10 Water Management for Ecosystem Health and Food Production

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Abstract

The integrated, efficient, equitable and sustainable management of water resources is of vital importance for securing ecosystem health and services to people, not least of which is food production. The challenges related to increasing water scarcity and ecosystem degradation, and the added complexities of climate change, highlight the need for countries to carefully manage their surface water and groundwater resources. Built upon the principles of economic efficiency, equity and environmental sustainability, integrated water resources management (IWRM) can be shaped by local needs to maximize allocative efficiency and better manage water for people, food, nature and industry. However, the flexibility of the approach means that it is interpreted and applied in ways that prioritize and address immediate challenges created by demographic, economic and social drivers, often at the expense of environmental sustainability – and hence also of long-term food security. The need to more explicitly include ecosystems in water management practices and safeguard long-term food security can be addressed partly by refining the notion of 'water for food' in IWRM as 'water for agroecosystems'. This would also serve to eliminate much of the current dichotomy between 'water for food' and 'water for nature', and deliver a more balanced approach to ecosystem services that explicitly considers the value and benefits to people of a healthy resource base. The adoption of an ecosystem services approach to IWRM, and incorporation of environmental flows as a key element, can contribute to long-term food security and ecosystem health by ensuring more efficient and effective management of water for agroecosystems, natural systems and all its other uses.

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Background

The water cycle enables ecosystems to provision goods such as food, fuel and timber; to regulate and support the environment and its biological diversity; and to provide for cultural services and fundamental ecological processes (Millennium Ecosystem Assessment, 2005; Gordon *et al*., 2010; Chapter 3). Thus, ecosystem integrity and long-term health are at the very centre of sustainable food production, and efficient, equitable and sustainable management of water resources is crucial for both ecosystem health and food production. The challenges related to increasing water scarcity and climate change (Chapters 2 and 5), highlight the need to achieve the greatest possible water use efficiency in an economically, politically, environmentally and socially acceptable manner. Several options for improving the efficiency of water use for both food production and the maintenance of ecosystem services have already been discussed, and the concept of environmental flows has been introduced (respectively, in Chapters 5, 8 and 9). Arguably, the more challenging issue has been how to implement these advances (e.g. Naiman *et al*., 2002; Rowlston and Tharme, 2008; Le Quesne *et al*., 2010) and to enhance water-use efficiency, while increasing food production and simultaneously meeting ecosystem needs. In many instances, the need to address this issue stems from the fact that water savings from agricultural efficiency are channelled back into further agricultural production, rather than to securing adequate long-term ecosystem health.

Historically, attempts to balance water for food, people, nature and industry have typically led to the further entrenchment of silo-like, sectoral policy making and planning at national government level, the result of which is fragmented water governance that takes little or no account of water uses beyond the interests and jurisdiction of individual sectors. Recognition of the lack of sustainability of such an approach under conditions of water stress, competing demands and high variability in water availability has resulted in an explosion of interest in integrated water resources management (IWRM) in recent years (e.g. Snellen and Schrevel, 2004). Since the adoption of the Agenda 21 principles in 1992, an increasing number of nations have introduced national policies that adhere to the principles of IWRM and include associated strategies (UN Water, 2012). In a global survey with 133 country responses, more than 70% stated that water management had been introduced in national policy and legislation to actively account for water resources development, impacts by other sectors and multiple demands (UN Water, 2012). Similar evidence exists for countries in sub-Saharan Africa over the last 10 years. In a survey of 24 eastern and southern African countries, it was clear that most countries had put into place the enabling conditions in terms of policies founded on the principles of IWRM (GWP Eastern Africa and GWP Southern Africa, 2010). The operationalization of IWRM still lags behind though owing to resources gaps in finance, and in human and institutional capacity.

Refining Integrated Water Resources Management (IWRM)

IWRM can be described as 'the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems' (GWP Technical Advisory Committee, 2000). Built upon principles of economic efficiency, social equity and environmental sustainability, sometimes referred to as the 'three Es', the IWRM approach offers the possibility of taking into account multiple economic, social and environmental needs. It takes the form and function of an all-encompassing management framework that can be used to consider and apply regulatory instruments, and to assimilate other practical measures that address water resources management. A good introduction to IWRM for policy makers and practitioners is the GWP (Global Water Partnership) ToolBox (GWP Toolbox, 2008).

Key to IWRM is an inter-sectoral approach that strives to ensure effective coordination of all sectors and uses of water; this is the 'IWRM comb' that is shown in Fig. 10.1. For example,

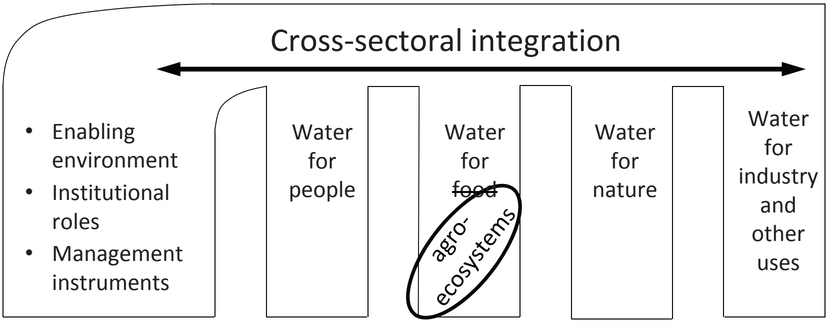

Fig. 10.1. The integrated water resources management (IWRM) comb (after GWP Technical Advisory Committee, 2000). Note: in this book, it is proposed to refine 'water for food' to 'water for agroecosystems', as discussed in the section entitled 'An Ecosystem Services Approach to Water Management' and shown in this figure.

planners for domestic water supply and sanitation (water for people), for irrigation and fisheries (water for food), for nature conservation (water for nature) and so on, must take other users' needs into consideration, particularly in terms of water allocation and the resulting impacts of allocation decisions. Management coordination based on a hydrological unit such as a lake, river or aquifer, rather than on political boundaries that may divide bodies of water, is another central aspect of IWRM. The combination of inter-sectoral and basin approaches makes IWRM suitable for efficient management of water in landscapes of various natural and agricultural ecosystems.

Some practitioners and scientists have criticized IWRM as being, for example, difficult to implement, insensitive to cultural differences and as not sufficiently encompassing emerging issues, such as climate change and water security (e.g. Biswas, 2004; Rahaman and Varis, 2005; Matz, 2008; Medema *et al.*, 2008; Chéné, 2009; Saravanan *et al.*, 2009).

However, in reality, IWRM plans and practices applied at regional, national and local levels are heavily influenced by local circumstances, requirements and interpretations (UN Water, 2012). For example, some stakeholders may refuse or be refused the opportunity to engage in an integrated management approach, and some plans may be developed based upon administrative borders, such as a city, or for a specific purpose, such as a flood situation, rather than on a specific hydrological unit, but the result may still be regarded by those involved as IWRM. While few would disagree that the operational reality of IWRM is highly complicated in trans-boundary situations (where various countries, states or regions have their own agendas and may be reluctant to cooperate with each other), many practitioners would agree that IWRM is just a tool, and it is the responsibility of those involved to determine how it should be used. Because of its flexibility and inclusiveness, IWRM is seen as a key prerequisite for ensuring climate resilience and water security (e.g. Kundzewicz *et al.*, 2007; WRG, 2009; AMCOW, 2012).

International efforts are currently being made to try to address the apparent conflict between short-term economic growth and sustainable water resource management by growing calls for green growth and green economy strategies that build upon the foundations of sustainable development (UNEP, 2011). In terms of future scenarios, the challenge that an increasing number of both developed and developing countries will face is how to reconcile a growing gap between water demands and available supplies in a way that meets their development objectives in a cost-effective way (WRG, 2009).

It is not unusual for political decision makers to work with operational planning horizons based on periods of no more than 5 years – what may or may not happen in 100, 50 or even 20 years is beyond their direct control.

As a result, priorities are typically shaped by the immediate challenges created by demographic, economic and social drivers; these, in turn, colour decisions regarding allocation efficiencies, and concerns about the environment are subordinated. From a resource policy and planning perspective, it is hence important to recognize the broad objectives that lie behind the promotion of sustainable or efficient water management through the adoption and application use of IWRM. For example, at the national level, countries invariably have numerous economic, social, environmental and political demands and counter-demands for multiple goods and services that require water as an input. Dealing with trade-offs and finding synergies between water for food and for other ecosystem services, as well as maintaining ecosystem integrity, is a huge challenge.

One way to address this challenge is through the application of a range of supply-side measures, such as: the development and operation of reservoirs and dams; improved maintenance of systems (including leakage control); rainwater harvesting; reuse/recycling of water; the development of surface and groundwater resources; and the application of water transfers. These measures increase the available resources; for efficiency, demand-side measures need to be applied as well.

Increasing Use Efficiency Through Demand Management and Allocative Efficiency

Considered in its most basic form, the term ‘water use efficiency’ assesses the amount of water needed to produce a given unit of any good or service (e.g. Seckler *et al*., 2003). As discussed in Chapter 8, water use efficiency usually takes into account the water input, whereas water productivity uses the water consumption in its calculation, although the terms are often used interchangeably.

Minimizing the amount of water needed (reducing the demand) for the same outputs will result in greater efficiency. The aim is not always to reduce water use, but rather to optimize its utilization. From a food production point of view, much of the attention in the area of water use efficiency is given to how to maximize the amount of material produced per unit of water (thereby increasing ‘water productivity’, as discussed in Chapter 8). Sharma *et al.* (2010) combine analyses of water productivity, poverty linkages and institutional constraints to generate a series of recommendations for better integrated water management in the Indus and Ganges Plains of India. From the standpoint of ecosystem health and services provision, the aim of water use efficiency is to optimize the provision of a range of ecosystem services for a given amount of water and to maintain ecological integrity (e.g. through environmental flow provision). As with food production, it is crucial for such optimization that water is provided at the right time and in the right amount and quality.

For certain water uses, such as agriculture, industry and cities, water demand management is an effective means of increasing water use efficiency. The ultimate benefits of water demand management can be expressed in different ways: as gains yielded by increased economic efficiency of water use; as avoided losses resulting from current or future droughts, or from environmental degradation or ecosystem sustainability; and as avoided or postponed capital costs of enhanced water production. These benefits are complementary, but may not necessarily reinforce one other. Where current water supply meets the demand under normal conditions, the water demand management policies can create ‘buffer’ capacity against periods of below-normal water availability and thus help to avoid some of the costs inflicted by drought. Finally, where some water demands cannot be satisfied, such as in drylands (Chapter 6), water demand management can help to achieve the production of more value from the available water.

Representative demand-side measures that can contribute to water efficiency include:

- The application of economic and market-based instruments to motivate desired decision making, such as water tariff schemes with increasing rates based on volume used.
- The introduction of technologies and methods to increase water utility, such as the use of treated municipal wastewater for irrigation.

- The application of regulatory instruments that can be used to guide users, such as laws on the quantity and timing of abstractions.
- Awareness raising and capacity building instruments, such as information campaigns that inform users about the consequences of their actions or inactions.

Where matching demand with supply is not possible, allocative efficiency, a form of demand management, may be adopted. The goal of allocative efficiency is to maximize consumer satisfaction from available resources (Economic Glossary, 2012). IWRM is a useful tool for facilitating allocative efficiency, as its application provides the means by which various uses can be weighed and compared. In theory, who gets which water in what quantities and when is regulated by principles relating to economic efficiency, social equity and environmental sustainability – the 'three Es'. However, as noted above, in real life IWRM is interpreted and applied in multifarious ways, so its application is not always in harmony with the 'three Es'. This creates another set of challenges and raises questions on what is included and what gets left out – and on what basis such decisions are made.

While demand management measures applied through IWRM may be useful for increasing water use efficiency for economic sectors in the short term, beyond the textbooks these measures are not yet adequately addressing the vital role of ecosystems in sustainable water management and food production. There is a need to more explicitly include ecosystems in demand management practices.

An Ecosystem Services Approach to Water Management

Regardless of the overall framework for water resources management, be it IWRM or some other, there is growing recognition that more practical approaches to the fundamental issue of ecosystem management must be employed to support food production, ecosystem resilience and environmental sustainability (Molden, 2007). Healthy ecosystems provide a wide range of valuable services (Millennium Ecosystem Assessment, 2005), and better ecosystem management can benefit agriculture and improve system water productivity in several ways (Chapter 3). Increased yields in resource-conserving agriculture can go hand in hand with reduced environmental impacts through increased water use efficiency and productivity, improved water quality and increased carbon sequestration. Balancing the goals of agricultural ecosystems with landscape ecosystem services can produce synergies and improve overall water productivity (Keys *et al.,* 2012). Water management that mimics natural water storage can improve agroecosystem water use at the same time as maintaining hydrological links with the surrounding landscape; this, in turn, preserves the water needed for additional ecosystem services (Keys *et al.*, 2012).

An integrated approach to land, water and ecosystem management could be based on IWRM (Falkenmark, 2003), could incorporate elements of the ecosystem services framework (ESF), and could benefit from a multiple-use water services (MUS) approach (van Koppen *et al.*, 2006, 2009). The three approaches are integrative by nature, and promote a more comprehensive view and analysis of water resources and uses, although they tend to be applied at different scales and with different entry points. For example, MUS is applied at the local level and with a focus on water supply infrastructure, IWRM starts with higher level policies, institutions or organizations, and ESF addresses ecosystems at the basin scale (Nguyen-Khoa and Smith, 2010).

More specific policy options and management approaches can help to strike a balance between increased food production and the preservation of ecosystems (Gordon *et al.*, 2010). For example, improved management practices on agricultural lands can increase the efficiency with which water is used to produce food, thereby allowing the opportunity for securing environmental flows with the saved water. Shifting from monocropping to multifunctional agroecosystems can create synergies among ecosystem services, meaning that all of the services are valued and cared for rather than just the crop yield output and its associated water productivity (Fig. 10.2)

(Molden *et al*., 2007; Nguyen-Khoa and Smith, 2008).

The conversion and integration of an agricultural production system into a multifunctional agroecological landscape that delivers more balanced combinations of ecosystem services will take time, even if such a conversion is immediately biophysically practicable and socially acceptable. It involves not only the management of water and other natural resources such as land, but also an integrated approach at landscape or basin level (this is discussed in more detail in Chapter 11). In the interim, the value of ecosystem services delivered by changes in agricultural practices can increase substantially through measures to increase water and land productivity, and interventions that support specific ecosystem functions (Molden, 2007).

So far, the focus of water management, including IWRM, has mostly been on planning, allocating and managing surface water resources for irrigation (agriculture), energy (hydropower), industry and domestic water supply, while recognizing the need to safeguard environmental flows for aquatic ecosystem functions in rivers, lakes, estuaries and other wetlands. However, water for irrigation is better dealt with as water for agroecosystems (Fig. 10.1), and water for nature (environmental flows) should be valued and managed on equal terms with other water uses. Furthermore, key ecosystem services depend on water in the soil profile and the aquifers that support terrestrial ecosystems. As a consequence of this, water resource management needs to adopt an ecosystem services approach, and to incorporate environmental flows and include soil water alongside surface water needs. Reconsidering the 'water for food' tooth in the IWRM comb (Fig. 10.1), and applying it as 'water for agroecosystems', would be a way to

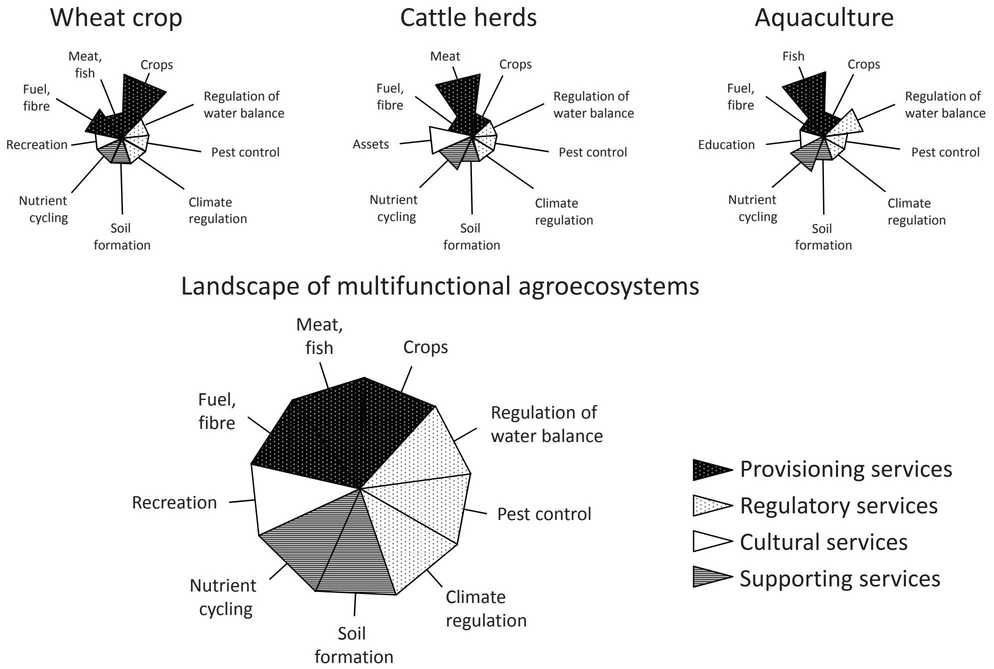

Fig. 10.2. Managing water for multifunctional agroecosystems would help a more balanced provision of provisioning, regulatory, cultural and supporting ecosystem services than single cropping (monocropping), extensive herding or peri-urban aquaculture (umbrella shape adapted from Molden, 2007; and Gordon *et al*., 2010).

eliminate much of the current, somewhat divisive dichotomy between ‘water for food’ and ‘water for nature’ (Fig. 10.3). Thus, it would help to deliver a more balanced approach to ecosystem services that explicitly considers the value and benefits to people of a healthy resource base.

A major challenge to adopting an ecosystem services approach to water management is that the role and valuation of water in regulatory and supporting services remains poorly understood (Chapter 4), both in agroecosystems and in non-agricultural ecosystems, particularly with respect to soil- and groundwater-dependent systems. Moreover, water and accessible biomass together comprise an estimated 99% of all provisioning services (Weber, 2011). So even if there is a deliberate and increased emphasis on applying a policy of truly integrated management, this may not be sufficient to ensure that all or most of the desired ecosystem services are accounted for. It is, therefore, important to encourage the use of adaptive management and adopt the precautionary principle when planning sustainable water management practices. Adaptive management, taking into account the adaptive capacity of the water resources themselves (precipitation, surface water and groundwater), as well as the adaptive capacity of their governing institutions (Pahl-Wostl *et al*., 2007; Pahl-Wostl, 2009), is also key to responding to the implications of climate and other environmental changes for water resources and ecosystems.

An important implication of adopting an ecosystem approach is that, in agroecosystems, more so than in natural ecosystems, water requirements will change according to societal decisions on the extent to which water use is to be optimized for the full range of ecosystem services or, more typically, and often at greater risk to ecosystem integrity, maximized for particular combinations of services. In the same way, society ultimately decides the future level of health at which any natural ecosystem

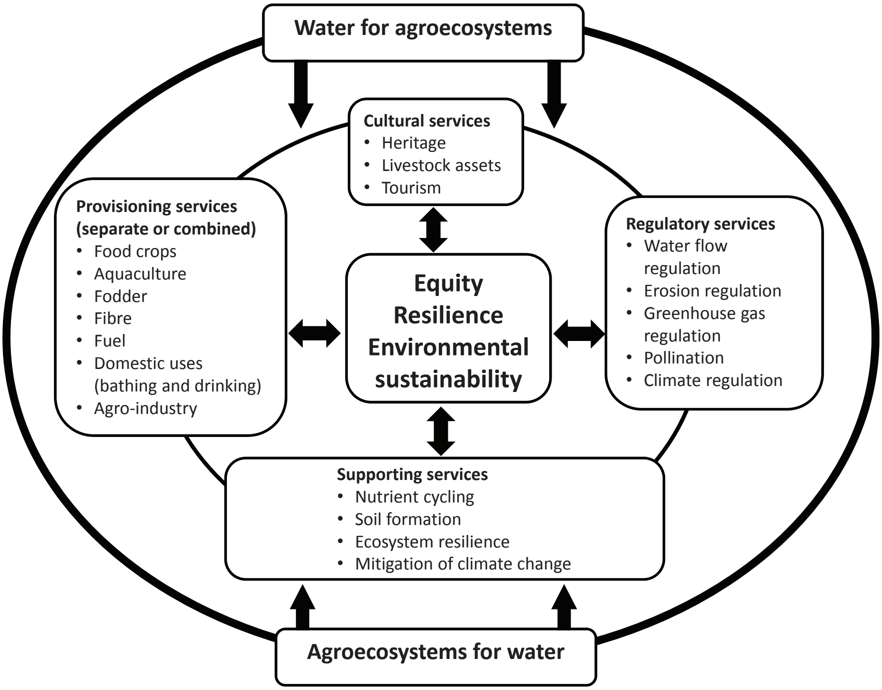

Fig. 10.3. Water for multifunctional agroecosystems would bring more equity, environmental sustainability and economic efficiency.

should be managed (Poff *et al.*, 2010). It is then a scientific question as to how much water is needed to achieve that particular level of health, and what the implications might be of not fully satisfying ecosystem water needs. Environmental flow assessments are an essential part of answering this question.

Applying Environmental Flows: Securing Water for Ecosystems

Water resources managers and scientists are increasingly integrating the concept and practices of environmental flows (Chapter 5) into IWRM, thereby increasing its likely uptake by other national, state and international actors. Such uptake is more likely to succeed where regulatory, economic and other market-based instruments, as well as awareness and capacity building, are applied within the IWRM framework to encourage greater water efficiency by planners and users.

Environmental flows may be thought of within an IWRM context in terms of 'environmental demand', similar to the way in which agricultural, industrial or domestic water demand are considered (Smakhtin and Eriyagama, 2008). These flows are aimed at maintaining an ecosystem in, or restoring it to, some scientifically defensible, societally prescribed or negotiated condition, also referred to as a 'desired future state', an 'environmental management class', an 'ecological management category' or a 'level of environmental protection' (e.g. DWAF, 1997; Acreman and Dunbar, 2004). In this way, environmental flows are commonly envisaged and approached as a negotiated trade-off, compromise or balanced optimization between objectives for river basin development on the one hand, and the maintenance of natural ecosystem integrity and biodiversity on the other (Naiman *et al.*, 2002; Postel and Richter, 2003).

The Global Environmental Flows Network has focused even more strongly on the connection with 'water for ecosystem services', defining environmental flows as 'the quantity, quality and timing of water flows required to sustain ecosystem services, in particular those related to downstream wetlands and aquatic ecosystems and the human livelihoods and well-being that depend on these ecosystems' (adapted from eFlowNet, 2010). In that sense, agroecosystems could also be integrated into the ecosystems served by environmental flows. Korsgaard *et al.* (2008) developed a Service Provision Index (SPI) that links ecosystem services to flows, and allows for the valuation of environmental flows in socio-economic terms; this could potentially be used to more effectively integrate environmental flows into IWRM. Thus, values are put on ecosystem services served by environmental flows in the same way as they are put on ecosystem services (beyond food production) from agro-ecosystems. The increasing application of environmental flow assessments is making the vital connection between ecosystems and environmental flows explicit (Tharme, 2003).

The importance of the entire range of daily, seasonal and inter-annual variations in water flows (or levels) in sustaining the complete native biodiversity and integrity of aquatic ecosystems is well established (Poff *et al.*, 1997; Bunn and Arthington, 2002). Maintaining this full spectrum of naturally occurring flows and their inherent pattern of variability in a river (or other water body) is, however, often not feasible given the various competing sectoral demands associated with water resources development (for domestic supply, irrigation, flood control, hydropower, navigation, etc.), as well as changes in catchment land use and climate. With increasing alteration of the water flow regime from its natural pattern comes increasing ecological risk (Richter, 2009; Poff *et al.*, 2010). Hence, the higher the level and degree of assurance of ecosystem health and delivery of ecosystem services that are required, the more water will need to be reserved or allocated – as part of water resources planning – for maintaining ecosystem condition, and the more the system's flow magnitude, timing and pattern of variability will need to be preserved.

Many methods for environmental flow assessment that directly or indirectly encompass the above tenets have been developed over the years (e.g. Tharme, 2003; Acreman and Dunbar, 2004; IWMI, 2007). They differ significantly in their required information and other resource needs and, therefore, in the commensurate degree of resolution and confidence in their recommendations, and level of water resource planning or management for which they are most suited. Moreover, the majority of approaches to date have been applied for individual rivers, reaches or infrastructure projects, rather than for river systems or multiple projects at the whole-basin scale (Poff *et al.*, 2010).

Rapid planning (desktop) methods, typically of the lowest resolution and confidence, are based primarily on hydrological indices derived from the analysis and characterization of hydrological time series (e.g. Tennant, 1976; Hughes and Hannart, 2003; Smakhtin and Anputhas, 2006); in recent years, increasing effort has been dedicated to using more ecologically relevant flow indices (Tharme, 2003). Other approaches, such as higher confidence holistic methods, follow a rigorous protocol that typically addresses diverse ecohydrological and social components and processes, involves significant fieldwork and time, and employs a multidisciplinary panel of experts to derive the environmental flows needed for the ecosystem and for any directly dependent communities (e.g. Arthington, 1998; King *et al.*, 2003; Esselman and Opperman, 2010; see also Box 10.1). These approaches also rely on monitoring and adaptive management of the implemented flow recommendations in order to ensure that water management objectives are met for all water users (Konrad *et al.*, 2011).

Until recently, few countries, states or basin agencies had initiated environmental flow determinations at the river network or basin level, or at even broader scales, arguably because the groundwork necessary for such an approach was not yet laid. With the emergence of the ELOHA (ecological limits of hydrologic alteration) framework for assessing environmental flow needs in a large basin or region, particularly when in-depth studies cannot be performed for all its rivers (Arthington *et al.*, 2006), it is now possible to set environmental flow standards rapidly across large geographies (see Poff *et al.*, 2010). At present applied largely within the USA (see Box 10.2) and Australia, ELOHA is fast gaining traction in other places, such as Latin America, where the need for greater environmental sustainability in basin water management is outpacing project-specific flow assessments.

Regional scale environmental flow assessments at whole basin, state or even country scales, often seem to promote more rapid and deeper engagement with national policy and regulatory frameworks and basin water resource management processes (as in the example in Box 10.2) than those at single project or site level. To date though, two of the major bottlenecks for the successful implementation of environmental flows, regardless of the scale at which environmental flows are determined, remain the inadequate involvement of stakeholders throughout the process and the lack of appropriate governance structures for effective implementation (Poff *et al.*, 2003; Le Quesne *et al.*, 2010). Recognition of this deficiency in water governance (Pahl-Wostl, 2009), coupled with inadequate inclusion to date of environmental flows into those global water assessments commonly used to examine future scenarios for water and food security, has resulted in various projects and programmes advocating further integration of these elements, so that true sustainability can be achieved in IWRM. An example is given by the Global Water System Project (GWSP; see Alcamo *et al.*, 2005) and its Global Water Needs Initiative (GWNI; see GWSP, 2013). Such initiatives continue to build on earlier work to address environmental water scarcity at a global scale – work which illustrated that even with the inclusion of environmental flow estimates of the order of only 20–50% of the mean annual flow in a river basin, large parts of the world already are, or will soon be, environmentally water stressed (e.g. Smakhtin *et al.*, 2004), so placing long-term resource sustainability at risk. However, this might not be the case if supporting and regulating ecosystem services in agroecosystems are enhanced through IWRM.

Conclusions

Built as it is upon the principles of economic efficiency, equity and environmental sustainability, integrated water resources management (IWRM) offers a comprehensive and adaptive management framework to support water

Box 10.1. Adopting a scenario-based approach to environmental flows in Tanzania. An example based on the Pangani River Basin Management Project (PRBMP) (IUCN, 2010; King *et al.*, 2010; PRBMP, 2010).

The Pangani River Basin covers about 43,650 km^2, mostly in Tanzania, with approximately 5% in Kenya. Flows in the basin have been reduced from several hundred to less than 40 m^3/s, as a result of largely uncontrolled irrigation and urban water demand. The remaining water is seriously over-allocated, with shortages affecting all water users – from mid-basin irrigators, to electricity producers further downstream, to coastal fisher communities with declining fish stocks owing to saline intrusion; conflicts are thus on the rise among the various sectors.

The International Union for the Conservation of Nature (IUCN), through its Water and Nature Initiative (WANI; see Smith and Cartin, 2011), started the multi-partner Pangani River Basin Management Project (PRBMP) in 2001 in order to improve management of the basin's water resources and to reduce the conflicts that were arising. The project aimed to: (i) assess environmental flow requirements to effectively conserve the basin's natural resources; (ii) establish fora for community participation in water management; and (iii) raise awareness about climate change impacts and adaptation strategies.

The project's flow assessment, undertaken in 2004–2008, used a modified Downstream Response to Imposed Flow Transformations process (DRIFT; see King *et al.*, 2003), and involved field and desktop work by a multidisciplinary expert group. Fifteen development scenarios and their associated flow scenarios were evaluated, and three reports were generated: 'state-of-the-basin'; 'flow assessment-scenario evaluation decision support system (DSS)'; and 'water allocation scenarios'. The results are currently being presented to stakeholders at all levels, with particular emphasis on the Pangani Basin Water Board (formerly Office), the governmental organization responsible for allocating water in the basin. Consultations with stakeholders are intended to raise awareness of the water issues in the basin, help select the best development path for the river and facilitate the integration of the selected environmental flow scenario into an integrated water resources management (IWRM) plan for the basin.

Box 10.2. Basin to statewide application of ELOHA in Colorado, USA: the Watershed Flow Evaluation Tool (Sanderson *et al.*, 2011).

To meet the need for regional flow management that addresses environmental sustainability in Colorado State, USA, the ELOHA (Ecological Limits Of Hydrologic Alteration) framework (Poff *et al.*, 2010) was applied to develop a Watershed Flow Evaluation Tool (WFET) for estimating flow-related ecological risk at a regional scale. The WFET entails: (i) modelling natural and developed daily streamflows; (ii) analysing the resulting flow time series; (iii) describing the relationships between river attributes and flow metrics (flow–ecology relationships); and (iv) mapping of flow-related risk for key in-stream and riparian biota. Two watersheds with differing geomorphic settings and data availability were studied, and the WFET was successfully implemented to assess basin flow-related ecological risk in one of them; active channel change and limited data precluded a successful application in the second basin. The WFET will be further used in Colorado to evaluate the risk of impacts on river ecosystems under future climate change, and to evaluate and balance ecosystem needs at the large scale within water development scenarios, such as for municipal water supply or energy development.

management for healthy ecosystems and food security. Associated economic and market-based, regulatory, awareness and capacity building instruments can be applied to manage demand and encourage greater water efficiency by planners and users.

As the focus of IWRM so far has mostly been on planning, allocating and managing surface water resources for irrigation, industry and water supply, there are good opportunities to recognize and embrace the need to safeguard environmental water for aquatic ecosystem health and long-term resiliency. The provision of key ecosystem services depends on adequate surface water, water in the soil profile and the aquifers of groundwater-dependent wetland and terrestrial ecosystems. Consequently, water resource management needs to adopt an ecosystem services approach that incorporates all elements of the water resource and give due attention to the value of allocating water for ecosystems – agroecosystems and non-agricultural or natural ecosystems alike. Better ecosystem management can, in turn, benefit food production and improve system water productivity in several ways.

To reflect this more directed focus on ecosystems, it is proposed to rephrase the ‘water for food’ tooth in the IWRM comb to ‘water for agroecosystems’. This approach will avoid much of the current dichotomy between ‘water for food’ and ‘water for nature’ (or environmental flows) and help to deliver more balanced suites of ecosystem services, including those essential for food security.

The concept of environmental flows provides a basis for calculating the amount of water (quantity, quality and timing) required to sustain ecosystems and safeguard their services to people. This can also be applied to the ‘water for agroecosystems’ tooth in the IWRM comb. Water resource managers are increasingly applying the concept of environmental flows to IWRM and adopting the associated best practices, thereby increasing its likely uptake by other national and international actors.

To conclude, managing water efficiently for agroecosystems, nature and all other water uses by incorporating environmental flows and adopting an ecosystem services approach to IWRM can contribute to basin water sustainability, long-term food security and ecosystem health.

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