Market opportunities associated with hydrological services in a tropical montane cloud forest

Landscapes, memories and water

Narratives, perceptions and policy-making on land and water in Monteverde, Costa Rica

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1 Introduction

Using the watershed as a unit to understand upstream-downstream relationships is not new (Mourraille, Porras and Aylward, 1995). Within the context of this study it means looking for optimal land use scenarios upstream to improve on-site and off-site hydrological services. The trick is to be able to maximise the living conditions of all involved. And, potentially, generate a new source of income from market initiatives, including Payments for Environmental Services.

Changes in water flows and their quality, especially during the dry season, constitute a major problem all over the tropics. In the particular case of cloud forests, it is generally thought that clearance of trees will result in loss of the extra input of moisture from passing clouds, leading to potentially lowered groundwater tables and thus reduction of stream baseflow. There are however, very few cases when the scientific base feeds directly into policy-making. And even less often are poor people participants in the decision-making process, thus limiting the potential livelihood and welfare gains.

Context shapes policies (Mayers and Bass 2004). Physical, cultural, political and environmental conditions, and decisions made in the past, will determine the way policy is determined and the effects it has. An important aspect is how scientific knowledge becomes part of the policy making process. This includes how the message is put across (and to whom), how it is understood, who benefits from the dominant belief structures, and how is it shaped by local historical patterns and people's perceptions of "how things work".

In relation to science and policy, it is possible to distinguish at least four possible situations that could affect the viability of land and water policies:

1) *The scientific knowledge does not exist;* it is incomplete, or imprecise.
2) *The scientific knowledge exists, but it is not communicated to policy makers, and even less to communities.* Even in cases where sufficient scientific knowledge exists, poor communication of results to stakeholders – particularly low-income inhabitants of upper reaches of remote catchments - and policy-makers means that potential livelihood and welfare gains are often not realized.
3) *Policy-making and science fail to take into account local perceptions on land and water*. If local stakeholders have a different set of beliefs than those upon which policy is made, then the long-term viability of land reforms could be seriously undermined by lack of commitment. Added to this, marginalized groups might be further hindered if they have little democratic voice or influence in determining policy, as is often the case in rural areas in developing countries.
4) *Policy-makers fail to take into account the particular history of a region*. How has the area evolved and developed through time? Who are the main stakeholders? What are their perceptions of policy and the government?

1.1 Objective of this study

This report focuses on situations displayed in (3) and (4), where policy-makers and science fail to take into account people's sets of perceptions and the particular history of a region. The report draws on evidence from the Monteverde area in Costa Rica, where a large study is currently being conducted to determine the links between cloud forest and water flows[1], as well as the socio-economic impacts and market opportunities associated with changes in land use. While the combination of both studies will provide important base information to inform a possible negotiation system among stakeholders downstream and upstream to improve watershed management, it remains unclear what their own perceptions are when it comes to understanding relations between land use and water, and what are the main drivers of land use changes according to local history.

The report has three components:

1. A detailed review of the different stakeholders and economic activities in the study area;
2. A narrative analysis[2], which collects information from local stakeholders, especially from the remaining pioneer settlers in the area and their descendants, and investigates the historical settlement pattern of land use changes and its relation to water resources. It also provides information about future trends of land use changes in the Monteverde area.
3. An analysis of the local perceptions and beliefs of the relation between land use and water, following the concept of "mother statements" suggested by Calder (1999) (see methodology below). The information from this study will be contribute to the design of land use scenarios dependent on the support of the different stakeholders within the watershed.

1.2 Methodology of analysis

The study is based on an exhaustive review of existing documents and reports about the local history of the watershed, especially the Monteverde Area, and a literature review of land use and water studies around the world. The main body of the study was obtained through collection of primary information that included:

- Inception workshop (August 2002)
- Guided observation through several exploratory field trips
- Informal meetings with remaining pioneers
- Semi-structured face-to-face interviews
- 10 focus groups[3] carried out with local groups including dairy and coffee producers, municipality representatives, environmental organisations, tourist

[1] For more information about this project please look at: www.cluwrr.ncl.ac.uk/projects/costarica/index.html

[2] People organize their experience and their memories mainly in the form of narrative. For instance, a good story is the one that can be lived vicariously by others. The power of the narrative technique is to get trustworthy data about feelings and understanding of key people. The success of this tool depends on the responsiveness of the informants (Booth, et al, 2000).

[3] A focus group is a very interactive and participative data collection technique, and its use is highly recognized and valued by the international scientific community. A focus group is conformed by 6 to 12 homogeneous participants, invited to meet together in order to discuss their perceptions on a particular topic problematic under study. Focus groups must be carefully planned and implemented by a very skilled person. This document reports on 10 focus groups with an average participation of 7 persons per group. Previous contact with a key member of

board, water utilities, and women groups between January and February 2003. Communities visited include Las Nubes, La Cruz and San Luis, located on the Pacific side of the continental divide.

The focus groups were used as a very important tool for the discussion of narrative issues and the perceptions with respect to the "mother statements" presented by Calder (1999):

- Forests increase rainfall
- Forest increase runoff
- Forests regulate flows
- Forests reduce erosion
- Forest reduce floods
- Forests ‘sterilize’ water supplies, by improving water quality

Participants were asked what they thought were the relations between land and water, which in most cases was immediately understood as forest (or its absence) and water. If necessary, participants were prompted with a particular question (*"do you think that forest increase rainfall?")*. For the narrative study participants were asked about three main time blocks: before 1950, around the 1980's and during the present time. Participants were asked to comment on different issues, such as their reasons (or their family's) to come to the area, what they thought were the main attractions, limitations, role of the goverment, incentives, social services, etc. In all situations participants were asked to consider how did the forest enter in the economic considerations of the time, and how this affected its value through time. Participants were also asked how they thought that the hydrology of the place had changed and what were the possible causes of these changes. They were also asked what were, according to their own experience, the most pressing issues related to water in their communities.

2 General description of the area

The Arenal watershed (41,332 ha, see Figure 1) lies on the Atlantic side of the Guanacaste and Tilarán mountain chains that form the Continental Divide in Costa Rica. The upper parts of this watershed can be subdivided intro three main micro-basins: Río Chiquito (9,136 ha), Aguas Gatas (2,724 ha) and Caño Negro (7,248 ha). This particular study concentrates on the upper part of the Arenal Watershed, and it includes two other sub-watersheds (Cañas and Guacimal) that drain directly into the Pacific Ocean rather than into Lake Arenal. The economic importance of this watershed (with its extension into the Tempisque watershed area) in the northern part of Costa Rica is evident (see Figure 2 and Table 1 for description of stakeholders).

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the community or group was made with anticipation and a date was set for the meeting. Most of these meetings took place during the evenings, and lasted between 60 and 90 minutes depending on the interest of the group. The groups consulted include: dairy communities of Las Nubes, San Luis and La Cruz, directive board and coffee producers in El Dos, directive board of the Monteverde Cheese Factory, municipality, local aqueduct, tourism board (CETAM), and women's group CASEM.

Figure 1. The Arenal Watershed

Source: Aylward et al (1998)

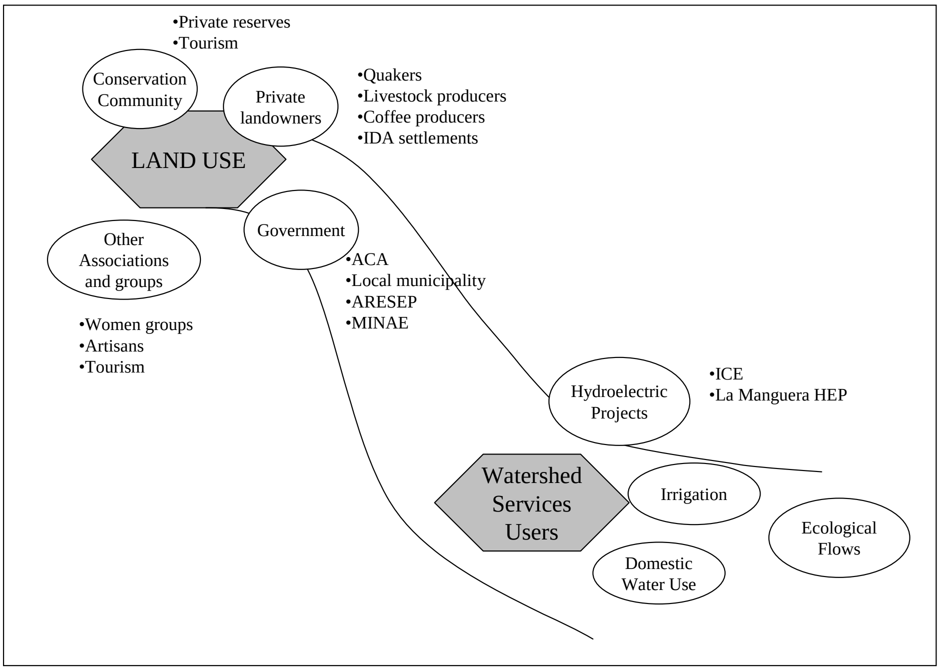
Weather characteristics in the upper parts of the catchments[4] are responsible for the existence of important areas of cloud forest, and in turn the existence of a very important conservation community and tourism activities in the area. Private reserves cover approximately 33,300 hectares. Other economic activities in the area include livestock (dairy[5] and meat), small areas of agriculture, ecotourism and small patches of reforestation.

The middle parts of the watershed are mostly dedicated to extensive ranching and some agriculture. Farms are mostly large and their owners live in the nearby town of Tilarán. Water is stored in the Arenal Reservoir, an inter-annual artificial lake created to feed into a system of three hydroelectric plants arranged in cascade (known as the ARCOSA system, which provides over a third of the electricity produced in the country). From the hydroelectric power system, water flows through a private fish farm and an area of intensively irrigated farms, mostly dedicated to rice and sugarcane plantations, before draining into the Palo Verde National Park, an important wetland that hosts a large population of migratory birds. The wetland serves as a filter for water that drains into the Gulf of Nicoya, one of the most productive estuary ecosystems in the world, which accounts for approximately 20 percent of the total fisheries harvest in Costa Rica (Hazell *et al* 2001, Aylward *et al* 1998).

[4] Climate in the upper parts of the watershed is transitional, where wind patterns from the Caribbean meet those from the Pacific and create a variety of microclimates. Weather conditions are a result of a combination of global phenomenon such as polar cold fronts, tropical storms and hurricanes and local phenomenon as topographic position and winds (Lawton and Dryer, 1980). Cloud formation is encouraged on the Caribbean cost by the westerly winds. These clouds climb the eastern slope of Costa Rica's mountains, cooling as they travel, and arriving heavy with rain and mist by the time they reach the continental divide.

[5] Dairy production is sold to a local cheese factory

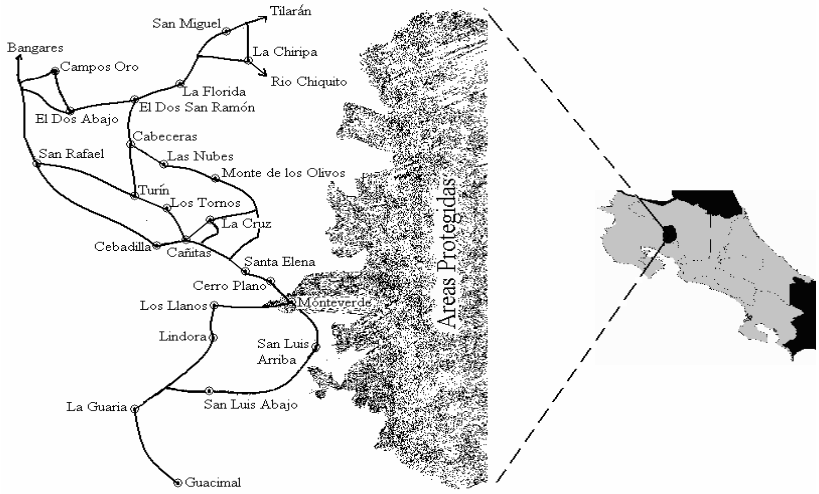
Figure 2. Upstream-Downstream relationships



The lower basin is relatively isolated in terms of human habitation. There are a few landholdings, with small producers dedicated to diary farming[6] and hiring out to large ranchers. Río Chiquito, the most important population area, was a flourishing community several decades ago but was isolated with the construction of the Arenal dam. About 5 years ago the main source of employment - an open cast gold mine - was closed because of negative environmental impacts. A strong migration process has since occurred in the area, and at the moment there is only approximately 100 inhabitants in the community. Services are limited to a small primary school and one local shop. The main water users in the lower part of the basins are the two Hydroelectric Projects: ICE-ARENAL and La Manguera (located on the Caribbean slope), a small private initiative. Water is then diverted from the Atlantic to the Pacific through an irrigation canal managed by the SENARA project, ending in an important area of wetlands (Palo Verde).

[6] Milk is sold to Dos Pinos, a national cooperative for dairy products.

Figure 3. Population centers in the upper catchment areas



The main stakeholders and a brief description is presented in Table 1. For more information and details, please see Porras, Miranda and Hope (2005).

Table 1. Main stakeholders in the study area

Name	Character	Activity	Description
Private Producers			
The quaker community	Private	Dairy farming, ecoturism	Arrive in 1952 from Alabama, USA.
Monteverde Producers	Private	Cheese/dairy products	Supports sustainability by providing technical assistance on soil conservation, awarding prizes for sustainability effors and refusal to accept new producers in areas that are not suited to dairy production.
Livestock producers	Private	Dairy and met producers	Small and large producers. Represented by the Livestock Producers Association
Coffee farmers	Private	Agriculture	Agriculture (mostly coffee), associated to regional cooperatives: Coope Santa Elena and Coope El Dos.
Institute for Agrarian Development	Parastatal	Agriculture	Silvopastoral programme dealing with the resettlement of landless peasants unto smallholdings.
Foresters	Private	Forestry	Small and medium foresters (mostly for reforestation and wind-breaks), linked to a regional foresters association (AGUADEFOR)
Main Cloud Forest Reserves			
Monteverde Cloud Forest Reserve	NGO	Forest Protection/ ecoturism/research	Monteverde Cloud Forest Reserve. Covers approximately 10,000 ha of cloud forests. Managed by TSC.
Monteverde Conservation League + Children's Eternal Forest	NGO	Forest protection/ ecoturism/sale of WS/research	Largest private reserve in CR (22,000 ha). Incentive programs for soil conservation and reforestation in the area adjacent to R Chiquito. Sales watershed services to La Esperanza Hydropower (incremental payments of $3 to$10 ha/yr over 5 years) – see note apart
Santa Elena Reserve	Community Reserve	Forest Protection/ ecoturism /research	Private reserve covering 310 ha of cloud forest, entrusted to the Santa Elena High School. Opened in 1992 as means to protect the forest and generate revenue for local people.
Some Local Groups and Associations			
Monteverde Institute	Private NGO	Education	Dealing mostly with education on

Name	Character	Activity	Description
			environmental issues, the MVI is highly involved in local sustainable development.
Women Associations	Local group	Community issues	*Fuerza Femenina* is a strong small group of local women of all backgrounds dealing with local issues of sustainable development from a household point of view.
Association of Guides	Local group	Environmental education, guided tours	Controls the quality of certified guides within the cloud forest. Members must be local.
Tourism Chamber	Local group	Community issues	Groups together a wide variety of stakeholders to tackle community issues such as overdevelopment, and to push for regulation on the establishment of tourist activities.
Artisans Cooperative	Cooperative	Crafts	Promotes new economic activities in the form of crafts for its members (mostly women).
International Scientific Community	Various	Support	International agencies dealing with development, research, purchase of land, and new economic activities.
Public Sector			
Ministry of Environment (MINAE)	Government	Regulatory	Responsible for approving/assigning water concessions for hydroelectricity. Assigns permits for forest cutting and oversees violations to laws.
Arenal Conservation Area (ACA)	Government	Regulatory	Local administrative unit of SINAC and MINAE, comprising 204,320 ha of Arenal National Park, four protected areas, a national wildlife refuge and a buffer zone in which sustainable development is promoted.
Local municipalities	Government	Regulatory	Managers of local aqueducts. The Municipality of Tilarán has negotiated unsuccessfully with ICE arrangements for local people to share in the benefits of the Arenal hydropower system.
Acudectos y Alcantarillados (AyA)	Goverment	Domestic Water Provider	Provides domestic water in the Santa Elena community, and quality control advise for other local rural aqueducts.
Regulatory Authority of Public Services (ARESEP)	Government	Regulatory	Defines prices for electricity, domestic water use, irrigation, park entrance fees and other basic service tariffs.
Educational sector	Public and private	Education	Community primary public schools, two secondary schools, and several language schools in the area.
Stakholders: Main downstream water users			
Costa Rican Electricity Institute (ICE)	Government	Hydroelectricity	Control the Arenal-Corobici-Sandillar (ARCOSA) Hydroelectric complex, that feeds from waters from R.Chiquito microbasin. Supplies approximately 50% of national electricity.
La Esperanza Hydropower Co	Private	Hydroelectricity	Located on the Atlantic slopes (outside Arenal Watershed) but receives water from cloud forests in the upper parts of the watershed owned by MCL.
SENARA	Government	Irrigation	National Water and Irrigation System, feeds on water from the ARCOSA project and supplies water for the PRAT irrigation project in Guanacaste (over 15,000 ha of agriculture (mostly rice and sugar cane)).

Source: Porras, Miranda and Hope (forthcoming)

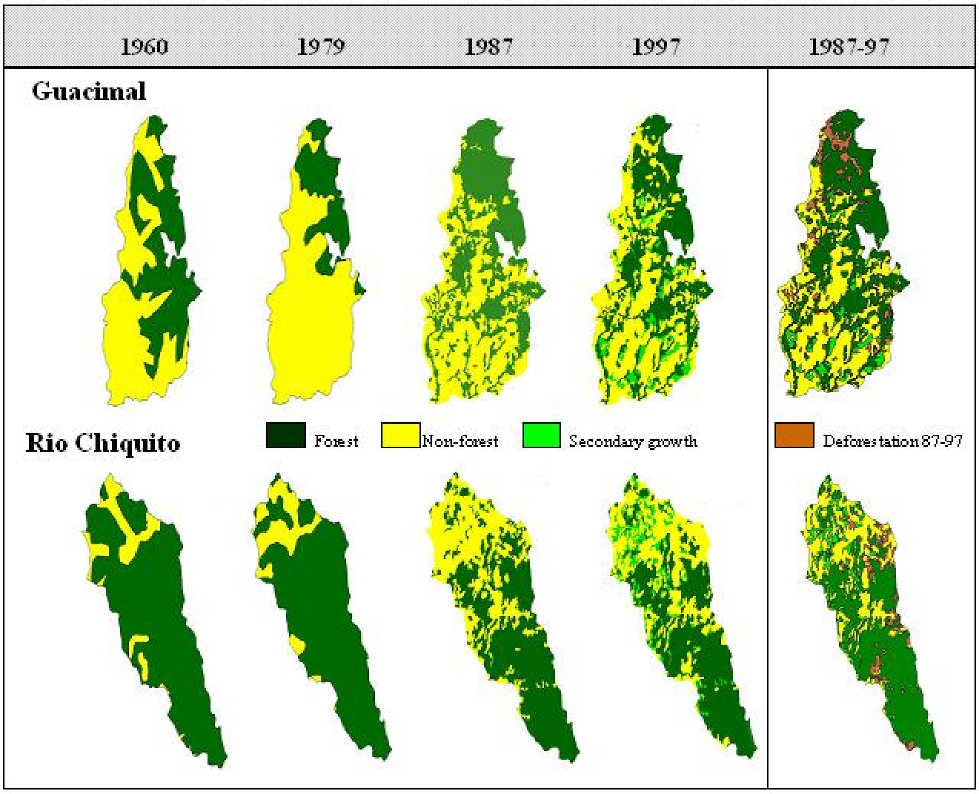
3 Reconstructing the history through narratives

Land use has changed significantly in the study area. Forests were initially cleared to give way to pastures as the main economic activity. And during the past 15 years a combination of environmental policy and economic drivers seem to be reversing the trend - albeit slightly- and bringing forests back on the map (see Figure 4).

This Section of the study tries to reconstruct the changing patterns of land use in the watershed through the collective memories of local inhabitants and the revision of existing documents. The methodology included personal interviews with key local people and several focus groups in the area[7]. Section 1.2 presents a more detailed explanation of the methodology. The second part of this study attempts to distill how they have perceived the changes in land use and water resources in the area. This Section presents the historical settlement of the upper parts of the watersheds into three main periods of time:

1. The first period: from early settlers to the 1950s.
2. The second period: from the arrival of the Quaker community to 1985.
3. The third period: technological advances in the dairy industry and the ecotourism boom.

Figure 4. Land use changes in Rio Chiquito and Guacimal watersheds, 1960-97



Source: J Calvo, ITCR

[7] For transcripts of the focus groups please contact the authors.

3.1 Early settlers, before the 1950s

Early inhabitants of Pre-Columbian Costa Rica were mostly nomade tribes, hunters and gatherers. Around 500 B.C. they began to move from tribal societies to chiefdoms. The main indication of human activity in the study area comes from the Malekus people. Very little is known of them, but pottery shards found near Santa Elena suggest that they possible crossed Tilarán's range traveling from the Caribbean to the Pacific. There is not evidence of important settlements in the area, although some participants in the Focus Group in San Luis mentioned the existence of Indian burials in the area.

Human settlements began to appear in the Arenal Watershed late in the XIX century. The discovery of gold in Guacimal and Abangares attracted a range of immigrants. Nowdays, it is possible to find descendants from Spanish, Portuguese, Italian, Ukrainian and Chinese ancestry in the area of Guacimal and Abangares. The Gold Rush was short-lived, and Guacimal begun to loose its importance and population with the collapse of the mine. However, some disappointed gold diggers decided to stay and become subsistence farmers in the area (Quirós[8], 2003 pers. com).

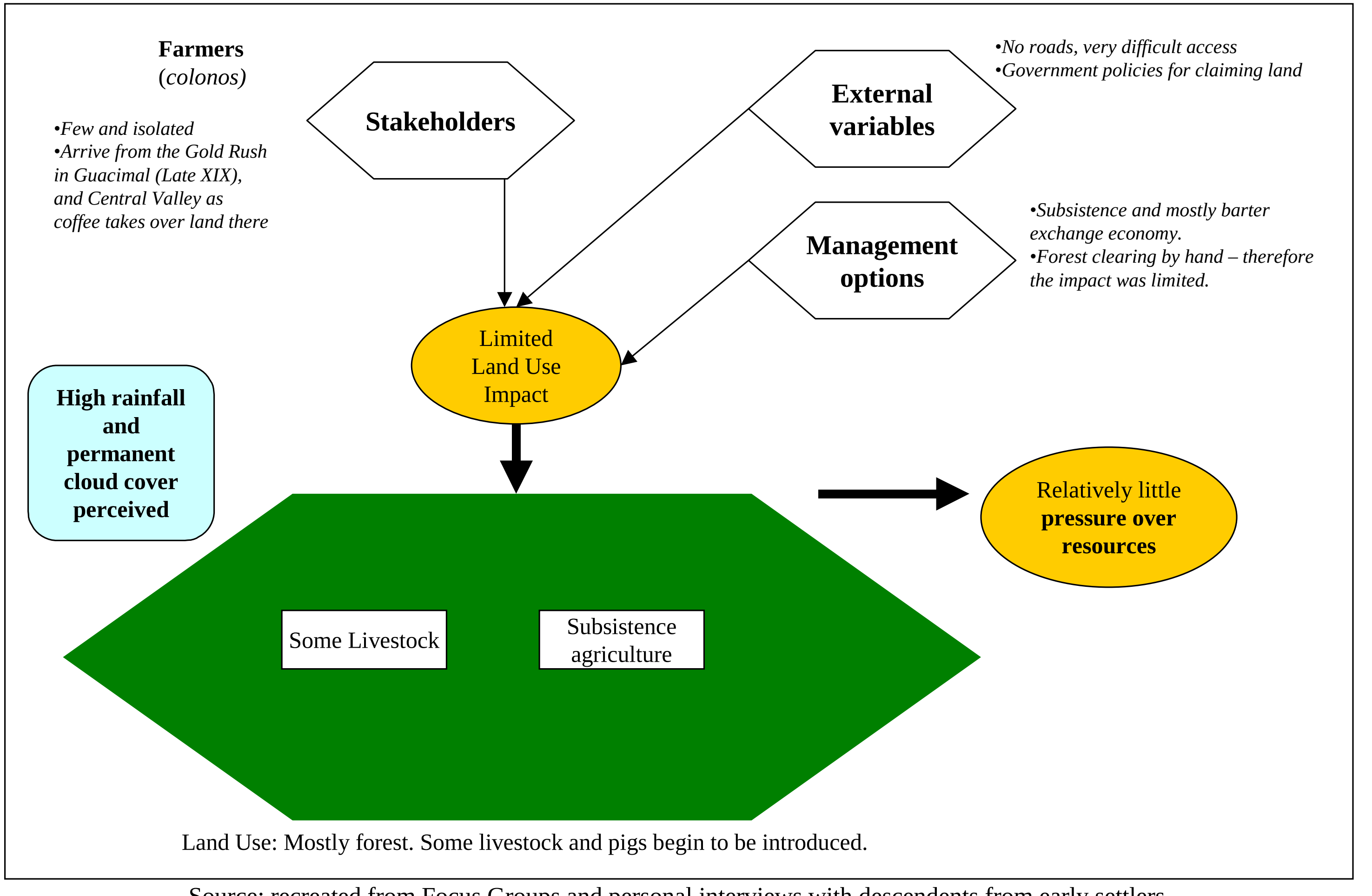
At the same time, pressure on lands in the Central Valley from the expansion of coffee and urban areas contributed to early migration processes. The upper parts of Rio Chiquito, Caño Negro, Guacimal and Cañas watersheds were settled during the early 1900's by early pioneers from the middle parts of the country -mostly San Ramon and Naranjo- and from Guacimal. Landscape occupation followed up the same patterns of the Costa Rica colonization and the 'Family Providers' Law, 1934, which stated that land had to be cleared to prove ownership.

> **Law and Land Conversion.** The Family Providers Law, enacted in 1934, "would be the toot cause of massive destruction of forests". It awarded 20 hectares of unused public land to heads of families. This in turn led to the creation of the Land Tenancy Information Law (1941), which awarded up to 300 ha of unused forest public land to anyone who could prove effective ownership. This was done through land clearing, although not everyone had the intentions, or means, to cultivate the land afterwards. Watson *et al*, 1998.

During the 1940s, in an effort to reduce the economic influence of the coffee oligarchy, the government targeted a series of new economic activities. Livestock activities were given new support. The nationalisation of the bank system provided cheap credits, and the expansion of roads and communication systems opened new market possibilities. Additionally, low up-front costs and good international prices for meat resulted in a major commercial expansion for cattle ranching at country level. By the 1970s, Costa Rica was the fourth largest exporter of meat to the United States (Aylward et al, 1998).

[8] Emilce Quirós, 80 years old, is the granddaughter of Batista Oliverio, one of the Italian miners who become a farmer and raised a big family in Guacimal.

Figure 5. Land use patterns until first half of the XX Century



Source: recreated from Focus Groups and personal interviews with descendents from early settlers.

"My grandfather came to the area from San Ramón, around the years of 1850. He came first to Santa Elena but didn't like the soils, so he came down to the San Luis area and began what it is now the town. There used to be Indians here. You can still find some burials. It was a hard life. There were only traditional remedies with herbs. Only the strong ones survived"**. Focus Group, San Luis.**

"By the mid of the last century the price of the land was incredible cheap. My father bought 200 hectares of forested land from my grandfather for only US$0.25. Only a small part of that forest was cleared". **Arguedas, J. pers.comm.2003**

"It was so remote and isolated that people hiding from the authorities found a safe haven to begin a new life". **Brenes[9], pers.comm.**

All in all, the colonisation process in Monteverde and Guacimal area was very slow and isolated. Cattle ranching was done in relatively small scale before the 1950s. During this time only the middle parts of the Guacimal watershed were linked to the rest of the Country's economy. The upper parts of the catchments remained covered by cloud forests, and the few families living there subsisted from small patches of agriculture, small pig farming and a few heads of cattle. Distances were long and difficult, and with no bridges, roads and access only through horse trails, reaching out to external markets was a near impossible task. The problem was particularly acute during the rainy season because of the intensity of the rivers' flow (Suarez, 2003 pers. com).

"Times were very hard. Santa Elena was hopeless. The grass was bad. Agriculture was bad. The only thing to do was dairy farming, and it didn't give much anyway. Milk was only sold to the cheese factory and coffee to Beto León. We had to get the milk out on a horse. It can now be done on a truck and it takes one a half hours. Just imagine how it was before". (**Focus group, San Luis).**

"When I arrived to La Cruz 50 years ago life was very hard. There was a lot of forest, and a lot of poverty. Houses were built with whatever local materials we had. Even roofs were made of wood and only a handful of houses had metal roofs. The houses had earth floors. No electricity. There was only one radio. There wasn't even a mill, and things were made using an axe. People didn't have much vision. Some made illegal rum, the farms were patches of grasses with two or three cows. Large patches of forests were slashed and burnt to grow a bit of maize for subsistence. People survived by barter exchange. There were no jobs, and if anyone needed a labourer, it was paid by returning the labour. Perhaps only three persons would hire properly, and the Quakers, but we didn't have Quakers here. You could make about 1,50 colones for a hard-working day, and anyone with a thousand colones in his pocket was considered a millionaire. Anything to sale had to be taken out in horses. You couldn't sell anything in Santa Elena, you had to go all the way to Las Juntas". **Focus Group in La Cruz.**

"My sister Louvigina got married and went to live in Monteverde (before the 1950s). She used to say that the humidity was permanent, and everything was always wet. It rained all year round, it was very misty, and sometimes it was impossible to see anything at all. Sometimes the sun would creep out, a little bit, and everybody would be cheery…Sometimes the *temporales* (rainstorms) would last for days without stopping, four or five times a year, and the rivers would be so swollen that we wouldn't be able to cross them. The coldness was unbearable…one had to go with several layers of clothing all the time". **Fragment of an interview to Rosa, daughter of Bastista Oliverio, an Italian immigrant who arrived to Guacimal in 1902.**

[9] Brenes is descendent from one of the La Cruz first settler. He arrived to thi area when he was 4 years old.

The general perception of descendents from early settlers in the area is that landscape was densely forested, cloud cover almost permanent throughout the year, and precipitation, in the form of rainfall or mist, was stronger than in present times. The impacts that such isolated form of living had on the environment was relatively small. The landscape remained forested in the upper parts, and land use changes were small due to isolation. Figure 5 presents a summary of this period. When the Quaker community arrived in 1950 there were probably 10 other families at most living in the area (Arguedas, 2003 pers com).

3.2 Local forests transformed into pasture, 1950-1985

Attracted by the generous land laws in Costa Rica, the Quaker community arrived to the Monteverde area during the early 1950s[10]. Arriving from Alabama, they bought 3,750 acres of (mostly) forested land from local families. A new stage of the region's settlement process began with their arrival. The process, a combination of their enthusiasm, engagement with existing local families and an array of national level policies, resulted in large scale land conversion.

> "The Quakers cut a lot of forests and turned them into pastures, but there was already a lot of deforestation. In the last part of the 1980s the pastures changed again. Many pasturelands became hotels, other people began reforestation, and others abandoned plots that quickly became secondary forests. A large part of San Luis was pastures, and now it is secondary forest". **Focus Group, San Luis.**

Large areas of forests gave way to agriculture and dairy farming. Better shelters and roads began to be built, and the production of cheese, instead of fresh milk, facilitated the access to external markets. Because road access was easier on the Pacific, the Guacimal watershed was cleared earlier than the Rio Chiquito Watershed (see Figure 4). While livestock dominated the new land uses, other economic activities such as coffee, begun to be introduced in the area as alternative crops. Coffee was introduced during the 1970s, at a time when the high international prices due to the frost in Brasil made the activity very profitable (see Porras, Miranda and Hope (forthcoming), for in-depth description of each activity).

At the same time, as early as the 1950s, the scientific interest in the biota of the Monteverde cloud forests began its ever-increasing trend (Koens, 2003). From the time when the first Monteverde scientific studies were published in magazines and bulletins in the USA and Europe, the area quickly became the *must visit* place for cloud forest researchers, some of which later become active members of the community, playing a key role in Monteverde's development. According to Nadkarni (2000), there are over 250 publications about Monteverde, written between 1966 and 1995.

[10] Part of the Quaker faith is the belief that there is an inner light in everyone and that this inner light is in essence a piece of God. Most Quakers consider themselves pacifists. The Quakers founded the Cheese Factory, the Friends School and in an attempt to protect the areas watershed purchased much of the land that now makes up the Monteverde Reserve. The Quakers have played a major role in the development of the community and this is one of the things that make Monteverde a special place (Adapted from *http://www.quaker.org/)*.

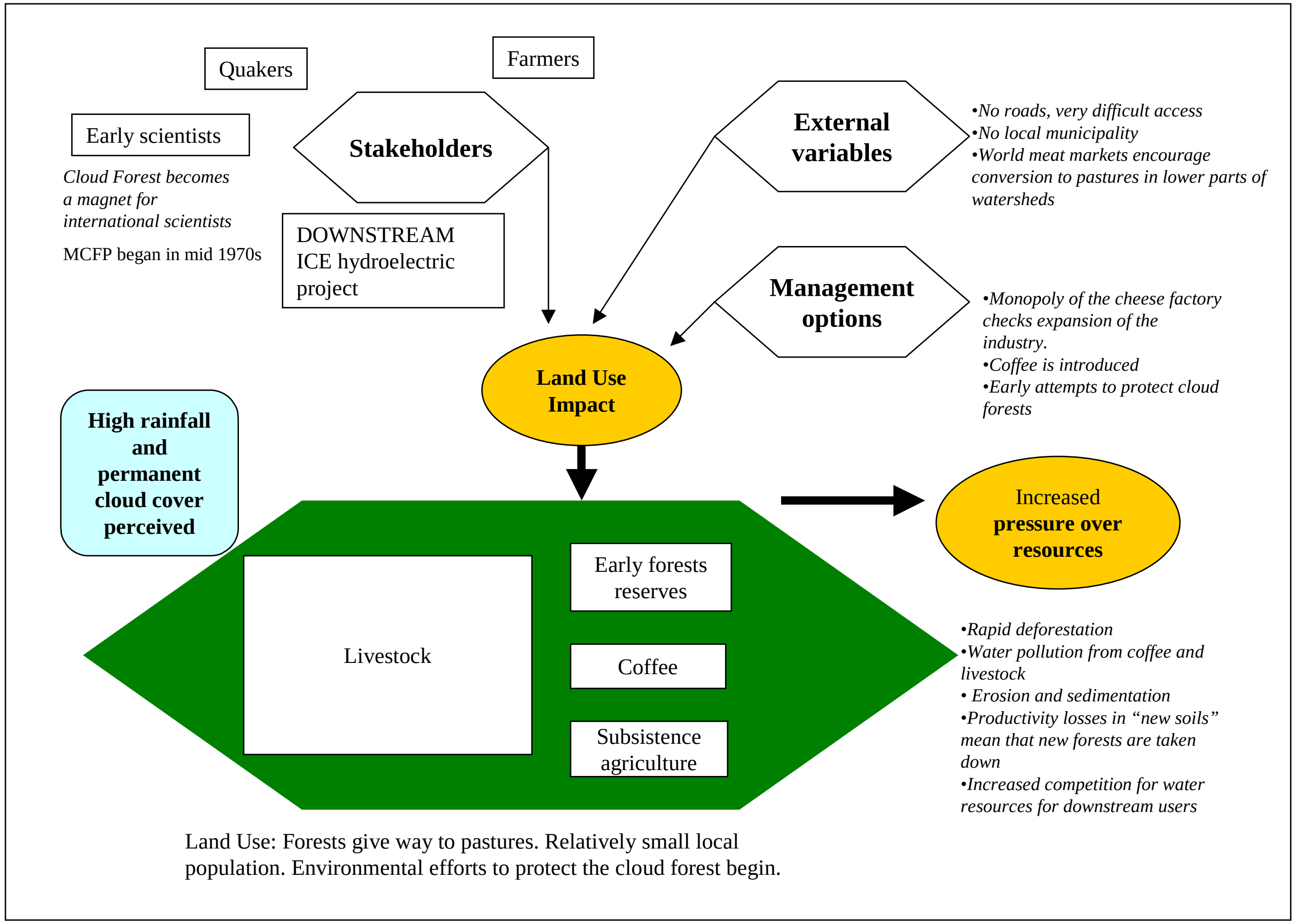
Even during this process of drastic changes in the landscape, the Quakers recognized the importance of the cloud forest for the provision of permanent, stable and clean water (Pateman, 2002). They set aside forested areas near the headwaters of the Rio Guacimal, to remain undisturbed and safeguard the water source of their hydroelectric project. In 1972, and to prevent land use changes in the surrounding cloud forest, visiting scientists George and Harriet Powell joined forces with longtime resident Wilford Guindon to establish a 328-hectare wildlife sanctuary. In 1975, the community watershed reserve received a grant of US$40,000 from the World Wildlife Fund, forming the initial core of the Monteverde Cloud Forest Biological Reserve. The creation of private reserves for the conservation of cloud forest became a magnet first for scientific tourism, and then extended to include a wide range of ecotourism that changed dramatically the economic drives of the upper watershed.

> The Cloud Forest area attracted scientists, especially drawn to the small and brilliantly colored Golden Toad, discovered in 1964 by the Organization for Tropical Studies. This specie was not only new but also endemic, and became the "logo" to encourage cloud forest preservation. Sadly, the Golden Toad seems to have disappeared.

Downstream, the Costa Rican Electricity Institute (ICE) began the construction of the Arenal reservoir during the late 1970s. The project created an artificial lake that diverts water from the Atlantic to the Pacific side of the continental divide. It currently has three hydrological plants that provide over a third of the country's total capacity. An immediate effect of this project was the displacement of local towns and ranching activities, especially in Tronadora, onto the higher and steeper slopes of the upper areas of the watershed.

Prior to the construction of the dam, ICE commissioned an environmental impact assessment (CCT, 1980), which suggested the State to purchase lands in Rio Chiquito, where the terrain was more rugged and prone to high sediments. Unable to do so, partly because of the cost but also because of high opposition from local ranchers, ICE implemented a 50-m wide riparian buffer strip around the reservoir (Fernandez-González and Aylward, 1998). During the 1980s the Arenal Forest Reserve was created (later renamed the Arenal-Monteverde Protected Zone). This reserve included most of the land not yet occupied of the Caño Negro and Aguas Gatas microwatersheds on the Atlantic. These areas became part of the Arenal Conservation Area (ACA), when the country was divided into Conservation Areas during the 1990s. Kauch and Tosi (1989) suggest that part of the colonisation of this period is the result of land speculation, where farmers claimed land with prospects of selling it back to the government for protection.

Figure 6. Land use patterns from 1950 to the mid 1980s



Source: recreated from Focus Groups and personal interviews with descendents from early settlers.

As for the previous period, participants in the focus groups and personal interviews in the area perceive that rainfall was stronger during this period than nowdays. However, several environmental impacts of the land use patterns commence to emerge. According to the participants, the rapid deforestation that took place in the area produced increased erosion and sedimentation, and there was a need to expand the agricultural frontier often due to losses in soil productivity. The coffee and dairy industry ran unchecked and wastes were thrown in rivers damaging the water quality. Downstream users began to increase with the introduction of the Arenal hydroelectric project and the expansion of new population centers in the mid parts of the watersheds.

The isolation of the upper parts of the watershed contributed to the creation of an independent spirit and the ability to cope with situations on their own. While the government provided other regions with electricity and water, Monteverde developed its own small hydroelectric project and water service. Other services, such as civil registry, had to be done in the nearest city, Puntarenas, several hours away. By 1984 the national census only reported 400 permanent inhabitants in the area.

Overall, the dynamic spirit characteristic of the Monteverde inhabitants started during this period. Parallel to rapid changes in land use was the increasing awareness for water and biodiversity conservation. The last one, alongside the recognision of the majestic beauty of the cloud forests, became the central pillars of a next historical period led by of technology and tourism.

3.3 The technological and ecotourism era: 1985-2000s

The next period in Monteverde is characterised by important technological improvements in the dairy activities and the boom of ecotourism as an economic activity.

The seeds for environmental awareness were planted during the historic period described previously. Non-governmental organisations (NGOs) played a key role in the transformation process of local landscapes towards rehabilitation of degraded forests. At the same time dairy producers -organised by the Monteverde Producers group and partly pressed by local NGOs- set in motion a set of changes aimed to increase land productivity and reduce pressure to convert more forest. The coffee industry also began to improve their production process and reduce environmental damage, while appealing for international recognition and access to new niche pro-environment markets. Some of these technological breakthroughs included improvement in the herd (for dairy), innovative soil conservation practices like windbreaks, the introduction of new grass or crop varieties and grains to complement animal diet (see Porras, Miranda and Hope (forthcoming).

Most of the initial tourists in the area were scientists. Visitation increased as the area became better known. However, and perhaps luckily, the difficulty of access meant that it was only real "nature-lovers" who arrived. Until the 1990s there were very few public facilities in the area, but the situation changed considerably with the strengthening of conservationist NGOs (such as the Tropical Science Centre and the Monteverde Conservationist League), whose fundraising campaigns showed the area's beauty and biodiversity to the world, and with the introduction of the tourism incentives by the Costa Rican government[11]. The ecotourism booming era was kickstarted in Monteverde.

A range of livelihood combinations began to emerge. Some locals gambled and completely changed their main economic activity from dairy to ecotourism. Others decided to explore the new activity alongside their regular farm activities. But for all, isolation was a thing of the past.

The tourism industry became the main source of income for the region. New jobs stimulated immigration to the area, making the population grow from 400 to over 6000 in less than twenty years (INEC, 1984, 2000). The new Monteverde comprises "mini-communities" within itself. Permanent residents, both Costa Ricans and (mostly) USA citizens, include dairy farmers, hotel and restaurant owners and workers, scientists, volunteers, religious groups, etc. Seasonal visitors include the large amount of tourists and migratory work forces. The cultural life began to change and according to some locals, Monteverde has more the characteristics of a city than a rural area, with international cuisine, pubs, and jazz concerts if one can navigate through the heavy rain, mud, and bumpy roads!.

In 2001 Monteverde received approximately one million tourists (personal communication, CETAM, 2002). Projections from CETAM indicate twice as many by the year 2010. Projects like the paving of the main access roads seem doubled-edge, as it could increase even more the number of daily visitations to the area.

Threats to the cloud forest. The cloud forests in Monteverde face serious environmental issues. One of the most urgent problems concerns the existence of the cloud forest itself; studies have shown that the cloud has been lifting, providing less mist and rain to the environment beneath. There are two hypotheses explaining this lifting: global warming and deforestation. In a study published in NATURE in 1999, Pounds et al. asserted: "The biological and climatic patterns (in Monteverde) suggest that atmospheric warming has raised the average altitude of the base of the orographic cloud bank".

This conclusion is built on evidence that evaporation from warm ocean surfaces released heat as it condensed, accelerating atmospheric warming and decreasing the difference in temperatures between the lowlands and the highlands. In response to this, the cloud-formation height, which is dependent on relative humidity surfaces, has moved up. The study also showed that the increasing dry periods in Monteverde are "associated with warm episodes of the El Nino/Southern Oscillation". This study provided much evidence to support the "lifting-cloud-base hypothesis" and global warming has been widely accepted as at least part of the cause.

Another theory advanced to explain the lifting cloud is that of lowland deforestation. In a study published in Science, Lawton et al. (2001) advanced the theory that "reduced evapotranspiration after deforestation in tropical lowlands decreases the moisture content of the air mass flowing up the slopes of the adjacent mountains. This increases the lifting condensation level and thus the elevation of the cloud deck. The model results thus suggest that deforestation in the lowland tropics of the trade wind zone tends to shift the cloud forest environment upward in adjacent downwind mountains". This theory does not contradict the global warming results; in fact, its authors maintain that the two theories are complementary. Both causes could have an effect on the moisture levels and thus height of the clouds, and both recognize the danger of the cloud deck disappearing altogether.

[11] Since the 1990's tourism has received important incentives from the government, for example preferential credit, tax exemptions, and educational programs oriented to tourism careers.

The fast and spontaneuous growth has had important economic, social, and environmental consecuences. According to Koens (2003) there is a remarkable gap in social and environmental aspect although economic variables are positive. Even though ecotourism is the main source of income, issues of sustainability are still weak. A recent study by the the Monteverde Institute (Kim *et al,* 2003) found that, although drinking water[12] is of good quality, there are nevertheless significant levels of pollution in rivers resulting from the disposal of untreated domestic and industrial waste waters. A meeting of local stakeholders held in 2002[13], confirmed during the focus groups that one of the main concerns related to water was availability and quality for drinking purposes. Nitrate concentrates and the potential harms of uncontrolled urban expansion were signalled as some of the main threats to water in the region. Little concern was expressed about sediments or soil erosion problems in the upper parts of the watershed. This, however, remains an issue for the downstream hydroelectric project.

While the upper parts of the watershed witnessed the ecotourism boom, further down in the watershed the conservation versus development debate was taking another direction. Most of the livestock activity has been historically concentrated in Rio Chiquito, where land use maps show that the area under pasture has increased significantly since 1960 (Aylward *et al* 1998). However, Bolaños (1995) suggests that there has been no significant change since the early 1980s, mostly because most of Rio Chiquito was already occupied by then.

Ranchers received heavy critisism from conservation groups. In 1993 the Arenal Conservation Area (ACA)[14] was created and began a watershed management plan. Livestock activity was made a target because of its short-term private land use, and conversion from pasture to forest was strongly advocated, to the almost general opposition of ranchers (Fernández-González and Aylward, 1998). This "anti-pastures" agenda was not supported by recent hydrological studies conducted in the area. A series of extensive biophysical and socio-economic studies in Rio Chiquito showed that …"pastures fares better than forest in comparison, and even in the upper watershed, cloud forest land, where water sources for the reservoir originate, the hydrological impact could be improved by interspersing pasture where forest now reigns…" (Fernández-González and Aylward, 1998).

However, scientific evidence does not always figure high in the defining factors for policy-making, and the popular belief that forests are good for water. These issues will be discussed in the next Section.

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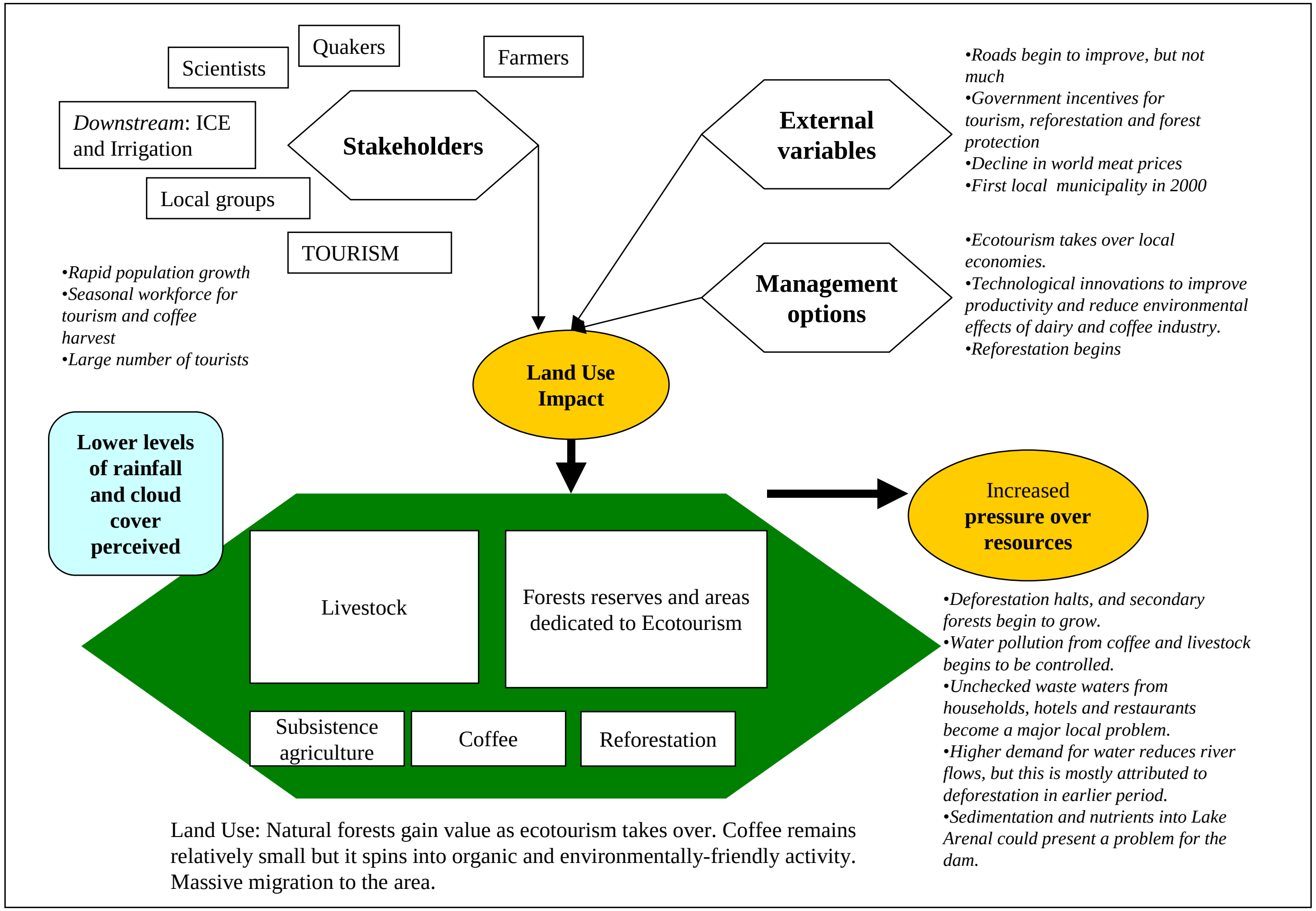
[12] Drinking water in the area comes from water springs and wells.

[13] The stakeholder meeting was held on August 29th 2002 during the Initiation Workshop of this Project. See Footnote 1 for more details. The consultation included producer and consumer groups: coffee, dairy, civil society, women groups, tourist board, cheese factory, plus more formal organisations and institutions, including local municipality, water board, ICE, FUNDECOR, FONAFIFO, PRAT, MINAE and others

[14] ACA was created building on existing reserves and including new forest areas with the economic help of WWF Canada. Additionally, ACA promotes sustainable development in the area in agroindustry, reforestation and ecotourism.

Figure 7. Land use patterns from the mid 1980s to the 2000s



Source: recreated from Focus Groups and personal interviews with descendents from early settlers.

4 Local perceptions of water resources

> *"There can never be water without trees. When I was a child there was forest, and water, and animals. During my youth I saw it all disappear with deforestation and forest fires that dried up everything. Nowdays, there is more protection, and water flowsare coming back again. I believe that if there are trees, there is water".* CETAM Focus Group, Monteverde

This section of the Study looks in more detail at how do local people perceive the relation of forest and water resources, according to their own experiences. The information was collected through focus groups in the communities and personal interviews. Participants were asked what they thought were the functions of the forest with respect to water resources. If necessary, they were prompted with questions related to forests and their relation to rainfall, runoff, flow regulation, erosion, flood control, and water quality. See Section 1.2 for more methodological details.

4.1 "*It used to rain more*" - Popular perceptions in Monteverde

The general feeling from the personal interviews and focus groups is that local people feel that it used to rain more in the past. The "*past*" can be described as 20 years, 50 years, or more, depending on the age of whoever tells the story.

> "Nowdays, it rains less in summers than 30 years ago. But now the government* has bought and kept more forest, there is a tendency of more clouds now, and it gets colder again". **Focus Group in Las Nubes.** *Note: there seemed to be confusion about the private reserves and the government.
>
> "When I was little the creeks used to fill up a lot more, especially during the rainy season when it was impossible to cross it. From about 15 years to now it hasn't fill up that much". **Focus Group in Las Nubes.**

According to participants, the main functions of the forests are:

- Forests increase rainfall (and produce water)
- Forests capture moisture from the clouds;
- Forests reduce evaporation from rivers, springs and ponds;
- Forests regulate flows after rain events;
- Forests increase infiltration of water, and regulate water during dry events;
- Agroforestry increases productivity of soils

4.1.1 Forests increase rainfall and produce water

In the particular case of Monteverde, Costa Rica, participants of the focus groups are adamant in their point of view that forests have a definite effect on rainfall. According to participants in the focus groups, the ways by which forest affect rainfall are through recycled evaporation, allowing the formation of clouds that become rain again (*"it's not only the sea that produces rain")*, and by trapping the clouds and fog coming from the Atlantic.

"It's a fact that it rains less nowdays, especially during the dry season. But the protection and increase of forests in the upper lands means that there are more clouds now, it gets cooler and rainfall is beginning to increase again. And this affects pastures. It's not good for milk production, pastures are not good quality and agriculture is almost out of the question because it rains too much". ***Rancher in Las Nubes***

"The forest reserves in the upper lands help with the moisture through maintaining a cloud base and increasing rainfall". ***Rancher in La Cruz***

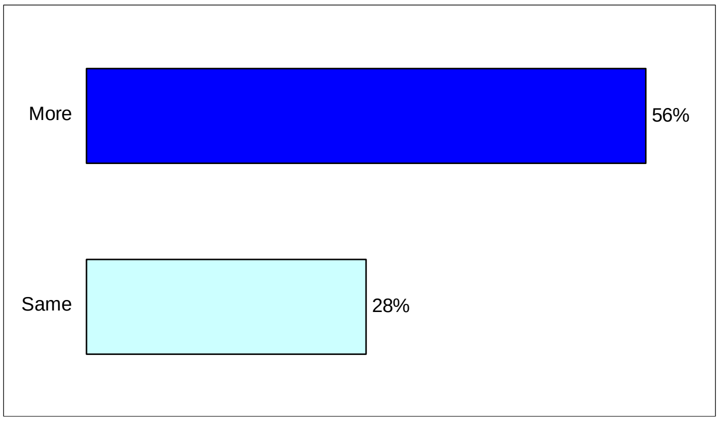
"One of the main functions of our forests is to capture the clouds coming from the Atlantic". Monteverde Producers Executive Board Focus Group**.**

"Forest maintain moisture and convert evaporation back into precipitation, like a sponge".

"I believe that there must be a positive relation between forest and rainfall. Even if altitude and life-zones might affect, it used to rain more before, when the country had more forest as a whole" ***Independent policy advisor, San José.***

For the majority of participants in the focus groups there is a direct relation between forest cover and rainfall ("*there is more rainfall when there is more forest*"). Over half of the survey respondents (56%) belief that cloud forest produce more rainfall than any other type of land use, including other types of forests, forest plantations and agriculture (see Figure 8).

Figure 8 P&B of the influence of cloud forests over rainfall, N=39



All participants in the focus groups perceived that in the past sunny days were rare, as clouds were constantly over the region and there was a lot of horizontal precipitation even if there was more pasture than today. Some participants believe that while global warming have affected the current (lower) precipitation levels, reduced water levels today are also a consequence of past deforestation. The positive effects from current reforestation and forest protection measures take some time to make effect and will be seen in the future.

There is, however, a growing perception (especially outside the cloud forest area) that forests do not necessarily have a strong influence over rainfall, which is defined by other environmental conditions, like the existence of seasons.

4.1.2 Forests reduce evaporation of water bodies

According to the focus groups, one of the functions of the forest by which they help maintain water flows in the system is through the prevention of evaporation from springs; by providing shade and shelter and maintaining the humidity in the ground. Deforestation exposes water bodies to the sunlight and increases evaporation, and therefore reducing water flows.

> "Forests keep the moisture in the soil and rivers by providing shade to water springs and preventing evaporation". ***Tourist board member***
>
> "Even if forests don't increase water levels, they provide shade and help reduce fires which have effects on the water. The lower parts of the watershed don't have trees and you see fires all the time, and it is very dry". ***Women's group CASEM***
>
> "Forest keep moisture and therefore allow water to exist. There are three springs in our family farm. Until some years ago our father would cut down trees without thinking, but now we know that it will reduce water. We have started reforesting with trees and banana plants. ***Women's group CASEM.***

4.1.3 Forests regulate flows after rain events

General perception in the upper part of the watershed is that forests help regulate and soften the impact of rainfall, compared to other types of land use and reduce immediate runoff. Participants argued that river levels after events of high intensity of rain take longer to peak when there is forest when compared to open pastures:

> "It's easy to see the effect of forest over runoff just by looking at the rivers coming from the Reserves after heavy rainfall. When it rains the rivers recharge slowly but when they are full they take longer to go down to their normal levels. In Rio Chiquito, on the other hand, where there is less forest, rivers rise and fall again very quickly after the storm". ***Rancher, Las Nubes de Monteverde***
>
> "Forests absorb rainfall and reduce the speed of water runoff. But also improved-agriculture could get similar results" ***Independent policy advisor, San José***
>
> "Forest plantations with "thirsty" species, such as conifers, will help to dry-up the soil and reduce surface runoff during and after rainfalls. You can see this happening when you compare pine plantations with those areas with pastures or, even worse, urban areas with pavements and roads. ***School teacher, San José***

4.1.4 Forest increase infiltration of water

The sponge effect, where it is believed that forests' roots will soak up the rain and slowly release it back to the rivers, or "guide" it through the soil to the underground reserves where it comes back again as springs, is strongly intertwined into people's set of beliefs:

> - "Forests soils infiltrate water"
> - "Forests act as an interception filter: collects water and inserts it back to the rivers".

- "Forests are a sponge. Forests capture water from the clouds, infiltrate it, and the water comes back up in the lowlands. Water springs have their origin in upland forests".
- "Forests keep and maintain water flows. Where there is no forest, everything else is dry and barren". **Quotes from Focus Groups on infiltration**

There were some reports on experience of tree species actually decreasing water flows, although this was more of a "lone cry" than general feeling. One woman in the CASEM focus group explained that some trees "suck-up" the water, and other types of trees help infiltrate and increase water in the springs:

> "Trees like *guachipelín* will reduce water. Other trees, like *Higuerón,* with all the broad leaves, protect against the sun. You know the popular saying: "*where there's an higuerón there's water"*. Native species are good”. ***Women's group CASEM.***

There are some local studies that put forward the sponge effect, although this is still debated by the international scientific community. Ortiz (2002), presents results from experiments which support the sponge effect theory, arguing that forested lands in the exercise have greater underground water storage capacity than pasture areas. Nevertheless, the study has received significant critique about the experiment design which puts the results in doubt. These issues are later discussed in Section 4.3 and the **Appendix**.

4.1.5 Forests help regulate water in dry events

According to a representative from the Aqueduct, deforestation will reduce the quantity and quality of water, with particular effects during the summer. According to the community aqueduct, Monteverde has sufficient resources to supply water for its population, even with a 14% population growth rate (CETAM, focus group). While the authorities do not expect problems supplying water for private homes and hotels, they foresee a possible reduction in streams due to an increase in water use, but also from deforestation.

Most of the water shortages could be expected during extreme events, such as El Niño. The community already experienced some problems during 1994 and 1998, and according to the Aqueduct there might be some shortages during the dry season of 2004. Most of these problems tend to happen in the middle to lower parts of the watershed, where river levels drop to about 25% of their normal levels. It is interesting to note that nobody from the upper parts of the watershed mentioned water shortage during the focus groups.

4.1.6 Agroforestry systems increase productivity

Agroforestry systems began to be introduced in Monteverde during the mid 1980s, mostly as windbreakers[15]. Due to altitude and the wind patterns, in December and January the area suffers from very strong winds coming from the Atlantic, with negative impacts on wind erosion and dairy productivity. The introduction of windbreak reforestation projects, while initially rejected (*La Cruz Focus Group)* is

[15] See Porras, Miranda and Hope (2005, forthcoming) for more information about windbreaks in the area.

now regarded as highly beneficial. According to farmers in the focus groups, it is estimated that dairy productivity has increased approximately 20% per hectare. While farmers perceive a reduction in usable pastureland due to the introduction of trees, the benefits in increase productivity far outstrip the costs. Trees as windbreakers are seen as providing a series of benefits, including reduction of runoff, increase in soil productivity, protection of pastures against wind erosion and generation of other benefits such as fruits, medicine plants, biodiversity corridors, and, very important for local farmers, improvements in landscape beauty.

> "In the past 15 years the Cooperative has tried to help with the reforestation process, with the help of incentives from the Government*. We have planted about 35 to 40 thousand trees per year since 1989. We help farmers obtain government incentives for this, and work with them to install agroforestry system, such as shade coffee and windbreaks, using native species such as poró, avocado, citrics, and trees that provide households with timber. There have been important effects, such as reduction of wind and runoff erosion, increased soil productivity, and better landscape beauty. There is less need for herbicides". ***El Dos Focus Group***. *****note: incentives from the Government refers to payments for environmental services.

Not everybody agrees with this. Some participants in Las Nubes believe that, because they are located in the upper parts of the mountains, trees enter in direct competition for light, and the resulting quality of pastures is very poor and this has negative economic for the farmers: "*we know that trees are good for water, but we wish we could cut them and improve the productivity of our land* (dairy farmer in Las Nubes).

An interesting aspect is the dual perception of soil quality within the forest. For some participants, forests usually have good quality of soil because of all the layers of organic matter from the trees (*San Luis Focus Group*), making newly converted lands into highly productive areas. This concept was expressed as "*tierra nueva*" (new soils). Other participants expressed that while it is true that erosion is nearly non-existent in forests, all the organic matter that makes "new soils" so desirable actually comes from the canopies, and if the area is deforested it would quickly lose its fertility and become barren, and produce a lot of sedimentation because of the topography and sharp slopes of the area (*Municipality Focus Group).* This is the moment when, according to participants in San Luis, these areas would turn into "tierras viejas" (old soils) and it became necessary to deforest new areas (*"volcar montaña otra vez"*).

Some agroforestry systems are good, but some fast-growing plantations like cypresses are not considered beneficial because they dry up the soil. Localized efforts are being made by the Coffee Cooperative El Dos to introduce reforestation with native species, as learning experience taught them that some exotic species reduce water supplies.

> "It is important to rescue the credibility in reforestation projects. Some years ago it was the boom about eucalyptus and pine, and later on we were told that it was actually not good for water. We need to learn more about the tree species. The problem is that even if there is research done into this, it doesn't come to the communities but stays in offices and desks". (El Dos Focus Group.

For some participants in the focus groups living in the middle or lower parts of the watershed, it is difficult to engage in reforestation because it is expensive, but also because trees will dry up for lack of water and pest attacks.

One member of the Aqueduct expressed that, although the effect of reforestation was possibly imperceptible or non-existent in terms of water levels, its importance was in terms of reduction of erosion and acting as a barrier in water springs.

4.2 Downstream perceptions

4.2.1 Hydroelectricity

Due to the inter-annual nature of the Arenal reservoir, ICE production engineers have advocated the view that forest cover is irrelevant for water flows and in fact, the area in the watershed "might as well be paved", without negative consequences for the hydroelectric services (Fernández-González and Aylward, 1998). This argument has had support from local ranchers who argue that well managed pastures can promote runoff and prevent erosion and sedimentation. For obvious reasons, conservationist groups oppose this view, and substantial tension exists in the area. Supprting this view, an in-depth study coordinated by the International Institute for Environment and Development, the Tropical Science Centre and the Universidad Nacional (Aylward *et al*1998), indicates that: "pasture fares better than forest in comparison, and even in the upper watershed, cloud forest land, where water sources for the reservoir originate, the hydrological impact could be improved by interspersing pasture where forests now reign".

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4.2.2 Irrigation

Water from the reservoir feeds into the largest irrigation project of the country (SENARA). Largely, land use in the upper parts of the watershed is not perceived as a major threat to the supply of water flows, and their main concerns are related to infrastructure and flows management.

According to representants from the irrigation project[16], while the institution does not have a defined environmental policy, it is interested in making sure they are able to receive (and then supply) the required water flows. The main environmental threats in the watershed SENARA perceive are:

1. The absence of an integral watershed management plan, which results in water pollution. Local municipalities (Cañas and Tilarán) do not have regulation plans, or political will, to protect water resources. Pollution comes from direct discharge from septic tanks, and wastewaters from domestic, industry, and dairy farms.
2. Pollution from wind-driven garbage from landfills located nearby the irrigation canals.

[16] Interviews with Nora Pineda. Regente Ambiental. DRAT. npineda@senara.go.cr, and Roberto Spesny. Departamento de planificación Senara. December 2004. For more details on the irrigation project see Porras, Miranda and Hope (forthcoming).

3. Excess of water in the drainages resulting from inefficient use of water. For example, La Mula creek, which cuts through the Palo Verde Wetland National Park has lost the seasonality characteristics (dry in summer, wet in winter) required for the wetland. The excessive use of water means that the creek is always full.
4. Deforestation and illegal logging in the upper parts of the watershed result in losses of soil fertility and increased sediments in the drainages.
5. Water pollution with pesticides from irrigated farms could get in the Wetland and have negative environmental impacts.

The main environmental services SENARA expects are not land-use related. "Better water quality" is mostly related to the authorities either establishing new guidelines for wastewaters, or making sure that existing regulations are followed. SENARA also needs "constant water supply from the reservoir throughout the year". Water for irrigation depends on the energy production from ICE. Currently SENARA needs between 42 to 70 m3 of water, depending on the season. SENARA's water requirements during the dry season are easily met because the hydroplants operate every day. Their problem is the wet season, when hydroelectricity production is not constant in the Arenal Reservoir and water is not passed through the canals. Charges for irrigation are extremely subsidised (approximately $45/ha/yr) and the organisation is not able to generate the funds it would need to make water storage tanks and regulate flows. A recent study by Pineda, Environmental Regent of DRAT, suggests that the tariff should be approximately $65/ha/yr.

The main environmental service that SENARA receives is water, and the institution is not particularly interested in other environmental services (such as biodiversity, landscape beauty or carbon sequestration). Environmental issues are not a priority for the institution. Their efforts are concentrate on irrigation systems, cleaning existing canals, and saving water flows. However, the organisation takes active part in local and national water-related discussions. It has an environmental regent who gives support in environmental issues.

The ideal water use in the upper parts of the Watershed is forestry cover in riparian areas and high slopes, improved pastures and organic agriculture with soil management. In the lower parts of the watershed the Institution would like more efficient water use and organic production.

4.3 The scientific evidence

The Appendix presents a review of the science behind land use, forest and water resources. In short, the main effects from forests with respect to watershed environmental services are (Calder, 2002):

- Experiments from catchments indicate lower runoff from forest compared to other areas under shorter vegetation. However, particular characteristics of tree species and soil types will affect the degree by which evaporation and transpiration affect runoff.
- Competing effects from increased infiltration and higher evaporation and transpiration from trees could result in higher or lower dry-season flows, and

the effects are likely to be specific. Afforestation will most probably not lead to higher dry season flows.

- While natural undisturbed forests might have lower rates of erosion, the effect from disturbed forests or forest plantations could be the opposite. It all depends, at the end, on management techniques and tree species that minimize soil impact.

A quick internet-based consultation about the linkages between forests and water done by the author using the Rimanchik network based in Perú produced 15 responses. Answers came from forest engineers and NGO advisers. The results indicate that, according to this group of experts, the links of forests and water are:

- Forests do not necessarily increase rainfall, unless cloud forests by increasing horizontal precipitation.
- Surface runoff is reduced to a certain extend through increases in infiltration rates. However, only the existence of organic matter will help improve soil porosity. Big conifer forests, for example, that do not allow for other vegetation to grow, will not stop runoff and possibly increase it.
- Forests reduce erosion and sedimentation, especially through the existence of different layers of vegetation that break down the intensity of rainfall drops, and soil erosion through heavy winds.
- Forest control small-scale flood events.
- Forests increase water quality through reduced levels of sedimentation and by lowering water temperature with shade, therefore reducing formation of microorganisms.
- Forest control soil structure with their roots, therefore soil quality is better.
- Most people mentioned that forests increase infiltration rates making more water available during the dry season (*sponge effect)*.
- Water flows in rivers increases with forests. Only one response indicated that flows will decrease because trees capture water before it reaches water bodies.

4.4 Overlapping the results

If land use policy should be based in science, then the question is whether or not science overlaps with people's perceptions on forests and water. Comparing the results from local perceptions in Section 4 with that of scientific research in the Appendix, it seems at first glance that there is a considerable gap between experts' opinion, general public, and science. However, what seems to be widely known in the expert community is not necessarily reaching down to land stewards in upper watersheds.

It is important to stress that while there is a significant amount of cloud forest in Monteverde, and science indicates that in that particular case forest could increase precipitation through the capture of fog, most of the perceptions of inhabitants of the upper and middle parts of the watershed regarding forest effects on water extended to other types of forests as well.

Table 2. Overlapping science, people and experts

People's P&B	Expected Effect [2]	Science	Experts' opinion
Forests increase rainfall. Deforestation decreases rainfall.	Especially in the case of cloud forests, the expected added benefits from horizontal precipitation contribute to higher streamflows, with added importance during the dry season.	Rainfall is not likely to be influenced by forest, unless at the very large scale. Even cloud forest's contribution, through horizontal precipitation, is relatively small.	Similar to science. However, cloud forests are perceived as contributing to water flows, especially during the dry season.
Forests reduce surface runoff, but increase infiltration.	The root network and low soil compaction from forests creates more permeability in the soil and prevents water reaching the streams and leaving the watershed too quickly.	Forests reduce runoff. Infiltration rates affected by types of soil and the existence of organic layer.	Same as science.
Forests increase dry-season flows by soaking-up water in rainy season and slowly releasing it back in the system.	The more even distribution of water throughout seasons is very important for run-of-river facilities or those with small reservoir storage. Prices of energy generated during dry-season are usually higher. But not for inter-annual facilities where total annual flows are more important.	Dry-season effect uncertain. Depends on the difference between losses through higher evapotranspiration and gains through infiltration.	Same as people's P&B
No information about floods was collected locally during the focus groups because they do not occur in the upper/middle parts of the watersheds.	Downstream hydroelectric projects in the area suffer from extreme events every 4-5 years. These events are linked to higher yields of sediments. It is perceived that change from forest cover will increase the frequency of the events (Rojas and Aylward, 2001).	Flood benefits can be felt only in small events and small watersheds.	Similar to science.
Forests have lower levels of erosion and sedimentation.	Increased siltation of reservoirs has direct costs in terms of dragging and stopping production to so that. The machinery is also affected by sand and suspended particles. Sediments can reduce the live storage of a reservoir, but could also have a positive effect if they land in the dead storage area (Aylward *et al*, 1998)	Natural forests have little erosion and sedimentation. Properly managed forests could have reduced levels of sedimentation compared to un-managed pastures.	Soil management and natural forests have lower levels of erosion and sedimentation.
Forests increase water quality.	(see above)	Most natural forests will provide good water quality. Adverse effects are likely to come from bad management techniques rather than forest themselves.	Same as P&B

[2] Based on Rojas and Aylward (2002). See Porras (2005) for more information on hydroelectric projects.

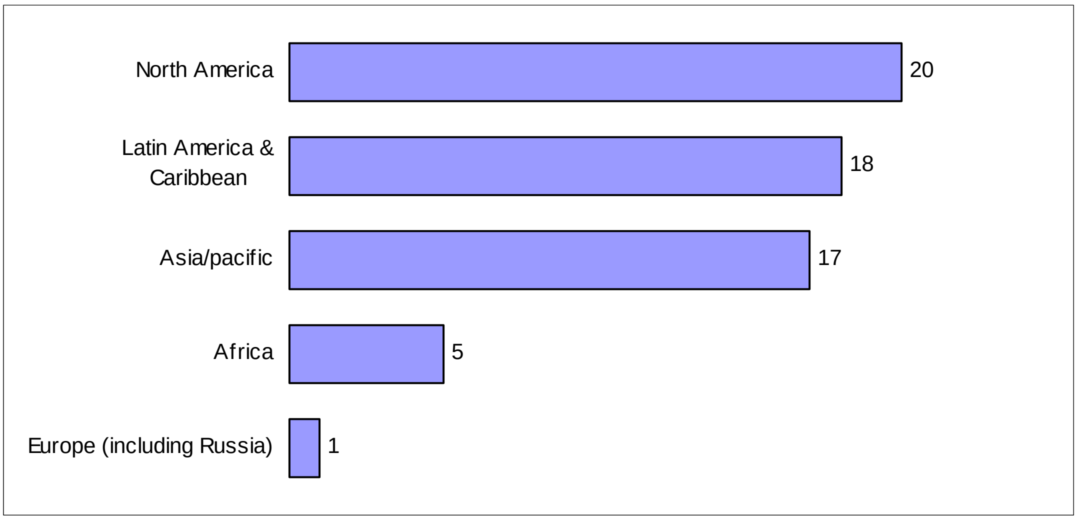
5 Effects over policy making

How do people's beliefs affect policy making? This section concentrates on the on-going development of Market-Mechanisms for Watershed Protection and how the findings from the Monteverde study fit into this.

5.1 Upstream/downstream compensations

Market-based mechanisms are currently being heralded as an alternative to management of environmental goods and services at watershed level. It is expected that markets will encourage not only environmental protection, increase economic efficiency and save public funds. A considerable number of initiatives around the world has been identified by Landell-Mills and Porras (2002), where 61 cases of markets were found in 22 countries (see Figure 9), most of them "marketing" to water quality and regulation. In most of these cases, the private sector seems to dominate the supply and demand (in the form of private landholders for the former and large projects for the latter), while intermediaries have mostly taken the form of government, local municipalities and NGOs.

Figure 9 Markets for Watershed Services: summary of global initiatives



Source: Landell-Mills and Porras (2002)

There is however, little information as to what do watershed markets mean for welfare and poverty alleviation. While economic benefits could take the form of income generation for suppliers, new jobs, cost savings in relation to command and control and source pollution control, increased efficiency in hydroelectric and water supply systems and other positive spin-offs for other water-user activities, there could be significant economic costs to watershed management in the form of provision of watershed protection, transaction costs associated with the market, and opportunity costs of forgone land uses. Social benefits highlighted in the literature review included health benefits, environmental education, training in improved land uses, improved recreational opportunities, and reduced sound and smell pollution. Other benefits include social institution strengthening, improved scientific knowledge and land title clarification. It is worth noting that the literature review did not present any information as to social costs of watershed markets, and nearly in general, little or nothing was said as to what markets might mean for poor households. In most cases, it is simply assumed that people will benefit, and no especial measures are taken to understand the impact of markets in their livelihoods, and how to maximize their potential participation in them. The main constrains identified in market development were especially related to (Landell-Mills and Porras, 2002):

- High transaction costs, in the case of multiple-stakeholder transactions, lack of cost- effective intermediaries, poorly define property rights (for land tenure and service rights), and the lack of clear and comprenhensive regulatory framework.
- On the demand side: lack of scientific evidence of the relation of land use and water, lack of participation of key stakeholders, and lack of willingness to pay.
- On the supply side: low awareness of market opportunities and the capacity to exploit these, lack of credibility in service delivery, and cultural resistance.

One issue that the development of watershed markets must overcome is property rights. While land resources are not that problematic and land has 'owners' (private property and large reserves), water ownership must be determined. In Costa Rica, water rights belong to the State, and the Ministry of Environment has control over it, granting exclusive rights to particular users but not allowing user right transfers, therefore eliminating the possibility of creating water markets. Until now, implicit water prices are obtained through the value of land nearby water works (rivers, springs, lake, and water canals of the irrigation system), and licences to use water for recreation. Prices for domestic water use, irrigation, and entrance fees are decided by an independend authority: ASESEP (Celis and Segnestam 2001).

5.2 Markets for Watershed Services in Costa Rica

The effects of land use, and particularly changes on forest cover, on water quantity and quality have been an on-going debate in Costa Rica, particularly during the past years with the introduction of the Payments for Environmental Services and the recent involvement of private groups as demanders of better and more reliable water resources. The Law states that owners of forests could claim compensation for the environmental services their forests produce, in the form of biodiversity conservation, carbon sequestration, landscape beauty and water conservation. From the beginning these four services have been bundled together for simplicity sake, and the only difference allowed within types of forest is for conservation (US$200/ha/over 5 years), sustainable forest management (US$320/ha/over 5 years), and reforestation projects (US$450/ha/over 5 years).

The amount of payment initially established tried to consider different aspects, including the opportunity cost of land[17]. Additionally, the law was introduced at the

[17] This remains one of the flaws of the system, as the opportunity cost was selected in terms of pasture for the whole country, not allowing for variation within the country. For example, Miranda, Porras and Moreno (2003) present an analysis of the impact of PES within the central region of Costa Rica and suggest that reforestation projects are not likely to take place in the amount initially expected because the opportunity cost of land in the area is much higher than the suggested payment.

time when carbon markets were being presented as a glamorous opportunity in the international markets, and this is reflected in the payment levels allowed for reforestation (i.e conservation projects receive considerably less than reforestation as the amount of carbon to sequester in the former is smaller). Since that, new developments have taken place at local, national and international level that question the way that the Law is being applied. While international consensus has not been reached in terms of carbon markets, local initiatives for watershed conservation have been put forward as a more reachable target for marketing environmental services, with a "packed produce" of improved water quality, quantity and improved dry season flows.

While the scientific evidence of the physical links between water and land use (especially forest cover) appear to be tenuous, and in some cases non-existing or even counterproductive, local initiatives are already underway and payments are being collected and allocated within different watersheds. There is not common consensus as to what is being sold and bought, and it could be argued that while current initiatives may have evolved based on a willingness to improved public relations on the part of companies or even on the precautionary principle of risk reduction if land use changed, it is not likely that long term initiatives will survive unless it is clear that a tangible service is really taking place.

Watershed services provided by forests have been recognized in Costa Rica for a long time. As early as 1888 a decree was passed declaring a 2-km wide strip of the sides of Barva Volcano as State-owned land, with the objective of protecting the streams and springs that supplied drinking water to the towns of Alajuela and Heredia (Watson et al. 1998). Nevertheless, the first case of an incipient case of market for watershed services took place in 1997, when the National Company of Power and Electricity (CNFL) agreed to pay landowners located in the Virilla watershed in order to ensure conservation and reforestation of existing forest on their land.

While the scientific evidence of the physical links between water and forest cover (conservation or reforestation) appear to be tenuous, and in some cases non-existing or even counterproductive, local initiatives are already underway and payments are being collected and allocated within different watersheds (Table 3). There is not common consensus as to what is being sold and bought, and it could be argued that while current initiatives may have evolved based on a willingness to improved public relations on the part of companies or even on the precautionary principle of risk reduction if land use changed (Calvo, 2000; Rojas and Aylward 2003, Pagiola 2002, J Kellenberg per.comm. 2001), it is not likely that long term initiatives will survive unless it is clear that a tangible service is really taking place.

Table 3. Markets and Payments for Hydrological Services in Costa Rica

Service/Mechanism/Case	Status	Summary
1. Hydrological Services to Hydropower Production		
(A) Transfer Payments: *FONAFIFO and Hydropower Companies*		
(i) Energia Global: Don Pedro and Rio Volcan Hydroelectric plant	Implemented and coming to a close, likely to be renewed	Company pays $10/ha/yr and FONAFIFO pays the remaining $30/ha/yr. FUNDECOR acts as intermediary. Over $43000 were allocated during the first year. Contracts are for 5 years.
(ii) Hidroelectrics Platanar (1)	Ongoing implementation	Company pays $15/ha/yr and FONAFIFO the remaining $25/ha/yr. For landholders without land titles the Company pays $30/ha/yr. FUNDECOR and CODEFORSA are intermediaries. Contracts are for 5 years.
(iii) Compañia Nacional de Fuerza y Luz (3) – Aranjuez, Balsa and Cote	Ongoing implementation	Company covers the full amount of the payment ($40/ha/yr) plus expenses for FONAFIFO ($13/ha during the first year and $7/ha for the remaining years. Contracts are for 10 years. There is no other intermediary between the company and FONAFIFO.
(B) Voluntary Contracts		
(i) Esperanza HEP and Monteverde Conservation League	Ongoing implementation	The agreement settles a dispute over some land where the hydroelectric plant is to be built, granting the right to the company to build and use the water during 99 years, after which infrastructure and land will be the property of MCL. Payments are made gradually starting with $3/ha during the first year, to $10/ha during the fourth year. After the amount of payment is variable and depends on production and sale price.
2. Hydrological Services to Water Supply		
(A) Transfer Payments: *FONAFIFO and Industry*		
(i) Costa Rican Brewery	Agreed	The company (FLORIDA ICE & FARM) agreed to pay US$45/ha/yr for 1000 ha located in the watershed where their water originates. It also pays additional money to FONAFIFO and FUNDECOR to administer and monitor the programme. More recently it liased with EHSP (see below) to pay for environmental services in overlapping areas.
(i) Melia Playa Conchal Hotel	Proposal	The company is exploring the option of developing a management plan for the watershed of the Nimboyores River in order to ensure the protection of the water source in the long term. This water will be key for the development of the hotel's expansion projects.
(B) Water Use Charges		
(i) Heredia Public Water Supply Company	Charges levied to water consumers, payments to forest owners pending	Company collects 1.90/m3 in 1999 to help protect the company's catchment areas (Ciruelas, Segundo, Bermudez, and Tibas rivers). Payments to landowners have not begun yet.

Source: Adapted from Rojas and Aylward, 2003

Despite the large number of initiatives within the country, markets are incipient and are constantly changing. The national context is very dynamic and evolves quickly, therefore allowing for improvements and adjustments "on the go". Additionally, very little attention is being put onto the social effects of the Payments for Environmental Services. Although it is clear that markets for environmental services are not a poverty alleviation tool, the question of how the PES is altering the rural landscape and what are their effects on people's livelihoods has not been put forward strongly enough. For example, Miranda, Porras and Moreno (2003) suggest that the use of PES in the central valley of Costa Rica has not necessarily changed significantly the landscape since most payments have been allocated on relatively wealthy landholders who maintain their forest on their own interest, and most are not interested in reforestation because it does not pay enough to compete with other existing land uses (i.e coffee, dairy farms or possible urban developments). Nevertheless, in other areas of the country the situation might vary, small landholders might feel forced to enter into long-term reforestation projects because they lack alternatives for their land and might decide to abort the programme if market situations changed. In these cases, it may be wiser to introduce other land use systems that improve watershed management and provide short/medium term livelihoods for small landholders.

While it could be argued that for the Costa Rican case the matter of land use change has become largely academic now that deforestation in Costa Rica has virtually come to a halt in the last few years (from 16,400 ha/ year in 1986-1997 to 3,300 ha/year in 1997/2000; Sánchez-Azofeifa and Calvo, 2002) (J. Fallas, personal communication, November 2001), the question of diminished streamflows following forest removal is as acute as ever elsewhere in Central America (Kaimowitz, 2002) where upland forest protection is much less secure (IUCN-ORMA, 2001). Even further, the continued pressure to undertake revegetation activities, particularly reforestation, and the environmental services payments that promote such efforts is strong in Costa Rica, as elsewhere in the world. The need to better understand not just the hydrology but also the economics of reforestation or watershed management efforts is tremendous as demonstrated by Kaimowitz (2002). However, social issues have often been tertiary in this process due to top-down and centralized approaches to watershed management.

5.3 Markets for Watershed Services in Monteverde

This section outlines the local feelings with respect to their forests and the externalities they might create. This section reviews the potential room for upstream/downstream negotiations to improve land use.

5.3.1 "Our forests provide many benefits"

The concept of forests and their role in the provision of environmental services is strongly rooted in the farmers and producers of the Monteverde area. The recognision of benefits also brings the issue of fairness of compensation, but it is not clear who should compensate for what. It is also remarkable that, despite the existence of the Payments for Environmental Services programme in Costa Rica for several years, Monteverde is still lagging behind in joining the programme.

- **Forests provide many benefits…and trade-offs**

Participants in the Focus Groups recognise the importance of forests for the maintenance of environmental services, especially biodiversity, espiritual values, and water.

As Windbreakers: “Trees in windbreaks are important to protect the cattle in areas very exposed to strong winds. Those are the places where reforestation is important. I don’t think that it’s to increase water, because there’s already plenty of it”. Farmer in Las Nubes Focus Group.

“We wish we could just cut all the trees down and get as much light as possible for pastures. But we know that if we do that we’ll loose all our water”. Farmer in Las Nubes”.

“Trees are life. Yes. But we wish we could cut them down, and get more milk so we can sell it”. Farmer in Las Nubes.

- **Compensation is fair**

Farmers believe that if their forests are producing environmental services and someone else is benefiting, then its is only fair that they should be paid for what they already generate in environmental services, but also to change land uses upstream.

“Is it fair to limit production in order to plant more forest?. Yes, I think so. If we continue deforesting we’ll end up badly. But there should be some kind of help to reforest. For us is better to have less trees and more pastures”. Farmer in Las Nubes.

“We used to receive payments from the PES, but not any more. We have a small reserve of 10 manzanas, and were getting payments of 10,000colones/hectare. But they’ve suspended the payments, arguing that we need to put them in a separate title deed. I think that the money is just sitting with MINAE, and not with the people who are really protecting the nature. The PES could be very important. We are all small producers. If I have 20 ha with half under conservation, that would give funds to complement income for several families. If timber was well paid then we’d live of that, but that’s not the case. And then, if we are producing $1350/ha in clear oxygen, then why shouldn’t we receive that? There should be justice. I don’t think that it’s feasible to have a charge for water downstream. Besides, the damage is reciprocal. If we reforest, we will loose the water upstream, too”. Farmer in La Cruz.

“We receive many benefits from the forest. But ICE also benefits a lot from this forest. How much would they benefit if all this area was forest?”. *Municipality Focus Group.*

- **Who should pay**

Finance for reforestation should be through incentives, such as PES (El Dos Focus Group). However, several participants pointed out other groups (ICE, and water users downstream) should also pay directly. However, most participants in the focus groups agree that it would be very difficult to get people from downstream communities to pay for watershed services (*“capaz que nos matan!”- Focus Group in La Cruz).*

“Most of the water from here goes to the Arenal Lake and it is ICE and the Irrigation project who use them. They should pay. And some people from towns, like Cabeceras. But I don’t think that we could ask them to pay.”. **Las Nubes Focus Group.**

However, local perceptions about ICE are not very positive.

“We conserve forest just to let the water come to ICE. I oppose their policy of expropriation…they can just come and take your land away, without consultation”.

> "It's not fair that we have to keep the forest only for ICE. There is a new proposal to let water resources under the control of MINAE, but I do not agree. What is then the purpose of the Water Utilities? To pass on monthly bills to the houses, or should it be to regulate water?.
>
> "What is the benefit for ICE of forests up in the watershed? Monteverde should receive compensation from ICE for the forests it keeps. How much would that be? If a farmer stops dairy farming to reforest, how much is he losing? ICE should be paying for that."
>
> "When ICE created the lake, they didn't compensate everybody. They diverted rivers that other towns were using. Even the municipality of Tilaran lost when the area was inundated and the towns and *fincas* were lost. The municipality doesn't even receive compensation for the space that the lake takes…why do we have to pay property taxes then?"
>
> **Municipality Focus Group**

- **Solutions**

"Patches of forest and pasture would be the most beneficial land use. The forest will guarantee the provision of water, and the pastue areas will provide the light that we need for the cattle". Farmer in Las Nubes Focus Group.

5.3.2 Why are they not engaging?

While the Payment for Environmental Services (PES) has been implemented in Costa Rica for some years already, its involvement in Monteverde has been more limited and the most significant beneficiaries are the private reserves rather than individual private landowners.

Several reasons were mentioned during the Focus Groups for the lack of active participation in the PES scheme:

- **Land Titles:**

One landowner in La Cruz received payments for 10 hectares, but later on had problems related to property titles and the payments were cancelled. There are many cases in which landowners do not have clear property titles, and the process to actually obtain them could be a long, tedious, and expensive process that they are not willing to face.

- **Opportunity cost:**

While some landowners in the Monteverde area have significantly increased the value of their forests through ecotourism activities, there is still a large amount of people who depend on other land uses for their living. Another problem that was evident in the area is the dependency of cattle in the forest. Several farmers pointed out that while cattle prefers open, light areas of pastures, sometimes they need to take refuge in forested parts (for example, during storms or high winds), and to complement their diet. This has been a traditional activity that would not be allowed under the PES, and would directly affect them negatively.

- **Perceived negative effects of more forests:**

There are some landowners, living in the upper parts of the watershed, that perceive that increasing the area under forest will result in more humidity and cloudiness in the area, and this will affect negatively their agriculture activities.

- **Too much regulation:**

Farmers are reluctant to loose the freedom from Government intervension they have enjoyed for a long time. They fear that the current levels of regulation are too high, and signing in to the PES would just give a "green light" for further controls.

> "Not long ago I had some arguments with [MINAE] because they won't let me use my trees. They live out of regulation, but I don't. If I need to use my forest, I have to do it in hiding, and I feel as I was robbing myself". Farmer in Las Nubes.

- **Lack of information**

It because evident during the Focus Groups that perhaps the single most important reason to explain the lack of participation in the PES programme is actual lack of information. Many farmers had not even heard of the PES, assuming that it was just another set of [ever changing] incentives to reforest. Others had many strongly rooted ideas of expropriation. Others felt that this was something out of their reach and only for the big private reserves. Much of this reserve to participate could be overcome, slowly, with information oriented to the farmers.

A random survey of over 100 landowners in the area showed that not one individual was receiving PES, and less than half of them were even aware of the programme (Hope 2004, see below for more detail on the survey).

> **PES perception in Monteverde.** The impact of the PES on livelihoods is evaluated across a range of qualitative responses to respondents' knowledge and perceptions of the policy (see table below). Less than half of each of the three livelihood groups were aware of the PES policy. Coffee farmers reported the highest level of awareness (46%), followed by livestock farmers (34%) and then tourism (22%). Only one percent of livestock farmers had applied for the payment and this farmer (n=1) had been unsuccessful in receiving the payment. Open-ended questions in the survey instrument generated a range of responses to why respondents had not applied for the PES. Four categories emerged from the responses: information, low returns (US$ per ha), land title and commitment. 'Lack of information' was the dominant reason (61%) why livestock farmers had not applied for the payments. One in three coffee farmers cited this reason, whilst a similar proportion (32%) identified the low returns of the payment level. The opportunity cost of payments compared to other productive land uses is identified as a constraint to wider adoption of PES policy in the Varilla watershed in Costa Rica (Miranda et al., 2002). Livestock farmers also identified 'low returns' but given that the majority of the sample knew little to nothing of the PES policy this proportionately lower percentage of responses to a second-order constraint is consistent with their lack of information. Coffee farmers' increased knowledge of the qualification criteria for PES stated that lack of a title deed to the property was a another limitation (28% of responses) to uptake of the policy. Seven percent of livestock farmers recorded title deed ownership as a constraint, also. Finally, there was a lower proportion of respondents who described a reluctance to enter into land contracts with the government. Though this represents a minority of responses here (9% of coffee and 13% of livestock), this theme surfaced regularly in discussions with farmers based on widespread 'distrust' of government land management.

6 Summary and recomendations

The main findings and recommendations of this study are:

- Science and popular perceptions differ, and this can affect both policy-making, and the possible success and uptake of new land use policies.
- Land use changes fast.
- Urbanisation, not deforestation, is the main threat.
- A people-centered approach is needed.
- Government perception is poor, mostly because of lack of communication.
- Uptake of payments for environmental services by small private landholders has still some way to go.

6.1 Science and popular perceptions differ

Different groups' perceptions into knowledge, attitudes and beliefs on land/water relationships vary substantially in humid tropics. Perhaps the strongest debate focuses on the effects of forest (or deforestation) on water quality, quantity, and the effect on low flows. There has been a historical trend of predictions (many times alarming), of the relations between change of forest cover, and soil and water degradation. According to Saberwal (1997), the majority of these predictions are characterized by:

- an absence of empirical data to support particular scenarios of degradation,
- an absence of long-term data to enable the detection of directional points,
- a failure to separate naturally occurring events from those induced by human activities; and
- a failure to distinguish seasonal from permanent changes in vegetation cover.

Saberwal (1997) suggests that the desiccating influence of deforestation was amply discussed in Europe since the 17th century, as an input used by European foresters to press for the establishment of forest reserves in France and Germany, and the institutionalisation of forest conservation. European forestry held a notion that forests played a crucial role in influencing climate – through increased precipitation and moderation of temperature extremes. The European influence can be traced in America and India until the beginning of the 20th century, period in which most of their forestry experts were educated in Europe. The connection between forests and rainfall was useful for foresters to gain greater control over forestlands, although empirical meteorological data proved otherwise.

The larger debate of forests and water is principally fuelled by the collision of viewpoints and economic needs of land settlers and colonisers, engineers, scientists, conservationists and environmentalist, united with existing power institutions. While scientific ideas may have provided material for the formulation of the discourse, the institutional context in which it has taken place has provided its shape and direction (Saberwal, 1997). Calder (2002), suggests that the disparity between scientific research and policy agenda, especially when linked to dry-season flows, "has arisen through the extensive promotion of certain land uses and engineering interventions by vested interest groups in the absence of any effective dissemination of the scientific evidence which may allow a contrary view". The economic implications of such approach are found in the form of wastage of development funds on "unachievable targets and the unwarranted blame of upland communities whose practices have generally had only marginal impacts on downstream flooding".

A new study by World Bank-WWF Alliance for Forest Conservation and Sustainable Use[18] shows that protecting forest areas provides a cost-effective means of supplying many of the world's biggest cities with high quality drinking water, providing significant health and economic benefits to urban populations. Well-managed natural forests can minimize the risk of small landslides, erosion, and sedimentation. They contribute to filtering pollutants, such as pesticides. According to the report, adopting a forest protection strategy can result in massive savings. The report argues that, for example, it is much cheaper to protect forests than to build water treatment plants.

Common perception in Central America is that forests increase rainfall, captures water from precipitation and slowly releases into the ground, protect water springs during summer, protect against intense flooding events, and reduce sedimentation (Kaimowitz, 2001). This perception is found nearly all over the world. A quick e-mail about local perceptions conducted in Vietnam (IIED, no date) indicates that people belief almost in general, that forest increase flows in rivers and streams, increase dry-season flows, increase rainfall, control floods, and reduce sedimentation (Elaine Morrison, personal communication 2003). Similar quotes abound around the world. The effects of the Mitch Hurricane in Central America in 1998 were largely blamed on deforestation by common consent from politicians, media, environmental groups, and international agencies. A quick search in the Internet shows at least 55 references to the aggravating effects of deforestation:

> "Mitch Hurricane calls attention on environmental degradation":
> http://www.laneta.apc.org/urgencias/ips01-14.htm
>
> "Damages in watersheds due to deforestation: the Mitch case": PRISMA, Guatemala.
> http://www.metabase.net/docs/prisma/03391.html
>
> "Deforestation, poverty and global warming aggravated the Mitch effects":
> http://csf.colorado.edu/forums/elan/may99/msg01118.html

The devastating effects of deforestation are often cited around the world, most of the time without strong scientific data to back up these statements (Saberwal, 1998). In 1986, referring to deforestation in the Himalayas, the environmentalist Norman Myers, (winner of the 2001 Blue Planet Prize), indicates that:

> "Primarily because of deforesation in their headwater regions, the river systems are increasingly subject to disruption, leading to floods followed by droughts…The Himalayan forests normally exert a *sponge effect*, soaking up abundant rainfall and storing it before releasing it in regular amounts over an extended period. When the forest is cleared, rivers turn muddy, and swollen during the wet season, before shrinking during drier periods…Flood disasters are becoming more frequent and more severe" (*cited in Saberwal, 1998).*

The link between land use and water have been a concern for scientists during many years and in more recent times decision makers are becoming more aware of the economic implications of bad watershed management. Changes in land use could not only affect water resources (liability of the river to flood, the magnitude of such flood,

[18] For more information see **http://www.wwfca.org/php/news/artireport07ing.php**).

sediment loads and the dry season flows), but soil degradation could also be a result of overgrazing, poor irrigation and land management, and over-exploitation of vegetative cover (Calder, 1999; Russell, 1981).

A clear understanding of these links is key to design appropriate policy measures to improve watershed management. Myth-based policies could result not only in a waste of economic resources, and time, but could also have potential negative consequences that would be felt in the medium and long term. While for a long time it has been the task of the goverment to ensure the provision of watershed services, an emergence of new alternatives that could prove more efficient and cost-effective, in the form of market-based mechanisms for environmental services, in which the “consumer pays” principle becomes the main driver, but it is also expected, and demanded, that a true service be delivered.

6.2 Land use changes fast

Land use has important economic values in the upper and middle parts of the watershed. In the upper parts, the introduction of new technologies, such as windbreaks, has increased the productivity of dairy farming. Coffee industry is managing to access niche pro-environment markets and obtaining premiums. Ecotourism has given a whole new value to natural forests, and the local population is rapidly capitalising on these values through activities such as hotels and guided tours.

Rapid urbanisation -not deforestation- is the problem. The general perception in the study area is that water is under threat from population expansion. Deforestation has had major impacts, but it is not the only factor affecting water resources:

> *Water flows decrease because of higher competition:*
> According to most participants, the lower parts of the watershed have less water because of deforestation: ("*Up in the mountain forest we have waterfalls and water is plentiful. However, as you go down the watershed everything has been deforested and is dry*"). Water is abundant in winter, but lower parts of the watershed, like Guacimal, suffer from serious water shortages during the dry season. However, while there seems to be a widespread belief that deforestation in the watershed has contribute to lower water levels, there are some who indicate that water levels downstream are decreasing because of higher competition for water for pipelines. Some groups, like the Aqueduct, worry that the increasing demand of water for new pipes will reduce water available downstream, especially during the summer. Improving watershed management and smooth provision of water flows throughout the year will imply more than just engaging in watershed conservation, but looking into water distribution among different users.
>
> *Water quality deteriorates for lack of control:*
> Reduced water quality in rivers and waterways is considered as one of the most serious problems that the area faces. Participants in the focus groups indicated that tourism must be controlled to avoid negative impacts on the environment, especially in terms on unrestricted growth of tourism-industry

and the lack of controls on basic services such as wastewater disposal and traffic control.

6.3 Government perception is rather poor

> "Thank God the government has stayed away from here" (CETAM focus group)
>
> "We haven't had many government incentives here. We haven't had municipality (until recently), or hospital. There aren't any *politicos* with land in this area…it is only the pioneer families and their descendants, with our new vision for conservation (CETAM focus group).

Monteverde and its surrounding areas have evolved almost free from governmental intervention. In fact, it is only a year ago that the region has its own local municipality located in Santa Elena. Most people are highly suspicious of the government and its institutions, and recent the high level of restrictions imposed on the use of forest within their own properties ("*I need to use my own forest, but have to do it sneaking around and feeling as if I'm robbing myself" farmer in Las Nubes).*

Government institutions have limited control or actual authority in the area. Despite the existence of laws, there is little monitoring and most people do as they want. Control over land use has come primarily from the dairy and the coffee Cooperatives, who try to put environmental regulations to their providers.

> "There are many problems with the government and the local authorities. They have many laws but nobody follows them, and instead of helping they just interfere with everything. Laws should be more localised…what is good for San José is not necessarily good for this parts". Focus Group in El Dos.

This situation means that, if negotiation for watershed management is to take place, government intervention will be seen with suspicion.

6.4 A people-centered approach

Protection, People, and Progress. Sustainable development, as explained by a farmer during the focus group in La Cruz, has to deal with protection, people, and progress. If forests provide important environmental services to local, regional and international users, it is only fair that land stewards receive compensation from either engaging in forest protection or abstaining themselves from forgone economic benefits of other land uses. It is important to create new sources of employment for young people to prevent migration to other areas.

Historic isolation. Another key element for the success or failure of any development proposal is the historic isolation of the area, which has contributed to the independent spirit of the inhabitants. The upper parts of the watershed, in particular those surrounding the cloud forests, have had a history of isolation from the rest of the country. This has contributed to forge the independent character of its inhabitants. Until very recently the area had very few economic activities, and land tenure is largely in the hands of descendants from the first settlers, the Quakers, or the Reserves.

Roads: a double-edge sword. Roads are always a conversation topic in Monteverde. Roads are unpaved. During the rainy season they are thick with mud and in the dry season they are covered with fine dust that permeates into clothes and lungs. A 4x4 vehicle is strongly recommended during both seasons as the higher clearance and the traction can be essential.

There is controversy surrounding the decisions for paving the road. A minority of people, mostly living in what is actually Monteverde, some of them Quakers, oppose the paving of the roads for a number of valid reasons. Part of the reason being the influx of people it could bring and all of the associated problems that come with large numbers of people, pollution, social problems, etc… Some people would like to see Monteverde stay the same. It is hard to stand in the way of "Progress" and a bill was signed to pave parts of the road. That was 2 years ago and so far there is no pavement and people are not holding their breath. Things can be a slow process with the Costa Rican government.

Continuous learning from research. It is important for landowners to learn from experience about the types of species used for reforestation ("*in some cases there are trees close by to water sources, not because they help keep the water but because they need it, we need to learn about that" (coffee producer in El Dos))*. Communities have lost credibility in previous reforestation programmes that used massive amounts of eucalyptus and conifers, as they were later on discovered to be harmful for water. One coffee producer complains of the large amounts of research done, but the little of it that goes back to the communities where it was originated.

6.5 Setting up negotiations for markets has a long way to go

> PES is perceived as a threat. The way that the current PES programme in Costa Rica is seen by some participants of the focus groups as another way to expropriate lands for them. "*It doesn't work out for me. I have 60 ha of forest. I could be receiving $3000 per year, but it will be as if I'm selling it off to the government, because I cannot even touch my own forest after that, even if I need it" (dairy farmer in Las Nubes).* Another restriction is the lack of land titles, and the high costs of obtaining one to take part in the programme. It is quite likely that landowners will refuse to be part of the government PES, and any market will probably have to be highly local in order to gain support.

The importance of watershed protection and conservation has been on the political agenda of governments and international agencies for a while. In more recent years, the emergence of the private sector in response to lack of effectiveness in governmental measures has cropped up in the form of markets for watershed services. Landell-Mills and Porras (2002) presented a review of 61 cases of market mechanisms in watershed protection around the world, and the number of initiatives and enthusiasm by supporters is steadily increasing. The basic premise is that improved land use in the upper part of the watershed, normally assumed as forest protection or reforestation, has positive effects on water services, and downstream water users will compensate upland land stewards for the protection of such services. It is worth to note that while the development of similar markets for carbon sequestration have strong scientific considerations, the expansion of markets for watershed services is characterised by a nearly total absence of strong, consistent, defendable scientific evidence that support the claims made.

Does it really matter what people belief? If the overall objective of integrated watershed management is to improve environmental conditions upstream, and improve livelihoods through payments for watershed services, surely it does help if people belief that trees and forest improve water flows. Upstream forests will be improved, upstream people will receive payments, and downstream people will willingly pay for forest conservation. In many watershed conservation initiatives, putting science in place is costly, and many times impossible due to lack of information. So why does it matter?

It matters because funds are limited, and decisions are costly. Two extreme situations in which policy does not take into account science are presented below:

> *Situation: "Reforest large areas of watershed to reduce sedimentation".*

If the project does not consider possible effects on higher evapotranspiration the overall effect of the project would be significant reductions in water flows. For example, the initial Law 21 in Panama proposed large reforestation of the Panama Canal Watershed, but initial studies revealed that water flows could be significantly reduced in dry seasons causing potentially important losses for the passage of ships through the canal (Aylward et al 2001).

> *Situation: "Hydroelectric companies paying upstream reforestation projects to improve their local PR image".*

There are cases in which hydroelectric companies might be willing to engage in payments for watershed services, not so much because they are convinced of the hydrological service they receive but to improve local acceptance and image. However, situations like this can be fragile and prone to be dropped by the company at any time. Only when there is a real threat to the company's input, long-term commitments are likely to succeed.

In the same way, it is important to understand what people living in uplands think of the effects on water arising from their land management decisions. The knowledge of which land use measures must be taken to provide a service for which they could receive a payment is one key aspect to ensure the success of the market. Misinformation, or erroneous beliefs, might bring land stewards to embark in costly land use activities that will derive no service in the medium or long term, and therefore no compensation. Likewise, sceptical landowners might not be interested in engaging in new watershed management programmes despite the existence of payments, if they have suspicions about the seriousness of the programme.

While the protection of forests is worthwhile in environmental, cultural, social, economic and hydrological terms, it is important to understand the rightful linkages between forests and water in order to design the appropriate measures of watershed management. Taking the wrong land use measures, like assuming that reforestation with conifers or fast growing species will increase water flows, could potentially have serious economic effects downstream if flows are actually reduced. Understanding what the linkages are will help design the appropriate measures to ensure a more effective integrated watershed management.

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8 Appendix

A review of linkages of land use and hydrology

The hydrological cycle is basically driven by the energy received from the Sun. The Earth reflects part of the energy (34% on average), distributing the rest between air, water, soil and geological formations (Jermar 1987). The albedo (coefficient of reflection) depends essentially on the surface type, state and quality of atmosphere above and the angle of the sun rays. For example, on average stretches of water reflect 10% of the energy, lawns 15%, forests 20%, deserts 30% and snow 80% (Jermar 1987). Fluctuations in the soil and water temperature and evaporation are the result of the acceptance of effective radiation. This hydrological cycle is an uninterrupted process of water motions.

Most of the Earth's water is stored in the oceans (94.2%), 4.13% is stored as groundwater, and 1.25% in ice sheets and glaciers. Only a very small fraction (0.019%) corresponds to surface water on land and soil moisture (0.0055%), while rivers carry only 0.00008% of the total water of the planet. Finally, a tiny proportion of water is kept as atmospheric vapour (0.00096%) (M.I. L'vovich, 1979, quoted by Shawn 1983). This total amount of water is indestructible (Viessman et al 1977) and the hydrological budget can be considered a closed system.

The hydrological cycle could be summarized as a continual cycle of:

1. Precipitation
2. Interception (evaporation and evapotranspiration)
3. Surface runoff
4. Percolation into the subsoil (groundwater)

Heating of the water surfaces (the ocean being the most important one) causes *evaporation*, defined as the transfer of water from liquid to gaseous state. According to Shawn, this vapour remains stored in the atmosphere for an average of 10 days, when through a process known as *condensation* the water vapour changes back to the liquid state and forms clouds. With favorable conditions, *precipitation* (in form of rainfall or snow) is produced either returning to the ocean surface or to the land surface.

In the second case, before precipitation reaches land surface, it can be *intercepted* by vegetation from which water might return back to the atmosphere as evaporation. Rainfall reaching the ground may go down as *run-off* and join creeks and rivers, or it might *infiltrate* into the ground.

Water in the soil *percolates* through the unsaturated layers to reach the *water table*, where the ground becomes saturated, or it might be taken back up by the vegetation to be *transpired* back into the atmosphere. The surface run-off and the *groundwater* flow together and join in surface streams and rivers, and might be temporarily held in lakes, but finally flow into the ocean.

It has been long discussed the effect that land use would have on the hydrology of a region. In tropical areas, this discussion falls immediately on the grounds of tropical forests and alternative land uses. These forests provide abundant environmental and socio-economic benefits and can be used in different ways (Bruinjzeel (1992)):

1. Maintain forest with little or no disturbance, for nature reserves, steep headwater areas of strategic catchments, or geologically unstable areas.
2. Management of natural forests for continuous production of timber and NT products.
3. Clearing of forests and subsequent use of land for grazing, farming, tree plantations, mining, settlements, etc.

In most developing countries, land use changes are a daily occurrence. While it might be desired to maintain strategic natural forests, few countries can afford to do so. Existing natural forests are threatened with requirements for agricultural lands, firewood, timber and pulp demands. At the same time, water requirements downstream are increasing: hydroelectric and irrigation projects, transport, industry and growing cities all demand higher amounts of water. All actions taken at different stages of the watershed could have important effects on quantity and quality of water, with serious externalities over other users downstream.

Rainfall and Precipitation

"The distribution of forest is a consequence of climate and soil conditions - not the reverse". Bands et al, 1987.

Water is present in the atmosphere in the form of water droplets, vapour and ice crystals or snow. Precipitation occurs as a result of a balanced process. When the air is pure and it becomes greatly saturated, then water vapour become water droplets. The presence of small particles, or aerosols, provide the nuclei around which water droplets are formed.
Moist air must be cooled to near its dew point, a process that could happen through:

- the rising of air by an impeding mountain range that causes a reduction in pressure and lowering of temperature without transference of heat,
- the meeting of two very different air masses,
- the contact between a moist air mass and a cold object, such as the ground.

Once cloud droplets are formed, their growth depends on other tension forces such as the humidity of the air, rates of transfer of vapour to water droplets and the latent heat of condensation released. Condensed water appears in various forms of clouds.

There are major categories of precipitation types: convective, orographic and cyclonic (Viessman et al 1977). **Convective precipitation** is typical of the tropics, brought about by the heating of the air at the interface with the ground. They might take the form of light showers or high intensity storms. The tropical zones located in the trade belts in latitudes 5-25^{o} north and south of the Equator present irregular wind patterns and the development of tropical maritime air masses. The cloud-forming activities here are forceful and subsequent rainfall can be considerable, with up to 300 mm falling in 24 h. **Orographic precipitation** results from the mechanical lifting of moist horizontal air currents above natural barriers, such as mountain ranges. Finally, **cyclonic precipitation** is associated with the movement of air masses from high to low pressure regions, created by the unequal heating of the earth's surface.

Nevertheless, although the main driver for precipitation is linked to geographical situations, it has been long debated what the effect of land use change (i.e. deforestation) would be. Theory states that the height of trees will increase the orographic effect which will, in turn, lead to an increase in rainfall. The effect, however, is likely to be only slightly (Calder 1999), as the possible increase in rainfall will be most of the time captured by the canopy and evaporated again.

There are some claims that land use could affect precipitation patterns and forestation will increase rainfall, or conversely, that deforestation will reduce rainfall. Most of the time this assertion is related to the positive effect, or feedback loop, between forests and local or **'recycled' precipitation**, formed by the evaporation of water trapped in the tree canopy. There is the notion that variability of land surface at mesoscale can influence the amount of precipitation and its spatial distribution. It is claimed that any local wind circulation that concentrate water vapour from transpiration or wet canopy evaporation, favour the formation of clouds (Bonell, unpublished). Rainfall is said to increased by a combination of factors such as energy budget, frictional effects, changes in horizontal convergence and vertical velocities; but also more rapid evaporation from intercepted rainfall over vegetation.

Regional models have shown that, at a mesoscale level, total conversion of land use in the Amazon will lead to decreases in rainfall. The magnitude of this change is not a common figure and it reflects the degree of uncertainty involved. It might range from estimates as high as 50% (Saleti et al 1979), later dismissed because of ambiguous estimation techniques, to a low value of 6% estimated by the Institute of Hydrology in 1994 (Calder 1999) (see Table 8-1).

Table 8-1 Model results of relation of deforestation and rainfall (in large basins)

Effect on precipitation	Description	Source
50% reduction	Following total land conversion in the Amazon basin. Estimation techniques and assumptions used do not sustain the assertion.	Saleti et al (1979) (cited in Bonell 2001)
25-35% reduction	Following total land conversion in the Amazon basin. Minimum of <10% near the Amazon river estuary and >50% in the SW at the foothills of the Andes.	Eltahir & Bras (1994) (cited in Bonell 2001)
>20% reduction 34% reduction	Following land conversion for the Southern part of the Amazon basin (modeling resolution of 500 km). Amazon basin, length scale of 2750 km.	Trenberth (1999) (cited in Bonell 2001)
6%	Following total removal of the Amazon basin. The effect will be higher in the drier north-east of the continent, at about 0.5 mm per day.	Institute of Hydrology 1994 (cited by Calder 1999)
Not changed	Studies of historical rainfall records in	Calder 1999

	Southern India failed to show any decrease despite the large-scale conversion of the dry-deciduous forest to agriculture.	
27%	Estimated percentage of 'local' rainfall for the West African region.	Gong & Eltahir (1996) (cited in Bonell 2001)
"significant" effect	Role and effect of meridional conditions of land surface (vegetation cover and soil moisture) in the dynamics of the west African monsoon and rainfall variability.	Zheng & Eltahir (1998) (cited in Bonell 2001)
'significant' reduction	Reductions in rainfall in Florida, USA, where much of the summer rainfall depends on 'local' evaporation from the everglades, and much of these areas have been subject of continuous land use changes.	Pielke et al (1999) (cited in Bonell 2001)
30% increase	Estimated from a complete forest cover in a 400x400 km by 30% compared to a 3-D mesoscale model simulation for bare soil in south-west France. The effect is strengthened by frictional effects associated with the passage of weather fronts from the sea to land along coastal areas.	Blyth et al (1994) (cited in Bonell 2001)

Perturbation associated with land clearance include (Wilson and Henderson-Sellers 1983):

- increased surface albedo (reflection capacity of solar radiation, with white clouds and snow reflecting about 90% of radiation and dark tropical ocean absorbing nearly all of it);
- perturbation of the carbon cycle and greenhouse effects;
- local changes in the water balance;
- addition of particulates to the troposphere, both directly from combustion and by increasing the wind-blown dust, and

perturbation of the hydrological and turbulence characteristics over areas where tall forest stands are replaced by low crops of cleared land.

During rainless periods, tropical montane cloud forests (TMCF), such as the existing forest in the upper part of Monteverde, Costa Rica, play an essential role in providing water downstream through the capture of water from the clouds by capturing and condensing cloud droplets through vegetation surfaces, a process known as **horizontal precipitation** (HP) (Bruinjzeel and Proctor 1995). The quantity of HP depends both on vegetation factors (height of vegetation, canopy size and structure, biomass, type of leaves and epiphytes) and climatic conditions (moisture content, drop sizes, velocity and direction of passing air, orientation of forest ridge or slope, and duration of the process). Total recorded amounts of HP could vary from 70 mm for an elfin forest in a 3100 m in Venezuela to 940 mm in a 1300 LMF in eastern Mexico (cited by Bruinjzeel and Proctor 1995). Through a combination of horizontal precipitation and low evapotranspiration rates, values of annual streamflow for TMCF (expressed as a ratio of incident rainfall) are among the highest reported for any tropical forest.

It is still uncertain the effect of forest clearing on total water yield, as the final effect will partly depend on the relative magnitudes of HP and evapotranspiration of original and new vegetation cover. If contributions of HP are very high (and evaporation very low) then streamflow will probably decrease after conversion. However, if HP contribution is relatively low, it is almost certain that forest clearing will cause soils to become wetter and water yield to increase (Steinhardt 1979 and Blackie 1979, cited by Bruinjzeel and Proctor 1995). Nevertheless, seasonal flows might be affected differently, particularly if the infiltration capacity of the soil is affected (i.e. decreased) by land conversion.

Reaching the soil surface: interception and runoff

Evapotranspiration. Evaporation is probably the most difficult phase to calculate in the hydrological cycle, yet it accounts for a considerable part of the water in circulation. This process can happen in two ways:

- *evaporation* from water surfaces, like rivers, lakes, reservoirs or ponds. It is relatively easier to estimate this variable if the water body capacity is known and there is no leakage.
- in the form of transpiration from vegetation (also known as *evapotranspiration*), as water is lost through interception of precipitation by vegetation leaves and transpired water from the plants. It is very difficult to estimate, and final amounts of evapotranspiration depend on the type of vegetation, its ability to transpire and the availability of water in the soil.

Evaporation depends crucially on water available. If the body water disappears, then open water evaporation stops, while plants could keep drawing their water from the soil where moisture is held under tension. The rate of transpiration is finally affected y the stomata in the leaves, or their capacity to transpire, the soil moisture content, and by meteorological factors. A series of physical factors affect both processes. These factors are (Shaw 1994):

a) *Latent heat*, required to change from liquid into gaseous form. In nature it is provided by the energy of the Sun, in the form of solar (short-wave) and terrestrial (long-wave) radiation.
b) The *temperature of the air*, affected also by the Sun. As the temperature of the air increases so does the amount of water vapour it can hold and it can vaporize faster. Evaporation is high in tropical regions and lower in polar regions.
c) The *saturation deficit of the air*, or the amount of water that can be taken up by the air before it becomes saturated. This variable corresponds to the difference between the saturation vapour pressure at the air temperature and the actual vapour pressure of the air. Therefore, more evaporation occurs in inland areas where the air is usually drier than coastal regions with damp air from the sea.
d) *Wind speed* also affects evaporation. As water evaporates, the air above the evaporating surface becomes more humid until saturation point and it no longer holds more vapour. If it is windy, drier air will substitute the humid air and evaporation will increase. Therefore, evaporation is greater in areas with plenty of air movement and lower in sheltered localities where air tends to be stagnated.

Wind speed and air temperature could have conflictive effects. Windy areas (which increases evaporation) are usually cooler (which should imply lower evaporation), and sheltered areas are often warmer. Over large catchment areas it is the general characteristics that will have the most important final effect.

e) The *atmospheric pressure* or weather pattern. Low atmospheric pressure is usually associated with damp unsettled weather, with air well charged with water vapour and conditions are not conducive to aid evaporation.

f) The nature of the *evaporating surface*, as it modifies the wind pattern. Friction originated by a rough, irregular surface reduces wind speed, but tends to cause turbulence and the subsequent increase in the vertical component in the wind will enhance evaporation. On the other hand, strong winds over a flat, open water surface can cause waves which provides increased surface for evaporation and turbulence. There is little friction from wind passing through smooth surfaces, and evaporation here is mostly affected by horizontal velocity.

If there exists a continual supply of water, then evapotranspiration is regulated by meteorological conditions. The evaporation plus transpiration from a vegetated surface with continuous water supply is known as *potential evaporation*, or the maximum potential loss rate due to the prevailing meteorological conditions.

If there exists a continual supply of water, then evapotranspiration is regulated by meteorological conditions. The evaporation plus transpiration from a vegetated surface with continuous water supply is known as *potential evaporation*, or the maximum potential loss rate due to the prevailing meteorological conditions. Diverse studies (summarized by Calder 1999) indicate that in both very wet and very dry conditions, evaporation from forests is likely to be higher than from other shorter crops, due to higher atmospheric transport of water vapour from the rough surfaces in the former, and to the deep rooting of trees that allows them to obtain water from deeper soils as compared to shorter crops.

The reduction of forest canopy through tree cutting decreases the evapotranspiration losses, resulting in increased water yield in streams from the harvested area (Hamilton and Pearce 1988). The magnitude of the effect decreases as regrowth of natural vegetation takes places, which happens more rapidly in high rainfall areas (6-10 years). The effect is similar if trees are replaced with short season arable crops, especially in areas with good rains and pronounced dry season (Russell 1981).

Hibbert (1967) and Pereira (1973) (both cited by Lal 1983) observed that cutting down natural forests increases streamflow at a rate generally proportional to the reduction in forest cover over the basin. Land management studies conducted in western Nigeria (a 44-ha basin) indicate that deforestation increases runoff and interflow component significantly. During the 3 year study, results show that at the beginning of the dry season in January, the baseflow increased from nearly zero to 3.2 mm/month. Possible explanations include:

- Direct storm runoff increases because of gradual deterioration of surface soil structure and infiltration;

- Baseflow increases because of gradual decrease in bush regrowth and the no utilization of subsoil water by shallow-rooted seasonal crops;
- Storage capacity is limited by the decrease in organic matter content and in the relative proportion of retention pores in the soil profile.

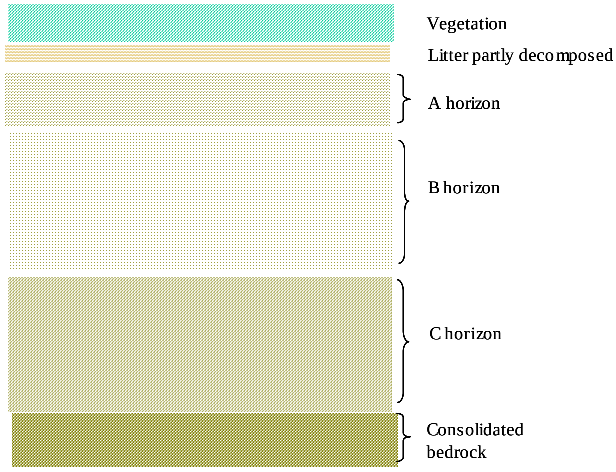
In summary, the increase in direct runoff and baseflow is associated with corresponding decreases in soil water storage, evapotranspiration and surface detention (Lal 1983). Agronomic practices (crop and soil management) that causes frequent and prolonged exposure of the soil to raindrop impact permit much more surface runoff. Lal (1983) suggest several possible measures to avoid soil exposure in an agricultural context:

- Replacing natural vegetation with plantation crops, such as rubber, oil palm, coffee, and cocoa, will eventually restore the soil-vegetation equilibrium (Lal 1983, Russell 1981,
- Pereira (1973, cited by Land (1983)) reported that deforestation followed by tea planting would cause lower runoff and erosion that if followed by re-planting.
- Agroforestry maximises output without increasing the risk of soil erosion. A combination of deep-rooted annuals can maximize water use and should decrease baseflow. Woody perennials on terrace banks can stabilise the back slope and decrease the risk of their breakage and eventual failure.

According to Russell (1981), planting faster-growing production forests to replace slow-growing indigenous forests, need not cause any disturbance to the river flow compared with the original natural forest, so there is no conflict between their role for production and watershed production.

Reaching the soil. The soil is conformed by different layers (see Figure 8-1 below). The top layer consist usually of vegetation litter and partly decomposed debris lie on the surface above the A horizon, which is a layer generally friable and rich in humus. The B horizon is mainly composed of well weathered parent material, with its structure modified by roots and living creatures. The C horizon is unconsolidated rock material with a wide range of particles and stone sizes. Below this layer there is usually consolidated bedrock. *The thickness of these layers depend on geological structure and geomorphology of surface features*.

Figure 8-1 Idealized soil section



Note: based in Shawn (1983), p.81

The function of the soil as water store depends on the packing of the clay or sand particles and the amount of space between the solids. Most of the water comes from melting snow or from rainfall, and it infiltrates the soil layers by gravity and surface tension through the pores of the soil, until it reaches the saturated layer of the soil where all the pore space is occupied by water. The surface over which the water pressure equals atmospheric pressure is defined as the *water table*.

The wetness of the soil can be assessed in the form of volume fraction (θ), equivalent to the depth ratio of soil water (i.e. the equivalent depth of free water relative to the depth of soil for a unit plan area). Soil moisture can be related to precipitation and evaporation depths. Table 8-2 shows that there is less water available at field capacity in a sandy soil as it drains quickly, and the retention capability of the soil increases with the clay content of the soil. At the permanent wilting point, a clay soil contains a significant amount of water.

Table 8-2 Soil water content (volume fraction θ)

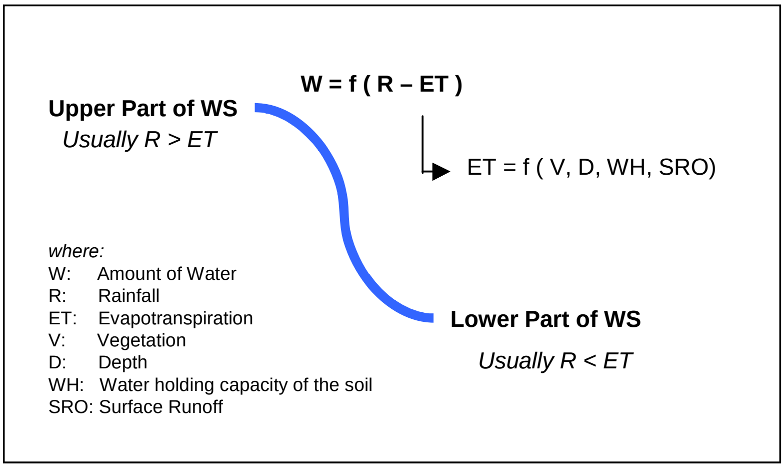
Type of soil	Clay content (%)	Saturation	Field capacity	Permanent wilting point
Sand	3	0.40	0.06	0.02
Loam	22	0.50	0.29	0.05
Clay	47	0.60	0.41	0.20

From Shawn (1983), reproduced from Marshall and Holmes (1979) *Soil Physics*, Cambridge University

Natural forests usually help increase the capacity of the soil to retain and infiltrate water down by providing a layer of mulch, leaf cover and humus. This rich debris is the most important factor contributing to water infiltration, rather than the existence of trees *per se*. For example, forestry plantations with removed litter and heavy machinery passing through might compact the soil and actually reduce infiltration.

According to Russell (1981), most perennial rivers in the tropics arise in highlands with an excess of rainfall over transpiration (R>T), and run to lower sections in the watershed where the reverse usually occurs and lack of water could prove a potential problem during dry spell. The water leaving the area and the seasonal flows of the river depend on land use management in the upper part of the watershed, by keeping up the infiltration rate of rainwater into the soil at least as a high as the normal maximum intensity of rainfall as measured over a suitable time period. *This usually happens where the natural vegetation has been little disturbed, for this normally produces a soil surface capable of absorbing the rainfall and of allowing it to percolate into the deeper subsoil and seep out into the river as springs (Russell 1981;).*

Figure 8-2. Rainfall and Evaporation in the Watershed Context



Source: Based on Russell, E.W. 1981

It might be profitable for the river basin as a whole to develop land use systems for the uplands that minimize transpiration demands there, therefore increasing the water available for use in the lowlands.

Seasonality and Forests

Low-flow effects: the sponge effect

According to Hamilton and Pearce (1988), the so called 'sponge effect':

> "*has no scientific basis, and all controlled experiments have shown increased streamflow throughout the year after reducing forest cover, with the largest proportional increases in the dry season. One exception would be the case of severe soil erosion or soil compactation, where the ability of the soil to absorb water is greatly reduced and dry season baseflow is not maintained. This, however, is not a scientific report based on controlled experiment from any catchment. Afforestation or reforestation over large parts of the watershed will normally reduce streamflow during dry season. One possibility is to have continuous cuttings (thinnings) or final harvests in mosaic patterns over the reforested watershed. If properly done, reforestation could reduce erosion*".

Hamilton and Pearce (1988) report that most of the case studies reported by Bosch and Hewlett (1982) the greatest percentage of increase in yield occurs in the low-flow period, as "*Some streams that ceased to flow during the dry season remained perennial following cutting*" (Gilmour 1977 reported by Hamilton and Pearce 1988).

This result can be explained because the very deep roots of natural forest and many perennial grasses will dry the soils to depths of four to five meters during dry spells without their transpiration rated being largely affected, whilst short rooted crops tend to use water from the top (one to one and-a-half meters deep). (Russell 1981)

This is a particular important result where dry season flows are particularly important. Cutting could be beneficial, provided that it was repeated when water yields have declined due to regrowth (Hamilton and Pearce 1988). As Hicks et al (1991) report, the increase in dry-season flow is likely to be short lived, and could even be reverted to lower levels than the original vegetation, if "thirstier" species take over following logging (see following case study). Since the eighties, Hough (1986) has given management suggestions involving tree removal in the semiarid miomboo woodlands of Southern Africa in order to increase dry season flows.

In conclusion, the competing effects of evaporatranspiration versus infiltration will either result in increases or decreases in dry-season flows (Calder 1999). These effects are likely to be site specific and related to the type of soil in the area, as well as the type of forest and the precipitation amount. It is not possible, however, to affirm that reforestation (or afforestation) programmes will definitely result in increase dry-season flows.

Aquifers Recharge

A fairly event of water flow is obtained when the system of upland use maintains the infiltration rate of rainwater into the soil at least as high as the normal maximum intensity of rainfall. These conditions tend to prevail when natural vegetation has been little disturbed, producing a soil surface capable of absorbing the rainfall and allowing it to percolate into deeper subsoils and seep out into the river as springs (Russell 1981).

Tree-cutting activities decrease the evapotranspiration rate, which in turns normally results in higher stored soil moisture and therefore more water available to recharge groundwater, springs, and wells (Hamilton and Pearce 1988). The reduction in interception allows a greater percentage of rainfall to reach the forest floor. The additional precipitation would either contribute to higher runoff, evaporate or infiltrate the ground. If the understorey vegetation, litter and forest root mat are kept after tree-cutting, infiltration rates need not be affected and groundwater recharge would be maximised. On the opposite, the use of heavy logging machinery would compact the soil and decrease infiltration rates, resulting in larger runoff amounts and lesser groundwater recharge.

Flooding and storm protection

> *"…fuelwood cutting in the Middle Hills of Nepal is 'deforesting' the hills, decreasing forest area, and initiating a series of erosional and hydrologic effects that lead to destruction and death in the lower Ganges" (presented by Hamilton and Pearce 1988).*

The precedent assertion is one of many views widely held by foresters and the media, making stormflow protection is a major concern for downstream communities affected by deforestation and/or degradation in the upper parts of the watershed.

Floods are a natural phenomenon, in which rivers discharge any excess water arising from occasional large rainfall events. Their effect is likely to be interpreted as good or bad, depending on the actors involved and the intensity of the event. For example (Calder 2002):

- Agricultural and fishing activities in the lowlands could benefit from mid-intensity floods that carry sediments and nutrients from the uplands, however, as the flood intensity increases the risks and hazards of destruction also increase.

- Forestry activities in the uplands could benefit from political support and funding for their activities in exchange of the perceived benefits that forests will have on reducing floods. However, for big events, tress can fall during the storm and block waterways.
- Wetlands located in the lowlands can benefit from the seasonal effects of floods.
- Engineers benefit from the creation of costly structures to alter the drain system of the watershed.
- Scientists (hydrologist, agronomists, soil scientists, economists, and social scientists) benefit from funding for their research in the area (as long as there is a problem there is a need for research).
- The media benefit from coverage and possible sensationalist stories related to the floods.
- Politicians will respond to where votes lie.
- Development organisations (local, national and international) will try to accommodate for a solution that can be easily defended.

Floods are partly linked to local land use systems, but generally this is only true for small rainfall events and small scale watersheds. There is however a great temptation to blame floods on agricultural systems in the upper parts of the watershed, especially if deforestation is involved, and in more recent years, large floods have been linked to global warming. As explained in previous sections, all forests tend to have higher evaporation rates than other types of vegetation, and natural forests exhibit higher infiltration rates, due to porous soils and the existence of understorey and humus layers. The combination of these two factors generally contributes to lower runoff and lower soil erosion rates. This is not necessarily the case for forest plantations, where infiltrations rates could be reduced because:

- Natural understorey, mulch, or humus layer usually does not exist (for example, in teak, eucalyptus and pine plantations);
- Lack of proper management activities involved with the preparation of the plantation and logging activities (design of drainage systems, road construction, road use, use of heavy machinery that compacts the soil, etc).

Trees can have a positive effect in stabilizing slopes due to the binding effect of their roots. Stormflow, peakflow volumes and duration are usually increased by harvesting (Hamilton and Pearce 1988). Downstream effects are intensified if roads, skid trains and log landings have not been well prepared and maintain. Results from Bosch and Hewlett (1982)'s review of 94 catchment experiments indicate that in almost all the cases tree cutting without mechanical logging resulted in increases in peak flows, and in many cases an increase in stormflow volumes (Halmilton and Pearce 1988). Forest operations (not conversion to agriculture) in upstream catchments have not been shown to increase flood flows seriously in major streams. (Hewlett 1982). *However, the relative magnitude of these events is inverse to the magnitude, intensity or duration of the storms. For large storm events there is little impact of land use changes.*

The role of forests as stream-flow regulators has been extensively discussed since the beginnings of the 20th century, when during 1908-1911 foresters made use of this connection to advocate for the Weeks Act (Saverwal, 1997). The Act, which proposed to federally buy and manage watershed forests in the interest of protecting commercial interests linked to navigation of inland waterways, was opposed by ranching and timber interests but also engineers who demanded clear evidence of such relationship. Several assertions like the one below were not based on any scientific evidence but rather on political grounds and were later on dismissed by the broader scientific community.

> *Gifford Pinchot, Head of the Forest Service, talking on the Ohio floods in 1907: "The great flood which has wrought devastation and ruin in the Upper Ohio Valley is due fundamentally to the cutting away of the forests on the watersheds of the Allegheny and Monongahela Rivers" (Saberwal 1998).*

Land use and soil erosion

Forests have long been attributed with lowering soil erosion. In fact, there are several cases when natural forests are indeed beneficial (Calder 1999):

- Natural forests have a high infiltration rate that reduces surface runoff and erosion transport;
- Tree roots increase soil stability, which together with the reduction in soil water pressure tend to reduce erosion;
- Forestry or agroforestry system might be preferred on steep slopes to retain mass movement of soil.

Soils in the humid tropic are typically unstable. Quick desiccation following intense storms causes a surface crust that drastically reduces soil infiltration, especially where soils have lost their protective cover vegetation (Lal 1983). Rapid deterioration in soil structure is partly because of low soil organic matter content.

Non-wood products harvesting is unlikely to have major detrimental impacts on water quality, with the exception of removal of forest litter (Hamilton and Pearce 1988), which has been used traditionally for mosquito repellent coils (Philippines), livestock bedding and cooking fuel (Himalayas). If over-harvested, leaf litter removal could have serious effects on the hydrological regime. Forest litter is not only important in nutrient cycle but has an extreme importance in protecting the soil from raindrop impact, minimizing slash erosion. In this sense, the litter is considered in many cases more important than the high forest canopy. In fact, high forest canopy of large-leaved species can increase raindrop impact.

Deforestation, method of land clearing and development, and tillage systems significantly increase soil erosion. A monitoring exercise of 3-4 ha basins at IITA, Ibadan reported the following results (see Table 8-3) (Lal 1983):

- Soil erosion under dense natural perhumid and seasonally humid forests is usually low, resulting in low sediment loads of rivers draining tropical forested river basins;
- Traditional farming with incomplete clearing have minimal runoff and soil loss;

- Complete manually clearing followed by mechanised farm operations reported 48 mm runoff and 5 ton/ha of soil loss over 3 years.
- Mechanically cleared land followed by mechanised farm operations reported 201 mm runoff and 15 ton/ha of soil loss.

The most effective soil conservation system of land clearing and management was manual clearing followed by no-tillage. Soil erosion and runoff loss from shear blade clearing was within acceptable limits. Sediments from machine cleared plots was greater than that from manually cleared plots.

Table 8-3 Effects of methods of deforestation and post-clearing soil management on runoff and soil erosion*

Treatment	Basin area (ha)	Runoff mm:		Soil erosion (t/ha)	
		1979	1979-81	1979	1979-81
Forest	15	T	T	T	T
Traditional farming	2.6	3	6.6	0.01	0.02
Manual clearing+no-tillage	3.1	16	16.1	0.4	0.4
Manual clearing+conv. tillage	3.2	54	79.7	5	9.8
Shear blade clearing+no tillage	2.7	86	105	4	4.8
Tree pusher-root rake/no tillage	3.2	153	170	15	16
Tree pusher-root rake-conv.tillage	4	250	331	20	24.3

T=unmeasurable trace. Source: Lal (1983). * from an alfisol for maize-cassava-maize-cowpea rotation from 1979 to 1981. Land was cleared in 1979

Soil erosion is usually most severe in the first year after the clearing, but after the soil has stabilized, erosion depends more on postclearing soil management than on the methods of land clearing (Lal 1983).

The heralded adverse effects of deforestation and soil erosion are mostly related to unsuitable forest management techniques, rather than the removal of trees *per se.* Some of them include (Calder 1999): bad logging techniques that increase the compaction of the soil; drainage activities that might initiate gully formation; road construction can mobilize sediments; excessive subsequent grazing by animals that lead to soil compaction; removal of understorey and greater erosion risk; and splash-induced erosion from drops falling from the leaves of forests unto an unprotected soil.

A study by Drs Edwards and Blackie (reported by Lal and Russell 1981) of the analysis of 16 years of data show that a complete commercial tea estate with roads, houses, factory, offices and workshops can be developed in a stream source of tall forest without long-term damage to soil stability to the amount and regulation of streamflow. Areas prone to shallow debris slides because of steep slopes and soils with low or no cohesion benefit from stability provided by tree roots. In these situations, intensive wood products extraction can accelerate the landslide activity. Roads, skidding, or other ground disturbances can also increase this risk.

According to Hamilton and Pearce (1988), increased **stream sediment** is not necessarily a consequence of logging, when careful logging and management practices are followed. However, this is not generally the case in most tropical countries, where sediments following tree-cutting are potentially distressing on aquatic life, reservoir siltation rates, altered stream channels, and reduced water quality for domestic and industrial use.

The use of streamside buffer strips and selective logging are the most important measures to control sediment delivery into the water.

Litter extraction, and fuelwood harvesting temporarily breaks the nutrient cycle process and part of **the nutrient budget** can be lost through leaching and water movement. Removal of foliage with wood represents a further loss in the nutrients. Fast-growing fuelwood plantations which are totally harvested can cause declining productivity on many tropical soils (Jorgenson and Wells, cited in Hamilton and Pearce 1988).