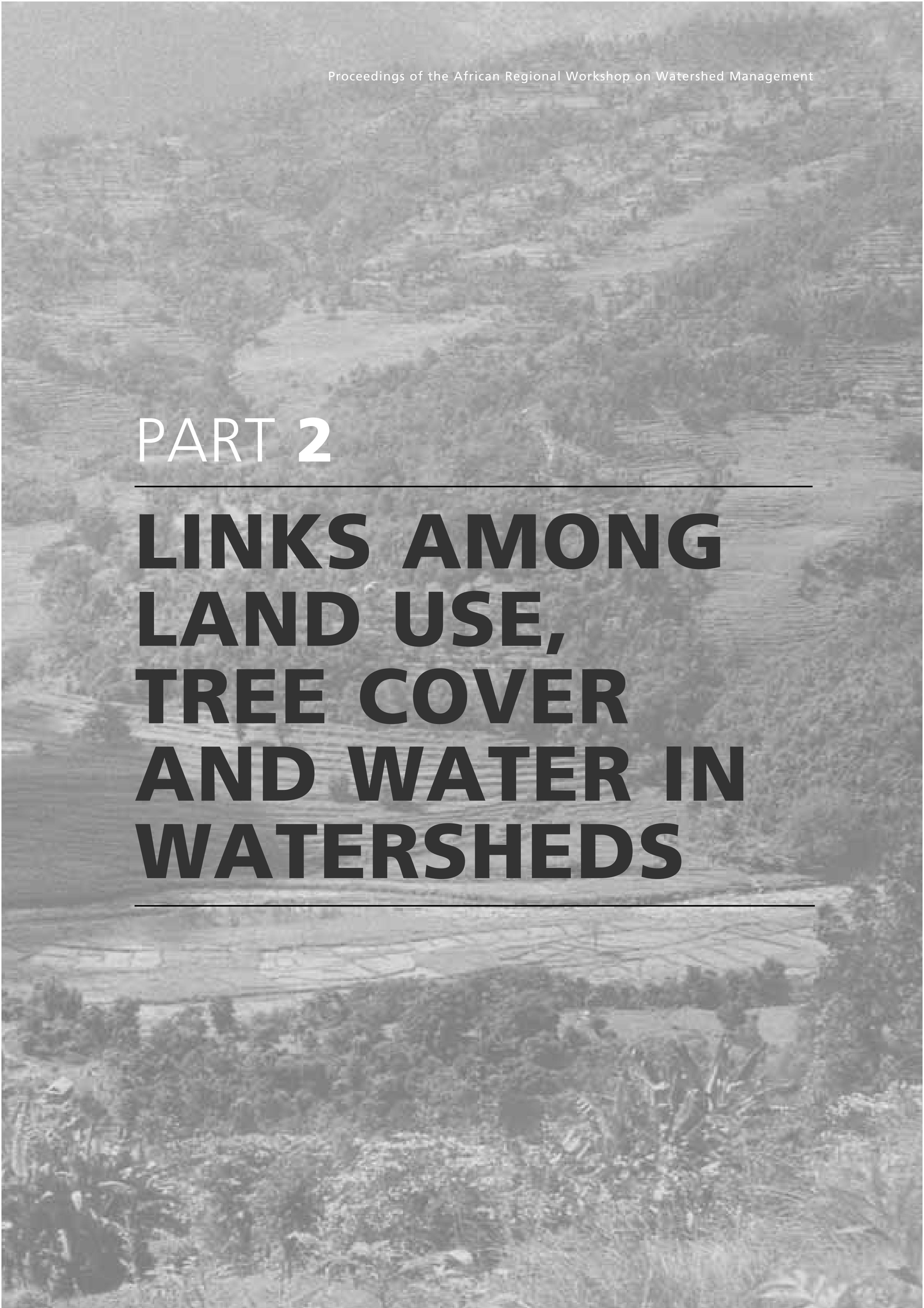

# PART **2**

# LINKS AMONG LAND USE, TREE COVER AND WATER IN WATERSHEDS

# CHAPTER 3
# LAND–WATER RELATIONSHIPS IN RURAL WATERSHEDS

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Some forms of land use have a negative impact on the availability and quality of water resources. Sustainable land-use practices can reduce or mitigate this negative impact, and justify the need for a watershed approach in which considerations of water resources are adequately addressed in terms of land use.

The Land and Water Development Division of FAO has recently embarked on a programme to develop and promote instruments and mechanisms to share benefits and costs arising from upstream land use in rural watersheds. The programme has four main elements:

- improving understanding of land–water relationships in rural watersheds;
- collecting evidence through case studies on impact valuation and watershed cooperation mechanisms;
- developing guidelines for use at the decision-making and technical levels;
- disseminating findings through policy guidance, technical assistance, seminars, etc.

Preliminary results of the programme and the case studies used in preparation of this report can be accessed on the Internet at: www.fao.org/ag/agl/watershed.

This paper presents a review of current practices and knowledge on land-use practices related to water protection, and reviews the need for further research and knowledge synthesis and dissemination, as well as the implications in terms of watershed management policies.

## THE PROBLEM

It is usually admitted that land use has an impact on the hydrological regime and quality of water downstream. The relative importance of such impact varies with the type of land use, the size of the watershed, climate, soil characteristics, topography, geology, etc., and is well documented (Bosch and Hewlett, 1982; Bruijnzeel, 1990; Calder, 1999). Yet, in the past, the relative importance of all these factors and the need to consider the specificities of each situation have not been fully understood by the public and decision-makers, leading to misconceptions about the main causes of floods and droughts in particular. The media, some NGOs, government officials, and in some cases even scientists have often convinced the public that deforestation is among the main causes of changes in water regimes, leading to increased floods and reduced dry season flows in rivers. Many agencies have funded conservation and reforestation programmes in response to these concerns (Kaimowitz, 2004).

A better understanding of the factors determining these impacts is needed in order to avoid misleading generalizations. Valuing of these impacts is also required in order to assess the potential for developing mechanisms to share benefits and costs between upstream and downstream water users. Several types of sharing or compensation mechanisms are possible, and a review of current experience and practices is needed to assess their potential.

This study is based on the following three assumptions:

- In watersheds, there is a distinction between on-site and off-site impacts of land-use practices.
- Land users in upstream watersheds tend to adopt practices that optimize their return.
- In the absence of upstream–downstream cooperative mechanisms, land users will seek to optimize direct (on-site) benefits only.

As we will see in the following, these assumptions are important to understanding the potential and limitations of watershed management approaches when seen from a downstream perspective.

## BIOPHYSICAL IMPACTS OF LAND USE ON WATER

A large number of experiments and surveys have been conducted in the past 40 years, particularly in the field of forest hydrology. Comprehensive reviews of these experiments have been provided by Bosch and Hewlett (1982), Calder (1999) and Bruijnzeel (1990; 2004) for moist tropical forests. In particular, studies have focused on the impact of land use (especially forest cover) on rainfall pattern, river runoff, floods and low flows, sediment transport and water quality. These impacts are reviewed briefly in the following.

### Impact of forest cover on rainfall

For a long time scientists have been looking for evidence of the positive impact of forest cover on rainfall, but research on how forest cover affects rainfall remains inconclusive (Kaimowitz, 2004). The higher evaporation rate and greater aerodynamic roughness of forests compared with agriculture and pasture lead to increased atmospheric humidity and moisture convergence, but so far observation of enhanced rainfall in forested areas could not be attributed to forests themselves. Orographic effects and the impact of trees on the way rain gauges capture rainfall explain the observed differences (Bruijnzeel, 2004). For the moment, one cannot discard the possibility that land-use change can cause significant changes in rainfall patterns. The discussion is not made easier by the fact that rainfall is highly variable in space and time. In conclusion, the impact of forest cover on precipitation, if proven, seems to remain marginal compared with other factors responsible for rainfall variability, short- and long-term cycles and climate change. Clearly, in this field, natural factors (and possibly climate change) have a much more important impact on rainfall than any possible change in land use.

### Impact of land-use change on the hydrological regime

Changes in land use may have an impact on the hydrological regime of a river basin. In some cases, the impact is evident. Forest clearing, for instance, has an impact on the infiltration rate and recharge of aquifers. In many other cases, however, the relation between land use and the hydrological regime is not so clear. A debate still exists, for instance, on the impact of wetland management on flow regimes: some research tends to prove that it has a negative impact (increased peak flows, reduced base flow), while other research notices an increased water storage capacity, leading to reduction in peak flow (Bullock, 1992).

Research shows that land use affects the infiltration of water into the soil, and any change in land use that compacts the soil or diminishes porosity will increase runoff and peak flow during rainfall events and, arguably, flooding (Kaimowitz, 2004). However, such findings hold mostly for small areas. At the large scale, the extent, intensity and distribution of the storm effect are likely to have a much larger impact on runoff than land-use change is. Most studies attempting to relate large-scale flooding events with land-use change have remained inconclusive.

In the forestry community, the tendency has often been to isolate forests from other types of land use and to assess the impacts of forested land on the hydrology of watersheds. In most cases, questions related to the improvement or conservation of a river's hydrological regime cannot be expressed only in terms of extent of forest cover, and a much more comprehensive approach is needed. In a downstream perspective, all types of land use need to be considered, including forested land, rangeland, agricultural land, urbanized areas, roads and badlands.

Another tendency among foresters is to take for granted the positive role of forests in terms of water resources and to ignore any possible negative implications. While it is clear that a good vegetative cover contributes to stabilizing the land and reducing the erosion of rainfall, forested land also shows significantly higher evapotranspiration rates than rangeland or agriculture, leading to an overall reduction in the amount of water available in rivers. Where water resources are scarce, countries increasingly tend to consider forests as a water user and consider afforestation programmes as part of their integrated water resources management plans (Gallart and Llorens, 2001).

Forest operations can also play a significant negative role in the hydrology of small watersheds. Forest roads are considered to be among the most dangerous types of land disturbances in terms of erosion, and the way forest exploitation is conducted can have devastating impacts on soil and erosion.

### Erosion and sediment load of rivers

Everyone agrees that sedimentation can adversely affect reservoirs, waterways, irrigation systems and coastal zones. A change in the sedimentation load of a river can also affect the river's biology and have implications in terms of fish production or biodiversity.

While there is a relation between the rate of erosion and the amount of sediment transported by the rivers, this relation is far from being simple. Erosion and sediment transportation are a natural process and vary widely, according mainly to the geology and climatic conditions. At the farm level, there is clear evidence that land-use practices can have a significant impact on the rate of erosion, either positively or negatively. Changes in land cover, from forest to agriculture for instance, usually induce an increase in soil erosion. On the other hand, good agricultural practices can substantially reduce the erosion hazard.

However, the impact of such land-use practices on the overall sediment yield of river basins is very difficult to assess. It is generally admitted that the bulk of sediment load of rivers originates from specific locations within the watershed, and that most of the sediments are brought into the river during extreme climatic events. In addition, research has shown that the routing time of sediments inside a river basin is relatively slow, and that over the life span of a reservoir very few sediments of the upper watershed travel more than 100 to 200 km. Thus, the impact of land-use practices on the sedimentation rate at one point in a large river, if any, will be felt only several decades later. A major difficulty consists in distinguishing between natural and human-induced sediment load.

### Chemical and organic water pollution

In regions of intensive agriculture, inappropriate application of fertilizers and pesticides may result in parts of these chemicals being washed out of the field and sent to the rivers or aquifers, where their concentration may cause pollution problems for water users downstream. Although rather localized in nature, cattle feedlots, which are now recognized as a major cause of pollution, are also usually considered as non-point-source pollution, and are included in this category.

The category of non-point-source pollution is usually the easiest to assess as it introduces radical changes to the chemical composition of the water. However, the complexity of the degradation process of some chemicals, mostly pesticides and toxic trace elements, combined with measurement problems, represents a serious constraint to the quantitative assessment of this sort of pollution. Non-point-source chemical and organic pollution of water resources are mostly concentrated in industrialized countries, but an increasing number of regions in developing countries where intensive agriculture is practised are faced with similar problems. As is the case, for instance, in peri-urban or commercial agriculture.

In all cases (impact on rainfall, flow regime, sediment load and chemical pollution), the relation between land use and its impact on water degradation is complex and not straightforward. While processes can be described in general terms, as they are presented above, each case is unique. Assessing and quantifying the impact of land use on water quality in a given river requires a thorough analysis of the situation and a clear understanding of the physical processes.

The type of problem, the scale of the watershed, the distinction between natural and human-induced hazard, the chemical processes, and the distinction between point-source and non-point-source pollution are all elements that need to be fully understood in order to ensure that adequate response be given to a specific problem. Some myths that have been used to justify watershed management programmes clearly need to be revisited.

### Scaling up non-linear processes

Scale is probably the most important parameter in assessing the impact of land use on water. Table 1, drawn from a review of numerous case studies, is an attempt to classify the potential impact of land use on different aspects of water regime and quality as a function of basin scale. It was discussed during the electronic conference on land–water linkages in rural watersheds organized by FAO in 2000 (FAO, 2002). Only in very small watersheds can we expect to see a significant impact of land use on water regime and water availability. This is owing in large part to the variability of the hydrological regime of watersheds, due to variable precipitations. Sediment load, for instance, will depend much more on the intensity of extreme rainfall events than on land use. As the size of the watershed increases, the impact of land use on most of the characteristics of the hydrological regime becomes insignificant compared with that of natural factors. On the other hand, the impact of land use on water quality can be observed at larger scales. Cumulative effects of pollution, for instance, can result in an impact that can be observed even in large river basins.

TABLE 1
**Potential impact of land use on aspects of river regime**

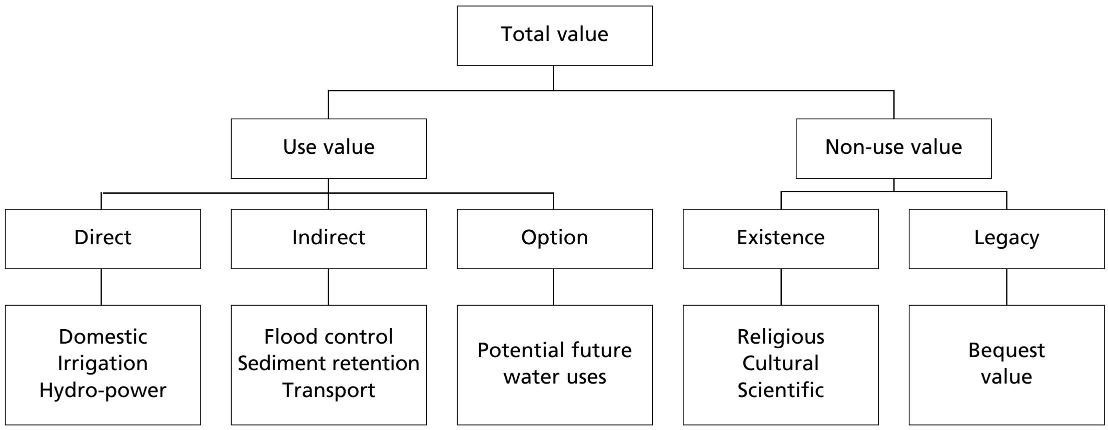
| OBSERVABLE IMPACT OF LAND USE ON: | WATERSHED SIZE (km²) | | |
|---|---|---|---|
| | Small (0.1–10) | Medium (10–100) | Large (100 and greater) |
| Average flow | X | - | - |
| Peak flow | X | - | - |
| Base flow | X | - | - |
| Groundwater recharge | X | - | - |
| Sediment load | X | - | - |
| Pathogens | X | - | - |
| Nutrients | X | X | X |
| Salinity | X | X | X |
| Pesticides | X | X | X |

## VALUING THE IMPACTS OF LAND USE

Valuing the impact of land use implies the capacity to value water. While it is practically impossible to assess the full value of water, as it implies considerations of value judgement – particularly on the non-use values of water (existence, legacy, see Figure 1) – it is relatively easy to assess the value in terms of use of water, in particular domestic uses, irrigation and hydropower.

The most frequent cases of valuation of water are those related to domestic water use of hydroelectricity. In the Sao José watershed in Brazil, a problem arose when suspended sediments and chemicals from agriculture led to excessive treatment costs. Through negotiation with farmers, a decision was taken to adopt improved agricultural practices: soil conservation measures, and the introduction of no-tillage and organic farming. The reduction of treatment cost was estimated at US$2 500 per month. A total investment of $103 000 was proposed, which would be paid off in four years (Bassi, 2002).

FIGURE 1
**Assessing the value of water**




## MECHANISMS TO SHARE BENEFITS AND COSTS OF LAND USE

Mechanisms are needed to link upstream land users with downstream water users. Several options are possible. *Payment for watershed services* (FAO, 2004a) is a subset of the principle of payment for environmental service, by which a value is assigned to some types of land use in a watershed where beneficiaries can easily be identified (as in the case of the Sao José watershed described above). Other mechanisms include incentives, technical advice, agreements on the marketing of agricultural products, etc. Of interest to many farmers, particularly in Latin America and southeastern Asia, is the possibility of providing land titles or land-use rights in exchange for the adoption of sustainable land-use practices in watersheds.

## IMPLICATIONS FOR WATERSHED MANAGEMENT PROGRAMMES

Watershed management has evolved with time, from a purely natural resources management approach (essentially top-down) to a community development approach in which people's participation is at the centre of the planning and development process. In the former approach, emphasis was put on the management of land, soil and water conservation, and on afforestation. The watershed was a logical planning unit, as erosion and sedimentation control was considered an important objective of the programmes. Such programmes have been successful, particularly in areas with low population density and where important and valuable infrastructure downstream of the treated areas required protection. They were usually associated with structural interventions (dykes, check dams, etc.) and are still valid today.

Such approaches, however, are not adapted to areas with substantial population density, where conservation requires meeting the needs of local populations. In such cases, to be successful, any attempt to improve the management of natural resources needs to satisfy the immediate and mid-term needs of the population of the watersheds. Community watershed development programmes have shown the need to adopt a participatory approach, empowering local populations, developing local capacity and institutions, and fostering cooperation among resources users.

As a result, watershed management programmes evolved from an approach where the focus was mainly on natural resources conservation to an approach with the focus on people's priorities. One major implication of this shift in priorities is that the beneficiaries of watershed management activities are the farmers themselves (on-site benefits), rather than the downstream populations (off-site benefits). The watershed boundaries become less relevant as planning units (except in cases where micro-watersheds correspond to a social division of the landscape) and are replaced by a socio-administrative division of the land that is of greater relevance to the local population. The downstream impact of watershed management programmes becomes therefore much less relevant.

## CASE STUDY: GALLITO CIEGO, PERU

The case of Gallito Ciego watershed in Peru shows how a good impact assessment can positively influence investments in watershed actions and avoid non-productive actions. A hydroelectric dam was built on the river, with a storage capacity of 573 million $m^3$ for a watershed area of 3 480 $km^2$. Annual rainfall varies in the watershed between 40 and 1 300 mm, and average runoff is 816 million $m^3$/year. After construction of the dam, a problem of rapid siltation of the reservoir appeared, threatening the investments and hydroelectric potential. One of the possible options that were considered was to invest in soil and water conservation actions to reduce the rate of siltation of the reservoir. However, a careful study of the land-use situation in the watershed showed that such an option would not be feasible for the following reasons:

- On the watershed scale, cultivated land was relatively small, and improvement in agricultural land use would have had no significant effects on erosion and sediment transport.
- Most sediment transport occurred during extreme climatic events.
- The area of most severe erosion was beyond human control.

The study concluded that any attempt to reduce reservoir sedimentation could only be successful if it focused on structural measures in the river bed (check dams, riverbank protection), and that there would be little scope for watershed management activities (FAO, 2004b).

## CONCLUSIONS

Good land husbandry practices are a key ingredient to the sustainable management of natural resources in rural watersheds. Their impact on the hydrological regime and quality of water downstream may be significant, and deserves careful attention. However, care should be taken to avoid generalization about the impact of land use on water. In particular, misconceptions of the role of forests and the link between erosion and sedimentation may lead to ineffective investments in watersheds.

Watershed management programmes must be considered as one element of water conservation strategies. Land use may not have a significant impact on water downstream, particularly when dealing with problems of sedimentation or floods. In such cases, and based on estimates of the value of the services they provide, structural measures may be required in the watershed.

In other cases, watershed management programmes involving land users can be justified on the basis of downstream benefits. The impact of land use on water can have significant downstream benefits or costs, particularly regarding water quality and downstream users' drinking-water facilities. In such cases, it could be worth investigating mechanisms that explicitly recognize this upstream–downstream linkage and allow downstream users to provide upstream land managers with some sort of compensation for good land-use practices.

In many cases, it is impossible to assess the total value of water-related services, in part because of the difficulties in assessing non-use values. The easiest cases are those related to the need to treat water for drinking purposes, for which a number of examples exist of agreements between water utilities and land users upstream (Landell-Mills and Porras, 2002; FAO, 2004a). In other cases, companies using water downstream may be interested in being portrayed as environmentally conscious, providing incentives or subsidies to land users in watersheds, even in the absence of clear links between land use and water.

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# CHAPTER 4
# WATERSHED MANAGEMENT– CAN WE INCORPORATE MORE EVIDENCE-BASED POLICIES?

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## ACRONYMS

| | |
|---|---|
| **CAMP** | Catchment Management and Poverty Alleviation (project) |
| **CLUWRR** | Centre for Land Use and Water Resources Research |
| **DFID** | Department for International Development, United Kingdom |
| **FAWPIO** | Forest and Water Policy – Improving Outcomes |
| **IIT Delhi** | Indian Institute of Technology |
| **IRC** | International Water and Sanitation Centre |
| **IWMI** | International Water Management Institute |
| **IWRM** | Integrated Water Resource Management |
| **NFPP** | Natural Forest Protection Programme |
| **NGO** | non-governmental organization |
| **NRI** | Natural Resources Institute |
| **SFA** | State Forestry Administration |
| **SFRA** | stream flow reduction activity |
| **SLCP** | Sloping Land Conversion Program |
| **WfW** | Working for Water |

Unsound land and water (and power) policies are arguably wasting billions of dollars of development funds on unachievable targets (see Box 1). The impacts are worldwide and of a massive scale. Solution will require confronting complex and messy real-world situations and recognizing that land and water policies and practices at the international, national and local levels are generally driven, dominated and exploited by the vested interests of sectoral, powerful and wealthier groups: government departments, departments and divisions of international and national development organizations, non-governmental organizations (NGOs), the research community, and industry.

BOX 1

**ROOT OF THE WATER PROBLEM**

In his article on the world's water problems ("Ten questions the west must answer", *$H_20$* supplement, 23 August), John Vidal writes: "If we learned not to cut down forests, we'd find that there was more water for everyone." This illustrates a widely held misconception, which is arguably leading aid organizations to waste billions of dollars on afforestation programmes.

Hydrological studies show that most forests will evaporate significantly more water than shorter vegetation, and reduce water for recharging aquifers or supplying rivers.

In countries such as South Africa, the true role of forests in relation to water is well understood. The South African Water Act, rather than promoting forests, effectively imposes a "stream flow reduction activities" tax on high water-consuming land uses such as plantation forestry and sugarcane.

In the United Kingdom, highlighted by Mr Vidal as one of the most water-stressed countries in Europe, the impact of forests is also becoming better understood. Both water and forestry interests now accept that upland coniferous afforestation will reduce annual stream flows by, typically, 20 percent.

In the lowlands of England, recent studies at Sherwood Forest indicate much greater impacts. Compared with grassland, oak forest will reduce long-term recharge by about 50 percent and pine forest by about 75 percent – under pines, only in a year of high rainfall (such as 2000) will the "water pulse" pass the root zone to reach the aquifer.

While there may be many reasons to promote forests, they need to be considered in relation to the adverse effects on water resources.

I. Calder, letter to *The Guardian,* 4 September 2003.

## POLICIES BASED ON MISPERCEPTIONS

Examples of policies based on misperceptions may include the following.

***Southeast Asia:*** Possibly half a million livelihoods have been lost because of logging bans imposed on the basis of myth-based perceptions of forest and flood interactions.

***India:*** Watershed development projects that were implemented with unsound understanding of land and water interactions are resulting in perverse outcomes: for poorer people, less access to water from common property water pans; unsustainable rates of groundwater depletion; and catchments reaching closure with serious downstream and environmental impacts.

***China:*** Afforestation under the Natural Forest Protection Program (NFPP) and the Sloping Land Conversion Program (SLCP) has been driven and promoted by the State Forestry Administration (SFA) partly on the basis of what could be regarded as very optimistic perceptions of the benefits of forests to the water environment. These programmes may again be leading to perverse outcomes: detriment to rural livelihoods, disadvantage to minority ethnic groups, reduced downstream and transnational water flows and reduced food production (Calder, forthcoming). Li Zibin, Vice-Minister of China's National Development and Reform Commission states that "…China had reconverted 7.86 million ha of farmland to woods, and planted trees on 11.33 million ha of bare hills and land between 1999 and the end of 2004" (*China Daily*, 2004). In this period, China's grain production fell from 512.3 million to 430.7 million tonnes. Although other factors may be affecting grain yields, the removal of 7.86 million ha of farmland is clearly a massive land-use change for any country, and must surely be a significant factor in the reduced grain production in China.

***India:*** Power policies in India, where farmers receive subsidized or free electricity, have led to situations where there are no economic controls on groundwater pumping for irrigation. Water tables are exceeding 200 m depth in some states, preventing poor people from obtaining access to groundwater through handpumps and forcing them to buy water from tankers.

A big challenge (problem or opportunity) for the development community now is how to implement IWRM concepts in a wider resource management context where there are:

- increasingly severe and conflicting demands on the land and water resources to supply food, water and timber, together with conservation, amenity, recreation and environment products;
- sectoral conflicts among the water, land, power generation and irrigation sectors;
- concerns that upstream management of land and water in watershed development projects generally ignores downstream impacts, particularly transnational and coastal interests.

Implementation of the well-meaning IWRM concepts will require confronting the complex and messy real-world situation in which it is important to recognize that land and water policies and practices at the international, national and local levels are generally driven, dominated and exploited by the vested interests of sectoral, powerful and wealthier groups, often at the expense of the poorer segments of society.

## THE SCIENCE PERCEPTION AND FUTURE RESEARCH NEEDS

Two of the many myths or conventional wisdoms relating to forestry and water (see Hamilton, 1987; Hamilton and King, 1983; Bruijnzeel, 1990; Calder, 1998; 1999; 2002; 2004) are reviewed here as a means of investigating the disparity between the "science" and the "public" perceptions and to identify the remaining gaps in our knowledge. The "conventional wisdoms" considered are:

- forests increase runoff;
- forests regulate flows.

**Forests increase runoff?**

In recent years, a new understanding has been gained of evaporation from forests in dry and wet conditions based on process studies. These studies, and the vast majority of the world's catchment experiments, indicate decreased runoff from areas under forests as compared with areas under shorter crops.

The studies indicate that in wet conditions interception losses will be higher from forests than shorter crops, primarily because of increased atmospheric transport of water vapour from their aerodynamically rough surfaces.

In dry (drought) conditions the studies show that transpiration from forests is likely to be greater because of the generally increased rooting depth of trees as compared with shorter crops, and their consequent greater access to soil water.

Thus, in both very wet and very dry climates, evaporation from forests is likely to be higher than that from shorter crops. Consequently, runoff will be decreased from forested areas, contrary to widely accepted myths.

The few exceptions that lend some support to the myth are:

- cloud forests, where cloud-water deposition may exceed interception losses;
- very old forests; Langford (1976) showed that following a bushfire in very old (200 years) mountain ash, *Eucalyptus regnans,* forest covering 48 percent of the Maroondah catchment – one of the water supply catchments for Melbourne in Australia – runoff was reduced by 24 percent. The reason for this reduction in flow has been attributed to the increased evaporation from the vigorous regrowth forest that had a much higher leaf area index than the former very old ash forest.

***Conclusion:*** Notwithstanding the exceptions outlined above, catchment experiments generally indicate reduced runoff from forested areas as compared with those under shorter vegetation (Bosch and Hewlett, 1982).

***Caveat:*** Information on the evaporative characteristics of different tree species/soil type combinations is still required. In both temperate and tropical climates, evaporative differences among species and soil types are expected to vary by about 30 percent.

**Forests regulate flows/increase dry season flows?**

Although it is possible, with only a few exceptions, to draw general conclusions with respect to the impacts of forests on annual flow, the same cannot be claimed for the impacts of forests on the seasonal flow regime. Different, site-specific, often competing processes may be operating, and the direction, let alone the magnitude of the impact, may be difficult to predict for a particular site.

From theoretical considerations it would be expected that:

- Increased transpiration and increased dry period transpiration will increase soil moisture deficits and reduce dry season flows.
- Increased infiltration under (natural) forest will lead to higher soil water recharge and increased dry season flows.
- For cloud forests, increased cloud-water deposition may augment dry season flows.

There are also observations (Robinson, Moore and Blackie, 1997) indicating that for the uplands of the United Kingdom, drainage activities associated with plantation forestry increase dry season flows, both through the initial dewatering and – in the longer term – through alterations to the hydraulics of the drainage system.

Observations from South Africa indicate that increased dry period transpiration reduces low flows. Bosch (1979) demonstrated from catchment studies at Cathedral Peak in Natal that pine afforestation of former grassland not only reduces annual stream flow by 440 mm, but also reduces the dry season flow by 15 mm. Van Lill, Kruger and Van Wyk (1980), reporting studies from Mokobulaan in the Transvaal, showed that afforestation of grassland with *Eucalyptus grandis* reduced annual flows by 300 to 380 mm, with 200 to 260 mm of the reduction occurring during the wet summer season. More recently, Scott and Smith (1997), analysing results from five of the South African catchment studies, concluded that percentage reductions in low (dry season) flow as a result of afforestation were actually greater than the reduction in annual flow. Scott and Lesch (1997) also report that on the Mokobulaan research catchments under *Eucalyptus grandis,* the stream flow completely dried up by the ninth year after planting. The eucalypts were clear-felled at age 16 years, but perennial stream flow did not return for another five years. They attribute this large time lag to very deep soil moisture deficits generated by the eucalypts, which require many years of rainfall before field capacity conditions can be established and recharge of the groundwater aquifer and perennial flows can take place.

Studies in India draw similar conclusions. Sikka *et al.* (2003) investigated the impacts on both flood flows and low flows of converting natural grassland to eucalypt plantation in the Nilgiris region of south India. The detailed and long-term (1968 to 1992) paired catchment experiments in the Nilgiris, where the responses from a control catchment under natural grassland were compared with those from a catchment with 59 percent eucalypt cover, which were monitored over a period encompassing two rotations of the eucalypt crop, indicate very significant reductions in low flows during the dry season. Expressed in terms of a "low flow index" (defined as the ten days average flow being exceeded for 95 percent of the time of the flow record), the low flows were reduced by approximately one half during the first rotation, and by one quarter during the second rotation of the eucalypt crop.

Bruijnzeel (1990) discusses the impacts of tropical forests on dry season flows, and concludes that the infiltration properties of the forest are critical in how the available water is partitioned between runoff and recharge (leading to increased dry season flows).

***Conclusions:*** Competing processes may result in either increased or reduced dry season flows. Effects on dry season flows are likely to be very site-specific. It cannot be assumed that it is generally true that afforestation will increase dry season flows.

***Caveat:*** The complexity of the competing processes affecting dry season flows indicates that detailed, site-specific models will be required to predict impacts. In general, the role of vegetation in determining the infiltration properties of soils, as it affects the hydrological functioning of catchments through surface runoff generation, recharge, high and low flows, and catchment degradation, remains poorly understood. Modelling approaches that are able to take into account vegetation and soil physical properties, including the conductivity/water content properties of the soil and possibly the spatial distribution of these properties, will be required to predict site-specific impacts.

## EXAMPLES OF ONGOING RESEARCH ON THE ROLE OF FORESTS AND WATER

Two examples are given of ongoing interactive research in South Africa and India that are addressing questions of policy related to land-use change involving forestry and the water environment. Interactive, in this context, implies that the eventual users, or stakeholders, of the research interact closely with the researchers in both the design stage (by helping to define the objectives of the research and ensuring that the necessary resources are mobilized) and the implementation phase (by monitoring and steering the research programme). Experience of using this model for the management of applied environmental and hydrological research programmes has shown that it has a number of benefits:

- The users, through close involvement with all phases of the research, assume ownership of the programme, and are more likely to both "believe in" and take up eventual research findings.

- Best use is made of existing knowledge and data resources by building on the collective resources of all the stakeholders.

- The interaction between users and researchers through stakeholder group meetings not only facilitates linkages and information flows between the users and the researchers, but also facilitates linkages and information flows among the users themselves. This in itself has often been seen as an important output of the interactive research programme. Increasingly, it is being recognized that successful integrated land use and water resources management requires not only a sound science base, but also understanding, commitment and collaboration among the different organizations responsible for and affected by integrated management.

- The formation of a representative stakeholder group with a diversity of interests and perspectives is more likely to achieve the ultimate goal of integrated land-use and water resources management by ensuring that all aspects of development affecting water resources, basin economics, ecology/conservation, socio-economics and the sustainable livelihoods of basin inhabitants are considered and represented.

It is also believed that if stakeholder groups can be formed with representatives comprising both the science and the public perceptions this may, through a process of "action learning", provide a means of reconciling disparate views.

The two examples considered in the following subsections demonstrate the continuing need to improve our understanding of the biophysical linkages between forests and the water environment, particularly in relation to the impacts on seasonal flows. These examples also illustrate the different degrees of "connectivity" between science and policy in the different countries.

**South Africa, Catchment Management and Poverty Alleviation (CAMP)**

The Government of South Africa has recognized that not only is there usually a high cost in terms of lost water associated with fast-growing commercial plantations, but there may also be dangers associated with "escaping" plantation trees. The government is addressing these issues through policy instruments that include legislation and government-funded programmes:

- The National Water Act (Government of South Africa, 1998) declared commercial forestry as a "stream flow reduction activity" (SFRA) and, as such, requires that it is managed through the issuing of water-use licences and is subject to water resources management charges.
- The multi-billion rand Working for Water (WfW) programme (DWAF, 1996) is being implemented for the control and eradication of alien invading tree species. The expectation is that without this programme the invaders would eliminate indigenous plant species and seriously reduce water resources. The programme also has a major poverty alleviation component, through specifically targeting the poorest in society for employment.

The SFRA legislation and WfW programme highlight a number of issues relating to forest and water management; these issues are probably not specific to South Africa. They include how to devise and implement forest and water policy instruments, such as SFRA and WfW, which will meet the requirements of integrated water resources management (water resource, basin economics and conservation) while also meeting the demands of major international and donor organizations (such as the World Bank and the United Kingdom's Department for International Development [DFID]) that policies should have an equity dimension and support and enhance (particularly the poorest) people's livelihoods.

These questions are being addressed within the Catchment Management and Poverty Alleviation (CAMP – Figure 1) project, which is supported by DFID in South Africa, the United Republic of Tanzania and Grenada, under the direction of a stakeholder group comprising forest, water and poverty interests: members from both United Kingdom and South African universities and research institutes, the South African Department for Water Affairs and Forestry, the WfW programme and an NGO. The South African focus of the study was chosen to be the Luvuvhu catchment in Limpopo province, which drains into the Limpopo River at the border with Zimbabwe and Mozambique (Figure 2). The Luvuvhu catchment illustrates the acute problems posed for water- and land-use management related to forestry activities: there is potential for a considerable increase in the area of commercial forestry, it is currently affected by alien invader tree species, it is water-short, and it has high levels of poverty.

The project is investigating how different scenarios of forest cover, which may result through application or non-application of WfW and SFRA instruments, will affect the hydrological regime and water availability, which will, in turn, affect economic production and people's livelihoods. The linkage between water availability and people's livelihoods has been assessed through a survey carried out at a number of communities (Figure 2).

FIGURE 1

**The CAMP project is investigating how two forest and water-related policy instruments, the WfW programme and the charging of landowners for SFRAs, will affect water resources, catchment-scale economics and livelihoods**

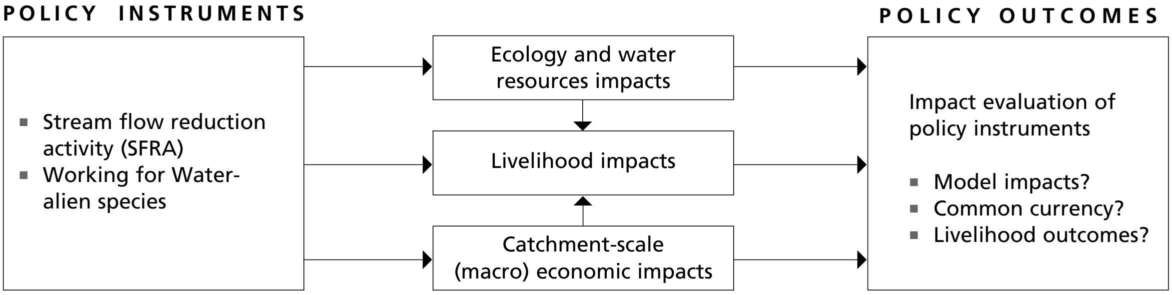
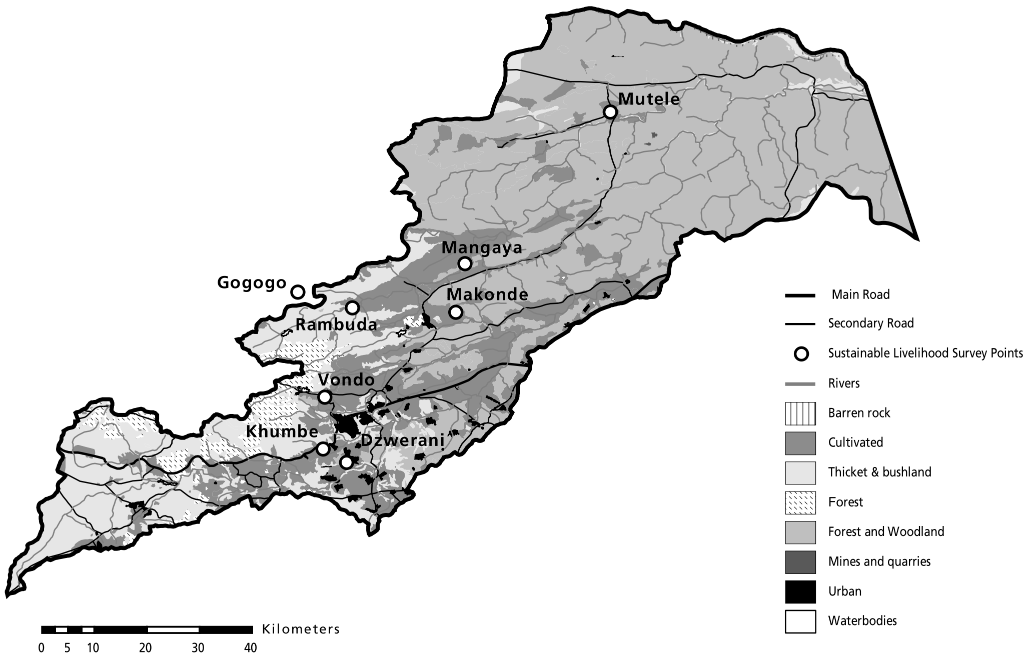



FIGURE 2

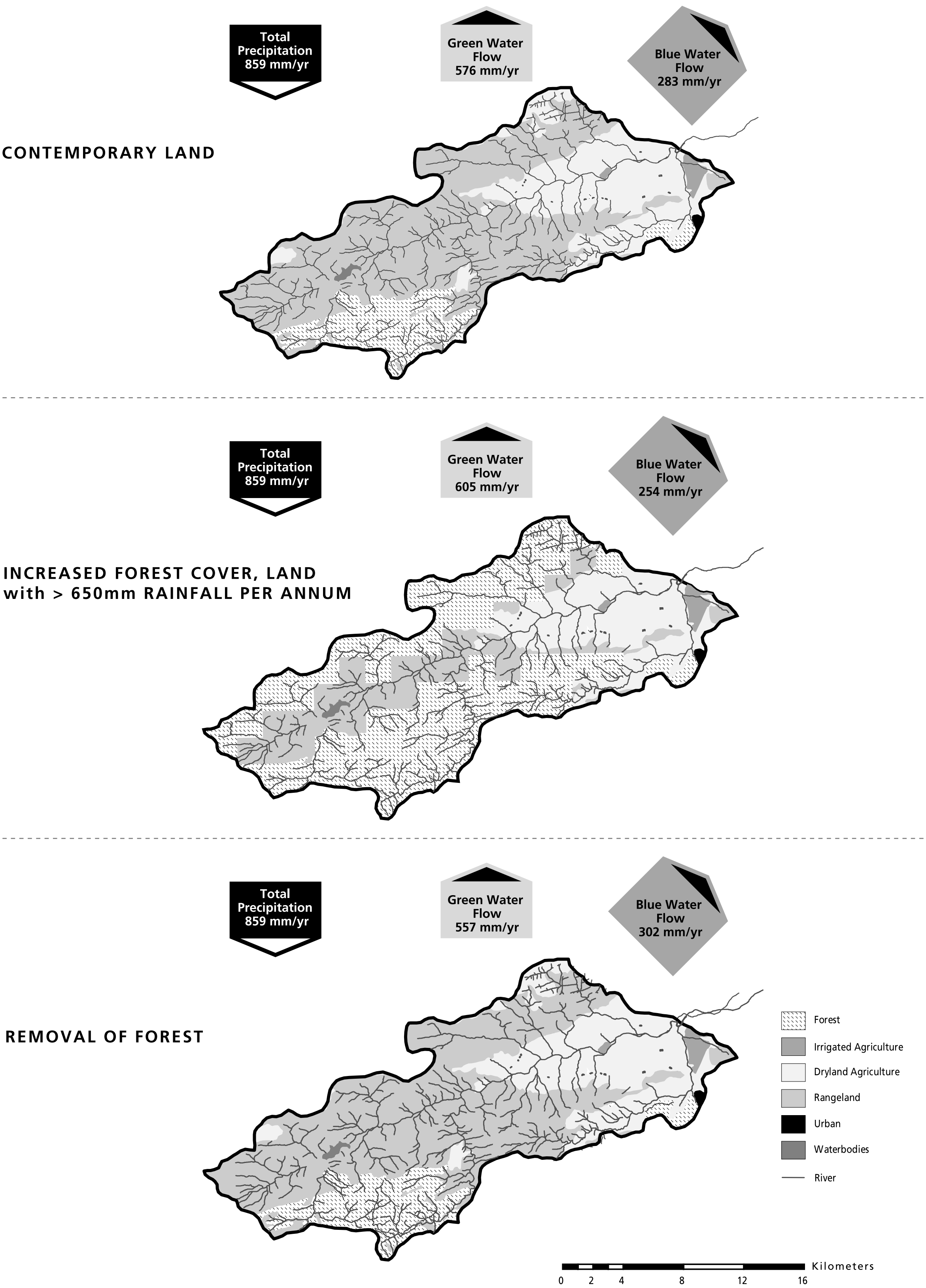
**Land use and communities where livelihoods assessment was carried out on the Luvuvhu catchment, Limpopo Province, South Africa**




Changes in river flow and evaporation as a result of changing land cover are being assessed through the use of two land-use-sensitive hydrological models, the Hydrological Land Use Change model (HYLUC – Calder, 2003) and the Agrohydrological modelling system (ACRU – Schulze, 1995). Both models have been used extensively in forestry-related studies (Calder, 1999; Jewitt and Schulze, 1999) and have been configured for use in the Luvuvhu. In these models, the nomenclature adopted by Falkenmark (1995; 2003) is used to highlight the role of land use in hydrological functioning, with respect to flow out of the catchment, termed "blue water", and evaporation, "green water" (Figure 3).

FIGURE 3

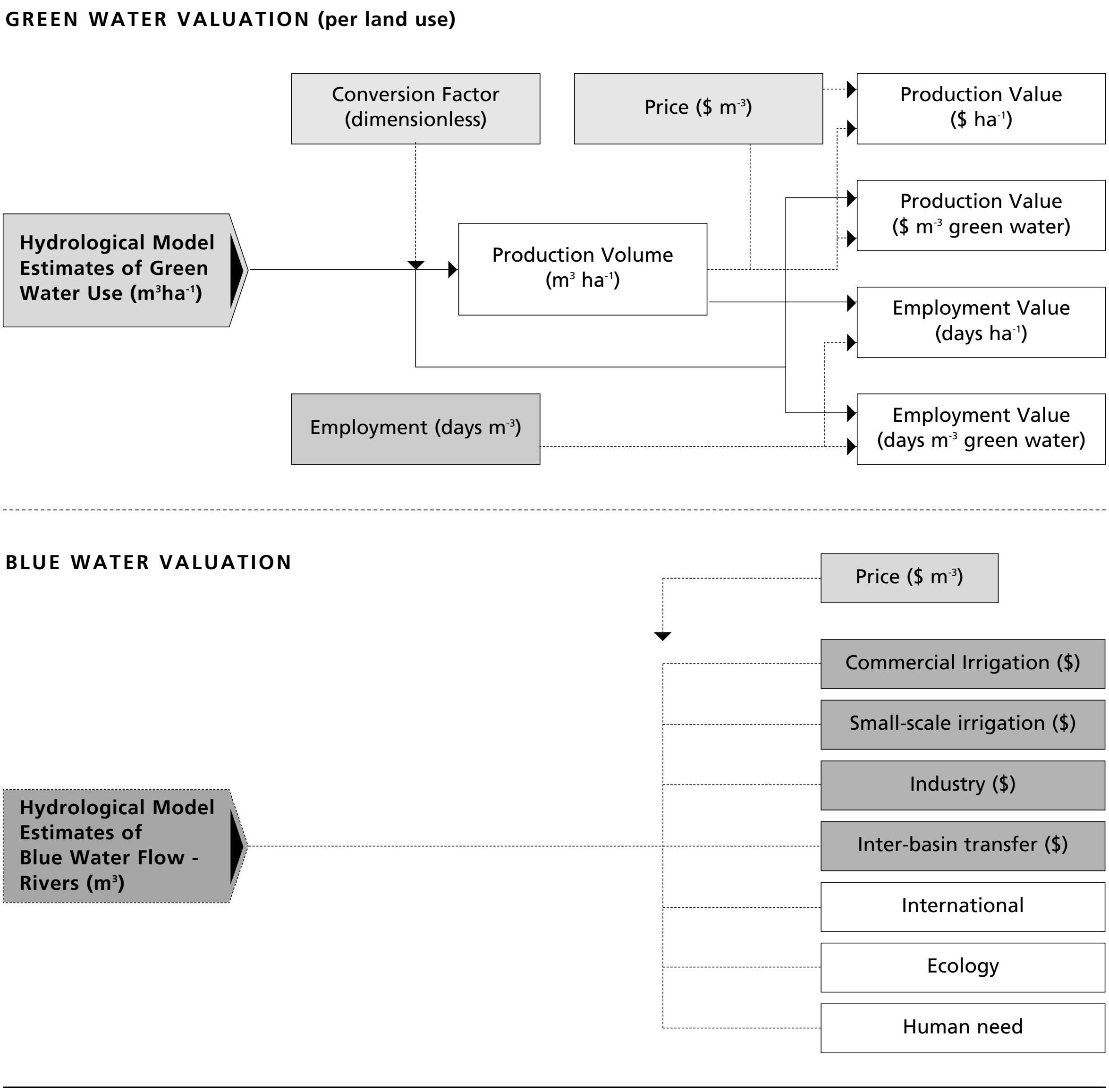
**Example of how changes in forest cover on the Tengwe subcatchment of the Luvuvhu affect green and blue water flows (expressed in units of depth of water over the catchment)**



A framework has been devised for understanding the linkages between water flows and the economic and livelihood values of water when it is used in its green or blue forms (Figure 4). This framework is currently being calibrated for the Luvuhu, and will be used to analyse the economic and livelihood benefits of the different forest cover scenarios (later studies will investigate combinations of different forest and irrigation scenarios).

FIGURE 4

**Framework for evaluating blue and green water flows in terms of production value and employment (surrogate for livelihood) value**



The analysis carried out so far has demonstrated a somewhat unexpected linkage, or rather lack of linkage, between water availability and livelihood benefit. The livelihood survey indicates no statistically significant relationship between poverty (calculated in terms of income rather than expenditure) and greater access to water (whether provided through reticulated supply or through being in a higher rainfall area). The implication, from the data available at present, is that provided the statutory provision of 25 litres of water per capita per day is being met, further provision of water will not greatly increase livelihood benefit. Evidence also suggests that while there may be food security gains from increased water provision (e.g. for irrigation of kitchen gardens), the poorest in society are less likely to benefit; wealthy households with greater access to home-based reticulated supplies will benefit most (Moriarty, Butterworth and Van Koppen, 2004; Hope and Gowing, 2003).

### India – Watershed development, forest and water policies

The public perception of the beneficial role of forests in relation to the water environment is very strong in India, and this is reflected in government policy. This public perception persists despite the many locally conducted scientific studies that present a different view (see e.g. Sikka *et al.*, 2003).

***Policy drivers:*** The Government of India has long recognized water as one of the most limiting resources to development. In 1987, a National Water Policy was published, and this has recently been renewed and updated (Government of India, 2002). A focus of this policy is on improving water supply to meet the identified water allocation priorities:

- drinking-water;
- irrigation;
- hydropower;
- ecology;
- agro-industries and non-agricultural industries;
- navigation and other uses.

The National Water Policy also promotes watershed management and increasing forest cover as a means of conserving water. Forestry is regarded as less water-demanding in drought-prone areas:

> 3.4 Watershed management through extensive soil conservation, catchment-area treatment, preservation of forests and increasing the forest cover and the construction of check-dams should be promoted. Efforts shall be to conserve the water in the catchment.
>
> 19.1 Drought-prone areas should be made less vulnerable to drought-associated problems through soil moisture conservation measures, water harvesting practices, minimization of evaporation losses, development of the ground water potential including recharging and the transfer of surface water from surplus areas where feasible and appropriate. Pastures, forestry or other modes of development which are relatively less water demanding should be encouraged. In planning water resource development projects, the needs of drought-prone areas should be given priority.

The Policy also recognizes the need for maintaining an information system on water:

> 2.1 A well developed information system, for water related data in its entirety, at the national/ state level, is a prime requisite for resource planning. A standardized national information system should be established with a network of data banks and data bases, integrating and strengthening the existing Central and State level agencies and improving the quality of data and the processing capabilities.

***Watershed development projects:*** Since the 1990s, some US$500 million per year have been spent on watershed development programmes (Kerr, 2002) that have the general aim of alleviating poverty by improving the quality and quantity of water resources. The water component of these programmes has mainly concentrated on improving water supply through the construction of new surface water reservoirs (usually termed "tanks" in India), or the desilting of existing tanks, and the construction of rainwater harvesting structures, e.g. check dams and contour bunding, which are designed to increase the recharge of water to aquifers. There is a limit to what can be achieved through "supply-side" measures. This limit is reached when surface and groundwater storage schemes, and the exploitation of water from these schemes, are such that there is no flow of water out of the catchment and the catchment becomes, using the International Water Management Institute's (IWMI) terminology, a "closed" system. Many catchments in India are already "closed" or rapidly approaching this state (see e.g. Batchelor, Rama Mohan Roa and James, 2000; James, 2002; Batchelor, Rama Mohan Roa and Manohar Rao, 2003).

As catchments approach closure, two dis-benefits are evident: the cost-effectiveness of engineering constructions reduces to nil; and flows out of the catchment, which may be required for ecological purposes and for the benefit of downstream users, are lost. When virtually all the resource is utilized, in this closure state, there can be no overall benefit obtained through the construction of more storage structures or more measures for increasing aquifer recharge. Upstream users can only capture waters at the expense of reduced availability to downstream users within the catchment. When supply-side options are exhausted, improvements in economic and livelihood benefits can only be achieved through higher-value usage of the existing, nearly fully utilized resource and improved "demand" management.

The beliefs of the rural development offices and NGOs entrusted with implementing these watershed development programmes – that irrigation, soil water conservation measures and forestry are all "good things", promoted by government policy, and that more will therefore necessarily be better for the watershed – may have contributed to the present state of affairs of near closure on some catchments. Large-scale promotion of these measures within watershed development projects without the promotion of a monitoring and water information system, as required by government policy, has meant that the detection and recognition of these adverse impacts have been slow or have not even occurred yet.

Clearly, it is important that the gap between the institutional and the science perceptions of the role of forests and water be closed, as considerable amounts of development funds are currently being expended in the erroneous belief that tree planting will increase groundwater recharge within watershed development projects (Calder and Gosain, 2003; Calder, forthcoming). Equally if not more serious is the concern that the present focus on forestry programmes for improving water resources may be diverting attention away from the more urgent need for increased demand management measures for controlling the abstraction of groundwater for irrigation use. In some southern Indian states, groundwater tables, which, perhaps three decades ago were within 10 m of the surface and accessible by hand-dug wells, now exceed 100 m.

A perverse outcome of many watershed development projects is that it is often the richer farmers, with access to boreholes with electric submersible pumps, who are benefiting (in the short term) from increased groundwater access. Poorer downstream villages that traditionally have relied on common property resources – water in the village tank and water from village hand pumps – have often been disadvantaged by both increased use of upstream soil and water conservation measures and structures that have resulted in less flow into the village tank. An unexpected outcome of the widespread promotion of these measures is that water that was previously regarded as common property, water in the village tank, is effectively being transferred into private property, the property of landowners, who benefit from the increased infiltration on their land through increased growth of their crops or forest and who can benefit from the increased groundwater recharge beneath their land by reaching it through boreholes with electrically powered submersible pumps. It is now recognized that in many parts of India the increased use of submersible pumps has lowered groundwater tables to depths that are in accessible to hand pumps. Local people who formerly had free access to groundwater through hand pumps are now having to purchase their water supplies from tankers. It would be expected that in these situations where, in contrast with South Africa, there is no per caput free right to water of any quantity, increased access to water by the poor in India would have major livelihood benefits.

At present, there is no effective demand management of groundwater abstraction for irrigation, and as electricity for farmers is either provided free or is heavily subsidized by the government, farmers have little incentive even to reduce the cost of pumping water. This has serious resource implications not only for water and lowering water tables but also for electricity production. Pumping water for irrigation from ever-increasing depths has led to groundwater pumping accounting for a major proportion of all the electricity generated in some southern Indian states.

The interactive research project that has been set up to address these issues with collaborators, government stakeholder departments and NGOs (including IIT Delhi, the Department of Science and Technology, Winrock International and state government departments and NGOs in Himachal Pradesh and Madhya Pradesh) was initiated in January 2003 and is expected to help close the gap between science and public perceptions.

## CONCLUSIONS

It is concluded that to move towards a reconciliation of the different perceptions and to put in place better policies and management systems, in which policy is better connected with science and which avoid perverse policy outcomes, further efforts will be required to:

- understand how the belief systems underlying the science and public perceptions have evolved within different stakeholder groups, and understand how these beliefs may be influenced to enable a more science-based policy development process;

- develop management support tools, ranging from simple dissemination tools that can demonstrate the impacts of land-use decisions on the water environment, to institutions and local people and to detailed, robust and defensible hydrological models that are needed to help implement the new land and water policies;

- understand better the impacts of land and water-related policies on the poorest in society. It is argued that many present policies may not be benefiting the poor significantly and may even in some situations be resulting in perverse outcomes. Research conducted in the Luvuvhu catchment in South Africa indicates that, where in the country there is a right to free water for each inhabitant (25 litres/caput/day), increasing this entitlement, at a large cost to the government, may not significantly increase the livelihood benefits to the poorest people. It is believed that richer people would be most able to benefit from increased supplies. In India, where water policies are such that there is no free entitlement, it is suggested that the implementation of present forest and water (and irrigation) policies, which are again very expensive to donors and government, is also mainly benefiting richer communities;

- understand better and recognize how different land and water-related policies may be affecting the ownership of water resources. Watershed development policies that promote increased infiltration of water through structural (e.g. check dams, bunding) or non-structural (e.g. afforestation) measures may be transferring what would have effectively been a common property resource – the water running into a communally owned village tank (reservoir) or the river (a government-owned resource) – into an effectively privately owned resource of the landowner, who can afford the installation of electrically pumped groundwater supplies, or forest owner, whose forest consumes extra quantities of water compared with most non-irrigated land uses;

- develop guidelines for best practice in land and water management based on cross-region experiences of research and policy developments. This could include the development of better management tools and the sharing of knowledge through "bridging research and policy" networks. (A programme of research: Forest and Water Policy – Improving Outcomes [FAWPIO], which incorporates many of the items outlined above, is currently under discussion with development organizations.)

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