Available online at www.sciencedirect.com
ScienceDirect
Forest Ecology and Management 251 (2007) 110–120
Forest Ecology and Management
www.elsevier.com/locate/foreco

Forests and water—Ensuring forest benefits outweigh water costs

Ian R. Calder

Centre for Land Use and Water Resources Research, Devonshire Building, Newcastle University, Newcastle upon Tyne NE1 7RU, United Kingdom

Abstract

Throughout the world forestry programmes are often promoted for their environmental, biodiversity, carbon sequestration, bio-fuel, timber production, amenity and social benefits. Not always are the water resource costs taken into account. This paper discusses the need for an improved forest impact assessment framework to assist policymakers and planners in making evidence-based decisions on forest and land use policy. Although forest hydrology has made major advances in recent years science findings have not always reached the policy domain. Examples of the need for the improved connection of science and policy are given for China, India, Panama, UK and Japan. New tools and approaches are suggested for helping to bridge the research to policy gap and to ensure that forest programmes are set in the context of long-term sustainable land and water management. The paper echoes the call by the International Union of Forest Research Organisations for a task force on forest and water interactions to address these issues.

Keywords: Forest and water interactions; Forest policy; Watershed development; Bridging research and policy

1. Introduction

Throughout the world there is increasing interest in land and water developments and policies in which forestry is a central focus. But are these policies always based on our best scientific understanding of the forest and water interactions? Do the benefits always outweigh the costs? Watershed development projects, often with forestry as an important theme, are widely promoted as the means for alleviating poverty, raising food production and for improving the environment. Bio-energy plantations are being investigated with renewed vigour in many countries in both the developing and developed world following recent rapid increases in the costs of fossil fuels. Bio-energy plantations are promoted as an alternative and possibly cheaper and more environmentally friendly source of fuel. But to what extent do these energy production benefits outweigh other possible water resource, societal, food production and conservation costs? Payments for environmental services schemes are frequently based around maintaining or increasing forest cover. They are often promoted as 'win–win' mechanisms where not only can environmental services be maintained at less cost than man-made structural interventions but equity and poverty alleviation benefits can also be achieved through payments to the upland poor. The success of these policies is heavily dependent upon how forests interact with the water environment. Particularly critical is our understanding of how forests may influence and modify extreme events such as floods, droughts and landslips—events which can sometimes have devastating societal consequences.

The public perception that forests are, in all circumstances, necessarily and always good for the water environment, that they increase rainfall and runoff, regulate flows, reduce erosion, reduce floods, 'sterilize' water supplies and improve water quality, has long been questioned by the scientific community. The evolving modern science perception suggests a more complex and generally less advantageous view of forests in relation to the water environment. However, within this complexity, within the range of forest and soil types throughout the world, within the different competing processes which can sometimes move outcomes in either positive or negative directions, and from the wealth of studies that have been carried out and summarised from around the world (Bosch and Hewlett, 1982; Hamilton and King, 1983; Hamilton, 1987; Bruijnzeel, 1990, 2004; Calder, 1992, 1998, 2000, 2005; Best et al., 2003; Zhang et al., 2001; Jackson et al., 2005; Farley et al., 2005; Nisbet, 2005) there are perhaps some broad rules (reflected in the editorial review) that we can suggest to policymakers:

- Water use: Water use of forests is generally greater than that from other shorter and un-irrigated crops leading to reduced

E-mail address: i.r.calder@ncl.ac.uk.

0378-1127/$ – see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.foreco.2007.06.015

annual flows from catchments. Fast growing plantation species have often been found to cause major reductions in catchment flows—older plantations and slower growing indigenous forests are likely to exhibit lesser reductions in flow.

- Floods: At the small catchment scale and for small-scale flood events forests will have significant mitigating effects but for the largest, most damaging flood events and at large catchment scales benefits are likely to be minimal. Forest management activities such as roads and drainage ditches, through increasing the effective density of the stream network, can contribute to local flooding.
- Dry season flows: It is possible that the higher infiltration rates under forest soils will exceed the extra evaporation expected from forests leading to greater groundwater recharge and positively increased dry season flows. However, the vast majority of results reported from field studies around the world (see, e.g. the most recent review by Farley et al., 2005), particularly those dealing with plantation forests as compared with other well-managed land uses, indicate neutral to negative impacts, i.e. reduced low flows.
- Erosion: Erosion rates from natural forests are likely to be amongst the lowest of any land use but this is not necessarily the case for plantation forest. In poorly managed plantations, roads, drainage ditches, logging, and monoculture plantations with little understorey subject to splash-induced erosion, may cause erosion rates higher than those from well-managed agricultural land and pasture.
- Water quality: Water quality would normally be expected to be good from forests. An exception may occur in high pollution climates where deposition rates of atmospheric pollutants may lead to catchment acidification and high nitrate concentrations in soil and groundwater.

The questions arise as to whether forest and water policies in different countries in the world are always based on our best modern science perception and whether our best science is being effectively communicated to policymakers and, if not, how can we go about bridging the gap between science and policy. This paper discusses these issues together with the need to develop impact assessment methodologies to evaluate the multitude of positive benefits and consider these alongside any water costs.

2. Improving the link between science and policy

2.1. China: the Natural Forest Protection Programme and the Sloping Lands Conversion Programme

The major floods in China in 1998 precipitated the early announcement of the Natural Forest Protection Programme (NFPP), which stipulated the protection of natural forests throughout the country and imposed a complete ban on logging in the upper reaches of the Yellow and Yangtze Rivers. The erosion-prevention programme named the Sloping Land Conversion Programme (SLCP) was announced at the same time. The stated purpose of the SLCP, as announced by Prime Minister Zhu Rongji, was to reduce environmental degradation. The SLCP called for the re-vegetation of 31 million h of land on steep slopes ($>25^{\circ}$). The state promised to subsidize 2.55 tonnes of grain and about US$ 36 per year to farmers for every hectare of such cropland converted to forestry around the upper reaches of the Yangtze. But forestation may not be the only way to achieve a vegetation cover on the slopes to achieve erosion mitigation. Recent summaries of research findings in relation to forests and floods (CIFOR and FAO, 2005; Calder and Aylward, 2006) have also questioned the assumed benefits of forests in relation to flood mitigation, particularly in relation to the most severe (infrequent) events and at the large catchment scale. It should also be borne in mind that any possible flood and erosion mitigation benefits are likely to be at the expense of negative impacts on water resources. Hydrological research carried out throughout China (Wei et al., 2005) and for the Loess Plateau (Zhang et al., 2006) recognise inconsistencies in some results, perhaps reflecting the wide range of forest and soil types experienced, but report that the majority of studies show a decrease in annual runoff with increasing forest cover (inline with the world wide review of Bosch and Hewlett, 1982). The inconsistencies, indicating increases in annual runoff with forest cover in some particular locations, nevertheless deserve further investigation and may be indicative of very low transpiration rates from old and sparse forests.

The China Council for International Cooperation on Environment and Development sponsored a group of international and national experts to look at the NFPP and SLCP programmes. The report (World Bank, 2002) found that the blanket application of the current logging ban is not the best way to achieve conservation with development. In the case of the NFPP the impacts on local livelihoods were extensive and, in many cases, severe. The report also indicated that the provision of free grain to farmers involved in the scheme is leading to a distortion of local markets and puts downward pressure on prices therefore decreasing incomes for farmers who are not involved in the SLCP and still rely on crop production. Given these lessons, the report recommended a number of actions. These include, with regards to the NFPP:

- remove the ban on logging from collectively owned and develop a strategy to move to the sustainable management of the forests;
- develop a detailed forest land use plan which ensures protection of old growth natural forests;
- in the interim, compensate collective forest holders for losses caused by the ban and increase the level of compensation to those impacted by the logging ban on state-owned forests.

And with regards to the SLCP:

- develop a strategy to engage other sector agencies in reducing sedimentation from engineering works;
- with the active participation of local officials and representatives of stakeholders, improve the targeting and implementation of the programme by adopting specific

environmental targeting criteria and more market-based mechanisms such as bidding;
- develop a 'sustainability strategy' to continue the positive benefits of the programme following the end of the subsidies. This strategy would include an aggressive piloting and advancement of alternative funding sources for these payments for ecosystem services, including a redesigned 'Ecosystem Compensation Fund' and promotion of new markets and payment schemes for carbon sequestration;
- build capacity at all levels for more decentralized, flexible, multi-sector approaches to policy planning, implementation, monitoring and evaluation in the affected provinces.

The NFPP and SLCP were policies put in place by the State Forestry Administration. The central precepts, that forestry is necessarily always good for preventing erosion and the best way to reduce floods, have not gone unquestioned by other ministries. A panel of academics from the Chinese Academy of Sciences has voiced concern about the policies, recognizing also the water resource downside of forestry in reducing water flows and aquifer recharge. These appeared in the form of suggestions on the official website of the Ministry of Water Resources (Ministry of Water Resources of China, 2003).

The official monitoring programmes of the NFPP and SLCP are generally viewed as 'too academic' and are very expensive to operate except at very low sampling frequencies. Almost all the field data are on inputs and on the number of trees planted and their early survival. There is very little information to allow the Government to judge the real success or otherwise of these programmes or who are the winners and losers. Research aimed at determining these real impacts would not only be of value to the government in China in developing future land use policies but would also, through linkage with the NFPP and SLCP programmes, present one of the best opportunities for really progressing our science understanding of the biophysical and socio-economic impacts associated with such large changes in land use. Wei et al. (2005) also recognise the importance of further research in forest hydrology in three specific areas:

1. Snow hydrology, which is important for understanding the hydrological processes operating in the temperate and boreal forests of China.
2. Impacts of forest management practices on hydrology, including selection of harvesting levels or percentages in a watershed, riparian management strategies, selection of various forest structures and silvicultural practices.
3. Application of hydrological models—where there are sufficient data or understanding in forest hydrology, application of hydrological models can within a short time help evaluate the impacts of different forest management scenarios on hydrology.

2.2. India: forestry and watershed development policy

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 locally conducted scientific studies on plantation forest in the Nilgiris, Dehra Dun, Karnataka and Kerala which present a different view (see, e.g. Sikka et al., 2003; Mathur et al., 1976; Bahadur et al., 1980; Sharda et al., 1988, 1998; Samraj et al., 1988; Calder et al., 1992; Kallarackal, 1992).

The Government of India has long recognised water as one of the resources most limiting to development. In 1987, a National Water Policy was published and this has been recently renewed and updated (Government of India, 2002). A focus of this policy is towards improving water supply to meet the identified water allocation priorities for drinking water, irrigation, hydro-power, ecology, agro-industries and non-agricultural industries and navigation and other uses. The National Water Policy also promotes watershed management and increasing forest cover as a means of conserving water. Interestingly, and in contrast to research conducted both in India and the rest of the world, forestry is regarded as less water demanding in drought prone areas:

> "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."

> and

> "Drought-prone areas should be made less vulnerable to drought-associated problems through soil moisture conservation measures, water harvesting practices, minimisation 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." (Government of India, 2002)

In comparison with irrigated areas forestry could be regarded as less water demanding, but scientific research conducted throughout the world indicates that forest water use is at least equal to if not considerably greater than that from other land uses because of the higher interception losses in wet conditions and the often higher transpiration losses in dry conditions arising because of the greater soil water access of deeper root systems. Recent reports (Hindustan Times, 1996) that the Government of India is working on inviting private sector participation to achieve 33% forest cover by 2012 and that the Environment and Forests Ministry is preparing a Memorandum of Understanding for this purpose, suggest there is still insufficient awareness of the likely water resource downsides of such actions.

Since the 1990s some 500 million US dollars per year have been spent on watershed development programmes (Kerr, 2002) which have the general aim of alleviating poverty by improving the quality and quantity of water resources. Forestry is often a core component of these programmes together with measures aimed at improving water supply through the construction of new village level surface water reservoirs (usually termed tanks in India) or desilting existing tanks, and the construction of rainwater harvesting structures.

There is ultimately 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 is such that there is no flow of water out of the catchment and the catchment becomes a closed system in the International Water Management Institute's terminology. Many catchments in India are already closed or rapidly approaching this state (see, e.g. Batchelor et al., 2000, 2003; James, 2002). As catchments approach closure two disbenefits 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 utilised, in this closed 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 water at the expense of reduced availability to downstream users within the catchment.

The forest and water policy-improving outcomes (FAWPIO) study was funded by the United Kingdom Department for International Development (DFID) and has been operating with DFID and World Bank supported watershed development projects in Karnataka. The project recently called for a major revision of watershed management policy, citing the increased intensification of agriculture that has occurred over the past 15–20 years as the principal cause of reduced catchment flows and catchment closure (Calder et al., 2007a,b). The increased abstraction and use of groundwater for irrigation; the increase in areas under horticulture and plantation forestry; and rainwater harvesting structures, field levelling and field bund construction, are all contributing factors to reduced flows.

The public beliefs that irrigation, soil water conservation measures and forestry are all unambiguously beneficial activities may have contributed to the present state of affairs of near closure in many catchments. Large-scale promotion of these measures within watershed development projects without the promotion of an effective monitoring and water information system, as required by the National Water Policy, has meant that the detection and recognition of these adverse water resource impacts has been slow or has not yet occurred.

Calder et al. (2004) have suggested that considerable amounts of development funds are being expended in the erroneous belief that tree planting will increase groundwater recharge within watershed development projects in India and that it is important to have better connection between the institutional and science perceptions of the role of forests and water. Equally if not more serious, is the concern that the present focus on plantation 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 300 m (Calder et al., 2007a). Ultimately some balance has to be found between high (e.g. irrigation and forestry) and low (rain fed agriculture and pasture) water using land uses within a catchment to ensure that total water use is sustainable and remains less than the rainfall. At present the excess of evaporation over rainfall is met through groundwater mining. Some of the new tools and approaches developed by the FAWPIO project for addressing these issues are described in Section 3.

2.3. The Panama Canal

The continued functioning of the Panama Canal is a central concern of the Government of Panama. In 1996, a Regional Plan (Intercarib/Nathan Associates, 1996a,b) was produced with USAID support that advocated massive reforestation (104,000 ha) of the lands in the Panama Canal Watershed that were under agricultural use, primarily for livestock production. The report was based on the assumption (perceived wisdom) that the reforestation programme would have a positive impact on water quality and quantity and erosion, and lead to increases in both annual and dry season flows. The proposals in the report were enshrined in Panamanian Law in 1997 (Law 21). The Government of Panama later requested the World Bank to support it in designing a project that would assist them in carrying out their responsibilities in the watershed under Law 21.

As part of the preparatory phase of the project design the World Bank commissioned various studies to investigate the current land use in the catchment together with the hydrological and economic impacts of the proposed change in land use. The Centre for Land Use and Water Resources Research at Newcastle University carried out the scoping study into the hydrological impacts of the proposed land use change (Calder et al., 2001). The study involved the application of the HYLUC (Calder, 2003) spatially distributed evaporation model using local information on land cover and land use and previously published default vegetation parameters for forest and non-forest land cover (Calder, 1999). The model described the recorded flow regime for three of the major subcatchments of the Panama Canal Watershed and three of the experimental catchments operated by the Smithsonian Tropical Research Institute, within an error of 10%, which was essentially commensurate with the experimental error of the observations. The results were calculated in terms of cumulative flow for the fully forested Chagres and partially forested Trinidad catchment, respectively.

The predicted reduction in runoff on conversion of full pasture to full forest plantation (calculated as cumulative run off under plantation cover less cumulative run off under pasture, as a percentage of run off under pasture) ranged from 18% for the Chagres catchment (3420 mm annual rainfall) to 29% for the drier Trinidad catchment (2222 mm annual rainfall). Initial analysis of the hydrological data was not able to provide evidence for a significant linkage, either positive or negative, between land use and the low flow response.

Insights into why some catchments might show a low flow response to a change in forest cover whilst others do not can be derived from modelling studies and through experiments. For example, if the capacity of the groundwater reservoir supplying low flows is of moderate depth, such that it is always full at the end of the wet season irrespective of whether the vegetation above has high or low evaporative properties, then the decay of these stores during the dry season flow would be essentially the same. Alternatively, if the groundwater reservoir had a larger capacity, such that it was not always filled, especially when overlaid by a type of vegetation with high evaporative properties, then a much reduced dry season flow would be expected. Therefore, we might expect that although the higher evaporation from forests as compared with short crops would always result in reduced annual flows, the effect on low flows might be significantly modified by the geology, and might range from a zero signal to one that is similar to the degree of annual flow reduction. It is possible that the interplay of these different environmental factors on the Panama Canal watershed is such that, whilst annual flows are reduced, there is no measurable effect on low flows, i.e. the effect is within the 'noise' arising from year-to-year climate variation and measurement error.

Rather than supporting the conventional wisdom that afforestation would increase flows to the canal reservoirs and enhance the capacity of the canal, this study indicates that annual flows would be reduced and, if there is no significant effect on low flows, the capacity of the Canal will be reduced by ~10%. Aylward (2002) reviewed the hydrological and socio-economic issues relating to the Law 21 proposals for the Panama Canal and concludes that "further analysis of the low flow issue is therefore essential".

The study of Calder et al. (2001) also indicated that the expected benefits of an afforestation programme in terms of erosion control may not be achieved. Virtually all the commercial planting within the watershed is with teak, and herbicides are usually applied to reduce competition from understorey weeds during the establishment stage. It has been shown (Hall and Calder, 1993; Calder, 1999) that teak plantations growing in conditions without an understorey are susceptible to splash-induced erosion. The combination of splash-induced erosion and the use of herbicides may therefore not result in either reduced sedimentation or improved water quality from these plantations.

2.4. United Kingdom: lowland forests and water resources

The UK Government's 1995 White Paper on Rural England included a proposal, mainly on conservation and amenity grounds, to double the area of woodland cover within England by the year 2045. This proposal was made at the same time that the UK was experiencing the driest and warmest summer on record; conditions that led to widespread water supply shortages and costly drought relief operations in some regions. Questions were later raised (House of Commons Environment Committee, 1996) concerning the possible impacts on UK water resources and the water environment of the combined effects of climate change and such a large expansion in woodland.

Although the water quantity impacts of upland afforestation in the UK had been broadly understood by the late seventies (see, e.g. Calder, 1979; Calder and Newson, 1979) less was

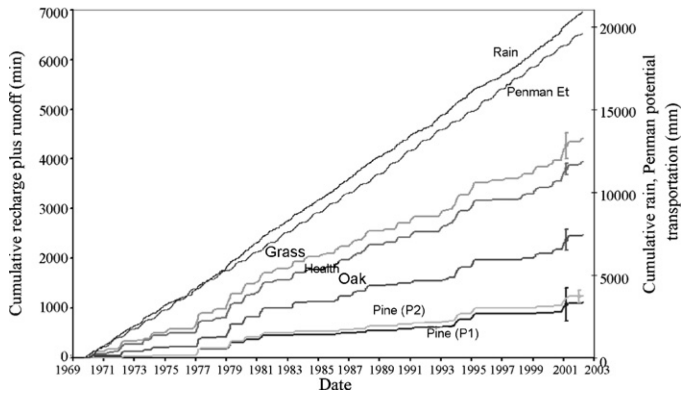

Fig. 1. Cumulative recharge predicted for grass, heath, oak and pine vegetation at Clipstone, UK, using the locally calibrated HYLUC model, together with cumulative values of measured rainfall and Penman potential transpiration for short grass (right hand scale) (*Source*: Calder et al., 2003a).

known about the controls determining forest evaporation in the lowlands. Recognising these difficulties, the Department of the Environment, Transport and the Regions (DETR) commissioned a scoping study to investigate the possible range of water resource impacts associated with woodland plantations. Field studies involving meteorological and soil water measurements were later initiated in February 1998, at Clipstone Forest, part of the new Sherwood Forest, in the Midlands of the UK to test and refine the earlier scoping study model predictions.

Results from these studies indicated large percentage reductions in recharge from forest as compared with grassland (Calder, 2003; Calder et al., 2003a,b). Long-term recharge rates would be reduced by about half (48%) beneath oak and by three quarters (75%) under pine as compared with grassland (Fig. 1). For years of average annual rainfall no recharge will occur at all beneath the pine forest; only for years of significantly higher than average rainfall and storm events, such as the very wet autumn of 2001, will significant recharge take place. Similarly large reductions in recharge under forest have been reported from The Netherlands by Van der Salm et al. (2006) where, as compared with arable land, oak reduced recharge by 64% and spruce reduced recharge by 79%.

The field studies also indicated concerns over water quality (Calder et al., 2003b). Concentrations of nitrates in the soil water beneath the root zone of the pine forest were found to exceed the World Health Organisation's limits for drinking water. In high pollution (industrial) climates the deposition of most atmospheric pollutants, both in the gaseous and particulate forms, are likely to be higher in forests, because of the reduced aerodynamic resistance of forest canopies as compared with those of shorter crops. The high deposition load together with the high evaporation from the pine forest is sufficient to explain the high observed concentrations of nitrate (and chloride). Within the next few decades it is believed that the nitrate pulse will reach the groundwater table.

2.5. Japan and Mekong basin: forestry for flood control?

In Japan, a conflict exists between engineering and forestry interests concerning the best ways to mitigate floods. The

Ministry of Land, Infrastructure and Transport promotes public works and engineering interventions whilst the Japanese Forestry Agency promotes 'Green Dams' as the solution to flood control. Kuraji (2005) of the University Forest in Aichi, part of the University of Tokyo, has pointed out the fallacy of relying on forests (Green Dams) as the principal solution to flood control. The Japan Water Agency and the River Bureau of the Ministry of Land, Infrastructure and Transport have also identified the ineffectiveness of forests in ameliorating major floods pointing out that forest soil, which has the capacity to absorb a proportion of small storm rainfall and ameliorate small floods, will be fully saturated and have no ameliorating effect for the largest storms. This would almost certainly be the case for storm events with 100 years return periods, the event magnitude which is used as the design rainfall for the flood control plans of Japan's rivers.

The total reliance on either concrete dams or 'Green Dams' for flood control is misplaced. As discussed above Green Dams are unlikely to be effective in controlling large flood events. Concrete dams may also fail in extreme circumstances. A more integrated approach to floodplain management may avoid these difficulties. For example the Mekong River Commission promotes four measures: (1) land-use planning measures, aimed at keeping people away from the floodwaters; (2) structural measures, aimed at keeping floodwaters away from the people; (3) flood preparedness measures, which recognize that no matter how effective the above types of management measures are believed to be, an overwhelming flood can always occur; and (4) flood emergency measures that help affected people to cope with the aftermath of floods.

2.6. Costa Rica: payments for environmental services

Policies involving the use of payments for environmental services (PES) are being explored in many countries of the world. Environmental services can be regarded as the flow of valuable services that natural systems provide to society. In some situations land cover can provide similar services (e.g. erosion control and ensuring water quality) to those that can be achieved by man-made physical interventions involving check dams or water treatment works, and can therefore substitute them. There are cases where such schemes, have been economically successful. A much cited example is that of New York's water supply. To avoid costly fines for not meeting federal government regulatory water quality requirements, New York City officials negotiated payments to upstream landowners for better watershed management at a cost of $1.5 billion which was far less than the cost of a proposed filtration plant, estimated to cost $6–8 billion (Forest Trends, 2003; City of New York, 2004). What is less often cited is that New York City may yet be forced to install a filtration plant on public health grounds (New York Times, 2006), which would obviate any economic benefit of the PES scheme.

The perceived success of such schemes has led many organizations, including development organizations, to promote them as 'win–win' mechanisms where not only can environmental services be maintained at less cost than man-made structural interventions but equity and poverty alleviation benefits can be achieved through payments to poor upland residents. Whilst the concept is very appealing, some caution is indicated by closer scrutiny of the underlying motives behind some of the schemes; the biophysical understanding upon which they are based; the existence of any buyers for the schemes; and the distribution of actual benefits (Calder, 2005).

Rojas and Aylward (2003) offer some very interesting insights into the motives underlying markets for environmental services schemes in Costa Rica. These motives may also apply to forest related markets schemes in other parts of the world. They pointed out the powerful nature of forestry interests in Costa Rica at the time when a structural adjustment programme was being negotiated with the World Bank. The terms of the agreement required the elimination of subsidies to the productive sectors, including the forestry sector. The forestry interests saw PES schemes as the ideal way of repackaging the subsidies in a way that would be more acceptable to the World Bank. Rojas and Aylward state:

> "However, 17 years of subsidies to the forestry sector had allowed room for the creation of an influential institutional framework to support and lobby in favour of the forestry sector's interests. These groups exerted pressure and opposed the complete elimination of forestry subsidies."

These proximate variables, including the development of forestry incentives in Costa Rica, the transition to give subsidies to forest conservation in addition to reforestation, the pressure from international financial institutions to eliminate subsidies, the internal pressure to keep the forestry subsidies, when combined with the broader expectations for market opportunities associated with climate change, ecotourism and certification all served as a basis for the legal definition of payments for environmental services (PES) that emerged in the Forestry Law of 1996.

The Vice President for Environmentally and Socially Sustainable Development of the World Bank (Johnson, 2002) conveys the public perception of the biophysical understanding upon which many markets-based systems are founded, by stating that:

> "The hydrological services provided by forests, such as clean and regulated water flow, and reduced sedimentation, for example, are typically only noted when natural disasters, flooding, siltation of reservoirs and scarcity of water occur as a result of the removal of forest cover."

However, this message makes no mention of the reduction in total water flows that will almost certainly occur from forested lands as compared with those under shorter vegetation types. A detailed study carried out by Landell-Mills and Porras (2001) drawing on a total of 287 PES case studies worldwide is also very revealing with regard to the underlying basis and outcomes of the schemes, particularly in relation to poverty alleviation benefits. They arrived at the following cautionary conclusions:

> "Amidst the flurry of activity to promote payments for watershed protection, little attention has been given to

impacts. Questions need to be asked as to whether markets provide a preferable mechanism for delivering watershed services to tried and tested regulatory systems. The literature provides little insight on this issue. For the most part, studies offer superficial reviews of economic, social and environmental benefits with virtually no assessment of costs. Moreover, the literature fails to convince us that markets offer the optimal way of achieving improved watersheds. The lack of attention to equity impacts of emerging payment schemes raises a number of concerns.''

A more recent study by Hope et al. (2005) investigated these issues in more detail and found that the Costa Rican PES programmes create a market distortion that promotes land speculation in upper watershed areas, particularly in strategic areas where buyers for market services may exist (such as above hydro-power reservoirs). Furthermore, it appears that the logic of the presently constructed PES programme is not so much directed towards providing incentives to improve land management practices but more towards compensation for benefits deferred. It also recognized that there are justifiable concerns that PES policies might lead to land evictions of the poor as wealthier elites are provided with incentives to gain control of land resources. Wunder (2001) has argued that promoting policies that generate increased competition for land in tropical forests is unlikely to improve the livelihoods or welfare of the rural poor. Hope et al. (2005) question both the equity basis and the scientific basis of the schemes, stating that it appears inequitable as well as dubious that the downstream poor would be willing, or able, to pay for environmental services from upper watershed land owners. They suggest that the bases of the schemes are more founded in the public perception rather than the science of forest–water interactions.

3. Examples of dissemination and management tools

3.1. EXCLAIM dissemination tool

The GIS-based EXCLAIM tool was developed specifically as a means for disseminating knowledge of land and water interactions to non-specialists and policymakers (Calder et al., submitted). It has been applied to demonstrate the impacts of catchment interventions, including changes in forest cover, in a range of countries including India, South Africa and Costa Rica (Calder, 2005). Where the appropriate socio-economic data is available the tool can demonstrate how spatial changes in land use impact on job opportunities and economic production values. The tool can also demonstrate the effects of climatic variability. This allows the impacts of different land use change scenarios to be investigated for not only an average rainfall year, but also, through the use of a slider bar, a range of rainfall years. The slider allows anything from the driest to the wettest years in an historical record to be selected by moving the slider over the range of 5–95‰ rain years. A recent development of the EXCLAIM tool (Calder et al., 2007b) involves the joint incorporation of sliders which determine the extent of irrigation and forested areas within a catchment together with a slider which controls the extent of water retention measures and water reservoirs within a catchment. In combination these sliders are able to show:

- how different land uses determine the sustainability of the catchment with respect to evaporative water loss and how large areas under irrigation, or combinations of areas under irrigation and forestry, can lead to unsustainable rates of evaporation that exceed the precipitation input;
- that increasing reservoir storage and densities of rainwater harvesting and soil-water retention structures will reduce annual flows from a catchment;
- how different combinations of land uses and water retention structures alter the balance between groundwater and surface flows.

The impact of changing the proportions of different land uses and the degree of reservoir storage under different climate scenarios can be illustrated using as an example the Mustoor Catchment in Kolar District, Karnataka, southern India (Fig. 2).

Through movement of the respective sliders, the changes in water flows are indicated, following the 'green' and 'blue' water terminology of Falkenmark (1995). Overall evaporation from the catchment (green water) is shown as a green upward pointing arrow, whilst corresponding changes in the liquid water flows out of the catchment (blue water) are shown as blue arrows. A horizontal blue arrow represents surface flow. A vertical arrow depicts net groundwater recharge; this is shown as a blue downward pointing arrow when net groundwater recharge is positive, and as a red upward pointing arrow when negative (i.e. when the net groundwater abstraction for irrigation exceeds groundwater recharge over the catchment). The impact of different densities of water retention structures on surface, groundwater flows and evaporative flows, as a result of increased evaporation from water retained behind the structures, can be investigated through movement of the 'tank storage' slider. All combinations of land use and tank storage scenarios can be investigated under different climate scenarios through the use of the 'climate' slider; ranging through the median rainfall year to the one in five wettest year or the one in five drought year.

For the present case scenarios of areas under tree crops, irrigation, and tank storage, and for a median rainfall year, the tool indicates that net groundwater recharge is negative and surface flows out of the Bairekur tank (the last tank in the cascade of tanks in the catchment) are zero.

The tool can be used to show that only in the one-in-five wettest year would both surface and groundwater flows be positive with this scenario. It can also be used to show that doubling the forest cover on the present scenario results in reduced recharge over the catchment resulting in an increased negative recharge. However, if with this scenario the areas under irrigation are reduced to zero and there are no water retention structures in the catchment, the catchment is seen to return to an almost pre-anthropogenic state with positive surface water flows and groundwater recharge. Ultimately, to return catchments to a sustainable status with regard to water

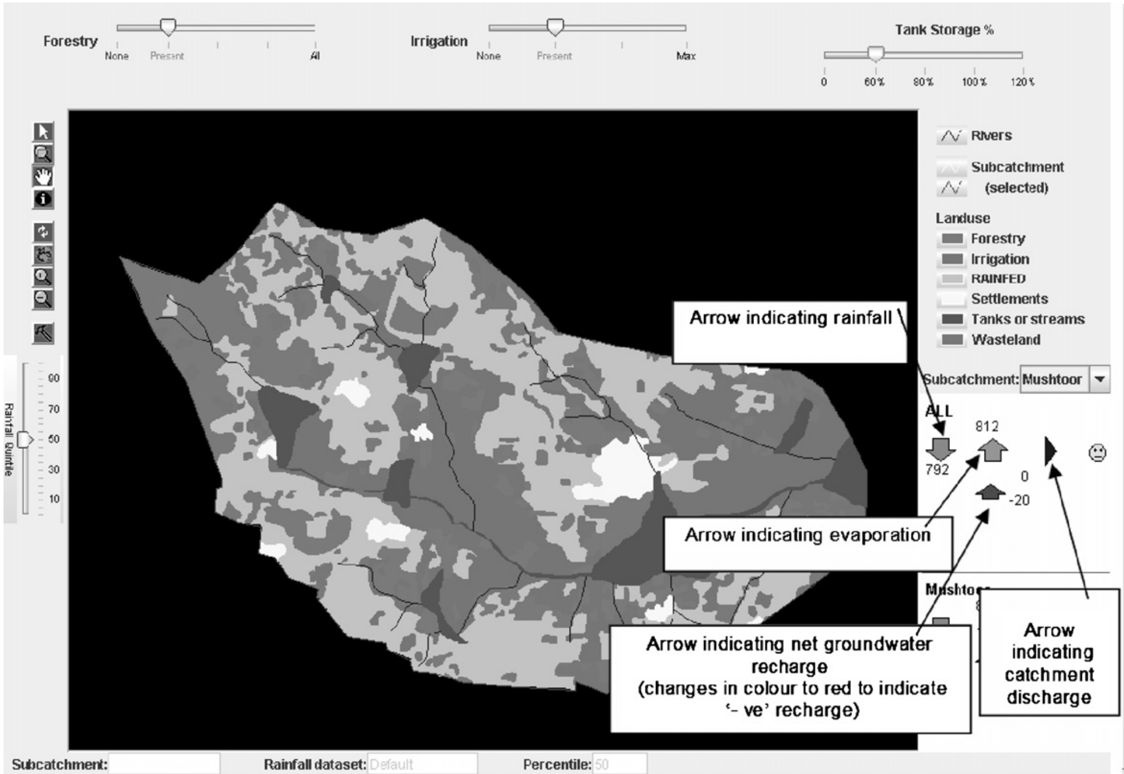

Fig. 2. Current state of development of the EXCLAIM tool for the Mustoor Catchment showing present case scenarios of areas under tree crops, irrigation and tank storage for a median rainfall scenario. For this scenario the tool indicates that net groundwater recharge is negative and surface flows out of the Bairekur tank (last tank in cascade) are zero. Total blue water (surface plus groundwater) flows from the catchment are negative.

flows will require a balance between high and low water using land uses and appropriate use of water retention structures. This could be regarded as jointly managing both the evaporation from the catchment (green water) and the surface flows (blue water) and an approach for achieving this sustainable conjunctive management is described in the next section.

3.2. The quadrant approach to ensuring sustainable water resource management

It has been proposed by the author that to ensure sustainable use of water resources thereby maintaining water flows to downstream users, including those in cities receiving water from water supply reservoirs, and to maintain environmental flows, consideration should be given to two issues (Calder, 2005). First, the sustainability of land uses within a watershed with respect to evaporative use should be considered, determining if (in the absence of any bulk transfers of water into the watershed) the long-term precipitation (P) exceeds the total long-term evaporation (E) from the different land uses. Secondly, it should be considered whether surface flows (Q_s) exceed a required minimum flow (Q_m). Minimum flow criteria could be defined variously. Conventionally this would be defined in terms of an agreed seasonal or annual minimum volume flow. Alternatively, for reservoir catchments, criteria could be defined in terms of return periods of surface flow exiting the catchment, for example 1 or 5 years. It could then be considered that $Q_s > Q_m$ if the return period for flows was less than 1 or 5 years. This definition would then approximate conditions, if there are reservoirs in the watershed, of whether or not the final reservoir (or tank using Indian terminology) has spilt within the last year or has spilt within the last 5 years. The four combinations resulting from this analysis indicate preferred options for the management of evaporation from land uses and for the management of surface flows. Using the Falkenmark (1995) green and blue water terminology, these could be referred to as the green water and blue water management options (Fig. 3):

(1) $P > E$ and $Q_s > Q_m$:
- Green water: opportunities for enlarged areas of land uses with increased evaporation, e.g. irrigated areas and forestry.
- Blue water: benefits may be gained from further soil and water conservation (SWC) measures and water retention structures. Consider increasing density of structures, rehabilitate structures.

(2) $P < E$ and $Q_s > Q_m$:
- Green water: reduce areas of land uses with increased evaporation, e.g. reduce irrigation and forestry. Consider increasing areas of water providing land uses such as dryland agriculture.
- Blue water: only local benefits (at the expense of downstream users) will be gained from further SWC measures and water retention structures. Consider increasing efficiency of existing structures through

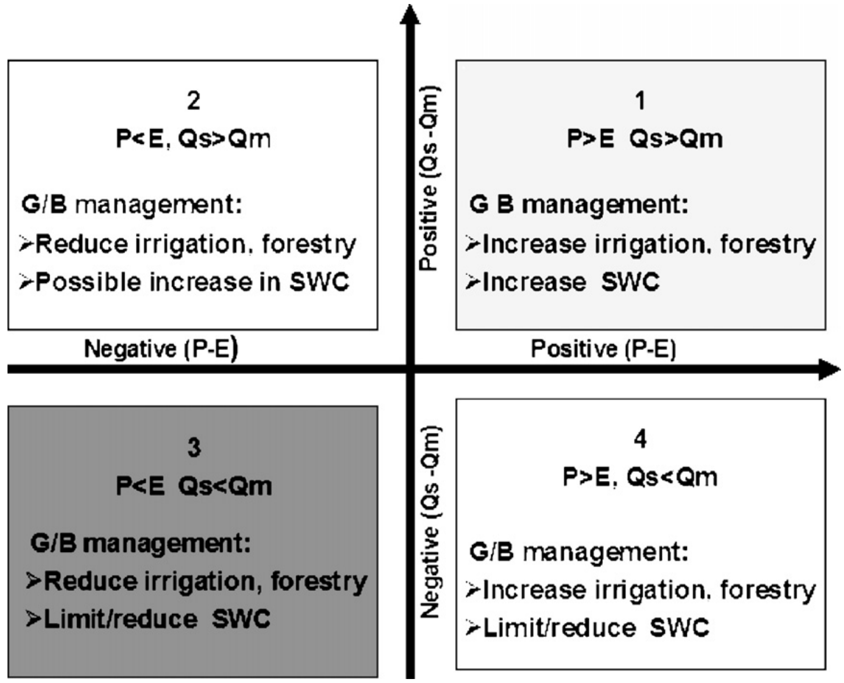

Fig. 3. Catchment conditions that can be used to identify green and blue water management options and whether benefits would be derived from further soil water conservation measures and water retention structures.

measures such as deepening (reduces evaporative losses by reducing the surface to volume ratio).

(3) $P < E$ and $Q_s < Q_m$:
- Green water: reduce areas of land uses with increased evaporation, e.g. reduce irrigation and forestry. Consider increasing areas of water providing land uses such as dryland agriculture.
- Blue water: no overall benefits from further SWC measures and water retention structures. Consider reducing density of structures and/or increasing efficiency of existing structures through measures such as deepening.

(4) $P > E$ and $Q_s > Q_m$:
- Green water: opportunities for expanding areas of land uses associated with high evaporation, e.g. irrigated areas and forestry.
- Blue water: no overall benefits from further SWC measures and water retention structures. Consider reducing density of structures and/or increasing efficiency of existing structures through measures such as deepening.

The quadrant diagram (Fig. 3) may help to direct development funds to those situations where further structural measures are likely to have an overall benefit (quadrant 1) and to scale back investments in catchments which are approaching conditions of catchment closure (quadrants 3 and 4). The approach also makes clear the interconnecting management options regarding green and blue water management and shows that in quadrants 2 and 3 development efforts would be better directed at green water management by reducing catchment evaporation losses, rather than by managing blue water through further water retention measures.

4. The need for new initiatives

The role of forests in relation to the sustainable management of land and water resources remains a contentious issue in many parts of the world. This is despite a significant advance in scientific understanding of forest and water interactions based on almost a century of research in forest hydrology. Problems have often arisen from a failure both to communicate results effectively to policymakers and planners, and to challenge entrenched views, and new approaches and dissemination tools are required to address this problem.

From the country examples discussed in this paper, it is clear that perceptions of the water benefits of forests held by some members of the public and policymakers, particularly in relation to floods of all scales and low flows, may not be supported by the science in many cases. However, the science findings are themselves associated with considerable uncertainty, highlighting the need for further research. These are difficult subjects for field experimental study, requiring accurate long-term flow measurements. Combinations of field studies and modelling may have particular value. As discussed under the Panama study (Section 2.3) modelling studies may have value in identifying particular environmental conditions or combinations of environmental conditions, e.g. of vegetation cover and geology, that may or may not result in an alteration of low flows.

The importance of increasing our understanding of the interactions between forest and water, and of communicating this to policymakers, is growing. With the rapid recent increases in the price of fossil fuels there is a renewed interest in bioenergy. Short rotation coppice and short rotation forestry and biodiesel crops are being considered in many countries. This raises a number of questions. How much water will be consumed in the growing of these crops as compared with other land uses? (It has been suggested that the virtual water use, i.e. the water evaporated in the production of sugar-based alcohol fuels, is as much as 20,000 L of water for each litre of fuel produced.) Will the promotion of bio-energy schemes have serious impacts on catchments which might already be moving towards closure? A new project initiative, Funded by the European Union EuropeAid Co-operation Office (CLUWRR, 2007) will be investigating these issues and making policy recommendations based on case studies in Uganda, China, India and South Africa.

A further initiative that has the aim of communicating research findings to policymakers and planners is the new task force on Forests and Water Interactions of the International Union of Forest Research Organisations (IUFRO, 2007) which will aim to identify where there is a consensus amongst the forest hydrology community on the key forest and water issues discussed above and to highlight those that remain poorly understood as the focus for further research. It will also aim to develop a framework to allow the overall benefits and costs of forestry schemes to be assessed in relation to timber supply, biodiversity, societal and environmental impacts, particularly where the water impacts relate to the water environment.

References

Aylward, B., 2002. Report to the World Bank as Part of the Program for the Sustainable Management of the Rural Areas in the Panama Canal Watershed. Falls Church, VA, USA.

Bahadur, P., Chadra, S., Gupta, D.K., 1980. Hydrological studies on experimental basins in the Himalayan region. In: Proceedings of Symposium on the Influence of Man on the Hydrological Regime with Special Reference to Representative and Experimental Basins, Publ. 130, Helsinki, Finland, pp. 163–170.

Batchelor, C.H., Rama Mohan Rao, M.S., James, A.J., 2000. Karnataka Watershed Development Project: Water Resources Audit. KAWAD Report 17. KAWAD Society, Bangalore, India.

Batchelor, C.H., Rama Mohan Rao, M.S., Manohar Rao, S., 2003. Watershed development: a solution to water shortages in semi-arid India or part of the problem? Land Use Water Resour. Res. 3, 1–10.

Best, A., Zhang, L., McMahon, T., Western, A., Vertessy, R., 2003. A Critical Review of Paired Catchment Studies with Reference to Seasonal Flows and Climatic Variability. Murray-Darling Basin Commission and CSIRO, Canberra, Australia.

Bosch, J.M., Hewlett, J.D., 1982. A review of catchment experiments to determine the effects of vegetation changes on water yield and evapotranspiration. J. Hydrol. 55, 3–23.

Bruijnzeel, L.A., 1990. Hydrology of Moist Tropical Forests and Effects of Conversion: A State of Knowledge Review. UNESCO International Hydrological Programme, Humid Tropics Programme, UNESCO, Paris.

Bruijnzeel, L.A., 2004. Hydrological functions of tropical forests: not seeing the soil for the trees? Agr. Ecosyst. Environ. 104, 185–228.

Calder, I.R., January 1979. Do trees use more water than grass? Water Services.

Calder, I.R., July 1992. The hydrological impact of land-use change (with special reference to afforestation and deforestation). In: Proceedings of the Conference on Priorities for Water Resources Allocation and Management, Natural Resources and Engineering Advisers Conference, Overseas Development Administration, Southampton.

Calder, I.R., 1998. Review Outline of Water Resource and Land Use Issues. SWIM Paper 3. International Irrigation Management Institute (IIMI), Colombo, Sri Lanka.

Calder, I.R., 1999. The Blue Revolution. Land Use and Integrated Water Resources Management. Earthscan, London.

Calder, I.R., 2000. Land Use Impacts on Water Resources. FAO Electronic Workshop on Land-Water Linkages in Rural Watersheds, Background Paper 1, September 18–October 27, 2000 (available at http://www.fao.org/ag/agl/watershed/).

Calder, I.R., 2003. Assessing the water use of vegetation and forests—development of the HYLUC, hydrological land use change model. Water Resour. Res. 39, 1318.

Calder, I.R., 2005. Blue Revolution, Integrated Land and Water Resources Management, 2nd ed. Earthscan, London.

Calder, I.R., Aylward, B., 2006. Forest and floods: moving to an evidence-based approach to watershed and integrated flood management. Water Int. 31, 87–99.

Calder, I.R., Newson, M.D., 1979. Land use and upland water resources in Britain—a strategic look. Water Resour. Bull. 16, 1628–1639.

Calder, I.R., Hall, R.L., Adlard, P.G. (Eds.), 1992. Growth and water use of forest plantations.Proceedings of the International Symposium on Growth and Water Use of Forest Plantations, Wiley, England.

Calder, I.R., Young, D., Sheffield, J., 2001. Scoping study to indicate the direction and magnitude of the hydrological impacts resulting from land use change on the Panama Canal Watershed. Report to the World Bank. In: Centre for Land Use Change and Water Resources Research, University of Newcastle, UK.

Calder, I.R., Reid, I., Nisbet, T., Green, J.C., 2003a. Impact of lowland forests in England on water resources: application of the hydrological land use change (HYLUC) model. Water Resour. Res. 39, 1319.

Calder, I.R., Reid, I., Nisbet, T., Armstrong, A., Green, J.C., Parkin, G., 2003b. Study of the Potential Impacts on Water Resources of Proposed Afforestation. DEFRA website: http://www.defra.gov.uk/environment/water/resources/research/.

Calder, I.R., Amezaga, J., Bosch, J., Fuller, L., Gallop, K., Gosain, K., Hope, R., Jewitt, G., Miranda, M., Porras, I., Wilson, V., 2004. Forest and water policies—the need to reconcile public and science perceptions. Geol. Acta 2, 157–166.

Calder, I.R, Gosain, A., Rama Mohan Rao, M.S., Batchelor, C.H., Snehalatha, M., Bishop, E., 2007a. Watershed Development in India-1) Biophysical and societal impacts. Environment, Development and Sustainability. Accepted: September 4, 2006, published first online at http://dx.doi.org/10.1007/s10668-006-9079-7.

Calder, I.R., Gosain, A., Rama Mohan Rao, M.S., Batchelor, C.H., Garratt, J., Bishop, E., 2007b.In: Watershed Development in India. 2. New Approaches for Managing Externalities and Meeting Sustainability Requirements Environment, Development and Sustainability. Accepted: August 8, 2006.

Calder, I.R., Garratt, J., James, P., Nash, E., submitted for publication. Models, myths and maps: development of the EXploratory Climate Land Assessment and Impact Management (EXCLAIM) tool. Environ. Modell. Software.

CIFOR, FAO, 2005. Forest and Floods: Drowning in Fiction or Thriving on Facts? http://www.cgiar.org/insightdev/upload/291/145_BCIFOR0501.pdf.

City of New York, 2004. New York City's Water Supply System, Watershed Protection. New York City website. http://www.ci.nyc.ny.us/html/dep/html/watershed.html.

CLUWRR, 2007. Rural Energy Production from Bioenergy Projects: providing regulatory and impact assessment frameworks, furthering sustainable biomass production policies and reducing associated risks. http://www.cluwrr.ncl.ac.uk/research_projects/ongoing_research/prj_Re-Impact.php.

Falkenmark, M., 1995. Land and water linkages: a synopsis. Land and Water Integration and River Basin Management, Land and Water Bulletin, vol.1. Food and Agricultural Organisation, Rome, pp. 15–17.

Farley, K.A., Jobbagy, E.G., Jackson, R.B., 2005. Effects of afforestation on water yield: a global synthesis with implications for policy. Glob. Change Biol. 11, 1565–1576.

Forest Trends, 2003. Developing Markets and Payments for Forest Ecosystem Services. Forest Trends website. http://www.forest-trends.org/keytrends/pdf/techbriefs/7forestservices.pdf.

Government of India, 2002. National Water Policy. Ministry of Water Resources, New Delhi.

Hall, R.L., Calder, I.R., 1993. Drop size modification by forest canopies—measurements using a disdrometer. J. Geophys. Res. 90, 465–470.

Hamilton, L.S., 1987. Tropical watershed forestry—aiming for greater accuracy. Ambio 16, 372–373.

Hamilton, L.S., King, P.N., 1983. Tropical Forested Watersheds. Hydrologic and Soils Response to Major Uses or Conversions. Westview Press, Boulder, Colorado.

Hindustan Times, 1996. Govt invites private sector to increase forest cover to 33%. Hindustan Times, June 5, 2006. http://www.hindustantimes.com/news/181_1713542,00020009.htm.

Hope, R.A., Porras, I.T., Miranda, M., 2005. Can Markets for Environmental Services Contribute to Poverty Reduction? A Livelihoods Analysis from Arenal, Costa Rica. Report under the DFID Forestry Research Programme, Project No. R8174.

House of Commons Environment Committee, 1996. First Report Session 1996–97: Water Conservation and Supply. The Stationary Office, London.

Intercarib/Nathan Associates, 1996a. Análisis del Uso Actual y Potencial de los Recursos Naturales de la Región Interoceánica, Volumen 1 de 2. Informe I. Intercarib S.A. y Nathan Associates, Inc., Panamá (in Spanish).

Intercarib/Nathan Associates, 1996b. Análisis del Uso Actual y Potencial de los Recursos Naturales de la Región Interoceánica, Volumen 2 de 2. Informe I. Intercarib S.A. y Nathan Associates, Inc., Panamá (in Spanish).

Jackson, R.B., Jobbagy, E.G., Avissar, R., Roy, S.B., Barrett, D.J., Cook, C.W., Farley, K.A., le Maitre, D.C., NcCarl, B.A., Murray, B.C., 2005. Trading water for carbon with biological carbon sequestration. Science 210, 1944–1947.

James, A.J., 2002. Quantified Participatory Assessment for the Water Resources Audit of the Andhra Pradesh Rural Livelihood Project, Kalyandurg Mandal, Anantapur District. UK DFID, Delhi.

Johnson, I., 2002. Payments for Environmental Services. http://www.biodiv.org/doc/reports/fin-wbank-en.pdf.

Kallarackal, J., 1992. Water use of eucalypts in Kerala. In: Proceedings of the International Symposium on Growth and Water Use of Forest Plantations. Wiley, England, pp. 290–297.

Kerr, J., 2002. Watershed development projects in India, an evaluation. Research Report 127. International Food Policy Research Institute, Washington.

Kuraji, K., 2005. Green dam—a concept based on myths of the benefit of forest on water. In: Proceedings of International Conference on Headwater Control VI: Hydrology, Ecology and Water Resources in Headwaters, Bergen, Norway, June 20–23, 2005, pp. 51–52.

Landell-Mills, N., Porras, I.T., 2001. Silver Bullet or Fool's Gold? A Global Review of Markets for Forest Environmental Services and their Impacts on the Poor. Instruments For Sustainable Private Sector Forestry Series. International Institute for Environment and Development, London.

Mathur, H.N., Babu, R., Joshik, P., Singh, R., 1976. Effect of clearfelling and reforestation on runoff and peak rates in small watersheds. Indian For. 102, 219–226.

Ministry of Water Resources of China, 2003. Panel of Academics from the Chinese Academy of Science suggestions in relation to the SLCP. http://shuizheng.chinawater.com.cn/zcyj/20030208/200302080026.asp.

New York Times, 2006. New York's Water Supply May Need Filtering. http://www.nytimes.com/2006/07/20/nyregion/20water.html?ex=1311048000&en=f05a00ac878be967&ei=5088&partner=rssnyt&emc=rss (July 20, 2006).

Nisbet, T., 2005. Water Use by Trees. Information Note. Forestry Commission, Edinburgh. , In: http://www.forestry.gov.uk/pdf/fcin065.pdf/$FILE/fcin065.pdf.

Rojas, M., Aylward, B., 2003. What are we Learning from Experiences with Markets for Environmental Services in Costa Rica? A Review and Critique of the Literature. IIED, London.

Samraj, P., Sharda, V.N., Chinnamani, S., Lakshmanan, V., 1988. Hydrological behaviour of the Nilgiri sub-watersheds as affected by bluegum plantations. Part I. The annual water balance. J. Hydrol. 103, 335–345.

Sharda, V.N., Samraj, P., Chinnamani, S., Lakshmanan, V., 1988. Hydrological behaviour of the Nilgiri sub-watersheds as affected by bluegum plantations. Part II. Monthly water balances at different rainfall and runoff probabilities. J. Hydrol. 103, 347–355.

Sharda, V.N., Samraj, P., Samra, J.S., Lakshmanan, V., 1998. Hydrological behaviour of first generation coppiced bluegum plantations in the Nilgiris sub-watersheds. J. Hydrol. 211, 50–60.

Sikka, A.K., Samra, J.S., Sharda, V.N., Samraj, P., Lakshmanan, V., 2003. Low flow and high flow responses to converting natural grassland into bluegum (Eucalyptus globulus) in Nilgiris watersheds of South India. J. Hydrol. 270, 12–26.

Van der Salm, C., Denier van der Gon, H., Wieggers, R., Bleeker, A.B., van den Toorn, A., 2006. The effect of afforestation on water recharge and nitrogen leaching in The Netherlands. For. Ecol. Manage. 221, 170–182.

Wei, X., Liu, S., Zhou, G., Wang, C., 2005. Hydrological processes in major types of Chinese forest. Hydrol. Process. 19, 63–75.

World Bank, 2002. China: Wrestling with How to Reconcile Conservation with Development in Western China. The World Bank Office, Beijing. In: http://www.worldbank.org.cn/English/Content/451w6356162.shtml (Press Release, November 25, 2002).

Wunder, S., 2001. Tropical forests and poverty alleviation—what scope for synergies? World Dev. 29, 1817–1833.

Zhang, L., Dawes, W.R., Walker, G.R., 2001. Response of mean annual evapotranspiration to vegetation changes at catchment scale. Water Resour. Res. 37, 701–708.

Zhang, Z., Wang, S., Sun, G., McNulty, S., Zhang, M., Li, J., 2006. Application of a physically based distributed watershed hydrological model MIKESHE in a small watershed of the Loess Plateau, Western China. In: Liu, S., Sun, G., Sun, P. (Eds.), Extended Abstracts from the Conference on Forest and Water in a Changing Environment, Chinese Academy of Forestry, Beijing, China, August 8–1, 2006.