3 Water-related Ecosystem Services and Food Security

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Abstract

The ecosystem setting of both agriculture and water provides a conceptual framework for managing the needs of agriculture for water and the impacts of water upon agriculture. Water underpins all benefits (ecosystem services) that ecosystems provide, including all agricultural production. The availability of water, in terms of both its quantity and quality, is also influenced heavily by ecosystem functioning. Understanding this relationship of water, ecosystems and their services with agriculture is at the heart of understanding, and therefore managing, water and food security. There are opportunities to move beyond seeing the agriculture–ecosystem–water interface as one of conflict and trade-offs, towards simultaneously achieving both increases in sustainable food production and improvements in the delivery of other ecosystem benefits by agriculture through more widespread adoption of ecosystem-based solutions. These concepts and approaches are explained briefly here as an introduction to understanding the interlinkages between ecosystem services, water and food security in subsequent chapters of the book.

Background

The water cycle is a biophysical process, heavily influenced by ecosystem functioning. The healthy functioning of ecosystems underpins a multitude of benefits (services) derived from ecosystems. Water is a critical component in maintaining these functions, while keeping them resilient to change (Costanza *et al*., 1997). The presence and absence of water in the landscape very often determines the characteristics of several supporting and regulating functions, e.g. preserving nutrients and removing pollutants (Falkenmark, 2003).

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This chapter provides an introduction to how agriculture depends upon, and influences, water in this ecosystem context. Importantly, this context brings with it opportunities for managing ecosystems as solutions to achieve water and food security, which are further developed in subsequent chapters in this volume, notably in Chapters 4 and 9.

The water cycle at the agroecosystem scale is illustrated in Fig. 3.1. Water is a key factor to be managed to enhance agricultural benefits, whether in rainfed or in irrigated farming systems. In rainfed farming systems, management aims to maximize soil infiltration of rainwater and soil water holding capacity or, in some cases, to drain excess water to ensure good growth. In irrigation, the same management aim is met from water derived from external sources (surface or groundwater sources) at timely intervals for the crop.

The implications of considering water in this ecosystem context are twofold. First, as explained further below, water underpins many ecosystem benefits, food production being only one. Although it has long been established that using water in agriculture has implications for other uses, there remains, in many circles, limited understanding of how these impacts are delivered, their importance and how they can be managed. Secondly, water management policies in agriculture can be dominated by considering visible surface water and groundwater (e.g. irrigation), whereas the less visible parts of the water cycle (e.g. land cover and cycling through soils) are important and can often be underemphasized. Molden (2007), for example, noted that while potential productivity gains are available in irrigated agriculture, perhaps the biggest opportunities lie with rainfed agriculture, which largely involves improving rainwater retention by soils (see Chapter 8). Some ecosystem-driven aspects of the water cycle that merit better attention include:

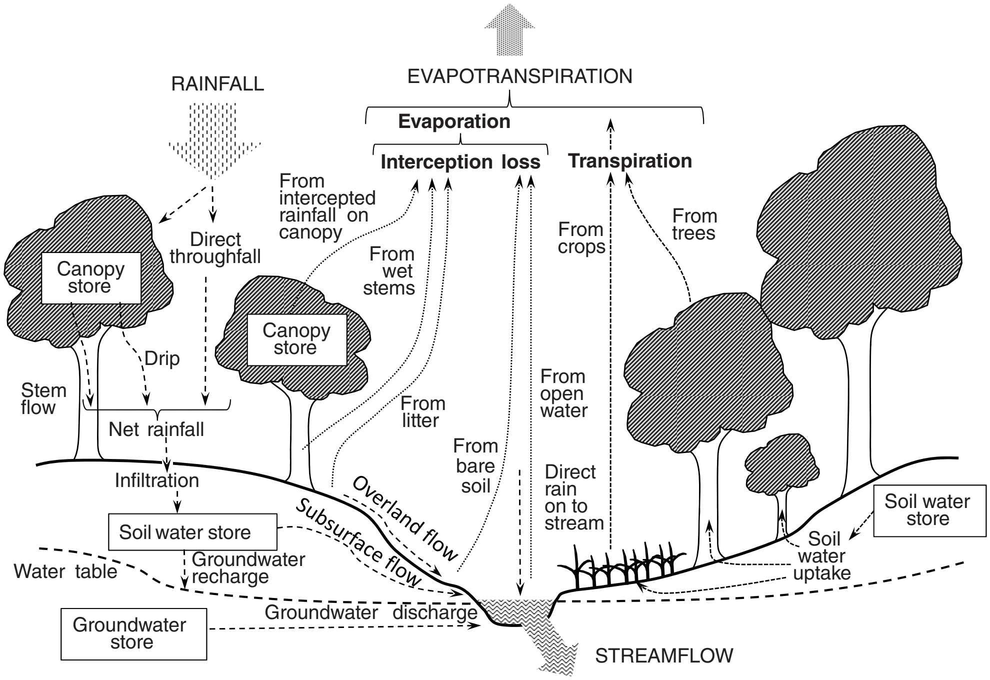

Fig. 3.1. The hydrological cycle in an agroecosystem.

- The role of wetlands in regulating surface, and in some cases groundwater, flows (see Chapter 7).
- Soil functionality, particularly in retaining water not only as water security for crops but also as a major component of the overall water cycle (desertification, for example, is a process essentially driven by loss of water from soil; see also Chapter 4).
- The importance of vegetation (land cover) as a major component of the water cycle (Box 3.1).
- How ecosystems can be regarded as a 'natural water infrastructure', which functions in a similar fashion to human-built (physical) infrastructure and therefore offers options for addressing water management needs.

Water management in agriculture thus essentially requires a very comprehensive approach. In many situations, focusing too much on managing visible surface water results in water 'supply' (in terms of the absolute quantity of physical surface water) being considered an unmanageable variable (driven essentially by unpredictable rainfall). In fact, this is far from the case, as Box 3.1 illustrates.

The ecosystem context of water presents a paradigm shift in how we think about the water–food–environment interface. Historically the water–environment interface has been largely one of conflict in which the 'environment' (or ecosystem!) has been regarded as an unfortunate but necessary victim of development. An alternative approach is to view water management as the management of water use and ecosystems in order to deliver multiple ecosystem benefits in a mutually supporting way (Fig. 3.2).

Agroecosystems

Agriculture is an ecosystem management activity from which primary and secondary agricultural products are appropriated by humans (Fresco, 2005). An 'ecosystem' can be defined as a dynamic complex of plants, animals, microorganisms and their non-living environment, of which people are an integral part (UNEP, 2009). All agricultural activities depend on a functioning ecosystem, for example healthy soil or the presence of pollinators, but can also have impacts on the ecosystem beyond the immediate interests of agriculture, for example downstream water pollution. Defining the management components of ecosystems is largely a matter of scale. Discrete ecosystem types can often be identified (for example, soils, wetlands, mountains, drylands, forests) but, although some management activities might focus on these discrete elements (for example, managing soil in a field), the reality is that all these components are interconnected, and particularly so through water (see Figs 3.1 and 3.3).

In this book, we refer to areas where agriculture is the dominant land use activity as 'agroecosystems' in order to recognize both the dependency of agriculture on the ecosystem and its setting within the broader landscape (Conway, 1987). Certain components of agroecosystems are particularly relevant to the

Box 3.1. The importance of vegetation in managing water

Deforestation can decrease regional rainfall through the loss of cloud-forming evapotranspiration from the forest. Local climate then becomes drier, thereby accelerating ecosystem change. Science suggests that in the Amazon, for example, feedback loops mean that apparently moderate deforestation of 20% could mean that a tipping point is reached beyond which forest ecosystems collapse across the entire basin (Vergara and Scholz, 2011). This would have devastating impacts on water security and other ecosystem services that would reach far beyond the Amazon Basin itself, including through impacts on regional agriculture and global carbon storage. Worryingly, deforestation in the Amazon is already of the order of 18% (Vergara and Scholz, 2011).

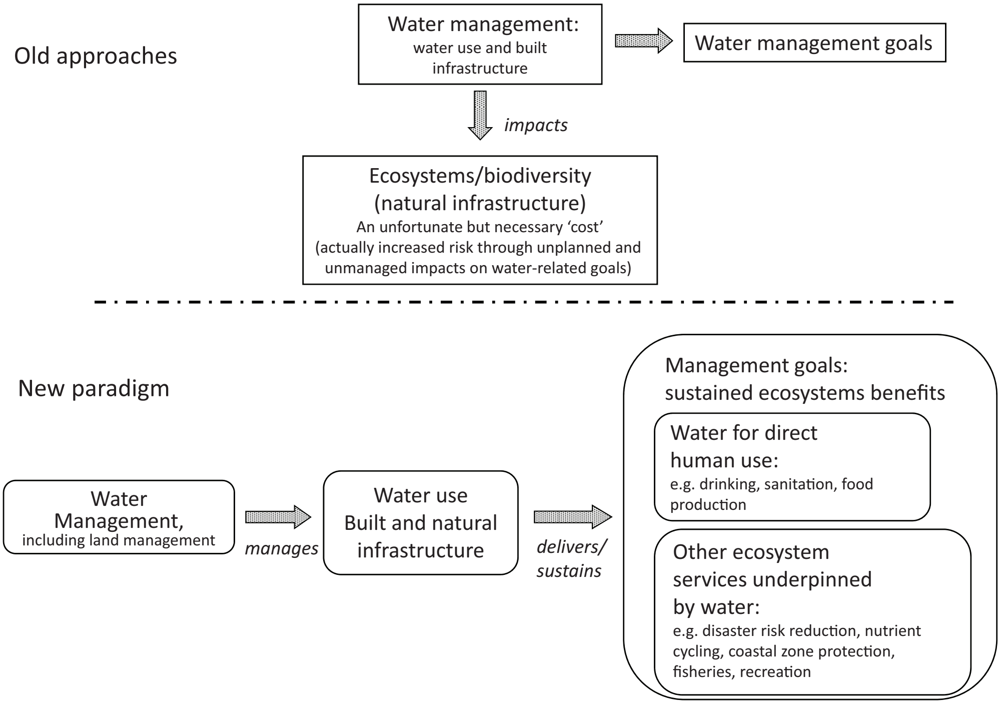

Fig. 3.2. Evolving approaches to the water–ecosystem interface.

scope of water and food security. These include: open water bodies (such as wetlands, rivers and lakes) that can supply water to agriculture but also compete with agriculture over water, and are affected by agrochemicals such as fertilizers and pesticides; and soils, which are the immediate source of water for most crops. Most agroecosystems, certainly at the larger scale, contain a mosaic of multiple land use types. These can vary from, for example, large expanses of natural or managed forest and plantations, such as coffee and rubber plantations, through to hedgerows used to divide fields or protect riverbanks, interspersed with human settlements and transport infrastructure. The combinations of land use types and activities, together with the topographic and climate setting, results in certain clearly identifiable agroecosystem types, such as the rice systems in South-east Asia or the vast cereal plains of the Midwest USA. Each of these has its own particular issues of vulnerability and management.

In order to understand ecosystem services, this book considers a continuum of ecosystem conditions from undisturbed pristine ('nature') areas to highly managed and altered systems. While the condition of an ecosystem can greatly determine its ability to function, and therefore provide services (benefits), a highly modified area (e.g. intensively monocropped farmland) is still an ecosystem. Debate about 'natural' versus 'managed' ecosystems is largely redundant as approaching 90% of the earth's terrestrial surface is influenced, in at least some respect, by human activity (Ellis and Ramankutty, 2008; Ellis, 2011). Almost all so-called natural ecosystems are influenced by people as hunters, gatherers and foragers actively managing the landscape to facilitate their harvesting of food and other useful products (Bharucha and Pretty, 2010). If climate change influences are included, there is arguably no 'natural' area left at all. The focus needs to be: what services do we want the landscape to provide (including, where desired,

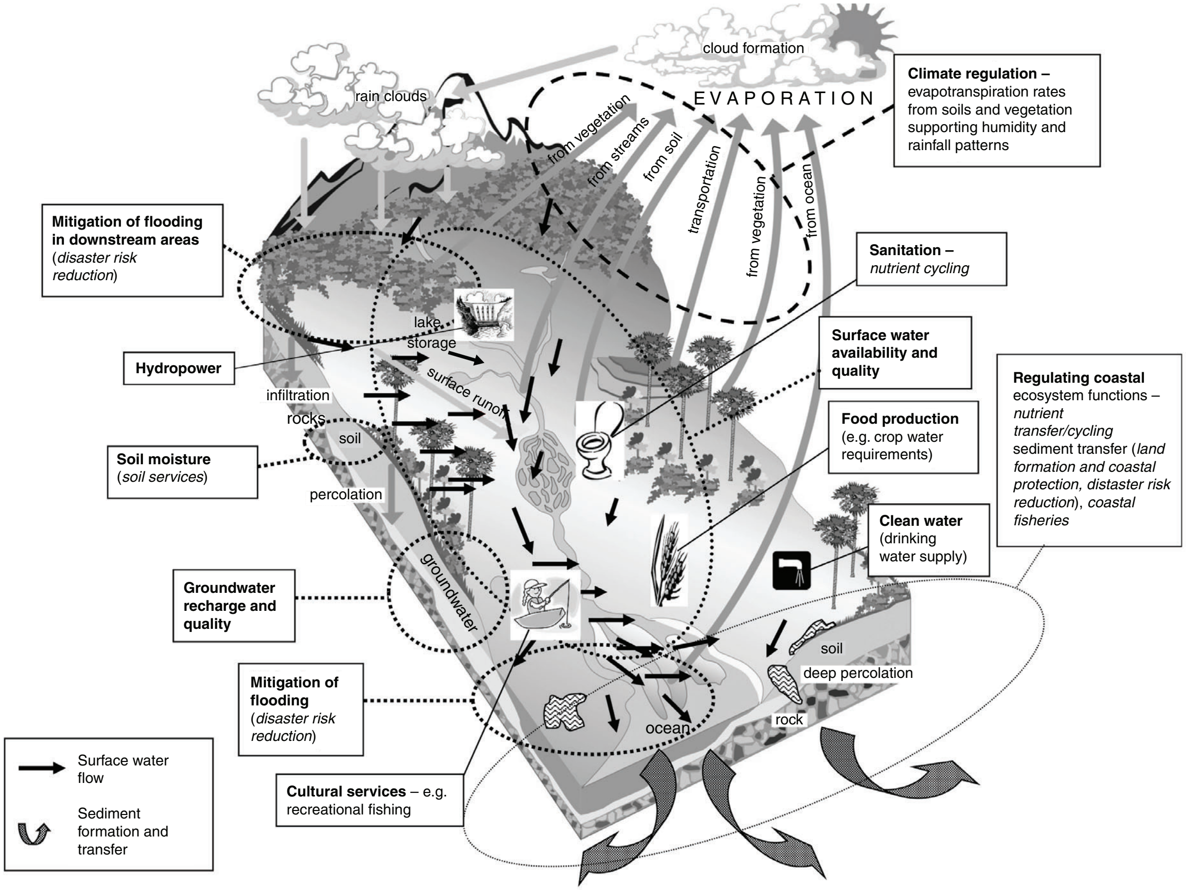

Fig. 3.3. A conceptual framework illustrating the water cycle and ecosystem services in a simplified landscape setting. The figure lists in italics (in the boxes) some of the water-related benefits to people (ecosystem services) that ecosystem functioning provides. In reality, the various services illustrated, and others, are more dispersed, interconnected and affected by land- and water-use activities (not shown in full) (based on MRC, 2003).

the various benefits of 'nature') and how can it be managed in order to sustain the desired supply of those services.

An agroecosystem perspective also helps to give value to ecosystem services (see next section). According to FAO, agroecosystems are ecosystems in which humans have exercised a deliberate selectivity and modified the composition of existing fauna and flora for agricultural purposes (OECD, 2011). Together, these agroecosystems cover over a third of the total terrestrial area. Agroecosystems both provide and rely upon important ecosystem services (Zhang *et al*., 2007). For example, sustainable flooded rice–aquaculture systems build upon the disease and pest regulation and nutrient cycling services provided by a healthy aquatic ecosystem to underpin food production (of both rice and fish), and also provide nutrient cycling and water regulating services beyond agriculture.

Agriculture in the ecosystem context has been explored in detail by the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) (McIntyre *et al.,* 2008). In addition to providing food (for a nutritious diet), fibres, fuel, fodder and related employment (agriculture is a major employer: globally, 40% of livelihoods depend on it; McIntyre *et al*., 2008), agriculture also delivers a variety of other goods and ecosystem services, and fulfils various social and cultural roles. For example, farmers are key stakeholders in managing landscapes and the cultural benefits associated with them.

Aquaculture has been an integral part of many agroecosystems for thousands of years, producing additional food and cash to supplement crop and livestock production, making more efficient use of feed and fertilizer inputs, and facilitating nutrient retention and recycling from manure, agricultural and food processing by-products, and domestic wastewater. It is especially crucial for poor women who often have few other income-earning opportunities (UNFPA, 2009).

The characteristics of various types of agroecosystems are determined by environmental factors (e.g. climate, topography, water availability and soil type in which they are situated) but also by the socio-economic setting, including demand for products, traditional and historical practices, supporting policies, technical capacity and financial capital availability. These, together with other factors, determine the farming systems in place and the way they evolve. Water availability plays a key role in farmers' risk management strategies. Water availability varies naturally throughout the year, and between years, in most farming systems. The inability to predict the exact amount available throughout a growing season results in significant uncertainties for farmers. However, the highest level of risk is associated not with mean supply but with extremes in water availability from both flooding and drought. Farmers adopt various strategies to cope with such risks; for example, through crop diversification, so they have at least some production in the event of an extreme event. None the less, the very existence of water-related risks is a major constraint to investment aimed at increasing agricultural productivity, particularly for poor, and therefore more vulnerable, farmers.

Ecosystem Services

The benefits that we as humans derive from ecosystems, such as timber, food, water and climate regulation, are referred to collectively as ecosystem services (Millennium Ecosystem Assessment, 2005a); further details are provided in Chapters 4 and 9. The concept of ecosystem services is used to analyse trade-off scenarios when human well-being and ecological sustainability need to be addressed simultaneously. The ecosystem perspective aims to bridge interdisciplinary gaps between fields as far apart as religion and biology, political science and geology or engineering and biodiversity, thereby addressing the system comprehensively.

The availability of water at any time or place, in terms of both its quantity and quality, is also a service provided by ecosystems, and one of obvious importance to agriculture. Because water is required for ecosystems to function, all ecosystem services (excepting some of those provided by marine environments, particularly oceans) are underpinned by fresh water (Aylward *et al*., 2005; UCC-Water, 2008).

Ecosystem services can be grouped into four different types (Millennium Ecosystem Assessment, 2005a), as follows:

- *Provisioning services* are essentially the tangible products (or goods) that are used directly by humans. These are among the most recognizable in terms of human use and are thus most frequently monetized but are not necessarily the most valuable. Relevant examples include freshwater (directly used, e.g. for drinking), energy from hydropower and all food (including all the products of agriculture, livestock rearing, forestry, fisheries and wild-caught products such as bushmeat). Globally, provisioning services have been maximized, particularly by agriculture, at the expense of reductions in other services (listed below), resulting in a serious imbalance (Millennium Ecosystem Assessment, 2005a).
- *Regulatory (or 'regulating') services* are the benefits that ecosystems provide in terms of regulating ecosystem-dependent processes. Relevant examples include: climate regulation (including precipitation), water regulation (i.e. hydrological flow), water purification and waste treatment, erosion regulation and water-related natural hazard regulation. Such services are sometimes less tangible at farm and field scales, and can be more difficult to assess economically (although there are exceptions; natural hazard regulation, for example, is more easily assessed because the impacts of disasters can often be quantified in fairly standard economic terms). In some instances, these services can be replaced by technology but often at a higher cost than that of maintaining the original service (Cairns, 1995): e.g. any infrastructure or operational costs in treating water to make it potable are essentially expenditures on replacing the original water purification and supply functions of ecosystems, which previously provided this service free.
- *Cultural services* include the spiritual and inspirational, religious, recreational, aesthetic and educational benefits that people derive directly or indirectly from ecosystems: for example, the recreational benefit of a lake for fishing. Some are more easy to value (e.g. through amounts spent on recreation, including transport and accommodation costs), but others are less tangible and often difficult to quantify or monetize. Nevertheless, the importance of cultural service values should not be underestimated; they represent some of the clearest examples of the pitfalls of monetized economic valuations. An example is the case of pastoral livestock, where cultural values can override economic values in terms of development and land management, and include 'antiquity, role in the agricultural systems, farming techniques, role in landscape, gastronomy, folklore and handicrafts' (Gandini and Villa, 2003).
- *Supporting services* are those that underpin broader ecosystem functioning and hence contribute to sustaining other services. Examples include soil formation and nutrient cycling, both of which are essentially water based and aquatic ecosystem driven processes.

The tendency to maximize provisioning services at the expense of the other services is partly because most provisioning services are marketed and the market value does not reflect the external costs of impacts on other services (Millennium Ecosystem Assessment, 2005a). This can particularly affect poor people as they are often more closely and directly dependent on several ecosystem services, and are affected the most severely when services degrade, for example, the availability of clean drinking water or of firewood (WRI *et al*., 2008). This situation is likely to get worse under the influence of population growth, continued abuse of ecosystem services and global climate change (Mayers *et al*., 2009). Water-related ecosystem services, derived essentially from how ecosystems underpin the water cycle, are important renewable resources. They provide many promising solutions to the need to achieve sustainable agriculture: for example, restoring soil ecosystem services can be key to sustaining water availability for crops, reinstating nutrient retention in soil, and cycling and reducing erosion and rainfall runoff (hence reducing water-related impacts downstream); examples of such approaches are provided in subsequent chapters. However, enacting these solutions requires good governance, and more research is needed on how to secure the regulatory and supporting services of ecosystems in order to help with poverty reduction (Mayers *et al*., 2009).

Changes in the local or regional availability of water, and its quality, whether due to agricultural or any other influence, consequently have implications for the delivery of ecosystem services at local and regional scales (Fig. 3.3). The management of the interdependency between water and ecosystem services, underpinned by ecosystem functions, and illustrated in Fig. 3.3, is at the heart of meeting two of the major challenges facing agriculture – water security for food security and water security for other purposes – and is therefore a core subject of this book.

Although many ecosystem services are known to be important to agriculture, the mechanistic details of their provision, or reduction, remain poorly understood (Kremen, 2005), and we lack ways to quantify many ecological services in a manner similar to measures of marketed goods and services in the economy (Dale and Polasky, 2007). Moreover, the provisioning services that we can measure depend upon a wide variety of supporting and regulatory services, such as soil fertility and pollination (Millennium Ecosystem Assessment, 2005a) that determine the underlying biophysical capacity of agroecosystems (Wood *et al*., 2000). Agroecosystems can also be affected by activities beyond agriculture, such as impacts on water from non-agricultural sources, which might reduce agricultural productivity or increase production costs (Zhang *et al*., 2007).

Ecosystem services are central to the well-being of all humans but are particularly directly relevant to the livelihoods of the rural poor. For example, while agriculture, forests and other ecosystems together comprise 6% of the gross domestic product (GDP) in Brazil and 11% of that in Indonesia, these ecosystem services contribute more than 89% of the GDP to poor households in Brazil and 75% to those in Indonesia, thus benefiting 18 and 25 million people in Brazil and Indonesia, respectively (TEEB, 2010). Hence, there is significant potential to contribute to poverty reduction through the better management of agroecosystems.

Balancing Multiple Ecosystem Services

One of the main challenges to achieving water and food security is land and water management that balances the continued delivery of the full suite of necessary ecosystem services required to sustain overall well-being. Because these ecosystem services are largely interdependent, and in particular because of the interlinkages that occur through water use and impacts (Fig. 3.3), there is often, but not always, a trade-off element in decision making. Trade-offs, though, are not necessarily linear (an increase in one service does not necessarily decrease another by an equal amount), and there is room to move the ecosystem services debate on: from a 'trade-off mentality' to one of achieving efficient use of ecosystems. For example, through identifying approaches that achieve food security objectives and at the same time meet other sustainable development objectives for water.

Simplistically, there are two aspects of managing ecosystem services at the water–food interface:

- First, managing those water-related ecosystem services that are required in order to sustain increased agricultural productivity (e.g. improved water retention by soils). With these, there is an incentive for agricultural policies, and in particular for farmers, to manage these services.
- Secondly, managing those services that are under the influence of agriculture but do not benefit agricultural communities directly ('downstream impacts'). Here, there are limited or negative incentives for agriculture, and especially for farmers, to manage such impacts. For example, asking farmers to manage land better (to benefit downstream users, perhaps through improved water quality) is unlikely to be popular with them if they incur increased production costs. Solutions to this dilemma, other than regulation, include: (i) identifying behavioural change that benefits both farmers and other stakeholders (win–win outcomes); and (ii) in particular, identifying ways and means to improve incentives for farmers to change

their behaviour through payments for ecosystem services (as discussed further in Chapter 9).

Improved knowledge of the whole range of ecosystem services, their benefits (values) and costs (social, financial, water) can help to achieve better decisions on water and land use (Millennium Ecosystem Assessment, 2005a; TEEB, 2010). Well-balanced decisions, including trade-offs where necessary, can often enhance overall ecosystem services without sacrificing productivity (Millennium Ecosystem Assessment, 2005a; Bennett *et al.*, 2009). The separation of ecosystem services into market and non-market goods leads to a disconnect between economics and environmental sustainability because variations in non-market goods are not reflected in economic pricing and monetary flows (Wilson and Carpenter, 1999; Millennium Ecosystem Assessment, 2005a); there are no direct market-based economic incentives to sustain important ecosystem services if these are not valued, priced and traded. An example is that few, if any, stakeholders pay the full environment costs of water use. Groundwater recharge and climate regulation are other examples where an individual's benefits from these services are not directly linked to the cost of using them (Millennium Ecosystem Assessment, 2005b).

By estimating the value of an ecosystem's market and non-market goods, hidden social and environmental costs and benefits can be made visible (Wilson and Carpenter, 1999). Some regulating and supporting services can be brought into markets and evaluated in financially driven decision-making processes by exploring the costs of substituting for them. For example, a watershed's purification functions can be monetized by comparison with the cost of substituting a water treatment facility to fulfil these needs for a community. Some ecologists, however, have argued against this logic, suggesting that humans cannot fully substitute for the functions of these regulating systems, especially as they contribute to multiple services and biodiversity (Ehrlich and Mooney, 1983). This dilemma is one of the central issues of debate on the valuation of ecosystem services (Ehrlich and Mooney, 1983; Heal, 2000; Pimentel *et al.*, 2001; Kremen and Ostfeld, 2005; Millennium Ecosystem Assessment, 2005a). Nevertheless, in many cases, the costs of replacing services have been shown to exceed the costs of restoring or sustaining them, particularly in the case of water, and because policy makers often respond more to financial than to academic arguments, more integrative valuation approaches can generate positive policy shifts (TEEB, 2010).

It is not always the case that options are simple choices between meeting human needs through services from ecosystems or through their artificial replacement. Most landscapes are now highly managed, and built (physical) water infrastructure invariably coexists with natural (ecosystem) infrastructure, presenting increasing opportunities to manage both together to improve efficiency (see the example of the Itaipu watershed in Chapter 9).

Valuing ecosystem services can assist considerations of the costs and benefits of different options for achieving water and food security, and set the issues in their proper broader context. Table 3.1 provides an example of the valuation of ecosystem services delivered by various ecosystem types at the global scale. Although not necessarily applicable at the local scale, the results illustrate a number of important points. Collectively, values derived from regulatory, supporting and cultural services, generally outstrip values for provisioning services (goods produced) in all areas, and by a considerable margin (the value of ecosystem services in agriculture is further examined in Chapter 4). Despite this, most areas have historically been managed almost exclusively for provisioning services (in particular for food, which usually delivers among the lowest values of all). Water-related services (including water regulation and water-driven supporting services) generate some of the highest values of all.

Previously, Costanza *et al.* (1997) had suggested that wetlands provide more valuable food per hectare annually than other ecosystems: the total global value of food from wetlands was estimated at US$84.5 billion, while four times the area in cropland was calculated to produce a food value of US$75.6 billion. This was explained by the difference between high-value fish and shrimps, versus low-value grains. However, wetlands are the most valuable of all ecosystem types, not only because of aquatic food production but (in fact) primarily because they yield high benefits by providing and regulating water. Yet, despite this, wetlands show the most rapid rate of loss among all biomes – principally through agricultural impacts on water and the conversion of wetlands to farming (see also Chapter 7).

Hurricane Katrina, in 2005, prompted one of the most comprehensive and relevant detailed assessments of ecosystem services, as affected in particular by agriculture. This conclusively illustrated the pitfalls of sector-based planning for land and water resources management, and the economic and human costs of ignoring ecosystem services in river basin planning and development (Box 3.2).

Conclusions

The concept of 'sustainable food production' involves achieving the necessary increases in agricultural productivity, while simultaneously bringing the impacts of agriculture on ecosystems within manageable limits and in the face of significant resource challenges (as outlined in Chapters 1 and 2). The ecosystem setting of water within agroecosystems, and the way in which this determines the benefits (ecosystem services) that water provides, both within and beyond agriculture, offers a framework for identifying solutions to achieve sustainable agriculture. Further expansion of this approach is provided in subsequent chapters. To many readers, these concepts will not be new, but there is ample evidence that they are not being mainstreamed into agricultural planning and management. If they

Table 3.1. Estimation of the annual average value of ecosystem services of terrestrial biomes (in 2007 US$[a]/ha; adapted from van der Ploeg *et al.*, 2010).

Ecosystem services	Tropical forests	Other forests	Woodland	Grass	Wetlands	Lakes and rivers
Provisioning						
Food production	121	496	68	54	709	94
Water supply	300	152		378	1,598	3,361
Other provisioning[b]	1,466	45	291	22	433	
Cultural	373	25	–[c]	4	3,218	1,337
Regulatory[d]						
Water flow regulation	19	1	–	–	4,660	–
Extremes	92	–	–	–	1,569	–
Other regulatory	1,711	143	432	686	1,460	2,642
Supporting[e]	1,008	399	–	99	2,104	–
Annual total (2007 US$/ha)[f]	5,088	1,261	792	1,244	15,752	7,433

[a] The international (Geary-Khamis) dollar is a hypothetical unit of currency that has the same purchasing power parity that the US$ had in the USA at a given point in time, in this case 2007, for which the unit is abbreviated 2007 US$.

[b] Other provisioning services include raw materials, and genetic, medicinal and ornamental resources.

[c] A nil return (–) indicates that insufficient data were available.

[d] Regulatory services include water flow regulation; waste treatment and water purification; moderation of extreme events such as floods, droughts and storms; and other regulatory services such as influence on air quality, climate regulation, erosion prevention, pollination and biological control.

[e] Supporting services include nutrient cycling, habitat services and maintenance of genetic resources.

[f] The total (van der Ploeg *et al.*, 2010) may differ from calculated sum because of rounding.

Box 3.2. Agriculture and ecosystem services in the Mississippi River Delta (based on Batker *et al.*, 2010)

The history of management of the Mississippi River Basin, and impacts of this on its delta, present a case study illustrating the importance of valuing, and paying attention in agricultural policies to managing broader water-related ecosystem services.

River deltas are dynamic and complex ecosystems driven largely by hydrology, including the regular transfer of sediments and nutrients from the catchment into lowlands and the estuary. Their functioning underpins numerous ecosystem services, in particular land formation. This, in turn, delivers benefits through the maintenance of coastal stability and erosion regulation, thereby, for example, reducing disaster vulnerability. The Mississippi River Delta, in common with the deltas of many rivers, has been highly modified: its hydrology has been changed through water abstraction, principally for agriculture, while reservoir construction, also for hydropower, has interrupted sediment transfer. Additional physical infrastructure has had to be added, with high investment and operational costs; in effect, this is required to compensate for losses in the services originally provided by the ecosystem; examples include continual dyke and coastal defence development and maintenance in order to deal with a destabilizing estuary. The resulting degradation of the associated wetlands infrastructure is now widely regarded as a major contributing factor to the scale of economic and human losses resulting from hurricanes. In 2005, hurricane Katrina, in particular, was a catastrophic reminder of the pitfalls of paying insufficient attention to managing ecosystem services.

The study by Batker *et al.* (2010) estimated that if treated as an economic asset, the minimum asset value of the natural infrastructure provided by the Mississippi River Delta ecosystem would be US$330 billion to US$1.3 trillion (at 2007 values) in terms of hurricane and flood protection, water supply, water quality, recreation and fisheries. Importantly, the study also suggested that rehabilitation and restoration of this natural infrastructure would have an estimated net benefit of US$62 billion annually. This includes reduced disaster-risk vulnerability, and savings in capital and operational costs for physical infrastructure solutions (including factoring in the economic costs to existing users of reallocating water use).

As very pertinent to this book: agriculture has historically been a key driver of water-allocation policy in the Mississippi River (as in most river systems), yet the value of food and fibres produced by agriculture represents only a fraction of the value of the multitude of other services provided by the ecosystem, particularly by its wetlands (see Chapter 4 for more details on the values of ecosystem services in the Mississippi Delta).

This example illustrates: (i) the importance of understanding how ecosystems function and what ecosystem management offers in terms of cost-effective solutions (or avoiding problems in the first place); (ii) the importance of valuing ecosystem services more holistically; (iii) that the issue is not of one benefit versus another (in this case agriculture versus wetlands downstream) but of how to manage the river infrastructure (both physical and natural) to achieve the optimal outcome. Restoring optimal ecosystem services does not require agriculture to be compromised, but it does require a different risk management and investment approach.

There are now very many major cities, much larger than New Orleans, particularly in Asia, that are located in river deltas that are subject to a similar history of agriculture and water management. Hopefully, lessons learned from the Mississippi River Delta can help to achieve food security in these areas that is not at the expense of other security needs.

were, this book would not need to be written and sustainable agriculture would already have been achieved. This chapter identifies the opportunity to move beyond seeing the agriculture–environment relationship as one of conflict and trade-offs to looking at how improved ecosystem based management can deliver solutions that will simultaneously increase agricultural productivity and deliver improved broader ecosystem benefits.

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