IUCN. 2007a. *Socio-economic baseline Assessment for Pangani River Basin: The Role of River Systems in Household Livelihoods*. Unpublished technical report. Pangani Basin Water Office, Moshi and IUCN Eastern Africa Regional Program.

PBWQ/IUCN. 2007b. *Pangani River System – State of the Basin Report – 2007*. PBWQ, Moshi, Tanzania and IUCN Eastern Africa Regional Program, Nairobi, Kenya.

Pearce D., Atkinson, G., and Mourato, S. 2006. *Cost-Benefit Analysis and the Environment. Recent Developments*. OECD Publishing.

Peterson, G.D., Allen, C.R. & Holling, C.S. 1998. Ecological resilience, biodiversity, and scale. *Ecosystems* 1:6–18.

Poff N.L., Allan J.D., Bain M.B., Karr J.R., Prestegard K.L., Richter B.D., Sparks R.E. & Stromberg J.C. (1997) The natural flow regime. *BioScience* 47: 769–784.

Postel, S. & Richter, B.D. 2003. *Rivers for life: Managing Water for People and Nature*. Island Press: Washington, DC.

Pusey, B.J. and Arthington, A.H. 2003. Importance of the riparian zone to the conservation and management of freshwater fish: a review. *Marine and Freshwater Research* 54: 1-16

Pyo, H. 2002. *The Measurement of the Conservation Value for Korean Wetlands Using the Contingent Valuation Method and Cost-Benefit Analysis*. Korean Maritime Institute, Seoul, Korea.

Gambia, Republic of the. November 2006. *Poverty Reduction Strategy: 2007-2010*. Department of State for Finance and Economic Affairs.

- Ramsar 2001. Wetland products. Wetland-values and function. The Ramsar Convention on Wetlands Background papers on Wetland Values and Functions: [http://www.ramsar.org/info/values\\_products\\_e.pdf](http://www.ramsar.org/info/values_products_e.pdf)
- Reiser D.W., Wesche T.A. & Estes C. 1989. Status of instream flow legislation and practise in North America. *Fisheries*. 14: 22–29.
- Richter, B. D., Warner, A. T., Meyer, J. L., Lutz, K. 2006. A Collaborative And Adaptive Process For Developing Environmental Flow Recommendations. *River Research and Applications* 22:297–318.
- Ringler, C. and Cai, X., 2003. *Addressing Environmental Water Values in an Integrated Economic-Hydrologic River Basin Modeling Framework*. Paper presented at the Workshop on Integrating Environmental Impacts into resource allocation models of the Mekong River Basin.
- Rogers, P., Bhatia, R., and Huber, A., 1998. *Water as a Social and Economic Good: How to Put the Principles into Practice*. TAC Background Paper No.2, Global Water Partnership, Stockholm, Sweden.
- Rosales, R., Kallesoe, M, Gerrard, P., Muangchanh, P, Phomtavong, S., and Khamsomphou, S. 2003. *The Economic Returns from Conserving Natural Forests in Sekong, Lao PDR*. IUCN, Asia Regional Environmental Economics Programme and WWF, Lao Country Office, Vientiane, Lao PDR.
- Sadoff, C. D., Whittington, D., & Grey, D. 2003. *Africa's International Rivers: An Economic Perspective*. World Bank, Washington DC.
- Sathirathai, S., 1998. *Economic valuation of mangroves and the roles of local communities in the conservation of natural resources: Case Study of Surat Thani, South of Thailand*. International Development Research Centre, Ottawa.
- Scanlon J, Iza A. A. 2003. International Legal Foundations of Environmental Flows. *Yearbook of International Environmental Law*. Oxford University Press, Volume 14
- Schuyt, K and Brander, L. 2004. *The Economic Values of the World's Wetlands*. World Wide Fond for Nature (WWF), Gland/Amsterdam.
- Schuyt, K and Jansen, J., 1999. *Economic Valuation of the Lake Chilwa Wetland*. Danida, Copenhagen, Denmark.
- Schuyt, K.D. 2005. Economic consequences of wetland degradation for local populations in Africa, *Ecological Economics* 53: 177–190.
- Seidl, A. F. & Moraes, A. S. 2000. Global Valuation of Ecosystem Services: Application to the Pantanal da Nhecolandia, Brazil. *Ecological Economics* 33: 1-6.
- Seyam, I. M., Hoekstra, A. Y., Ngabirano, G. S. & Savenije, H. G. 2001. *The Value of Freshwater Wetlands in the Zambezi Basin*. Conference of Globalization and Water Resources Management: the Challenging Value of Water.
- Silvius, M.J., Oneka, M, & Verhagen, A. 2000. Wetlands: Lifeline for people at the edge. *Physics and chemistry of the earth part B – Hydrology Oceans and Atmosphere*. 25: 645-652
- Slaymaker, T. & Newborne, P. 2004. *Implementation of Water Supply and Sanitation Programmes Under PRSPs: Synthesis of Research Findings from Sub-Saharan Africa*. London: Overseas Development Institute and WaterAid.
- Southgate, D. & Macke, R. 1989. Downstream benefits of soil conservation in Third World hydroelectric watersheds. *Land economics* 65: 38-48
- Tennant, D.L. 1976. Instream flow regimens for fish, wildlife, recreation, and related environmental resources. In: *Proceedings of the Symposium and Specialty Conference on Instream Flow Needs II* (eds J.F. Orsborn & C.H. Allman), pp. 359–373. American Fisheries Society, Bethesda, Maryland.
- Thibodeau, F. R. and Ostro, B.D. 1981. An economic analysis of wetland protection. *Journal of Environmental Management* 12: 19-30.
- Turner, R. K., Cooper, P., Paavola, J., Farber, P, Jessamy, V & Georgiou, S. 2003. Valuing nature: lessons learned and future research directions. *Ecological Economics* 46: 493-510.
- Turner, R. K., Pearce D., and Bateman I., 1994. *Environmental Economics*. Harvester Wheatsheaf.
- Turner, W.R., Brandon, K., Brooks, T.M., Costanza, R., Da Fonseca, G.A.B., and Portella, R. Global conservation of biodiversity and ecosystem Services. *BioScience* 57(10): 868-873.
- Turpie, J., Smith, B., Emerton, L., and Barnes, J., 1999. *Economic Valuation of the Zambezi Basin Wetland*. IUCN Regional Office for Southern Africa, Harare, Zimbabwe.
- UNEP GEO-4. 2007. *Global Environment Outlook: environment for development. Chapter 4: Water*
- United Nation: Official UN site: Ratification status Conventions. <http://untreaty.un.org>
- United Nations Development Programme (UNDP). 2005. *Environmental Sustainability in 100 Millennium Development Goal Country Reports*. New York: UNDP.
- US Environmental Protection Agency. 2008. *Subsidies for Timber, Minerals, and Water Extraction* Accessed November 25th, 2008 <http://yosemite.epa.gov/ee/epalib/incen2.nsf/02139de58cd4f6e18525648c00670434/52560d7e8b805baf85256acd0054e68a1OpenDocument>
- Wallace, K.J., Beecham B.C. & Bone, B.H. 2003. *Managing Natural Biodiversity in the Western Australian Wheatbelt: A Conceptual Framework*. Department of Conservation and Land Management, Perth.
- Welcomme, R.L, Bene, C., Brown, C.A., Arthington, A., Dugan, P., King, J.M. and Sugunan, V. Predicting the water requirements for river fisheries. In: *Wetlands and Natural Resource Management* (Verhoven, J.T.A., Beltman, B., Bobbink, R. and Whigham, D.F. Eds.) Ecological Studies Vol.190, Springer-Verlag, Berlin, Heidelberg, p.123-154.
- Woodward, R & Wu, Y., 2001. The economic value of wetland services: a meta-analysis. *Ecological Economics* 37: 257-270.
- World Bank. 2008. *Global Monitoring Report*, Washington, DC: World Bank.
- World Bank. 2001. *World Development Report – Attacking Poverty*. World Bank, New York, US.
- World Commission on Dams. 2000. *Dams and Development*. (<http://www.dams.org/report/>)
- World Resources Institute (WRI) in collaboration with United Nations Development Programme, United Nations Environment Programme, and World Bank. 2005. *World Resources 2005: The Wealth of the Poor – Managing Ecosystems to Fight Poverty*. Washington, DC: WRI.
- WWF. 2008. Living Planet Report. [http://assets.panda.org/downloads/living\\_planet\\_report\\_2008.pdf](http://assets.panda.org/downloads/living_planet_report_2008.pdf)
- Zhi, L., Guangchun, L., Yi, H., Shuang, Z., Sgobbi, A., Markandya, A., Gorla, A. & Giupponi, C. 2007. *Towards More Sustainable and Market-based Ecological Compensation Mechanism -A Pilot Project of Payments for Ecological and Environmental Services in Lijiang, China. A Study Report and Implementation Guide*. CI, TNC and the World Bank.



## Securing Water for Ecosystems and Human Well-being: The Importance of Environmental Flows

Healthy water ecosystems simultaneously serve multiple aspects of human well-being, especially among poor communities living close to the land-water interface. Ecosystem services have real economic value today and special importance in mitigating future problems and economic losses related to climate change. To preserve and benefit from these services, water managers

must ensure that an environmental flow regime is maintained in rivers and wetlands. The report highlights the connection between flows, ecosystem services and human well-being and concludes that environmental flows and the ecosystem services they support are critical to achieving all eight of the United Nation's Millennium Development Goals.



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