

## 5 Forest Cover and Global Water Governance

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**Abstract:** Globally, water is recognised as a key resource for growing cities and to sustainably increase production of food and energy under threat from climate change. There is also increasing recognition of the need for more sustainable and transparent management of water resources. Trees and forests, be they cultivated more or less intensively or natural forests in various degrees of degradation and fragmentation, have a central role in water cycling and for protecting water quality. This chapter reviews the role and function of forests in water cycling and management, but also how this knowledge and/or beliefs affect policies and governance of forests with regard to water management. The main objective is to develop a common understanding of the basis of the role of forest management in water governance and a readiness for the diversity of scenarios in a global change perspective on these issues. The chapter gives a short review of the biophysical understanding of forest and water relationships, and also how this leads to different perceptions and policies on the ecological services, or benefits, that forests provide. Perceptions of such benefits are dependent on a number of factors, including what characteristics of water quality or quantity are desired, and also what are the different dependencies and perceptions of the values provided by the forests themselves, apart from their effects on water resources. In relation to this, descriptions of current and developing governance systems, such as “payment for environmental services” are given. In conjunction, the strong link between the role of trees in soil and water management, and the increasing role of forests for carbon sequestration and climate change adaptation are discussed. Major conclusions include emphasis on preparedness for solutions where forest management is part of water governance in landscape perspectives to meet the needs of many different land users. In this sense, we emphasise that general policies cannot meet sound forest and water governance, but locally/regionally based models and scenarios need to be used as the basis for governance systems. In many parts of the developing world, this puts demand on more empirical data as well as national capacities for research and governance, including transparency and local involvement of stakeholders.

**Keywords:** trees, water quality, water supply, water use, flood control, green water, PES, REDD, drought, climate change, modeling



### 5.1 Background and Introduction

#### 5.1.1 Water Will Be Increasingly Precious for Development

More than 1.2 billion people live under physical water scarcity (in areas with more than 75% of river flows withdrawn for various reasons) (UN 2009).

Another 1.6 billion people live in areas of economic water scarcity where human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands. At the same time, a target under the Millennium Development Goals (MDGs) is to “halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation.” The United Nations (UN) is forecasting that the population of the planet will increase with another 3 billion people until 2050. Most of this population growth



Anders Malmner

**Photo 5.1 In less developed countries the responsibility of household water supply is often with women and children and can take considerable time (northern Lao PDR).**

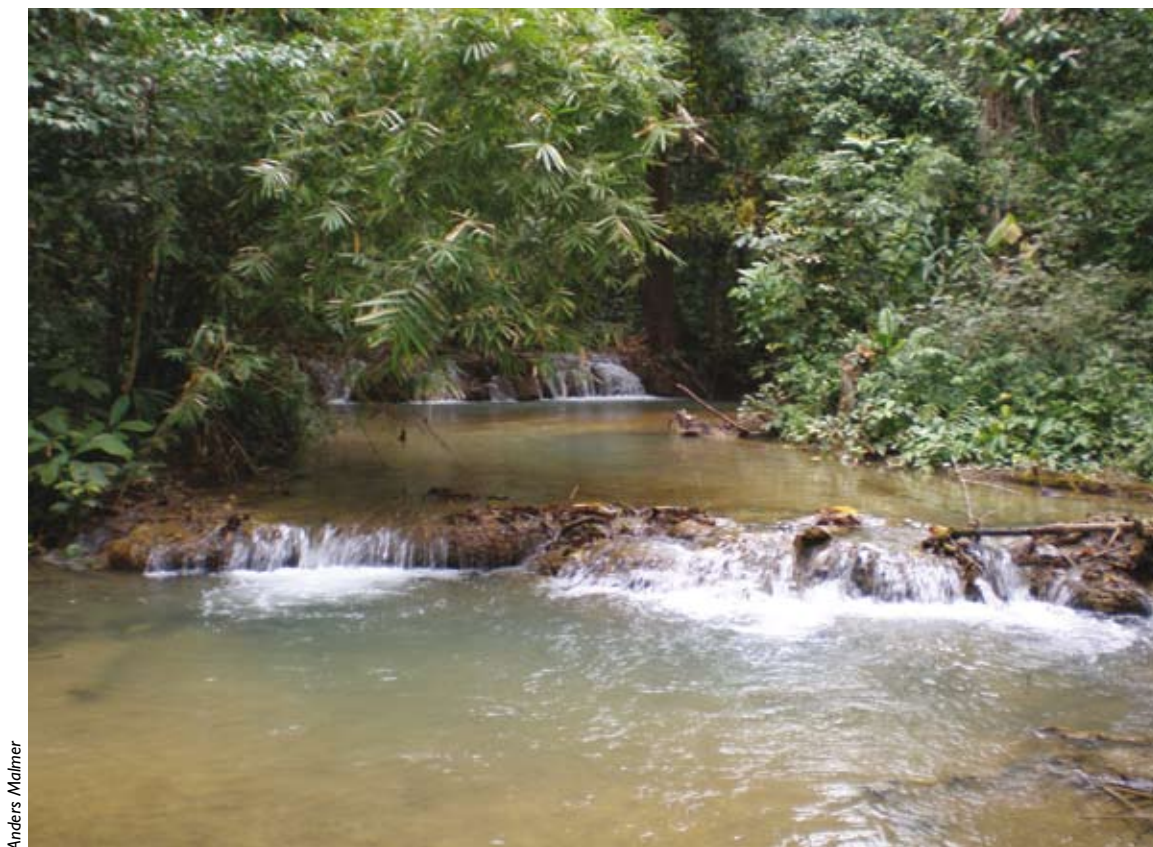
will take place in drier regions, and most of these people will live in cities to be supplied with clean water. At the same time, the expected increased use of biofuels to replace fossil fuels, the increased need for food, and the need to adapt to climate change, are all expected to put a tremendous demand on water. Hence, water will be increasingly central for development and climate change adaptation.

### **5.1.2 Forests Play a Key Role in Drivers of Change for Water Availability**

The relationship between forests and human water supply is often central in perceptions of water in regional, landscape, and watershed scales. In most parts of the world, local rainfall is not enough to sustain agriculture, industry, and household water consumption. Surrounding “upland” areas, often with traditional non-intensive human activity, are looked upon as important sources of groundwater and stream-water for downstream users. These water source areas are often either forested, under deforestation, or are historically deforested. The management and state of these (forest-) lands may conserve or reduce water supply and quality, as will be reviewed below.

Looking ahead, there are a number of increasing global trends that influence both forest management and water use, and that enhance the links between them. Over time, at scales of decades and even centuries, the rates of forest clearing have evolved according to a pattern described as “the forest transition” (Rudel et al. 2005). Changing rates of deforestation correspond to a trajectory of forest cover change – from abundant forest and low rates of forest loss, to accelerating deforestation and often massive loss of forest cover. Eventually, deforestation slows and forest cover reaches a nadir beyond which afforestation occurs, either naturally on abandoned land, or through strategic land use planning mostly as plantations (Kauppi et al. 2006). Outside of forests, the proportion of trees on farms varies considerably among countries, but throughout the tropics, the number of trees on farms is increasing (FAO 2005). The increase in forest area is so far mainly through monoculture plantations. Findings on the effect of forest cover on hydrological processes are, however, variable for different places. For example, in China, streamflow increased due to reforestation in the upstream area of the Yangtze River (Cheng 1991), whereas it increased following deforestation in the Loess Plateau area (Liu and Zhong 1978).

General development of previously poor societies most often leads to increased water consump-



Anders Malmer

**Photo 5.2 Forests may help in water quality and flow regulation(Lao PDR).**

tion. Many of the MDGs, not only the ones directly dealing with water, put pressure on increased availability of water through increasing food production, increased sanitation and health care, and also through increasing pressure on the alternative use of forest land (for agriculture and urban development).

A number of the effects of global climate change are also putting pressure on the relationships between forests and water. Firstly, increased or decreased rainfall and temperature will, of course, directly affect water availability, and will, evidently, also lead to changes in nature and distribution of forest cover spatially and/or qualitatively. Secondly, carbon mitigating measures with Clean Development Mechanism (CDM) and Reducing Emissions from Deforestation and Degradation (REDD) projects are expected to increase dramatically in the near future, leading to increasing and improving forest cover with large consequences on water management (Trabucco et al. 2008). Thirdly, the quest for non-fossil fuels will lead to increased forest cultivation for energy purposes in some cases, and may also lead to conversion of forests to other energy crops in other regions. Obviously, the fate of the relationships between forests and water under climate change and climate change adaptation will be very complex and difficult to forecast, depending on large regional differences; added to which there are partial weaknesses in the

empirical base for forest hydrology (Malmer et al. 2010) and uncertainties in governance and economic development (Oki and Kanae 2006).

### **5.1.3 Problems for Science and Its Policy Interface**

The interactions of forests, land, and water have long been discussed and debated. The role of forests in sustaining water supplies, preventing soil erosion, and in the control of catastrophic floods and landslides, has been claimed and challenged (e.g., Hamilton and King 1983, Andreassian 2004). Land use/cover is intrinsically linked with the hydrological cycle, therefore, a land use decision is often a water decision (Bosch and Hewlett 1982, Falkenmark 1999). Sustainable management of forest land by upland farmers may contribute to a timely volume and quality of water, reduced sediment, and reduced risk for flooding for downstream ecosystems and societies. There are many perceptions and generalisations about the above-mentioned perceived benefits of forests on water management, but tree planting in one part of a landscape may not boost all the water-related benefits in all other parts of the landscape (e.g., Calder et al. 2004). One example is the strong

**Box 5.1 Water challenges in the Sahel – human or natural. An example of complexity***Jonas Ardö*

The Sahel is a zone with a gradient from arid to semi-arid environments south of the Sahara and stretching from the Ethiopian highlands to the tip of West Africa in Senegal. The region has been known for desertification, droughts, and famine since the mid 1980s, reflecting long term decreasing rainfall in the region since the 1960s, even if a period of precipitation recovery has been reported (Hickler et al. 2005, Giannini et al. 2008), especially for eastern Sahel (Ali and Lebel 2009). Savannahs and parklands, characterised by the co-dominance of trees and grasses, are important, multi-purpose ecosystems in the Sahel where tree density determines ecosystem properties.

Initially, there was strong emphasis on the human component as causing the degradation in this region through too-intensive grazing, wood collection, or cultivation. Political instability has worsened situations, but, looking back, periods of wet seasons with higher rainfall have also been shown to allow recovery in areas previously struck by desertification (Olsson 1993, Hickler et al. 2005, Olsson et al. 2005). Natural global fluctuations, mainly of sea surface temperatures, are today the main explanation for existing long-term trends of drier wet seasons in semi-arid West Africa, although positive feedbacks from land surface changes are likely to amplify ocean-forced climate change (Giannini et al. 2008).

In this region, water harvesting techniques to

increase infiltration on site from scarce rainfall are becoming increasingly important (Barron 2009). Also, management of soil organic matter (SOM) is crucial for water infiltrability, water-holding capacity, as well as for carbon storage. In this matter, trees have a role. Gnankambary (2007) has shown that in traditionally cultivated parklands, infiltrability is higher under trees than in between – a very important finding in landscapes where traditionally cultivated land with trees is becoming more scarce (McCauley 2003). Additionally, inter-cropping (agroforestry) reduces soil evaporation; improves soil structure, soil texture, and soil nutrient status; and can increase water use efficiency (Ardö et al. 2008).

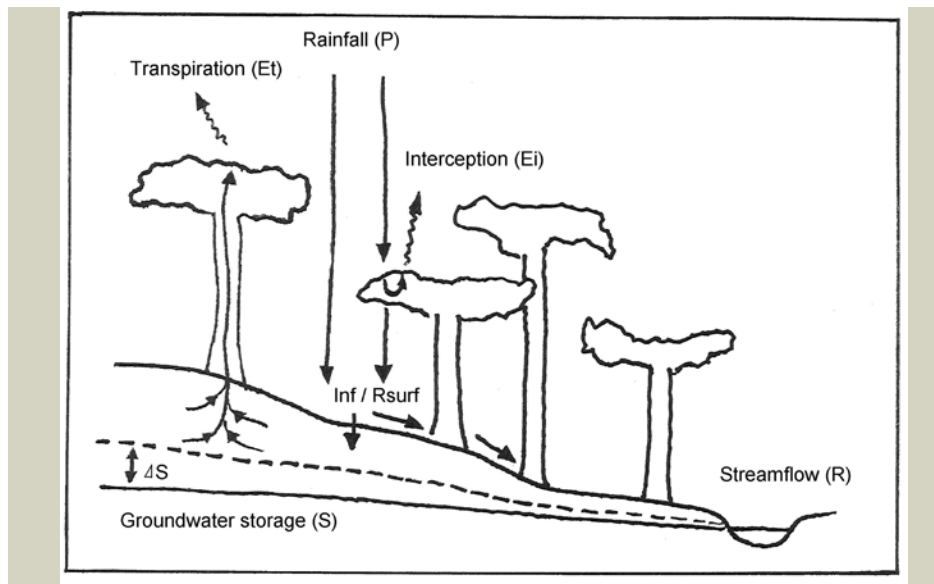
SOM, as supplied by trees and/or mulched harvest residues, may improve adaptation to a drier climate by improved harvest in dry years and dry spells (allowing more available water in topsoils (e.g., Ouattara et al. 2008). Such projections on vegetation response to future climate, as simulated by Global Circulation Models (GCMs) for more tree-dominated ecosystems, may well be valid for the Sahel, as suggested for East Africa (Doherty et al. 2009). Still, competition for land for large-scale commercial use and smallholder need for land, with or without trees included, will increase in the Sahel. This has to be met with a multitude of strategies proposed for the efficient governance and sustainable use of land, water, and forest resources to adapt life styles to climate change and climate variability, as well as to maintain food security.

link and possible synergy, or the trade-offs between tree planting, soil carbon storage, and water infiltrability of soils on one hand, and the increased water use by the planted trees on the other hand (Malmer et al. 2010).

Hence, the study of the hydrological consequences of forest cover is complicated by great spatial and temporal variability of land use/cover change, as well as hydrological systems. Much of the current understanding of forest cover effects on hydrology is derived from controlled, experimental manipulations of the land surface at particular scales and limited time periods. The often-used paired watershed study has its limitations, often lacking experimental replication across a full range of natural conditions (Andreassian 2004) and giving results for a “black box full-landscape unit,” and, as such, not giving data for resolving questions about landscapes with complex land-use distribution (Bruijnzeel 1990, 2004). There

are few examples for controlled long-term studies on permanent land “conversions” (e.g., forest to agriculture, agriculture to urban, etc.) at multiple scales (DeFries and Eshleman 2004).

Understanding the role of forest cover in freshwater and hydrologic processes, and the feedback of hydro-meteorological processes to forest cover, are also emerging aspects of global change science and hypothesis development (e.g., Jackson et al. 2005, Sheil and Murdiyarso 2009). The effect of forest cover changes on climate, especially redistributed rain on continental landscapes, such as in the Amazon basin, is still unclear given the current methodological limitations (Costa 2005, Malmer et al. 2005). On various scales, advances in satellite remote-sensing technology and the availability of new data (e.g., hydro-meteorological data), together with progress in computation and statistics, have significantly enhanced modelling capabilities for pre-



**Figure 5.1** The main effects of trees on water. Evapotranspiration from rain trapped in tree crowns ( $E_i$ ) and water taken up from soil ( $E_t$ ) is generally greater for forest than other vegetation. On the other hand the ratio between water infiltrated into soil in relation to quick surface runoff ( $Inf/R_{surf}$ ) is also greater under trees. The total effect on change in groundwater storage ( $\Delta S$ ) is often negative for planted monocultures compared to old growth forest and grassland but is also highly dependent on site specific characteristics. The value of the extra water used by trees has to be balanced against other societal values like soil stability, wood production and carbon sequestration etc. (e.g., Trabucco et al. 2008).

dicting hydrological consequences of forest cover change and for forecasting ecosystem changes. For some regions and land uses, though, there is still a lack of empirical data for model validation and input (typically the seasonal tropics) (Scott et al. 2005, Malmer et al. 2010).

Previous generalisations about forest and water relationships are often taken for granted (cf. Box 5.2) and will need to be more scientifically defensible, site-specific, and flexible in the face of uncertainty and natural variability because land use will need to be more intensified, complex, and efficient in order to meet the trends and challenges described above. We will need to have better knowledge and tools to understand and to manage trade-offs and synergies between forests and water management. Even if the trends are global, the relevant scale for the management of forests and water is in the land-use mosaic of landscapes and watersheds. The academic and societal readiness, mirrored in ongoing adaptation and in preparedness to meet challenges, is intensely varied in different regions. This chapter aims to review current trends and the knowledge base for integrated forest and water management.

## 5.2 The Role of Forests in Water Cycling

### 5.2.1 Trees Use More Water

It is a fundamental fact that trees use more water than most other crops or natural vegetation. This water use (Evapotranspiration, ET) consists of evaporation from rainfall (precipitation, P) trapped in the tree crowns (interception,  $E_i$ ) and evaporation from the leaf stomata (transpiration,  $E_t$ ) driving the water transport in the tree for its water and nutrient uptake (Figure 5.1). Because of the larger leaf area and deep rooting, ET of a forest is almost always larger than ET for other vegetation following deforestation, leaving a larger water surplus to feed groundwater and streamflow (Bosch and Hewlett 1982). This could also be expressed as a positive relationship between biomass production and water use (Rockström 2003).

The conceptual model of distinguishing between green water (vapour flows needed for all vegetation –  $E_t$  and  $E_i$  in Figure 5.1) and blue water available for human and societal use in groundwater storage and streamflow (Falkenmark 1999), is helpful and often used in the science-policy interface.

**Box 5.2 Controversy: Do forests act like sponges to conserve water?***Anders Malmer*

Since the 1970s the potential of deforestation to degrade soils and increase surface runoff has been strongly demonstrated, not least in the tropics, where there is higher pressure on the land and faster soil processes (Eckholm 1976). Desertification, failures of rehabilitation and clean water supply, declines in soil fertility and resulting famines, have prompted research on soil degradation. Maintaining trees, implementation of physical measures like contour ploughing and terracing, and tree management concepts like agroforestry, have repeatedly been proved to sustain nutrition, soil organic matter (SOM), and infiltrability in trials at plot scale (Hurni and Tato 1992).

Similarly, the benefits of reforestation by improving water availability has also been taken for granted for decades, (i.e., forests maintaining infiltrability and thereby promoting local groundwater recharge in the wet season, to improve dry season water availability, or trees acting as “sponges”). One reason for the controversy is that the “sponge

theory” contradicts the scientific evidence that trees use more water from soil and groundwater. Much less research has been done in these aspects of water use compared to the above described aspects of soil quality, because it is more difficult, partly because portions of the processes needing research occur below ground, demand more expensive equipment, entail long-term efforts, and are difficult to do in larger heterogeneous landscapes. Very few empirical studies have been established in tropical semi-arid regions; the ones that do exist all confirm decreasing groundwater resources upon reforestation. Thus, billions spent in reforestation for water improvement, and even the justification for “payment for ecosystem services” (PES) schemes, can be questioned (Kaimowitz 2005). However, many forest hydrologists still argue that synergies or trade-offs between soil quality/sustained production, water quality and water quantity needs to be better known for more edaphic and socioeconomic situations (Scott and Prinsloo 2008, Trabucco et al. 2008, Malmer et al. 2009).

**5.2.2. Trees Protect Soils and Water Quality**

Most soils (apart from very coarse-grained ones) need biological activity and organic material to maintain a soil structure with sufficiently large soil pores, so that water will enter the soil (infiltrate) rather than run off over its surface. With low infiltrability (Inf), more water may become surface runoff (R<sub>surf</sub>) during rain events, and may cause erosion and carry sediments to streams. A healthy vegetation cover is important for maintaining high soil infiltrability. The vegetation continuously produces biomass and provides organic matter to the soil to balance the decomposition of organic matter. Trees, whether solitary or in forest stands, are most efficient litter producers. When vegetation is over-used, such as under different combinations of deforestation and non-sustainable grazing and agriculture, litter-fall is dramatically reduced and soil organic matter (SOM) decreases, as decomposition will supersede litter input until an equilibrium with lower SOM and less-effective soil structure and infiltration is reached (Perrolf and Sandström 1995).

**5.2.3 Trees Assist Groundwater Recharge in Contrast to Fast Surface Runoff**

Soil with a healthy tree cover, or where trees are sustainably re-introduced, have higher infiltrability (Ilstedt et al. 2007). With deforestation and diminishing SOM content, as described above, infiltrability is reduced. This process is faster in the tropics due to more rapid SOM decomposition and soil reworking by organisms (bioturbation), and even more so in semi-arid regions because of less efficient vegetation succession to protect the soil surface from heating, and erosion of the less compact topsoil (Perrolf and Sandström 1995). Furthermore, it is argued that trees maintain more macropores (from decomposed roots and soil bioturbation) to a greater depth in the soil, which has been shown to be important for more efficient water percolation to the groundwater (Elsenbeer 2001).

**5.2.4 How Do Trees Control Streamflow, Baseflow and Stormflow?**

There are often expectations on the role of forests in flood control. For example, under current discussions about negative effects of climate change, much

interest is centered on too much water for the Asian monsoon-dominant region and too little for large parts of Africa. Sustained dry season flows of rivers to downstream users in semi-arid areas, and areas facing an increasing risk of dry spells, and the role of forests in these situations is under scientific debate (Box 5.2). Reviews of accumulating empirical studies (Farley et al. 2005, Scott et al. 2005) and meta-analysis of available empirical data (Locatelli and Vignola 2009) claim that the effect of trees using more water than other land uses over-rides the effect of possibly better groundwater recharge, leading to ultimate reduction in baseflows compared to non-forested areas. However, there is a growing awareness about the paucity of studies in tropical semi-arid areas (Locatelli and Vignola 2009), especially when planting trees in degraded soils (Scott et al. 2005, Malmer et al. 2010).

The link between forest cover and flooding has been challenged for decades. At larger scales, the flood-reducing effect of a good forest cover seen in small plots and catchments with 100% homogeneous land-use typically disappears (e.g., Wilk and Hughes 2002). In fact, studies in America and the Himalayas indicate that the increase in infiltrability of forested lands over non-forested lands where the soil remains essentially sound, is insufficient to influence major downstream flooding events (Gilmour et al. 1987, Hamilton 1987). In fact, studies in America, South Africa, and the Himalayas indicate that the change in vegetation type alone (forest cover compared to non-forested lands) where the soil remains essentially sound, is insufficient to influence major downstream flooding events (Bosch and Hewlett 1982, Gilmour et al. 1987, Hamilton 1987). Instead, the intensity, amount, and spatial distribution of rainfall are the key elements determining the extent and magnitude of damage caused by such disasters, although local geology, forest cover, and steepness of slopes are also important contributing factors. Massive programs of forestation that have often been proclaimed as “the answer” for preventing floods are simply not supported by scientific evidence (FAO and CIFOR 2005). Rather, van Dijk et al. (2009) showed and discussed population density to be a strong determinant in a complex relationship with flooding. Recent meta-analysis also cannot support significant differences in stormflows between forests and open land, but again, as for baseflows, the data set is poor (Locatelli and Vignola 2009).

### 5.2.5 Spatial Impacts

Scale is still considered to be the unresolved problem in hydrology. Much is known about hydrological processes in forests at a small catchment scale

(e.g., 10 to 1000 ha). Kiersch (2001) concluded that land use impacts on hydrological parameters and sediment transport are inversely related to the spatial scale at which the impacts can be observed. The forest cover effects on freshwater and flooding can be measured only in relatively small basins where a large portion of land cover is changed (Bruijnzeel 2004). In contrast, impacts of land use changes on water quality parameters may be relevant to society at the higher meso- and macro-scales (Table 5.1). While the documentation of effects of human interventions at the micro-scale is easily possible, the changes in flood peaks, sediment load, and baseflow at the landscape and regional scales are the result of a mosaic of land uses, changing over time, and superimposed on natural processes at a larger scale (like large-scale frontal rainfall), which typically makes the effect of the natural process more dominant (Ives and Messerli 1989).

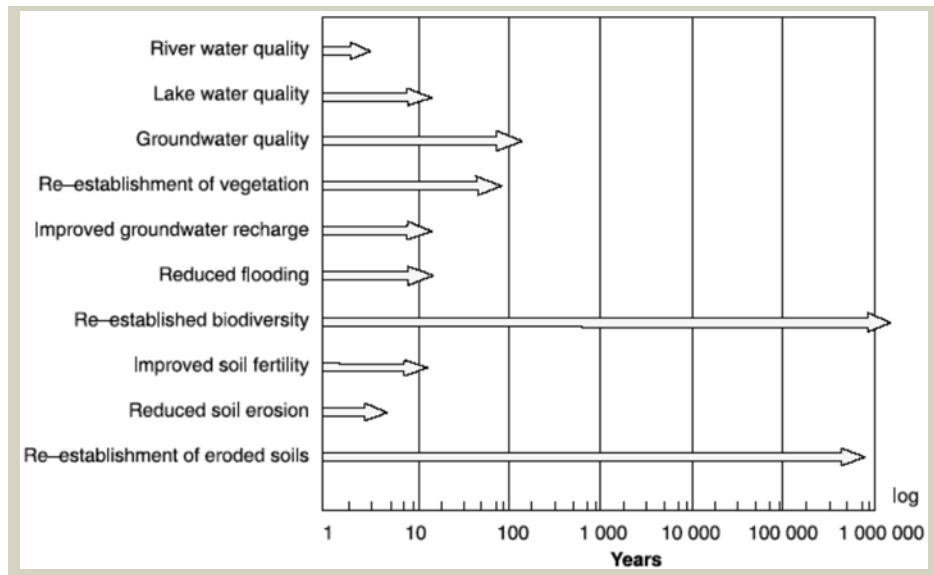
### 5.2.6 Temporal Impacts

It is also important to note that the impact of these land use and cover changes is variable in terms of the time scale (Figure 5.2). While river and lake quality can be restored in relatively short time, severe impoverishment of biodiversity may be irreversible in a human time perspective. Any planting of trees or current changes in the land use and cover that involve indigenous flora or the natural multiplication of fauna, such as soil physical rehabilitation, takes time and is an investment in the future. The positive effects of any intervention of this kind will only become apparent in the years to come. If fast effects are required, other means will need to be employed.

Bruijnzeel and Bremmer (1989) noted that, especially in the case of sediment in rivers, time is a very important factor. Even after a beneficial land use change, there is still enough sediment stored in the system from prior erosion (man-made and natural) that may lead to elevated sediment loads in the rivers for long times. A more detailed example of the impacts of different land use decisions on water quality, and at what spatial and temporal scales these impacts are active, is given in Table 5.1.

### 5.2.7 Combinations of Spatial and Temporal Effects

Floods and droughts are not new phenomena. In history, cycles are revealed within which major flooding tends to occur at fairly regular intervals (see Box 5.1). These cycles appear to be driven by major climatic



**Figure 5.2** Logarithmic diagram showing the time scale of impact/rehabilitation after land use change-induced disturbances (Batchelor and Sundblad 1999).

patterns (such as those resulting from the influence of cyclical warm ocean currents) (Giannini et al. 2008). Extreme weather events occur as a result of normal fluctuations of climate, although there is an increasing frequency that may not be within normal range. Furthermore, frequent extreme weather and floods cause more loss of human life and property due to poor land use practices, poor planning, and urbanisation on flood-prone areas. Badly designed and constructed infrastructure (e.g., roads along steep slopes, dams built near seismic faults) can lead to disasters, particularly in vulnerable habitats such as in mountainous regions. Mountain farmers are often blamed for cutting forests or for badly constructed terraces when floods and erosion/landslides occur. But often these are a result of bad planning, including such things as tunnels constructed for roads and developments that create new drainage patterns (Xu and Rana 2005). Urbanisation has also transformed formerly vegetated land (e.g., forests and wetlands) to impermeable surfaces in a basin, with little or no water storage capacity, thereby increasing river flow (Falkenmark 1999). The area of impervious surfaces in catchments is often directly related to the size of floods (Wissmar et al. 2004). In some places, natural stream channels have been straightened and deepened, and structures such as dams and embankments have been built to reduce local flood risks. These “solutions” may have served to help reduce flood impacts locally, but often have the effect of shifting the problem further downstream.

### 5.3 Governance: Old and New Perceptions and Paradigms on Forests and Water

To understand governance arrangements for forest ecosystem management, the relationship between the functioning of ecosystems and the provision of specific human-welfare benefits to users of ecosystem services must be understood (Fisher 2009). A closer look at how forests are perceived in land-use and environmental water policy and governance reveals a broad range of perceptions and strategies that range from crude to carefully planned. Depending on environmental and socio-economic situations, forests may be embraced as production units for combining wood production and water services, for strict water conservation purposes by forest conservation, or for mining the groundwater (Box 5.5).

#### 5.3.1 Uplanders – Lowlanders – Urban People

In Asia shifting cultivators in upland areas are often blamed by the lowlanders as having caused flooding and deteriorating water quality by deforestation through shortening fallow times and increasing the area of land being used. Interestingly, in the same regions, the same farmers may be blamed for lack of water during dry seasons and droughts due to the same treatment of upland forests (e.g. Malmer et al. 2005). From the forest and water relationship as outlined above, this may hold true, but may be very

Table 5.1 Spatial and temporal constraints on water quality evolution.

Major causes / Issues	Major related issues <sup>1</sup>	Space scale	Contamination <sup>2</sup>	Time scale Clean-up <sup>3</sup>	Human control
Population	Pathogens Eutrophication* Micro-pollutants	Local Regional Regional	< 1yr < 1–10yr < 1–10yr	< 1yr 1–100yr 1–100yr	Density, treatment Treatment Various
Water management	Eutrophication* Salinisation Parasites	Regional Regional Regional	< 1 yr 10–100 yr 1–10 yr	10–>100 yr 10–>100 yr > 100 yr	Flow Water Balance Hydrology
Land management	Pesticides Nutrients (NO <sub>3</sub> ) Suspended solids** Physical changes	Local-regional Local-regional Local-regional Local	< 1yr 10–100yr < 1–10yr < 1–10yr	1–100yr > 10yr 10–100yr > 100yr	Agrochemicals Fertiliser Construction/clearing Cultivation, mining, construction, clearing
Sources					
Megacities	Pathogens Micropollutants	Local Local-regional	< 1yr < 1yr	< 1yr 1–10yr	Population, treatment
Mines	Salinisation Metals	Local-regional Local-regional	10–100yr < 1yr	10–>100 yr 1–100yr	Types of mines
Global climate change	Salinisation	Global	> 10yr	> 100yr	Fossil-fuel emission, greenhouse gases
Natural ecological conditions	Parasites**	Regional	Permanent	Permanent	Ecosystem management
Natural geochemical conditions	Salts Fluoride** Arsenic**, metals**	Regional Local-regional Local-regional	Permanent Permanent Permanent Permanent	Permanent Permanent Permanent Permanent	

<sup>1</sup> \* is relevant primarily to surface water and \*\* is relevant primarily to groundwater

<sup>2</sup> area scales: local – <10 000 km<sup>2</sup>, regional – 10<sup>5</sup> to 10<sup>6</sup> km<sup>2</sup>, and global – 10<sup>7</sup> to 10<sup>8</sup> km<sup>2</sup>

<sup>3</sup> lag between cause and effect, yr = year

Source: Modified from Peters and Meybeck (2000).

difficult to prove. To blame the uplanders may be an easy way to generalise and not deal with more complex reasons, including governance of all people living within the whole landscape (e.g. Colfer 2005), and land uses downstream. Developing hydropower, lowland irrigation schemes, and other water-demanding land uses are felt as strong indicators of development, and are therefore often less easy to identify as problematic in the complex effect of human activity on water.

### **5.3.2 Trade-offs Between Soil Protection and Water Delivery**

From the above technical background, there may well be a case for a trade-off between using forest cover to protect soil and water quality on one hand, and reduced dry season water quantity on the other hand. These trade-offs relate to regional differences not only in ecology, but on priorities in intensity of land-use, set by urban/rural people and ambitions in rate of economic and societal development. Boxes 5.3 and 5.4 give two regional examples of this from China and from South Africa.

### **5.3.3 Governance Systems for Water Resources**

In the report of the 1st UNESCO (United Nations Educational, Scientific, and Cultural Organization) World Water Assessment Programme, governance, largely defined, refers to a variety of partnerships and networks that different actors (e.g., government, civil society, private sector, scientific organisations) establish to organise collective actions. In our specific case, governance thus refers to organised interactions among this variety of actors to promote sustainable use of ecosystems and their hydrological services. There is no commonly shared definition of water governance as such, but many different perspectives have been considered (financial issues, institutional arrangements, and relationships between social and ecological systems).

The large and increasing literature on governance (Kjær 2004) has not achieved a common definition of the concept. From among the different definitions found, we have built a definition for our study that draws on Huitema et al. (2009), who defined governance in reference to the complex issues associated with water resources as follows: Governance is the result of both the formally stated rules (e.g., policies, laws, etc.) and informal interactions of actors in networks that are a relevant collective response to environmental degradation problems. In general, the

protection of regulating ecosystem services is challenged by high uncertainty in the understanding of the hydrological cycle's responses to climate change and land use change, by the need to deal with competing and changing demands for the resource, by scarce resources to enforce actions, and by a largely weak institutional framework in regulation of land and water use (UNESCO 2003). In these complex contexts, efforts to improve governance of ecosystems for the sustainable provision of hydrological services should be guided by the principle of adaptive governance (AG), where flexibility and learning mechanisms are allowed to occur across sectors and scales (Olsson et al. 2005). To promote AG, aspects such as preparation, leadership and windows of opportunity are key for success. For instance, preparation phases need self-organised networks and leadership to improve common understanding of the social and ecological characteristics and dynamics of the system at hand. This implies sharing information, building trust, and identification of organisations that have authority and legitimacy to promote the participation of actors from different sectors and scales (i.e., leadership). Windows of opportunity, such as a given crisis or conflict over water, might be a trigger for starting discussions and inter-disciplinary groups.

Under this perspective, some experiences from around the world can help us outline some successful stories, lessons learned, and opportunities that can improve governance for maintaining the provision of these important services. We should be aware, though, that many features of these cases are context-specific. In analysing case studies we find that a variety of approaches ranging from top-down establishment of national laws, enforcement, and financing for the protection of key ecosystems in the provision of hydrological services, to local level initiatives where agreements and collaborations are reached by relevant actors defined around the provision and use of hydrological ecosystem services (HES).

#### *Payment for Ecosystem Services*

Examples of national initiatives can be the "Payment for Ecosystem Services" (PES) cases, such as the Environmental Services Payment Program (ESPP) implemented by the National Fund for Forest (FONAFIFO) laws in Costa Rica, the Fund for Protection of Water (FONAG) in Ecuador, or the Mexico Forest Fund (Wunder et al. 2008). In these cases, efficiency of the PES scheme is determined by the extent to which quantification of real services delivered to users is possible with the use of national data at low levels of details, and where effective users are varied and scattered (Engel et al. 2008). On the other side, local decentralised initiatives – such as Vittel in France, Wimmera catchment initiative in Australia,

**Box 5.3 China: Optimising land use is first priority***Jianchu Xu*

In the world's most populated country, maintaining all lands in high production and environmental services delivery is a high priority. The severe droughts in 1997, and the massive floods in 1998, prompted China to take two unprecedented conservation actions: the development and implementation of the Natural Forest Protection Program (NFPP), and the Sloping Land Conversion Program (SLCP) or Grain-to-Green Program.

The NFPP conserves natural forests through logging bans and enforced afforestation with incentives to forest enterprises. The SLCP converts cropland on steep slopes to forest and grassland by providing farmers with grain and cash subsidies. These actions resulted from the realisation that those droughts and floods were at least partially caused by farming on steep slopes, and on defor-

estation in the upstream regions (Liu et al. 2008). An increase in forest area, mainly through plantation, to the tune of more than 4 million ha per year during 2000–2005, was recorded in China (FAO 2007). Planting trees in arid margins may exacerbate droughts. The key is that the right tree has to be planted in the right place. Deciduous trees, which shed their leaves during the dry season, consume less water.

Chinese shares of water resources are far below the world average. With rapidly growing urbanisation, there are competing and increasing demands for water. In order to solve the water scarcity, China launched the South–North Water Transfer Project to meet water demands in mega-cities, such as Beijing. The problem of providing water to growing urban centres, industry, and optimised land use is approached through large-scale adjustment of river systems (Berkoff 2003).

**Box 5.4 South Africa: Empty rivers downstream of forest plantations***David Scott*

Natural forests in South Africa probably never exceeded 0.7% of the land area, so there was always a shortage of wood for construction, fuel, paper, and other timber products. The shortfall in timber supplies was countered by the establishment, from the late 19th century, of forest plantations using introduced pine, eucalypt, and acacia species. By the 1930s, complaints from farmers about the plantations having a negative effect on water supplies led the government to start a hydrological research program to quantify the influence of plantations on streamflow (Wicht 1967, Dye and Bosch 1999).

A network of paired catchment experiments was established across various forestry regions of the country. These experiments unequivocally showed that the replacement of native vegetation (grassland, shrublands, or scrub forest) with timber plantations in the high-rainfall areas suitable for forestry, had

led to marked reductions in streamflow. These reductions could be crudely averaged at 120 mm per year over the life of the plantation, but were higher in wetter zones and in wetter years, though the reductions were relatively greater (larger proportions of streamflow used) in drier zones. In addition, the low flows (dry season flows) were affected to a greater extent and earlier than was the total water yield (Scott et al. 2000).

Based on this research, the government introduced the Afforestation Permit System in 1972 to control the expansion of timber plantations. This system has since been replaced by a provision in the National Water Act of 1998 that classifies forestry as a “streamflow reduction activity” that will require the forest industry to pay for water use licenses. This provision has been dubbed as “paying for rain” by the disgruntled forest industry. The water license fees are intended to pay for catchment management services.

and the Heredia Public Service Enterprise (ESPH) in Costa Rica, where land uses are likely to produce the desired HES are more clearly targeted – might show higher efficiency in financial and institutional terms (i.e., clearer identification of providers and users of HES) (Wunder et al. 2008). When considering strategies to improve the provision of ecosystem services (ES), other issues should also be considered beyond direct economic incentives, especially in develop-

ing countries (Kosoy et al. 2007). For example, in Bolivia, where PES options have been explored in decentralised contexts, weak property rights regimes and little trust in formal administrative institutions have been signalled out as important aspects (Asquit et al. 2007). Similarly, in a recent study of a Costa Rican watershed, where high opportunity costs are attached to sustainable management of upstream land for HES provision, enlarging a capacity build-

**Box 5.5 Different development and needs drives forms of governance**

In the poorest semi-arid regions, water quantity is historically the big issue. Streams and wells running dry is equal to famine for people who do not have resources to buy water (bottles or tanks) from somewhere else. Water quality (siltation) is also problematic if water for consumption is taken from streams. However, with increasing development, there will be more wells and both water quantity and quality may be problematic for growing industry, intensive agriculture, and urban populations.

Central America is an interesting region where the forest and water relationship faces very different strategies in the different countries. Costa Rica has a mid-range economy, where large land owners dominate and hydroelectric power generation provides more than 80% of its energy. Given this, and with a humid climate essentially lasting all year, physical

water quality is the single most important concern about water. In combination with the very important ecotourism industry, Costa Rica has seen the most developed PES (payment for environmental services) scheme to conserve forests in the highlands (not in the lowlands, which were already taken up by intensive fruit production) (Pagiola 2008). Several neighbouring countries, including Honduras and Nicaragua, have regions with longer dry seasons, where providing water to develop irrigation for agriculture and for consumption in urban centres, is an increasing problem. In these countries, it is difficult to conserve forests where many poor people practice subsistence agriculture, and where there is a lack of social institutions, such as education and research, which could work to help solve the problems.

ing and technical assistance program was selected as a priority option by both upstream providers and downstream users of ecosystem services, while PES was not set as a priority by these stakeholders. In this setting, strengthening existing, or promotion of new, institutions and resources (beyond the existing PES scheme) is demanded to promote these types of activities. Major challenges to effective conservation of HES (be it PES schemes or other types of activities) are associated, among others, to institutional weaknesses in the definition of property rights, legitimacy in mechanisms for distribution of incentives, and limitations in understanding and quantifying highly uncertain provision of ecosystem services due to limited availability of data and asymmetric sharing of information (Engel et al. 2008).

*Beyond PES*

Beyond PES initiatives, centralised or decentralised policy initiatives (e.g., integrated conservation and development projects, national laws for water and/or watershed conservation) have been reported in the literature as showing irregular efficiency outcomes (Engel et al. 2008). For example, in the context of national initiatives, the Global Water Partnership (GWP) has promoted the Integrated Water Resources Management (IWRM) concept in the international arena to include management of provision and use of hydrological ecosystem services in national plans. Indeed, some experiences in integration of the IWRM approach in national plans do exist. Nevertheless, a UN report (2006) indicates that although many efforts have been undertaken for integrating IWRM

(and management of key hydrological ecosystem services) in national plans, effective institutional changes have been slow due mainly to low capacity, limited awareness and political support, and inadequate funding. Generally, these initiatives show a low degree of implementation, scarce decentralisation of capacities and resources, and little ownership by local stakeholders, which otherwise could encourage conservation of watersheds and their key ecosystems (UNESCO 2003). On the other side of the argument, the UNESCO report did highlight successful cases, such as the revised river law in Japan, which emphasises cross-scale collaboration to foster basin conservation through a step-by-step consensus-building process where information sharing between local inhabitants, private companies, government administration, and experts improved the creation of a common vision on the ecosystem degradation problems and possible solutions (UNESCO 2003). Windows of opportunity are also an important trigger for developing concerted actions in the protection of hydrological ecosystem services. In this respect, in the case of Costa Rica's Reventazon watershed, erosion affects the productivity of farms upstream and downstream there are problems with a hydropower dam due to the upstream land mismanagement and extreme precipitation events (Marchamalo and Romero 2007). Although the specific preferences of both upstream and downstream stakeholders (academic, farmers, hydropower) differ (Marchamalo and Romero 2007), the common perception of this shared HES degradation problem has triggered an ongoing institutional process that brings together actors from the agricultural sector (farmers, extension offices, ministry of agriculture), who want to influ-

ence upstream land uses, and downstream users of soil regulation services provided by the hydropower sector. Running processes aiming at sustainable provision of HES requires flexibility to understand how different actors can be interested and part of the solution, and leadership to promote the building of new institutional spaces for their interaction and actions. In this aspect, the case of Reventazon watershed, leadership by policy-makers representing local interests in the national assembly was an important factor in the constitution of the first law-decreed watershed committee with a mandate to function as an institutional space for the coordination of actors involved in provision and use of hydrological ecosystem services.

## 5.4 Global Change Challenges Old Generalisations

Future forests at a glance will be very different from our reference, which often tend to be a mixed old growth forest with low intensity forestry or forest management for non-timber forest products. Those references and images are often also the carrier of our perceptions and knowledge base for effects of land-use on water management. In some regions, deforestation may prevail to make way for other crops, or as a result of climate change, but in other regions, forests will expand again. In between these two extremes, the most common situation in the warmer latitudes today is various forms of secondary bush land and poorly stocked extensively used forests (World Resources Institute 2009). With an expected increasing intensity and diversity of cultivation, combined with different patterns of small or large landowners' rights, landscapes and watersheds will be increasingly complex with regard to spatial land-use distributions, and so will the water issues as well. This will put a high demand on developing the technical and socioeconomic knowledge base for managing these new landscapes as well as for developing relevant policies, institutions and legislation for dealing with this new situation.

### 5.4.1 Links with Carbon Storage Are Strong

In recent decades, soil rehabilitation and its associated benefits on water and fertility management has been a driver for many re/afforestation programs. However, for many reasons, this has been an uneven struggle, where rates of deforestation, degradation and desertification have superseded planting. Many of the desired soil improvements are positively related

to SOM and carbon storage, that are also desired instruments for carbon sequestration and conservation as part of the CDM or REDD. In future it would be desirable to modify the CDM guidelines and design the REDD systems to optimise both carbon storage and water management. Malmer et al. (1999) and Ilstedt et al. (2007) have shown, through both field investigations and through meta-analysis, that the time required to achieve significant improvement in soil properties such as infiltrability can vary between 2 to 20 years, depending on tree species and the initial condition (degree of soil disturbance, natural succession, whether the land is in forest plantation or in agroforestry). More research on relationships between quality and quantity of increase in carbon in soils (at reforestation, rehabilitation or conservation of various forests) is in strong need in the tropics.

### 5.4.2 Natural Forests or Forest Plantations

The “forest sponge controversy” (Box 5.2) is a typical example of where the desired return to a previous “better situation” by reforestation may not hold true, at least not in all aspects of water effects. The situation prior to the original deforestation typically saw a mixed forest with respect to species and ages, and including gaps from dead trees. The new forest is often a monoculture that completely and homogeneously covers the area concerned, often with young, vigorously growing trees. The effect on soil conservation may be achieved, including improved infiltrability, for most of these forest plantations. However, Ilstedt et al. (2007) indicated there is much less efficiency in soil biological improvement because some of the leaves are less decomposable, such as teak leaves and pine needles. Also, Ziegler et al. (2009) point out that some industrial plantations, such as those for rubber, involve terracing by crawler tractors, which may severely disturb topsoils and water infiltrability (cf., Malmer and Grip 1990). Irrespective of the type of plantation, the desired goal of improving groundwater recharge, which was degraded by the earlier deforestation, may be exchanged (and therefore not met) for higher water use by the new forest plantation. Depending on efficiency in management, forest plantations can be highly successful in meeting expected production rates and thereby have a large negative effect on the amount of water available for other uses. On the other hand naturally or spontaneously regenerating secondary forests may be in very different shape, depending on the degree of ecosystem or soil degradation, and young indigenous trees may use as much water as eucalypts (Fritzsche et al. 2006). Studies of other industrial forest plantations have been severely lacking, but Guar-



Anders Malmer

**Photo 5.3** Water management in mixed land-use landscapes will be an increasing challenge with increasing production demands and changing climate (Costa Rica).

diola-Claramonte et al. (2008) in southwest China found potentially high sub-surface soil water use for evapotranspiration in one stand of rubber. But again, the effect of conversion to a rubber monoculture on catchment or regional hydrology depends, in part, on the water use of the original displaced vegetation across broader scales.

There has been little testing or study of intermediate forest production systems, those between natural forest management and planted forest monocultures. Piotto (2008) used meta-analysis to show mixed species plantations to be more productive than monocultures. However, not enough is known either about the biophysical dynamics (e.g., management, productivity, carbon and water balances) or their socio-economic problems and possibilities (e.g., economy of scale, profitability to small scale farmers, industrial logistics).

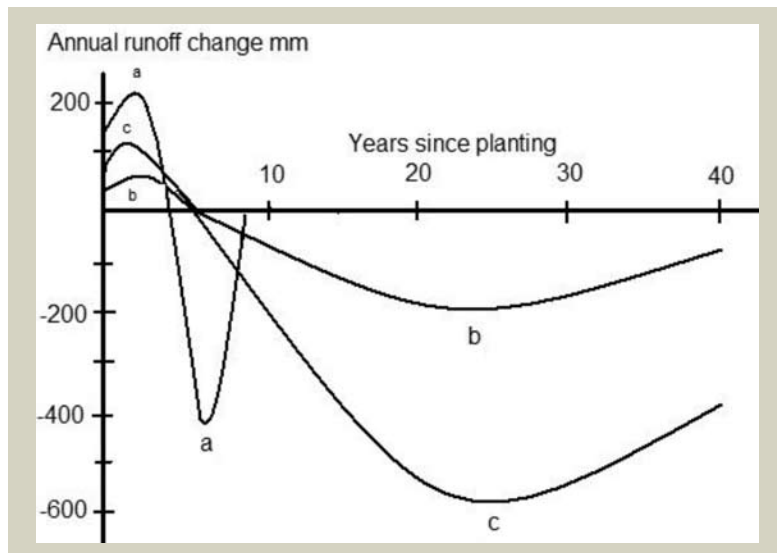
It is also inaccurate to view “untouched forests” as stable. Old perceptions of an ecological climax have already been revised (e.g., Whitmore and Burslem 1978), and evidence from both South America and Africa indicate that even old forests do increase their biomass under current atmospheric change (e.g., Baker et al. 2004), possibly also indicating an effect on increased water use even by the conserved

forests. Selectively logged forests may also be much more vulnerable to (natural) disturbances, such as fire, or long periods of drought, or possibly more frequent droughts due to climate change (Malmer et al. 2005).

#### ***5.4.3 Climate Change Adaptation May Cause Higher Intensity Land-Use and Ecological Change***

The increasing demand on biomass production will stimulate intensive forest land-use with shorter rotations. Increased risks from climate variability (droughts and low frequency high magnitude storms) may also steer investments to cultivation systems with short rotations that face less such risk. Actual climate change may also cause and add to needs for quick changes in land-use through modification to primary factors like temperature and rainfall for production as well as secondary factors as pests, etc.

Hydrological simulations for southwestern China show that the effect of climate change on surface water, baseflow and streamflow was offset by the effect of forest cover change (Ma et al. 2009). The



**Figure 5.3 Patterns of streamflow increase/decrease due clearing and planting to vigorously growing forest plantations: a) *Acacia mangium*, Malaysia 5°N (Malmer et al. 2005), b) global mean "Shrubland" to *Pinus/Eucalyptus* (Farley et al. 2005), c) Old-growth *Eucalyptus* to regenerating *Eucalyptus* 37°S (Kuczera 1987). (Source: Malmer et al. 2010.)**

seasonal variation of streamflow was influenced by the seasonal variation in rainfall. The earlier date of monsoon and the variability of rainfall resulted in greater monthly streamflow extremes. According to the model, the rainfall was influenced by the forest cover, which thereby had a strong influence on streamflow.

All in all, increasingly dynamic landscapes will make water budgets more complex and increase the demand for technical, institutional and societal management of the co-ordinated management of forests and water.

## 5.5 Knowledge Base and Institutional Support for Future Management

The integrated management of forests and water will require a thorough knowledge of hydrological systems combined with appropriate tools such as biophysical and economical models to enable institutional, regulatory and other solutions such as PES.

### 5.5.1 Empirical Data

As was described in Box 5.2, there have been too few good studies of forest hydrology in the tropics and from the seasonally-dry tropics in particular (Bruijnzeel 2004, Scott et al. 2005, Locatelli and Vignola 2009, Malmer et al. 2010). Available studies tend

to be rather old; Locatelli and Vignola (2009) did a meta-analysis using data from 20 studies but only five of these were completed within the last 20 years. Global reviews contain little work that derives from the tropics; for example the most comprehensive global review of the effects of reforestation on water (Farley et al. 2005, Jackson et al. 2005) contains only three out of 26 studies from within 25° of the equator. None of these studies involved tree planting on formerly deforested and degraded land, so this attempt at global generalisation clearly falls short of adequately representing the full tropical situation (Malmer et al. 2010).

Much of our knowledge on the forest-water relationship derives from long term experiments, where the whole of a small catchment is treated (e.g. harvesting of forest, afforestation, or some other forest operations; National Academy 2008). Results from such experiments thus represent extreme effects, whereas sensible management would include forests of various ages in the landscape. The areas of recently harvested forests will increase water availability for other uses and would partly balance the higher water use of the most productive forest stands in the landscape (Figure 5.3). With sufficient empirical input, models could help us to plan the distribution and timing of forestry operations to balance the production of forests and water in the landscape.

### 5.5.2 Over-Simplification of Some Models

Process-based conceptual models can provide generally applicable tools to support policy formulation and landscape planning (Joshi et al. 2004). Such models exist in biophysical, as well as in socio-economic applications. IWRM may combine models in multidisciplinary approaches. The problem with wide-scale application is often a lack of model validation for the region in which it is being used, and the balance between over simplification (due to lack of input data) and more technically sophisticated models. An example of this are the more simplified models of water use in landscapes that do not take account of the soil quality factor, particularly in relation to evapotranspiration (e.g., Calder et al. 2004); or the use of more ecologically-based models that include the effects of water movement and storage in the soil (e.g., Walker et al. 2007). The more simplified model may be readily applicable in an economically depressed country, but may not give the right answers on how much and where in the landscape forests and other land-uses would be best located.

### 5.5.3 The “Trialogue Model” for Adaptive Water Governance: Key Features and Lessons Learned

After a decade of application experience, the full potential benefits of IWRM have yet to be realised, especially in developing countries (Turton et al. 2007). These authors outlined several potential causes of this failure. They argue that in developing countries, weak institutions and centralised governments have reduced the opportunities for achieving the benefits of IWRM. They use the “trialogue governance” (TG) model to assess the performance of case studies around the world. The TG model underlines the importance of interaction among three distinct communities of practice, namely: government (rule-focused); society (directly interested in environmental governance, especially in developing countries that are strongly dependent on natural resources); and science (including basic research, interdisciplinary research, and technology and knowledge transfer research).

The experiences presented by these authors leads them to support the “trialogue governance” model as an effective framework for assessing and improving the effectiveness of governance with regard to hydrological ecosystem services. More specifically, adequate communication, especially in the science-civil society interface, has increased participation by society in the decision-making processes in South

Africa. Conversely, the case study in a developed country such as Australia points to other aspects that influence the effective implementation of the TG model. Here, Doolan (2007) supports the effectiveness of the TG model by pointing to factors such as: i) community ownership and commitment, ii) improved understanding of river conditions and processes, iii) improved regional institutional structures from narrowly focussed (i.e., only on engineered solution to control erosion damages) to whole catchment processes needing multidisciplinary approaches (i.e., hydrology, geo-hydrology, economy, media-communication); and iv) the development of a state-wide integrated policy framework that included additional funding for supporting government commitment to the decentralised process of watershed management.

## 5.6 Concluding Remarks

We identify eight concluding notes on “forest cover in global water governance:”

- 1) Trees and forests provide soil protection and improved water quality relative to other land uses.
- 2) Tree effects on retaining water at site and on reducing undesired stream flooding is not as simple as often generalised, especially in tropical regions with dynamically changing (forest) land uses.
- 3) Economic development, as well as mitigation and adaptation to climate change, will induce more intensive and (potentially) efficient land uses that demand much better knowledge, tools, and governance for optimal water use and delivery in increasingly complex land-use patterns in landscapes.
- 4) Spatial and temporal planning of forest land use in the landscape is crucial for the use and delivery of water from forests, as well as recognizing the role of different forest types in these aspects (natural/old growth, intermediate, and forest plantations).
- 5) Each landscape requires individual planning and analysis, integrating the biophysical effects with the societal and economic setting and possibilities for development.
- 6) In many developing tropical countries, conclusions 3) and 5) above demand development of both academic capacity for the development of an improved knowledge base, as well as the adaptation of institutions, models and tools for the specific region.
- 7) Conclusions 5) and 6) above are necessary to promote a common understanding of problems and processes to identify short term solutions and future visions.

- 8) Empowerment of local people, self-organised networks, and key organisations within watersheds are necessary for the development of policy in for the sustainable management of forest and water resources.

We can conclude, then, that facing the challenges of improving governance of complex social-ecological systems such as those characterising the provision and use of HES, requires modelling of scenarios to feed learning processes of the different stakeholders. This approach may promote a common understanding of the problems and the identification of possible alternative solutions.

Furthermore, a shift is needed in the way that policy-making is accomplished; moving away from the government lead top-down approach to the empowering of key organisations in self-organised networks that already exist in many watersheds. Indeed, key organisations in networks can help to bridge gaps between different sectors and scales.

To meet the increasing demands for water for social and economic development, both governance and biophysical tools and their integration need to be developed. This means there is a need to build academic capacity in tropical countries, both to support forest and water management nationally and regionally, and to produce more empirical knowledge for proper modelling of the effects of various land-use scenarios on water resources.

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