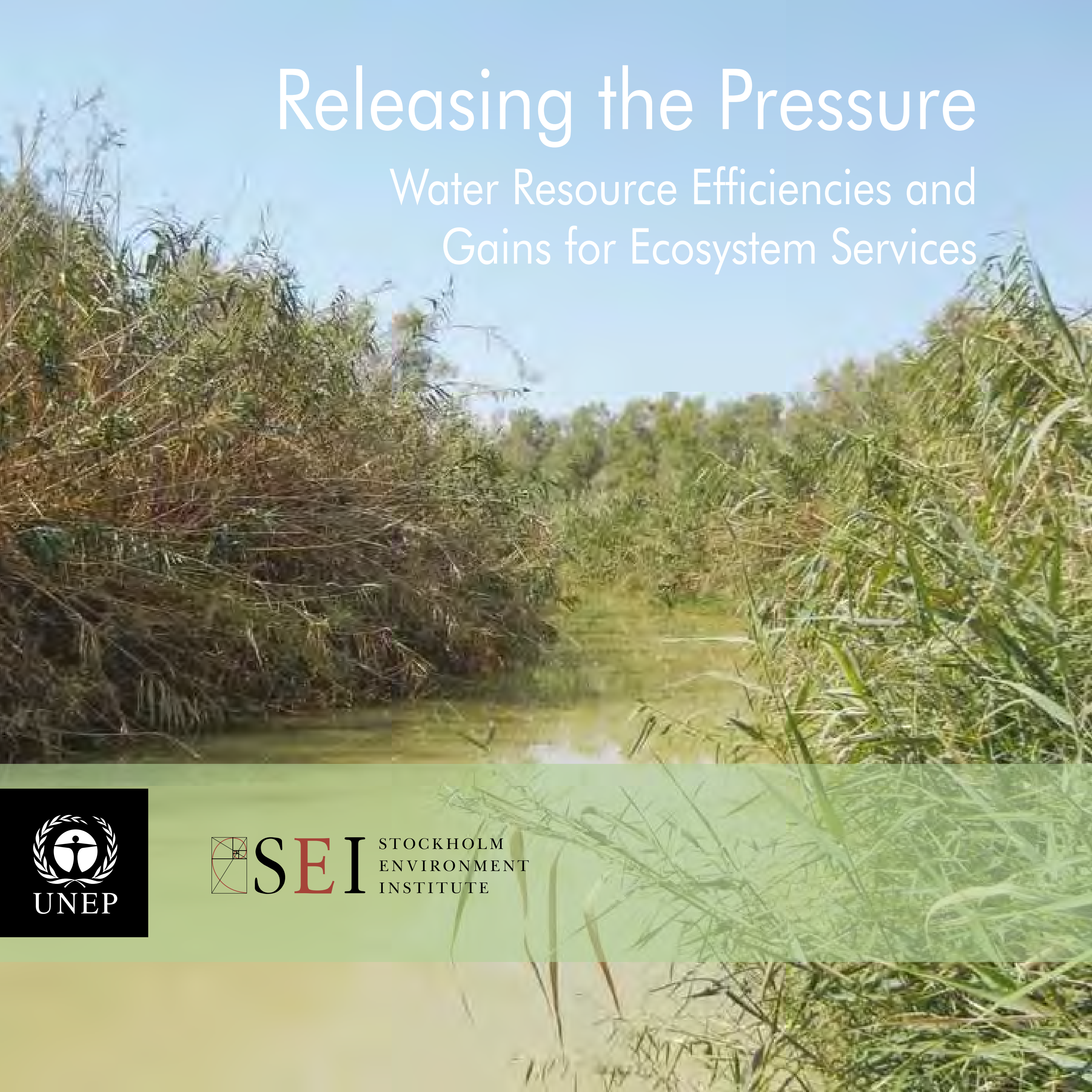

Releasing the Pressure

Water Resource Efficiencies and Gains for Ecosystem Services

UNEP

SEI STOCKHOLM ENVIRONMENT INSTITUTE

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CREDITS

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PREFACE

Releasing the pressure: water resource efficiencies and gains for ecosystem services

At Rio+20 in 2012 the world will renew commitments and define more decisive ways of implementing sustainable development—20 years after the Earth Summit of 1992.

Despite progress in respect to the Millennium Development Goals for example, 13 per cent of the population still lacks a daily clean water supply.

Meanwhile there are growing concerns over the loss and degradation of aquatic habitats such as wetlands, lakes and river systems, in part due to the syphoning off of these precious resources to agriculture and energy developments.

The inequity in access is particularly challenging for the poor and marginalised, affecting vulnerability and opportunities in terms of livelihoods. The report puts water productivity at the centre of the debate but with a wider concept and context of what productivity actually means and to whom.

This is a challenge, because all too often the benefits from ecosystem services are neither immediately recognized, nor easily valued. Water productivity as a concept (use of water per amount of produce) has been widely used in agriculture. This has led to water productivity gains often being out of balance with other water requirements in landscapes.

Assessing water productivity narrowly—for example by simply looking at crop, fodder and forest produce-- will continue to under-value the role of water for wider society and the economy.

Recognizing these wider benefits generated by water in respect to for example nutrient flows, cooling, providing habitats, and other supporting and regulating ecosystem services, is the aim of our work.

This report uses various cases to illustrate how to broaden the concept of water productivity and ecosystem services. It suggests ways in which water productivity can be used for addressing more balanced water resource management, so as to achieve multiple benefits for local people.

It complements the recent collaboration between UNEP-IWMI on the ecosystem services approach to water and food security and UNEP-Stockholm Environment Institute collaborations on rainwater harvesting.

With future challenges in water supply affected by climate change, and increasing demand by population growth and development, water will be a critically restricted resource for a growing number of people. This report forms the next contribution to the important issue on how to enhance the productive use of water for multiple needs.

Achim Steiner

Under Secretary General and Executive Director

KEY MESSAGES

*The **KEY MESSAGES** are listed here, and then explored in detail throughout the following document.*

1. The quantity, timing, and quality of water flows in landscapes need to be sustained to improve human well-being reliant on landscape ecosystem services.

2. Pressure on limited water resources can be managed, and thus made available for other ecosystem services, by using known management interventions to improve water productivity in low-yielding rainfed crop production.

3. Trade-offs between agro-ecosystem services and landscape ecosystem services must be managed so that improved agricultural water management and water productivity may lead to synergies with the surrounding landscape.

4. Wetlands maintain key regulating and supporting ecosystem services at landscape scales, thus contributing to high landscape water productivity in terms of multiple benefits for human well-being.

5. Livestock management practices can have co-benefits that require less water, allowing the unused soil water to support the surrounding landscape.

6. Forest ecosystems provide multiple services for human well-being locally, regionally, and globally, and should be considered as productive uses of water flows.

7. Managing both natural and man-made water storage in landscapes can support and enhance productive uses of water for ecosystem services and human well-being.

8. Agricultural water productivity gains are optimal when they are connected to and balanced with the surrounding supporting and regulating ecosystem services thereby ensuring adequate water flows for a wide range of uses in the landscape.

9. Integrated water resources management (IWRM) can be an approach to govern the complexity of upstream-downstream water-dependent ecosystem services, because water links multiple ecosystem services and multiple users of ecosystems services.

10. Capacity building and awareness raising, via the sharing of successful ecosystem services valuation practices can facilitate the integration of ecosystem services into IWRM programs.

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Overview

Water is under increasing pressure for supporting both various functions in society whilst sustaining healthy ecosystem services (ESS) in landscapes. These pressures impacts human well-being, and there is a growing need to consider the productivity of how water can be used for multiple benefits. Water productivity is a concept used to assess water use and resource efficiency. However, due to the multiple uses of water by humans and ecosystems, it is not evident that one measure of efficiency can capture the multifaceted and multi-sectoral benefits that water provides. By using water productively at one scale of space and time, important functions of water flows at other levels of use and demand, or disparities in the beneficiaries of water flows between men versus women, or wealthy versus poor. Finally, it is particularly important to consider water productivity in terms of the trade-offs between managed agricultural ESS and the surrounding landscape ESS. Resource efficiency must refer to a broad web of ESS, including agro-ecosystem services. Human well-being has the potential to be greatly improved via the mainstreaming of activities that address water flows and efficiencies in landscape ESS, particularly for facilitating a transition to a Green Economy.

Objective

This document discusses the need to balance short-term water productivity gains – in particular in agriculture - with the long-term role that water flows provide for maintaining sustainable landscape ESS, and serving multiple benefits to human well-being.

Content

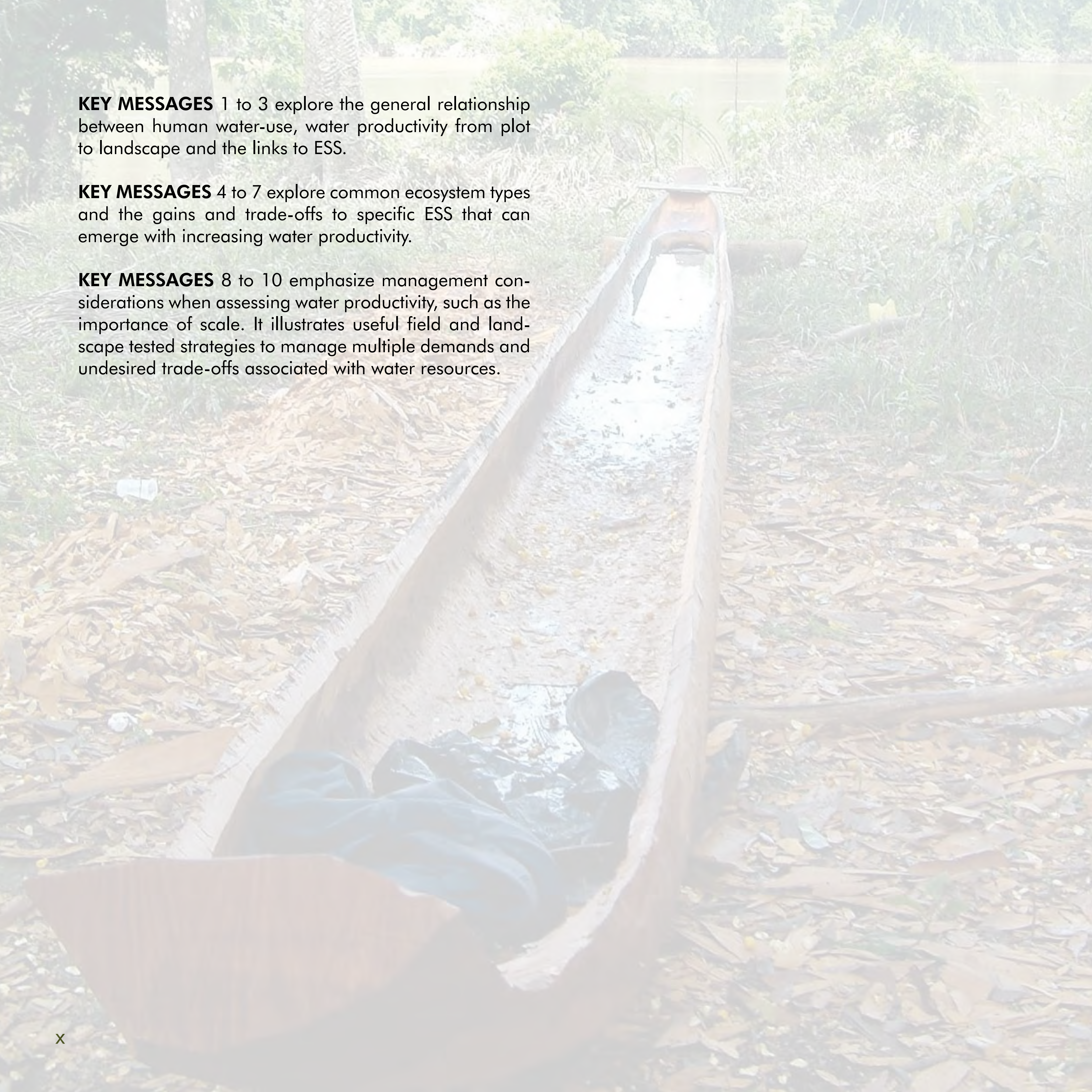
The document provides a summary of concepts around the nexus of water productivity, water flows in landscapes and ecosystem services. It gives examples (through case studies) on the trade-offs and opportunities between water productivity improvements and the water-related services provided by other ecosystems. The document connects to broader UNEP themes such as the Green Economy and Resource Efficiency with an explicit emphasis on improving livelihoods through recognition of the importance of landscape ESS beyond agriculture. Case studies are used to substantiate the key messages and to discuss additional dimensions, such as gender, scaling and potential policy opportunities.

Intended audience

This document strives to be relevant to practitioners, in the areas of planning and management of agriculture, planning of land-use, forestry, biofuels, and water, and natural resource management. Our goal is to encourage practitioners to begin exploring what types of ESS gains and trade-offs exist in their local context such as watersheds, landscapes, countries, or basins, and how they may be linked to the allocation of water.

Document structure

This document is structured around a set of KEY MESSAGES, with each one explaining a key aspect of the relationship between how humans use water, the issue of water productivity related to its use, and potential impacts on different ESS.



KEY MESSAGES 1 to 3 explore the general relationship between human water-use, water productivity from plot to landscape and the links to ESS.

KEY MESSAGES 4 to 7 explore common ecosystem types and the gains and trade-offs to specific ESS that can emerge with increasing water productivity.

KEY MESSAGES 8 to 10 emphasize management considerations when assessing water productivity, such as the importance of scale. It illustrates useful field and landscape tested strategies to manage multiple demands and undesired trade-offs associated with water resources.

INTRODUCTION

Water flows are fundamental to the multiple ecosystem services (provisioning, cultural, regulating, and supporting) that sustain social-ecological systems.

KEY TERMS

Agro-ecosystem - Terrestrial ecologies that are intensively modified and used by humans for the specific purpose of growing produce, including: rainfed & irrigated croplands, livestock grazing lands, and multi-use systems.

Agro-ecosystem services - Ecosystem services provided by managed agro-ecosystems such as cropland (food, fibre, and fodder), pastures, and multi-use agro-forestry systems.

Bundles of ecosystem services - Sets of ecosystem services that repeatedly appear together across space or time (Raudsepp-Hearne *et al*. 2010).

Ecosystem services - The benefits that people obtain from ecosystems.

Human well-being – "The freedom of choice and action to achieve basic material for a good life, health, good social relations, and security. Well-being is at the opposite end of a continuum from poverty, a pronounced deprivation of well-being" (UNEP EMP 2008).

Landscape ecosystem services – ecosystem services provided by ecosystems at the landscape scale, and not actively managed by humans.

Social-ecological systems – The integrated system of humans and the ecosystems that support and are impacted by human livelihoods.

Water productivity – The amount of benefits (material and nonmaterial) that are generated by a given volume of water. Several variations of the concept exist, notably crop water productivity (CWP), livestock water productivity (LWP), and monetary efficiency.

Introduction

Water flows connect and link different ecosystem services (ESS) across a landscape, with precipitation falling onto it as rainfall and then flowing through it in rivers, the soil, and aquifers. These water flows sustain various ESS that support human well-being, societies and economies at various scales. To understand the role water plays in sustaining ESS, it is important to distinguish different types of services and the role of water in sustaining them.

ESS provide direct and indirect support for people

ESS can be defined as *the benefits that people obtain from ecosystems* (MEA 2005). There are four broad types of ESS: provisioning, cultural regulating and supporting; which all are essential to deliver and support well-being for humans (Box 1 on ESS). In many cases, water and soil are fundamental components to enable the supply of the ESS. Humans have directly benefited

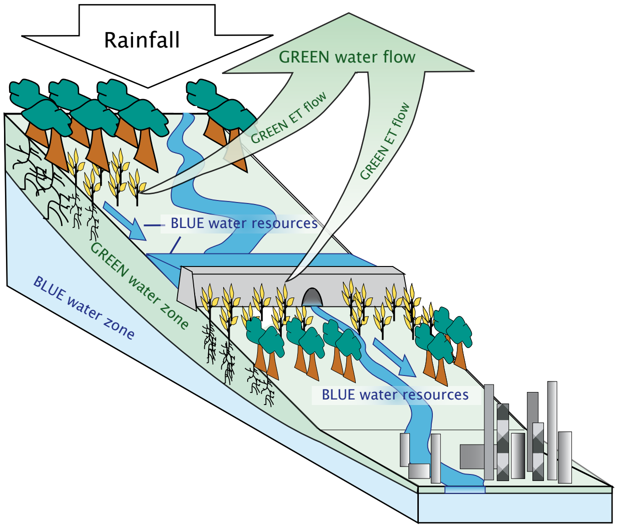


Figure 1: Blue and Green water flows throughout the landscape

(Adapted from Falkenmark, 2008)

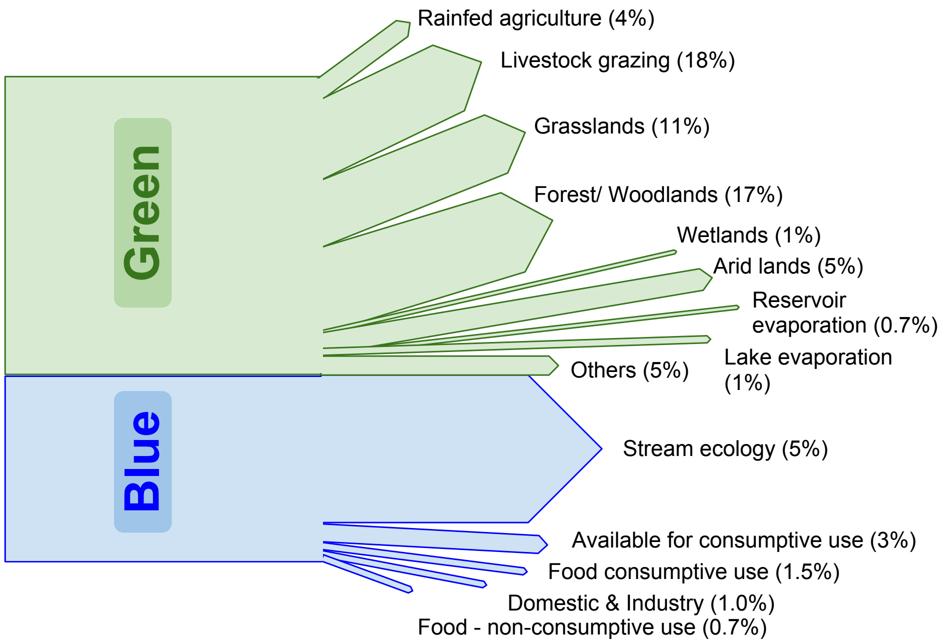


Figure 2: Fraction of blue and green water used to sustain various ESS

(Adapted from Rockström, 1999)

from a range of ESS, notably food, fodder and firewood. Indirectly this provisioning of food, fodder and fibre relies in turn on supporting and regulating services, that for example maintain nutrient and water flows for agricultural and natural lands. Thus, a unit of water or a unit of land can contribute to multiple ESS.

Separating the sources - Blue and Green water flows

In addition to the different types of ecosystem services, separating water flows into two broad categories, blue and green water, is useful for understanding which ecosystem services interact with which parts of the hydrologic cycle (Figure 1). **Blue** water flows are largely water in its liquid form, such as in rivers, lakes, wetlands and aquifers. **Green** water falls to the land surface as rain, and is stored as soil moisture, and returns to the atmosphere via transpiration from plants or evaporation from the soil or other surfaces.

The distinction between blue and green water sources is important, because each type is associated with specific ESS.[1] Blue water performs ESS primarily related to aquatic systems, and, also substantially contributes to global food production in irrigated agriculture. Green water sustains ESS primarily related to terrestrial systems. In order to further distinguish the blue and green flows of water, total water flows can be partitioned in terms of how they are used within a a landscape. In Figure 2 total, global freshwater flows from the continents are partitioned according to green and blue flows sustaining various land-uses. This conceptual figure emphasizes the role of water flows in providing multiple ESS, and the role of green and blue water sources for different types ecosystems.

Distinguishing between green and blue water sources allows specific management activities to target improving bundles of ESS. For example, increasing in stream flows (blue water) could benefit "blue bundles" such as stream ecology, and availability of irrigation and drinking water. Also, quantities that are associated with the different flows (e.g. storm runoff = 27 per cent) are theoretical estimates at the global scale, and will not necessarily reflect the actual water flow partitioning for any given ecosystem or landscape type.

Distinguishing between green and blue flows can also help in identifying which types of ESS are generated (Table 1).

Recognizing these multiple uses of water to produce ESS, in addition to widely recognized water uses for supply, sanitation, irrigation and aquatic habitats, can help safeguard sustainability in water resource management at a broader scale. It can also lead to increased efficiency in water allocation, and avoid undermining sustainability in terrestrial ESS as well as aquatic ESS, due to water withdrawals. Assessing water flows and water use in multiple ESS in addition to the conventional agricultural produce, will lead to recognition of water use not only for direct economic benefit, but also for sustaining ESS that underpin human well-being and the resilience of ecosystems. Likewise, understanding how the ESS benefit different groups (e.g., men versus women, wealthy versus poor will help address and balance inequities in benefits and trade-offs in of distribution from water and ESS use (Boelee, 2011).

1 This text will incorporate the green/blue framework because "green water" is often used interchangeably with soil moisture, and "blue water" is often used interchangeably with liquid water such as in streams, rivers, lakes and wetlands, as well as irrigation withdrawals in agriculture. Where the key message refers to water in general, no distinction will be made between green and blue water.

Table 1: Sample of some of the roles water plays in providing ecosystem services

	Type of Ecosystem Service			
	Provisioning	Cultural	Regulating	Supporting
GREEN	Transpiration (e.g. crops, trees)	Transpiration (e.g. forests for tourism, sacred groves)	Evaporation flowing downwind to later fall as precipitation [a]	Nutrient and salt dilution in root zone
BLUE	Aquatic habitat (e.g. fish); Irrigated, high-yield crops;	Clean water (e.g. tourism, sacred springs)	Sediment transport from upstream to downstream, to replenish river deltas and eroded soils	Transport of carbon, nitrogen in water bodies

[a] Recent research suggests that large terrestrial areas contribute evaporation that falls as downwind precipitation, and that changes in the land cover could lead to changes in the volume of moisture evaporated (e.g. Gordon *et al*. 2003; Keys et al. submitted; Schaefli *et al*. 2011; Tuinenbeurg *et al*. 2011).

Box 1: Ecosystem Services (ESS)

The science of ESS has emerged steadily over the past few decades. In 2005, the Millennium Ecosystem Assessment (MEA, 2005) published their comprehensive assessment of human impacts to ESS, and they defined four broad categories to classify ESS. UNEP has expanded these definitions (which are provided below) in the "Ecosystem Management Programme: An Ecosystems Approach."

Provisioning services are products obtained from ecosystems, including: bioenergy or biofuels, fisheries, timber, and crops. Provisioning services can often be assigned economic value, since they are easily bought and sold in local and global markets.

Cultural services "are the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences." Although these services are 'nonmaterial', e.g. 'beautiful' waterfalls, those nonmaterial benefits can improve livelihoods of nearby people, e.g. incomes from ecotourism.

Regulating services "are the benefits obtained from the regulation of ecosystem processes," including: climate regulation, natural hazard regulation, water regulation, water purification & treatment, and disease regulation.

Supporting services "are necessary for the production of all other ESS. They differ from provisioning, regulating, and cultural services in that their impacts on people are either indirect or occur over a very long time, whereas changes in the other categories have relatively direct and short-term impacts on people." Supporting services are often considered to be free, because beneficiaries are not expected to pay for them.

KEY MESSAGE 1

The quantity, timing, and quality of water flows in landscapes need to be sustained to improve human well-being reliant on landscape ecosystem services.

KEY TERMS

Benefits – The material and non-material produce and services that contributes to human well-being and livelihoods.

Ecosystem service water productivity (ESSWP) – The ecosystem services benefits or gains per unit water input.

Resilience – The magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behavior (Holling 1996).

Water is vital to sustain the functions of ecosystem services (ESS). In the landscape human development alters water availability through depletion, timing of availability by changing stream morphology, and usability by pollution, thereby altering the ecosystems and services that water sustains. Managing the use of water, as well as the benefits and potential trade-offs between human development and ESS, is critical to minimize negative consequences for human well-being, maintaining landscape ecosystem function, and maintaining overall social-ecological resilience.

Humans change water flows in ecosystems

Precipitation, as rain and snow, is often the primary source of water in landscapes. Human activities begin to affect available water resources when water enters the landscape, i.e. when the precipitation hits the soil and infiltrates (as green water) or diverts as surface runoff to rivers, and lakes (as blue water). By managing the soil and affecting the soil surface, the infiltration of rain is affected, and thus the volume of water stored in soils and the volume recharging groundwater. By altering vegetation, there are changes in the rate of uptake of water from soils, affecting the remaining soil water that can recharge groundwater, or flow downstream to rivers or water bodies. Through withdrawals of water from rivers, lakes and groundwater, shifts in flow patterns are made. Humans, and our various land and water activities, tend to change four aspects of water in landscape:

- The quantity of green water available in soil for vegetation uptake
- The quantity of blue water in streams and water bodies
- The timing of water flows and storage recharge
- The quality of water

All these changes will affect the ESS that water supplies.

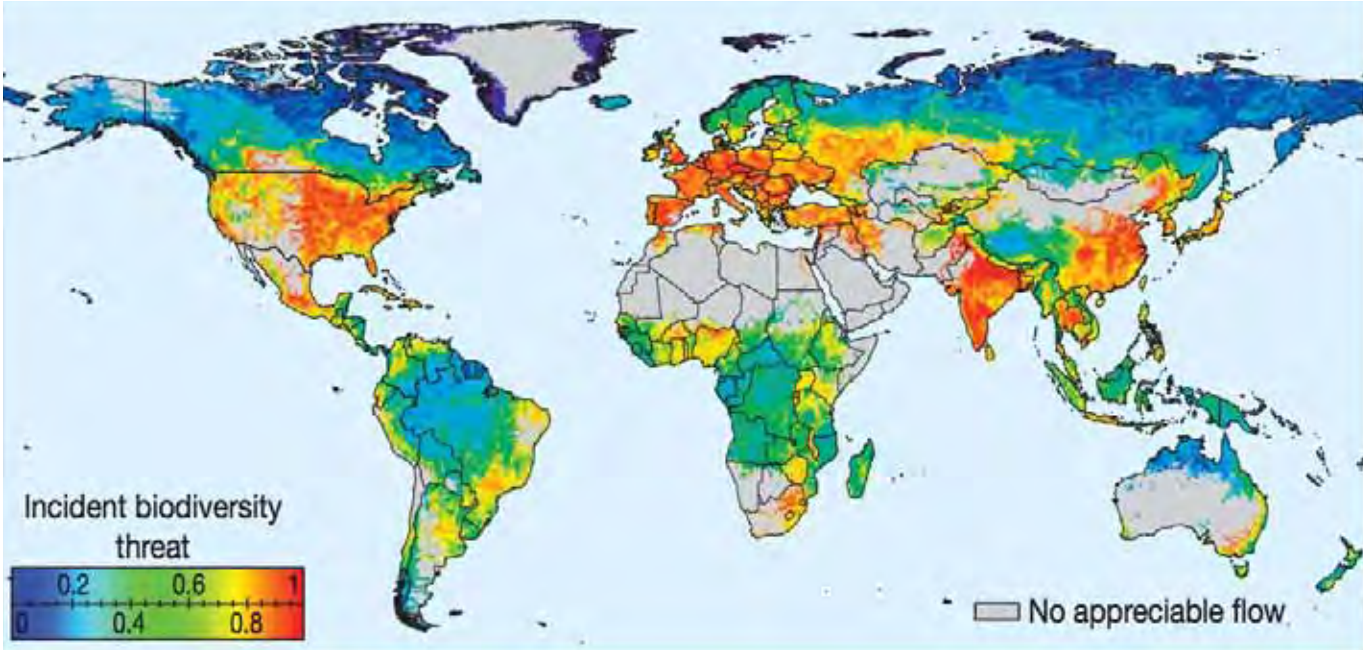


Figure 3: Global distribution of the threats to biodiversity posed by degradation of water flows
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Water flows support ESS beyond the immediate benefits of irrigated agriculture

The changes humans make to the quantity, timing of water flows, and quality are often viewed purely in terms of the immediate benefit. For example, irrigated agriculture represents an appropriation of blue water resources for an immediate benefit. This water use produces crops that have may be consumed for subsistence, or sold for income. As a result of the economic value that is associated with blue water appropriation, any blue water that is not appropriated for agro-ecosystem produce is often considered "wasted" or "unused," since the flows are going to produce indirect, unvalued benefits.

Environmental flows are critical to landscape ESS

These "unused" water flows are often called *environmental flows*, and are fundamental to sustaining landscape ESS. Environmental flow requirements to support landscape ESS can be considerable, in many cases as high as 50 per cent of blue water flow (McCartney and Smakhtin, 2010). Additionally, recent research has indicated that global aquatic biodiversity is tremendously affected by degradation of water flows in river networks (Figure 3). In the figure, values of "Incident biodiversity threat" close to zero indicate that degradation of water resources have little to no impact on aquatic ecosystems, whereas values closer to 1 indicate that the degradation has a very large impact on ecosystems.

Blue water flow is required for landscape ESS, and for the underlying support of terrestrial and aquatic ecosystems. These environmental flows, found in streams, rivers and lakes, are key for regulating and supporting ESS that are essential for livelihoods (see: Case Study: Value of ESS to livelihoods in rural Cambodia). Therefore, understanding the trade-offs associated with changes to quantity, quality, and timing of water flows is important for long-term sustainability.

Similarly, green water is required for other landscape ESS, particularly rainfed terrestrial vegetation such as: forests, savannahs and shrublands. These ecosystems not only provide key regulating and supporting ESS, but also provide support for livelihoods. For example a forest may provide food, fibre, and livestock forage, and all these services depending on green water in the soil from rainfall.

Water quality affects human well-being in two primary pathways: directly, through low water quality; or indirectly, if poor water quality degrades other ESS. Examples of reduced 'blue water' ESS include: loss or deposition of sediment (e.g. from erosion), dissolved particulates (e.g. salt), and suspended solids (e.g. human or animal waste). Water quality issues are associated with human activities, and have a clear set of causes, such as: lack of sanitation in upstream communities, return-flow from irrigated agriculture containing higher salt concentrations, and high sediment loads from degraded areas.

Finally, the timing of water flows is a considerable challenge for human societies and the ESS supported by water. In many parts of the world, the seasonal hydrological cycle is inconsistent with human needs, especially for agro-ecosystem production. Therefore, humans manage the hydrologic cycle to fit their needs, for example via the storage of floodwater in reservoirs. This change in the seasonal flow of water can have impacts for landscape ESS, especially those that depend on seasonal flooding cycles, e.g. fisheries.

Managing quantity, quality, and timing for human well-being

In many situations the changes humans have made to local water flows have altered surrounding and downstream landscape ESS. This has had significant impacts for human well-being and poverty alleviation. The poorest members of communities are often more dependent on sustainable landscape ESS than their wealthier counterparts to provide their livelihoods (see Case Study: Value of ESS to livelihoods in rural Cambodia). Alterations of water flows and water storage to benefit particular human needs have impacts on other water uses and the benefits they sustain. By managing water the productivity of water is altered as benefits change or are re-distributed for humans and the environment.

Understanding the implications of changes to water flows and storage, and the implications on ecosystem service provision is necessary for making further sustainable reductions in human well-being (see in Key Message 3: Case Study: Watershed management to improve productivity in Kothapally, India; and in Key Message 6, Case Study: Watershed rehabilitation in Darewadi, India). The further explores the comparative reliance of various income groups on landscape ESS.

Thus ESS are highly valued by local communities and changing the quantity, quality, or timing of these services can have significant, negative impacts to human well-being. Furthermore, disaggregating the beneficiaries of the ESS is necessary to understand the impacts of specific changes to quality, quantity, and timing of water flows.

Box 2: Disaggregating ecosystem services and well-being

Sustainable, productive ESS are often equated with increases in human well-being (Figure 4), regardless of the type and nature of the ESS. The fact that human groups are often stratified based on income and gender, with some groups having more or less access to resources and opportunities, can create mismatches and trade-offs between ESS and their beneficiaries. As a result of these mismatches and trade-offs, marginal populations can suffer, especially women and the very poor.

Figure 4 illustrates the key components of disaggregating ecosystem service provision from human well-being. The first frame (i) illustrates the conventional, aggregated framework of ESS directly influencing human well-being. The second frame (ii) illustrates a simple separation of how different ESS benefit different aspects of human well-being. Finally, the third frame (iii) illustrates the tradeoff between two mutually exclusive ESS that benefit human well-being.

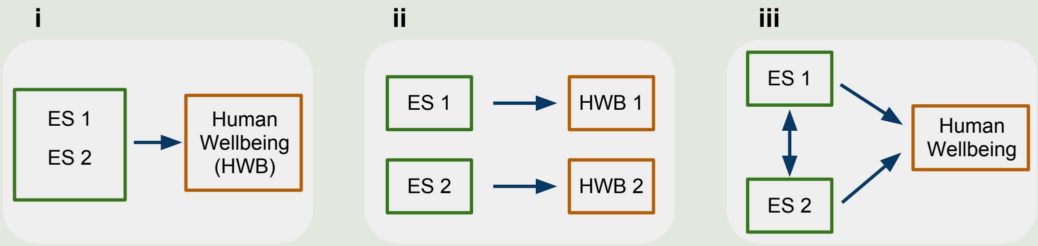

Figure 4: Conceptualization of ESS and human well-being that do not disaggregate (Adapted from Daw *et al.* 2011)

Figure 5 depicts how different issues influence how beneficiaries do or do not receive the benefits of ESS. The bold outlines show increases in ESS flows and human well-being; i represents the influence of barriers to access ecosystem service flows; ii depicts the contribution of ESS to well-being depends on the context, with ESS contributing more to A than B's well-being, due to existing wealth; iii shows the trade-offs between ESS and differences in win/losses depending on which ESS are accessible (e.g. if ES1, then B receives no benefits); iv shows how ESS can benefit A indirectly, by first passing through B. (Adapted from Daw *et al.* 2011)

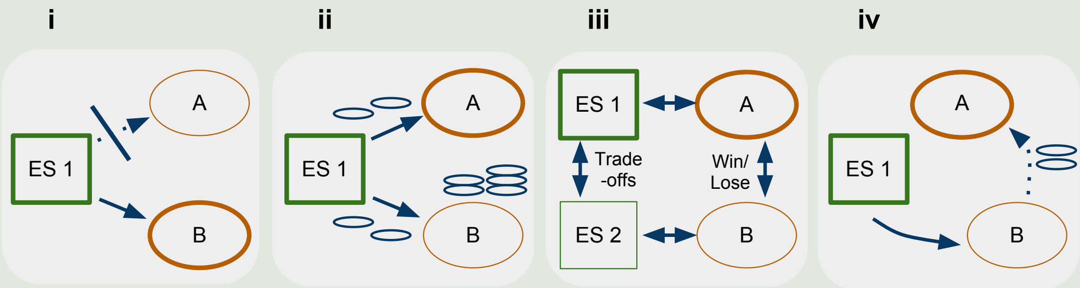

Figure 5: Aspects of disaggregating ESS and human well-being relevant to poverty alleviation (Adapted from Daw *et al.* 2011)

These figures illustrate that when well-being is disaggregated into constituent beneficiaries (e.g. A & B) it is possible to more accurately track the consequences of a given activity. A more detailed understanding of specific ecosystem service processes, and the specific pathways that can lead to improved well-being, requires in-depth understanding of feedback loops, win-lose situations and non-linear accumulation of benefits. Likewise, it is critical to monitor and evaluate the differential beneficiaries, particularly with regard to marginalized populations, especially women.

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Case Study: Value of ESS to livelihoods in rural Cambodia

Landscape ESS provide critical support for rural livelihoods in many communities on the Tonle Sap lake and wetlands system, in Cambodia. Disaggregating the beneficiaries reveals the importance of different ESS depending on the household income leve.l

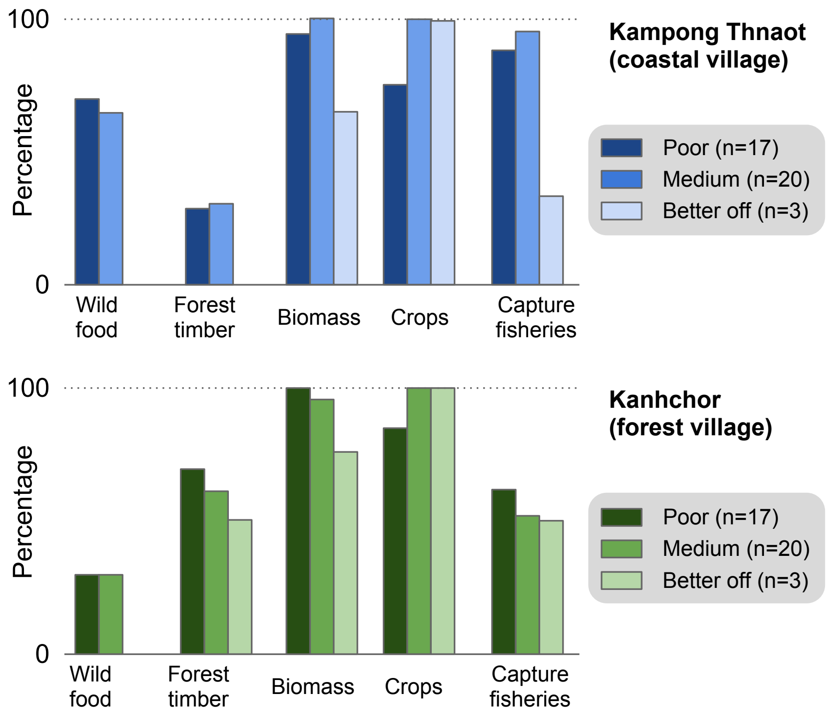

Figure 6: Use of local ESS as percent of the households of different income groups (Persson *et al*. 2010, CDRI 2010)

In all cases, "Poor" and "Medium" income households rely on ESS for income more than the "Better off" households. The types of ESS vary in importance depending on household locations (costal versus forest). What is consistent, though, is the importance of sustaining the function and resilience of the surrounding ESS for the well-being of the poorest members of society.

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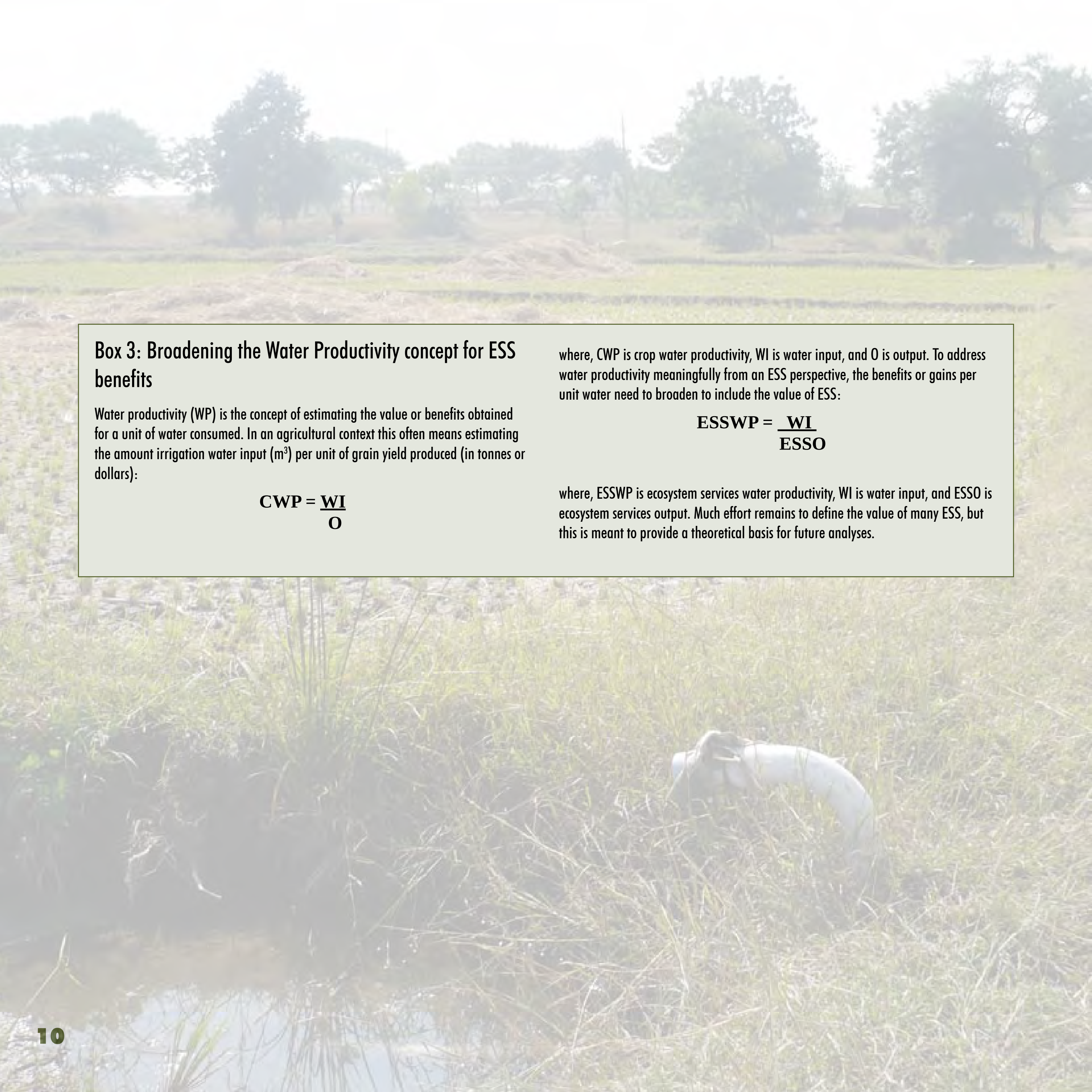


Box 3: Broadening the Water Productivity concept for ESS benefits

Water productivity (WP) is the concept of estimating the value or benefits obtained for a unit of water consumed. In an agricultural context this often means estimating the amount irrigation water input (m^3) per unit of grain yield produced (in tonnes or dollars):

$$CWP = \frac{WI}{O}$$

where, CWP is crop water productivity, WI is water input, and O is output. To address water productivity meaningfully from an ESS perspective, the benefits or gains per unit water need to broaden to include the value of ESS:

$$ESSWP = \frac{WI}{ESSO}$$

where, ESSWP is ecosystem services water productivity, WI is water input, and ESSO is ecosystem services output. Much effort remains to define the value of many ESS, but this is meant to provide a theoretical basis for future analyses.

KEY MESSAGE 2

Pressure on limited water resources can be managed, and thus made available for other ecosystem services, by using known management interventions to improve water productivity in low-yielding rainfed crop production.

KEY TERMS

Yield gap - The gap between potential and actual yields for a specific crop, where potential yields are dictated by climate (the physical environment), and actual yields are dictated by management (the social environment).

Agro-ecosystems, especially rainfed crop production, are important to human societies

Agro-ecosystem production represents one of the largest abstractions of human water use, including food, livestock grazing, aquaculture, fodder, and fibre production systems (Figure 2). In particular, rainfed crop production is vitally important to global food supplies, occupying 80 per cent of the world's cropland and providing 60 per cent of the world's cereal crops.[2]

Meeting the food demand from a growing global population with changing diet preferences, with more food per capita and more water demanding food items, will increase the pressure for ever-larger volumes of consumptive water use in agriculture (Rockström *et al.* 2007). Increasing industrial and municipal demands, mainly due to the rapidly growing global urban population, will appropriate much of the water available in streams, lakes and shallow groundwater (blue water). The large number of dwindling rivers and depleted aquifers found today reveal the unsustainable blue water use during the past century, and show that it is impossible to repeat past water development to meet future food needs with the same technologies and demands on environmental sustainability, while expecting an acceptable economic return on investments. Therefore, rainfed agriculture (which uses green water) will remain a dominant source of crop production. Improving the productivity of water used in rainfed agriculture is an untapped opportunity to meet food, fodder and fibre demands of a growing population, whilst ensuring water flows to sustain existing irrigation schemes (especially in South and East Asia) as well as other landscape ecosystem services. Increasing productivity in an ecologically balanced manner will be fundamental for moving towards a green economy in the coming decades.

Agro-ecosystem productivity could be much higher than current yields

Rainfed agro-ecosystems are often low yielding for multiple reasons. Inherently variable rainfall and low soil fertility are important, but more important are knowledge of enhanced techniques and access to necessary farming inputs, including: improved genetic materials, agro-chemicals, nutrients, energy, and labour. There is a difference between what can potentially be produced

2 Molden, D. (ed) (2007) Water for Food - Water for Life: A Comprehensive Assessment of Water Management in Agriculture. International Water Management Institute. Earthscan. London, UK.

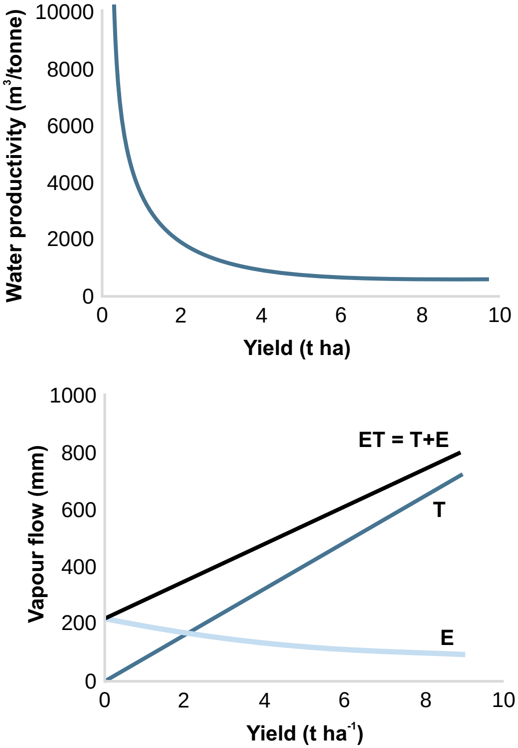


Figure 7: Water productivity and vapour flow at the field scale

(Adapted from Kijne *et al*. 2009)

in a given physical environment, and what is actually being produced. This difference in yields is commonly referred to as the *yield gap*, which refers to the gap between potential and actual yields for a specific crop. The yield gap, between actual and potential yields, can be closed by good management practices that increase water productivity.

Water productivity improves significantly at lower yields and tends to stabilize at higher yields (Figure 7a). This is due to the lower amount of transpiration and within plant evaporation at low yield (and low plant densities) (Figure 7b).

Large geographical areas that are dominated by smallholder farming systems currently experience low water productivity, in terms of how much water is used to produce a given benefit e.g. tonne of grain (Figure 8). Thus there are large areas that can be significantly improved by increasing water productivity, i.e. the amount of biomass per drop of water used in the crop system. These areas are largely located in rainfed dominated crop systems, in sub-Sahara Africa, Eastern Europe and central Asia.

Rainfed agro-ecosystems can improve yields with existing techniques

Increasing water productivity in current low yield in crop systems around the world can be achieved with various known and well-tested management interventions in agro-ecosystems. Solutions exist and are available for rainfed and irrigated agro-ecosystems that are adapted to the local context and crop practice. Several of these interventions do not just improve water productivity in terms of yield increase per unit water, but improve a wide range of other livelihood gains. These can include labour-related gains (i.e. the amount of labour used for crop management resulting in more yield), as well as area productivity gains (i.e. more yield per unit land utilized or per unit investment into the crop production system), and post –harvest management. These management techniques endorse strategies that enhance infiltration of water into the soil, that enhance soil water holding capacity & availability, and that enhance crop water uptake. A wide range of technologies that employ these methods exist and are already used widely. These include soil and water conservation, minimum tillage, water harvesting systems (including supplemental irrigation), fertilizer inputs (nitrogen, phosphorus, potassium; NPK), and integrated pest management. Another major improvement in crop production can be achieving timely management that focuses on matching specific actions to specific times of the year. Information systems such as rainfall forecasts are

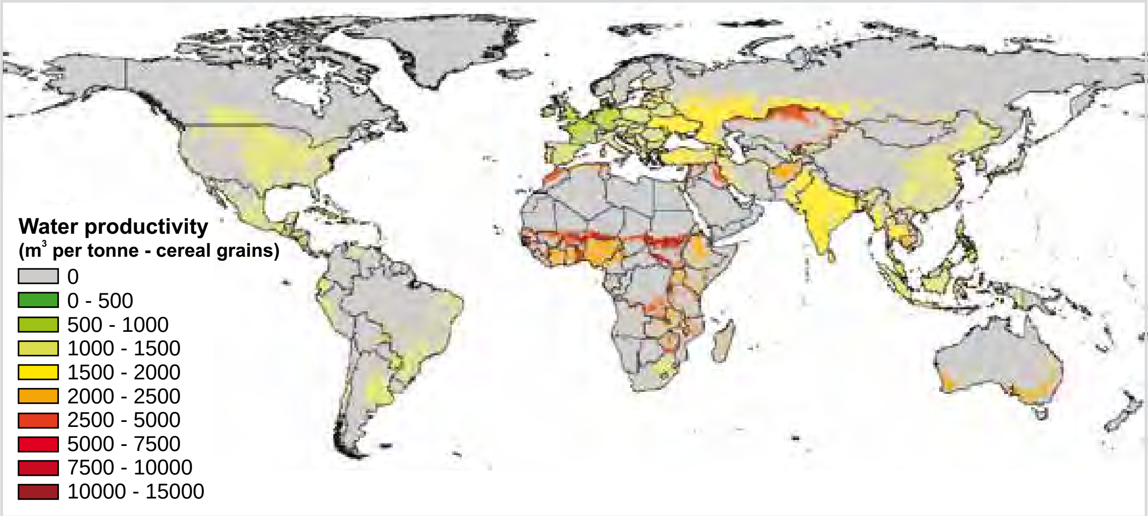


Figure 8: Water productivity for cereal production (Kijne *et al*. 2009)

very important because they affect farmers' decisions on what and when to plant, whether or not to fertilize, and when to hire additional labour. Some of these methods are further explored in the following case studies.

Scaling up agro-ecosystem management to increase global yields

Crop production can be increased dramatically with well-established management techniques in rainfed agriculture. Closing the current yield gaps to within 95 per cent of potential yields in rainfed agriculture could potentially produce 2.3 billion tonnes of additional grain, a 58 per cent increase, whilst maintaining current water appropriations (Foley *et al*. 2011). This would lead to decreased need for horizontal cropland expansion to attain food security, and less demand for appropriation of blue water for irrigation. Both green and blue water resources can be left to sustain other ecosystem services in landscapes beyond the agricultural production of crops and animal husbandry. Shifting agro-ecosystems to increase efficiencies both per unit water and per unit land can happen.

Management works, but it can go too far

Agro-ecosystem management is effective at both improving yields, while improving the productivity per unit land and water. However, as the next Key Message will demonstrate, improving the efficiency of agro-ecosystems in certain ways, can lead to trade-offs between agricultural ecosystem services and the surrounding landscape ecosystem services.

Case Study: Water productivity in Burkina Faso

Agricultural production in environments with high rainfall variability, such as the Sahelian region of sub-Saharan Africa, often results in yields below potential levels. This is often blamed on the dry, drought-prone climate of the region. However, in order to improve crops yields, more than the water deficit must be addressed. Researchers show dramatic improvements in yields can be achieved with specific management techniques combining the application of fertilizer and supplemental irrigation.

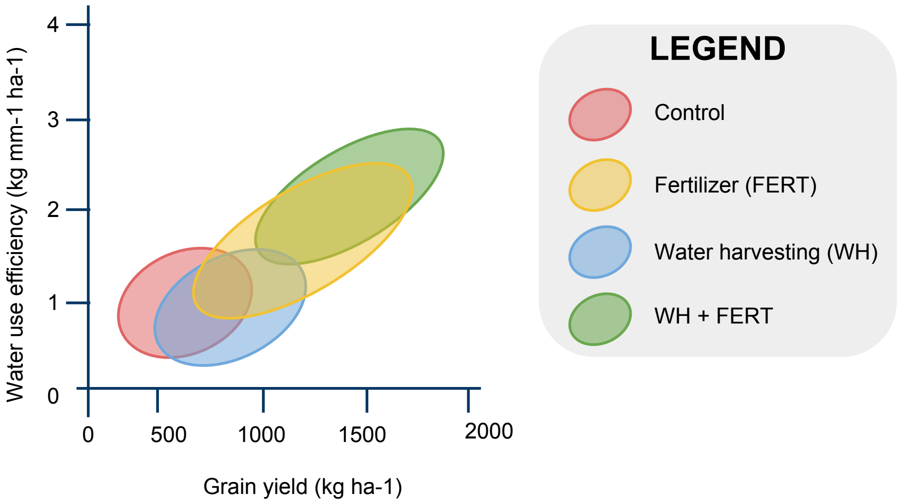


Figure 9: Water-use efficiency for sorghum in Burkina Faso (Adapted from Rockström *et al*. 2002)

Water harvesting and fertilizer application can as much as triple yields. The implications of this potential increase in yields are important for sustaining human well-being, by improving the livelihood of poor, rural farmers. Additionally, this potential increase in the productivity of a given volume of water is important, since the same water can produce three times the yield in this particular location, allowing water flows in the surrounding landscape to continue to sustain ecosystem services.

Reference

Rockström, J., Barron, J., Fox. P. 2002. Rainwater management for increased productivity among small-holder farmers in drought prone environments. Physics and Chemistry of the Earth. 27 (2002): 949-959.

Fox, P., Rockstrom, J. and Barron, J. 2005. Risk analysis and economic viability of water harvesting for supplemental irrigation in the semiarids. Agricultural Systems 83(3): 231- 250

Case Study: Global water productivity improvements with management

Assessments at the global scale indicate that crop production can be increased significantly. The management techniques employed are the "vapour shift" (VS, reducing "unproductive" soil evaporation by planting more crops) and "rainwater harvesting" (RH, for supplemental irrigation).

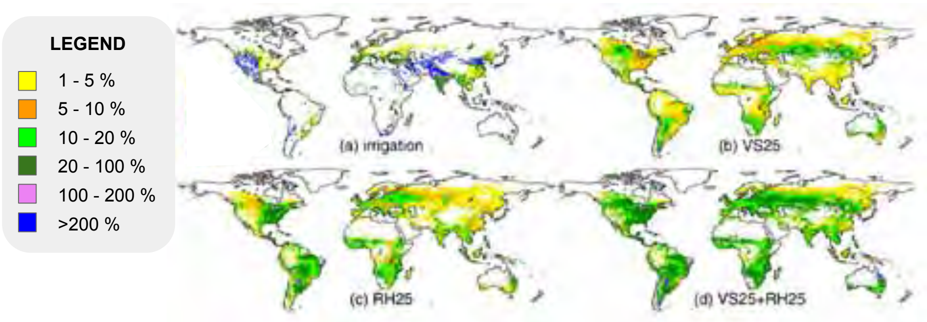


Figure 10: Increase in Net Primary Productivity with various water management strategies (Adapted from Rost *et al*. 2009)

The results overwhelmingly indicate that large increases in agricultural production are possible using existing management techniques, particularly in regions that suffer from chronically low yields such as Sub-Saharan Africa.

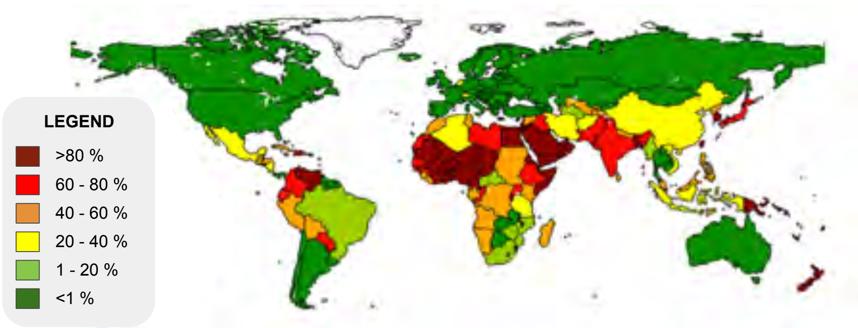


Figure 11: Percent of future water stressed population, given population, climate and CO_2 change (Adapted from Rost *et al*. 2009)

The importance of the management techniques explored in these simulations are going to be essential for providing adequate food supplies in the future, especially as irrigation water becomes increasingly scarce. But even with 25 per cent deployment of known agricultural management techniques, multiple pressures (using IPCC A2 scenario assumptions of population, economic, and CO_2 increases) will threaten agro-ecosystem sustainability (Figure 11). For that reason, landscape ecosystem services will continue to be an important source of complimentary, non-agricultural support especially for resource limited rural populations in least developed countries.

References

Rost, S. Gerten, D., Hoff, H., Lucht, W., Falkenmark, M., and Rockström, J. 2009. Global potential to increase crop production through water management in rainfed agriculture. Environmental Research Letters. 4 (2009): 044002.

KEY MESSAGE 3

Trade-offs between agro-ecosystem services and landscape ecosystem services must be managed so that improved agricultural water management and water productivity may lead to synergies with the surrounding landscape.

KEY TERMS

Trade-offs: "Win-lose" situations in which benefits to one activity serve to reduce the benefits of another activity, including unintentional negative impacts and negative externalities.

Synergies: "Win-win" situations in which benefits of one activity serve to amplify the benefits of a related activity.

Water use for agro-ecosystem services often leads to trade-offs with landscape ecosystem services

As agriculture develops and expands, more water resources in the landscape are used for food, fodder and fibre production. The water resources used are both the soil moisture (i.e. green water) and liquid flow (i.e. blue water). By solely maximizing agricultural production such as yields, the benefit of water to sustain ecosystem services is ignored. It is important to determine the need for balancing water use in both agriculture and for ecosystem services in the surrounding landscape so that the trade-offs can be managed equitably and efficiently. In the past, water use for agricultural production has mainly focused on appropriation of blue water resources for irrigation, or green water resources via expansion of rainfed crop or expansion of grazing. Using a water productivity concept coupled with assessing use and benefits of ecosystem services from various water and land-uses can assist in managing benefits and trade-offs between use of water for agriculture and agro-ecosystems, versus other benefits. A coupled analysis helps identify co-benefits of water uses, and occasionally identify when and where water management techniques that improve the productivity of agro-ecosystems (as those discussed in Key Message 2). It can also drive water-use competition. An example of water trade-offs between agro-ecosystem water-use productivity gains and landscape ecosystems is given in the in the Case Study: Watershed management to improve productivity in Kothapally, India.

Improvements in water productivity in agro-ecosystems are almost always considered as "positive." However, the above case illustrates that there can be unintended consequences that negatively affect the ecosystem services in the surrounding landscapes. Monitoring these potential consequences is essential for ensuring that improvements to local livelihoods do not come at the expense of livelihoods downstream (see Key Message 8 and 9).

Improving surrounding ecosystem services can lead to ESS synergies

By managing the trade-offs associated with agro-ecosystem water use, increased benefits may be provided through landscape ecosystem services. Gordon *et al.* (2010) identified three specific strategies that may be deployed to manage these trade-offs:

Case Study: Watershed management to improve productivity in Kothapally, India

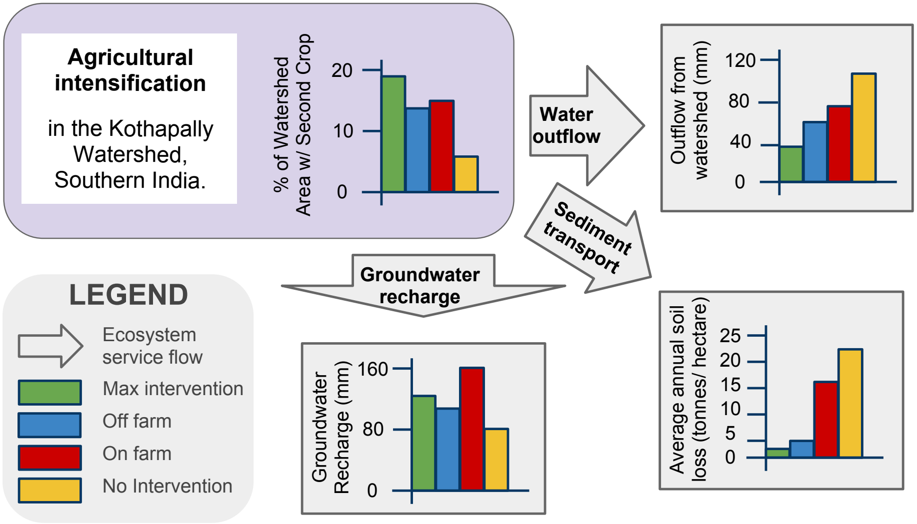


Figure 12: ESS synergies and trade-offs associated with agricultural water management in Kothapally, India

During the past 30 years, local and national actors have promoted watershed management to enhance benefits for rural livelihoods and sustainably use land and water resources. The Kothapally watershed, Southern India, is a typical semiarid densely populated watershed which experienced reduced capacity to support a growing population and increasing soil degradation, aggravated by high intensity rainfall normally experienced in tropical semiarid lands of India. In 1998 -2000 the local communities begun to reinvest in the land and water resources, aiming to increase livelihood benefits through more productive use of land and water resources. By adopting combinations of various soil water management interventions, the water flows in the landscape have changed, and as a consequence, various key ecosystem services have been affected.

The changed landscape water flows have affected several processes including: soil loss, water infiltration, groundwater recharge, downstream flows, and crop yields. Substantial benefits have been measured as a result of the improved land and water management, but it has also some incurred some costs.

The colored bars refer to different levels of intervention of soil water conservation measures; “No Intervention” = no measures, “Off Farm” = check dams in the stream network, “On farm” = Contour and graded bunding, broad beds, and furrow practices, and “Max intervention” = both on and off farm measures of agricultural water management strategies.

Connecting water productivity gains to ecosystem services

The Kothapally case illustrates the multiple benefits associated with local improved water productivity improvements, especially as improved overall local sustainability. The rainfall has not changed, but the use of rainfall, i.e. water productivity, has been improved through increased soil moisture retention enabling increased rainfed crop yields and enabled recharge of groundwater, further used as irrigation of a high value crops. These factors contribute to improved local livelihoods and reductions in local poverty.

The external consequences are mixed with positive consequences such as increased soil retention within the watershed and improvements in water quality. However a negative consequence of the water productivity gains has resulted in reductions in outflow to downstream users (including aquatic flows). This case study illustrates the importance of embedding local agricultural productivity gains within external impacts to surrounding downstream ecosystem services.

References

Garg, K.K., Karlberg, L., Barron, J., Wani, S.P., and Rockström, J. 2011. Assessing impacts of agricultural water interventions in the Kothapally watershed, Southern India. Hydrological Processes. In press.

- Decrease the volume of water required for each unit of agricultural produce grown, and reduce excess nutrient pollution into waterways. These efforts will serve to reduce quantity and quality impacts downstream

- Link management of downstream ecosystems with upstream agricultural water management. Explicitly link stakeholders who are part of unavoidable trade-offs between upstream and downstream water use.

- Pay attention to synergies between on-farm agricultural productivity and off-farm landscape productivity. This is acknowledged to be a major shift in current agricultural decision-making processes.

Improving surrounding ecosystem services

By managing the trade-offs associated with ESS, synergies between the intensively managed agro-ecosystems and the surrounding landscapes can emerge, such as increased pollinator activity with increased agricultural pollen. Identifying these and other key synergies that enable communities to depart poverty traps, and build up the green economy, are critical for long-term ESS management.

The following Key Messages will explore additional human activities that are related to specific landscapes and the associated attempts at changing these landscapes to maximize the productivity of water flows.

Table 2: Ecosystem services typically negatively affected by yield gains (from increased water-use efficiency)

	Local/internal	Downstream/external
Soil quality	reduce organic matter , soil nutrient cycling and biodiversity sustaining nutrient cycling Increased salinity can accelerate	
Soil quantity		Downstream sediment transport dependent on local tillage methods
Water quality		Streamflow is sustained, with less water withdrawn from system.
Water quantity	Variable, depending on method of irrigation	Reduced, as less water (return flow?) is available due to higher irrigation efficiency
Ground water	Reduced due to increased uptake of soil moisture	

KEY MESSAGE 4

Wetlands maintain key regulating and supporting ecosystem services at landscape scales, thus contributing to high landscape water productivity in terms of multiple benefits for human well-being.

KEY TERMS

Wetlands – "Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres" [from the Ramsar Convention, Article 1.1].

Wetlands and their wasteful reputation

Wetlands have always been under pressure from agricultural expansion and intensification. Draining or diverting water flows from a wetland for the purpose of increasing the agro-ecosystem productivity (generally for irrigation) has historically been a common practice. Wetlands and marshes were often considered "wasteful" since large volumes of evaporated water could have a higher value as irrigation for marketable crops, compared to sustaining habitats for biodiversity or regulating water flows in the landscape. To estimate and value the true benefits of water use in wetlands or in agro-ecosystems, the full range of benefits they provide should be considered before taking action to change them.

Wetland Management or Mismanagement?

Historically, marshes, wetlands, and swamps have been identified as targets of "reclamation" intervention, whereby wetlands have been drained for other uses, including: expansion of agricultural land, aquaculture, withdrawal of freshwater for irrigation, riverside industry, human settlement, or for port development. Though these activities have generally been beneficial to maximize agricultural productivity, particularly crop yields they have also degraded landscape ecosystem services (ESS). Fundamental ESS that are supported by wetlands include the regulating services of natural hazard mitigation (e.g. flood protection) and provision of baseflow, i.e., stream flow and shallow groundwater during season with limited rainfall. A third critical service is the process of natural filtering of nutrients and pollutants - in particular treatment of nitrogen and phosphorus compounds. Finally, wetlands provide vital carbon sequestration (especially peatlands) as well as critical habitat support. In many areas this loss of services has been disastrous for not only livelihoods, but also downstream inland water bodies and river deltas. There are multiple examples of agricultural practices in previous wetlands and marshlands that have failed to replace the above mentioned multiple ESS. In addition to the loss of regulating services, losses of provisioning ESS are also possible, depending on the level of local reliance on the wetland (explored in the case study below).

Case Study: Value of wetland ecosystem services in Barotse Floodplain, Zambia

Summary

The Barotse Floodplain in the western Zambezi Basin, Zambia, comprised of seasonal wetlands, and intermittent grasslands and woodlands. The residents of the Bartose Floodplain, predominantly the Lozi people, have a mixed livelihood that is highly dependant on the wetland, including fishing, farming, and livestock production.

Value of wetland ESS

The importance of provisioning services to local livelihoods is high accounting for more than 75% of subsistence livelihood income, as well as 20% of household cash income (Figure 13).

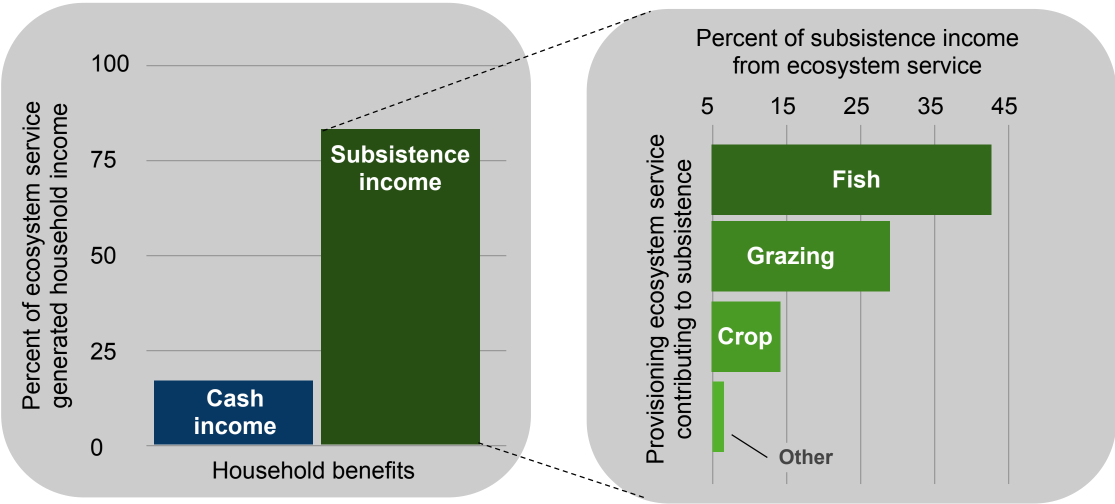


Figure 13: The annual value of the Barotse Floodplain provisioning ESS, per household

It is clear that provisioning services provided by the wetland ecosystem, represent a major part of livelihood support for the Lozi people. The floodplain-wide value of the Barotse provisioning services were estimated at greater than $11 million/ year for an area of 550,000 hectares. Agro-ecosystems in the Barotse Floodplain benefit directly from the water resources in the wetland via gardens, sediment replenishment by the Zambezi River and from water filtration and groundwater recharge, via the wetlands.

Given the level of dependence on ESS provided by the local wetland, the Lozi and other residents of the Barotse Floodplain must engage the upstream portion of the Zambezi River, to ensure the long-term sustainability of the wetland resources.

Reference:

Emerton, L. (ed). 2005. Values and Rewards: Counting and Capturing Ecosystem Water Services for Sustainable Development. IUCN Water, Nature and Economics Technical Paper No. 1, IUCN- The World Conservation Union, Ecosystems and Livelihoods Group Asia.

Wetland ESS stabilize agro-ecosystems, facilitating improved human well-being

As demonstrated by both case studies, wetlands often provide critical services to the human societies around them. In rural societies specifically, the benefits of wetlands to sustainable agro-ecosystems are more pronounced, given their disproportionate reliance on the complimentary provisioning benefits of landscape ESS.

In addition to the provisioning and cultural ESS, wetlands support and regulate the functioning of much broader landscape ecosystem processes. Wetlands represent critical points in the hydrological system, where the value of regulating and supporting ESS can be much larger than provisioning services. Attempts to value these hydrological functions alongside other regulating and supporting functions of wetlands are often bypassed in both policy and the management of the landscapes and societies (Figure 8). Thus, the water productivity can be considered very efficient when also accounting for the supporting and regulating services supported by the water flows through wetlands and marshlands. Even when using various valuation methods, the value of replacement provisioning services (such as crop production) are consistently below the aggregated values of supporting and regulating services of wetlands.

Though these values are theoretical, the importance of wetland systems cannot be overstated. Ensuring the function and resilience of wetland systems globally and locally is equivalent to receiving billions of dollars worth of services, annually.

Through reclamation for agricultural purposes, long-term, highly-valued wetland ESS are exchanged for short-term benefits. Additional field-based evaluations of the changes in value and type of ESS that are available post-reclamation are necessary for the relation of evidence-based policies. It is likely that these evaluations will strengthen the argument that wetlands are a productive use of water both for human well-being and for supporting landscape ESS And these must be considered in comparison with water productivity of converting wetlands into part or fully irrigated agro-ecosystems.

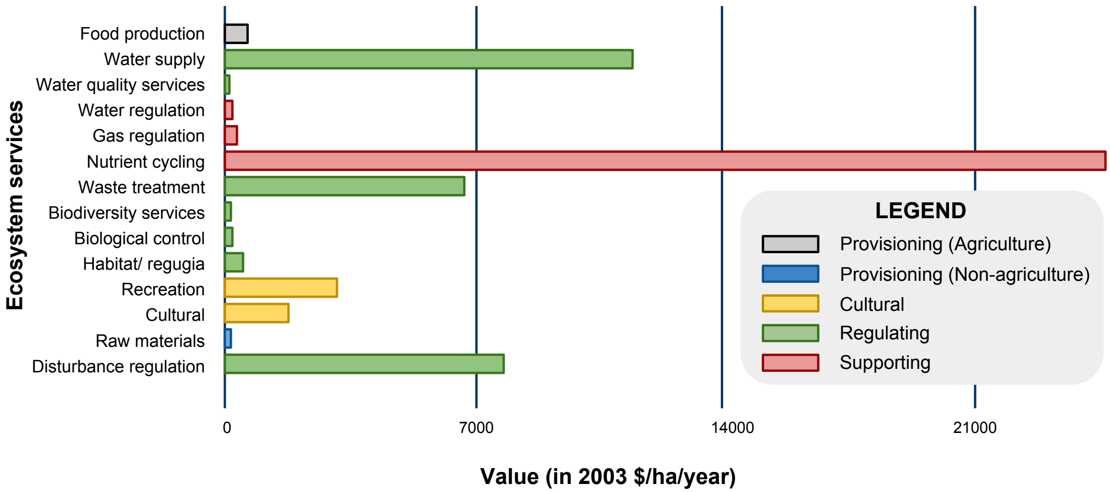


Figure 14: Average value of ecosystem services in wetland ecosystems, by type of service

Case Study: Wetland trade-offs in Hail Haor, Bangladesh

Wetlands in Northern Bangladesh are known as haor, and one such wetland, Hail Haor supports a large number of people through commercial and subsistence fisheries, as well as regulating services in the form of flood protection, and supporting a biodiverse habitat. In addition, non-fish provisioning services related to agriculture e.g. pasture, rice cultivation, and cultural services (e.g. recreation) are important (Table 3). Declining fisheries were identified as a consequence of years of draining water from Hail Haor for rice cultivation. To address this issue, a team of local, national, and international actors coordinated a wetland rehabilitation effort.

Table 3: Value of wetland resources for the Hail Haor wetland, in Northern Bangladesh (Thompson and Balasinorwala, 2010)

Types of goods and services	Total returns	Value per area (USD/Ha)	Per cent
Commercial fisheries	988,967	80.5	12
Subsistence fisheries	1,470,142	119.5	18
Non fish aquatic products	2,249,091	182.9	28
Boro rice value	1,122.276	91.2	14
Project/biodiversity funds	767,146	62.4	10
Pasture value	708,134	57.6	9
Flood control	412,007	33.6	5
Recreation	123,473	10	2
Transportation	153,924	12.5	2
Total in USD	7,995,160	650.2	100

Continued expansion of rice cultivation was identified as a livelihood strategy that threatened regional sustainability, and thus a strategy of wetland rehabilitation was pursued. Local representatives from eight Resource Management Organizations (RMO) identified an area of Hail Haor that could be set aside for protection and rehabilitation while not affecting the livelihoods of the poorest residents.

The protection strategy successfully improved overall ecosystem function and increased ESS provision. Fish catch improved by 80% across the entirety of Hail Haor, and local fish consumption increased by 40%. Additionally, as a result of the ban on fishing and aquatic plant harvesting in the protected area, the number of resident bird species increased, leading to ecotourism in the region – an income generating activity that had never occurred in Hail Haor. When accounting for the multiple values of the wetland the overall water productivity increased, in terms of economic value per hectare of wetland.

Reference:

Thompson, P. and Balasinorwala, T. 2010. Wetland protection and restoration increases yields, Bangladesh, available at: TEEBweb.org.

KEY MESSAGE 5

Livestock management practices can have co-benefits that require less water, allowing the unused soil water to support the surrounding landscape.

KEY TERMS

Livestock water productivity (LWP) - The economic value of livestock produce per unit water.

Non-productive depletion – Water that is unused in an agro-ecosystem (especially livestock systems), such as water that evaporates from the soil column rather than being transpired through vegetation.

Livestock production chains and water productivity

Livestock and the produce of animals for meat, milk and eggs is a water-consuming agricultural activity. A substantial amount of water is needed to supply livestock and other animals with fodder, which ultimately consumes water for its growth. Livestock rearing is often associated with various impacts on local landscapes and ecosystem services. The livestock sector claims one third of global croplands, including >40 per cent of the cereal production, and 30 per cent of the global land surface for pastures (FAOStat 2011).

A land use is always also a water use, and the role of livestock production in relation to global water resources and water-related ecosystem services is consequently of vital importance for future environmental sustainability, as well as for food security. Livestock production is a multifaceted activity with a wide range of combinations of animal species, breeds, production systems, scales of production, and it occurs in many different climatic zones. At the global level, livestock contribute 15 per cent of total food energy and 25 per cent of dietary protein. The sector ranges from being a vital livelihood component for about 70 per cent of the world's 1.4 billion "extreme poor" to being a multinational enterprise, with more than 50 per cent of pork and poultry meat from industrial systems (FAO 2009). The losses during conversion of feed biomass to animal products multiply water demands for animal foods compared to vegetal foods. With projected rising global demand for animal products the competition for land and water will be fierce, which will have profound effects on food security (Herrero *et al.,* 2010).

Dividing up the livestock sector

The livestock sector can generally be divided into three major production systems: industrial; mixed; and grazing (Notenbaert *et al.* 2009), and two major animal groups, mainly grain fed monogastric animals (like pigs and chickens) and ruminants (like cattle, sheep and goats), that can utilize a wide combination of grazing, roughage and feed concentrates. The water use by livestock is almost entirely related to evapotranspiration of feed, fodder or grazing lands, and the amount of drinking and service water is estimated to less than two percent (Peden *et al.* 2007). Depending on the animal types and livestock system chosen the impact on water resources will thus be different. Local production with extensive grazing animals will only appropriate green water resources, and thus only compete with other local terrestrial ecosystems. Livestock production that uses feed or cultivated fodder requires additional water resources, and can compete with not only terrestrial ecosystems, but also aquatic ecosystems as fodder may be grown relying on rainfall and irrigated (blue water) for its production.

Livestock water productivity and its components

Generally, livestock systems affect the hydrological cycle in three ways. (1) Through water withdrawals for irrigation which can deplete groundwater resources and reduce river flows and impact associated ecosystem services and water uses downstream. (2) Through land cover changes, e.g., with increasing runoff formation when permanent vegetation such as forest is converted to crop or grazing lands. Reductions or increases in water flows affect the environmental conditions for all ecosystems connected to the livestock system. (3) Through changes in land use management, for example, increasing grazing pressure can affect water use by compacting soils and increasing runoff (Deutsch *et al.,* 2010). Additionally, the concept of improving livestock water productivity is explored in greater detail below in the Case Study: Livestock water productivity in the Ethiopian highlands (Descheemaeker *et al*. 2011). Livestock water productivity can be divided into three components. The first part is related to evapotranspiration (ET) during cultivation of feed crops and fodder, or from grazing lands. The second part relates to the conversion efficiency of feed and fodder to meat, egg or milk. This relates to, on the one hand, animal management as animal health, providing shelter or supplying drinking water and, on the other hand, to fixed factors like choice of animal species and breeds, herd size, scale of production, and environmental preconditions at the site of production. The third factor relates to improving the "coupled" feed-livestock water productivity, which includes e.g. choice of production system (e.g. mixed systems can utilize crop residues), strategic sourcing of animal feed (i.e. less water intensive feeds), and optimization of grazing pressure (e.g., Peden *et al.* 2009).

To optimize the water use and increase water productivity in livestock production consequently means to optimize a whole range of combinations of ecosystem services and is thus much more complex than optimization of crop cultivation, which is already quite intricate. With livestock production taking place in vastly different climatic zones and with a multitude of factors impacting the water productivity per livestock item, it is important to remember that the absolute water productivity value is difficult to compare, and must instead be viewed and compared within a defined, or comparative, production system.

Opportunities for improving ecosystem services and livelihoods in livestock land and water use

Given that livestock management is a critical component for livelihoods and well-being in developing countries, reducing negative impacts to water flows and amplifying positive relationships should be a priority. Table 4 lists potential management strategies and their outcomes in terms of ecosystem services and livelihoods.

Livestock can be part of a sustainable strategy for poor farmers to create virtuous circles (opposite of vicious cycles) and eventually exit poverty (CA 2007; Mortimore and Adams 2000). This is true because livestock can feed on crop residues, provide organic compost for crop production, and supplementary (or primary) income for rural farmers.

Table 4: Implications of particular livestock management activities on ecosystem services

Local Management	Outcome	
	Ecosystem Services	Livelihoods
Rotate livestock herds /managed grazing pressure	Reduce vegetation loss and soil compaction, allowing forage to return and increasing infiltration of green water to groundwater table	Increase livestock productivity without losses in soil productivity
Manage manure and waste for fertilizer	Soil enrichment Reduced pollution of local and downstream water supplies Reduced GHG emission of methane	Increased crop production, reduced money spent on fertilizer
Manage crop residues for livestock feed	Reduced vegetation loss/biodiversity loss, since residues used for feed	Increased landscape vegetation provides complimentary livelihoods
Choose climate appropriate livestock breeds and size of herds	Reduce excess water use (e.g., for cooling livestock), Reduce soil and vegetation degradation	Reduce expenses for maintaining exotic species Improve survival and economic value of survival livestock

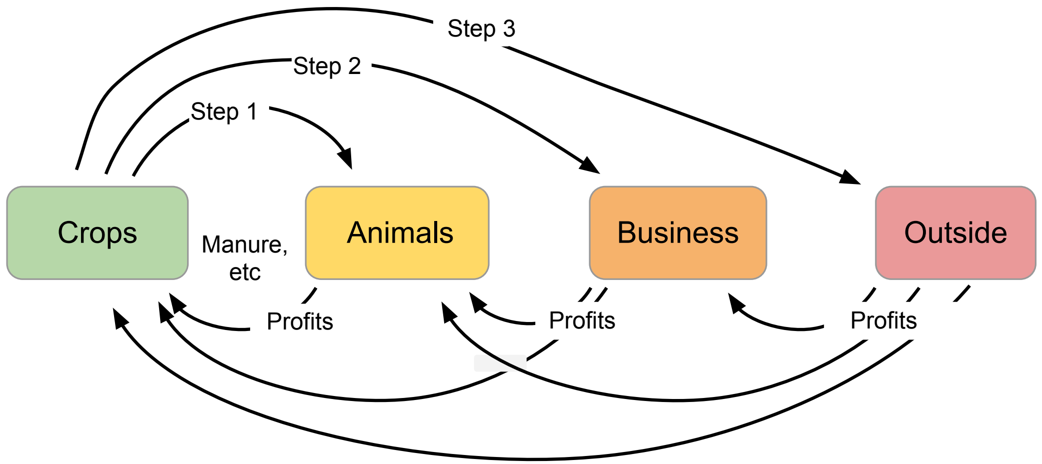


Figure 15: Diagram for how livestock rearing can integrate with poverty alleviation goals

(Adapted from Mortimore and Adams 2000)

Case study: Livestock water productivity in Ethiopian highlands

Livestock are complex components of the farm system, because the both consume resources (e.g. feed, water), and provide them (e.g. milk, meat). Similar to crop water productivity (CWP), it has become useful to understand livestock water productivity (LWP), which is defined as the economic value of livestock per unit water.

Actual LWP in smallholder farming systems is considered to be well below potential LWP, and thus increasing this without adverse environmental impacts is an important area of research. In this case, researchers used field observations, group discussions, and semi-structured interviews, were used to create a baseline scenario of livestock water productivity for smallholder farms in the Ethiopian highlands.

From this baseline, various on-farm interventions were simulated in a spreadsheet model focusing on three broad categories: (1) feed interventions, (2) water interventions, and (3) animal interventions. (For details on the interventions and the assumptions used in the simulations please refer to the study Descheemaeker, K. *et al.* 2011).

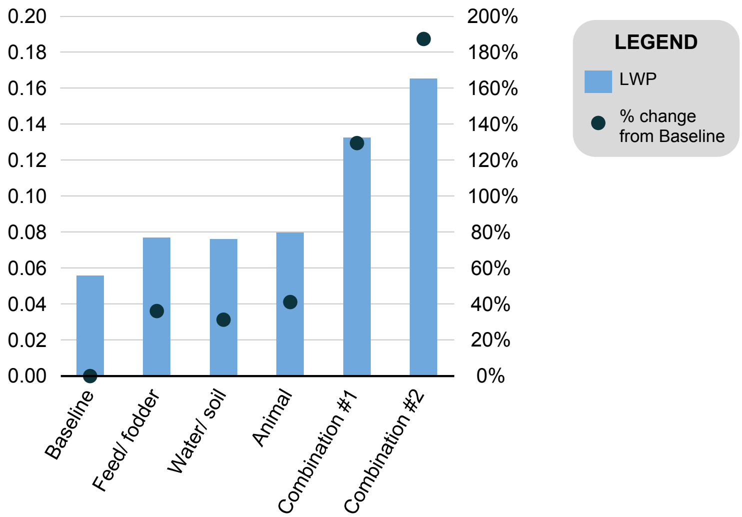


Figure 16: Increases in livestock water productivity (LWP) with different interventions

The results of the simulations indicated that LWP in smallholder farming systems can be improved - in some cases dramatically so. In those cases, available land and water resources are used more efficiently to produce more livestock, and subsequently improved nutrition, household income, and sustainable intensification. However, the authors also acknowledge that the increases are achieved (at least in part) by reducing surface runoff and deep percolation of rainfall, which could have negative impacts for downstream ecosystem services.

Future analyses should consider the impact that on-farm improvements to water productivity are not achieved at the cost of to off-farm ecosystem services.

Reference:

Descheemaeker, K., Amede, T., Haileslassie, A., and Bossio, D. 2011. Analysis of gaps and possible interventions for improving water productivity in crop livestock systems of Ethiopia. Experimental Agriculture. 47 (S1): 21-38.

"Non-productive depletions" must be reframed

As in crop agro-ecosystems, the concept of "unused water" is used in livestock systems, here referred to as "non-productive depletion" (Molden 2007). This can refer to water that is evaporated, discharged via flood, infiltration to the groundwater table, and polluted via contamination with animal waste.

By recognizing that most of the above "non-productive depletions" could be important sources of water for surrounding landscape ecosystem services, the term "non-productive" is often inaccurate. Thus, it is important to embed livestock management in the broader system of interconnecting human and natural landscapes.

KEY MESSAGE 6

Forest ecosystems provide multiple services for human well-being locally, regionally, and globally, and should be considered as productive uses of water flows.

KEY TERMS

Non-timber forest product (NTFP) - Complimentary provisioning ESS from forests, such as fibre, fruits, nuts, wild game, etc.

Forests are productive users of water

Forests are a major component of the terrestrial landscape, covering approximately 127 million hectares globally, and they have a strong coupling to the hydrologic cycle (Rudel 2009). Forests provide a very rich diversity of ecosystem services, including habitats for various species of flora and fauna. Improvements in the productivity of water in agro-ecosystems, in terms of more benefits per unit land area, can result in less pressure exerted on nearby forests, because there is less need to expand cropped area to meet crop production demands. Actions taken to increase forest cover, such as afforestation, reforestation, or protection of existing forested areas, can have varying effects on the local water flows, in some cases increasing local flows, and in other cases, decreasing local flows depending on extent, location and diversity of species. In terms of the type and diversity of ecosystem services that improve human well-being, and should therefore be considered a productive use of water flows.

Forest-based provisioning services contribute significantly to human well-being

Forests are especially important to communities that are near or below the poverty level. In such livelihood systems, forests provide a range of complimentary sources of income, including timber and non-timber forest products (NTFPs), such as fibre, fruits, medicine, nuts, and wild game. The total value of the benefits provided by forests ecosystems can be high (in the order of wetlands, see Key Message 4), especially when the potential value of regulating and supporting services are included. Although regulating and supporting services are rarely valued in the conventional sense (e.g.,cash value per unit benefit), some efforts are being made to assign a value to some of these services, such as carbon sequestration and carbon emissions. Table 5 depicts the estimated value of different forest-based ecosystem services globally, in US dollars per hectare.

Natural forests versus managed forests

Natural forests, meaning forests that are not actively managed including many tropical forests, (particularly in the interiors of the Amazon and the Democratic Republic of the Congo), provide important regulating ecosystem services notably water quality regulation and some protection from flooding, at least in systems where flooding is common. According to a recent study, an average of 12 per cent of terrestrial forests were planted forests (Rudel 2009). Although management can also occur in

Table 5: Global estimates of the value of forest-based ecosystem services (From UNEP 2011)

Service	Estimates of value (USD/ha)	Source
Genetic material	<0.2 to 20.6 0 to 9,175 1.23	Simpson *et al.* (1996); Lower estimate: California, Higher estimate: Western Ecuador Rausser and Small (2000) Costello and Ward (2006) mean estimate for most biodiverse region
Watershed services (e.g. flow regulation, flood protection, water purification)	200 to >1,000 (multiple services, in tropical forests) 0 to 50 (single service)	Mullan and Kontoleon (2008)*
Climate regulation	650 tp 3,500 340 to 2,200 (tropical forests) 10 to >400 (temperate forests)	IIED (2003)* Pearce (2001) * Mullan and Kontoleon (2008)*
Recreation/tourism	<1 to >2,000	Mullan and Kontoleon (2008)*
Cultural services (existence values)	0.03 to 259 12 to 116,182 (temperate forests)	Mullan and Kontoleon (2008)* Mullan and Kontoleon (2008)*

* Lowest and highest estimates from review of valuation studies

non-planted, naturally occurring forests, management activities are concentrated in planted forests.

Management activities associated with forestry (harvest of timber/ logging, from e.g. plantations a/o natural forests) can undermine the regulating functions forests provide such as flood protection, nutrient cycling, sediment reduction, and filtration/purification afforded by 'natural' forests. This issue of natural versus managed forests has led to some confusion about the dependencies of water flows to sustain various ecosystem services associated with forests (see "Myths" box, and Case Study below)

Forests landscape of ecosystem services

Forests provide direct and indirect support for local subsistence livelihoods, as well as supporting benefits for agro-ecosystems and a range of other external services such as carbon sequestration and climate protection. By improving water productivity on existing agricultural lands, particularly in low-yield areas, the pressure on forests will be reduced. As a result, forests will continue to provide critical complimentary support to livelihoods and well-being, as well as provide much needed regulating and supporting ESS.

The ESS associated with forests, many of which are regulating and supporting services, are most clearly charac-

Box 4: "Myths" of forests and water flows

Conventional wisdom suggests that forests have many positive characteristics that are almost universally beneficial to the surrounding landscape. However, these topics have been systematically explored, and surprisingly many of them are not as intuitive as originally thought.

MYTHS "Forests…"	REALITY	EXPLANATION
"Increase rainfall"	Mixed	Increased (decreased) local transpiration may lead to slightly increased (decreased) local precipitation, but the "…effects of forests on rainfall are likely be relatively small."
"Increase runoff"	False	"…experiments indicate reduced runoff from forested areas, relative to shorter vegetation."
"Regulate flows" and "Increase dry-season flow"	Mixed	Different forests exist with different soils and vegetation, so the "… effects on dry season flows are likely to be very site specific; … it cannot be assumed that afforestation will increase dry-season flows."
"Reduce erosion"	Mixed	"… competing processes may result in either increased or reduced erosion from forests; … the effect is likely to be both site- and species' specific" also, "Management activities like cultivation, drainage, road construction, road use, and felling increase erosion."
"Decrease flood risk"	Mixed	"There exists little scientific evidence to support anecdotal reports of deforestation causing increased floods." But, "Field studies indicate that it is often the management activities associated with forestry such as cultivation, drainage, road construction, and soil compaction during logging, which are likely to influence flood response."
"Improve water quality"	True	"Except in high pollution catchments, water quality is likely to be better from forested catchments."

Similarly to recognizing and accounting the multiple benefits by water flows through the wetlands, understanding the multiple benefits provided by forests is necessary for an accurate assessment of the benefits and costs associated with a given land-use change. Potential water productivity gains should be measured relative to landscape productivity, not as "farm-only" productivity. In this way, the benefits associated with water flows through forests (and its subsequent value to livelihood activities) should be included in an assessment of a given management activity of forests.

Reference:

Calder, I. 1998. Water-Resources and Land-Use Issues. SWIM Paper 3. Colombo, Sri Lanka: International Water Management Institute.

terized at the watershed or basin scale. This is because the beneficiaries of the ecosystem services are not only in the forest area itself, but also in the surrounding landscape, and downstream of the forests. This concept of watershed-scale assessment of forest benefits is often related to the hydrological functions, i.e., support of baseflow downstream during dry periods, or maintaining groundwater at a desired level. The carbon sequestration services provided by forests are increasingly valued as part of global climate adaptation efforts, particularly with regard to REDD+ (Reducing Emissions from Deforestation and forest Degradation). UNEP has led efforts to clarify the much more extensive role of forests in providing ESS beyond carbon sequestration, so as to strengthen the case for REDD+ (UN-REDD 2008).

Case Study: Benefits of natural forests in Sekong, Lao PDR

The direct and indirect benefits of forest ecosystem services are all dependent on water. In the Sekong province of Lao PDR, These benefits included provisioning services (e.g. timber and non-timber forest products, NTFPs) and regulating services (e.g. watershed protection, flood control, biodiversity conservation, and carbon sequestration). However, different beneficiaries can be identified, and not all benefit form the same ecosystem services (Figure 17).

Table 6: Estimated value of ecosystem services in Sekong Province, Lao PDR

(after Rosales *et al*. 2005, Emerton 2005)

Types of Use/Benefit	Annual Value (USD/ha)
DIRECT USES	
NTFP	398 - 525
Timber	10.35
INDIRECT USES	
Watershed protection	
Fisheries and aquatic resources	0.47
Agricultural production	2.5
Micro-hydropower facilities	0.003 - 0.02
Potential hydropwer supply	233 - 1,581
Flood control	92.3
Biodiversity conservation	
Conservation expenditures	0.07
Bioprospecting	0.11 - 0.55
Carbon sequestration	1,284.00

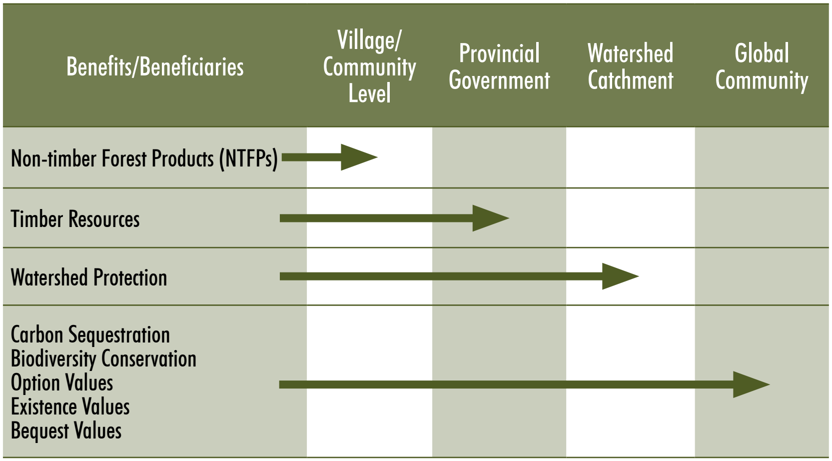


Figure 17: Recipients of forest ecosystem services in Sekong Province, Lao PDR. (Rosales *et al*. 2005)

Given that local livelihoods appear to be most reliant on NTFPs, it is useful to understand the value of these NTFPs relative to the other ecosystem services evaluated (Table 6).

The value of NTFPs is among the highest per hectare ecosystem service among those evaluated in Sekong Province. The average annual household income in Sekong Province is $120. However this figure ($120/year) ignores "non-cash income", which is overwhelmingly provided by NTFPs (between 85% and 45% of non-cash income, depending on income category).

Agro-ecosystems and forests provide multiple benefits for local livelihoods

As NTFPs provide a large fraction of local livelihoods (in terms of cash and non-cash income), as well as the underlying support that the watershed receives from flood protection and biodiversity conservation, forests are an important component of understanding coupled agro-ecosystem and forest-based societies.

References:

Emerton, L. (ed). 2005. Values and Rewards: Counting and Capturing Ecosystem Water Services for Sustainable Development. IUCN Water, Nature and Economics Technical Paper No. 1, IUCN- The World Conservation Union, Ecosystems and Livelihoods Group Asia.

Rosales, R., Kallesoe, M.F., Gerrard, P., Muangchanh, P., Phomtavong, S., and Khamsomphou, S. 2005. Balancing the Returns to Catchment Management: The Economic Value of Conserving Natural Forests in Sekong, Lao PDR. IUCN Water, Nature and Economics Technical Paper No. 5, IUCN — The World Conservation Union, Ecosystems and Livelihoods Group Asia.

Box 5: A quick guide to water use in forested systems

The vertical arrow refers to streamflow (Q), with Qs referring to total surface water flows, and Qm referring to minimum agreed seasonal (or annual) flow. So, the top part of the chart refers to when surface flows exceed the minimum flow requirement. The horizontal arrow refers to precipitation, P, and evaporation, E. The right side of the chart refers to situations where precipitation exceeds evaporation, whereas the left side of the chart refers to situations where evaporation exceeds precipitation.

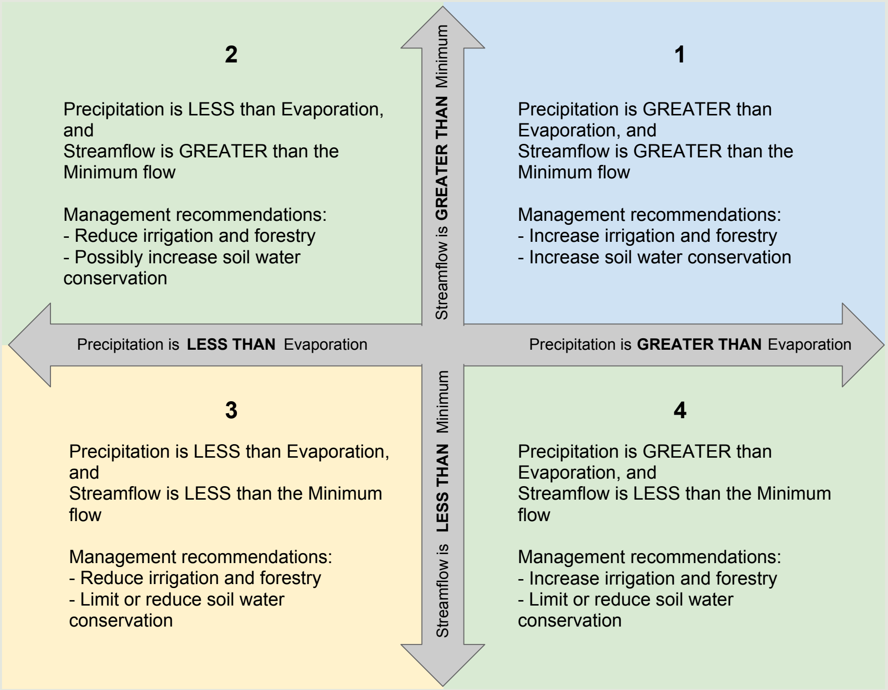


Figure 18: Catchment conditions to identify green and blue water management options

The local water resource manager could consult the chart above, and find where the streamflow and precipitation/evaporation pair matches local conditions. Once the pair of conditions is identified, the general management strategy is listed in the box. For example, if precipitation does not exceed evaporation, and surface water flows do not exceed minimum streamflow requirements, then the manager is "in" Quadrant 3, which recommends reduced irrigation, reduced forestry, and limited soil water conservation (SWC). Though the chart is not perfect, and is not appropriate in every situation, it provides a valuable tool for assessing whether and how forested areas can fit into the broader mosaic of water uses. Furthermore, this type of tool that seeks to explicitly link forestry with generalized best management practices is necessary for allocating water flows between forests and other water uses.

Reference:

Calder, I. 2007. Forests and water Ensuring forest benefits outweigh water costs. Forest Ecology and Management. 251: 110-120.

Ensuring forest benefits outweigh water costs

Integrating forestry into water management efforts is necessary to ensure the value of forest ecosystems are accounted for in landscape water use. The context specific impacts of deforestation, reforestation, and afforestation on water flows can be a challenge for managers to identify suitable pathways for improving local livelihoods whilst supply water to various demands within the watershed and downstream. The "quadrant approach to sustainable forestry" can provide useful direction as to whether an increase or decrease in forested area is complimentary to local water resources (see Box: A quick guide to water use in forested systems).

Case study: Afforestation-driven Wetland Loss in the Maasin Watershed, Philippines

Planting trees in the upper part of the Maasin Watershed (in the Phillipines) has caused an ecosystem that was once swampy, to transition to a drier, forested ecosystem. Historically, the Maasin watershed, was managed to support paddy rice. However, in the mid-1990s, decisions were made to afforest large parts of the 6,750 hectare watershed. 2,685 hectares of plantation trees were planted (with an average survival rate of 90.6%). Of this 2,685 ha, 61.8 kms of stream bank protection was successfully accomplished throughout the watershed; 40 meters on either side of the river, beginning in 1995. Preliminary evidence suggests that the plantation has changed local hydrology, reducing outflow to downstream rice paddies, and changing the species of plants and animals in the area. Landscapes have transitioned from moist, wetland ecosystems, to drier forest ecosystems. This has implications for local hydrology, local plant and animal life, as well as many aspects of management. Importantly, many creeks (and one waterfall) have dried up (including: Mianas Creek, Igot Creek, Bungol Creek, Lanag Creek, Bugtason Creek, Basian Creek, Kamiri Creek, Kamiri Waterfall).

Table 7: Landscape characteristics before and after affforestation in the Maasin Watershed, Philippines

	Before deforestation	After afforestation
Species	Paddy rice	Mahogany, gmelina, bamboo, rattan
Water features	Streams with baseflow all year Swamp/wet lands	No base flow Wetlands ceased

Figure 19: Photo of dried creek bed from the Maasin Watershed, after the afforestation project

This case study represents a call for in-depth analysis of the type and magnitude of impacts from afforestation in the Maasin Watershed. Special attention should be paid to any changes in the livelihoods associated with ecosystem services on which local communities depend.

Reference:

Salas, J.C. (personal communication). 2007. Kahublagan sang Panimalay Foundation. September, 2007.

KEY MESSAGE 7

Managing both natural and man-made water storage in landscapes can support and enhance productive uses of water for ecosystem services and human well-being.

KEY TERMS

Rainwater harvesting (RWH) – A range of technologies including enhanced soil infiltration and storage as with soil conservation measures, but often extends to small-scale storage structures, tanks, sand-dams, and surface and sub-surface reservoirs. RWH is a common source of supplemental irrigation for crops, and dry-season water supply for livestock, aquatic resources and people.

Managed aquifer recharge – The intentional transfer and storage of surface (blue) water resources into sub-surface aquifers. This can be both simple and inexpensive (e.g., passive diversion of water to porous surface areas), or complex and expensive (e.g., capital intensive surface water injection).

Storage of water fundamental to human and ecosystem water security

Storage of water in landscape is essential to maintaining ecosystems and their services to humans throughout periods of reduced water availability. Identifying suitable methods and processes to manage both natural and man-made water storage are thus essential for continued provision of ecosystem services. Maintaining and improving water storage in landscapes will be essential in future climate change, when rainfall is expected to increase in variability, and increase in extreme events, such as rainfall intensity in storms, as well as periods of droughts and dryspells (IPCC 2011). Change of climate affecting rainfall variability will put pressure on current freshwater flows. More storage capacity can help reduce floods and bridge dryspells and droughts to adapt landscapes and well-being to future uncertainties.

Natural water storage is much larger than artificial storage

Water is stored throughout the landscape in both natural and manmade structures. These storage systems are recharged with water through natural and engineered processes. The capacity of large dams was estimated at 7,200 km^3, globally [3]. For comparison, the global storage of water in wetlands only, is estimated at 17,000 km^3, with many more km^3 water stored in soils (17 km^3), groundwater reservoirs (23,400 km^3), lakes (175 km^3), rivers (2 km^3), permafrost (300 km^3), and glaciers (km^3)[4].

Natural storage of freshwater is unevenly distributed and difficult to access. There is a great spatial and temporal mismatch of supply for human uses, particularly in

3 This volume does not include many of the large Chinese dams, for which data was unavailable; Data from World Commission on Dams. Dams and Development: A New Framework for Decision-Making. Earthscan. London, UK; and it does not say anything about actual water content in dams which of course varies

4 Oki, T. *et al.* 2006. Global Hydrological Cycles and World Water Resources. Science. 313, 1068.

semiarid and arid regions. This mismatch in supply and demand of freshwater affects the cost of access, and often ecosystem services are not prioritized for the limited available water resources (e.g. drilling for groundwater at depths >300 meters). Therefore, natural storage structures of water must be complemented by a variety of small to large engineering structures to ensure supply (IWMI, 2009).

Small-scale storage methods that mimic natural processes such as check dams, vegetation or stone bunds for infiltration are often more hydrologically connected to surrounding ecosystems than artificial storage techniques (e.g., concrete lined tanks). Management of landscape water storage features increase natural storage and can increase agro-ecosystem productivity and people's benefits (Barron, 2009). Additionally, water storage in permanent water bodies can harbor permanent predator populations, keeping down pests (e.g. malarial mosquitoes), whereas rainwater harvesting ponds or other temporary water storage facilities have been shown to provide habitat for malarial mosquitoes as well as other pests (e.g. Northern Ethiopia).

Several technologies can act to enhance natural storage capacity, ranging from enhancing the soil water storage capacity and infiltration, to various forms of tanks, ponds, dams and reservoirs, (Figure 20).

Management of water storage for improving agro-ecosystem water-use productivity

Water productivity is often addressed when improving agro-ecosystem through soil conservation, rainwater harvesting (RWH), and managed aquifer recharge. The key process is to improve water infiltration, which enhances water availability for vegetation, whether it is crops or natural vegetation. Depending on local landscape conditions, these infiltration processes can affect both downstream flows and groundwater infiltration. Thus, efforts to alter water productivity should consider the potential implications such activities may have on both downstream water-dependent ecosystem services and local groundwater recharge.

Groundwater processes and groundwater-dependent ecosystems must be considered

Groundwater and the storage of fresh water in shallow or deep aquifers are widely used to supply human and societal freshwater demands, especially urban demands. The benefits of groundwater storage include reduced evaporative losses, baseflow during dry seasons, and often high water quality, as recharging water filters through the soils en route to storage location in aquifer. Groundwater also plays an important role in maintaining many groundwater-dependent ecosystems (Table 8). As such, sustainable management of aquifers must be guided by sustainable yields, i.e. ensuring outtake is within the range of what is recharged.

Water quality is an important aspect of aquifer management. Recharge water that is full of contaminants can affect the entire aquifer and thereby risk the productivity of the water supplied to humans and ecosystems. Management of various surface flows can affect the recharge of shallow or deep groundwater. A particular impact can be the reduction of baseflow, as surface water is diverted to other flow paths such as transpiration or evaporation at the soil surface, thereby reducing the recharge to aquifers that supports baseflow. Assessing water productivity form a landscape systems perspective can help ensuring that various flows in the landscape are accounted for, and the value of shallow and deep groundwater resources are addressed alongside more evident surface flows. Understanding the relationship between groundwater resources and agro-ecosystem water productivity is critical to ensuring managed water storage is conducted in a sustainable manner.

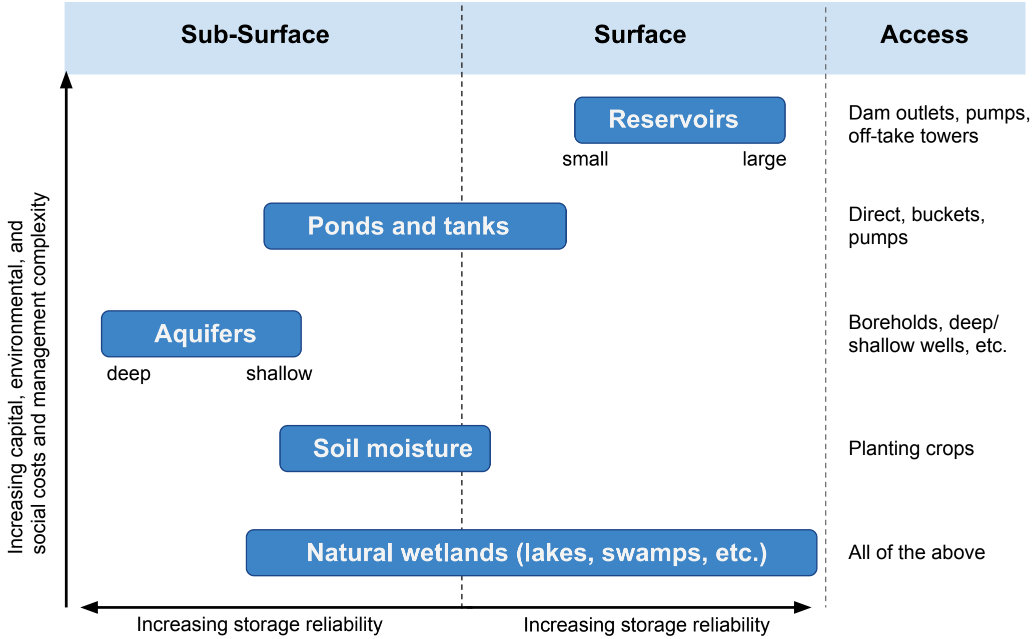


Figure 20: Conceptualization of the physcial water storage continuum

Adapted from McCartney and Smakhtin, 2010)

Table 8: Groundwater dependent ecosystems (GDEs)

(Eamus *et al*. 2006, Tomlinson *et al*. 2008)

Aquifer and cave ecosystems,
Ecosystems dependent on the surface expression of groundwater, e.g. mound springs, baseflow rivers, and estuarine seagrass beds,
Ecosystems dependent on the subsurface presence of groundwater, e.g. where vegetation has roots accessing groundwater.

Case Study: Sand dams in Kitui, Kenya

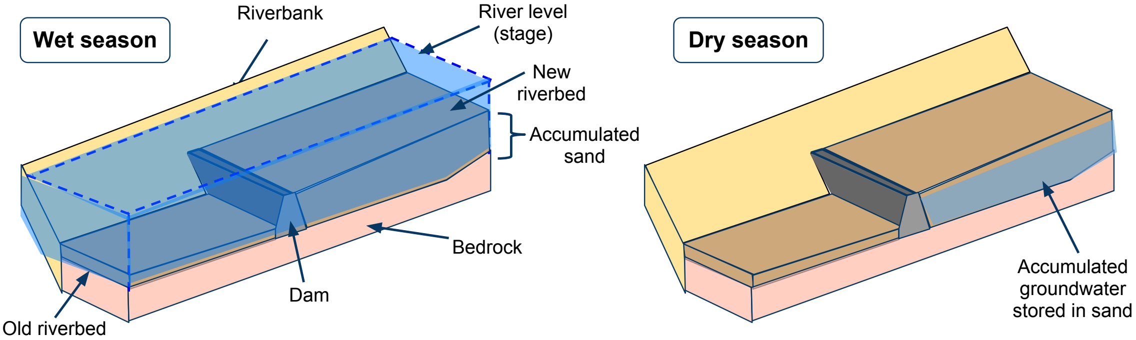


Figure 21: Cross-section of sand dam in stream channel, during the wet and dry season

In the Kitui area of Kenya, the sand dams is a type of water harvesting and storage that mimics natural water storage. A sand dam is constructed in the stream channel that captures sand behind a barrier (wall) and thus raises the groundwater level during the dry season (Figure 25).

These sand dams directly benefit the local livelihoods. Recent research compared two catchments with similar social and ecological characteristics one catchment included

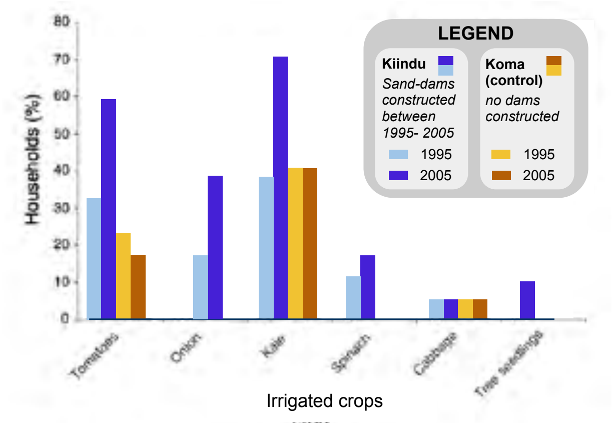


Figure 22: Percent of households with and without sand dams, within the Kitui region of Kenya

sand-dams (Kiindu) while another catchment did not have sand-dams (Koma). Economic data from 1995 were compared to data collected in 2005, because during that decade sand-dams were constructed in the Kiindu catchment.

On average, farmers living near sand dams experienced a 60% increase in livelihoods. Production of irrigated cash crops increased in the catchment with sand dams, while production in Koma stayed level or decreased (Figure 23). Complimentary income activities that require water supplies, such as for example brick-making [1], also increased in the location with sand dams.

The sand-dams had very little impact on downstream flow, with a reduction in annual streamflow of 3% between 1995 and 2005. This suggests that the sand-dams mimicked the function often provided by wetlands, or other natural storage by providing more stable baseflow during dry seasons.

Reference

Lasage, R., Aerts, J., Mutiso, G.C.M., and de Vries, A. 2008. Potential for community based adaptation to droughts: Sand dams in Kitui, Kenya. Physics and Chemistry of the Earth. 33: 67-73.

1 Water is necessary for mixing with clay to mould the bricks into the desired shapes.

Case Study: Managed aquifer recharge in Tunisia

Artificial groundwater recharge in a Northeastern catchment in Tunisia is currently used to replenish the Nadhour–Sisseb aquifer. In the absence of surface storage reservoirs, it is challenging to capture rainfall that flows into ephemeral streams (wadis), and evaporates in salt marshes (sabxa) . However, small upland reservoirs (approx. 1.7 million m^3) capture water during the flood, and release it more evenly (smoothing out the flood peak), By allowing the water to infiltrate through the wadi stream bed, the local groundwater is recharging it's the shallow aquifer. These reservoirs were originally intended to improve groundwater recharge, but the stored water is now being used for irrigation as well. As much as 30% of stored water is used for irrigation, while 40% is recharging groundwater. Therefore, as much as 70% of rainfall can be used productively for local water supply.

Modeling to enhance understanding of the system indicate that increasing the frequency of water releases can significantly increase the groundwater table by as much as 7.5 m. Given the arid, North African climate, storing water underground and retrieving the water later for irrigation, likely reduces evaporation losses while replenishing water that is removed from the groundwater table. A key question here is whether the trade-off of transferring water flows from the salt marshes to the groundwater table impacts the local landscape ecosystem services or local human well-being.

Reference:

Zammouri, M. and H. Feki. 2005. Managing releases from small upland reservoirs for downstream recharge in semi-arid basins (Northeast of Tunisia). Journal of Hydrology. 314 (2005): 125-138.

Managed aquifer recharge as a method for sustaining groundwater ecosystem services

Managed aquifer recharge represents an important method for balancing groundwater extraction for increasing the productivity of agro-ecosystems especially in drier climatic zones. Since the natural recharge rate of many groundwater aquifers is slower than the amount of time it takes to artificially remove (e.g. pump out) groundwater, the artificial reinjection of surface water can be an effective method for replenishing groundwater supply. Furthermore, this reinjection of groundwater can mimic natural baseflow of groundwater, supporting dry season flow.

Case Study: Watershed rehabilitation in Darewadi, India

In the Darewadi watershed, in India, an ambitious plan to rehabilitate a degraded system was undertaken. The local residents of the watershed, many of whom were farmers and livestock herders, relied on external sources of drinking water for nearly half the year, while irrigating a small area of cropland. The rehabilitation plan sought to increase recharge of local groundwater supplies, enabling improved water supply to increase the number of wells, and increase the area of irrigation.

The plan was based on community participation in phased grazing bans and regeneration of trees in the watershed. The plan was undertaken in 1996, completed in 2001, and evaluated again in 2005. The plan achieved many of its goals, among them eliminating water tanker visits, halving the depth of the groundwater table, nearly tripling the number of wells, and increasing irrigated land by more than 50% (Table 9).

Table 9: Local water availability before and after watershed development in Darewadi, India (Adapted from WRI 2005)

Impact indicator	Before watershed development	After watershed development	
	1996	2001	2005
Months requiring delivery of drinking water by tanker truck	February to June	Tanker free	Tanker free
Average depth of water table below ground level (in metres)	6.5	3.5	3.1
Number of active wells	23	63	67
Electric motors for pumping water	6	52	65
Land under irrigation	197 Ha	342 Ha	381 Ha

Agricultural incomes increased dramatically when farmers could utilize the recharged wells for irrigating crops after the watershed regeneration. The benefits of the rehabilitation disproportionately benefited the richest members of the community, but the poorest members are following, with doubling of farm labor wages, and increasing livestock-based incomes as the grazing bans were eliminated in 2001.

Rehabilitating the surrounding landscape to use natural water storage and filtration can improve overall agro-ecosystem sustainability, while facilitating long-term benefits to improved well-being.

References:

World Resources Institute. 2005. The wealth of the poor: managing ecosystems to fight poverty. World Resources Report. World Resources Institute.

KEY MESSAGE 8

Agricultural water productivity gains are optimal when they are connected to and balanced with the surrounding supporting and regulating ecosystem services thereby ensuring adequate water flows for a wide range of uses in the landscape.

Connecting water productivity gains in agro-ecosystems with the surrounding regulating and supporting ecosystem services is critical to ensure that productivity gains are sustainable in the long-term. If water productivity gains in agro-ecosystems (as discussed in Key Messages 2 and 3) undermine critical ecosystem services, the gain will come at a loss of valuable regulating or supporting ecosystem functions, which potentially could benefit more uses and users of the same water source. Some of these critical supporting and regulating services that are underpinned by fresh water flows include nutrient regulation and the appropriation of flows to sustain various land-uses types including forest, grasslands and wetlands alongside agro-ecosystems (Table 10).

Water productivity gains need to be part of a wider view of landscape uses

Due to water management efforts, including Integrated Water Resource Management (IWRM) strategies often being part of multiple actors and institutions, water productivity gains in agriculture are often considered separate from other landscape uses of water. This perception has unintended impacts on the allocation of water to surrounding ecosystem services, especially water needed to sustain regulating and supporting ecosystem services. For example, water that is transported from the main stem of a river in concrete lined canals, changes the volume of water that is infiltrated into surrounding soils, in some cases by as much as 50 per cent (Meijer *et al*. 2006). The use of lined canals could be considered an improvement on existing water-use productivity in the irrigation system and for crop production. However, the 'lost' water in a 'leaking canal system may sustain important ecosystem services (e.g. groundwater recharge) that support local livelihoods. Thus the productivity gain achieved with lined canals may not necessarily be a gain in the whole system, because the long-term consequences for local livelihoods could be significant and irreversible (see Case Study: Groundwater depletion and ecosystem loss in Luancheng, China).

Water use in landscapes must address downstream ecosystem services

Similar to the infiltration that was necessary in the North China Plain, other upstream-downstream management systems have emerged to mimic natural processes that facilitate the balance of upstream and downstream ecological needs. In the following case study of Balinese paddy rice management connected and disconnected water-dependent ecosystem services in landscapes are finely balanced through livelihood dependences. A small management change upstream, due to ignorance of the wider context of water flows and interdependent ecosystem services, led to a large reduction basin-wide human well-being.

The case studies in this section illustrate that agro-ecosystem productivity is directly connected to the surrounding regulating ecosystem services. Ignoring those services may be beneficial in the short-term, but if the negative

Table 10: Principal regulating functions relevant to water productivity

Regulating service	Example of agro-ecosystem or landscape benefits
Water regulation	Flood control; stream base flow secured / storage during dry season or dry years
Nutrient regulation	Prevention of algal blooms or “dead zones” in aquatic sites coastal zones
Erosion regulation	Reduction of sediment in water ways
Water purification	Filtering of harmful substances in water
Pest regulation	Prevention of crop die-off from pests
Pollination	Increase in crop production
Agricultural water	Increase in crop production and crop productivity
Natural hazard protection	Maintenance of existing stream channel; prevention of catastrophic erosion, crop failure, or loss of farm investments (e.g. livestock)

consequences accumulate, they can eliminate and undermine any initial increases in productivity. This has important implications for sustainable livelihoods and human well-being, and thus efforts should be made to pro-actively include regulating and supporting ecosystem services into local to regional water management agendas. The functions of various species in landscapes can also have large implications on landscape productivity, and thus the water productivity. Ecosystem functions supported through water flows by for example pets and disease control, and pollination are often under-valued, and should be more explicitly integrated into management of water and the role of water to connect ecosystem functions for human well-being, income and prosperity.

Case Study: Groundwater depletion and ecosystem loss in Luancheng, China

In Luancheng County, North China Plateau, agriculture is predominantly irrigated due to the low rainfall of 500 mm y-1. This irrigation water comes from mining groundwater stored in aquifers beneath the Plateau. As a result of high evaporation rates, and low groundwater recharge, groundwater levels have steadily dropped since the mid-19th century (Figure 29).

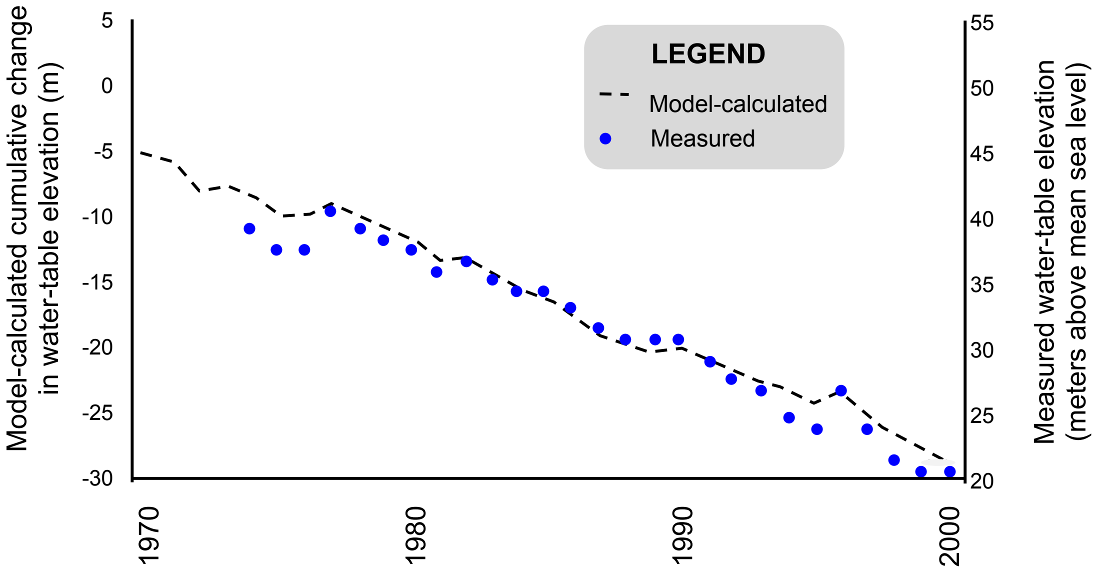


Figure 23: Water table change due to agricultural water-use in Luancheng County, 1962-2000 (Kendy *et al*. 2003)

In addition, over-extraction of groundwater for crop production, the regulating ecosystem services that are required for crop production are being undermined. Soils are becoming more saline as irrigated water evaporates from the soil and leaves behind salts. These salts are drained into the groundwater aquifer, thus leading to saltwater intrusion in the freshwater aquifer. From a long-term sustainability perspective, the over-extraction of groundwater is undermining agricultural productivity and the associated food security.

Long-term sustainability of the agro-ecosystem requires that the volume of water used to irrigate cropland must decrease. This would result in a reduction in crop production and must therefore be accompanied by introduction of crops with lower water demand (e.g. drought tolerant varieties of wheat). Even with these efforts, rehabilitation of the groundwater regime will take decades, given the exceptionally low rate of natural recharge.

Reference:

Kendy, E., Molden, D.J., Steenhuis, T.S., Liu, C., and Wang, J. 2003. Policies drain the North China Plain: Agricultural policy and groundwater depletion in Luancheng County, 1949-2000. Research Report 71. Colombo, Sri Lanka: International Water Management Institute.

Case Study: Connecting up- and downstream ecosystem service benefits with water in Bali, Indonesia

Summary

In Bali, rural farmers have grown paddy rice sustainably using intricate terracing for thousands of years on steep hillslopes. This has been possible through a system of self-governance involving an association of farmers (subaks) meeting in water temples and making group decisions on when to sow their rice, how much water to use in a given terrace, and how much water to allow to flow downstream. The up- and downstream communities are intricately linked through the flow of water and the benefits it generates to sustain both crop yield and regulating habitat for pest control (i.e. suppressing pest populations). In this system water productivity for a field is not the optimal scale of accounting and managing. Only when accounting for all benefits up- and downstream is the full value of the water productivity recognized. The reason for this system was to create sustainable, predictable harvests, whilst managing pests, specifically rats. The basic function of the regional water management process is to allow sufficient water to flow downstream (both surface and sub-surface flow) so that downstream farmers have enough water to flood their fields. This upstream-downstream partnership is crucial for the downstream farmers, because they need to have adequate water to grow their rice. The partnership is crucial for upstream farmers, because they need the downstream farmers to be able to flood their fields, so that they can kill-off potential pests (i.e. rats).

Disconnection and connection

In the 1970's, the Asian Development Bank (ADB) implemented a program to improve rice harvests as part of the 'Green Revolution' .The farmers stopped coordinating their irrigation activities between upstream and downstream, and implemented the ADB's recommendations, namely increased pesticide use and new irrigation schedules, and for some years, harvests improved. However, only a few years later, harvests collapsed as pests wiped out much of the crop. In response to failing harvests, the Balinese farmers returned to their traditional water temple management system and the agro-ecosystem began to return to its stable, productive state (Figure 25).

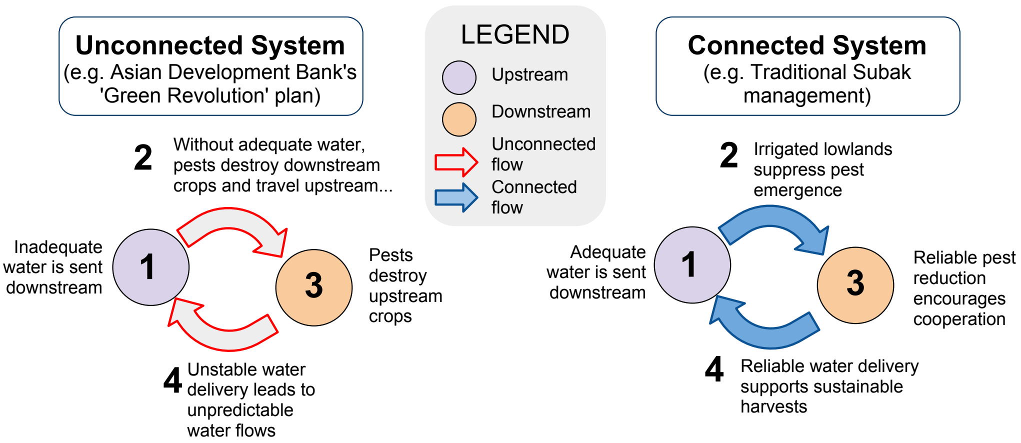


Figure 24: Connected and unconnected examples of agro-ecosystems and ecosystem services (Lansing and Fox, 2011).

Agro-ecosystems with adaptive governance systems can be resilient in the long-term

The critical point is that when addressing the multiple benefits of water flows through landscapes, water productivity gains are connected in local water management schemes, especially if that management cycle has "co-evolved" with the local watershed.

Reference

Lansing, J. S. and Fox, K. M. 2011. Niche construction on Bali: the gods of the countryside. Philosophical Transactions of the Royal Society B. 366: 927-934.

KEY MESSAGE 9

Integrated water resources management (IWRM) can be an approach to govern the complexity of upstream-downstream water-dependent ecosystem services, because water links multiple ecosystem services as well as multiple users of ecosystems services.

KEY TERMS

Integrated Water Resources Management – "A process, which promotes 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 2000).

Efforts to adopt best practices for balancing water productivity gains with ecosystem services are needed at multiple scales of water and ecosystem services governance and management. There is an urgent need to raise awareness regarding linkages between water flows through landscapes from field to basin scales and the support water generates to sustain various ecosystem services (ESS). Ultimately, this water flowing through landscapes sustains multiple benefits to human well-being and societies from local to global scales.

Challenges of water management

From a water process perspective, the appropriate scale of governance for water resources lies between the watershed and basin scale, because it is where the links between local and regional water supplies and demands are most apparent. It is also at this scale that the benefits of water-dependent ESS are available, especially provisional ecosystems services such as agricultural yields and livestock, and non-farm harvested resources from forest, rangelands, wetlands, and other aquatic habitats. For example, in a multi-basin research project for the Challenge Programme on Water and Food (Case Study: Challenge Programme basins and global water productivity opportunities), it was shown that at the basin-scale, there are still substantial water productivity gains to be made, in particular in low yielding areas with high incidence of poverty. Through a water productivity perspective, the opportunities rather than constraints are highlighted, and managers of water and land resources can take actions accordingly guided by the knowledge of where best to allocate resources.

However, supporting and regulating ESS often operate at different scales, both in terms of benefits and trade-offs. For example, significant changes to the timing of reservoir releases (e.g., timing of water flows) can cause significant problems for communities that rely on reliable water flows, such as the communities described in the Barotse Floodplain Case Study (Key Message 4), or the Waza Logone Case Study (Key Message 10). In order to negotiate upstream and downstream gains and losses in water and in ESS, better processes for negotiating water and land uses between multiple stakeholders need to be implemented.

Case Study: Challenge Programme basins and global water productivity opportunities

In September 2011, a synthesized understanding on water resources for agriculture and poverty alleviation in ten major basins in rapid development (see map) was released by the Challenge Programme on Water and Food (CPWF, www.waterandfood.org), a system-wide initiative by the Consultative Group on International Agricultural Research (CGIAR) .

The research findings suggest that in a majority of basins, less than 20% rainfall is used for agriculture (crops and pasture). And in most basins, both rainfed and irrigated crop and pastures could improve water productivity, with greatest opportunities to improve in the most poverty affected river basins. Improving water productivity in existing agricultural areas could provide double or triple food production in the studied basins. Further, the studies showed that all basins holds 'bright spots' with high agricultural water productivity, ensuring that water is maximized once it use withdrawn for crop production. These 'bright spots' can provide lessons learned for within basin knowledge transfer to improve water productivity in less well performing crop systems.

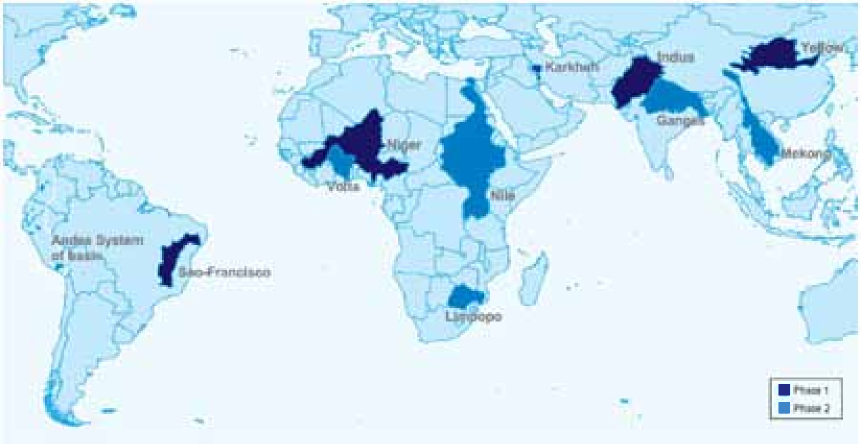


Figure 25: Phase 1 and 2 basins in the Challenge Program on Water and Food

Table 11: Potential to close yield gaps in CPWF basins by using more rainfall

	Area under crop and pasturea (%)	Basin rainfall used as actual evapotranspiration per year by crop and pasture[a] (%)	Potential to improve crop water productivity in rainfed crops alone by closing yield gap[b] (%)
Andes	6	7	-
Ganges	72	67	-
Karkeh	9	4	>39
Limpopo	18	16	-
Mekong	38	38	-
Niger	20	14	>60
Nile	8	6	12-39
Sao Francisco	10	10	-
Volta	14	11	59-67
Yellow river	46	50	>14

a Data from Mulligan *et al*, 2011

b Actual and potential yield levels from Cai *et al.* (2011) and Singh *et al.* (2009); water productivity estimated after Rockstrom (2003)

Physical and institutional mismatch inhibits recognition of ESS benefits

There is a mismatch between the scale of water productivity gains commonly assessed at the field or community scale, and the scale of regulating and supporting ESS, which is often recognized at the regional and global scale there is a very strong case to be made for addressing the management of water and water productivity for multiple ESS at the meso-scale (10- 10 000 km^2), because this is where multiple ESS impacts coincide with various management strategies of land and water resources. This has been demonstrated in various cases of land-use, including wetlands (Key Message 4), forests (Key Message 6) and agricultural land (Key Message 9). When taking a more comprehensive view on water productivity for multiple water-related ESS that benefit human well-being, a landscape approach can assist in determining the interlinkages between various water flows for multiple uses and users.

Integrated Water Resources Management (IWRM) can bridge water and ESS management

One approach that can help manage landscape and basin synergies and trade-offs of water uses is the Integrated Water Resources Management (IWRM) model. Inspired by the 1992 Dublin Principles, at the International Conference on Water and the Environment, IWRM explicitly seeks to address the necessity to maintain fresh water flows through the landscape, in particular for environmental water flows. The Global Water Partnership (GWP) defines IWRM as "a process, which promotes 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 2000) Additionally, the GWP lists three primary objectives of IWRM:

- Efficiency to make water resources go as far as possible;
- Equity, in the allocation of water across different social and economic groups;
- Environmental sustainability, to protect the water resources base and associated eco-systems.

Since the signing of the Dublin principles, national and international water management frameworks have been developed with these intentions both in developed and developing countries. Examples include both the European Water Framework Directive and the GWP's IWRM projects, which include thirteen African nations, ranging in size from very small (e.g., Swaziland) to very large (e.g. Ethiopia) (GWP, 2010).

Adoption of IWRM encourages management of water and ecosystem interdependencies

IWRM principles include water and ecosystems as part of the management agenda. Thus, rather than creating separate frameworks and institutions, IWRM provides an excellent point of departure to improve the management of water resources and flows that underpins multiple ESS at the watershed scale. By providing watershed scale coordination, IWRM can connect regional watershed management to local activities that influence and benefit from ESS.

ESS must be spatially and temporally consistent with IWRM programs

A first step in incorporating water-dependent ESS is to clarify which ESS are manageable at the landscape scale.

The temporal and spatial scope of IWRM polices (Figure 27) suggests that many but not all of the benefits and trade-offs associated with ESS are manageable at

Case Study: IWRM adoption in Berki River Basin, Ethiopia

In the Berki River Basin in Ethiopia, water is used to produce and sustain many different ESS, including for irrigated agriculture, drinking water, and religious rituals for the local Christian community. Since water is one of the scarcest resources in this region, any changes to the supply were often met with conflict. An example of this is that when a plan to install an additional set of groundwater pumps upstream was proposed, downstream stakeholders reacted angrily. Similarly, as a result of the construction of an upstream diversion by a local water authority, the downstream users responded by destroying the diversion.

In an effort to curb the water-related conflict the Ethiopian Water Partnership facilitated the creation of an IWRM plan to establish a concrete legal, administrative, and management framework under which the different parties could coordinate activities. As of 2008, the frequency of conflict has been reduced and local stakeholders are now much more aware of local water management.

As a result of this IWRM plan, communities throughout the basin will be able to continue to rely on the ESS generated by the stable water management regime through the active management and monitoring of resources by the IWRM plan.

Reference:

Global Water Partnership (GWP). 2010. Water Security for Development: Insights from African Partnerships in Action. GWP, Stockholm, Sweden.

the same scale. An important message is that IWRM policies are not equipped to manage supporting ESS, which tend to extend beyond the spatial and temporal scales of IWRM governance. However, IWRM policies are well positioned to manage many provisioning, cultural and, to some extent regulating ESS. For example the Waza Logone floodplain (in Key Message10) indicates that the benefits of allowing flooding to take place (to replenish wetlands, sediments, etc.) is more valuable than blocking the flow. However, this trade-off is only clear at the watershed scale, and thus would be undetectable without a management regime such as IWRM that operates at larger spatial and temporal scales.

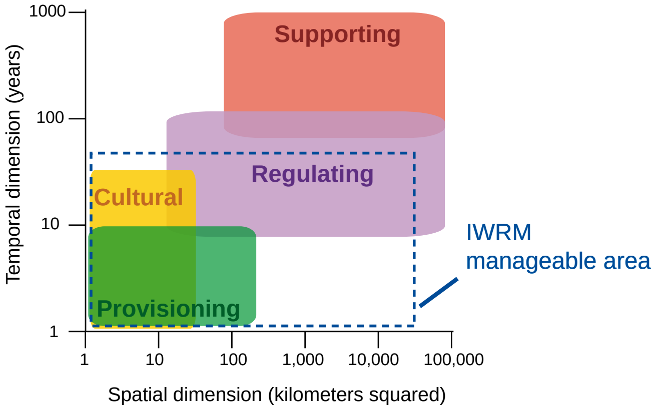


Figure 26: Spatial and temporal dimensions of ESS (note the log-log scale)

ESS-based management needs appropriate governance

The ecosystems services-based management approach rests on the idea that there are specific spatial and temporal scales that are most appropriate for management.

Figure 28 depicts the temporal and spatial dimensions for appropriate management of ESS. Regional scale management is needed to address water use and efficiency at higher spatial scales. Such issues can relate to aggregated impacts by water users at local scale, or downstream such as water quality influenced by upstream actors. Finally, global scale management may guide commitments and frameworks for the very long-term and global scale services, such as nitrogen and carbon cycling. Recognizing the important and different roles that local, regional, and global management plays towards governing the different types of ESS is a crucial step towards balancing water use with ESS function.

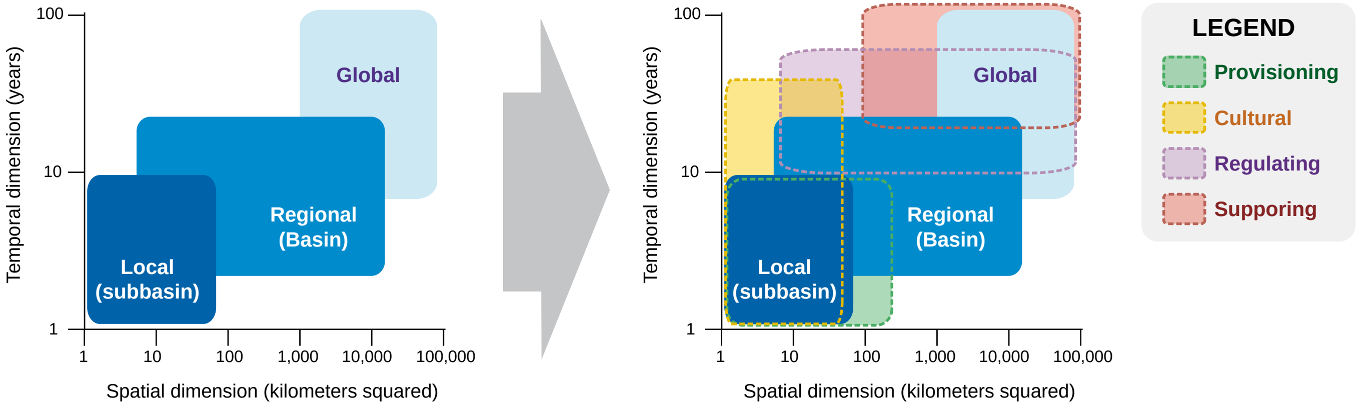


Figure 27: Scales of governance compared to the scales of ESS management

Acknowledging the value of ESS is critical for sustainable, integrated management

In order for IWRM to successfully integrate ESS into the scope of activities, it is important for the value of the ESS to be understood and evaluated by the participating stakeholders of the IWRM process (Costanza *et al*. 1997; Hermans *et al*. 2006). However, it is also important to recognize that value does not necessarily mean a monetary value. It can mean the cultural value of practicing a ritual, it can be the value of having a healthy family, or it can be the value of a community being able to water their livestock. Since water is a scarce resource, there are inherently potential trade-offs with upstream and downstream users of the same resource. Ignoring trade-offs, between agro-ecosystem crop and livestock production and surrounding landscape, ecosystems often end up redistributing economic and livelihood benefits unintentionally. Increasingly, various tools are being piloted an tested in different partsof the world to re distribute unintentional dis benefits of changing water flows and EES supported by these water flows. One such management tool that is being used to address this is various forms of Payment for ESS, or PES (Figure 28).

The growing number of implemented PES schemes, both public and private sector initiatives, provide ample opportunity for 'lessons learned' and transfer of knowledge between landscapes, basins and regions. The common two-part challenge associated with PES schemes is first, how to connect diffuse upstream providers of ESS benefits to concentrated downstream beneficiaries, and second, how to then transfer economic compensation from the beneficiaries back up to the ESS providers, without major transfer loss (Wunder *et al*. 2008). Additional challenges can involve monitoring and evaluation of benefits paid for, and when PES schemes have multiple goals beyond supply of a defined (or several defined) ESS, such as alleviation of poverty (FAO 2011). Yet, there are also successful examples how PES can operate and sustain multiple goals such as increasing sustainable benefits to

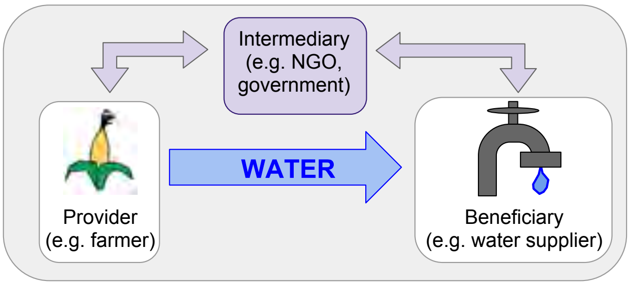
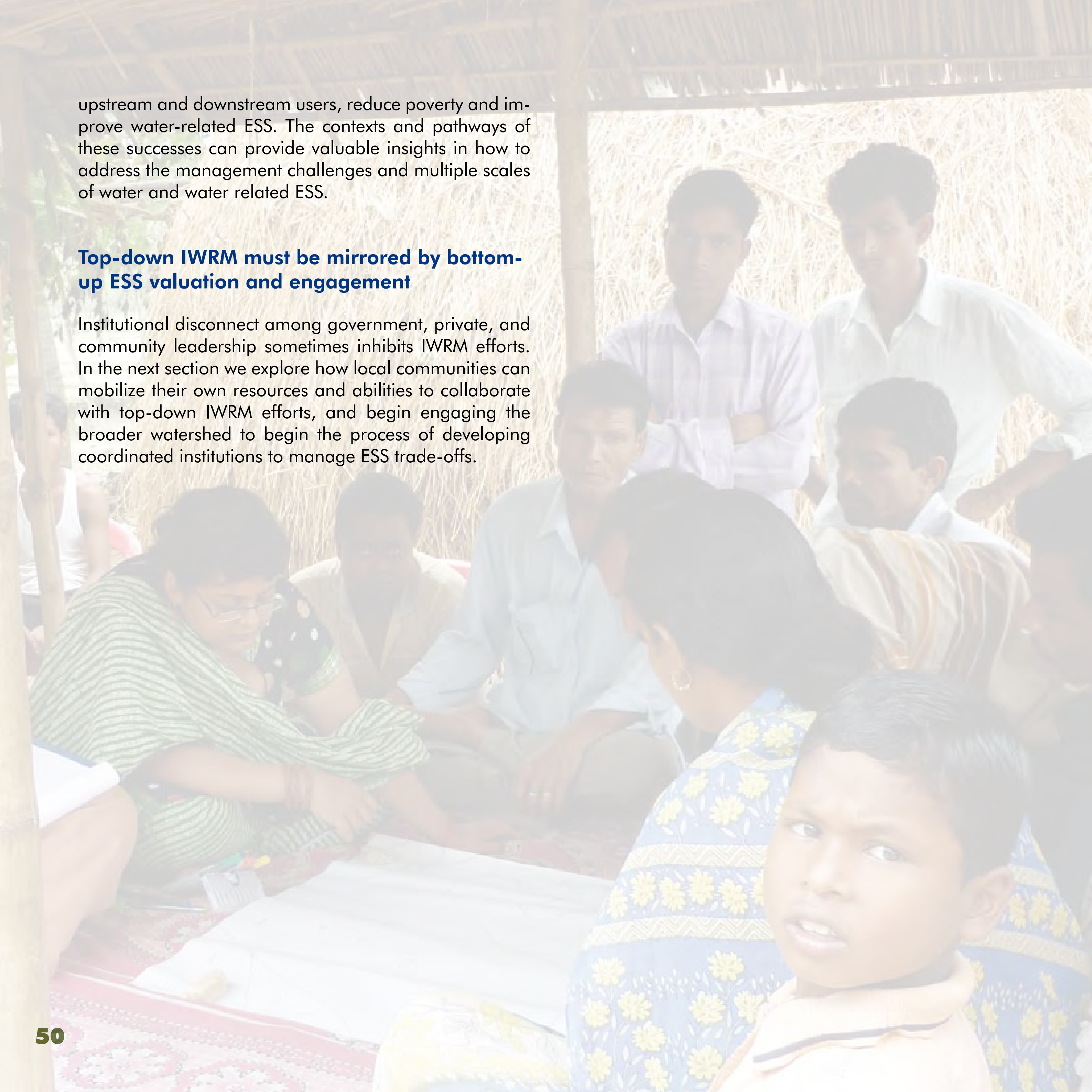


Figure 28: Conceptual depiction of payment for ESS (PES) schemes

(Adapted from FAO 2006)



upstream and downstream users, reduce poverty and improve water-related ESS. The contexts and pathways of these successes can provide valuable insights in how to address the management challenges and multiple scales of water and water related ESS.

Top-down IWRM must be mirrored by bottom-up ESS valuation and engagement

Institutional disconnect among government, private, and community leadership sometimes inhibits IWRM efforts. In the next section we explore how local communities can mobilize their own resources and abilities to collaborate with top-down IWRM efforts, and begin engaging the broader watershed to begin the process of developing coordinated institutions to manage ESS trade-offs.

KEY MESSAGE 10

Capacity building and awareness raising, via the sharing of successful ecosystem services valuation practices can facilitate the integration of ecosystem services into IWRM programs.

KEY TERMS

Ecosystem service valuation – Expressing the value of water-related ESS goods and services in order to inform sharing and allocation decisions. It covers both use and non-use values, extractive and in-situ use values, and consumptive and non-consumptive use values (adapted from Hermans *et al*. 2006).

Downstream dependence on upstream stewardship

The consequences of diffuse, upstream water productivity gains do not necessarily result in more water downstream. By maximizing productivity per unit land, as typically done for agriculture , each unit of water generates increased yield, but the absolute amount of water utilized remains the same. Shifting from focusing on water productivity per unit of agricultural yield, to water productivity per unit of ecosystem services (ESS), ensures that water benefits a wider range of users beyond agricultural use. In particular it enables the valuation of ESS alongside other more conventional benefits, especially in watersheds and basins where the upstream areas provide the majority of the water for downstream flow (Figure 31). This is valid for a range of large river basins e.g. the Nile, and the Tigris-Euphrates, as well as smaller basins such as the Jordan and Limpopo basins. Therefore, the benefits of water quantity, quality, and timing are reliant on good stewardship of water resources by upstream users and well as downstream users (Figure 31). The concept of diffuse upstream impacts concentrating downstream is evident in different aspects of water resources management, including flooding, pollution, and water withdrawals (Loomis *et al*. 2000). A case study of the Waza Logone floodplain, in Cameroon, illustrates the importance of upstream hydrological actions on downstream sustainability

Combining indigenous knowledge with scientific findings and methods

Local communities have substantial ability and commitment in developing knowledge-bases surrounding water resources and water-dependent ESS. This is true when circumstances are 'normal'; however when change is very sudden (e.g. a so-called shock such as devastating events as extreme drought, flood or tsunami), or very slow (spanning minimum 10 years up to multiple generations), or has impacts beyond the local landscape, local knowledge bases may not be sufficnet to cope. Therefore, in order to manage water resources and related ESS effectively new management strategies may be required to complement local initiatives. Ventures between local communities and expertise outside, or with research can greatly enhance the multi-scale management challenges of water and sustainable allocation to various ESS in landscapes.

Such partnerships are able to build new knowledge and understanding for adaptive management and effective

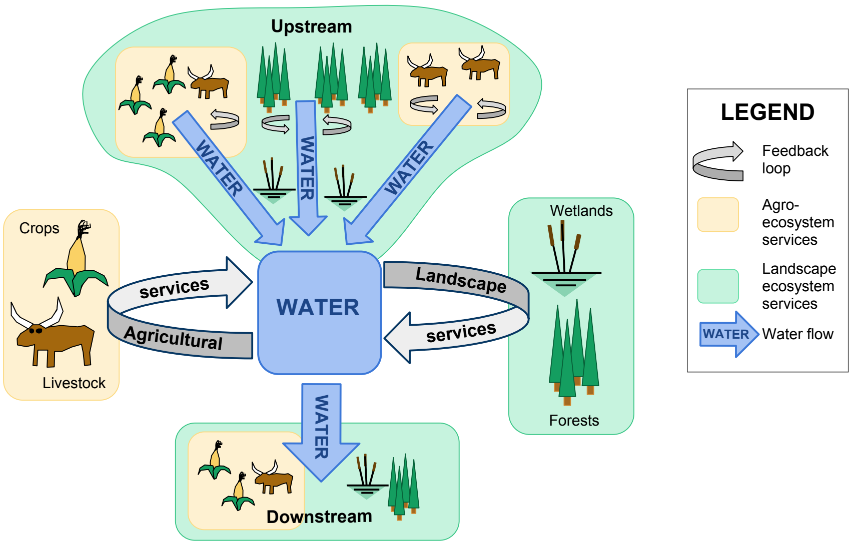


Figure 29: Idealized links between (upstream and downstream) and different types of ESS

use of water in landscapes. The findings in this document suggest that top-down efforts at the regional or watershed scale can coordinate and cooperate effectively with local participation and actions to enhance and foster stewardship of water resources to enhance and sustain multiple ESS at local and regional scale. An example of local ESS valuation is illustrated in the Stoeng Ramsar, Cambodia case study.

Equipping individuals and communities to manage water and ESS sustainably

There are many 'tools' that communities can use to help them understand how much water they are using, and to recognize the role of water to sustain different ESS within their area. There are many resources that local communities and watersheds can utilize for developing their own ESS valuation. But capacity to assist and guide these processes may need strengthening as the delegation of landscape management goes from global and national scales, into operation at meso-scales and local scales. Whereas such participatory consultation and operational management has been promoted for example in the Landcare Movement in Australia, and through Agenda 21 in EU, much remains to be done in tropical and subtropical rural settings where poverty is a dominant characteristic.

Many organizations have produced manuals for how to perform ecosystem valuation, for various levels of ESS. The United Nations Environment Programme (UNEP) has recently produced a manual for valuing regulating ESS, that is highly relevant for regional (basin-scale) water and ecosystems managers (Kumar *et al*. 2010). Additionally, other international organizations have developed tools, notably the International Union for the Conservation of Nature (IUCN). They have produced manuals on ecosystem valuation (IUCN 2004), as well as tools for specific ecosystem types, such as wetlands (Springate-Baginski *et al*., 2009).

Case Study: Downstream benefits of seasonal flooding in Waza Logone, Cameroon

The Waza Logone Floodplain lies in the far northern portion of Cameroon, and is one of the most biodiverse portions of the Sahel. Historically, the Waza Logone was a seasonal wetland that was flooded by the Logone River, and the seasonal rivers Mayo Tsanaga, Mayo Boula, and Mayo Vrick. However, due to extensive upstream irrigation, the flooding has been reduced by nearly 30% relative to 1970 flow rates. This has severely reduced wetland function and the associated benefits to local and regional livelihoods and incomes. A quarter of a million people live in the region, and the lack of seasonal flooding of the Waza Logone region has had significant consequences, including: agricultural losses from lack of irrigation, loss of 90% of fisheries, decrease in dry-season pasture, loss of grasses used in cultural and livelihood activities, and loss of surface water for livestock watering and transport.

Simulating the re-flooding of the Waza Logone to identify potential costs and benefits

In order to understand the potential value of the agricultural and landscape ESS that were lost as a result of the reduced flooding, a simulation of "re-inundation" was explored for the Waza Logone, to identify the types of services that would emerge from a flooded system.

Benefits outweigh the costs?

The economic value of the lost Waza Logone ESS were very significant for the region (Figure 32).

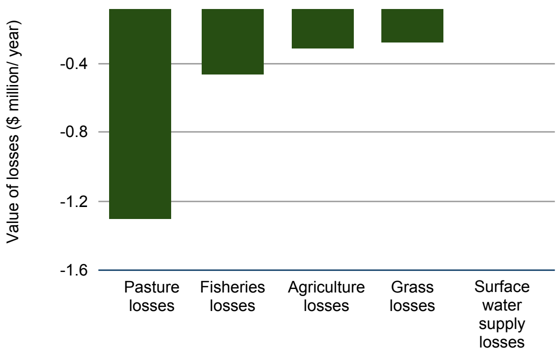


Figure 30: Value of the economic losses incurred from upstream appropriation of water resources (Emerton 2005)

Losses from potential pasture were the largest, equal to nearly all the other losses combined. The other losses are also significant, representing diverse methods of earning a livelihood. The benefit-cost ratio was positive indicating that the reinundation could be a net gain; the values ranged from $4.66 benefit for every $1 in costs for the minimum flood option, to as high as $6.57 benefit for every $1 in costs for the maximum flood option.

Reference:

Emerton, L. (ed). 2005. Values and Rewards: Counting and Capturing Ecosystem Water Services for Sustainable Development. IUCN Water, Nature and Economics Technical Paper No. 1, IUCN- The World Conservation Union, Ecosystems and Livelihoods Group Asia.

Case Study: Rapid, participatory ecosystem valuation in Stoeng Ramsar, Cambodia

Identifying the value of ESS in the poor, rural region of Stoeng Ramsar, Cambodia, is an important component of working towards alleviating poverty. Understanding which services are most important to the local community can improve the effectiveness of collaborations between internal and external efforts for improving livelihoods. However, a common problem for ecosystem valuation projects broadly, and for projects in the Stoeng Ramsar region specifically, is the ineffectiveness and failure of long, complicated contingent valuation surveys, especially when interviewees suffer from "question fatigue."

Rating	Value	Wetland uses
● ● ● ● ●	1,700,000	Fishing, washing, cooking/drinking
● ● ● ●	1,360,000	Transportation
● ● ●	1,020,000	Construction material, firewood
● ●	680,000	Aquatic animals, waterbirds, reptiles, irrigation, traditional medicine
●	340,000	Floodplain rice, recreation, dolphins
TOTALS	12,909,000	4,000 Riel = 1USD

Figure 31: Value of wetland ESS in Stoeng Ramsar, Cambodia (Edapted Emerton, 2005)

Rating	Poor	Less Poor
● ● ● ● ●	Rice	Medicine
● ● ● ●		petrol, cooking ingredients
● ● ●	Medicine, clothes	Rice, Hospitals, school, fishing gear
● ●	Hospitals, fishing gear, agricultural tools, seeds, petrol, household goods, cooking ingredients, social contributions	Piglets, clothes, seeds, agricultural tools, household goods, wine and cigarettes
●	Fish, livestock meat, weddings, boat purchases, transport	Social contributions, transport, weddings

Figure 32: Expenditures between poor and less poor members of the Veun Sean community, Stoeng Ramsar Site in Cambodia (Emerton 2005; Chong, 2005)

To address this shortcoming, a participatory valuation approach was employed that allowed for the community members to actively play a role in defining what ESS were important and how these were valued. The focal community was Veun Sean village in the Thala Borivat district. The participatory approach combined several methods for determining how ESS interacted with local livelihoods, including resource mapping, web diagrams of social networks, flow diagrams of wetland values, seasonal calendars, wealth rankings, and relative rankings of importance.wetland values, seasonal calendars, wealth rankings, and relative rankings of importance.

The project was particularly successful in illuminating the linkages between local ESS and livelihoods. Dynamics that could not have been identified using conventional surveys, became apparent, and patterns emerged as to how different aspects of ESS provision served to reinforce or degrade other aspects of village life. For example, health issues were identified as a major reason for low rice cultivation, which led to the need for rice purchases. These issues reinforced existing lack of income, which prevented purchases of health services and livestock (which would increase the potential area that could be cultivated).

The participatory approach empowered the local community to realize that it had the capacity to identify the components of local problems, which also increases the potential for developing successful relationships with regional, national, and international partners in the future.

References

Emerton, L. (ed), 2005, Values and Rewards: Counting and Capturing Ecosystem Water Services for Sustainable Development. IUCN Water, Nature and Economics Technical Paper No. 1, IUCN — The World Conservation Union, Ecosystems and Livelihoods Group Asia.

Increased awareness is needed to achieve uptake of ESS management

There is yet a lack of awareness among the inter-linkages between water flows in landscapes, the various ESS these flows sustains, and the ultimate benefits to human well-being , society and economies. At the global level, there is a continuous need for leadership and vision in sustaining the quantity and quality of water flows fro ESS. With growing demands on water resources of agriculture, and supply and sanitation, many water sources are poorly maintained to sustain both terrestrial and aquatic ESS. These demands will be growing significantly in the near and longterm future as growing populations, growth of income and lifestyle changes combined with climate change put additional pressure on water resources and the ESS the water flows sustain.

A first step towards improved governance is awareness of the issues, and recognition of their important. There is a continuous need to raise this awareness and knowledge among decision makers and investors to help improve local to global governance for a sustainable future, and for developing a green economy. A continuous effort to inform and educate water resource managers and decision makers is essential for meeting these future governance challenges. Raising awareness among local land-users and communities relying directly on local ESS that are supported by water flows both up- and downstream will ensure their involvement in any local management plan and action. Educating the next generation will help building a sustainable and equitable future, where water resources and the ESS they will rely on are efficiently managed for future generations to follow.

CONCLUSIONS

- Water-productivity gains have often been achieved out of balance with landscape ecosystem services, but there are important examples of how to bring these gains into balance (Key Messages 2, 3, 4, 5, 6).

- Narrow development agendas focused on specific targets (e.g. "more crop per drop") need to re-frame towards improving ecosystems services provision and human well-being, not just improving agro-ecosystems water use (Key Messages 2, 3, 4).

- Balancing the goals of agro-ecosystems with landscape ecosystem services can produce synergies and improve overall well-being (Key Messages 1, 2, 3, 8, 10).

- Management actions that mimic natural phenomena improve agro-ecosystem water use while remaining hydrologically connected with the surrounding landscape, thus sustaining the water use for additional ecosystem services (Key Messages 7, 8).

- Coordinating water management institutions can begin from the bottom-up, with communities empowering themselves using new, open-source ecosystem assessment methodologies (Key Messages 9, 10).

- Greater awareness of IWRM's potential to ensure ecosystems benefits are recognized, valued, and accounted for when assessing water demands in landscapes has yet to be achieved. (Key Messages 9, 10).

GLOSSARY

Agro-ecosystem – Terrestrial ecologies that are intensively modified and used by humans for the specific purpose of growing produce, including: rainfed & irrigated croplands, livestock grazing lands, and multi-use systems.

Agro-ecosystem services – Ecosystem services provided by managed agro-ecosystems such as cropland (food, fibre, and fodder), pastures, and multi-use agro-forestry systems.

Benefits – The material and nonmaterial produce that contributes to human well-being and livelihoods.

Blue water resource – Liquid water, rivers, lakes, wetlands and aquifers that is the basis for all aquatic life and that can be managed and controlled by engineered infrastructure.

Bundles of ecosystem services - Sets of ecosystem services that repeatedly appear together across space or time (Raudsepp-Hearne *et al*. 2010).

Ecosystem – A community of interacting biological organisms.

Ecosystem services (ESS) – The benefits that people obtain from ecosystems (see also Box 1: Ecosystem Services (ESS).

Ecosystem service (ESS) valuation – Expressing the value of water-related ESS goods and services in order to inform sharing and allocation decisions. It covers both use and non-use values, extractive and in-situ use values, and consumptive and non-consumptive use values (adapted from Hermans *et al*. 2006)

Ecosystem service water productivity (ESSWP) – The ecosystem services benefits or gains per unit water input.

Green water resource – The rainfed soil moisture available to plant roots, sustaining all terrestrial vegetation.

Human well-being – "The freedom of choice and action to achieve basic material for a good life, health, good social relations, and security. Well-being is at the opposite end of a continuum from poverty, a pronounced deprivation of well-being" (from UNEP EMP 2008).

Integrated Water Resources Management (IWRM) – "A process, which promotes 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 2000).

Landscape ecosystem services – Ecosystem services provided by ecosystems at the landscape scale, that are not actively managed by humans.

Livestock water productivity (LWP) - The economic value of livestock produce per unit water.

Managed aquifer recharge - The intentional transfer and storage of surface (blue) water resources into subsurface aquifers. This can be both simple and inexpensive (e.g. passive diversion of water to porous surface areas), or complex and expensive (e.g. capital intensive surface water injection).

Non-timber forest product (NTFP) - Complimentary provisioning ESS from forests, such as fibre, fruits, nuts, wild game, etc.

Non-productive depletion - Water that is unused in an agro-ecosystem (especially livestock systems), such as water that evaporates from the soil column rather than being transpired through vegetation.

Rainwater harvesting (RWH) - A range of technologies including enhanced soil infiltration and storage as with soil conservation measures, but often extends to small-scale storage structures, tanks, sand-dams, and surface and sub-surface reservoirs. RWH is a common source of supplemental irrigation for crops, and dry-season water supply for livestock, aquatic resources and people.

Resilience – The magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behavior (Holling 1996).

Social-ecological systems – The integrated system of humans and the ecosystems that support and are impacted by human livelihoods.

Synergies - "Win-win" situations in which benefits of one activity serve to amplify the benefits of a related activity.

Trade-offs - "Win-lose" situations in which benefits to one activity serve to reduce the benefits of another activity, including unintentional negative impacts and negative externalities.

Water productivity – The amount of benefits (material and nonmaterial) that are generated by a given volume of water. Several variations of the concept exist, notably crop water productivity (CWP), livestock water productivity (LWP), and monetary efficiency.

Wetlands - "Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" [from the Ramsar Convention, Article 1.1].

Yield Gap - The gap between potential and actual yields for a specific crop, where potential yields are dictated by climate (the physical environment), and actual yields are dictated by management (the social environment).

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United Nations Environment Programme
P.O. Box 30552 - 00100 Nairobi, Kenya
Tel.: +254 20 762 1234
Fax: +254 20 762 3927
e-mail: uneppub@unep.org
www.unep.org

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