Social and environmental aspects of watershed vulnerability in the Sri Lankan hill country

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Abstract

The impact of selected human land use practices on the behaviour of water in the land phase of the hydrological cycle of watersheds in the Sri Lankan hill country is analysed. The study is based on the author's ethnographic research and consultancy work in Sri Lanka since 1991. Eco-hydrological and socio-ecological models of the co-dependency of water and socio-economic development are presented. Tree plantations, vegetable cultivation, tea estates and smallholdings, rural settlement and road construction, as well as the use of forests and grasslands are discussed. Social constraints on implementing hydrologically sound land use, as well as the social actors and organisations involved are identified. Fundamental knowledge deficits among land users, selectivity of competing economic interests and the lack of an integrated water centred approach to land use are observed. Land users are oriented towards narrow and relatively short-term economic returns and high productivity land use. Watershed vulnerability is the composite effect of the ecological consequences of such social constraints. The need for scientifically up to date education of government organisations and the public on eco-hydrology, and for regulatory measures implemented by an adequately empowered 'watershed management authority' are stressed as policy recommendations.

Introduction

Water is an indispensable resource for both the maintenance of viable ecological systems and the sustainability of economic production. The expansion of economic activity and of human populations causes an ever-increasing demand on water resources, while at the same time adversely affecting the environmental conditions of water availability. Water scarcity as a result of land degradation and resource competition in montane watersheds, prevails in innumerable communities in tropical and sub-tropical countries. The use of polluting technologies in both agricultural and industrial production, as well as unsanitary hygienic practices, undermine the quality of drinking water. As a result the production of livelihoods, the physical health of human beings, and the integrity of environmental resource bases may be jeopardised.

Water is therefore not merely an engineering problem, but a social issue. However, scientific understanding, as well as public knowledge, of the relationship between water and society are as yet insufficiently developed. The failure to adequately consider social and environmental aspects of water in development projects may significantly contribute to unanticipated social, economic and environmental costs, and thereby lead to project failures. These in turn could result in social conflicts, the containment of which can be both costly and difficult.

In this paper, I will provide an overview of some of the more significant current land use practices, which adversely affect water availability and quality in the hill country of Sri Lanka. First, I will provide two theoretical models, which situate human land use in the context of social and ecological systems in general, and of the land phase of the hydrological cycle in particular. Then I will discuss the impact on water of the following selected land use forms: Tree plantations, vegetable cultivation, tea estates and smallholdings, rural settlement and road construction.[1] The hydrological significance of forests and grasslands will be pointed out. For each impact I will identify the social causes of hydrological vulnerability, specifically the cognitive and economic constraints experienced by involved social actors and organisations. In this context, I will point out some policy implications to address the problems indicated.

[1] Some other hydrologically adverse land use forms not studied by the author, such as gem mining or urban built-up and waste are not included in this discussion. This in no way is meant to underestimate their importance.

This study is based on ethnographic field research and consultancy work carried out in the Sri Lankan hill country since 1991. Participant observation, open-ended structured interviews, life histories, survey research, participatory rural appraisal, collaborative mapping and the evaluation of demographic data available from government sources were among the research methods employed. I studied the knowledge and land use practices of farmers, foresters, planters and development consultants, as well as engineers involved in water development, road construction and housing development projects. Research was carried out in the upper Mahaweli watershed, including the Uma Oya catchment in the Uva Basin and the Nuwara Eliya region, as well as the upper Walawe watershed, and the Knuckles Range.

The Sri Lankan hill country comprises the island's central mountain massif, the Dumbara massif and the Rakwana massif, ranging from 500 to 2524 metres altitude and extending roughly over 10,000 km^2. The hill country falls into both the Intermediate and Wet Zones with annual rainfall ranging from 900 mm to 5000 mm (Vitanage 1997; de Silva 1997; Pannabokke 1997). The annual and inter-annual distribution of rainfall is highly variable, and, depending on location, altitude and aspect, distinct micro-climatic conditions need to be considered in land use planning. The major river basins originating in the hill country include the Mahaweli Ganga, Maha Oya, Kelani Ganga, Kalu Ganga, Gin Ganga, Walawe Ganga, Kirindi Oya, Menik Ganga and Kumbukkan Oya. These nine carry about 41.2 percent of the total discharge volume of all of Sri Lanka's 103 river basins[2]. Their innumerable micro-catchments generate essential water resources for agricultural, household, industrial and electric power production.

Theoretical models

The cognitive framework within which we conceptualise socio-economic activity and development efforts and their relationship to ecological systems and their hydrological components is very important. This will determine whether we perceive or ignore the impact of human land use practices on water resources and the effects of water availability on our capacity for sustainable socio-economic production. In this section I am proposing two theoretical models which emphasise the co-dependency of social and ecological systems in general, and of water and human land use in particular.

Figure 1 demonstrates the need to analyse social and ecological systems as co-dependent (O'Connor 1989) networks. Human beings are powerful participants of ecological systems, who depend on the viability of other participating life forms (biomass) and geo-climatic phenomena (water) in order to produce their livelihoods. Human beings participate in water and biomass flows as members of social systems and their conduct in ecological systems is decisively shaped by social factors. The entire gamut of social relations - power, stratification, conflict, the market, the state, development – and systems of knowledge shaping their activities impinge on human resource use and the relations of co-dependency within ecological systems (Starkloff 1998a, 1995b). At the same time the state of natural resources decisively shapes the capabilities of social production systems and thus knowledge and social relations.

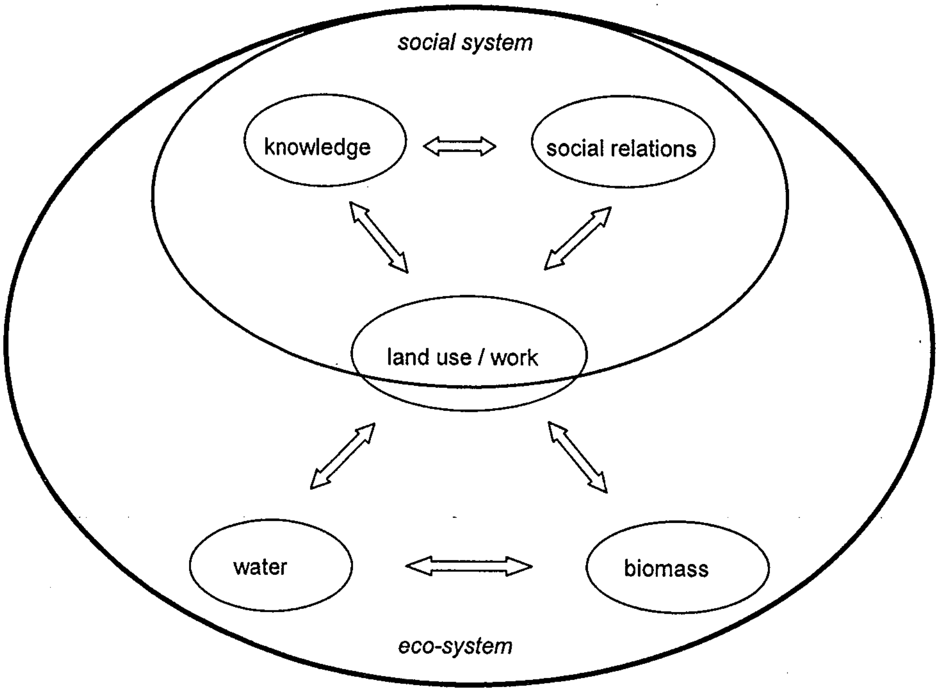
Land use and work constitute the interface between social and ecological systems. Therefore, mediated by human productive activity, pathways between the production of water and biomass are linked to social relations and knowledge systems in a reciprocal manner. Both degrading and sustaining systemic effects are transmitted along these pathways. The type of knowledge we apply to production is influenced by and influences reciprocally the social relations, in the context of which land use is organised. These then affect the production of biomass and water availability. Between biomass and water resources reciprocal co-dependency relations exist as well, where a certain type of biomass structure determines hydrological conditions and is at the same time affected by water availability itself. Water availability and the structure of biomass and soils in turn shape human land use and therefore social relations and our knowledge. Thus, the experience of water scarcity in many parts of the tropics and sub-

[2] Calculated from the data on discharge volume provided by the Survey Department of Sri Lanka (1988).

tropics has motivated us to rethink our current production systems and to seek to reorganise these in a sustainable manner.

Consequently, it is paramount that we do not perceive fragments of eco-systems as isolated resource bases of human land use, but view ourselves as embedded within eco-systems and the mutually structuring relationships in which we are forced to participate. If we fail to anticipate the potential consequences of our land use activities, we may be confronted with unanticipated consequences, which can adversely affect our ability to produce sustainable livelihoods and economic growth.

Figure 1: Socio-ecological model of production

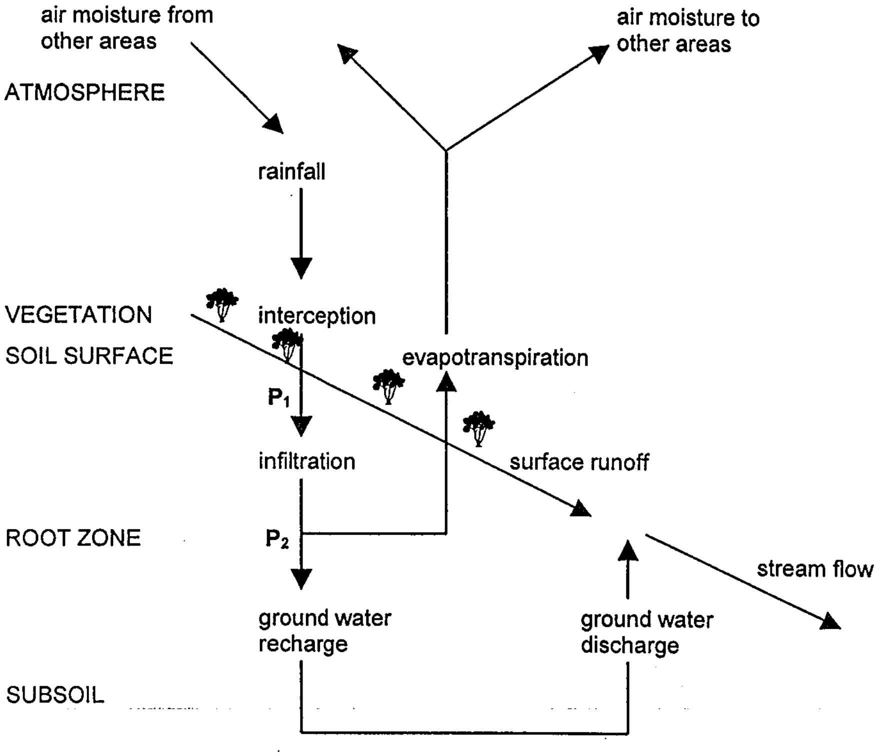


All components are co-dependent, interactive and mutually structuring. Social actors are participants in nature.

⟺ Indicates pathways, links or flows of energy, matter and information, transmitting both sustaining and degrading systemic effects. A given state of geo-climatic conditions is assumed.

The 'eco-hydrological' model depicted in Figure 2 further analyses the co-dependency between the behaviour of water, the production of biomass and human land use practices (Falkenmark and Lundqvist 1992; Falkenmark and Chapman 1989; ECE 1989, 1992; Bandyopadhyay 1988; Jayal 1985; Hamilton 1983; Bruijnzeel 1986). The relative quantitative distribution of rain water among three pathways in the land phase of the hydrological cycle - surface runoff, evapotranspiration and ground water recharge, partitioned at the soil surface P_1 and in the root zone P_2 - is determined by the structure of the vegetation and soil. Structures conducive to percolation and infiltration of rain water, such as forests and wet grasslands, minimise surface runoff, and ensure both plant growth and reliable dry season stream flow, on which irrigated agricultural crops, as well as households, industry and electricity production depend. Surface impermeability due to soil erosion and compaction, and/or excessive water uptake by vegetation, such as fast growing tree species, lead to landscape desiccation and water scarcity. Human land use practices therefore decisively affect the maintenance or degradation of the conditions of production of water, which in turn affect the viability of the production of human livelihoods (Starkloff 1998a).

Figure 2: Rainfall Partitioning 'P'



(Adapted from Falkenmark and Lundqvist 1992)

These models indicate the hydrological pathways along which polluting substances and effects are transmitted. Water necessarily flows through all components of ecological and embedded social systems and thus transports anything from human waste, through silt to industrial pollutants, which then may impair the viability of these systems.

Vulnerability of watersheds can thus be defined as the prevalence of land use forms which promote excessive surface runoff of rainfall at the expense of evapotranspiration and ground water recharge, as well as excessive evapotranspiration of infiltrated rainwater at the expense of ground water recharge. It is noteworthy that there is a necessary proportion of evapotranspiration, which sustains a biomass structure and permits the necessary catchment effect, i.e. infiltration and ground water recharge. In other words, each ecosystem component must be 'paid' for its services in order to function as a co-dependent participant. A sustainable ecosystem then would be one in which all participating components, including human beings and other biomass or life forms, as well as water and soils, are sustained in their existence without undermining the production conditions of others.

The eco-hydrological framework is not only an important conceptual device but provides us with a scientific explanation of unmeasured hydrological processes. For example, in the case of pine plantations, no representative longitudinal data was produced on evapotranspiration, soil moisture, stream flow patterns and silt load, before, during and after plantation establishment. Research in the 1980s neglected the geo-climatic conditions in the Uva and Sabaragamuwa Provinces, while the USAID funded Forest Department research station in Weweltalawa observed the behaviour of pines under the wettest rainfall conditions in the country (~ 5000mm) on closely guarded and fire protected plantations (Perera A. 1988; Gunawardena 1989). This procedure must be judged scientifically unsound.

The adoption of these theoretical premises provides us with a complex cognitive framework, from which guidelines for regulating human land use may be derived. It is, however, clear that mere technical insight into social and ecological necessities is insufficient to promote sustainable land use practices. These depend on human motivation and interest, which are shaped by socio-cultural perceptions and practices as much as social and economic constraints. For example, stratified property and power relations may provide large land users, such as the state or private corporations, with access to seemingly abundant resources and thus result in careless and wasteful use. This in turn would marginalise groups of smaller land users dependent on the same eco-system. These may thus be forced to overexploit the remaining scarce resources. Either group may make decisions based on fragmented knowledge, in which various land use activities occurring in the same watershed are perceived as independent of each other and of a social context. The resulting overall effect of such socio-ecological relations may be the wearing down of an eco-system. Therefore, sustainability requires an appropriate socio-cultural knowledge base and conducive social relations. The practical meaning of these concepts would need to be negotiated and regulated under consideration of existing power relations and environmental necessities. This is a difficult, but in my mind, indispensable task.

Land use and watershed vulnerability

In what follows I indicate the practical relevance of these theoretical considerations. I will deal with the hydrological impact of tree plantations, vegetable cultivation, tea estates and smallholdings, rural settlement and road construction, as well as with the involved actors' social constraints. Various policy recommendations are considered.

Tree plantations

Despite considerable controversy during the late 1980s and early 1990s, pine plantations have remained a dominant feature of the Sri Lankan Forest Department's current planting strategy (Starkloff 1998b). Between the 1960s and 1990, the Sri Lankan Forest Department had grown 18,614 hectares of pine and 18,570 hectares of eucalyptus in its Up-Country Division, making these the most frequently planted genera in the island's watersheds (Bharatie 1990). Despite their relatively limited extent, the eco-hydrological impact of tree plantations is considerable as they are invariably planted in the upper and mid-slopes of the hill country's micro-catchments. The decisive factors in the choice of these genera are the relative ease and speed of establishment, which reduces the cost of labour and other material inputs, and their fast growth, which provides for the earliest possible return on investments and the greatest volume of timber, fibre and/or resin per unit of time.

Globally, pine and eucalyptus are widely used as well to replace clear-felled forests and grasslands with monocrop plantations. They are an integral component of the Tropical Forestry Action Plan designed by the United Nations in conjunction with the World Bank and the World Resources Institute, 'to conserve and develop tropical forest resources on a long-term sustainable basis' (FAO 1987; World Resources Institute 1985; Environmental Defence Fund 1987; Shiva 1987; Wood 1988; Hamilton 1983).

In Sri Lanka during the 1960s research and forestry policy emphasised high productivity and thus concentrated on 'the building up of new industries and creating an economic base for the good of society' (Forest Department of Ceylon 1961). To make 'more, better and cheaper goods', 'ecological research' was carried out to find the most suitable species which would withstand the impact of 'severe environments', i.e. the grasslands of the hill country. The potential impact of the trees on such environments was never considered. Results of the trials persuaded local foresters and their advisors that pine and eucalyptus establish with relative ease and outgrow any indigenous forest species, which appear to be unable to survive seasonal moisture stress in the Uva grasslands. *Beeriya* was shown to be the only desirable indigenous timber species able to succeed under a canopy of eucalyptus. With the help of the Oxford Forestry Institute's data bank 'suitable' species and provenance were searched. *Pinus caribaea* from Belize (former British Honduras) and various species of eucalyptus from Australia were selected. Government financial resources supported planting at this point (De Rosayro 1945/46; Wood 1988; Bandaratillake 1988; Vivekanandan 1988).

As environmental discourse entered international development debates, 'production forestry' was coupled with 'conservation forestry'. In the context of Upper Mahaweli Watershed Management, the development of a new Forestry Master Plan and various IRDPs, the Forest Department received funds (US$ 16.5 million in loans and grants) and international development expertise from USAid, the World Bank, Finnida, ODA, UNDP and the Dutch government, to carry out the Reforestation and Watershed Management Project (RWMP). In the Upper Mahaweli watershed 9713 hectares of tree plantations were planted, consisting predominantly of pine and eucalyptus species. The rationale behind this strategy was the assumption that 'more trees' would cause 'watershed protection and soil conservation' (Bandaratilake 1988; Jaakko Poeyry 1986). The interest in bringing large expanses of the hill country watersheds under pine and eucalyptus could be legitimised by the circumstance that indiscriminate tree planting has become a popular ritual in environmental symbolics. The main sites of afforestation remained grasslands and abandoned degraded tea estates, which were summarily labelled 'denuded and degraded' (Perera W.R.H. 1988; Bharatie 1990; Bandaratilake 1988).

According to the 20 year evaluation of plantation resources carried out by ODA consultants at the Forest Department in 1991 (Forest Department of Sri Lanka 1991 a and b), and the then DFO Badulla, plantations established reasonably successfully, but were not adequately maintained, as thinning operations failed to be carried out. Foresters argued that the cost of harvesting pine from steep slope sites was above the current market price for private sources of fuelwood mainly from tea estates. Therefore thinning was unprofitable from the Timber Corporations perspective. Rather, the pine plantations are now leased out to local enterprises for tapping of oleoresin, thus making high planting densities desirable.

The controversy between farmers, foresters and environmentalists drew in politicians and members of Sri Lanka's academic community, and 'pinus' became a negative icon in the press and in general public discourse. The Forest Department was confronted with phasing out pines and started to exploit existing resources through successive tapping, thinning and eventual clear cutting. In response to public grievances about the experience of water scarcity in hill country villages, especially in the Intermediate Zone, some inter-planting trials were undertaken. Rows of trees within a few pine lots were cut, felled trees were placed as erosion barriers along the contour and various indigenous species were inter-planted. Once again 'more trees' were perceived as an environmentally sound measure. In the Kandyan Wet Zone Peradeniya University botanists experimented with inter-planting indigenous species under thinned pines. These established successfully due to higher rainfall. The impact on water resources remained unmeasured in these trials.

Desiccation of micro-watersheds afforested with pine and eucalyptus results from increased runoff generation at P1 and increased evapotranspiration at P2 of the rainfall partitioning in the land phase of the hydrological cycle. Pine and eucalyptus plantations present therefore, a worst case scenario for decreased ground water recharge.

In areas with regular seasonal dry periods, as in climatically exposed grasslands (*patana* and *talawa*), water demand of fast growing trees increases moisture stress in the soil surface and upper root zone. The canopy density of the ill-maintained plantations prevents the survival of the climatically adapted sun-tolerant grassland species which survive dry seasons through root dormancy. Shade-tolerant undergrowth, ecologically adapted to forest ecosystems, cannot establish. Litter matting from pine and eucalyptus adversely affects the capacity for seeding accidental species, promotes runoff and changes the chemical structure of the soil. The paucity of resources required by fauna reduces seed import and bio-diversity.

With the impact of inter-monsoon thundershowers and monsoon rains the plantation floor is eroded and the upper soil layers are washed away. In the plantations rocks are exposed, roots destabilised, and the soil structure is compacted due to the lack of moisture, micro-organisms and soil fauna.

These changes in the biomass structure effect increased runoff and evapotranspiration, thus unbalancing seasonal stream flow. In affected micro-watersheds, farmers and the author observed increased runoff, stream flow, earth slips and landslides during rainy periods. Erosive runoff causes silting of water courses, reservoirs and fields. During dry seasons, irrigation and household water resources decline or subside earlier in the agricultural cycle, than before plantation establishment.

If possible, farmers and villagers seek to cope by adopting pump irrigation from remaining water sources and by participating in household water supply projects. If these resources are not available, fields are abandoned or revert to rainfed cultivation, and household water is fetched from more distant sources, predominantly by women. All of these degradation phenomena and coping mechanisms impair the livelihood strategies of local households. They induce resource competition and potential conflict between farm uses and household uses, as well as between the Forest Department and the villagers.

Regular seasonal burning of pine plantations by villagers aggravates degradation effects. Burning is primarily a consequence of widespread anger among farmers. In addition, they burn the plantations to flush out wild boar as a pest control measure. Boars feed on pine roots, inoculated with mycorriza fungi to stimulate nitrogen fixation (Perera, A. 1988), and have increased in numbers. They raid the farmers' crops during the night.

Roaming cattle used to graze in the grasslands during daytime in rainy seasons and in the fallow paddy fields during the dry season. These were displaced after the planting of pine and eucalyptus, due to the loss of the cattle's habitat. Thereby, a crucial source of biomass processing and fertility was removed from local ecosystems.

The effects on water users of the hydrological impact of tree plantations vary depending on precipitation levels, which range between 1400 mm in the Uva Basin and 5000 mm in Weweltalawa. The longer the period of normal seasonal drought, the higher is the desiccation effect. In the Horton Plains (~ 3000 mm annual rainfall), one of the crucial catchments of the hill country, the dying back of cloud intercepting old-growth forests has been observed. The hypothesis that this is a consequence of the lowering of the water table of the plains by extensive planting of eucalyptus and pine 'buffer zones' around the lower slopes of the catchment (Palihawadena 1998), should be investigated. This would extend seasonal root zone desiccation beyond the critical tolerance threshold of the montane cloud forests. From Keppetipola in the Uva Basin to Aratenna in the Knuckles Range, farmers have complained bitterly about increased water scarcity. As the first upstream water consumers the plantation trees absorb considerable amounts of water resources and unbalance seasonal stream flow patterns on which local communities had depended for centuries.

By contrast, forests and grasslands had comprised environments high in bio-diversity (de Rosayro 1945/46), which provide an optimum catchment effect for locally specific geo-climatic conditions. The longer the typical dry season, the more forests and wet grasslands occurred only in sheltered gullies and hollows of micro-watersheds, while dry grasslands (*patana*) expanded over the larger climatically more exposed sites. In areas with less moisture constraints, forests cover larger areas and grasslands contain a higher concentration of sun-tolerant tree species (*talawa*). These dynamic constellations are conducive to less evapotranspiration in grasslands, while their runoff infiltrates into humus rich wet grasslands and forests located in gullies. In forests canopy interception and percolation further serve to slow down runoff and promote infiltration and soil moisture storage, which is slowly released into local water courses. The disturbance of these critical hydrological functions by the introduction of new land use forms interacts with the increasing water demands of a growing population to reduce the carrying capacity of micro-watersheds of the hill country. Pine and eucalyptus plantations, established on crown lands above most other water users, must be considered as a prime adverse impact.

The knowledge base of the foresters involved in plantation establishment was severely constrained by their lack of understanding of site-specific ecological and social conditions, and of the consequences of their activities. Forestry is not river basin centred and is not carried out with an eco-hydrological framework in mind. Rather, it is undertaken as a selective, fragmented activity, single-mindedly focussed on the production of a single commodity, wood for pulp and paper, timber, oleo resin and firewood.

The notions that indigenous tree species have a superior conservation effect than exotics, and that 'more trees are better' are generally accepted fallacies. These ignore climatically specific conditions and therefore the hydrological value of grasslands. The issue is not whether or not trees are indigenous, but their suitability in specific environments regardless of their geographic origin. Global movement of genetic resources during centuries has provided many of Sri Lanka's eco-systems with well adapted species, such as avocado, papaya, rambutan, cypress, bread fruit, and the like. The manner of plantation establishment, i.e. monocrops, under inappropriate geo-climatic conditions, the density of plantations and fast growth are the decisive issues.

Fast growing tree species in monocrop plantations were utilised because they promised the highest economic return on investments and made 'results' visible in a comparatively short period of time, a concern of any development project. The ignored or unintended adverse consequences of tree plantation establishment are treated as externalities, the costs of which are borne by land users other than the Forest Department.

The property rights of the state and the authority of the Forest Department legally sanctioned the industrialisation of forestry in the crownlands of watersheds. Farmers and villagers were excluded from access rights to resources from significant components of their former livelihood systems. They were never consulted about the land use conversion undertaken in their catchments. Even as they complained to the authorities about the effects of tree plantations, their knowledge was invalidated as unscientific, their grievances were evaded and inaction prevailed. Social distancing and exclusion decisively impair communication among the social actors involved in the pine conflict and continue to marginalise farmers. The only positive impact of the pine and eucalyptus plantations is the vastly increased opportunity for fuelwood cutting. This is, however, illegal and punishable, although it alleviates the often-acute shortages of firewood and thereby the pressure on gully forests in the Intermediate Zone.

Lack of plantation management betrays both cognitive and economic constraints, as well as a prevalent attitudinal problem among many governmental land users towards rational and reliable maintenance operations. The impact of not thinning overly dense canopy for 20 years was not considered. The lack of economic viability of thinned out pine timber served to rationalise the foresters' failure to follow prescribed procedures.

Foresters and all concerned land users need to acquire eco-hydrological knowledge and raise their awareness of the interdependence of various human user groups, other fauna and flora, and geo-climatic conditions. Water security and social equity need to be primary considerations of forestry projects, in order to avoid desiccation and resource conflict. Foresters need to revise their exclusive preoccupation with trees and consider grassland conservation and utilisation as one of their concerns.

Forestry requires organisational restructuring. Along with other governmental land use activities it needs to be integrated into river basin centred agencies, regulating and co-ordinating local land use activities. These institutions would bring various land users together at river basin, watershed and micro-watershed levels. These would undertake education among foresters, farmers, engineers, politicians and the interested public, and co-ordinate research and debates on land use planning, decision making and implementation, based on an ethic of equity and fairness. Property and access rights to crownlands of (micro-)watershed users need to be reorganised to ensure participation in land use planning and conservation measures among all pertinent actors.

Status rituals and attitudes serving to distance social groups from each other need to be unlearned to facilitate effective communication. Farmers need recognition as competent and interested land planners and users, capable of relevant contributions just as foresters, hydrologists or sociologists.

The pine and eucalyptus plantations need to be transformed through a range of conservation measures serving the interest of local land users in stabilising water resources and their livelihood needs. Conservation land use may include staggered felling of portions of the tree plantations in question; biological erosion control measures, such as sloping agricultural land technology (SALT); mixed forest gardens; low-extraction forests and wetlands in immediate catchments; improved grasslands for closely managed herding of cattle; and planned community based fuelwood production.

Specific measures would in the end need to be jointly developed by all land users and experts involved in a pine conversion project, under consideration of local conditions and carrying capacities.

Vegetable cultivation

The cultivation of exotic vegetables in the hill country dates back to the early colonial period. It turned into a widespread and successful production sector from the Second World War and expanded during the "Grow More Food" drive of the Sri Lankan government during the mid-1970s (Weitzel 1971; Abeysekera and Senanayake 1974). By now a productive and lucrative vegetable trade links hill country farmers with urban and rural consumers, mediated by the marketing services of traders and transport entrepreneurs[3]. Farmers employ green revolution technologies, involving improved seed varieties, agrochemical fertilisers, pesticides and weedicides, sprayers, kerosene pumps, and monocrop planting techniques. Corporate producers and wholesalers, private local traders, and the government's co-operative organisations provide these inputs. Input prices are high compared to farm gate earnings, particularly since the reduction of fertiliser subsidies (ARTI 1993). Vegetable fields are established in rotation with paddy fields, or by converting chena swidden cultivation into permanent hill fields, or by clearing forests and wet grassland, especially in or near gullies close to water sources (Starkloff 1998a, 1995a).

Vegetable cultivation contributes to landscape desiccation, water scarcity and seasonal imbalance of stream flow. The removal of forest and grassland flora and their replacement with clear-weeded high-productivity monocrops increases soil exposure to rainfall impact. Erosive runoff contributes to the silting of watercourses, reservoirs and fields. Agrochemical inputs reduce organic matter in the soil and destroy micro organisms and soil fauna. Soil water evaporation and soil erosion, and runoff increase at the expense of ground water recharge. These effects are aggravated by splash erosion where water pumping with 2-inch irrigation hoses is carried out.

The rotation of paddy and vegetable crops in valley fields involves the cyclical shift from bunded paddy fields to well-drained raised vegetable beds. This practice disturbs the structure of the soil and contributes to increased erosion and runoff. The disappearance of the fallow deprives the soil of fertility inputs (dung and green manure) and water retaining organic matter.

Agrochemical residues are leached into the pathways of water and expose downstream water users to pollution. Priyantha's research carried out in the Badulla district found that 76 percent of farmers applied more than the recommended dosage of pesticides, some at concentrations as high as 200 percent (1990). He indicates that as a result pests, which cannot be controlled by pesticides, have increased, as beneficial predators were eliminated.

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[3] No reliable data on the extent of vegetable cultivation are available, as the Department of Census and Statistics classifies cultivated lands in which vegetables may be grown as paddy, highland and homegardens.

Although many farmers worry about input prices, lack of organic matter in the soil, water pollution and scarcity, they fail to fully understand and acknowledge the adverse hydrological consequences of their own production practices. While many aspects of eco-hydrological knowledge are observable among farmers, most understand only unsystematic fragments and rarely apply these in their land use planning and practices.

Sustainable cultivation practices are constrained by farmers' interest in cash, needed in a modern competitive cash economy. Since producer incomes are relatively marginal and vulnerable to adverse weather conditions and market fluctuations, farmers lack the capacity to invest in conservation measures, and aim for short-term returns on their investments. High-productivity crops serve their interests and lock them into dependency relations with input traders, transport agents and retailers.

Furthermore, vegetable cultivation is an individualised form of cultivation and imposes less labour mobilisation constraints than paddy cultivation. High caste goigama farmers who are frequently under obligation to extensive reciprocal attam (exchange labour) relations therefore prefer it. Lower caste and estate labour vegetable cultivators, who are anyhow excluded from these labour mobilisation relations and frequently from paddy field ownership in the fertile valley bottoms, prefer vegetable cultivation as well.

Water scarcity motivates hill country farmers to reduce or abandon paddy cultivation. Diminishing returns lead them to intensify vegetable cultivation, and to expand further into forests and grasslands to increase their acreage. This effect interacts with population increase which has caused increasing subdivision of family plots and the opening up of new agricultural land where possible. By now very steep slopes, which experience degradation very quickly, have been brought under cultivation in the Uva Basin.

Farmers need to be reoriented towards an eco-hydrological conceptual framework, which requires education of extension officers as well. Small and mid-sized farmers' cultivation would have to be to be integrated into a river basin centred approach to land use planning and practice. Farmer participation in institutional land use planning discourses, decision making and implementation, needs to be ensured. Both research with farmers and representation of farmers in regulatory and implementing organisations can provide essential inputs.

Cost and pricing structures need to be influenced to ensure more equitable and higher returns on investments while freeing capital for farmer driven conservation measures. Diversification into perennial, value-added crops for export and local sale, needs to be encouraged. This may be done through subsidies, grants, loans and taxation. Farming practices that have less adverse hydrological impact would be rewarded with financial and institutional support, while high levels of externalities need to be punished. None of this can, however, work without ensuring that markets for ecologically sound products create sufficient demand to sustain conservation farming.

Conservation measures with the dual goal of increasing watershed capacity and economic returns should be tailored to the needs of cultivators with different levels of resources and incomes. These measures may include SALT using both tree and grass species; increase of organic matter and fertility (dung, compost, mulch), in combination with reduced application of agrochemical fertilisers (to ensure economically sustainable yields among low-income farmers); biological pest control and companion planting, in combination with reduced use of agrochemical pesticides (to ensure economic sustainability); as well as long-term investment in mixed perennial crops to diversify production among middle farmers and associations of small farmers. In all of these instances sound marketing is essential.

Increased use of cows for the production of milk (direct sale and value added processing) and manure requires careful management. Grassland feeding is feasible only if stocking densities are kept below specific thresholds to avoid erosion and overgrazing. Supervision by full-time herders, tethering and fencing may be needed to avoid crop damage from straying cattle. During nights cattle need to be locked in stalls. Stall-feeding may lead to over-cutting of grasslands, especially in gullies, and requires the planned production of fodder resources by farmers on allocated plots.

This complex set of requirements remains constrained by the limited acreage available to most farmers, a matter to be considered in watershed land use planning on decision-making levels higher than individual households. It remains furthermore constrained by desiccating land use practices of upstream users, such as the Forest Department. Successful conservation implemented by farmers is only feasible if sufficient water resources are available. The need for integrated planning and action, which overcomes the current state of fragmentation in knowledge and practices, appears self-evident.

Tea estates and small holdings

Tea estates cover an extensive land area in the hill country's watersheds and are a significant source of foreign income earnings in Sri Lanka. In Nuwara Eliya District 51,906 hectares, in Badulla District 30,406 hectares and in Kandy District 23,391 hectares were under tea in 1994 (Department of Census and Statistics 1997). The tea estates are currently in a process of transformation to increasing private ownership by corporate investors, although the state remains an important producer. In addition, small to midsize planters and farming households maintain 23,685 hectares of smaller tea gardens in Nuwara Eliya, Badulla and Kandy Districts (Sri Lanka Tea Board 1996). Larger estates in particular occupy the upper catchment areas of innumerable hill country watersheds and tend to be located above village land, thus impacting resource availability of downstream land users.

Tea cultivation has been thoroughly affected by green revolution high productivity technologies with the aim to maximise returns on investment. It involves the use of improved plant material, and agrochemical fertilisers, pesticides and weedicides. Biomass production on most tea estates is highly dependent on external nutrient inputs of agrochemical fertilisers. The sector consumes the greatest amount of inorganic fertiliser per hectare in the country. Between 1979 and 1987 overall applications increased from 425 kg/ha to 625 kg/ha (NARESA 1991). Amounts are likely to be lower in small private estates, where cash flow tends to be limited and access to credit is constrained, by comparison to large state owned or privatised plantations. The reduction of fertiliser subsidies would have further reduced fertiliser use.

Tea plantations are generally rainfed monocrops established on cleared forest and grassland. Various other perennial crops may to some extent be inter-planted. In well-maintained estates pruned tee trees form a dense low canopy which covers the ground almost entirely. High and low shade trees provide an intermittent barrier to direct sunlight. In degraded tea estates the groundcover is frequently interrupted, shade trees are often lacking, plant growth is inferior and the soil is eroded. This occurs particularly in old plantations requiring replanting, and on steep slopes.

Estates and smallholdings are based on an industrial labour mobilisation regime with a predominantly Tamil estate labour force. Vegetable cultivation and cattle rearing are important production components of hill country tea estates and a source of income for planters as well as estate labourers. The settlement of the estate labour force and of managerial staff involves considerable resource claims and impacts as well.

Historical research into the impact of tea plantations (Meyer 1983) suggests that farmers experienced reduction of stream flow and silting of paddy fields in addition to the loss of free biomass resources from crownland. Plantation establishment in the 19th and early 20th centuries met with frequent complaints and litigation. Typical degradation effects in tea estates are soil exposure due to clear weeding, reduction of organic matter in and compaction of the soil, and leaching of agrochemicals into pathways of water. As tea estates are frequently located on steep slopes, vulnerability to rainfall impact is evident. Conventional soil conservation measures such as terracing are often lacking. Recycling of biomass produced inside the estates is minimal. There is little build-up of leaf litter, and emerging ground cover of herbaceous plants is weeded frequently and removed, leaving the soil exposed. Even on very steep slopes where no tea can be grown ferns and grasses are often removed with hoes, causing minor earth slips. The tea plants are pruned before the onset of the rainy season, thus increasing the exposure of the soil to rainfall. Continuous treading of the slopes by estate workers compacts the soil or causes its dislocation. In Nuwara Eliya District 28,903 hectares (above 50 percent) of land under tea are considered poorly managed and account for 55.3 percent of total erosion in the district (Widanapathirana 1991).

The hydrological effects of tea plantations are similar to those in tree plantations. The dense planting of deep-rooted monocrops increases evapotranspiration compared with forest and grassland flora, and the degradation of the soil reduces infiltration and groundwater recharge. Hamilton reviewed studies of conversions of forested land to tea and other food or extractive tree monocrops and concluded that steep slopes, clear weeding and the lack of soil conservation measures were associated with increased surface runoff and erosion (Hamilton 1983).

Forests in proximity to tea estates, particularly in gullies and in the upper catchments, but also in areas distant from the estates, experience resource demand for fuelwood by both tea factories and the estate population. Pruned and lopped fuelwood from tea and shade trees can only partially and seasonally cover workers' demand for fuelwood. Homegardens are usually not a part of estate workers livelihood systems for lack of land, time and custom, and no self-produced sources are available. In the lower sections of estates gully forests are usually non-existent. They have been cleared and converted to tea, vegetable cultivation or fodder grass. In the upper sections closer to forest resources estate workers extract fuelwood from natural forests. Both dead and life trees (lopped branches as well as whole trees) are harvested. If extraction exceeds the forest's capacity for regeneration, forest cover in the upper catchments of tea estates is gradually reduced.

Fodder production for cattle maintained by estate workers and by estates themselves poses another threat to forests and grasslands. Particularly in gullies, persistent fodder cutting causes the exposure of soil to rainfall impact and thus erosion, and the regeneration of forestland is prevented. In so-called bio-tea estates in the Haldummulla Division, Badulla District, demand for fodder and green manure has increased tremendously to facilitate composting, the only source of fertiliser permitted. As a consequence, estate workers, who sell compost to the estates and milk to local processing facilities, are persistently clear- cutting fodder grass resources in micro-catchments and stream gullies, as well as on steep hills not utilised for tea. One of the estates involved operates three lorries with crews of up to 12 workers who regularly scavenge fodder grass in an area with a radius of 100km from Haldummulla town. In this case, a project seeking environmental sustainability actually increases demand for organic sources of fertiliser production and thus generates new externalities not accounted for in the internal production process.

Settlement conditions of the estate population pose various hydrological hazards as well. The staggering lack of toilets and the prevalent reluctance to use available communal facilities, cause widespread defecation into watercourses, and thus pollution of downstream water sources for drinking, bathing and washing. Housing facilities are ecologically unsound as well. The cutting of level platforms on steep slopes and the lack of proper drainage systems promote erosive runoff. These effects are further discussed in the section on rural settlement below.

Vegetable production in the estates is subject to the same impacts and constraints indicated in the section on vegetable cultivation. As many estates are located upstream of village cultivation their water demands and erosive effects directly impact the state of resources in the villages. Here resource conflict bears the potential for ethnic friction. In the Walawe Ganga catchment near Haldummulla downstream paddy farmers mobilised the local Grama Niladari to march into the vegetable fields of estate labourers located upstream, and destroyed their irrigation channels, claiming that these significantly reduced water availability during the yala cropping cycle.

Just as pine and eucalyptus plantations, tea plantations are responsible for the reduction of water availability, unbalanced seasonal stream flow and the silting of watercourses, reservoirs and fields. The application of agrochemicals severely alters the chemical composition of water resources, and human waste pollutes downstream water sources, all of which pose hazards to the health of human and other life. Their historical and continuing impact on forest and grassland resources is severe and has significantly altered the hydrological regime of the hill country. This impact is today perceived as more or less normal, since degradation in tea estates had been initiated already about 130 years ago. By contrast the additional impact of tree plantations and vegetable cultivation has been fairly recent. It must, however, be noted that each of the land use transformation undertaken since human settlement of the central hill country from approximately the 11th century adds to a cumulative degrading effect. The recent interventions have simply pushed the conditions of production of water beyond the threshold of viability, given the simultaneous increase in water demand.

The main social constraints involve again cognitive limitations, as the owners, operators and labourers of tea estates are generally ignorant of eco-hydrological dynamics and their production techniques are not oriented by such knowledge. Their training focuses on high productivity monocrops and thus fragments the tea sector from its environment. Moreover, the socio-economic purpose of estates the generation of profit from an export commodity, as well as the structure of production relations in estates favours single-minded productivism and the externalisation of environmental costs.

The relatively high cost of production based on agrochemicals, causes reluctance to invest in conservation measures. Especially in smallholdings, due to the relatively small scale of production, operators lack the necessary financial means to invest in replanting of degraded sectors and in soil conservation. Social constraints interact here with cognitive ones. Planters for example assume that weed competition would lower productivity, while it is not considered whether the costs of erosion losses and of fertilisers and weedicides outweigh the benefits of clear weeding. The bio-tea alternative may successfully address these issues, but generates new resource demands and externalities. In either case, profitable production is only maintained by externalising environmental cost factors and destabilising local eco-hydrological conditions.

The Upper Mahaweli Watershed Management Project (UMWP) was able to reform production practices among participating privatised tea estates to some extent with the introduction of biological erosion control measures. Large estates are comparatively easy targets for such programmes, since their top-down command structure permits the imposition of new production techniques on large expanses of land. The level of environmental knowledge among the management of these estates was observed as being comparatively high, due to extensive training and expert support from the UMWP. As long as plantations remain profitable, self-sufficient and sustainable biological erosion control may be expected to continue. The question remains how non-participating estates in the private and state sectors, as well as small holders can be motivated to implement the same measures.

In addition to biological erosion control, it will be necessary to introduce composting and mulching of weeds to increase organic matter content of the soil. Rehabilitation, protection and sustainable use of forests and grasslands in hydrologically sensitive areas will be needed. The early colonial practice of keeping gully and catchment forests within tea estates uncultivated to ensure water supplies to down stream users on and outside tea estates needs to be revived.

The current Estate Forestry / Buffer Zone Management Programme among private tea estates growing eucalyptus plantations for fuelwood and value-added timber processing needs to be carefully controlled to avoid further watershed degradation. The production of fuelwood and timber resources by estates themselves is desirable in order to address shortages and depletion of forest resources. Planting in hydrologically sensitive locations needs to be prevented.

Access rights to natural resources by estate workers need restructuring to avoid indiscriminate and degrading resource use. Without user rights which provide a personal stake in resource maintenance this impoverished social group will hardly be motivated to practice responsible land use.

Comprehensive education regarding eco-hydrological dynamics and improved land use practices will be required as well. Institutional structures integrating the tea sector into river basin land use planning as much as regulatory measures, need to be implemented with sufficient means for positive and negative sanctions. Tea producers need to be persuaded that they are not simply producing a single crop but are the managers and users of entire micro-watersheds responsible for either the degradation or maintenance of water and biomass resources on which they themselves, as well as other down stream users depend.

Rural settlement

The number and density of homesteads in the village and estate sectors have increased due to population growth[4]. Scarcity of housing motivates three strategies, the expansion of settlements by squatting and eventually acquiring titles in forest and grassland areas, or by subdivision of existing family homesteads, or by participation in rural village and estate sector housing projects. The latter allocate state land for dense settlement to rural households. In the hill country this invariably requires homestead establishment on hill slopes, some of which may be extremely steep. House construction is generally undertaken without environmentally sound design and water or soil conservation measures, and thus constitutes a considerable adverse impact on water resources.

Customarily level platforms (*gepola*) are cut into a slope to provide a construction site. The soil is thrown down the slope, smothers vegetation and topsoil of home gardens, forests and fields, and is left to erode with the rains. The increase of platforms, roofs, roads, paths and drains create impermeable surfaces which promote increased runoff and erosion (Kovacs, Zuidema and Marsalek 1989).

Increased settlement density simultaneously contributes to the reduction of ground water recharge and increases demand on water resources thereby lowering local water tables. The recent widespread rural water supply and sanitation projects failed in general to consider and carry out source protection. Insufficient upstream sources motivate groundwater extraction with open and tube wells. This practice has induced resource competition between up- and downstream users, especially between household and cultivation needs (Starkloff 1996). As a result of a NGO project in a village near Hali-Ela, Uva Basin, villagers had deprived themselves of water sources for their downstream paddy and vegetable fields by installing a water supply scheme. They eventually decided to dismantle their household water supply scheme, returned to their customary *pihila* (spouts) and cultivated their fields.

Water waste among household users is widespread but unmeasured. Local observation confirmed that many supply systems are ill maintained and leak perpetually, and that users fail to shut-off public and private taps, thus treating pipe borne water as if it was a stream. Water on tap in homesteads is far more wasteful if not used conservatively, in contrast to carrying pots from spouts and wells. While this is admittedly a burden for women, water users are motivated to conserve every drop of their heavy load.

Human garbage, faeces, agrochemical residues, and silt adversely affect the quality of household water supplies. Insufficient and polluted water lowers personal hygiene and impairs human health, especially among small children.

Home gardens have traditionally surrounded rural village homesteads and used to act as a sink for runoff from house sites, as well as a self-sufficient source of food and fuelwood. Current practice fails to maintain or establish homegardens with perennial trees. Extensive felling and establishment of vegetable cultivation have been observed in many old homegardens. At best tall trees are maintained at the peripheries of these gardens. New homesteads generally lack a canopy altogether and favour vegetable cultivation. Fast growing timber species, especially eucalyptus, have become a desired home garden cash crop. Again, the hydrological effect is increased runoff and evapotranspiration at the expense of ground water recharge.

[4] Except for Nuwara Eliya District, which experienced a 12.3 percent population decline, all hill country districts estimated population increases from 8.4 percent in Kegalla to 17.9 percent in Kandy between 1981 and 1990 (Department of Census and Statistics 1991).

The transformation of home gardens towards annual cash crops and fast growing timber tree species is, of course, a response to both the need for cash and the prevalence of land scarcity among villagers.

Ecological impact of human settlement in rural areas is among the least researched environmental problems and neither individual homesteaders, nor public housing projects undertaken by the state or NGO sector welfare organisations, consider eco-hydrological dynamics. Besides ignorance, the cost of housing prevents poorer households from investing in water conservation and erosion control measures. Furthermore, the lack of a long-term personal stake in a homestead of their own, undermines estate workers' interest in conservation.

Comprehensive and detailed research into prevalent housing practices and their ecological impact is needed. On the basis of research, an education project on eco-hydrological dynamics and the impact of current housing practices needs to be organised for the general public and state actors involved in housing. Currently, no regulatory framework promoting ecologically appropriate rural housing, which covers both individualised and state organised house construction, exists. Guidelines for improved design and construction of housing need to be developed. Regulatory agencies need to be able to positively and negatively sanction settlement practices. Housing and concerned government bodies need to be integrated into a river basin centred institutional structure of land use planning and implementation.

Among desirable improved techniques would be the introduction of houses on stilts to avoid cutting of *gepola* on steep slopes; proper rainwater collection and channelling from roofs to rainwater harvesting tanks, silt sinks and check dams for run-off; source protection of household water supply systems; the improvement of building materials to ensure durability as well as reduction of resource demand, for example for fuelwood in firing bricks; and the promotion of full-canopy homegardens around houses to trap run off and provide an immediate source of food and fuelwood.

Property and access rights to housing, particularly in housing projects, need to provide occupants with a clear stake in their homesteads and may be used as an incentive for environmentally improved techniques of design and construction.

Road construction and maintenance

In the hill country roads are built along the slopes of often-steep hills and mountains, thus posing potential erosive hazards which affect the surrounding land and water resources. Current road construction and maintenance practices are unsatisfactory from an eco-hydrological point of view. They promote erosive runoff, landslides, and silting of watercourses, reservoirs and agricultural lands. Road construction technology fails to adequately consider these impacts as much as the geo-climatic conditions under which it operates.

At the beginning of the 1997 April rainy season in the highland Uva, the Road Development Authority (RDA) of the Badulla district commenced road-widening activities along the road from Welimada to Bandarawela, Haputale, Beragala and Marangahawela. Along the upper side of the road, large earth removal vehicles scraped off earth and rocks. The debris was then dumped downhill into adjacent lands and along the road. In the process road drains and culverts were clogged with earth and rocks as well[5]. As the rainy period intensified the roads and the debris produced huge amounts of muddy runoff draining indiscriminately into gullies, streams and agricultural fields[6]. Meanwhile, road construction stopped in the second half of 1997 after the completion of road-widening activities, due to the lack of funds.

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[5] The same effects result from improper maintenance of road drainage channels. Once overgrown and silted drains and culverts are clogged, roads are destabilised due to seepage of stagnant water.

[6] Another example of this widespread condition was observed in the immediate catchment of the Samanalawewa reservoir: A paddy farmer reported flooding of erosive runoff into his homegarden from earth removal sites of the Samanalawewa wet-blanketing project and from eroding drains and culverts along the project's steep access road constructed in 1998. He feared that severe rains during the coming monsoon would carry water and silt into his house and paddy fields.

Ever since, erosive runoff from road-widening as well as from uphill land use is conducted along the road during rainfall events. Water is collected in stagnant pools above ill-maintained portions of the road, from where it slowly seeps under the road surface to cause its movement and breaking, and eventually land slides, due to soil saturation. In this instance, uphill land degradation and road construction interact to destabilise the landscape.

The 1997/98 landslides between Halpe in Sabaragamuwa Province and Koslanda in Uva Province along the main trunk road occurred predominantly below tea or pine plantations along portions of the road with ill-maintained drains. Curiously public blame was accorded to high levels of rainfall. However, high levels of intense rainfall are normal in tropical environments and land users need to consider such phenomena as routine conditions. The blame lies with people, not weather, since the hydrological conditions created by the land use practices of planters, foresters and the RDA have resulted in the destabilisation of the road.

Road engineers and workers are cognitively constrained by fragmented, single-issue oriented knowledge, which fails to take eco-hydrological implications into account. The lack of timely road maintenance indicates lack of proper planning and of a work ethic promoting responsible, reliable and environmentally sensitive work. These deficits are compounded by the lack of adequate funds and their cost-effective allocation. As in other land use impacts discussed above, carelessness, ignorance and the externalisation of environmental costs, can conspire to produce disastrous consequences.

The viability of a new highway system that directly connects hill country towns to additional trunk roads crossing the lowlands should be investigated. This would ease the volume of traffic on unstable hill country roads.

Improved road construction techniques would require proper geological surveys and reasonable siting decisions; proper fit of work schedules within climatic patterns (commence work at the end of rainy periods); removal and reuse or careful disposal of excavated earth and rocks; persistent maintenance of drains at all times; and the introduction of biological erosion control measures along roadsides.

These measures would of course increase the cost of road construction, but current externalities would be avoided and the true price of road construction would be at least to some degree borne by the responsible land user. Yet, upstream responsibility for increased silted runoff would still be evaded if road building was reorganised without changes in its socio-ecological context. The fact that road degradation results from interactive effects of various land use forms, affirms the need for integrated watershed and land use management which can target tea estates and the Forest Department alongside the RDA, and for a watershed management authority capable of supporting and enforcing compliance.

A final example illustrates this point from the perspective of the Uma Oya watershed. Along Welimada road dumping of debris from road widening by RDA, during several days of rainfall caused immediate silting of the Mahatotila Oya, a tributary of the Uma Oya. Uma Oya's heavy silt load is derived from erosive runoff in pine and eucalyptus plantations, tea estates, vegetable cultivation, urban and rural settlement, in addition to road construction. This silt load is eventually deposited in the Rantembe reservoir and adversely affects the project's power generation capacity.

Conclusion

Watershed vulnerability in the Sri Lankan hill country is the composite effect of the ecological consequences of a range of social constraints on human land use practices. Land use practices, which increase runoff and evapotranspiration of rainwater in the land phase of the hydrological cycle, at the expense of ground water recharge, impair the productive capacity of watersheds and consequently human livelihood activities. In my discussion I identified fundamental knowledge deficits among all land users, the selectivity of competing economic interests and the lack of an integrated water centred approach to land use as typical social constraints.

- The knowledge of land users tends to be fragmented and selectively oriented towards isolated interests. It lacks insight into eco-hydrological dynamics and the socio-ecological conditions and consequences of human land use practices. Land users therefore fail to adequately understand and acknowledge adverse hydrological consequences.
- In land use planning, interdisciplinary scientific research into social and environmental aspects of water remains an exception and public education on water and land use is inadequate.
- Land use practices are fragmented and selective as well, as they are focussed on the production of isolated goods or services. In a commoditised and competitive economic context, land users seek the highest economic return on investments within the shortest possible period of time. They therefore favour high productivity land use technologies and seek to externalise environmental costs.
- Low-income land users are particularly affected by scarcity of cash. However, the relatively high cost of agricultural production based on green revolution technologies constrains the financial capacity and/or willingness to invest in conservation measures among all land users. Similarly, the considerable cost of housing constrains the ability of low-income groups to invest in water conservation and erosion control measures.
- The lack of more equitable access rights to resources and the legally sanctioned capacity of state and corporate actors to dominate resources, disempower less affluent land users, who therefore fail to perceive long-term personal stakes in resources which would motivate their conservation.
- Communication among land users is frequently ineffective because of status rituals and social distancing. Experts and government officials tend to de-legitimise the knowledge of lower status groups.
- Inadequate planning, ignorance, carelessness and the lack of a satisfactory work ethic often prevent reliable and environmentally sensitive maintenance operations in land use activities.
- The lack of an institutional context capable of initiating, co-ordinating and regulating integrated watershed management within the context of river basins is a significant social cause of watershed vulnerability. Current governmental, non-governmental and private organisations involved in water and land use management are fragmented and lack shared communication and planning.

The following summary of policy recommendations, made in greater detail throughout my analysis of selected land use forms, indicates how the constraints outlined above may be approached. These are no more than general pointers intended to stimulate debates. I perceive the need for both an improved knowledge base shared among land users of a watershed and the institutional regulation and co-ordination of their interests and activities as the central tasks.

- All concerned land users need to acquire eco-hydrological knowledge. A comprehensive education project to familiarise people with eco-hydrological concepts, to inform them about adverse consequences of their land use practices and to promote alternative production strategies, needs to be implemented in schools, communities, governmental, non-governmental and private organisations, and the media.
- Interdisciplinary research on all social, environmental and technical aspects of watershed management will be an indispensable input into both education and project design and implementation.

- Currently fragmented groups and organisations, involved in land and water use, need to be integrated by watershed management authorities, which regulate and co-ordinate all land use activities occurring within a river basin. Site-specific local activities could be under the jurisdiction of micro-watershed management projects, and island-wide co-ordination could be carried out by an apex organisation within the national government.
- Among the functions of watershed management authorities would be research, education, public debate, the development of guidelines for ecologically sound and socially equitable water and land use, as well as the overall planning and supervision of the implementation of resource development projects in a river basin.
- To enforce such guidelines, the authorities would need to be empowered with sufficient means of positive and negative sanctions. Subsidies, grants, loans and taxation can be used to reward hydrologically sound land use or to punish high levels of environmental externalities. An effective legal framework needs to be established within which offenders who violate watershed integrity can be sanctioned.
- Participation of affected land users in debates, decision making and in project implementation, needs to be built into these authorities, to motivate interest in co-ordinated land use. These structures of communication need to overcome social distancing between different status groups.
- The authorities need the capacity to influence cost and pricing structures in order to ensure sufficient returns on land users' investments to free capital for conservation measures. They should also seek to support markets for environmentally sound products.
- Finally, watershed management authorities need to function as a forum to negotiate and regulate access rights to resources, in order to mediate potential resource conflicts among land users.

Well managed sustainable land use requires de-fragmentation of knowledge, authority and land use practices, and the establishment of information and biomass flows promoting a co-dependent existence of life forms and phenomena suitable for a watershed. Suitability is of course a matter of definition, of human judgement. The proposed watershed management authorities thus need to be sufficiently democratic and transparent to allow a free and scientifically sound debate about what kind of watersheds human beings can and want to live in.

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