WATER AND FISHERIES

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Introduction

This paper highlights the importance of fisheries and aquaculture in management of the world's water resources. It underlines the value of these resources and the critical importance of managing water quantity and quality for fisheries and aquaculture as well as for other human uses. This will require more holistic approaches to water management and the effective governance systems these require.

The World's water

Water covers 70 percent of our planet's surface, and our water resources total some 1.3 billion cubic kilometres. However of this amount only 2.5 percent is freshwater, and only a small portion of our freshwater is directly available to support human lives. More than two thirds of the 35 million cubic kilometres of freshwater are in the form of ice and permanent snow concentrated around the two poles or at high altitude and almost a third (eight million km^3) is found underground, whether in groundwater basins or as soil moisture. Lakes and rivers, including associated wetlands, contain a mere 0.3–0.4 percent of the world's freshwater (105,000 km^3) (Shiklomanov and Rodda 2003).

The inherent scarcity of the world's freshwater is further exacerbated by its unequal distribution, variable demand, and the history of land and water management in different regions and countries of the world. As a result of this combination of factors, the past decade has witnessed growing concern at the water crisis being faced in many parts of the world. An increasing number of countries are suffering from severe water stress (UN 2003, Falkenmark 2001) and this has led to growing calls for more efficient use of water in all sectors. Agriculture is the main user of water worldwide and the growing call for water efficiency has led to calls for a Blue Revolution.

As calls for water efficiency have increased, so has awareness of the need to embrace a wider understanding of the value of freshwater and in particular of the role of freshwater in sustaining natural ecosystems and the values they provide for people (Dugan 2005, Postel and Richter 2003). It is in this context that there has been growing attention focused on the value of fisheries and aquaculture as components of water management strategies that improve water productivity. In the following sections we set out this value and the implications for land and water management.

Freshwater and the value of fisheries

Nearly all freshwater ecosystems support fisheries in one form or another and these resources contribute significantly to total water productivity (Dugan *et al*. 2007). These include fisheries in lakes and rivers, together with those in their many associated wetlands. They also include the fisheries in coastal systems that are dependent on the freshwater and nutrients provided through river outflows to coastal lagoons, deltas, and inshore waters.

The latest official estimates of freshwater fisheries production give a value of 9.2 million tonnes per year (FAO 2006). While this is much smaller than the catch from marine systems, inland fisheries have sustained a growing trend of about two percent per annum worldwide (FAO 2002) and the potential for further increase in production is high in some systems (Kolding and van Zwieten 2006).

The economic value of these freshwater fisheries is high. Europe's inland recreational fishery has been valued at USD 25 billion a year (Cowx 2002), and wild fisheries represent seven percent of Cambodia's GDP and four percent of Bangladesh's. With a farm-gate value of USD 28 billion in 2003, the contribution of freshwater aquaculture has increased rapidly in recent decades and is now the major contributor to total inland water production (Figure 1).

In some regions the potential of inland fisheries is underexploited. For example, in West and Central Africa Neiland and Bene (2006) have shown (Table 1) that fisheries provide livelihoods

Figure 1: Production trend of marine and inland capture and marine and inland aquaculture. *Source*: FAO 2004, in Dugan *et al*. 2007.

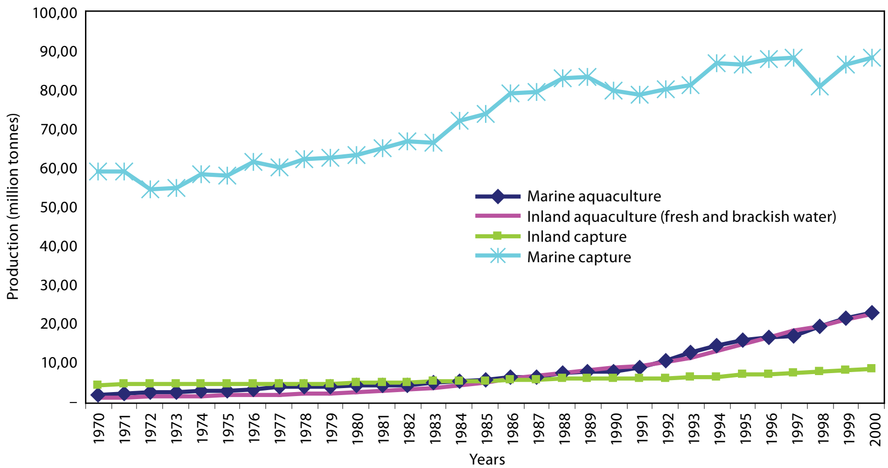

Table 1: Contribution of the fisheries of the major river basins and lakes in West and Central Africa to employment and income.

River basins and lakes	Employment (fishers)	Actual production		Potential production	
		Volume (metric tons per year)	Value (millions of USD per year)	Volume (metric tons per year)	Value (milllions of USD per year)
River basins					
Senegal-Gambia	25,500	30,500	16.78	112,000	61.60
Volta (rivers)	7,000	13,700	7.12	16,000	8.32
Niger-Benue	64,700	236,500	94.60	205,610	82.24
Logone-Chari	6,800	32,200	17.71	130,250	71.64
Congo-Zaire	62,000	119,500	47.80	520,000	208.00
Atlantic coastal	6,000	30,700	46.66	118,000	179.30
Lakes					
Volta	20,000	40,000	28.40	62,000	44.02
Chad	15,000	60,000	33.00	165,000	90.75
Kainji	20,000	6,000	3.30	6,000	3.30
Total	**227,000**	**569,100**	**295.17**	**1,334,860**	**749.17**

Note: Table excludes the numerous men and women who engage in part-time (seasonal or occasional) fishing. *Source*: Neiland and Béné 2006.

to more than 227,000 full-time fishers and yield and annual catch of about 570,000 tons, valued at USD 295 million (first sale value). They estimate however that the total annual fisheries production for this region (about 1.34 million tons with an estimated annual value of USD 750 million) is more than twice the estimated production.

As the analysis by Neiland and Béné (2006) indicates, inland fisheries are not only important for the value of the catch, but also because they provide an important source of income for 50–100 million people. For example, research in the Zambezi floodplain has revealed that inland fisheries generate more cash for households than cattle-rearing and in some cases more than crop production (Table 2). In Sri Lanka, recent economic valuations have shown the value of fisheries is about 18 percent of the total economic returns to water in irrigated paddy production (Renwick 2001). In addition, because fishers and, to a lesser extent, fish-farmers, can access cash year-round by selling fish, fisheries provide a 'bank in the water' for rural populations who lack access to formal financial systems. This contrasts with agriculture where farmers have to invest in, and wait for, harvest before earning cash returns.

Fisheries also serve as a major source of protein for more than one billion people, particularly in Asia and Africa. For example, people in Cambodia obtain about 60–80 percent of their total animal protein from the fishery of the Tonle Sap Lake and in Malawi, 70–75 percent of the total animal protein for both urban and rural low-income families comes from inland fisheries. This "rich food for poor people" provides a global average of 16 percent of the animal protein intake and also contains many vital vitamins, minerals, fatty acids and other micro-nutrients crucial to a healthy diet.

The water regime and inland fisheries

In view of the importance of fisheries and the potential of aquaculture, there is growing international recognition of the importance of ensuring that water is managed to secure these fishery benefits. Among the many challenges to achieving this, the most important is to sustain the quantity, quality, timing, and variability of the water flow they require (Welcomme and Petr 2004). Changes to water flow can occur naturally due to climatic variability, as seen in Sahelian rivers (Dansoko *et al*. 1976, Lae *et al*. 2004), but more commonly they result from human modifications to the flow regime, notably through the construction of dams and other water management structures, as a result of water off-take for agriculture, domestic and industrial use, and through land management changes in catchments.

These alterations in water flow generally lead to significant ecological changes in the rivers downstream, especially in those rivers that have significant floodplains and associated wetlands. These play an especially important role in fish feeding and breeding and reduced flooding reduces fish production (see also Box 1).

Reservoirs and most lakes also depend on flow from rivers or streams for their existence and productivity. Year-to-year fluctuations in the productivity of Lake Kariba and Lake Turkana illustrate the dependence of even large water bodies on river inflows – as these provide both variation in area and inflow of nutrients (Karenge and Kolding 1995, Kolding 1992). Other lakes, such as Lake Chilwa and Lake Chad, depend on inflow for their existence and in both, a reduction or failure in flooding from inflowing rivers results in diminished area and failure of their fisheries, although these are restored when more normal flow conditions reappear (van Zwieten and Njaya 2003). In the case of the Aral Sea water abstractions in support of irrigated agriculture for non-food crops led to the loss of about 50,000 tons of food fish per year (Petr 2004).

Coastal fisheries are also vulnerable to changes in freshwater inputs. For example, the pelagic fisheries of the eastern Mediterranean experienced a marked downturn following the regulation of the River Nile's flow by the Aswan High Dam (Nixon 2004). There is also evidence that coral reefs and their fish populations can be affected when freshwater discharge patterns are modified and in particular where land use results in excessive sedimentation. In fresh–salt water transitional zones in estuaries, changes to flow can affect the intrusion of salt water into the freshwater system and associated soils. This affects the distribution, reproduction, larval development and growth of many freshwater, brackish water and marine fish, crustacea and molluscs. Mangrove forests are particularly at risk in areas where coastal transition zones suffer changes in salinity by reductions in freshwater inputs or are degraded by declining sediment deposition.

Many forms of aquaculture are only viable if flow conditions are suitable. Successful rearing of fish generally depends on reliable supplies of clean water, although many rain-fed still-water ponds and more advanced recirculation systems may be extremely economical in their water use. Intensive running water culture systems need constant inputs of high quality water to ensure that there is sufficient oxygen for the fish and that wastes are removed; sufficient flow is needed in the river into which farm effluents are discharged to dilute wastes and nutrients without damaging the ecosystem (Brown and King 1996). In many parts of the world granting of licenses for fish farms is dependent

Table 2. Impact of other users of river and lake basins on fisheries (from Welcomme 2001).

Use	Mechanism	Effect
Power generation	Dams	Interrupt longitudinal connectivity
		Stops water flooding the floodplain (loss of habitat)
		Change water discharge patterns
		Sedimentation changes
		Entrainment of juvenile fish
		Entrainment of fish
	Uptake of cooling water	Changes to thermal regime
	Discharge of cooling water	
Flood control	Dams	As above
	Levees	Interruptions to lateral connectivity
Navigation	Dams	As above
	Channel straightening and deepening	Loss of habitat
		Changes in basin morphology
		Changes in the structure and functioning of the channel
		Wave creation and turbidity
Domestic use	Dams	As for dams
	Water transfers	As for water transfers
	Domestic sewage	Eutrophication or pollution
Agriculture	Dams	As for water transfers
	Water extraction	Altered flow regimes
	Diffuse fertilizers and animal wastes discharges	Eutrophication
	Pesticides discharges	Pollution
Forestry	Removal of vegetation cover	Altered runoff, increased sedimentation
		Acidification
	Monoculture of pines	
	Inappropriate use of alien species with high water requirements	Unsustainable use of groundwater
Industry	Waste discharge	Pollution
Mining	Discharge of waste and tailings	Pollution and increased sedimentation
Water transfers	Movement of water from one river to another	Changes in hydrology in donor and recipient basins
		Risk of transfer of organisms
Wildlife conservation	Protected areas	Usually positive reinforcing fisheries needs if incorporating sustainable use

on certain flow criteria being met and alterations to flow can place some of these in jeopardy.

This short review of the water management needs of fisheries and aquaculture illustrates how managing water for inland fisheries requires an ecosystem approach to the management of watersheds. This approach should consider not only water quantity and quality but also connectivity of the system because many highly mobile fish species need to be able to move between spawning, nursery and feeding areas within a basin. This management approach needs to consider land use practices, such as agriculture and forestry, as well as the needs of industry, urban areas and water borne transport that impact on basin processes and in turn on the quality, quantity and timing of flows (Table 2). The approach is further complicated by the fact that many river basins are transboundary and may be located across several countries. In these cases appropriate and effective international mechanisms to regulate and manage river flow are needed.

Environmental Flows

If fisheries and freshwater are to be sustained in river systems, water flows need to be maintained. These flows are called Environmental Flows (EFs) and, for fisheries purposes, are defined as that portion of the original flow of a river that is needed to maintain specific, valued features of its ecosystem or the quantity of water that must be maintained in a river system at all times to protect the species of interest for fisheries or for conservation and the environments on which they depend (Arthington *et al*. 2007). In addition to water quantity, EFs also need to consider factors of timing and rates of change (Box 1). Clearly a regulated river system cannot reproduce all aspects of natural flow, while at the same time providing for competing uses (Dyson *et al*. 2003). EFs are not intended to mimic a pristine river but rather to support the ecological functioning of the river to sustain its desired services to people and nature.

The type of environmental flow regulation needed to maintain fisheries depends on the primary cause of flow modification and the desired nature of the fishery in question. Restrictive management is required where water is abstracted directly from a donor waterbody. Some 70 percent of all water removed from rivers is for agriculture (FAO: AQUASTAT). Although this may be returned in part to the donor river, the discharged water may be of lower quality and quantity and the timing may also be inappropriate. The net impact of these high levels of removal on fisheries has rarely been investigated, although it is assumed from knowledge of the dynamics of fish populations in rivers that such effects are generally deleterious. However in some irrigated landscapes such as rice-farming systems, aggregated impacts of irrigation on fisheries production and on the livelihoods of fishing communities are not always negative at catchment level, as demonstrated in Laos and Sri Lanka by Nguyen-Khoa *et al*. 2005a.

Active management is required where releases from dams are involved. Damming has proved particularly detrimental to downstream fisheries (Jackson and Marmulla, 2000) by suppressing flood peaks and preventing the periodic inundation of floodplains downstream, altering their timing and preventing instream migration (Bunn and Arthington 2002) with negative consequences on the fishing communities. To combat these impacts artificial flow regimes are needed that allow for peak flows that are so timed as to act as triggers for breeding and should be of sufficient depth and duration as to flood riparian wetlands for sufficient time for young fish to grow. They should also allow fish to migrate, access riparian floodplains and otherwise complete their normal life cycles. The success of such approaches is illustrated by flood releases from the Pongolo Dam in South Africa that were sufficient to flood the Pongolo Flats downstream and rehabilitate the fisheries of the floodplain (Weldrick 1996). Active management can also be applied to poldered systems where the floodplain is enclosed to control flow for rice and other crops. Here correct management of the sluices controlling flow can favour fish as well as rice (Halls 2005).

While discussion of EFs has tended to focus first on water volume, we also need to consider quality. Good quality water is essential for breeding and growth of many fish species and the aquatic fauna and flora upon which they rely. Pollution by noxious chemicals, usually as a result of agriculture or industry, is always bad and, coupled with de-oxygenation caused by excess eutrophication, was responsible for the fishless nature of many European waterways in the 18th, 19th and early 20th centuries. The reversal of these trends, with the restoration of many fish species over most of the continent, emphasises just how significant rehabilitation and protection measures can be. Eutrophication is a problem mainly in lakes and reservoirs and has been the major cause of deterioration in such waters, to the extent that many initiatives to rehabilitate closed or semi-closed waters are based on control of nutrient inputs. In rivers, a certain amount of eutrophication appears to be a natural part of the downstream evolution of water quality but even this needs to be controlled to avoid total anoxia in the system and the elimination of species sensitive to low dissolved oxygen.

Intensive agriculture on riparian lands, coupled with inappropriate chemical use and land management is increasing chemical loading in the associated waterways. At the same time, changes in flow regime in rivers and discharge patterns to lakes can influence the dilution factors of pollutants and eutrophicating nutrients to a point where the waterbodies no longer provide adequate assimilation and aquatic organisms decline. Major demographic trends and increasing amounts of contaminated waters discharged by growing urban communities suggest that future trends will be for a lowering of water quality in many parts of the world. This trend is intensified by the designation by some countries of agriculture as the priority water use, because agriculture is itself the major source of diffuse water pollution and eutrophication.

RESPONSES OF FISH TO DIFFERENT FLOW CONDITIONS

After Welcomme and Halls 2004.

Most rivers have pronounced seasonality of flow throughout the year with one or more high water episodes (floods) alternating with periods of low flow. The relationships of fish to flow are complex and depend on various aspects of the hydrograph such as, timing, continuity, smoothness, amplitude, duration and rapidity of change of the floods (Figure 2). These are influenced by the extent to which the channels of the river are connected to the lateral floodplains and other seasonal wetlands. In rivers with less prominent floodplains the abundance of fish is conditioned more by the amount of water remaining in the river during low flow events.

Changes in flow affect different reaches of the same river in different ways. In upland reaches, alterations to natural flow regimes may affect the alternation of pools and rapids essential to the survival of fish. Deep water pools in rivers are particularly important as refuges and spawning grounds. In lowland reaches, the floodplain is essential to the reproduction, breeding and growth of many species. Flow manipulations alter the extent, duration and depth of wetland flooding and in some cases may suppress it entirely. The importance of the floodplain in maintaining fish catches is shown by the close correlation between flooding and catch in subsequent years.

Timing: The timing of the flood is important to many river fish species because of the synchronisation between physiological readiness, or stimulus, to migrate and spawn and the flood phase.

Continuity: Discontinuities in flow may be particularly damaging to breeding success and survival of young fish.

Smoothness: The smoothness of the flood is critical for certain types of spawning behaviour such as nest building and fish that spawn in marginal vegetation and shallow areas.

Amplitude: The amplitude of the flood is important for regulation of food production and spawning success. The greater the area of floodplain flooded the better the catch in the same or subsequent years.

Duration: The duration of flooding influences the time available for fish to grow and for them to shelter from predators.

Draw down: The dry season is a period of great stress to the majority of river fish species. At this time most species are confined to the main channels of the river although some specialists can survive in permanent floodplain waterbodies. Adequate water must remain in the system to ensure survival.

Box 1. Responses of fish to different flow conditions.

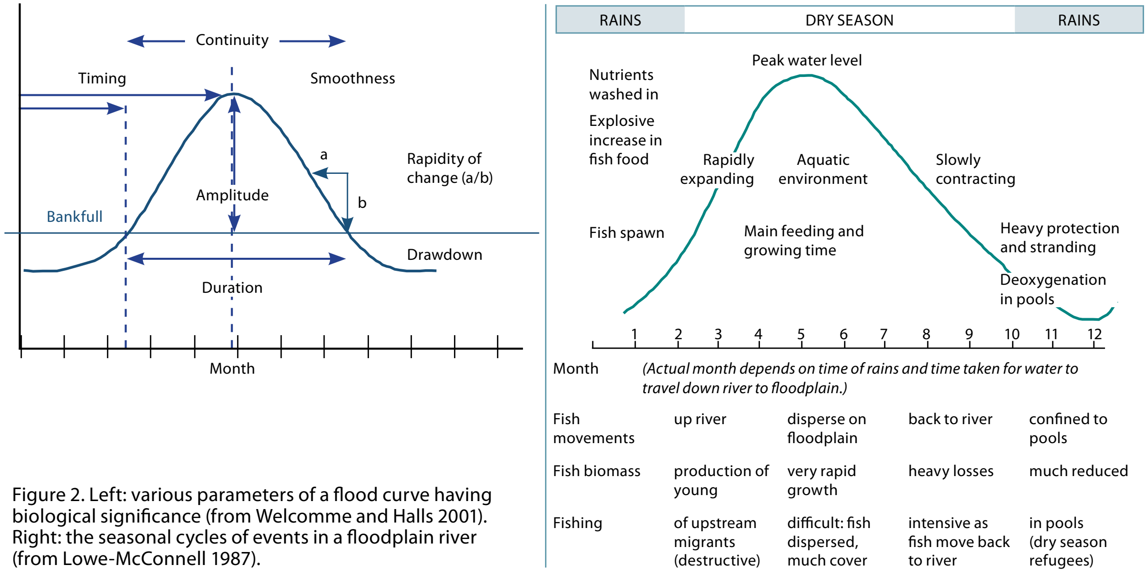

Figure 2. Left: various parameters of a flood curve having biological significance (from Welcomme and Halls 2001). Right: the seasonal cycles of events in a floodplain river (from Lowe-McConnell 1987).

Fisheries, agriculture, and water productivity

"Water productivity" is a tool to consider how to optimise the provision of services from water. The traditional use of the approach must however be considerably broadened to take fully on board the wider and more complex values that should be assigned to the benefits of fisheries and aquaculture. The value and future role of fisheries is substantial. The important but complex linkages between fisheries and poverty must be understood if desired poverty reduction outcomes through water use are to be achieved. It is not simply a choice between fisheries and other benefits from water. Well planned and managed systems can optimise all services. Fisheries and aquaculture considerations can be incorporated into agricultural systems resulting in net positive gains to water productivity. Agricultural practices can be modified so as to benefit fisheries, and where this incurs costs to agriculture these can be offset through increased net overall benefits. Tools are available to help achieve this outcome, although some need further refinement. The major constraints today are not technical but relate to the need for effective governance and institutional arrangements that enable the development of policies for water use that achieve clearly defined poverty reduction outcomes through fair, realistic and transparent trade-off decisions. Essential to this process is the effective and meaningful participation of stakeholders in the policy arena, and their involvement in management, particularly at the local level. Improved governance systems should be promoted based on the principles of subsidiarity and downward accountability, leading to a better integration of the needs and aspirations of the fishery-dependent communities into the wider multi-sector water management decision-making process. To support improved governance systems and improve poverty reduction outcomes major investment is required in the development of better valuation methods which demonstrate the full contribution of living aquatic resources, and in particular fisheries, to livelihoods.

Fish and other aquatic species can be integrated into other agricultural activities. For example, fish can be raized in rice fields or reservoirs. Integrated Agriculture – Aquaculture (IAA) optimizes the agricultural use of water and also presents numerous advantages such as the increased value of production, the reduction of risk and minimal labour required. Typically, "natural" rice paddies produce 120–300 kg/ha/year of diverse mixed fish and other animals which contribute directly to household diets and in some cases to profit margins. More intensively managed fish stocking and harvest has been shown to increase rice yields (due to weed control and the aeration of soils) by some 10 percent while producing up to 1,500 kg/ha of fish and reducing both the necessity for and costs of pesticides (de la Cruz 1994, Halwart and Gupta 2004). The community based management of fisheries, aquaculture and rice farming practiced in Bangladesh or Sri Lanka is a good example of achieving maximum synergy through appropriate technical and management interventions (Dey and Prein 2003). Fish production on these floodplains has increased from the traditional 50–70 kg/ha to 650–1700 kg/ha, while maintaining the rice production at 6–7 t/ha. Away from the paddy fields, livestock may be integrated with fish and crops where every constituent in the system helps to increase production and income. Livestock manures, household waste and cereal brans added to ponds feed aquatic plants and animals that in turn feed the fish; and finally, the mud that accumulates as sediment can be used to fertilize the land for fruit and vegetable crops. An additional benefit of the IAA system is that the water stored in farm ponds can be used to extend crop production into dry seasons, thereby increasing total production and attracting premium prices for out-of-season produce. This alone is a major asset and can greatly improve rural livelihoods in rainfed areas, such as in Africa.

Developing inter-sectoral policy framework adapted to inland fisheries

The consensus amongst practitioners and scholars is clearly that new evaluation techniques, investment approaches, and governance reforms can support and improve the contribution of fisheries and aquaculture to water productivity. The implementation of these approaches, however, still represents an enormous challenge for a large number of institutions in developing countries. Adaptive policy support mechanisms are required to ensure that reforms realise the potential benefits on offer in terms of local economic development and improved food security. In many countries the wider integrated natural resource management framework into which inland fisheries can fit is lacking. Effective policies for the conservation and sustainable use of freshwater biodiversity are also generally absent despite the increased recognition of its role.

Many countries have yet to develop national policy and legal frameworks tailored specifically for inland fisheries. More usually, inland fisheries continue to be placed under policy frameworks that evolved to address different coastal and marine fisheries issues. There is an urgent need for all countries to develop and implement frameworks specific to inland fisheries. These should in particular have explicit links to integrated approaches to sustaining aquatic environments.

An essential attribute of an effective inland fishery policy framework is the adoption of an ecosystem approach to fisheries (EAF). This is still a major challenge in the low-capacity and data deficient environment in less developed countries. However EAF offers a much better adapted framework for fishery management than the sector based approach still prevalent in the vast majority of those countries. This would involve fisheries considerations, and related environmental concerns, being included into integrated planning, particularly for water use. One mechanism to promote such integrated multi-sectoral approaches is through participatory scenario-based negotiations where the needs of stakeholder groups within fisheries can be better integrated with those of other interests, and take account of gender perspectives. These processes should in particular facilitate the establishment of inter-sectoral consensus mechanisms through the collective negotiation of land and water issues and their relationship to aquaculture and fisheries.

Acknowledgments

We thank the Comprehensive Assessment of Water Management in Agriculture for permission to base this paper on Dugan *et al*. 2007, and Robin Welcomme for use of Box 1.

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