Forests and Hydrological Services: Reconciling public and science perceptions*

Ian R Calder

Centre for Land Use and Water Resources Research, University of Newcastle upon Tyne, UK

Abstract

This paper compares and contrasts the science and public perceptions of the role of forests in relation to water quantity (annual and seasonal runoff and recharge) and erosion. It is suggested that the disparity between the two perceptions needs to be addressed before we are in a position to devise and develop financing mechanisms for the conservation and protection of indigenous forests.

Examples are given of three 'interactive' forest hydrology research programmes: in the UK, South Africa and Panama. Through the involvement of stakeholder groups, often with representatives comprising both the science and public perceptions, interactive research programmes were designed not only to derive new research findings but also to achieve better 'ownership' and acceptance of research findings by the stakeholders.

Following this approach, a new programme of research is outlined, aimed at improving our knowledge of forest impacts on seasonal flows and which represents DFID's contribution to the UN Year of Mountains, 2002.

It is concluded that to move towards a reconciliation of the different perceptions and to connect policy with science will require further research to understand how the 'belief' systems underlying the science and public perceptions have evolved, and better dissemination of research findings.

1. Introduction

When we draw up the 'balance sheet' for forest valuation, conventional wisdom would generally have us believe that there are high positive values attached to their 'hydrological services'. Financing mechanisms designed to help conserve and protect indigenous forests and to partly support the costs of reforestation programmes have traditionally referred to, and are often based on, this conventional wisdom.

But, this conventional wisdom — the public perception — that forests are, in all circumstances, necessarily good for the water environment, that they increase rainfall, increase runoff, regulate flows, reduce erosion, reduce floods, 'sterilize' water supplies and improve water quality, has long been questioned by the scientific community. Although these issues have been debated since the nineteenth century (Saberwal, 1997), to appreciate the evolving 'modern' science perception the reader is referred to reviews by Bosch and Hewlett (1982), Hamilton and King (1983), Hamilton (1987) Bruijnzeel (1990), Calder (1992), particularly as regards tropical forests, and the more recent reviews, in the light of new studies, by Calder (1999, 2000) and Bruijnzeel (2002).

It is suggested that organisations which are developing forest valuation and financing mechanisms should be aware that there is a disparity between the traditional public perception and the science perception of the role of forests

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in relation to water. There is an urgent need to move towards a reconciliation of these different views as these financial mechanisms are developed and preferably before external financing agencies are invited to contribute to these new schemes.

This paper aims to:

- Review and contrast the science and public perception of the role of forests in relation to water and identify areas where our science understanding remains weak and where further research is required.

- Provide examples of ongoing research programmes which are seeking to understand the role of forestry as it affects the water environment and the value of forests in relation to the value of water, in South Africa, Grenada and Tanzania (funded by DFID), in Panama (funded by the World Bank) and in the UK (funded by DEFRA).

- Outline a new research initiative, which represents the DFID contribution to the UN Year of Mountains 2002, which is aimed at addressing one major "grey" area in our knowledge of forest water interactions, that of the "regulating" function, and, more specifically, how forests influence dry season flows.

2. Contrasting the science and public perception & future research needs

This section is largely based on earlier published material (Calder, 1998; 1999) and the paper presented at the FAO electronic workshop on Land-Water Linkages in Rural Watersheds, (Calder, 2000). Here just three of the 'myths' or "conventional wisdoms" relating to forestry and water are reviewed as a means of investigating the disparity between the 'science' and 'public' perception and to identify the remaining gaps in our knowledge. The 'conventional wisdoms' considered are:

1. Forests increase runoff
2. Forests regulate flows
3. Forests reduce erosion

1. Forests increase runoff?

A new understanding has been gained in recent years 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.

These 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.

The new understanding indicates that 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 the widely accepted folklore.

The few exceptions, (lending some support to the folklore), are:

1. *Cloud forests* where cloud-water deposition may exceed interception losses.
2. *Very old forests*. Langford (1976) showed that following a bushfire in very old (200 years) mountain ash, *Eucalyptus regnans*, forest covering 48% of the Maroondah catchment, one of the water supply catchments for Melbourne in Australia, runoff was reduced by 24%. 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 are still required if evaporation estimates with an uncertainty of less than 30% are required. In both temperate and tropical climates evaporative differences between species and soil types are expected to vary by about this amount.

2. 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 and 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:

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

There are also observations (Robinson *et al*., 1997) which indicate that for the uplands of the UK, 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) has demonstrated, from catchment studies at Cathedral Peak in Natal, that pine afforestation of former grassland not only reduces annual streamflow by 440 mm but also reduces the dry season flow by 15 mm. Van Lill and colleagues (1980), reporting studies at Mokobulaan in the Transvaal, showed that afforestation of grassland with *Eucalyptus grandis* reduced annual flows by 300–380 mm, with 200–260 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 streamflow dried up completely by the ninth year after planting. The eucalypts were clear-felled at age 16 years but perennial streamflow did not return for another five years. They attribute this large time lag as being due 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.

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 which 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 these site specific impacts.

3. Forests reduce erosion?

As with impacts on seasonal flows the impacts of forests on erosion are likely to be site specific, and again, many, and often competing processes, are likely to be operating.

In relation to beneficial impacts conventional theory and observations indicate that:

1. The high infiltration rate in natural, mixed forests reduces the incidence of surface runoff and reduces erosion transport.
2. The reduced soil water pressure and the binding effect of tree roots enhance slope stability, which tends to reduce erosion.
3. On steep slopes, forestry or agroforestry may be the preferred option where conventional soil conservation techniques and bunding may be insufficient to retain mass movement of soil.

Adverse effects, often related to forest management activities, may result from:

1. Bad logging techniques which compact the soil and increase surface flow.
2. Pre-planting drainage activities which may initiate gully formation.
3. Windthrow of trees and the weight of the tree crop reduce slope stability, which tends to increase erosion.
4. Road construction and road traffic which can initiate landslips, gully formation and the mobilization of sediments.
5. Excessive grazing by farm animals which leads to soil compaction, the removal of understorey plants and greater erosion risk.
6. Splash induced erosion from drops falling from the leaves of tree canopies.

The effects of catchment deforestation on erosion, and the benefits gained by afforesting degraded and eroded catchments will be very dependent on the situation and the management methods employed.

Quoting Bruijnzeel (1990) “In situations of high natural sediment yield as a result of steep terrain, high rainfall rates and geological factors, little, if any influence will be exerted by man”. Also, in situations where overland flow is negligible as in drier land, little advantage will be gained from afforestation. Versfeld (1981) has shown that at Jonkershoek in the Western Cape of South Africa, land cover has very little effect on the generation of overland flow and soil erosion. On the other hand, in more intermediate conditions of relatively low natural rates of erosion and under more stable geological conditions, man-induced effects may be considerable. In these situations catchment degradation may well be hastened by deforestation so that, conversely, there may be opportunities for reversing degradation by well-managed afforestation programmes.

Even in these situations, afforestation should not be seen as a quick panacea. In heavily degraded catchments, such as those on the slopes of the Himalayas, so much eroded material will have been mobilised already that, even if all the man-induced erosion could be stopped immediately, it would be many decades before there was any reduction in the amount of material carried by the rivers.(Pearce, 1986; Hamilton, 1987). The choice of tree species will also be important in any programme designed to reduce erosion and catchment degradation.

Recent theoretical developments and observations (Hall and Calder, 1993; Calder 1999) confirm that drop size modification by the vegetation canopies of trees can be a major factor leading to enhanced splash induced erosion. These observations indicate that the degree of modification is species related, with tree species with larger leaves generally generating the largest drop sizes. The use of large leaved tree species such as teak (*Tectona grandis)* in erosion control programmes would therefore be ill advised, especially if there is any possibility of understorey removal taking place.

Conclusions: It would be expected that competing processes might result in either increased or reduced erosion from disturbed forests and forest plantations. The effect is likely to be both site- and species-specific. For certain species, e.g. *Tectona grandis*, forest plantations may cause severe erosion. It is a common fallacy that plantation forests can necessarily achieve the same erosion benefits as natural forests. Smyle (2000, *Pers. comm.*) has suggested that the erosion rates in undisturbed natural forest might be considered to represent a 'natural baseline' or 'background' erosion rate against which the erosion rates from all other land uses could be compared. The use of such an index may well be of value in land use management and the design of realistic erosion control programmes.

Caveat: Although conventional erosion modelling methods such as the Universal Soil Loss Equation (U.S. Department of Agricultural Research Service, 1961) provide a practical solution to many problems associated with soil loss from agricultural lands, they may not be adequate for the prediction of erosion resulting from afforestation activities. Process understanding of the erosive potential of drops falling from different tree species is not adequately appreciated and soil conservation techniques related to vegetation type, soils and slope characteristics have not yet been developed fully.

3. Examples of ongoing 'interactive' research on the role of forests and water

Three examples are given of ongoing 'interactive' research in the UK, South Africa and Panama which 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. This should be in both the design stage, by helping to define the objectives of the research and by ensuring that the necessary resources are mobilised, and also in 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 researchers but also facilitates linkages and information flows between the users themselves. This in itself has often been seen as an important output of the interactive research programme. Increasingly it is being recognised that successful Integrated Land Use and Water Resources Management requires not only a sound science base but also the understanding, commitment and collaboration between the different organisations responsible for and impacted 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 of both science and public perceptions, this may — through a process of 'action learning— provide a means of reconciling disparate views.

The policy issues that the interactive research programmes are addressing in the UK, South Africa and Panama are similar in each of the countries. They relate to how we can best manage forest lands to meet competing demands, particularly demands for production (e.g. timber and water), conservation, amenity and recreation (CARE) products or for supporting people's livelihoods. Underlying these policy issues is the value we attach to forests and water products and their impacts on society. Commercial forestry has often been promoted by development organisations because of its perceived environmental benefits. Yet science-based research has shown that many of the expected environmental benefits (which may in some cases be provided by natural forests) cannot be achieved through commercial plantations. Increasingly, we are becoming aware of the environmental dangers, rather than benefits, that have been caused by these plantations. Not only is there usually a high cost in terms of lost water associated with fast growing commercial plantations but, as has been recognised by the government of South Africa, there may also be dangers associated with 'escaping' plantation trees.

The three examples given below indicate the need to improve our understanding of the bio-physical linkages between forests and the water environment, particularly in relation to the impacts on annual flow and recharge in the UK and — for the Panama example — the role of forests in relation to dry season flows. In the South African example the issue is more in relation to the socio-economic aspects: assuming a knowledge of the bio-physical forest and water interactions the question is how can we arrive at forest and water policy instruments which best provide water resource, economic and livelihood outcomes. Alternatively, we could view this as: "how can we match resource-based development objectives with more people-focused, poverty alleviation objectives?"

These three examples also illustrate different degrees of 'connectivity' between science and policy. Forestry interests in the UK have traditionally been slow to accept hydrological research findings which show negative impacts due to forestry. The typical response from the forestry sector has been of delaying tactics: to claim the case has not been proved and to call for more research. South Africa demonstrates the greatest 'connectivity' and has forest and water policy and programmes such as the *Working for Water Programme* which are based on hydrological research findings. Panamanian policy was based on 'old paradigm' beliefs in relation to forests and water but may now be undergoing a transition.

Lowland forests and water resources in the UK

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. Climate change scenarios suggest that such droughts could become much more frequent over the next 50–100 years. 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 UK had been broadly understood by the late seventies (see e.g. Calder, 1979; Calder and Newson, 1979) it remains difficult to predict accurately the water quantity impacts of UK lowland afforestation (Calder *et al*., 1997; Calder, 1999) even under the present climate, for two main reasons:

1. In the lowlands of the UK, water use by transpiration generally exceeds that by interception. Tree physiology exerts a strong control over transpiration rates, depending on interactions between atmospheric demand and available soil water. Since this can result in lower or higher transpiration losses when compared with shorter crops, predicting evaporation differences, even under present climatic conditions, becomes very uncertain.
2. Prior to the execution of current studies, information on the evaporative losses for different tree species growing on contrasting soil types in lowland Britain was limited or non-existent. Virtually no information was available on the evaporative characteristics of woodland growing on drought-prone soils overlying sandstone geology or, for that matter, on derelict soils, yet it was expected that much of the new planting would take place in the Midlands of England on just these soil types. Consequently, it was not possible to determine the direction of the impact let alone the magnitude.

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 on chalk and sandstone. A part of this study, which is reviewed here, involved running the HYLUC97, GIS-based evaporation model, with trial model parameters derived from earlier work (Calder *et al*., 1997, 1999), at the Greenwood Community Forest site in the Midlands of the UK.

Scoping study application of the HYLUC model: Greenwood Community Forest in the English Midlands

To investigate the range of possible impacts resulting from broadleaf woodland expansion in the Greenwood Community Forest, the HYLUC model was applied using parameter values derived from an earlier modelling study and field studies over chalk, but amended to take into account expected differences in soil water availability within the sand and clay-loam soils of the Midlands.

The study site was the Greenwood Community Forest in Nottinghamshire. Nottinghamshire County Council supplied information on land use, soil type and geology as GIS files (Figure 1). Application of the HYLUC model then allowed the calculation of the range of impacts (Calder *et al*., 1997, 1999).

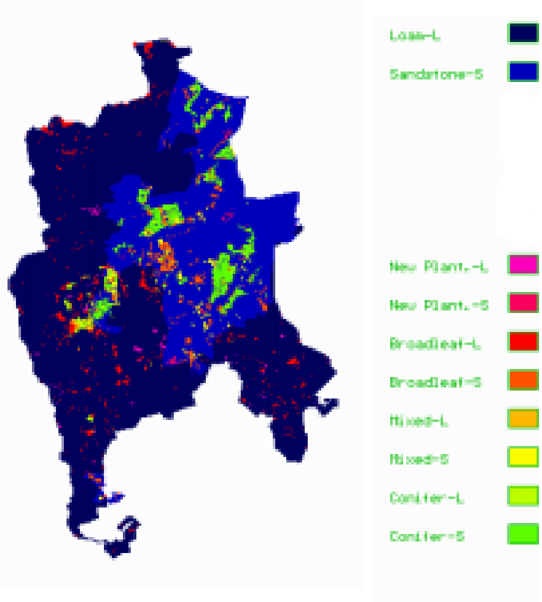

Figure 1 Forest covers within the Greenwood Community Forest. The light blue area represents the sandstone aquifer overlain by sandy soils, while the rest of the area is classified as clay-loam.

The model predictions of seasonal evaporation are shown in Figure 2. These indicate that, in the long term, annual evaporation from broadleaf woodland on sand soil is 93 mm higher than that from grassland and, therefore, afforestation would reduce the average recharge plus runoff by 51%. For broadleaf woodland expansion on clay-loam soil, the predicted reduction in recharge plus runoff would be 62%. The calculated cumulative recharge plus runoff from the Greenwood Community Forest is shown in Figure 3, assuming the present forest cover. Also shown is the calculated cumulative recharge plus runoff for the proposed three-fold increase in woodland cover, assuming that the

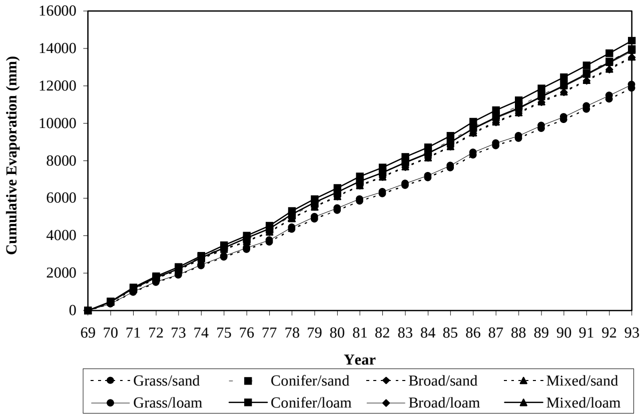

Figure 2 Predicted cumulative evaporation for different land uses within the Greenwood Community Forest. Average annual evaporation: Grass/sand, 460; Conifer/sand, 571; Broadleaf/sand, 553; Mixed/ sand, 554; Grass/loam, 486;Conifer/loam, 603; Broadleaf/loam, 594; Mixed/loam, 594 mm. Average annual rain: 628 mm.

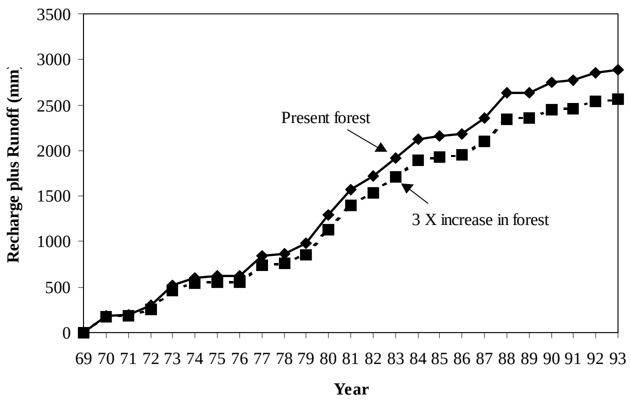

Figure 3 Calculated recharge plus runoff for the whole Greenwood Community Forest for the period 1969-1993 with the existing forest cover and with a threefold increase in forest cover.

increase is in proportion to the present distribution of forestry on the different soil types. Over the 24 year period from 1969 to 1993, the calculated average annual reduction in recharge plus runoff resulting from a three-fold increase in woodland cover within the Greenwood Community Forest from 9% to 27%, would be 14 mm (11%).

A stakeholder group was then formed comprising forest, water and land interests: members of the research team from two UK universities and the UK Forestry Commission and the funding body (then the Department of the Environment, more recently the Department of the Environment Transport and the Regions and now the Department of the Environment Food and Rural Affairs), the Environment Agency, the local County Council and water company and an agricultural extension agency. Under the direction of the stakeholder group, field studies were initiated in February 1998, at Clipstone Forest, part of the new Sherwood Forest, in the Midlands of the UK to test and refine the scoping study model predictions. Preliminary results from these studies indicate that the initial predictions of evaporation and recharge for broadleaf forest was broadly correct. For pine forest it appears now that the scoping study predictions were underestimating the impacts on recharge of afforestation with this forest type by predicting recharge rates 26% greater than is now believed to be the case. The field studies are now indicating annual recharge rates of only 30 mm per annum, less than a quarter of that expected under grass vegetation, a situation where for an average rainfall year no recharge will occur; recharge will only occur in much higher than average years.

Further expansion of lowland forest in the UK for conservation and amenity purposes needs to be considered in relation to the very significant impacts on water resources that this will entail.

CAtchment Management and Poverty alleviation (CAMP)

The government of South Africa has recognised that not only is there usually a high cost in terms of lost water associated with fast growing commercial plantations but that there may also be dangers associated with ‘escaping’ plantation trees. The South African Government, in the February 2000 budget, awarded a further R1,000,000,000 (over five years) to the *Working for Water Programme* (DWAF, 1996) for the purposes of controlling and eradicating 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 Programme highlights a number of issues relating to forest and water management, issues that are probably not specific to South Africa. These include how to devise and implement forest and water policy instruments which will

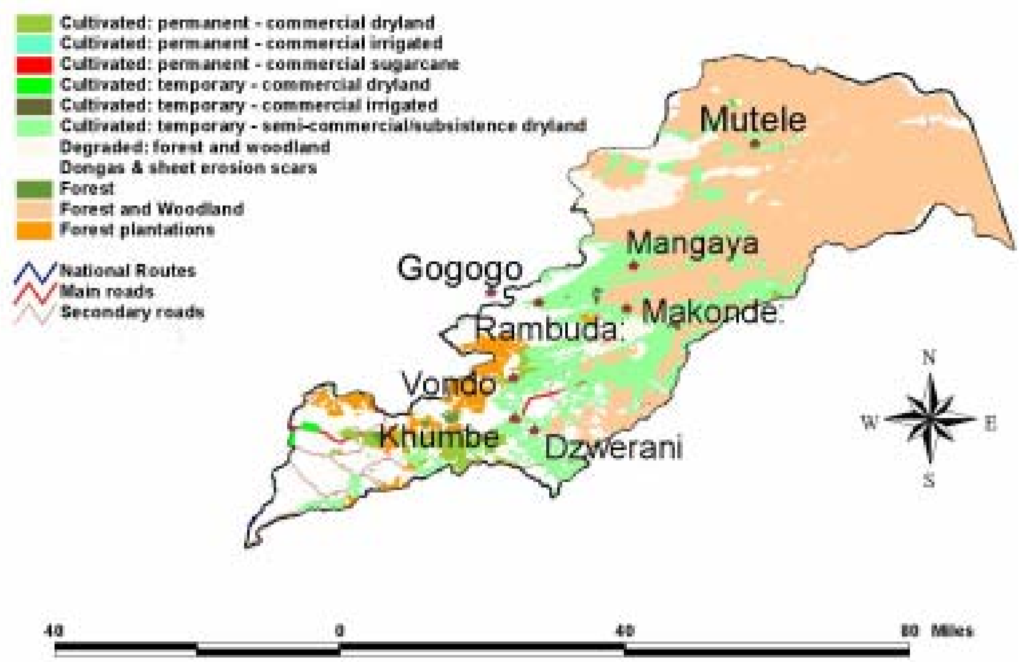

Figure 4 Land use, and settlements where Sustainable Livelihoods assessment was carried out, on the Luvuvhu catchment, Northern Province, South Africa.

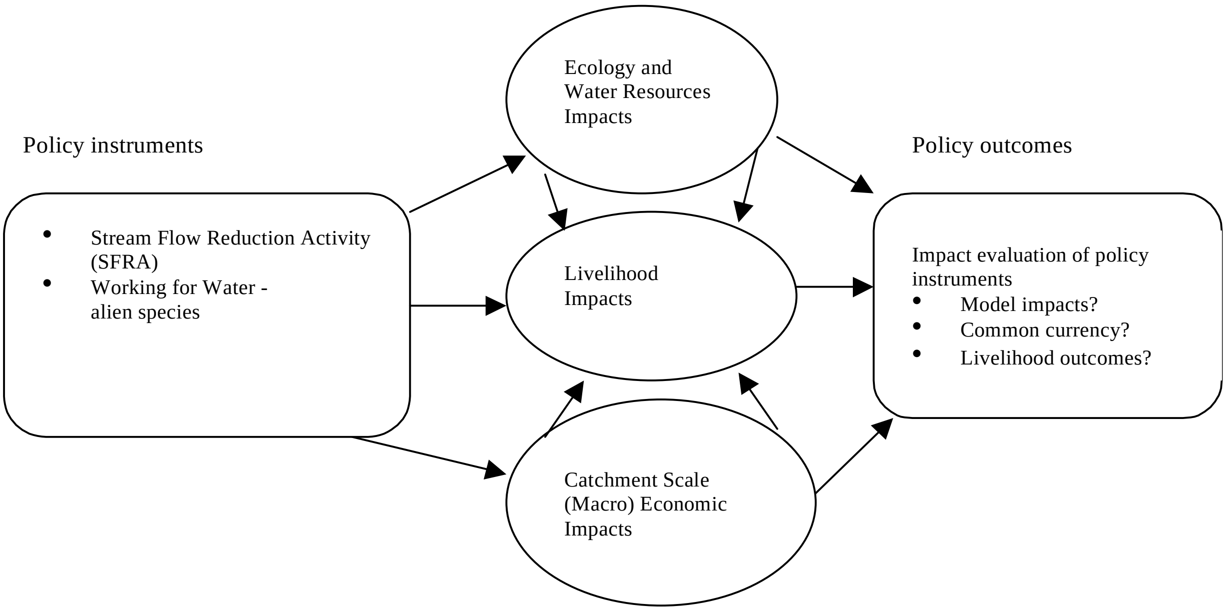

Figure 5 The CAMP project will investigate how two forest and water related policy instruments, the *Working for Water Programme* and the charging of landowners for Stream Flow Reduction Activities (SFRAs), will affect water resources, catchment scale economics and livelihoods.

meet the requirements of Integrated Water Resources Management (water resource, basin economics and conservation) whilst also meeting the demands of major international and donor organisations (e.g. World Bank and DFID). The 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) project that is supported by DFID in South Africa, Tanzania and Grenada. Under the direction of a stakeholder group comprising forest, water and poverty interests, members from both UK and RSA Universities and research institutes, the South African Department for Water Affairs and Forestry, the *Working for Water Programme* and an NGO, the focus of the study was chosen to be the Luvuvhu catchment in the Northern Province of South Africa.

The Luvuvhu catchment demonstrates 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 presently affected by alien invader tree species, it is water short and it has high levels of poverty.

The CAMP project is focusing on two forest and water related policy instruments which are currently being applied in South Africa, the Working for Water Programme and the charging of landowners for Stream Flow Reduction Activities (SFRAs). Commercial forestry and sugar cane are recognised as SFRAs. The CAMP project is attempting to model the impact of these two policy instruments within the Luvuvhu catchment as they affect not only water resources and catchment scale economics but also the livelihoods of the poorest in society.

Forests, water and the Panama Canal

The continued functioning of the Panama Canal is a central concern of the Government of Panama. The ownership of the Panama Canal was transferred from the government of the USA to the Government of Panama at the beginning of the new Millennium. During the period leading up to the change of ownership, major changes were also taking place in relation to the institutional understanding of land use and water resource issues which are now leading to a reconsideration of government policies with respect to the management of the canal basin.

With USAID support, a Regional Plan (Intercarib/Nathan Associates, 1996) had been produced earlier which advocated a large-scale reforestation (104 000 ha) of the lands in the Panama Canal Watershed which were under

Figure 6 The Bridge of the Americas crossing the Panama Canal

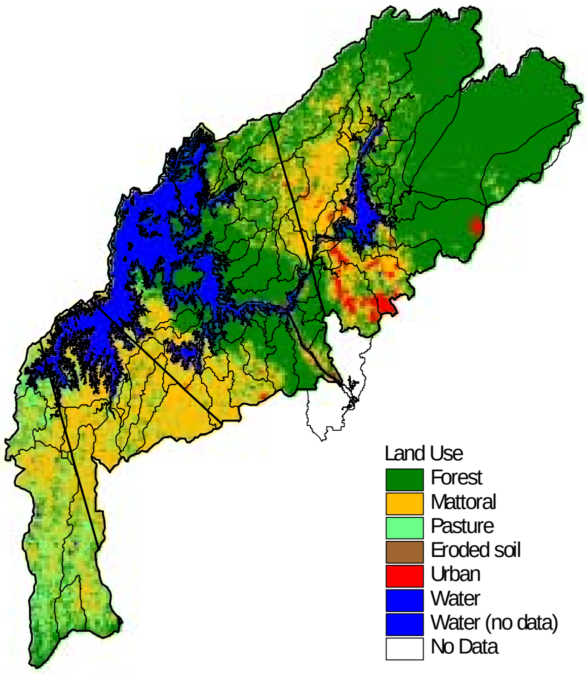

Figure 7 Existing land use in the Panama Canal Watershed

agricultural (primarily livestock production) use. The report was based on the perceived wisdom that the reforestation programme would have a positive impact on water quality and quantity and erosion, and necessarily increase annual and dry season flows. The proposals in the report were enshrined in Panamanian Law 21, in 1997. The Government of Panama later requested the World Bank to assist them in designing a project to help carry out their responsibilities in the basin under Law 21.

As part of the preparatory phase of the project design, the World Bank commissioned various consultancies and scoping studies to investigate the current land use in the catchment, together with the hydrological and economic impacts of the proposed change in land use.

Under the guidance and direction of a stakeholder group with canal, water, hydropower, land and forestry interests and comprising members from the Panama Canal Authority, the Ministry of Agriculture, the World Bank, companies dealing with forestry, hydropower and water, NGOs and local Universities, the Centre for Land Use and Water Resources Research at Newcastle University (Calder *et al.* 2001) carried out the scoping study into the hydrological impacts of the proposed land use change on the Panama Canal Catchments. The study involved the use of HYLUC, the spatially distributed, evaporation model used for the Sherwood forest study in the UK. This model has been shown to be applicable in both temperate and tropical climates of the world (Calder, 1999) and for Panama it was applied using local information on land use (see Figure 7) and previously published 'default' forest and non-forest model parameter values (Calder, 1999). The model was able to describe the recorded (cumulative) flow regime under both three of the major sub-catchments of the Panama Canal Watershed and three of the experimental catchments operated by the Smithsonian Tropical Research Institute, within an error (~10%) which was essentially commensurate with the experimental error of the observations. The results in terms of cumulative flow for two of the catchments, (extreme in terms of forest cover, the fully forested Chagres and the partially forested Trinidad) are shown in Figures 8 and 9. The predicted reduction in runoff on conversion of full pasture to full forest (calculated as cumulative run-off under forest 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).

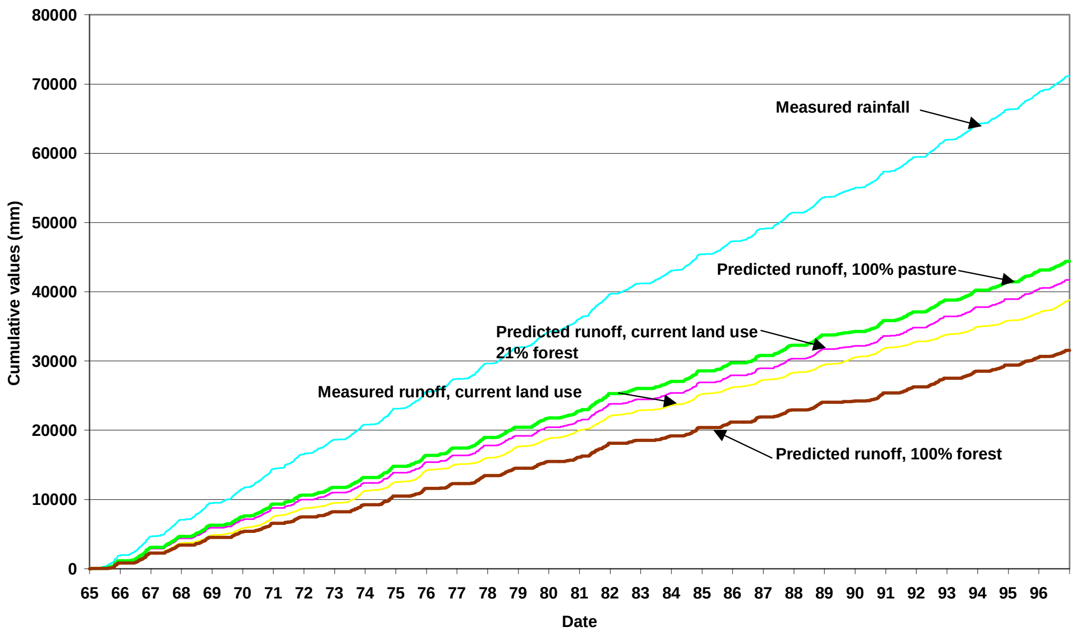

Figure 8 Rio Trinidad, measured rainfall and runoff together with runoff predicted by the HYLUC model for the actual land use (21% forest) and for scenarios of full forest and full pasture cover.

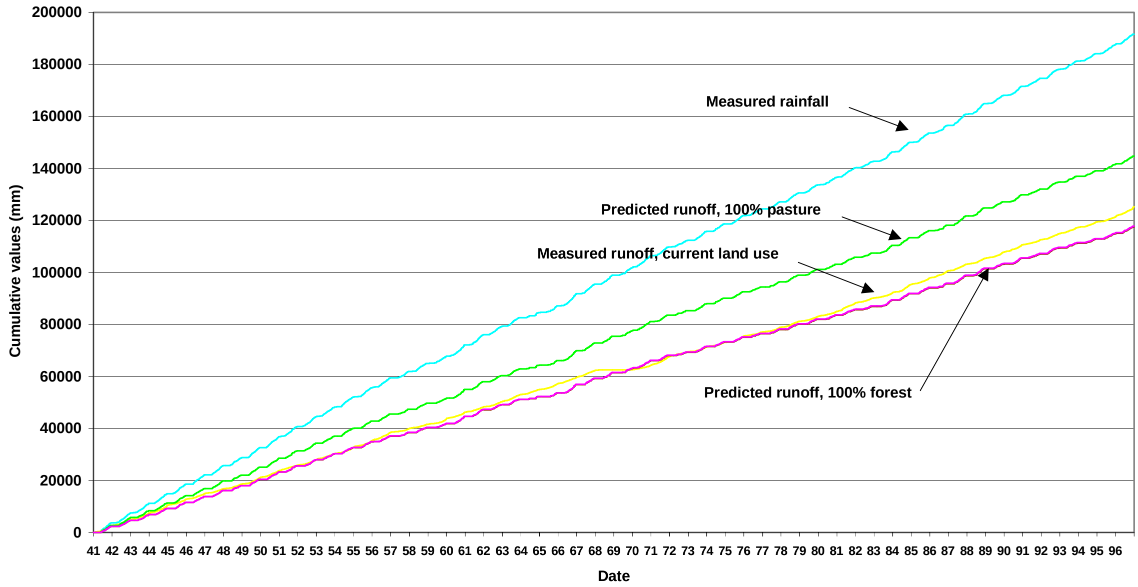

Figure 9 Rio Chagres catchment, measured rainfall and runoff together with runoff predicted by the HYLUC model for the actual land use (99% forest) and for scenarios of full forest and full pasture cover.

An initial analysis of the hydrological data, carried out during the scoping study, without access to stage discharge calibrations in low flow conditions and without full knowledge of when changes in catchment land use had occurred, was not able to provide evidence for a significant linkage, either positive or negative, between land use and the low flow response. A more detailed analysis, linked also to inverse hydrological modelling comparing observed and predicted seasonal flows, might be able to establish a significant correlation.

However, the study, rather than supporting the conventional wisdom that afforestation would increase flows to the canal reservoirs and thus enhance the capacity of the Canal, indicates that annual flows would be reduced and — if there is no significant enhancement of low flows resulting from afforestation — the capacity of the Canal will be reduced by ~10%. Aylward (2002) in reviewing the hydrological and socio-economic issues relating to the Law 21 proposals for the Panama Canal in the programme *Sustainable Management of the Rural Areas in the Panama Canal Watershed*, concludes that “further analysis of the low flow issue is therefore essential”.

The scoping study also suggested that expected benefits of an afforestation programme in terms of erosion control are also unlikely to be achieved. To date, virtually all of the commercial planting within the catchment is with teak and herbicides are generally applied to reduce competition from understorey weeds. In relation to the discussion above concerning the science and public perceptions, the science perception would indicate that this is a situation which may lead not only to very much increased rates of soil erosion as compared with the generally pastoral land use that it would usually replace, but also to a possible deterioration in water quality.

4. New DFID research initative into the effects of dry season flows

Although it is now recognised that on an annual basis forests will generally evaporate more water than other land uses and will therefore reduce annual runoff in rivers or recharge to aquifers, the position with regard to the effects on dry season or summer flows is far less clear. As discussed above, it is conceivable that competing processes associated with forests could result in increased dry season flows.

Two examples of situations where it is thought that this might be realised are high altitude cloud forests, which tend to occur in island or coastal regions, and at the other end of the altitudinal extreme, in semi arid regions with impermeable, often lateritic soils.

In cloud forest locations it is believed that the principal ‘competing process’ at work is the enhanced deposition of cloud water to the aerodynamically rough surface of forest as compared with the relatively smoother surface of shorter vegetation. It is known that the enhanced aerodynamic roughness above forests can lead to increased ‘mixing’ and enhanced turbulent transfer of both heat and water vapour between the atmosphere and the evaporating surface such that in wet conditions evaporation rates of water retained on tree canopies can be as much as ten times those from shorter vegetation. In cloud conditions, when cloud is passing above or through forest, the same enhanced turbulent transfer process will act in an opposite sense by increasing the transfer rates of cloud water deposition towards the forest canopy. Whereas evaporation rates of intercepted water from forest may be as much as ten times those from short vegetation, we might expect deposition rates of cloud water to forest to be as much as ten times those to short vegetation. When cloud conditions occur in the dry season it is quite feasible that cloud water deposition can represent a net gain of precipitation to forests which could lead to increased dry season flows. If, on an annual basis, the total cloud water deposition exceeds the total interception loss it is possible that, in some extreme situations, cloud forests may generate, even in the long term, greater runoff than catchments with short vegetation.

The significance and magnitude of cloud water deposition as a hydrological process, the geographic extent over which it can occur and the possible 'feedback' between forest and cloud base height are the subject of current research (Bruijnzeel *et al*., 1993; Bruijnzeel and Proctor, 1995; Gunawardena *et al.* 1998; Bruijnzeel and Veneklaas, 1998; Bruijnzeel and Hamilton, 2000; Bruijnzeel, 2001). For semi-arid regions, the 'competing process' may be the increased infiltration rate that we might expect under natural forest, or in some circumstances plantation forest, which allows water to infiltrate into forest soils at rates higher than those into soils under other vegetation types. Particularly in semi-arid regions, it is believed that non-forest conditions may lead to the formation of impermeable, possibly lateritic soils. In these situations it is conceivable that the increased rate of infiltration under forest may outweigh the higher evaporation rate, leading to increased soil water recharge which may, in turn, lead to increased dry season flows. An improved understanding of the ways in which natural and plantation forests affect the infiltration properties of soils with different site conditions is crucial in resolving the forest and low flows issue. Collaboration is sought, both to help devise improved methods for assessing infiltration rates under forest soils and to take these measurements under a wide range of forest and non-forest conditions around the world. Of particular value will be studies which monitor conditions through a land use change and especially so for studies which monitor conditions through a land use change which is then reinstated (Waterloo *et al.*, 1999).

In less extreme conditions the body of evidence would suggest that the reduction in dry season flows would be roughly in proportion to the expected reduction in annual flows, as has been observed from the detailed and comprehensive catchment studies carried out in South Africa.

Clearly it is important to establish an improved understanding of the conditions under which we might expect these dry season flow enhancements and the magnitude of the effect. Not only will this be important in relation to questions of catchment management and financial upstream/downstream compensation mechanisms, it will also be an important factor in affecting the livelihoods of communities dependent on the availability of reliable supplies of water throughout the dry season.

A new research initiative, which represents the DFID contribution to the UN Year of Mountains 2002, funded under DFID's forestry research programme, is aimed at addressing this major 'grey' area in our knowledge of forest water interactions, that of the 'regulating' function and, more specifically, how forests influence dry season flows. Recognising that these influences are likely to be both site- and tree-species specific, research is being carried out on a notional altitudinal gradient across the extremes of cloud forest in Costa Rica to the semi arid zones of lowland India. The hydrological research in Costa Rica is being led by the Free University, Amsterdam, in collaboration with other partners in Costa Rica and Europe. The socio-economic and 'livelihoods' benefits of dry season flows to downstream communities and the economic value of dry season flows for other economic uses in Costa Rica are being assessed under a linked programme being devised by Bruce Aylward (Aylward Consultants). The overall co-ordination of the programme is being carried out by the Centre For Land Use and Water Resources Research (CLUWRR) at Newcastle University.

Although the current focus is directed on Central America and India, collaborating partners are being sought from DFID partner countries to extend the scope of this work to other regions where catchment management programmes involving forestry have raised similar concerns about water resource and livelihood impacts.

5. Conclusions

It is concluded that organisations which are developing forest valuation and financing mechanisms should be aware that there is a disparity between the traditional public perception and the science perception of the role of forests in relation to water. There is a need to move towards a reconciliation of these different views which will require further efforts directed not only towards the scientific research but also to ensuring that these research findings are better disseminated and 'connected' to policy and decision-making on land use planning and forests. 'Interactive' research and the involvement of stakeholder groups is seen as one way of reconciling disparate views but for this approach to work it requires the necessary goodwill and political will on behalf of the stakeholders. Experience has shown that the stakeholder groups have, to date, functioned well in the UK with high attendance and commitment at meetings and a general acceptance of research findings. In Panama, local meetings of the stakeholder groups were very well attended but government clearance has, as yet, not been obtained to allow representatives of the group to attend a planned overseas workshop. For the RSA research, the group at present mostly comprises representatives from the project team organisations but it is planned to widen the scope of this group. Another approach to resolving disparate views is to research the organisational 'belief' systems to understand how the 'public' and 'science' perceptions have developed and evolved.

Major challenges and questions remain. How can we match resource and conservation-based development objectives with more people-focused, poverty alleviation objectives? Is it acceptable to use the 'useful myth' concept: that, in the public perception, forests are still regarded as good for water resources, as a means of 'protecting' indigenous forests? How valid is contingent valuation of forests and catchment services if the valuation is based on beliefs that we now regard as myths? Whilst progress is being made in connecting the science and public perceptions of how forests affect the functioning of the water environment, do we need now to focus on how to value better these different functions, particularly as these values may differ markedly between reservoired and non-reservoired catchments? When we look towards forests for their carbon sequestration benefits in preventing further global warming, should we not also be considering these benefits in relation to more local water resource disbenefits? These are some of the questions that still need to be resolved.

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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*, Aylward, 6935 Birch Street, Falls Church, VA.

Bosch, J.M. 1979. Treatment effects on annual and dry period streamflow at Cathedral Peak. *S. Afr. For. J.* **108**: 29–38.

Bosch, J.M. and 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, A publication of the Humid Tropics Programme, UNESCO, Paris.

Bruijnzeel, L.A., 2001. *Hydrology of tropical montane cloud forests: A Reassessment.* Land Use and Water Resources Research (LUWRR) http://www.luwrr.com/

Bruijnzeel, L.A., 2002. Tropical forests and environmental services: not seeing the soil for the trees? *Agric. Ecosystems and Environment.* In press

Bruijnzeel, L.A., Proctor, J., 1995. Hydrology and biogeochemistry of tropical montane cloud forests: what do we really know? In: Hamilton, L.S., Juvik, J.O., Scatena, F.N. (Eds.), *Tropical Montane Cloud Forests*. Springer Ecological Studies No. 110, 38–78.

Bruijnzeel, L.A., Veneklaas, E.J., 1998. Climatic conditions and tropical montane forest productivity: the fog has not lifted yet. *Ecology* **79**: 3–9.

Bruijnzeel, L.A., Hamilton, L.S., 2000. *Decision time for cloud forests*. IHP Humid Tropics Program Series 13, IHP-UNESCO, Paris, 41 pp.

Bruijnzeel, L.A., Waterloo, M.J., Proctor, J., Kuiters, A.T., Kotterink, B., 1993. Hydrological observations in montane rain forests on Gunung Silam, Sabah, Malaysia, with special reference to the 'Massenerhebung' effect. *J. Ecol*., **81**: 145–167.

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

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

Calder, I.R. 1992. The hydrological impact of land-use change (with special reference to afforestation and deforestation). *Priorities for water resources allocation and management,* Proc. Conf. Natural Resources and Engineering advisers conference, Southampton, July 1992. Overseas Development Administration.

Calder, I.R. 1998. *Review outline of Water Resource and Land Use Issues. SWIM Paper 3*. Colombo, Sri Lanka: International Irrigation Management Institute (IIMI). ISBN: 92 9090 361 9.

Calder, I.R. 1999. *The Blue Revolution, Land Use and Integrated Water Resources Management.* Earthscan, London, ISBN 1 85383 634 6.

Calder, I.R. 2000. Land use impacts on water resources. Background paper 1. FAO Electronic Workshop on Land-Water Linkages in Rural Watersheds. 18 September – 27 October 2000. http://www.fao.org/ag/agl/watershed/

Calder, I.R., Reid, I., Nisbet, T. and Robinson, M.R., 1997. *Trees and Drought Project on Lowland England*, Project proposal to the Department of the Environment, March 1997. Institute of Hydrology & Loughborough University.

Calder, I.R., Reid, I., Nisbet, T., Brainard, J. and Walker, D. 1999. UK water resources and planned lowland afforestation for community forests. *Proc. 2nd Inter-Regional Conference on Environment-Water*, September 1-3, 1999, Lausanne, Switzerland.

Calder, I.R., Young, D., and 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. Newcastle: Centre for Land Use Change and Water Resources Research, University of Newcastle.

DWAF. 1996. *The Working for Water Programme*, Ministry of Water Affairs and Forestry, Cape Town, South Africa.

Gunawardena, E.R.N, Calder, I.R., Rosier, P.T.W., and Chandrasiri, N. 1998. Hydrological importance of Horton Plains. *Proc. Final Workshop, University of Peradeniya - Oxford Forestry Institute Link Project.* Ed. H.P.M. Gunasena, University of Peradeniya, Sri Lanka.

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

House of Commons, Environment Committee. 1996. 1st report, session 1996-97: water conservation and supply. ISBN: 0 10 204297 7. The Stationery Office.

Intercarib S.A. and Nathan Associates. 1996. *Manejo Ambiental, Aspectos Institucionales, Economicos y Financieros:* Volumen 1 de 2, Informe Principal. Panama: Intercarib S.A. y Nathan Associates, Inc.

Langford, K.J. 1976. Change in yield of water following a bushfire in a forest of Eucalyptus regnans, *J. Hydrol*. **29**: 87–114.

Pearce, A.J. 1986. *Erosion and sedimentation*. Working paper. Environment and Policy Institute, Honolulu, Hawaii, 18 pp.

Robinson, M., Moore, R.E. and Blackie, J.R. 1997. *From moorland to forest: the Coalburn catchment experiment.* Institute of Hydrology and Environment Agency Report, Institute of Hydrology, Wallingford, UK.

Saberwal, V.K. 1997. Science and the desiccationist discourse of the 20th Century. *Environ. & History* **3**: 309–43.

Scott, D.F. and Lesch, W. 1997. Streamflow responses to afforestation with *Eucalyptus grandis* and *Pinus patula* and to felling in the Mokobulaan experimental catchments. *South Africa. J. Hydrol.* **199**: 360–377.

Scott, D.F. and Smith, R.E. 1997. Preliminary empirical models to predict reduction in total and low flows resulting from afforestation. *Water SA*, **23**: 135–140.

US Department of Agricultural Research Service. 1961. A universal equation for predicting rainfall-erosion losses. *USDA-ARS special report*. 22–26.

Van Lill, W.S., Kruger, F.J. and Van Wyk, D.B. 1980. The effects of afforestation with *Eucalyptus grandis* (Hill ex Maiden) and *Pinus patula* (Schlecht. Et Cham.) on streamflow from experimental catchments at Mokobulaan, Transvaal. *J. Hydrol.*, **48**: 107–118.

Versfeld, D.B. 1981. Overland flow on small plots at the Jonkershoek Forestry Research Station. *S. African For. J.*, **119**.

Waterloo, M.J., Bruijnzeel, L.A., Vugts, H.F. and Rawaqa, T.T. 1999. Evaporation from *Pinus caribaea* plantations on former grassland soils under maritime tropical conditions. *Water Resour. Res*. **35**: 2133–2144.