



Lessons from two long-term hydrological studies in Kenya and Sri Lanka

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Abstract

The rate and characteristics of land use change in tropical watersheds due to changing demographic, economic and policy factors have important consequences for catchment health and environmental services. Few tropical watershed studies have lasted long enough to facilitate a credible analysis of the long-term effects of land use change on the environmental services provided by watersheds. This paper examines the driving forces and patterns of historical land use change in two long-term watershed studies in Kenya and Sri Lanka and their hydrological impacts. The upper Ewaso Ng'iro north basin is located to the north and west of Mt. Kenya, and has experienced dramatic changes in both land ownership and land use due to rapid population growth of 7–8% per annum. The upper Nilwala basin is located in the south of Sri Lanka and the area has undergone serious deforestation over the last 50 years, for agricultural land uses mainly for tea and home gardens. The loss of watershed functions associated with the impacts of land use change and their socio-economic dimensions are discussed, along with lessons that can be drawn from these studies.

These case studies confirm the importance of long-term monitoring of the interaction between land use changes and catchment health. Moreover, the involvement of all stakeholders is crucial for problem identification through to the research and the search for any viable ecological, social and economical solutions. A holistic approach involving relevant disciplines in watershed studies is vital. The paper concludes that use of models that integrate both biophysical and socio-economic data should be encouraged to derive decision support tools for farmers and managers alike who are faced with resolving conflicts and other issues related to limited land and water resources.

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1. Introduction

Traditionally, the main aims of hydrological research have been to provide an understanding of the water balance operating in forested catchments or watersheds, the physical processes that control water

movement and the impacts on water quantity and quality (see Bachelor et al. (1998) for a historical account of pioneering catchment studies). Few of these long-term catchment projects survive to the present day in the tropics but their findings have nevertheless shaped much of the current decision making on land use.

Forested catchments or state forests are usually protected to keep out local communities, who value and depend on the ecological, economic and social func-

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tions that the forests provide. Conversion of protected forests or forested areas for agriculture has raised numerous concerns amongst policy makers and local communities about the loss of ecological functions, especially the increasing incidence of floods, sedimentation and the declining river flows (Tomich et al., this volume). In many developing countries, extensive areas are undergoing rapid land use changes, the largest change being due to afforestation and deforestation activities. Conflicts in water use stem from agricultural demands for irrigation water competing with those of industry, hydroelectric power, wildlife and human consumption. Therefore, in recent years there has been a growing pressure for participatory planning and management of water and other catchment resources.

This paper describes two of the few remaining long-term watershed studies in the tropics in an attempt to distil the lessons learned. The first is located on the slopes of Mt. Kenya, where water supply is critical, causing conflicts between various land users, wildlife and intensive irrigation. The other is located

in the humid regions of Sri Lanka, dominated by tea plantations. Both locations are densely populated.

1.1. Description of the study watersheds

1.1.1. The upper Ewaso Ng'iro basin

The upper Ewaso Ng'iro north basin is located to the north and west of Mt. Kenya. The basin extends between longitudes 36°30'E and 37°45'E and latitudes 0°15'N and 1°00'N (Fig. 1). The total basin area is 15,200 km² varying in altitude from 800 to 5200 m a.s.l. The basin can be divided into three sub-systems; the Ewaso Narok catchment (3380 km²), the Ewaso Ng'iro—Mt. Kenya catchment (4640 km²) and the Ewaso Ng'iro lower basin sub-system (7180 km²). The Ewaso Narok and the Ewaso Ng'iro—Mt. Kenya catchments are drained by perennial rivers which are controlled by forest, moorland and glacial hydrology as well as water abstractions. The lower Ewaso Ng'iro sub-catchment is characterized by runoff from ephemeral catchments, perennial flow from upstream

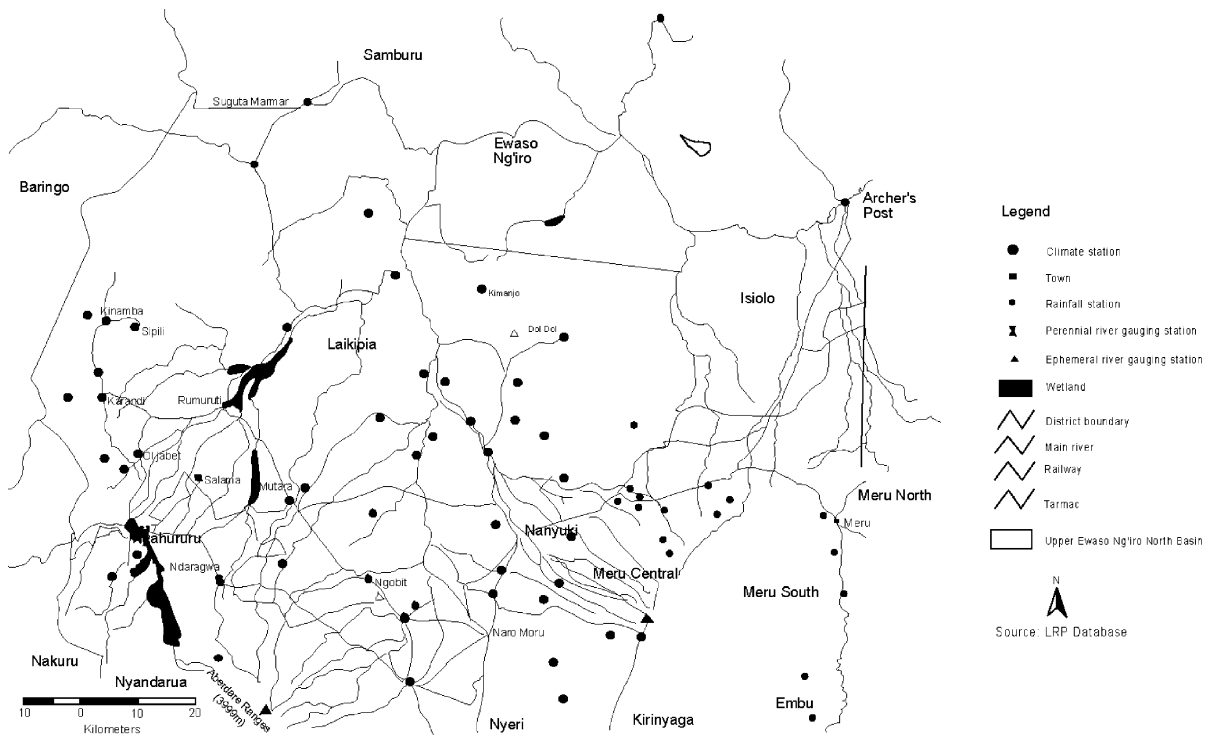


Fig. 1. The upper Ewaso Ng'iro basin, showing the hydrometeorological network.

highland sub-system, and spring flows close to the basin outlet. The Ewaso Ng'iro river is heavily dependent on the flow from Mt. Kenya during the dry periods while the lowland plains contribute significant proportions of the total flow during the wet periods which is attributable to the high surface runoff at the onset of rains.

The dominant soil types include the shallow and poorly developed soils on the steep mountain slopes, the well-developed soils on the plateau and gentle slopes and the poorly drained soils in the bottomlands and river valleys. The ecological gradient comprises of seven zones extending from the Alpine slopes of Mt. Kenya to the semi-arid and arid plains of the

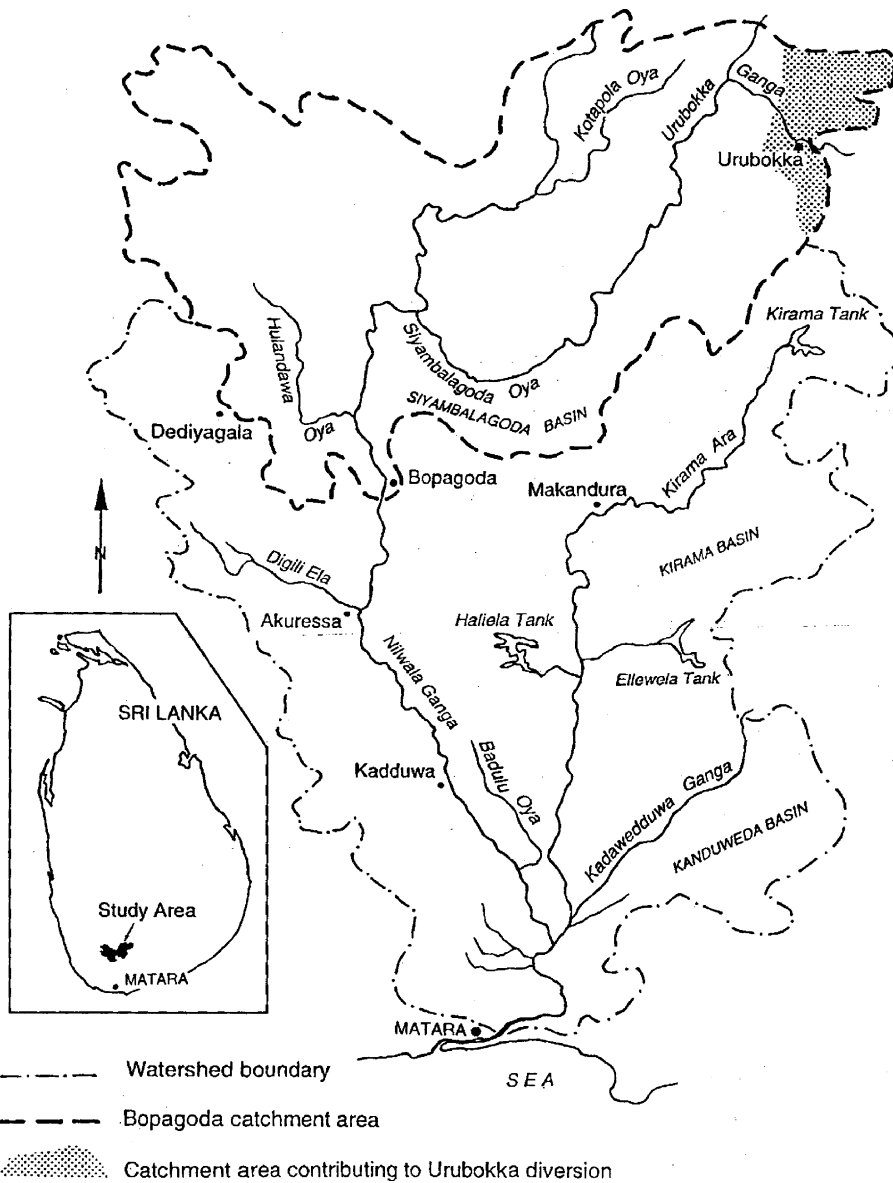


Fig. 2. The Nilwala river basin.

Laikipia plateau and the arid lowlands. The mean annual rainfall varies from about 1500 mm on the upper mountain slopes to 350 mm on the arid lowlands around Archer's Post. Depending on location within the basin, the seasonal rainfall distribution pattern can be bimodal, unimodal or trimodal. In the drier areas, rainfall is episodic and interspersed by lengthy periods of drought. Potential evapotranspiration on the other hand ranges from less than 1000 mm at higher altitudes to over 2500 mm at the lower altitudes. The basin thus represents a water-surplus highland area adjacent to a water-deficit lowland.

Since 1963 the basin has experienced dramatic changes in both land ownership and land use due to a rapid population growth of 7–8% per annum. The reduction of available land in the rangelands has led to serious land degradation illustrated by soil erosion gullies and deforestation due to charcoal burning. The water needs of small- and large-scale farmers and the rapid expansion of urban centers in the region cause problems of inadequate water from the many perennial rivers affecting both upstream and downstream users.

1.1.2. *The upper Nilwala basin*

The Nilwala River originates at an altitude of 1050 m, and traverses 70 km before the river flow is discharged into the sea at Matara (Fig. 2). The total river basin is 1073 km². The upstream course of the river from Bopagoda traverses a hilly terrain with steep longitudinal slopes and high flow velocities. The total area of the river basin demarcated by the Bopagoda reference point of the study watershed is 42,000 ha. However, there is an inter-basin diversion, which commenced three centuries ago and thereby the effective watershed study area is only 37,950 ha. The predominant soil type of the upper basin is red yellow podzolic soils associated with a dissected, hilly and rolling terrain. Alluvial soils are confined to the river valleys of the middle and lower parts of the basin while bog soils are found in the poorly drained lower reaches of the floodplain.

Sri Lanka is divided into three main geographical zones; the wet, dry and intermediate zones, demarcated according to present agricultural land uses, distribution of forest species, rainfall, topography and soils. The watershed study falls into the wet zone and the basin mean annual rainfall is about 3040 mm

with a 75% probability rainfall of 2033 mm. The rainfall distribution is bi-modal and monthly rainfall exceeds 200 mm during the March–June and August–December periods, but in other months it is about 150 mm. Water shortages are common between December and March due to the combination of shallow soils and steep slopes.

2. Approaches and methods used

2.1. *The upper Ewaso Ng'iro basin*

The status of natural resources in the basin has now been studied for more than 20 years. A comprehensive socio-economic database also exists. The two databases contain information on long-term meteorology, hydrology, land management, demography, settlement and land use dynamics and household typology. The hydrological and meteorological data from the monitoring network in the basin dating from 1960 to the present have been analyzed for trends. Using hydroclimatological and water abstraction data from the sub-catchments, the dry season flow of the Ewaso Ng'iro river was analyzed to determine the effect of the water abstractions (Gichuki et al., 1998a,b; Liniger et al., 1998). The levels of land degradation on crop- and grazing-lands were also analyzed from the database.

2.2. *The upper Nilwala basin*

Daily discharge at the Bopagoda gauging station recorded by the Irrigation Department from 1940 to 1997 were used for the analysis of runoff changes. Daily rainfall data for the stations within the watershed for the corresponding period were obtained from the Department of Meteorology.

Data on historical land use transformations in the watershed were derived mainly by a comparison of land uses depicted by aerial photographs available only for 1956, 1972, and 1983. These data could not provide a sequential picture of the land use changes between 1940 and 1997, hence it was necessary to consult a variety of key sources, including local residents with detailed historical knowledge of the watershed study area such as priests, retired government officers (e.g. school headmasters and village headmen) and farmers. In addition, various government

officials attached to various line agencies currently working in the area with a long service record were consulted. The information derived from these diverse sources revealed not only the major changes in land use during different time periods but also the causes underlying such changes. The compiled information clearly established the influence of a variety of factors on land use transformation. These factors included: migration from the more densely populated areas, government land use policies, various subsidies, production support services including extension facilities, availability of markets and technical knowledge, breakthroughs such as high yielding clonal (vegetatively propagated) tea, and the profitability of new crops under prevailing climatic conditions, etc.

Long-term trends in rainfall and stream flow were analyzed using the conventional techniques of moving averages and linear regression models for seasonal and annual totals. Analyses involved variations in annual runoff to reveal the changes in total water yield in the context of variations in rainfall and land use. Also, variations in runoff during low-flow and high-flow periods were analyzed separately to discern the trends in storm runoff (or direct runoff of storm events) and base-flow (or the contribution from groundwater) generation.

3. Consequences of land use change

3.1. Upper Ewaso Ng'iro basin

The following are the conclusions from the studies in this basin. (1) The most significant change that has taken place in the basin in the last 30 years is the conversion of grazing land, bush land and natural forest into small-scale farming areas. This has highlighted resource management conflicts. (2) The upper mountain areas with higher rainfall, better soils and good vegetation cover encourage groundwater recharge. However, major human-induced land use changes are taking place with limited soil and water conservation measures. (3) The major problems in the semi-arid areas of the basin are not only soil erosion due to inadequate cover but also inadequate water. Analysis of rainfall and stream flow data shows that the dry season flows are declining due to the impact of high rates of abstraction from rivers (Fig. 3). Over 70%

Table 1
Vegetation change (%) and runoff in Nilwala basin (1940–1995)

	Period		
	1940–1956	1965–1972	1985–1995
Natural forest	50	30	15
Tea plantation	14	30	50
Home gardens	20	26	15
Runoff (% of rainfall)	30	50	40

of the water abstractions are illegal (Gikonyo, 1998) while about 60% of the river flow is abstracted from the lower mountain slopes and adjoining savannah areas (Gichuki et al., 1998a,b). Pastoralists, livestock and wildlife are forced to move upstream in search of water because of declining water supplies.

3.2. Upper Nilwala basin

From the results of the analysis of long-term land use changes in this basin, the following results were obtained (see Table 1). In 1940, about 50% of the watershed area was under the natural forest cover which decreased to 43% by 1948 and to 30% by 1965. During the 1940–1947 period, deforestation was mainly for agricultural land uses of shifting cultivation, home gardens, and large-scale tea plantations. A consequence of opening up of large-scale (more than 50 ha) tea plantations by the British planters in crown lands (i.e. lands vested in the government during the period of British rule), has been a migration of people from the downstream areas to supply the labor force. During the 1948–1964 period, small tea holdings (varying from less than 1 to 5 ha) had the major forest replacement, particularly at steep headwater areas. Moreover, tea has also replaced other land uses such as shifting cultivation. The major factors for the expansion of tea small holdings were population pressure resulting mainly from migratory labor, the tea subsidy scheme made available to small holders, the introduction of high yielding clonal tea, and the allocation of small holdings to farmers by the government. Furthermore, the suitability of the existing climate for tea, effected a year-round income exceeding that of other agricultural crops. The changes associated with these land use transformations coupled with the reduction in forest cover from 50 to 30% during the 1940–1964 period was the generation of increased runoff (e.g.

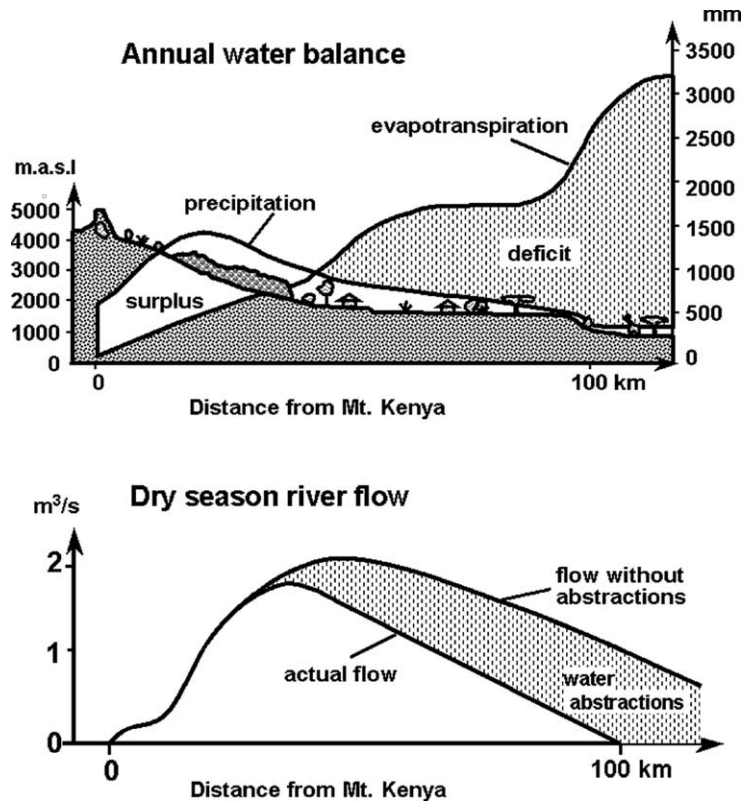


Fig. 3. Annual water balance and dry season flow in the Mt. Kenya—Ewaso Ng'iro basin (Liniger et al., 1998).

Fig. 4). In comparison with the 1940–1947 period, mean annual runoff has increased by 11% or 17.5 cm between 1948 and 1964. About 80% of this increase in water yield was due to increased base flow during

the normally low-flow periods in December–April and July–September. Increase in base flow following reduction in forest cover should be due to the reduction in transpiration during these low-flow

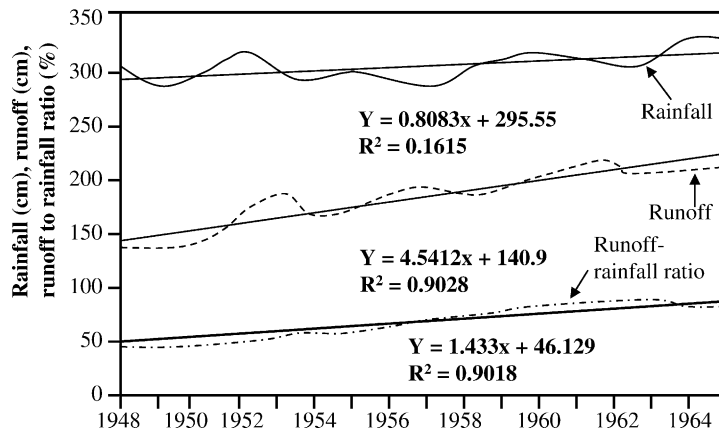


Fig. 4. Rainfall–runoff relations in the upper Nilwala basin (1948–1964; 5-year moving averages).

periods. Increased storm runoff on the other hand was mainly caused by reduced infiltration when forest is converted to the other land uses. The major land use transformations during the 1965–1997 period included a further reduction of the forest cover, but at half the rate observed during the previous period, with expanding small tea holdings. In consequence, by the end of 1997, less than 15% of the watershed was under natural forests, 50% was under tea, and the remaining 20% was under home gardens, and the balance was mostly under other plantation crops like cinnamon and rubber. Very high annual runoff to rainfall ratios were observed at the onset of the 1965–1997 period, but during the latter parts of this period, the ratio decreased to comparable values observed between 1940 and 1947 and even lower. This has resulted from the establishment of a perennial tree crop, which simulates natural forests with respect to transpiration. This clearly indicates that the new cover dominated by tea and home gardens is not as effective as natural forests in maintaining high infiltration rates (Elkaduwa and Sakthivadivel, 1999).

The large-scale conversion of forest into other agricultural land uses, particularly tea cultivation on steep lands in the order of 35% slope with inadequate conservation practices has led to accelerated rates of soil erosion. Its impacts have become detrimental to the long-term productivity of the land resources, particularly those on steep terrain. It was observed, especially in the tea lands that the loss of topsoil depleted soil fertility which made the farmers increasingly more dependent on chemical fertilizers.

The development of infrastructure such as roads and buildings associated with heavy disturbance of the topography without appropriate soil conservation measures has aggravated the sediment supply into streams, sometimes resulting in landslides from the indiscriminate removal of the toe support on unstable slopes. The degradation of stream channels due to high sediment supply from the watershed has further increased the likelihood of economic damage of flash floods, which have become more frequent with the rapid runoff.

A reduction in groundwater recharge has resulted in relative droughts following dry spells, especially on slopes due to lowered well levels, a diminishing

of perennial rivulets, springs and some of the first and second order streams. Thus, the domestic water supply during dry spells is a crucial issue and recently many domestic water supply schemes have been introduced to alleviate the problem. With a diminishing of stream flow during dry periods, farmers have experienced a water shortage during dry spells within both the dry and wet seasons.

The reduced flows have reflected in a reduced dependency on a reliable supply of good quality water in the downstream during the periods of low rainfall. Furthermore, the riverbed is below the sea level at the outlet and the seawater intrusion has increased with reduced low-flow regimes because there is a reduced freshwater pressure available to repel seawater as well as tidal influences. This threatens the quality of water supply to downstream areas. For example, relocation of the intake for Matara water supply scheme to a river point several kilometers upstream was effected in mid-1980s to ameliorate the salinity intrusion. On completion of the Nilwala flood protection scheme in the lowest section of the river, excessive drainage has resulted in the development of acid sulfate conditions in the coastal rice fields. One sound alternative to ameliorate this problem is to irrigate affected fields using the river as the source of water. However, this option remains questionable due to the inadequate low flows now observed in the river.

4. Loss of watershed functions

The two projects described in this paper demonstrate clearly that land use change can lead to the loss of important watershed functions. Evidence from the two projects has shown that there is a relationship between population dynamics and land use change. Land use and the resultant landscape mosaics on the other hand markedly influence water flow on the landscape and the geomorphic processes such as soil erosion, sedimentation and landslides. In both the Kenyan and the Sri Lankan case studies, it is clear that the conversion of land use from natural forest to small-scale agriculture often practiced without adequate conservation lowered infiltration of the soils causing an increased runoff and flash floods. In addition, river

water abstractions impacted on the dry season water supply functions of the watershed. The land use changes had negative effect on soil fertility and water quality.

5. Lessons learned

The two case studies illustrate that long-term monitoring of the interaction between land use changes and environmental parameters is important for determining trends in hydrology. This information is also important for the development of decision support tools for farmers and managers who attempt to resolve the conflicts that arise due to competition over limited land and water resources. Unfortunately, involvement of all the major stakeholders was minimal for both projects. In hindsight, the projects should also involve local communities in the monitoring of stream flow to ensure ownership of information. This is particularly pertinent at the Kenyan site because there is a common perception that water supply is not limited but then illegal abstraction becomes a major issue. Monitoring surface and groundwater use along the ecological gradient from stream source areas to the basin outlet at Archer's Post provided extremely useful information despite the denial of excessive abstraction.

Another important question is whether it is possible to anticipate future problems associated with land use changes. It can be concluded from these two case studies and also global literature that most biophysical consequences of deforestation are similar and predictable. Agrochemical problems from intensive irrigation of export crops are new but also predictable. In the Kenyan case study, political solutions to the resource use conflict appear to be generally more expedient than appropriate policies. Consequently, local politics is important in determining policies. The conflicts between upstream and downstream users associated with water scarcity and soil transfer could be resolved through a policy dialogue between all the stakeholders. To strengthen this approach, there is a need to empower the stakeholders by making scientific information available to them. In addition, appropriate incentives for equity and better and sustainable land management should be implemented.

6. Conclusions

Watershed problems have both biophysical and socio-economic dimensions. However, hydrologists and social scientists have developed predictive models independent of each other. The application of such modeling efforts is clearly insufficient to adequately address the kind of watershed problems outlined in this paper. Efforts must therefore be made to incorporate biophysical and socio-economic data in predictive modeling. Most monitoring networks in developing countries were initiated and maintained through funds from donor agencies. From the experience of the Kenyan case study, it is expensive to maintain a monitoring network that still yields reliable and high-quality data. Given the utility of the decision support tools that the two case studies have demonstrated, it seems logical to share the costs of maintaining the monitoring networks by all stakeholders. As to how long the monitoring should continue largely depends on the rate of change of land use and economic changes, and the speed with which scientists can develop robust predictive models that incorporate the biophysical and socio-economic variables. While the rate of land use transformations and fragmentation of large land holdings in the Mt. Kenya area was largely predictable, the widespread adoption of intensive irrigation for high-value crops was unexpected, especially by the large number of small holders. Thus, the original target of developing technologies for improving the water use efficiency of rain fed agriculture (Gichuki et al., 1998a,b) has shifted unexpectedly to improving water use efficiency of small-scale irrigation. The last challenge posed by the case studies is what viable mechanisms exist to influence local land use policies? There is need for policy dialogue between actors at different levels of action beginning with problem identification, the research process, and the transfer of findings of well-tested research into packages that can be understood and appreciated by everyone. Also, the different actors should examine together basin management strategies, law enforcement, water pricing and other measures agreed as necessary for equitable and sustainable use common resources. The interaction between land use and watershed function is particularly complex in the Mt. Kenya region, where agriculture, industry and wildlife management form

such an important part of the regional and country's economy.

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