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Multidisciplinary approach to support the design of a local policy of payment for hydrological ecosystem services, in a microwatershed located in northern Veracruz, México

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Dissertation abstract

It is common to assume that a deforestation processes affects the availability of fresh water in domestic pipelines. It is also frequent to read in ecosystem protection policies that one strategy to resolve water supply problems is to protect the natural forests in the headwaters. In Latin America, schemes of Payment of Hydrological Ecosystem Services (PHES) are proposed like to be an answer to confront water supply problems (i.e. FONAG-Ecuador, PSA-Costa Rica and PSAH-México, among others). Unfortunately, these policies are supported in cause-effect assumptions without scientific evidence, and enclose the risk of generating false expectations among water users and politicians. With the target to understand the complexity involved in the design of PHES policies, this thesis developed a methodology to generate basic information that will be used in the construction of local PHES policy. The methodological proposal was tested in a micro-watershed located in northern Veracruz, México, and consisted in nine steps: 1) to review the Federal and State laws that could regulate the implementation of a local scheme of PHES; 2) to identify communities with water supply problems; 3) to locate springs and to delimitate their recharge area (RA); 4) to measure spring base flows; 5) to identify main land uses in the RA and to determine their soil hydrologic behaviour; 6) to calculate the Opportunity Cost (OC) of the natural forests located in the RA; 7) to identify highland landlords points of view regarding a payment scheme to protect natural forest, to identify water user points of view regarding payment of land OC; and 9) to establish the feasibility to implement a local scheme of PHES with base in all the information generated. Results indicated that biophysical (i.e. geology, hydrology, land use, soil type and weather), socioeconomic (i.e. land use culture, water use culture and population growth), and other factors (i.e. hydraulic infrastructure and land tenure rights) need to be taken into account to design local PHES policies. For example; biophysical information helps avoid false expectations about land use change effect in the hydrological cycle. Socioeconomic data indicated that communities' organization is an activity that needs to be developed prior to the implementation of a PHES policy. Other information revealed that hydraulic infrastructure needs to be modernized with the objective of storing and distributing the fresh water released by the aquifer. In conclusion, the information generated with the multidisciplinary methodology proposed in this research indicated that a PHES policy is one part of the strategy to confront the water supply problem in the rural communities under study.

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1 Introduction

Around the world fresh water scarcity is an increasing problem caused by several factors such as, ecosystem service degradation, overpopulation, pollution, overdrawing, climate change and water misuse (Rosegrant *et al*., 2002a). In mountainous regions rainfall is often captured by mountain aquifers and released to springs and rivers (Winter *et al.,* 1998). These fragile ecosystems provide several ecosystem services that are used by people located in the lowlands (FAO 2004). Unfortunately, in developing countries these elevations face a paradoxical situation. On one hand, landlords located in the highlands need to change their natural land uses to activities that can generate something to self-consumption and to sale (i.e. agriculture or livestock). These land use changes can generate negative externalities that impact lowland citizens such as, water pollution, water scarcity, rivers sedimentation, and damages in hydraulic infrastructure, among others. On the other hand, lowland citizens perceive that their problems are caused by highland ecosystem degradation, but are not proactive in changing the situation (FAO 2004). A strategy to confront this problem is the establishment of Hydrologic Ecosystem Services (HES) markets where highland landlords are compensated for the positive externalities that they provide and lowland users pay for the use of these externalities (Pagiola *et al.,* 2002).

In Latin America several Payment for Hydrological Ecosystem Services (PHES) programs are being implemented at the country level [FONAFIFO in Costa Rica (Pagiola 2002), PSAH in México (SEMARNAT 2008)] and at the local level [FONAG in Quito, Ecuador (Echavarria 2002), PASOLAC in San Pedro del Norte, Nicaragua (Pérez 2009), FIDECOAGUA in Coatepec, México (Rickards and Piguerón 2009), CVC in Valle del Cauca, Colombia (Echavarria 2004), and ESPH in Heredia, Costa Rica (Bolaños 2004)].

In México a national wide scheme of payment for ecosystems services (PSA) is implemented by the National Forest Commission (CONAFOR) since 2003. This scheme considers three kind of environmental services generated by the forest, i.e. hydrological services, biodiversity conservation, and carbon sequestration. Also, the PSA scheme was designed to protect natural forests and is financed by the Mexican Government. In fact, from 2003 to 2008 CONAFOR spend 283 million of dollars to protect 1,739,642 hectares of forest. Unfortunately, this amount is not enough to protect all the fragile areas identified through the country (50 million of hectares). Finally, in the case of the hydrological ecosystem services, CONAFOR proposed to create local schemes of PHES with the participation of the citizens that use the water generated by the ecosystem under a policy named “Concurrent Funds” (Chagoya and Iglesias 2009).

Veracruz State is located in the Gulf of México. Due to its length (745 km), it borders six states (Tamaulipas, San Luis Potosi, Hidalgo, Puebla, Oaxaca and Chiapas), and encompasses several climate zones such as, humid Af, sub-humid Aw, humid-warm with rains all the year C(f), and sub-humid warm with summer rains C(w) (Köppen classification) (INEGI 2005).

In northern Veracruz, the drinking water for approximately 122,000 people (INEGI 2005) originates on the slopes of the “Otontepec Sierra”. Spring water is transported from the highlands to the lowland cities by a network of pipes and containers. However, the drinking water supply throughout the year is irregular and the problem is exacerbated during the dry season, from March to May (Regional Water Bureau-CAEV 2006, personal communication). "Otontepec Sierra", due to its geological characteristics (Robin 1976) generates high quality fresh water for nine municipalities (Tepetzintla, Ixcatepec, Naranjos-Amatlan, Chontla, Tantima, Tamalin, Chinampa de Gorostiza, Citlaltepetl, and Tancoco) (CAEV, 2006, personal communication). In the highlands the natural land uses are *Quercus oleoides* forest (Oak forest) and sub-humid deciduous forest (INEGI Vegetation Chart F 14-9). However, due to socioeconomic reasons natural land uses are being converted to other income generating activities such as livestock (beef and dairy) and agriculture (vegetables, corn, beans, coriander, fruits, citrus, and coffee). Additionally, households that live in lowlands cities and communities perceive that mountain drinking water production has decreased in recent years. Between 2001 and 2004, the Tepetzintla municipality faced a social confrontation due to a conflict between two neighborhood communities, "El Humo" and "Tierra Blanca", for the same mountain spring which could not supply enough water for both communities. This conflict generated a difficult political and social situation between the communities (Ing. Jesús Zeníl Méndez, Municipal President, period 2005 – 2007, personal communication). It is necessary to mention that populations have grown several times in the past few years in cities and communities located in the lowlands (INEGI 1960; INEGI 2005), which has resulted in an increased water demand. However, the current hydraulic infrastructure was constructed two decades ago which has essentially rendered it obsolete (Regional Water Bureau-CAEV 2006, personal communication).

Finally, water supply is a complex situation that may require a multidisciplinary approach. If the objective is to generate a proposal to confront a fresh water supply problem, it may be necessary to understand the problem in the context of biophysics, socioeconomics and policy (FAO 2000). However, if the proposal only considers one aspect of the problem, the risk to generate false expectations among citizens, politicians, and institutions could be high. Therefore, taking into account the complexity of the situation, the main objective of this dissertation is to develop a methodological proposal within the framework of a multidisciplinary approach that will aid in the development of local PHES policy. This research has implicit other objectives such as to record biophysical information of the different land uses in the recharge area, to calculate the opportunity cost of the productive land uses in the same area, to determine forest owners point of view regarding to receive a payment to protect their forests, to determine the water users point of view regarding payment for hydrological ecosystem services, to review the political framework that could impact an ecosystem protection project, and to identify other factors that could affect water supply.

2 Problematic

Drinking water situations in developing countries around the world are becoming increasingly more difficult every day. Population growth, natural land use changes, hydrological erosion, climatic changes, rises in *per capita* income, and water pollution, among other factors result in a scarcity of available fresh, clean drinking water. Insufficient quantities of safe drinking water are available to meet the minimum levels of health and income for more than one billion people across the globe (Rosegrant *et al.*, 2002a). It is important to note that access to adequate quantities and quality of available drinking water is one of the UNESCO Millennium Development Goals (Goal No. 7. Ensure environmental sustainability) (UN 2005; UNESCO 2006). In 2005, the United Nations reported that during the 1990^{s} access to improved drinking water sources increased substantially. However, over a billion people have yet to benefit, with the worst coverage in rural areas and urban slums (UN 2005).

While some of these programs are a step in the right direction, many of them are based on hydrologic and socioeconomic suppositions, such as more forests equal more water flow, more payments equal more ecosystem service (Bishop and Landell-Mills 2002; Kaimowitz 2005). It is important to remember that ecosystems are not a "Shoe factory". While there may be a willingness to pay for HES, ecosystems can only produce water within limits, because base water flow is regulated by several factors such as land use, geology, soil structure, topography and weather conditions (Bosch and Hewlett 1982), many of which are not under human control (Young 2004). In developing countries water supply problems in communities or cities could be exacerbated by obsolete hydraulic infrastructure (Madrigal and Alpízar 2008, Pérez 2009). In many cases these obsolete systems may not be able to supply sufficient water to the entire population within the community or city, regardless of how well run the PHES program is or how pristine the ecosystem is in the groundwater recharge zone. On the contrary the best hydraulic infrastructure cannot supply sufficient water to the community if the supplying ecosystem is degraded. Finally, in order to motivate and increase landlord participation in the PHES programs, land opportunity costs (OC) should be considered when calculating payments for HES in critical areas and water use tariffs should be established by consensus (FAO 2000). If these factors are not taken into account, PHES may be lower than the potential land OC, and/or households may avoid payment for services if tariffs are imposed by government, NGOs or other institutions, thereby discouraging landlord participation.

In México the demand for water increases every year due to population growth and a rise in *per capita* income. In the last century México's population increased by five times, from 25 million to 106 million (Meadows *et al.*, 2004). Unfortunately water availability does not increase year by year with the growth in population. To make matters worse the scarcity of drinking water is also compounded by pollution, erosion, overdrawing, and salinization, to name a few. Water scarcity in México has become a serious problem and has manifested in political conflicts between Tamaulipas and Nuevo León, and Guanajuato and Jalisco states (Fundación Gonzalo Río Arronte and Fundación Javier Barros Sierra, 2004).

3 Justifications

- A Multidisciplinary approach is needed to understand the relationships between land, people and water. This relationship performs numerous and simultaneous processes that vary across spatial and temporal scales, are non-linear, and occur in watersheds with heterogeneous characteristics. Moreover, impacts of land use practices depend heavily on interactions among site-specific biophysical characteristics, as well as on socio-economic factors (Meadows *et al.,* 1972; O'connor 1998; FAO 2000; Aylward 2002, Landell-Mills and Porras 2002; Alavalapati *et al.,* 2004; Pagiola *et al.,* 2004; Campos *et al.,* 2005).

- Multidisciplinary approach could help to generate useful information that could be included in a watershed management strategy (FAO 2000).

- Multidisciplinary information could help to design, with less uncertainty, a local policy of Payment for Hydrological Ecosystem Services.

- If this research doesn't use a multidisciplinary approach, results could generate false expectations in communities, municipalities and local institutions.

- Currently the "Otontepec Sierra" region does not have a strategy to address the drinking water supply problem.

- Municipalities that surround the mountain (Tepetzintla, Ixcatepec, Naranjos-Amatlan, Chontla, Tantima, Tamalin, Chinampa de Gorostiza, Citlaltepetl, and Tancoco) have similar fresh water problems, and methodologies used in this research could be applied in other microwatershed or municipalities.

4 Objectives

4.1 General objective

To generate a methodological proposal that helps in the construction of a local scheme of payment for hydrological ecosystem services based on a multidisciplinary approach, in a microwatershed located in northern Veracruz, México.

4.2 Specific objectives

To determine the hydrological behaviour (runoff, throughfall, infiltration rate, evapotranspiration, percolation, and bulk density) of the main land uses located in a groundwater recharge.

To calculate the opportunity cost of the main productive activity (livestock) located in the groundwater recharge zone.

To determine the lowland water users point of view regarding payment for hydrological environmental services generated by natural ecosystems.

To review the municipal, state, and national political framework that could impact in drinking water supply problem strategies.

To identify other factors that could affect water supply problem strategies (hydraulic infrastructure, weather conditions, population growth, and land tenure rights).

5 Literature review

The following literature review was divided in three sections. The first section shows a general approach about the fresh water situation in the world, in México and in the Otontepec Sierra. In the second section, hydrological information is showed with the objective to understand the hydrological cycle in a mountain, and the impact of the land use change in the hydrological behavior of the soil. The third section showed information that could help to know the different methods used to value the ecosystem services generated by the forest.

5.1 Water in the world

The future of water is highly uncertain in large part due to relatively uncontrollable factors such as weather. But other critical factors can be influenced by the choices made collectively by the world's people. These factors include income and population growth, investment in water infrastructure, allocation of water to various uses, reform in water management, and technological changes in agriculture. In addition, water is integrally linked to environmental health. Water is vital to the survival of ecosystems and the plants and animals that live in them, and in turn ecosystems help to regulate the quantity and quality of water (i.e. wetlands retain water during high rainfall, release it during dry periods, and purify it of many contaminants) (Rosegrant *et al.,* 2002a, Rosegrant *et al.,* 2002b).

Population and income growth are crucial determinants of water and food supply and demand. A world population of 3 billion people in 1960 doubled to 6 billion by 1999, with population growth rates peaking at 2.1 percent annually between 1965 and 1970, and declining progressively since then to 1.4 percent annually between 1997 and 1998. Further declines in global population growth rates are projected, with growth rates declining in later periods as birth rates fall in virtually all regions and declining mortality rates level off. In addition, it is important to mention that closely related to population and income changes is the transformation of demographic patterns. The most vital of these demographic characteristics, particularly in terms of projecting future water and food needs in fast growing economies, is the rate of urbanization. Urbanization influences the rate of growth in domestic and industrial water demand, as well as agricultural water demand through changes in food demand. Urbanization is projected to accelerate in the future, with the urban population of developing countries more than doubling between 1995 and 2025, while the rural population increases by 12 percent. By 2025, 53 percent of the population in developing countries will reside in urban areas (Rosegrant *et al.,* 2002b).

To face this complex problem several worldwide forums were developed. Between June 5th and 16th, 1972, the United Nations met in Stockholm for a Conference on the Human Environment considered the need for a common outlook and for common principles to inspire and guide the peoples of the world in the preservation and enhancement of the global environment. The second principle of this conference mentioned that "The natural resources of the earth, including the air, water, land, flora and fauna and especially representative samples of natural ecosystems, must be safeguarded for the benefit of present and future generations through careful planning or management, as appropriate". A second meeting was developed in 1992 in Rio de Janeiro, Brazil. In this meeting the Stockholm declaration was reconfirmed and expanded upon, with a focus on the role of the state in equity, sustainability and development. For example, the second principle mentioned “States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction”. A third summit was convened in Johannesburg in 2002. In this event the General Assembly expressed their alarm and were “Deeply concerned that, despite the many successful and continuing efforts of the international community since the United Nations Conference on the Human Environment, held at Stockholm from 5 to 16 June 1972, and the fact that some progress has been achieved, the environment and the natural resource base that support life on earth continue to deteriorate at an alarming rate” (UNEP 2006).

The World Water Council developed Four World Water Forums with the first two forums held in Marrakech, Morocco (1997) and The Hague, Netherlands (2000) respectively. The Ministerial Declaration identified meeting basic water needs, securing food supply, protecting ecosystems, sharing water resources, managing risks, valuing water and governing water wisely as the key challenges for our direct future. The third World Water Forum convened in 2003 in Kyoto, Japan. This forum took the debate a step further within the context of the new commitments of meeting the goals set forth at the Millennium Summit of the United Nations in New York (2000), the International Freshwater Conference in Bonn (2001) and the World Summit on Sustainable Development in Johannesburg (2002) (WWC 2006). In the fourth World Water Forum assembled in México City, the ministerial declaration reaffirms the critical importance of water, in particular freshwater, for all aspects on sustainable development, including poverty and hunger eradication, water-related disaster reduction, health, agricultural and rural development, hydropower, food security, gender equality as well as the achievement of environmental sustainability and protection. In addition, the declaration also reaffirms the commitment to achieve the internationally agreed upon goals on integrated water resources management (IWRM), access to safe drinking water and basic sanitation as stated in Agenda 21, the Millennium Declaration and the Johannesburg Plan of Implementation (JPOI). The declaration also reiterates the continued and urgent need to achieve these goals and to keep track of progress towards their implementation, including the goal to reduce by half the proportion of people unable to reach or afford safe drinking water by the year 2015 (WWC and CNA 2006).

In 2005, the United Nations also declared in the 7th Millennium Goal “Halve, by 2015, the proportion of the people without sustainable access to safe drinking water and basic sanitation”. Much slower progress has been made globally in improving sanitation, with an estimated 2.6 billion people – representing half the developing world – lacking toilets and other forms of improved sanitation (UN 2005).

Low water prices and poor cost recovery compromise the efficient maintenance of existing water infrastructure as well as the additional investment necessary to develop future water projects. Perhaps even more fundamental is low water prices encourage misallocation and wasteful water use in all sectors. A key motive for reforming water pricing policies is the growing competition between domestic, industrial, irrigation and environmental uses, especially in arid or semi-arid regions. If higher water prices could substantially reduce the withdrawal of water in other sectors, the savings would be available for environmental uses (Rosegrant *et al.,* 2002b). Despite the potential benefit of higher water prices, policymakers have found it difficult to raise them, especially in the agricultural sector, because of concerns over impacts on food production and farmer and poor household incomes, and about the associated political risk of increasing water charges (Molle 2001). Adding to the difficulty of pricing reform, both long-standing practice and cultural and religious beliefs have treated water as a free resource, and entrenched interest benefit from the existing system of subsidies and administered allocation of water. Equity concerns are intensified by evidence that the responsiveness of agricultural water demand to changes in water prices is generally very low, and that price increases sufficient to reduce demand significantly could greatly depress farm incomes (Berbel and Gómez-Limón 2000). Water pricing systems could be designed and implemented to provide increased incentives for water conservation without reducing incomes, and possibly even enhancing the incomes of the poor. In the domestic and industrial water sectors, water price increases could be made directly, replacing existing generalized subsidies with subsidies targeted to the poor (Rosegrant *et al.,* 2002b).

5.1.2 Water in México

5.1.2.1 Socioeconomic aspects

México is a Federal Republic comprised of 31 Federal Entities and a Federal District, which contain a total of 2,439 municipalities (including the 16 political delegations located in the Federal District) and 199,391 localities. The population has practically quadrupled from 1950 to 2005 (25.8 and 106.5 millions of inhabitants, respectively) (Meadows *et al*., 2004), and went from predominantly rural (57%) to predominantly urban (75%). The population growth rate has dropped significantly (from 3.0% in 1950 to 1.39 % percent in 2005), and it is estimated that by the year 2030 it will be just 0.66 % (INEGI 2005; CONAPO 2006).

5.1.2.2 Hydrological cycle in México

Annually, México received 1,488,192 million of cubic meters of water (hm^3) by rain. A little over 1,079,404 hm^3 is lost by evapotranspiration and returns to the atmosphere (72.5%) the rest (25.4%) runs off in rivers and streams (329,137 hm^3) or infiltrates into the subsoil (2.1%) and recharges groundwater (79,651 hm^3) (CNA 2008). In Figure 1, Imports (I) from other countries refer to the volume of water that is generated in countries with which México shares basins and/or watersheds (the United States of America, Guatemala, and Belize), and Exports (E) refer to the volume of water that México must deliver to the United States according to the 1944 water treaty (CNA 2008).

5.1.2.3 Natural water availability

In México the amount of water available per inhabitant showed a decrement from 17,742 m^3/inhabitant/year in 1950, to 4,427 m^3/inhabitant/year in 2005. However, the amount of water available and the number inhabitants varies considerably from one region to the other which leads to some cases of high water availability and others of adequate or low availability *per capita*. In México there are two major water availability zones; the Southeast region, and the North-Central-Northwest region of the country. Natural water availability in the Southeast is 7 times higher than in the rest of the country. In contrast, only 32% of the mean natural water availability is found in the North-Central-Northwest regions, whereas 77% of the population resides there and produces 87% of the Gross Domestic Product (GDP). It is important to mention that in México 15% of the mean volume of available natural water is used; nevertheless, in the northern part of the country over 40% of mean natural water availability is utilized. For this reason the United Nations Organization (UN) has classified México as a country under medium water stress (CNA 2008).

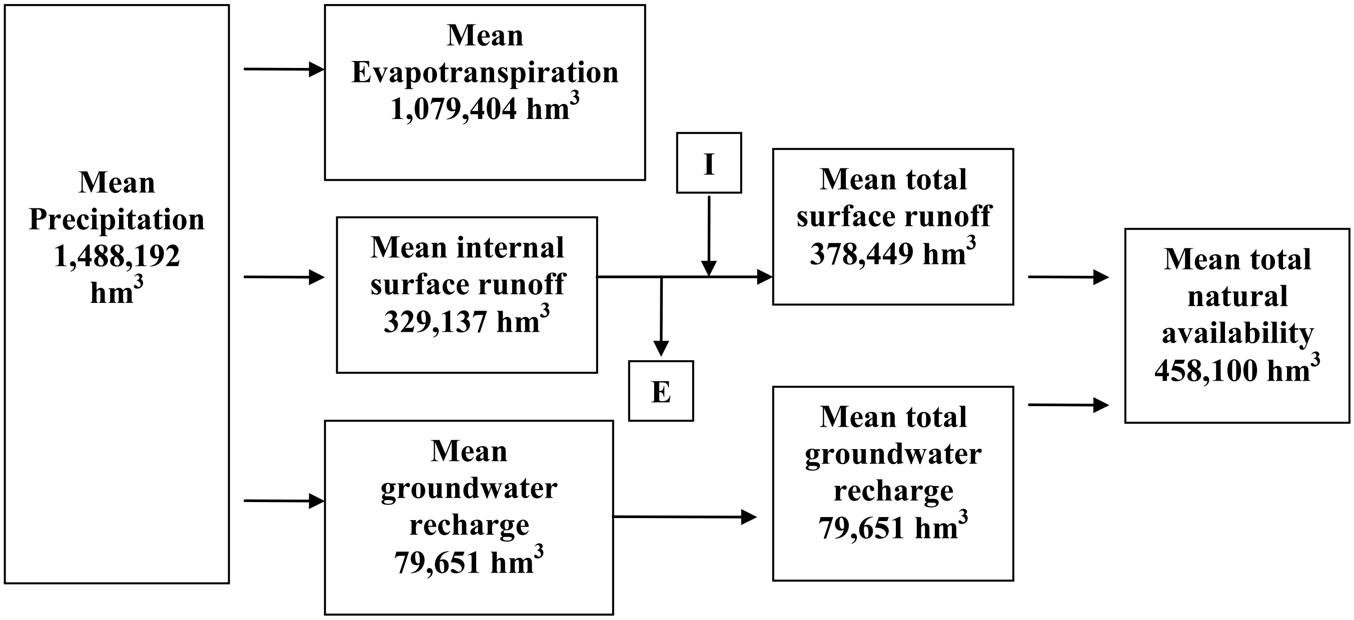

Figure 1 Components of the hydrological cycle in México (millions of cubic meters = hm^3). I = imports from other countries. E = Exports to other countries (Source: CNA 2008).

5.1.2.4 Northern Gulf of México region

Following the National Water Commission structure, the northern Gulf of México region has the following socioeconomic characteristics; a territorial extension of 127,166 km^2, a population of 4.94 millions of people, a population density of 39 inhab/km^2, a GDP of 6.6%, and 154 municipalities (CNA 2008). Additionally, the region has the following hydrologic characteristics; a mean annual precipitation of 853 mm (78% of precipitation in the region occurs between June and November). A mean total natural water availability of

25,500 hm^3 (1 hm^3 = 1,000,000 m^3), a mean natural water availability *per capita* of 5,162 m^3/inhabitant, a mean total surface runoff of 24,227 hm^3, and a mean total groundwater recharge of 1,274 hm^3. In addition, the region is considered by the UN as a moderate water stress zone. It is necessary to point out that this region is part of the tropical hurricanes corridor since a greater part of the moisture transported from the sea to the region's subhumid and semiarid zones occurs during these hurricanes. Finally, the main rivers in the region are; "The Panuco" measuring 510 km in length and a total basin area of 84,956 km^2, "The Soto La Marina" measuring 416 km in length and total basin area of 21,183 km^2, and "The Tuxpan" measuring 150 km in length and total basin area of 5,899 km^2 (CNA 2008).

5.1.2.5 Otontepec Sierra

The "Otontepec Sierra" (Nahuatl, cotontoc = cut, tepetl = mountain), an isolated volcanic mountain located in the northern Gulf of México region provides fresh water for nine municipalities (Tepetzintla, Chontla, Tancoco, Tamalin, Tantima, Ixcatepec, Chinampa de Gorostiza, Citlaltepetl, and Tancoco). The natural vegetation is sub-humid deciduous tropical forest and Oak forest (INEGI Vegetation Chart F 14-9); however, natural land use is changing to agriculture and livestock activities (Ing. Clemente Leyva, Veracruz State Water Bureau-CAEV, personal communication, 2006). Several communities that surround the mountain have social problems as a result of water scarcity and during the summer consumers only have access to water two days per week for a few hours per day. In addition, municipalities that surround the mountain do not have a sustainable watershed management strategy. In fact, in the past few years the only strategy to improve the communities' water supply was to "take" water from other springs in the mountain highlands (Jesús Zeníl Méndez, Municipal President of Tepetzintla 2005 – 2007, personal communication).

5.2. Hydrological cycle

The hydrologic cycle describes the continuous movement of water above, on, and below the surface of the Earth. The water on the Earth's surface (surface water) occurs as streams, lakes, and wetlands, as well as bays and oceans. Surface water also includes the solid forms of water, snow and ice. The water below the surface of the Earth is primarily ground water, but it also includes soil water. A simplified diagram shows the major transfers of water in the hydrologic cycle between continents and oceans (Figure 2). However, for understanding hydrologic processes and managing water resources, the hydrologic cycle needs to be viewed at a wide range of scales and as having a great deal of variability in time and space (Winter *et al.,* 1998).

Precipitation, which is the source of virtually all freshwater in the hydrologic cycle, falls nearly everywhere, but its distribution, is highly variable. Similarly, evaporation and transpiration return water to the atmosphere nearly everywhere, but evaporation and transpiration rates vary considerably according to climatic conditions. As a result, much of the precipitation never reaches the oceans as surface and subsurface runoff before the water is returned to the atmosphere. The relative magnitudes of the individual components of the hydrologic cycle, such as evapotranspiration, may differ significantly even at small scales, as between an agricultural field and a nearby woodland (Winter *et al.,* 1998).

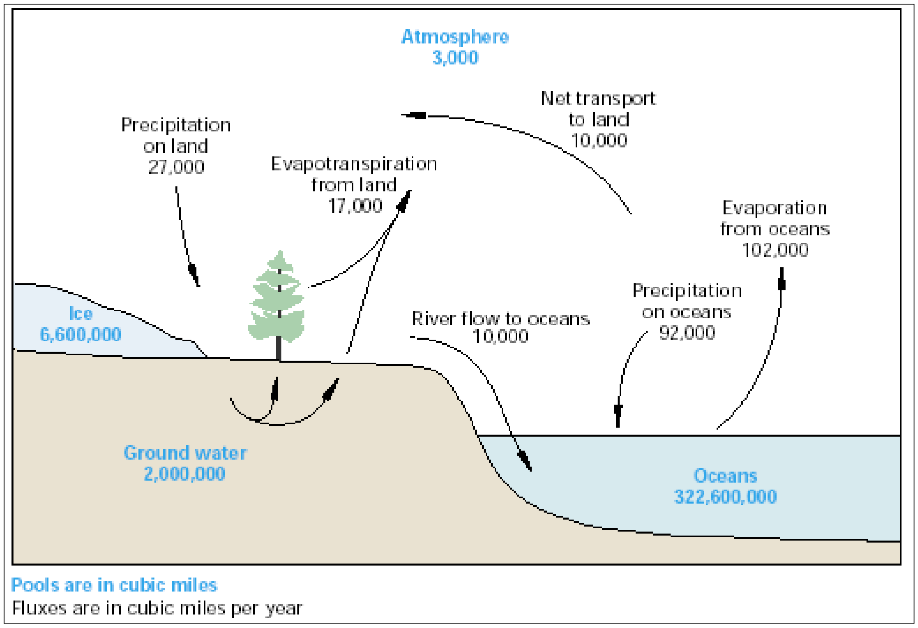

Figure 2. Earth's hydrological cycle, modified from Schelesinge, 1991 (source Winter *et al.,* 1998).

5.2.1. Infiltration of water into soil

The rate at which water passes into the soil is known as the infiltration rate and this exerts a major control over the generation of surface runoff. Water is drawn into the soil by gravity and by capillary forces whereby it is attracted to and held as a thin molecular film around the soil particles. During a rainstorm, the spaces between the soil particles become filled with water and the capillary forces decrease so that the infiltration rate starts high at the beginning of a storm and declines to a level which represent the maximum sustained rate at which water can pass through the soil. This level, the infiltration capacity or terminal infiltration rate, corresponds theoretically to the saturated hydraulic conductivity of the soil. In practice, however the infiltration capacity is often lower than the saturated hydraulic conductivity because of air entrapped in the soil pores as the wetting front passes downward through the soil (Morgan 1995).

In most areas where water shortages occur, maximizing the infiltration of rainfall into soil is indispensable to achieving food and water security. Land management should encourage infiltration as opposed to runoff. The amount of rainfall that infiltrates will be governed by the intensity of the rainstorm in relation to the soil's infiltration rate. Excessive tillage and loss of soil organic matter often result in reduced infiltration rate due to loss of surface porosity. When storm intensity is greater than soil infiltration rate, runoff will occur, resulting in a waste of water that should have been used for crop production and for recharging the groundwater. The rate at which rainfall infiltrates into soil is influenced by the abundance, stability and size of the pores into the rooting zone. In many soils the number of surface pores is rapidly reduced by the impact of raindrops, which break surface soil aggregates into small particles that clog surface seals or crusts with very few pores. The destructive raindrop action is avoided where there is a protective cover of crop foliage, residues, mulches or even weeds at or over the soil surface. Other factors that can reduce the number, proportion and continuity of transmission pores are traffic by machinery, humans and animals, which destroys large pores by compactation, and tillage (Suárez de Castro 1982; Stadtmüler 1994; Winter *et al.,* 1998; Brady and Weil 2002; Shaxson and Barber 2003).

Management of the soil can significantly affect infiltration and runoff; direct evaporation from the soil surface; the amount of soil moisture available to plants within range of their roots; and the depth to which roots can penetrate. How much water reaches each of these destinations over a given period depends on the physical condition of the soil and its influence on infiltration and runoff and on the atmospheric conditions as they affect evaporation and transpiration (Shaxson and Barber 2003).

The maintenance of soil porosity by mulch cover will allow the highest proportion of rainfall to be available as soil moisture for the crops and groundwater for the streams (Suárez de Castro 1982). The pore spaces in a soil vary in abundance according to the type of soil and how it has been managed (Shaxson and Barber 2003). Soils under natural vegetation generally exhibit high porosity because of high biological activity and lack of interference by man. Consequently they have superior physical qualities compared with most soils used for crops or grazing (Stadtmüller 1994; Brady and Weil 2002).

Pore spaces in soils vary in size, and both the size and continuity of pores have an important influence on the types of activities that occur in soil pores. Pores spaces from 0.0002 to 0.05 mm diameter retain water that can be absorbed by crops and are referred to as storage pores, whereas smaller pores (the residual pores) hold water too tightly for plants to be able to extract it (Villón 2002; Brady and Weil 2002; Shaxson and Barber 2003). Pores larger than about 0.05 mm diameter, referred to as transmission pores, allow water to drain through the soil and enable air to enter the pores as water drains out, table 1 shows the functions (Hamblin 1985 cited by Shaxson and Barber 2003).

Table 1 Functions and sizes of soil pores.

Pores size (mm diameter)	Pores description	Pores functions
< 0.0002	Residual	Retain water that plants cannot use
0.0002 – 0.05	Storage	Retain water that plants can use
> 0.05	Transmission	Allow water to drain out and air to enter
> 0.1 to 0.3	Rooting	Allow crop roots to penetrate freely
0.5 – 3.5	Worm holes	Allow water to drain out and air to enter
2 – 50	Ant nests and channels	Allow water to drain out and air to enter

Source: Hamblin 1985 cited by Shaxson and Barber 2003

5.2.2. Evapotranspiration

Evapotranspiration (ET) is the process that returns water to the atmosphere and therefore completes the hydrologic cycle (ET is the major component of the cycle). ET can be divided into two subprocesses: evaporation and transpiration. Evaporation essentially occurs on the surfaces of open water such as, lakes, reservoirs, or from vegetation and ground surfaces. Transpiration involves the removal of water from the soil by plant roots, transports of the water through the plant into the leaf, and evaporation of the water from the leaf's stomata into the atmosphere. In addition, ET can be divided into potential evapotranspiration (PET) and actual evapotranspiration (AET). PET is the amount of ET that would occur when there is unlimited water available. AET is the amount of ET that actually occurs when water is limited (Ward and Trimble 2004).

5.2.2.1. Evaporation of bare soil

Evaporation from bare soil is similar to evaporation from open water if the soil is saturated. If bare soil is not saturated, the process is more complex because water evaporates deeper in the soil, and the vapour must diffuse into the atmosphere. The rate of evaporation from bare soil is typically divided into two distinct stages. During the first stage, the soil surface is at or near saturation, and the rate of evaporation is controlled by heat energy input and is approximately 90% of the maximum possible evaporation based on weather conditions (Jensen *et al.,* 1990 *in* Ward and Trimble 2004). The duration of the first stage is influenced by the rate of evaporation, the soil depth, and hydraulic properties of the soil. The second stage, sometimes called the falling stage, begins once the soil started to dry. At this stage, evaporation occurs below the soil surface. The water vapour formed in the soil reaches the soil surface by diffusion or mass flow caused by fluctuating air pressures. The evaporation rate during this stage is no longer controlled by climatic conditions, but rather by soil conditions such as hydraulic conductivity. In addition, an important control of hydraulic conductivity is texture, so that for the given period of intensive drying, a given level of soil drying might be found significantly deeper in sand-textured soils than in clay-texture soils (Jensen *et al.,* 1990 *in* Ward and Trimble 2004).

5.2.2.2. Evapotranspiration from soil and plants

When plants are introduced into the system the complexity of measuring or predicting ET increases, because, plants transpire water, in addition to moisture evaporating from the soil surface or from the canopy surfaces (Ward and Trimble 2004). These processes will be explained with more accuracy in the following paragraphs.

Before precipitation gets to the ground, it normally must pass through vegetation: canopies, stems, grass blades, and vegetative bed litter on the ground. A small, but significant, amount is intercepted and retained on these surfaces. Evaporation of this retained intercepted water starts even during the storm and continues afterward until all the water is evaporated. Note that about the same amount of energy is required to drive evaporation of free water from the leaf as to drive transpiration from the leaf. Thus, plant transpiration is reduced commensurate with the amount of intercepted water to be evaporated from the leaves (Ward and Trimble 2004).

Transpiration was defined (Kramer 1983 *in* Ward and Trimble 2004) as the loss of water in the form of vapour from plants, and is basically an evaporation process. The transpiration of water that moves out of the leaves and into the atmosphere is responsible for the ascent of water from the roots and the rate at which water is taken in through the roots. The rate at which water moves through a plant is critical to the plant's functioning because water is the vehicle that carries nutrients and minerals into the plant. In addition, transpiration rate could be affected by some factors such as, type of plant, direct or indirect solar energy, temperature, relative humidity, roots depth, wind, and plant available water. It is important to mention that, the ability to extract water from soils in not directly correlated with roots depth. While more water may be available to lower roots, the energy required to pull that water up to the plant is great, so only a smaller amount may be extracted. In addition, profile structure can also influence the evaporation rate of the plant (Ward and Trimble 2004).

5.2.3. Subsurface water

Water beneath the land surface occurs in two principal zones, the unsaturated zone and the saturated zone (Figure 3). In the unsaturated zone, the voids—that is, the spaces between grains of gravel, sand, silt, clay, and cracks within rocks—contain both air and water. Although a considerable amount of water can be present in the unsaturated zone, this water cannot be pumped by wells because it is held too tightly by capillary forces. The upper part of the unsaturated zone is the soil-water zone. The soil zone is crisscrossed by roots, voids left by decayed roots and animal and worm burrows, which enhance the infiltration of precipitation into the soil zone. Soil water is used by plants in life functions and transpiration, but it also can evaporate directly to the atmosphere (Winter *et al*., 1998).

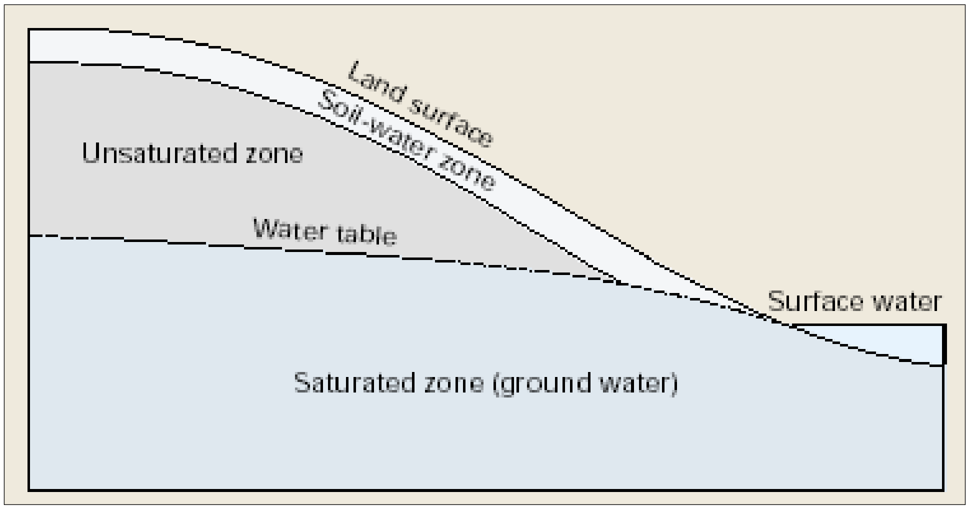

Figure 3 The water table is the upper surface of the saturated zone. The water table meets surface-water bodies at or near the shoreline of surface water if the surface-water body is connected to the ground-water system (Source Winter *et al.,* 1998).

In contrast to the unsaturated zone, the voids in the saturated zone are completely filled with water. Water in the saturated zone is referred to as groundwater. The upper surface of the saturated zone is referred to as the water table. Below the water table, the water pressure is great enough to allow water to enter wells, thus permitting ground water to be withdrawn for use. The depth to the water table is highly variable and can range from zero, when it is at land surface, to hundreds or even thousands of feet in some types of landscapes. Usually, the depth to the water table is small near permanent bodies of surface water such as streams, springs, lakes, and wetlands. An important characteristic of the water table is that its configuration varies seasonally and from year to year because groundwater recharge, which is the accretion of water to the upper surface of the saturated zone, is related to the wide variation in the quantity, distribution, and timing of precipitation. In addition, is important to mention that, in areas of steep land slopes, the water table sometimes intersects the land surface, resulting in groundwater discharge directly to the land surface (springs) (Figure 4) (Winter *et al*., 1998).

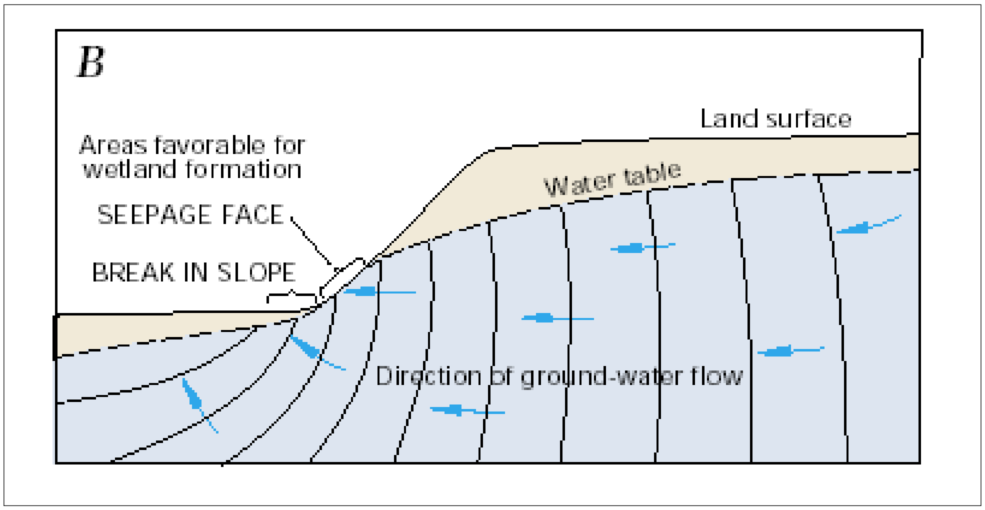

Figure 4 The source of water to wetlands can be from ground-water discharge at seepage faces and at breaks in slope of the water table (Source: Winter *et al*., 1998).

5.2.4. Groundwater

Movement of water in the atmosphere and on the land surface is relatively easy to visualize, but the movement of groundwater is not. Groundwater moves along flow paths of varying lengths from areas of recharge to areas of discharge. The generalized flow paths in Figure 5 start at the water table, continue through the groundwater system, and terminate at the stream or at the pumped well. The source of water to the water table is infiltration of precipitation through the unsaturated zone. In the uppermost, unconfined aquifer, flow paths near the stream can be tens to hundreds of feet in length and have corresponding traveltimes of days to a few years. The longest and deepest flow paths in Figure 5 may be thousands of feet to tens of miles in length, and traveltimes may range from decades to millennia. In general, shallow groundwater is more susceptible to contamination from human sources and activities because of its close proximity to the land surface (Winter *et al.,* 1998).

Transpiration by plants has the opposite effect of focused recharge. Again, because the water table is near land surface at edges of surface-water bodies, plant roots can penetrate into the saturated zone, allowing the plants to transpire water directly from the groundwater system (Figure 6). Transpiration of ground water commonly results in a drawdown of the water table much like the effect of a pumped well. This highly variable daily and seasonal transpiration of ground water may significantly reduce ground-water discharge to a surface-water body or even cause movement of surface water into the subsurface. In many places it is possible to measure diurnal changes in the direction of flow during seasons of active plant growth; that is, ground water moves into the surface water during the night, and surface water moves into shallow ground water during the day (Winter *et al*., 1998).

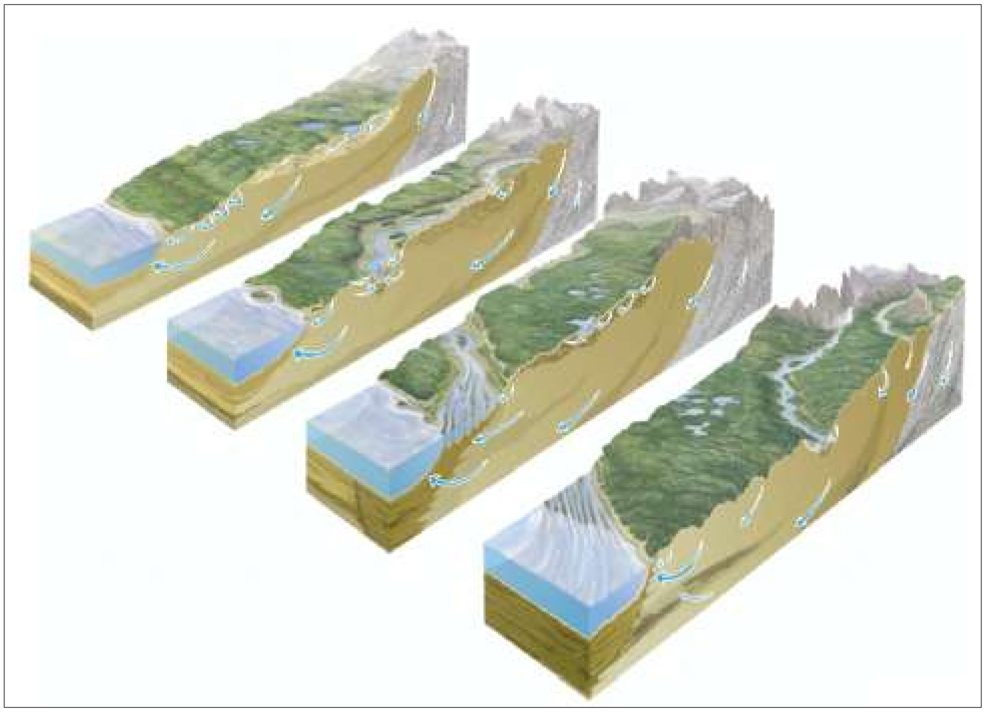

Figure 5 Groundwater movements along flow paths (Source: Winter *et al.,* 1998).

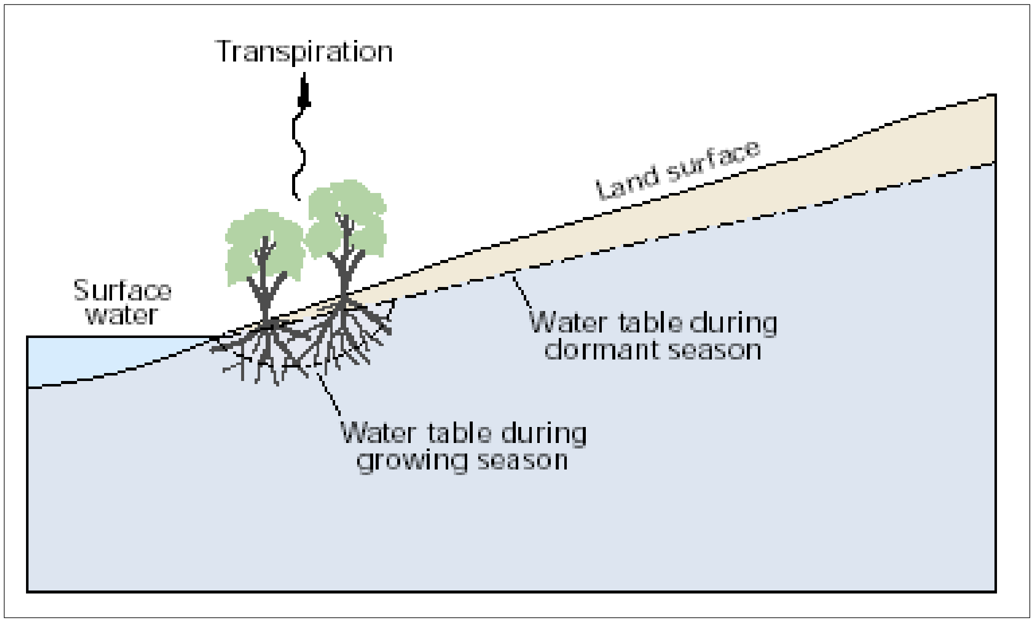

Figure 6 Where the depth to the water table is small adjacent to surface-water bodies, transpiration directly from ground water can cause cones of depression similar to those caused by pumping wells. This sometimes draws water directly from the surface water into the subsurface (Source: Winter *et al.,* 1998).

5.2.5. Soil erosion

Erosion and land use change are very strongly related. Rates of soil loss accelerate quickly to unacceptably high levels whenever land is misused. Under these conditions, the effects of geomorphological events of moderate and high magnitude in particular are exaggerated. Only in extreme events is the land cover influence overshadowed and extensive areas of land damaged, regardless of how they are managed. A combination of historical and geomorphological analysis emphasizes that erosion is a natural process but that its rate and spatial and temporal distribution depend on the interaction of physical and human circumstances. Soil erosion is therefore an integral part of both the natural and cultural environment (Morgan 1995).

Soil erosion is a two-phase process consisting of the detachment of individual particles from the soil mass and their transport by erosive agents such as running water and wind. When sufficient energy is no longer available to transport the particles, a third phase deposition occurs. Rainsplash is the most important detaching agent. A as result of raindrops striking a bare soil surface, soil particles may be thrown through the air over distances of several centimeters. Continuous exposure to intense rainstorms considerably weakens the soil. Soil is disturbed by tillage operations and by the trampling of people and livestock (Morgan 1995).

The process of water erosion is closely related to the routes taken by water in its passage through the vegetation cover and its movement over the ground surface. Their base thus lies in the hydrologic cycle. During a rainstorm, part of the water falls directly on the land, either, because there is no vegetation, or because it passes through gaps in the plant canopy. This component of the rainfall is known as direct throughfall. Part of the rain is intercepted by the canopy from where it is either returned to the atmosphere by evaporation or finds its way to the ground by dripping from the leaves, a component termed leaf drainage, or by running down the stem as stemflow. The action of direct throughfall and leaf drainage produces rainsplash erosion. The rain which reaches the ground may be stored in small depressions or hollows on the surface or it may infiltrate the soil, contributing either to soil moisture storage or, by percolating deeper, to groundwater. When soil is unable to take more water, the excess moves laterally downslope within the soil as surface or interflow or it contributes to runoff on the surface, resulting in erosion by overland flow or by rills and gullies (Morgan 1995). Additionally, it is necessary to mention that, the conservation effects of forest are due not only so much to the presence of the trees themselves but also to the litter of fallen leaves, twigs and branches, plus any low-growing vegetation. If the soil surface has not been damaged by trampling, less rainwater will runoff and more will infiltrate into the soil. The clear water, which runs throughout the year, more voluminous in the rain than in the dry season, has percolated through the litter of fallen leaves and branches on the forest floor, which both protects the surface from rain impact, and nourishes the soil organisms that maintain soil porosity. This water has traveled the slow route through the soil to the groundwater, which moves into the stream via springs and seepages along the streambanks (Stadtmüller 1994; Shaxson and Barber 2003).

5.2.5.1. Erodibility

The response of a soil to the erosion processes is complex, and is influenced by soil properties such as texture, structural stability, organic matter content, clay mineralogy, and chemical constituents. Some of these properties, like organic matter, can be altered over time by land use, management practices, and farming systems. Erosion of the surface layers can expose less erodible subsoils that may have different properties than the surface. Consequently, the erodibility of soil can change with time. The soil texture is important in determining erodibility. Sandy soils have lower runoff rates, and are more easily detached, but less easily transported than silt soils. Clay soils are not easily detached, but lower infiltration rates may lead to greater runoff and increased erosion. Silt soils tend to have the greatest erodibilities since particles are easily detached and transported, and consolidation of subsoils, or subsoils with higher clay contents, can lead to greater runoff (Lal and Elliot 1994).

5.2.5.2. Erosivity

The ability of erosion agents to cause soil detachment and transport is erosivity. The erosivity of rainfall is due partly to direct raindrop impact and partly to the runoff that rainfall generates. The ability of rain to cause soil erosion is attributed to its rate and drop size distribution, both of which affect the energy load of a rainstorm. The erosivity of a rainstorm is attributed to its kinetic energy or *momentum,* parameters easily related to rainfall rate or total amount (Lal and Elliot 1994).

5.2.6. Soil - Water relationships

The amount of water present in the soil will depend on how much of the rainwater remains in the soil after the losses by runoff, evaporation, and deep drainage. The amount of rainfall that reaches the groundwater and thus contributes to water security will depend on the extent to which the rainfall infiltrating the soil in excess of that needed to replenish the soil's water holding capacity and satisfy the transpiration needs of the crops. Good rainwater management aims to maximize the amount of rainwater that enters the soil, and to make the best use of it while it is there for crop use and for recharging the groundwater (Suárez de Castro 1982; Shaxson and Barber 2003). Contrary to that, damage in soil surface (i.e. compactation) affects surface infiltration properties and functional characteristics of the surface and soil pores immediately below soil surface (Suárez de Castro 1982; Russell *et al.,* 2001).

The quantity of water retained after 48 hours corresponds to the soil's field capacity (FC). FC is reached when a well drained soil is saturated to the limit of its rooting zone and the rainwater that does not drain out of the root zone within 48 hours is retained in soil pores smaller than about 0.05 mm diameter (the critical pore size may vary from 0.03 to 0.1 mm diameter). The maximum amount of available water that a soil can retain will vary with the soil's texture, organic matter content, rooting depth and structure. Soil organic matter is particularly important, because it can retain about 20 times its weight of water. Organic soils and medium textured loamy soils with high contents of very fine sand and silt generally have the highest Available Water Capacity (AWC). Clay soils have intermediate values, and soils with high content of coarse sand have the lowest AWC. The stone content of soils can also be very important depending on the nature and abundance of the stones. Some ironstone gravel > 2 mm diameter can contain more than 20 percent water at FC and porous limestone and chalk can also make significant contributions to the AWC of a soil. In contrast, a high content on non-porous stones will greatly diminish the AWC of a soil (Stadtmüler 1994; Shaxson and Barber 2003).

5.2.7. (De)forestation effect in the hydrological cycle

The general term "deforestation" is rather meaning-less as a descriptor of land-use change and each case needs to be defined properly (Bruijnzeel 1986). Low-intensity types of disturbance include such small-scale and short-lived events as natural tree falls and small clearings. Forest fires and slash and burn agriculture, generally produce a temporary effect. Selective logging of forests may also be ranked as a disturbance of (at least) intermediate intensity, depending on the volume of timber removed and the type of equipment used (Horne and Gwalter 1982 *in* Bruijnzeel 1990). As such, selective logging will usually have to be classified as a disturbance of moderate intensity at least, also because felling and extraction of large trees may produce so much damage to the surrounding vegetation that regrowth may be too slow for further profitable exploitation (Burgess 1971, and De Graaf 1986 *in* Bruijnzeel 1990). Generally, a forest subjected to one of the above-mentioned types of disturbance may recover to its previous state if left alone for a sufficiently long period. Clearly, this is not the case when forest is converted to permanent agriculture (grazing, cropping, extractive tree crops) or production forestry and these must all be classified as disturbances of high intensity (Bruijnzeel 1990).

An interesting research reviewed the results of 94 paired-catchment experiments, and concludes that "Variation in results is extreme but some general conclusions are justified. No experiments in deliberately reducing cover caused reductions in yield, nor have any deliberate increases in cover caused increases in yield" (Bosch and Hewlett 1982). In other words, removal of forest cover leads to higher streamflow totals, and reforestation of open lands generally leads to a decline in overall streamflow (Bruijnzeel 1990). More information is presented in the following paragraphs.

A study developed in the Eastern Transvaal escarpment, South Africa, measured the flow from different land use catchments; natural grassland (36.9 ha), forest plantation of *Eucalyptus grandis* (26.2 ha) and forest plantation of *Pinus patula* (34.6 ha). Soils are extremely shallow, but underlying rocks are permeable to roots and to water. Gauging of flow from the catchments under natural grass cover began in 1956. One of the catchments was planted to *E. grandis* in 1969 after 12 years of calibration, a second was planted to *P. patula* in 1971, and the third was maintained in the natural condition. Simple regression analysis procedures were used and showed that afforestation with *E. grandis* exerted an observable influence from the third year after planting (Figure 7), with a maximum apparent reduction in flow, expressed as rainfall equivalent, of between 300 and 380 mm yr^{-1}, and with maximum reductions in seasonal flow of about 200 - 260 mm yr^{-1} in summer and 100 - 130 mm yr^{-1} in winter. Authors concluded that, the simple linear regression analyses used here show very clear trends in the relationships between streamflow totals from treated catchment and those from the control, after treatment. Microwatershed forestation resulted in a decline in total annual streamflow, like that found in similar or analogous experiments elsewhere (Van Lill *et al*., 1980).

In the southwest of Western Australia research was developed using a neutron scattering technique to measure soil-moisture storage beneath native hardwood forests, plantations of softwood forests, perennial pastures and winter annual pastures growing in deep sands. The seasonal patterns of water use and of deep drainage to groundwater were calculated using measured soil-moisture characteristics. Soils were deep, coarse sands, located in the Spearwood Dune System. Results showed that the fourteen-year-old *Pinus pinaster* (Ait.) plantations, (1,200 trees per hectare), transpired more water than the native forest they replaced (evergreen-xerophytic, and adapted to seasonal droughts). The pines depleted the soil water faster, and to a greater degree. Deep drainage beyond 6 m was much less in the soil below the pine plantations than native forest (240 mm and 400 mm, respectively), indicating a decrease in recharge of shallow ground-waters. The perennial pastures (*Eragrostis curvula* and *Hyparrhenia hirta*) showed a pattern of water use, soil-water and deep drainage similar to the native forests. The winter annual pastures (*Bromus mollis*), however, used less water than the native forest, and deep drainage was increased. Authors concluded that, under these soil characteristics and management, the replacement of native forests with perennial pastures would have very little effect on deep drainage to a water table. The replacement of native forests with annual pastures, however, would lead to a significant increase in deep drainage. The appropriate balance between pine forests, native forests, perennial pasture and annual pasture may provide a basis for manipulation of recharge to the freshwater aquifers below (Carbon *et al.,* 1982).

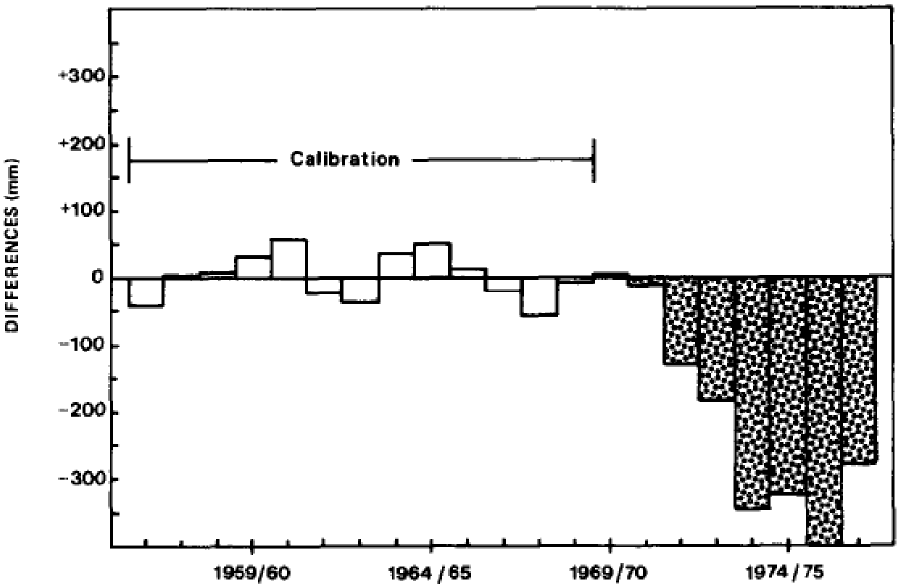

Figure 7 Differences between observed total annual (October - September) streamflow for Mokobulaan catchment A (*Eucalyptus grandis*) and flow predicted from the calibration (1956/57 - 1968/69) equation (Source: Van Lill *et al.,* 1980).

In the northern Brazilian state of Pará, a study was developed with the objective to assess the impacts of land use changes on plant available water (*PAW*), evapotranspiration (*ET*), and volumetric water content (*VWC*) in three different land uses; mature evergreen forest, pastures, and "Capoeira" (second growth forest on abandoned pasture land). Results indicated that *PAW*, between 0 and 8 m depth, for forest, pasture, and Capoeira ranged from 56, 400, and 138 mm, at the end of the 1992 dry season, to 941, 1116, and 1021 mm, during the 1994 wet season, respectively. The authors found significant differences ($p = < 0.05$), in deep (4 – 8 m) stocks of *PAW*, when comparing pasture with both forest types (pastures had higher *PAW* stocks). In contrast, mature forest and Capoeira *PAW* were not significantly different from one another at any depth during the experiment. Water balance estimates (based on measurements to 8 m depth) showed an average 10% decrease in *ET* from pasture compared to mature forest. Finally, they conclude that the pastures that are replacing mature forest in eastern Amazonia appear to be less well adapted to large fluctuations in moisture availability; and this is reflected in their canopy seasonality and steeper decreases in transpiration rates during drought events. And, rapid recovery of deep *PAW* utilization in second growth forest "Capoeira" implies that decreased transpiration and increased deep drainage are reversible effects of forest conversion to pasture (Jipp *et al*., 1998).

In Fiji archipelago, using micrometeorological and hydrological techniques, a study was developed with the objective to measure total evaporation (ET) in two forest plantations of *Pinus caribaea* and grassland (*Pennisetum polystachyon*). Forest plantations were 6 and 15 years old, respectively. The soils were classified as Typic Eutrustox (with a silty-clay to clay texture and a weak structure), and Udic Haplustoll (reddish-brown soils developed in volcanic breccias), for forest and grasslands, respectively. Results are shown in Table 2. Authors concluded that grassland reforestation resulted in a maximum decrease in annual water yield of 1,108 mm on a plot basis. Although they argued that a reduction of (at least) 500 – 700 mm would be more realistic at catchment scale. The impact of reforesting grassland on the water resources in southwest Viti Levu, Fiji is enhanced by its location in a maritime, seasonal climate in the outer tropics, which favoured larger difference between annual forest and grassland evaporation totals than other equatorial regions (Waterloo *et al*., 1999).

Table 2 Comparison of water balance components at *Pennisetum polystachyon* grassland, and young (6 years), old (15 years) *Pinus caribaea* forest plantations**.**

Parameters (mm year^{-1})	Grassland	Young plantation (6 years)	Old plantation (15 years)
Precipitation (P)	2,054	2,054	2,054
Transpiration (E_t)	551	1,394	1,198
Rainfall interception (E_i)	93	382	371
Litter interception (E_l)	102	155	153
Evapotranspiration (ET)	746	1,926	1,717
$Q\ (+\Delta S + L)$	1,308	128	337

Q = drainage or streamflow; ΔS = change in soil water and groundwater storage; L= catchment leakage
Source: Waterloo *et al.,* 1999

In the Blue Mountains of Jamaica research was developed over five years with the following objective; to investigate the effects on surface runoff, soil erosion and soil properties of secondary forest conversion to alternative land uses, such as agroforestry systems, traditional agriculture and bare land. The study area was located at 1,300 m.a.s.l., the soils were Eutric and chromic Cambisols, and the mean annual rainfall was 2,180 mm (70 years measured). Runoff and soil erosion results showed statistical differences ($p<0.001$) between secondary forest and conversion land uses. Compared with secondary forest, runoff levels were increased by 360% in the agroforestry system, 460% in the bare land, and 740% in traditional agriculture (Figure 8). In addition, mean runoff levels from agroforestry were statistically different than traditional agriculture ($p < 0.001$). Authors concluded that secondary forests efficiently protect soil and water resources, and agroforestry systems (contour hedgerows) reduce runoff and levels of erosion below those under conventional agriculture (McDonald *et al*., 2002).

In contrast to the studies presented above, the following research indicates different results in the hydrologic behaviour after a land use change. This study was located in La Mucuy, Merida State, in the Venezuelan Andes (2,300 m.a.s.l. and 3,124 mm rainfall year^{-1}). The research objective studied the water fluxes of a cloud forest in order to evaluate the hydrological impact of replacement by pastures (*Pennisetum clandestinum* Hochst. ex Chiov.) Results are shown in Table 3. Authors concluded that deforestation processes the cloud forest and its replacement by kikuyu pastures impacts water fluxes. The processes decreased water input and affected the partitioning of the water output, changing the vapour fluxes going back to the atmosphere and changing the surface and subsurface drainage. Comparison of fluxes in a cloud forest and a pasture under low grassing showed that the more complex structure of the cloud forest enables an equivalent of one month of extra rainfall due to cloud-water capture, and an increased interception of incoming water (Ataroff and Rada 2000).

5.2.8. Livestock and the hydrological cycle

5.2.8.1. Upper soil biomass effect on hydrological indicators

Biomass protects the pore integrity of the soil surface structure by dissipating the raindrop impact velocity, thus reducing the disaggregating potential of the rain, and pores are less likely to be clogged by disaggregated soil particles (Tromble *et al*., 1974; Suárez de Castro 1982; Thurow *et al*., 1986; Thurow *et al*., 1988; Stadtmüller 1994; Morgan 1995; Shaxson and Barber 2003). In addition, the type of organic cover (alive or dead) is not as important as the amount (Hofmann *et al*., 1983; Stocking 1994, Stocking and Murnaghan 2001). Taken in consideration the last comments, grasslands and silvopastoral systems with appropriate management would be a feasible alternative to protect a groundwater recharge because water intake is influenced by the quantity of biomass in the upper soil (Rauzi and Hanson 1966; Lusby 1970; Meeuwig 1970; Tromble *et al*., 1974; Buckhouse and Gifford 1976; Suárez de Castro 1982; Thurow *et al*., 1986; Warren *et al.,* 1986a; Young 1987; Papendick and Campbell 1988, Thurow *et al*., 1988; Rostagno 1989; Takar *et al*., 1990; Stadtmüller 1994; Morgan 1995; MAG/FAO 1996; Taddese *et al.,* 2002; Villón 2002; Shaxson and Barber 2003).

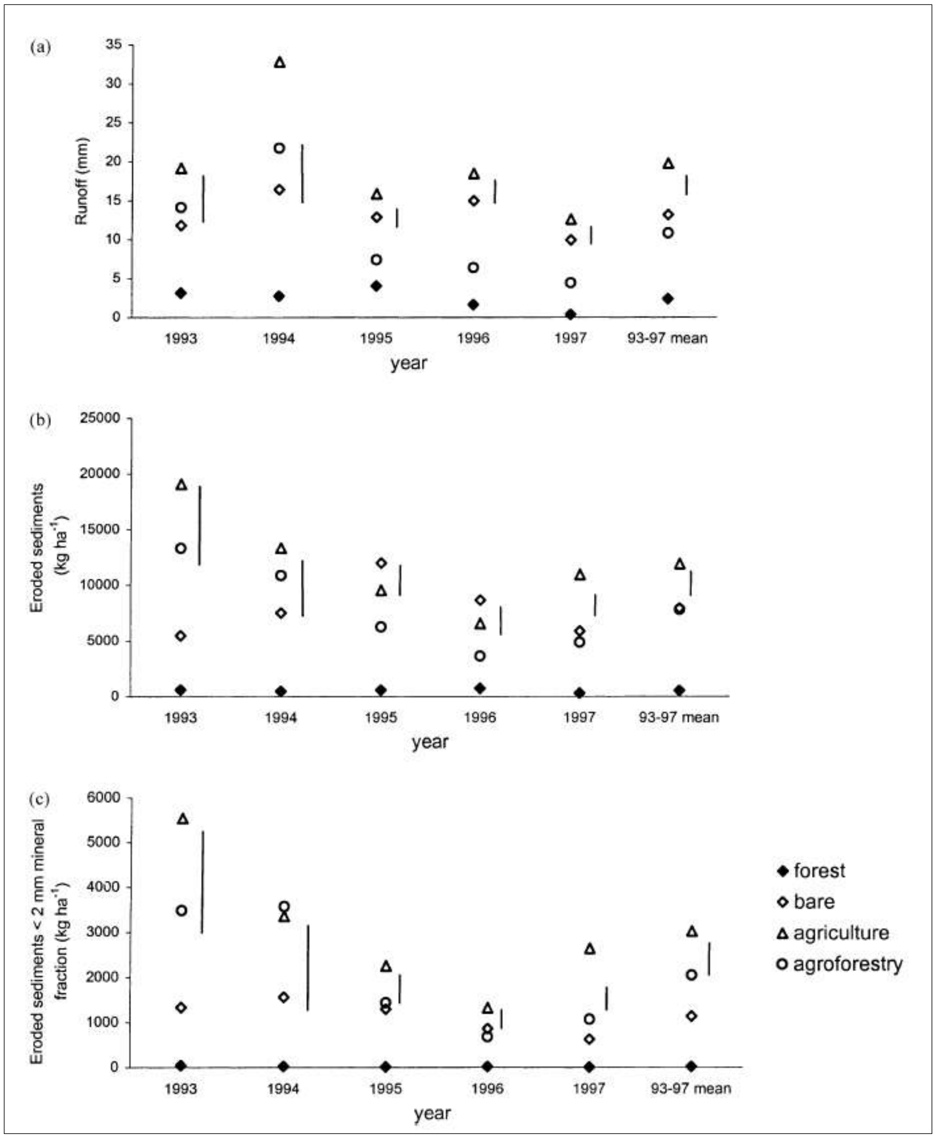

Figure 8 Quantity of surface runoff and eroded sediment per year from experimental plots: (a) surface runoff (mm); (b) total eroded sediment (kg ha^{-1}); (c) eroded mineral sediment < 2mm diameter (kg ha^{-1}). Vertical lines are the standard error of the difference between treatment values; year refers to the 12-month sampling period, e.g. 1993 = September 1992 to September 1993 (Source: McDonald *et al.,* 2002).

For soil protection under grassland management, residual biomass is assumed to be more important than the percentage utilization of annual production because of fluctuations in production from year to year. It was hypothesized that various residual phytomass levels had significantly different levels of runoff and infiltration because of the relationship between phytomass and other independent variables such as foliar area and basal cover (Lusby 1970; Suárez de Castro 1982; Bari *et al*., 1993; Stadtmüller 1994). In fact, soil conservation systems increasingly emphasize the role of organic matter, dead or alive, in arresting erosion. Management for soil conservation is now as much a question of encouraging vegetative growth as it is constructing physical conservation measures.

Perhaps, the major problem with such a conservation strategy is that it requires continuous, sensitive, and knowledgeable management of both the soil and the crop to be fully effective (Stocking 1994).

Table 3. Rainfall (pp), cloud-water interception (cw), transpiration (tr), foliage interception (fi), litter interception (li), surface runoff (r), soil evaporation (ev.s), soil storage (s) Drainage (D), in La Mucuy, Mérida, Venezuelan Andes.

System		**Inputs**		**Outputs**					
		pp	**cw**	**tr**	**fi**	**li**	**r**	**ev.s**	**s + D**
Cloud Forest	*%*	*91*	*9*	*16*	*51*	*6*	*1*	*0*	*26*
	mm	3124	309	558	1751	214	48		
Pasture	*%*	*100*	*0*	*66*	*7*	*0*	*2*		*25*
	mm	3124	0	2067	625		63		

(Source: Ataroff and Rada 2000)

In the northern Utah, USA research was developed to measure the influences of vegetation, soil properties, and slope gradient on infiltration capacity, and soil stability in high elevation grassland (2,700 m.a.s.l.). Results showed that plant and litter cover accounted for 75% of the variance in the amount of water retained. Bulk density (proportion of particles and aggregates larger than 0.5 mm), initial moisture content, and air-dry weight of life vegetation, accounted for 82% of the variance in water retained. In the case of soil erosion, plant and litter cover were most closely correlated with eroded soil (r = - 0.87). In addition, three other site factors (litter weight, slope gradient, and soil organic mater) in combination with cover, accounted for 83% of the variance (Meeuwig 1970).

Another study developed in northeastern Patagonia, Argentina, measured infiltration and sediment production of eroded and uneroded shrub interspace soils of an arid range site. The study area was intensively grazed over 30 years; however, 5 years before the research began, all livestock were excluded from the area. Results indicated that infiltration rates were 0.6 and 4.1 cm h^{-1} for eroded and uneroded soils respectively, and sediment production was higher in eroded than uneroded areas (616 *vs* 292 kg ha^{-1}, respectively). In addition, regression analysis indicated infiltration rates were positively related to litter cover (r = 0.94) (Rostagno 1989).

A study developed in the sub-humid zone in northwestern Pakistan tried to determine an appropriate residual biomass level that would protect a mountainous watershed by minimizing runoff. The results showed that the terminal infiltration rate was higher ($p<0.05$) in the treatment with the highest level of biomass, 5.22, 4.62, 4.35, 3.66 cm h^{-1} for 2667, 1432, 1020, 627 kg ha^{-1}, respectively (Bari *et al.*, 1993). Other research indicated that intense storms combined with sparse vegetal cover at the beginning of the rainy season may result in overland flow and erosion even where the percent sand content exceeds 90% (Takar *et al.*, 1990). Finally, it is important to mention that soils that have high inherent erodibility (less structure) need more protective cover than do soils that have low inherent erodibility (strong structure) (Meeuwig 1970; Stadtmüller 1994).

In conclusion, under the experimental conditions presented above, biomass in the upper soil layers reduces raindrop impact, improves infiltration rate, and reduces runoff. In addition, in the case of grasslands and shrubs with seasonal production, the residual phytomass is determinant in the hydrological indicators behaviour. Finally, soils with high risk of erosion need more biomass protection throughout the year than soils with low erosion risk.

5.2.8.2. Grazing management effect in hydrological indicators

The length of the grazing period (short periods are better than long periods) and the length of the rest period after grazing (long periods are better than short periods) have a high impact on the infiltration rate and sediment production in a grassland soil (Suárez de Castro 1982; Warren *et al*., 1986b; Stadtmüller 1994). Grasses and forbs help to restore biological and physical soil quality by adding large amounts of carbon to the profile from rapid turnover of roots that contain more than 70% of the total biomass of the prairie plants. Litter additions from the aboveground biomass also add carbon to the surface soil. This carbon plays a key role in redeveloping soil macro-aggregate structure that helps facilitate the high infiltration rates needed to get surface runoff into the soil profile (Schultz *et al*., 2004). Finally, several studies indicated that amount of grassland biomass to protect the soil, is mainly determined by how livestock are managed than by the grazing system *per se* (Thurow *et al*., 1986; Taddese *et al.,* 2002).

Several studies were developed to understand the effect of grazing management on hydrologic and soil indicators.

In semiarid northwestern Oklahoma, USA, a study was developed to determine the effects of non grazed, heavy (12 acres/Animal Unit AU), moderate (17 acres/AU), and light (22 acres/AU) stocking rates with beef cattle over a 20 year period upon water intake and water retention characteristics of Pratt loamy fine sand soil. The resulting water intake rates (cm h^{-1}) were 5.67, 9.12, 11.02, and 26.45, for heavy, moderate, light, and nograzed pastures, respectively. Penetration resistance (pounds per square inch) was 58.4, 37.9, 53.6, and 24.3 for heavy, moderate, light, and nograzed pastures, respectively (Rhoades *et al.,* 1964).

A similar study was developed in South Dakota to evaluate the effects of grazing intensities and vegetable cover on water-intake rates and soil properties. The research applied the following treatments over 22 years; light (3.25 acres/AU), moderate (2.42 acres/AU), and heavy grazed (1.35 acres/AU). Results indicated that water-intake rates in the light grazed treatment were nearly three times (2.95 inches h^{-1}) that of the heavy grazed (1.05 inches h^{-1}) and nearly twice that of moderate grazed (1.69 inches h^{-1}). The vegetal cover results showed the lightly grazed treatment had twice as much as total herbage (1,869 lb $acre^{-1}$) than the heavily grazed treatment (910 lb $acre^{-1}$). In addition, the statistical analysis showed that herbage and mulch accounted for 71% of the variation in water intake in the three different grazed treatments. Bulk density (g cc^{-1}) and pore space (% of total volume) were highly affected by the stocking rate level (1.29 and 7.7%; 1.24 and 8.4%; 1.17 and 10.6% by bulk density and pore space in high, moderate and light grazed, respectively). Runoff was 1.77, 1.53 and 1.39 inches h^{-1} for heavy, moderate and light grazed treatments, respectively (Rauzi and Hanson 1966).

Other research carried out in Colorado, USA compared rangelands with and without livestock activity (cattle and sheep) over a 10-year period. Results indicated grazed rangeland produced 30% more runoff than the ungrazed areas, while ungrazed rangelands had 45% less sediment than grazed areas (Lusby 1970).

A study developed in southern Texas, USA evaluated edaphic variables, vegetation and grazing management as they influence infiltration rate and sediment production in a rangeland. The following three treatments were evaluated: 1) A pasture with a high stocking rate (5.4 AU ha^{-1}) and continuously grazed for the past 27 years, 2) A pasture with a high stocking rate (5.2 AU ha^{-1}) and rotational grazing for the past nine years and, 3) A rangeland protected from livestock grazing, but accessible to wildlife, for the last 28 years. Results indicated that the bulk density was lower in the exclosure treatment (1.16 g cc^{-1}) compared with the two grazing systems (1.28 and 1.23 g cc^{-1} for continuous and rotation grazing, respectively). Total phytomass was similar in rotation grazing and exclosure (5,016 and 4,939 kg ha^{-1}, respectively) in comparison with continuous grazing (2,458 kg ha^{-1}). Infiltration rate was similar for rotation grazing and exclosure treatments (10.4 and 10.2 cm h^{-1}, respectively) in comparison with continuous grazing (4.41 cm h^{-1}). Finally, sediment loss was greater in continuous grazing (211 kg ha^{-1}) than the rotation pasture and exclosure (134 and 160 kg ha^{-1}, respectively) (McGinty *et al*., 1979).

The infiltration rate and sediment production of live oak (*Quercus virginiana* Mill.), bunchgrasses [*Bouteloua curtipendula* (Michx.)Torr.], and sod grass [*Hilaria belangeri* (Steud.)Nash.], as well as the effect of different livestock grazing systems (moderate continuous, heavy continuous, intensive rotation and without grazing) in these plant communities were evaluated in Edwards Plateau, Texas. Results indicated that total organic cover was the variable most strongly correlated with infiltration rate (R^2= 0.86). Total organic cover under oak was consistently higher than in the grass interspace, while bunchgrass sites were significantly greater than sod grass sites. There was no difference ($p \leq 0.05$) between grazing treatment pastures in total organic cover. In contrast, bunchgrass vegetation type had slower infiltration rates on the intensive rotation grazing system than on the moderate continuous grazing and without grazing systems (135 *vs* 190 and 160 mm h^{-1}, respectively). The sod grass vegetation type had slower infiltration rates on heavy continuous and intensive rotation grazing systems than on moderate continuous grazing and livestock exclosure systems (70 and 100 *vs* 160 and 150 mm h^{-1}, respectively). In addition, results showed that aboveground biomass was the variable most strongly correlated (R^2= -0.65) with sediment production. Grazing systems had differences ($p \leq 0.05$) in sediment production among plant communities. In the oak plant community, heavy continuous grazing had greater sediment production in comparison with intensive rotation, moderate continuous and without grazing systems (72 *vs* 13, 2 and 4 kg ha^{-1}, respectively). In addition, the bunchgrass plant community had greater sediment production with intensive rotation grazing in comparison to moderate continuous grazing and without grazing (1600 *vs* 190 and 210 kg ha^{-1}, respectively). Finally, the sod grass plant community had high sediment production with heavy continuous grazing than intensive rotation grazing, moderate continuous grazing, and without grazing (5600 *vs* 2300, 1400, and 900 kg ha^{-1}, respectively) (Thurow *et al.,* 1986).

A study developed in a semiarid rangeland of Edwards Plateau, Texas, tested the hypothesis of hydrologic improvement under intensive rotation grazing in relation to stage of rotation cycle and seasonal variability. The grassland had an intensive rotation grazing with a stocking rate of 8.1 ha^{-1} AU^{-1}. During spring and summer, the average rotation cycle was 56 days but slowed to 74 days during the dormant winter season. Results indicated that the infiltration rate was significantly higher ($p \leq 0.05$) and sediment production was significantly lower ($p \leq 0.05$) during the growing season than during periods of dormancy (155 *vs* 130 mm h^{-1}; and 900 *vs* 1,600 kg h^{-1}, respectively). In addition results showed that during the dormant season the infiltration rate and sediment production presented significant ($p \leq 0.05$) fluctuations between pre-grazed and post-grazed treatments (146 *vs* 111 mm h^{-1} and 1,241 *vs* 2,017 kg h^{-1}, respectively). In contrast, during the growing season the infiltration rate and sediment production between pre-grazed and post-grazed treatments were not statistically significant ($p > 0.05$) (Warren *et al.,* 1986a).

Bare soil was subjected to various trampling intensities in an intensive rotation grazing system in a semiarid rangeland in Sonora, Texas and was evaluated to determine the effect of trampling on infiltration rates and sediment production. The treatments applied in dry and wet soils were moderate trampling (8.1 ha^{-1} AU^{-1} yr^{-1}), intensive trampling (4.1 ha^{-1} AU^{-1} yr^{-1}), very intensive trampling (2.7 ha^{-1} AU^{-1} yr^{-1}), and no trampling (excluded from grazing and all other cultivation activities for 7 years). Results indicated that the mean infiltration rate was significantly higher ($p < 0.05$) and sediment production was significantly lower in dry soil trampled plots than in moist soil trampled plots (136 *vs* 122 mm h^{-1} of infiltration rate in dry and moist soil, and 3,078 *vs* 3,811 kg ha^{-1} of sediment production in dry and moist soils, respectively). Other results showed that under both moist and dry soil conditions, moderate trampling resulted in a significant decline ($p < 0.05$) on infiltration rate when compared to the untrampled paddocks (166 *vs* 140 mm h^{-1}, and 160 *vs* 133 mm h^{-1} for no trampling and moderate trampling in dry and moist soils, respectively). In dry soils, sediment production was significantly higher ($p < 0.05$) with moderate trampling than no trampling (2,827 *vs* 976 kg ha^{-1}, respectively). In addition, moist soils presented significant differences ($p < 0.05$) in sediment production between no trampling and intensive trampling (2,007 *vs* 4,274 kg ha^{-1}, respectively) (Warren *et al.,* 1986c).

A hydrologic study was developed in Edwards Plateau, Texas, with the following objectives; a) to determine the relationship of water interception storage to storm intensity and duration for the bunch-type midgrass sideoats grama [*Bouteloua curtipendula* (Michx.)Torr.] and the sod-type shortgrass curley-mesquite sod grass [*Hilaria belangeri* (Steud.)Nash.], and b) to characterize water interception by live oak canopy (*Quercus virginiana* Mill.) and litter. The first objective results indicated that the length of time needed to reach the storage capacity of the grasses varied with rainfall intensity. Interception storage capacity was significantly greater ($p \leq 0.05$) for sideoats grama dominated sites (1.8 mm^{-1}) than for curly-mesquite sod grass (1.0 mm^{-1}). The second objective results showed that for small rainfall events percent throughfall was approximately the inverse of percent foliar cover, implying that most of the water striking foliage was held within the canopy. In addition, results indicated that as storm size increased, percent throughfall increased due to drip loss from the canopy, eventually becoming fairly constant. Other results indicated that canopy, litter and stem intercepted 25.4, 20.7 and 3.3% of the annual rainfall, respectively. Finally, the distribution of water reaching the soil under live oak was variable. Stemflow concentrates water at the base of the trunks, whereas the soil under the canopy more than 100 mm away from the trunk would receive only 53.9% of annual precipitation (Thurow *et al.*, 1987).

The seasonal hydrologic responses as influenced by two soil types (sand and clay), two grazing intensities (exclusion and heavy communal grazing) and two cover types (shrub understory and interspaces) were quantified in a Somali rangeland. Results indicated that the infiltration rate on the sand site was significantly greater than the clay site (170 *vs* 129 mm h^{-1}, respectively). Grazing intensity did not have an effect on infiltration rates. The lack of difference between the exclosure and the grazed area may be due to the relatively short time (3 years) that the ungrazed area was excluded from grazing. The infiltration rates of the shrub understory and interspace were not significantly different in the sandy soil site. In contrast, the clay site results had significant infiltration rate differences ($p< 0.05$) between the shrub understory and shrub interspace (130 and 105 mm h^{-1}, respectively) (Takar *et al.*, 1990).

In the Atlantic Zone of Costa Rica a study was carried out to determine the hydraulic conductivity and bulk density in forests and old pastures (25 years) on two different soil types, Eutric Hapludand (rich soil) and Andic Humitropept (poor soil). The hydraulic conductivity results indicated that at depths of 0 – 30 cm, rich soils had more than twice the hydraulic conductivity at the forest sites than in pastures (284 *vs* 135 cm^3 day^{-1}, respectively). In contrast, the hydraulic conductivity at 30 – 60 cm soil depth yielded results between the forest and pasture sites that were slightly less different (348 *vs* 216 cm^3 day^{-1}, respectively). At both 0 – 30 and 30 – 60 cm depths, the hydraulic conductivity in poor soil was greater in the forest than in the old pastures (270 *vs* 211, and 289 *vs* 223 cm^3 day^{-1}, respectively). Hydraulic conductivity in poor soil was consistently less than in rich soils. Forest soils had lower bulk densities than old pastures in both rich and poor soils at 0 – 5 cm depth (0.68 *vs* 0.86, and 0.61 *vs* 0.72 g^{-1} cm^3, respectively) (Weerts 1991).

A study developed in the southwestern Iberian Peninsula tried to determine if isolated *Quercus ilex* L. trees could modify the ecosystem water balance. The water balance of the two ecological components of the Dehesa (tree-grass and open areas), was studied for three consecutive years. Results indicated that differences in the parameters of the annual water balance equation between the two ecological components were considerable. Evapotranspiration (E*a*) was consistently greater for the tree-grass component (591 *vs* 400 mm $year^{-1}$, for tree-grass and grass components, respectively). Open area soils that supported only annual grasses had considerable loss to drainage and runoff. During 1984-1985 these losses were equivalent to E*a* at all experiment stations and 60 – 85% of the E*a*, respectively the following year. Under the tree canopy, loss to drainage and runoff was only 40% and 20% of E*a* during the same two periods, respectively. Finally, the authors concluded that tree cover considerably limits water stress on Dehesas vegetation and permits more efficient use of the limited water resource by the ecosystem vegetation (Joffre and Rambal 1993).

Seasonal hydrologic responses such as runoff, soil loss and infiltration rate to cattle grazing pressure in a natural pasture were assessed in the Ethiopian highlands. Six treatments on two different slopes (0 – 4% and 4 – 8%) were studied; light grazing (0.6 Animal Unit

Month AUM h^{-1}), moderate grazing (1.8 AUM h^{-1}), heavy grazing (3.0 AUM h^{-1}), very heavy grazing (4.2 AUM h^{-1}), very heavy grazing on ploughed soil (4.2 AUM h^{-1}), and nograzing. Results showed that on the 0 – 4% slope, runoff on heavy and very heavy grazed plots was significantly greater ($p \leq 0.05$) than light and moderate grazed plots. In addition, soil loss on very heavy grazed plots was almost five times greater than nograzed plots (6.81 *vs* 1.43 t^{-1} ha^{-1} yr^{-1}, respectively). Similarly, on the 4 – 8% slope showed that soil loss on very heavy grazed plots was three times greater than no grazing (13.02 *vs* 3.98 t^{-1} ha^{-1} yr^{-1}, respectively). Finally, infiltration rate results were consistently higher in nograzing and light grazing in comparison to heavy and very heavy grazing. However, a difference was noted between slopes for the various plots. For example, the infiltration rate was three times greater ($p \leq 0.05$) on the nograzing plot than on the very heavy grazing plots (17.6 *vs* 5.3 mm h^{-1}, respectively) for the 0 – 4% slope. In contrast for the 4 – 8% slope site, nograzing plots had almost twice the infiltration rate than on the very heavy grazing plots (13.4 *vs* 6.8 mm h^{-1}, respectively). This difference was probably due to the fact that the topsoil on the 0 – 4% slope contained more fine-textured clay and silt particles, which are easily compacted, than on the 4 – 8% slope (Mwendera and Mohamed Saleem 1997).

A study was developed in fragmented woodland of *Eucalyptus salmonophloia* (F.J.Muell.) in South-Western Australia to measure the effects of livestock grazing and trampling on soil and landscape resource regulatory processes such as infiltration rate and soil water storage. The study used the following treatments; three woodlands regularly grazed by sheep in the past (heavily grazed) and three woodlands very occasionally or never grazed (ungrazed). Results indicated that surface soil bulk density was significantly higher ($p \leq 0.0001$) in heavily grazed than ungrazed (1.88 *vs* 1.42 g cm^{-3}, respectively). In addition, soil penetration resistance in the 0 – 20 mm fraction was 10 times greater in heavily grazed than ungrazed woodlands (5.24 *vs* 0.56 kPa cm^{-2}, respectively). Similarly, soil penetration resistance in the 0 – 40 mm fraction was significantly greater ($p \leq 0.0001$) in heavily grazed than ungrazed woodlands (5.89 *vs* 1.10 kPa cm^{2}, respectively). Finally, infiltration rates in ungrazed woodlands were double ($p \leq 0.01$) that of heavily grazed woodlands (120 *vs* 56 mm h^{-1}, respectively) (Yates *et al.*, 2000).

A study was developed to quantify the effects of forage canopy properties, soil surface relief, and hill slope on the hydrologic properties of the soil in hill grasslands in southern Hawke's Bay, New Zealand. The study looked at three canopy heights (denuded, 20 and 47 mm) and applied three treatments where the sites were trodden with 0, 4, or 8 mature cows for 40 minutes on a moderate (15^{o} – 18^{o}) slope. Results indicated that in untrodden sites the infiltration rate was slower in sites with 20 and 47 mm canopy heights than denuded in sites (4.7 and 4.0 *vs* 9.0 lt^{-1} m^{-2} h^{-1}, respectively). In contrast, the moderately trodden (4 cows for 40 minutes over 135 m^{2}) and severe trodden (8 cows for 40 minutes over 135 m^{2}) sites had faster infiltration rates with 20 and 40 mm canopy heights than denuded sites (7.8 and 8.8 *vs* 0.2 lt^{-1} m^{-2} h^{-1}; and, 4.2 and 9.6 *vs* 2.6 lt^{-1} m^{-2} h^{-1}, for moderate and severe trodden, respectively) (Russell *et al.*, 2001).

In Addis Ababa, Ethiopia researchers quantified the changes in the physical and hydrological properties of a Vertisol soil with moderate, heavy and no grazing regimes in grasslands with a slope of 4 – 8%. Results indicated that soil penetration resistance was higher in very high grazed plots than moderate grazed and nongrazed plots (350, 260 and

230 Kpa cm^{-2}, respectively). The upper soil layer was more compacted than the lower soil layer in all treatments. The initial water infiltration rate was higher in nongrazed plots than the infiltration rate in medium grazed and high grazed plots (650, 490 and 250 cm^{-1} hr^{-1}, respectively). The initial infiltration rate was faster due to ease of movement through the cracks, but infiltration was slowed as the soil attained saturation and the soil swelled. Soil loss in grazed plots decreased with the increase of biomass yields and soil was more compacted by livestock trampling during the wet season (Taddese *et al*., 2002).

Research conducted in Montana, USA, correlated that the amount of bare soil surface is linked closely to runoff and erosion amounts, and the raindrop impact alters soil structure and reduces aggregate stability, both during drought and grazing. Runoff results showed no statistical difference ($p \leq 0.05$) between drought and non-drought treatments, but indicated a statistical difference ($p \leq 0.05$) between grazed (0.470 mm^{-1}) and ungrazed (0.007 mm^{-1}) treatments (Emmerich and Heitschmidt 2002).

In conclusion, high stocking rates and inefficient grassing systems could reduce the amount of biomass that protect soil, decrease infiltration and hydraulic conductivity rates, and increase runoff, soil erosion, and bulk density. Also, under poor grazing management, grasslands with shrubs and trees had better hydrologic indicators than grasslands without shrubs and trees. Also to, runoff was higher and infiltration was slower during the grassland dormant season than during the grassland growing season. Additionally, rain interception by the tree canopy is higher in short and/or weak rainstorms than in long and/or intensive rainstorm events. Finally, soils with strong structure were more resilient to deficient livestock management than soils with weak structure.

5.2.9. Conclusions

Literature review showed in the above paragraphs generated several recommendations that could help to design a local scheme of Payment for Hydrological Ecosystem Services (PHES). For example: a) before to implement a local PHES policy, it is necessary to determine the regional hydrological cycle. With this information protection of non-critical zones could be avoided; b) the supposition about an increment in the base flow based in a land use change from grasslands to forest, need to be supported with regional hydrological information. Additionally, it is important to remember that there are other factors, in addition to land use change, that could modify an aquifer base flow, and some of them are out of our hands. For example: microwatershed size, geology, hydrogeology, soil type, and weather (amount of rainfall, rainfall distribution through the year, storm intensity, dry season, climate change, among others); c) forest plantations have different hydrologic behaviour than natural forests. Fast growing forest species exhibit higher transpiration rates than native low growing forest species. Also, inappropriate silvicultural management and logging activities with heavy machinery could generate soil erosion. Therefore, forest plantations with fast growing species should be avoided in recharge zones; e) livestock production systems with good grassland management could help to protect the soil and to reduce bulk density. However, to reach this target it is necessary to develop a very good grassland management plan (i.e. stocking rate control, rotational management, and grassland rest time).

5.3. Socioeconomics

The following bibliographic revision is organized as follows: the first part tries to explain the complexity of ecosystem services valuation, the second part presents the neoclassical welfare theory, and the third part reviews several methods to calculate the value of environmental services, with examples.

5.3.1. Environmental and resources valuation

Benefits provided by natural ecosystems are both widely recognized and poorly understood (IUCN *et al.,* 2004). What is increasingly clear, however, is that natural ecosystems are under enormous pressure around the world from the growing demands that humanity places on them. Growth in human population and prosperity translate into increased conversion of natural ecosystems to agricultural, industrial, or residential use, but also into increase demand of ecosystems inputs, such as fresh water, fiber, soil fertility, as well an increased pressure on the capacity of the natural ecosystems to assimilate humanity waste, including air and water pollution as well as solid waste (IUCN *et al.,* 2004; Pagiola *et al.,* 2004). In addition, ecosystems provide multiple direct and tangible benefits to humankind as well as intrinsic cultural services (Porras *et al.,* 2008). However, as demonstrated in the Millennium Ecosystem Assessment (MEA), many of these ecosystem services are being degraded or used unsustainably (MEA 2005). Unfortunately, the management of land and water interactions is difficult because of the public good characteristics of watershed services (FAO 2004). For example; in the one hand, landholders upstream can affect water quantity and water quality downstream through their decisions on land-management practices, but they have little incentive to consider these impacts because they are not affected directly. In the other hand, water users have little incentive to pay for improved watershed service provision if they cannot exclude non-payers from enjoying these benefits (Pagiola *et al*., 2002). In addition to, climate change has the potential to exacerbate water resource stresses in some areas of the world. For example: several models developed by Arnell in 1999, showed that although global average precipitation increases with climate change, much of this increase occurs over oceans and large parts of the land surface will experience a reduction in precipitation. This situation, coupled with the increase in evaporative demand associated with higher temperatures, means that river runoff would decrease across large parts of the world. In the particular case of México, models showed that this country will be increase from medium water stress in 2000 to high water stress in 2050, and the problem will be worst in the eastern coast (Arnell 1999).

If ecosystems are important, and to preserve them in their natural conditions will be a priority, to estimate the economic values of environmental and resource services could be a useful part of the information base supporting environmental and resource management decisions. The importance of this premise is illustrated by the following environmental and resource policy issue, which involves questions of economic values and trade-offs. The development and management of large rivers systems such as the Columbia River basin involve choosing among alternative combinations of hydroelectric power, water supply, and commercial and recreational fishing. There are also proposals to remove existing dams from many rivers. Are the ecological and recreational benefits of removing a dam greater than the costs in reduced power generation and water storage? And is it worthwhile to curb water withdrawals for irrigation or reduce discharges for power production to protect populations of salmon and other migratory fish? (Freeman III 2003).

The economic value of a resource-environment system as an asset is the sum of the discounted presented values of the flows of all of the services. Because many of these service flows are not bought or sold in markets and therefore do not have market prices (called market failure), the economic value of a natural asset may be quite different from its market value. For example, an acre of wetland might trade in the market for land on the basis of its value for commercial or residential development; but this value could be quite different from the value of its services as wildlife habitat and as a means of controlling floods and recharging aquifers (Freeman III 2003). There are several reasons markets fail to emerge, one of the most important is that many environmental services provided by forests fall into the category of *positive externalities* or *public goods* (Cornes and Sandler 1996). These positive externalities or public goods are a special class of externalities distinguished by their *non-excludability* and *non-rivalry*. Non-excludability means that consumers cannot be prevented from enjoying the good or service in question, even if they do not pay for the privilege. Where non-excludability and non-rivalry exist they undermine the formation of markets since beneficiaries of the good or services have no incentive to pay suppliers. As long as an individual cannot be excluded from using a good they have little reason to pay for access. Similarly, where goods are non-rival, consumers know that where someone else pays, they will benefit. In both cases beneficiaries plan to “free-ride” based on others’ payments. However, where everyone adopts free-riding strategies, willingness to pay for public goods will be zero and the product will not be supplied. Also, markets typically fail to compensate those who produce positive externalities due to the absence of property rights or other legal means to require payment for services rendered (Landell-Mills and Porras 2002).

To assess the instrumental value of nature, it is necessary to specify a goal and to identify the contributions that specific components of nature make towards the furtherance of that goal (Freeman III 2003; IUCN *et al.,* 2004). For example: ecosystems generated four kinds of services to the economy; First, *Provision services*, the resource-environment system serves as a source of material inputs to the economy such as fossil fuels, wood products, minerals, water, food and fish. Second, *Regulating services*, some components of the resource-environment system provide life-support services for people in the form of a breathable atmosphere and a livable climatic regime. Some of these life-support services can be measured in terms of changes in the health status and life expectancies of affected populations, i.e. flood and disease control. Third, *Cultural services*, the resource-environment system provides a wide variety of amenity services, including opportunities for recreation, wildlife observation, the pleasures of scenic views, and perhaps even services that are not related to any direct use of the environment (sometimes called nonuse or existence values). And fourth, *Supporting services*, the system disperses, transforms, and stores the residuals that are generated as by-products of economic activity (Freeman III 2003). The resource-environment system also serves as a repository of genetic information that helps to determine the stability and resilience of the system in the face of anthropogenic and other shocks (IUCN *et al.,* 2004; Pagiola *et al.,* 2004). Finally, in the specific case of the hydrological ecosystem services it is possible to divide them in five classes (Young 2004);

a) *Commodity benefits*. Those derived from personal drinking, cooking, and sanitation, and those contributing to productive activities on farms and in commercial business and industries (commodity uses tend to be private goods).
b) *Waste assimilation benefits*. Bodies of water are significant assets because of their assimilative capacity, meaning that they can carry away wastes, dilute them, and for some substances, aid in processing wastes into less undesirable forms.
c) *Public and private aesthetic, recreational, and fish and wildlife habitat values.* Once regarded as luxury goods inappropriate for governmental consideration, these types of benefits are increasingly recognized as important matters of public concern.
d) *Biodiversity and ecosystem preservation*. Nonuse values (often called *passive use*) constitute another potential economic value of water. In addition, to valuation of goods and services which are actually used or experienced, people are willing to pay for environmental services they will neither use nor experience.
e) *Social and cultural values*. More than for most commodities, social and cultural values relating to water are often in conflict with economic values. Because water is essential to life, and because clean water and sanitation are essential to health. For many, water has special cultural, religious, and social values, and these people prefer not to have them treated as an economic commodity.

When government, NGOs, or the society recognized that an ecosystem service is important for their wellbeing, they could generate several strategies to reduce ecosystem degradation. For example: in the forestry sector, governments around the world have heeded this advice and taken responsibility for forest protection in areas high in biodiversity, landscape beauty or critical for their watershed protection functions. For the most part governments have taken direct control for forest protection through public ownership and often elaborate regulation of extractive uses ("Command and Control" approach). However, governments have their own failings associated with imperfect knowledge, misaligned incentives, inefficient bureaucracies and rent seeking. Furthermore, as pressure mounts on governments to curtail spending and cut budget deficits, their ability to invest adequately in the provision of public goods and services is called into question. Where public authorities have been unable to tackle the public good problem, they have searched for ways to involve non-governmental actors. Efforts to transfer responsibility for forest environmental services out of the public sector have relied on a combination of regulation and market-based approaches, though the latter have become more prominent in recent years. Market approaches aim to alter incentives facing forest owners and users so that they act in ways consistent with government policy (Landell-Mills and Porras 2002).

5.3.2 Neoclassical Welfare Theory

The basic premises of neoclassical welfare economics are that the purpose of economic activity is to increase the well-being of the individuals who make up the society, and that each individual is the best judge of how well off he or she is in a given situation (Bockstael *et al.,* 2000; Freeman III 2003). Each individual's welfare depends not only on that individual's consumption of private goods and of goods and services produced by the government, but also on the quantities and qualities each receives of nonmarket goods and service flows from the resource-environment system. The anthropocentric focus of economic valuation does not preclude a concern for the survival and well-being of other species. Individuals can value the survival of other species not only because of the uses people make of them, but also because of an altruistic or ethical concern (Freeman III 2003). However, the last point of view could change in developing countries with economy problems; in these countries poor people try to survive every day using the local natural resources, setting the altruistic or ethical perspective in an irrelevant place (Barraza and Pineda 2003).

Economist recognize that people value things, including many important services of the earth's water supply, that they do not purchase through a market or a that they may value for reasons independent of their own purchase and use. The modern economic paradigm assumes that values of goods and services rest on the underlying demand and supply relationships that are usually, but not always, reflected in market prices (Landell-Mills and Porras 2002; Pagiola *et al*., 2002; Young 2004; Porras *et al*., 2008). Economy is not just the study of markets, but more generally, the study of preferences as an aspect of human behaviour (Hanemann 1994). The principal strengths of the economic approach to rational policy making are its focus on assessing the consequences (both beneficial and adverse) of policy actions and its attempts to be sensitive to the particulars of a decision. By expressing the consequences in terms of a common denominator of money value, it provides a method of considering and resolving tradeoffs among competing and value ends, including taking account of the economic costs (forgone benefits) of achieving those ends (Young 2004).

Some people may distrust economists' efforts to extend economic measurements to such things as human health and safety, ecology, and aesthetics, and to reduce as many variables as possible to commensurate monetary measures. Some skepticism about the economist's penchant for monetary measurement is not doubt healthy, but it should not be overdone. Some people argue that some things, like human health and safety or the preservation of endangered species cannot be valued in terms of dollars or other currency. However, the real world often creates situations where trade-offs between such things as reducing risk of death and other things of value cannot be avoided. Where individuals can choose for themselves among these tradeoffs, their values can be inferred from the choices. Where government policies affecting health and safety are involved, these policy choices imply values. The economist need to know how to approach the problem of making choices about such trade-offs and what information can be gathered to help in the problem of choice (Freeman III 2003). For example; not converting a forest ecosystem to agriculture preserves certain values to ecosystem services that forests may provide better than farmland, but it also prevents the enjoyment and benefits of agricultural production (Pagiola *et al*., 2004).

Economic efficiency may be defined as an organization of production and consumption such that all unambiguous possibilities for increasing economic well-being have been exhausted. Stated somewhat differently, economic efficiency is an allocation of resources such that no further reallocation is possible which would provide gains in production or consumer satisfaction to some firms or individuals without simultaneously imposing losses on others. Pareto efficiency is achieved when marginal benefits of using a good or service are equal to the marginal cost of supplying the good. Pareto optimality rests on several central judgments. The first of these is the judgment that individual preferences count; the economic welfare of society is based on the economic welfare in aggregate of its individual's citizens. Second, the individual is the best judge of his/her own well being. The third, more restrictive, value judgment is that a change, which makes everybody better off with no one becoming worse off, constitutes a positive change in total welfare (Young 2004).

5.3.3 Positive and Normative Economics

The activities of mainstream or neoclassical economists can be divided into two types. The first type, positive economics is concerned with observable facts and recurring relationships; it seeks to describe, explain, and predict economic phenomena. For example, what are the effects of changing prices, incomes, policies, or technologies on water consumption patterns? What role does water play in regional economic growth? The second type, normative economics, is concerned primarily with criteria for policy and questions of optimal policy. Normative economics employs the empirical studies and predictions of positive economics, and combines them with value judgments reflecting notions about the ideal society in order to derive policy recommendations. For instance, are government administrative agencies or markets preferable in accommodating changing patterns of demand of water? How much pollution should be permitted and with what type of policies? (Young 2004).

The normative branch of economics is called welfare economics. It combines value judgments regarding the nature of the desirable organization of society with positive studies of empirical economic regularities to develop policy recommendations (Freeman III 2003). Empirical economic methods are employed to predict whether a proposed policy initiative would produce beneficial effects in excess of adverse effects, both expressed in commensurate monetary terms. Normative economic analysis also must be based on some positive economic studies. Most economic policies can be described as incentives (which positively or negatively change the payoffs or incomes to members of the economy) or constraints (which impose limitations on the range of permissible economic activities). Examples of incentives are taxes and subsidies, such as a tax on pollution emissions or a subsidy to encourage pollution-reducing activities. A constraint might be a limited right to use water in a stream or canal (rate flow). Any economic evaluation of a proposed policy will rest, in addition to normative criteria, on empirically based (positive) predictions of the response of water-using consumers or producers to policy initiatives (Young 2004).

One problem in carrying out an analysis on environmental benefits or costs is that the values for some physical, technical, or economic parameters of the model may not be know with certainty. The state of the art in measurement is not sufficiently advanced to produce exact measures of value for many kind of environmental and resources changes (Freeman III 2003; FAO 2004; Wunder 2005; Porras *et al.*, 2008). This fact leads to the question; must policymakers wait for the further research to produce exact measures before they can use value and benefit information to guide decisionmaking? If not, how should they interpret the ranges of values that current research has produced? (Freeman III 2003).

The simplest approach is to base calculations of benefits and costs on the expected values of the uncertain parameters and to base decisions on the expected values. However, decisionmakers will often want to know more about the magnitude of the uncertainties in the estimates of benefits and costs. Decisionmakers could be provided with the upper and lower bounds of the ranges of values along with the expected values. If the benefits of a policy calculated with the upper end of the range are less than the lower end of the range of estimated costs, the policy is unlikely to be justifiable on economic grounds. And if the benefits calculated with the lower end of the range exceed the upper end of the range of costs, the economic case for the policy is quite strong (Freeman III 2003). However, in the case of hydrological ecosystem services the biophysical and geological variability in the watersheds (Bosch and Hewlett 1982; Winter *et al.*, 1998), and the uncertainty about the rainfall distribution around the world developed by the global climate change (Arnell 1999), increase the uncertainty in the assumptions used to build the socioeconomic and hydrological models.

5.3.3.1 Methods to measure environmental and resources values

The principal distinction among methods for valuing changes in environmental goods is based on the source of the data. The data can come either from observations of people acting in real-world settings where people must live with the consequences of their choices or people's responses to hypothetical questions, "observed" and "hypothetical" methods. However is more common to know these as *revealed preference* methods and *stated preference* methods. Revealed preference methods are based on actual behaviour reflecting utility maximization subject to constraints. One type of revealed preference method is based on observed choices in a referendum setting. If an individual is offered a fixed quantity of a good at a given price on a take-it or leave-it or a yes-no basis, observation of the choice reveals only whether the value of the offered good to the individual was greater than or less than the offering price. A family of discrete choice and random utility models has been developed for the purpose of deriving value measures from these choices (Freeman III 2003). Tables 3 and 3[a] provide a taxonomy of methods of nonmarket valuation of water investment and policies, broadly classified according to whether they are based on a inductive "*revealed preference*" or a deductive technique "*stated preference*" (Young 2004).

In most instances the environmental services does not have an offering price, but sometimes its quantity affects the choices people make about other things, such as quantities of market goods. In these cases, the value of the environmental service must be inferred through the application of some model of relationship between market goods and the environmental service. Most such models are based on the assumption of some kind of substitute or complementary relationship between the environmental service and market goods and services. Revealed preference methods involve a kind of detective work in which clues about the values individuals place on environmental services are pieced together from the evidence that people leave behind as they respond to prices and other economic goals. Additionally, it is important to mention that, although measuring values involves the use of economic theory and technique, value measures must be based on other types of knowledge (Freeman III 2003).

5.3.3.1.1 Contingent Valuation

Economists are generally much more comfortable observing individuals' valuations of goods and services through their behaviour in markets than eliciting their valuations through survey questionnaires. Economists prefer to observe purchasing decisions because these decisions directly reveal preferences, whereas surveys elicit statements about preferences. Nevertheless, for some public goods there are simply no, or very poor, market proxies or other mean of inferring preferences from observations. In such circumstances, many analysts have concluded that there may be no alternative to asking a sample of people about their valuations (Boardman *et al.,* 2001). The method of Contingent Valuation (CV) is widely presented as a way of "revealing" the references of the population consulted, based in axiomatic assumptions of, inter alia, a full substitutability between money-valued goods and the non-monetized environmental services/goods in question (O'Connor 2000). In Cost Benefit Analysis (CB), questionnaires designed to elicit preferences are normally referred to as Contingent Valuation (CV) surveys, or sometimes hypothetical valuation surveys, because respondents are not actually required to pay their valuations of the good. The primary use of CV is to elicit people's willingness to pay (WTP) for changes in the quantities of goods. Many kinds of goods, including water quantity and quality have been valued with CV surveys (Boardman *et al.,* 2001).

In CV studies the survey questionnaires differed: 1) the date of the interview and the address of the household or its location in the study area, 2) the age, gender and household status of the respondent, 3) household information would be collected such as the number of persons and their age/gender, their health, education, and occupation, and household income, expenditure and assets, 4) data is collected on the quality of the dwelling, whether it is owned or rented, and its costs, 5) comes the sources of the water used in the dwelling, quality and quantity, conflicts over access, seasonality of supply and demand, the price or charge payable for each separate fresh or waste water source used, household expenditure on water per time period, water storage facilities in the dwelling, current sanitation facilities, the uses to which fresh water is applied, and the degree of satisfaction with the existing services, 6) a "bidding game" (or a referendum technique) would be used to establish the household' willingness to pay for alternative projects and this would require some kind of description of the new scenario (Merrett 2002).

The CV method has the following features (O'Connor 2000):

1) People are utility-maximizers; their 'optimising' behaviour is based on preferences that are 'given' from outside the calculation domain
2) Subject is reactive, isolated, individual; views are private and not open to challenge; subject is confined to one role
3) Practice of the subject's calculative faculties and of their prudence
4) Question(s) decided by researchers
5) Citizen as 'customer' whose preferences and values it is the role of the policy-maker to satisfy and accommodate; relationship of mutual benefit – policy maker invulnerable
6) Quantified intelligence about people's concern which can be used both to validate policy and to estimate likely compliance with policy

7) Information is anonymous and unquestioned
8) What matters is how much information is provided
9) Methodology is sovereign, process is theory driven and circumscribed; condones existing distribution of rights; silences some voices (protest bids, income effects); open to manipulation by researchers
10) Validation through precedent, consistency with previous studies, convergence and methodological rigour
11) Digestible by bureaucratic and financial structures
12) The point of the exercise is in the outcome
13) Fosters ‘consumer’ habits and a managerial society.

5.3.3.1.2 Contingent Valuation, advantages and disadvantages

Advantages

The primary attraction of the CV method is that it can measure the economic benefit (or damage) of a wide assortment of beneficial (or adverse) effects in a way consistent with the economic theory. One major advantage is the ability to evaluate proposed, in addition to already available, goods or services. This is important in numerous cases where impacts of potential changes in water supply or quality cannot yet be observed. Additionally, CV can address values that cannot be dealt with any other way, such as nonuse or passive-use values (Hanemann 1994). In developing economies, the CV method has been successfully used to study demand for domestic water and sanitation improvements in rural villages (Riera 1994). Also, it is hypothesized that a CV survey study, carefully conducted, can be an effective scientific enquiry technique for insights into both qualitative and quantitative (monetary) dimensions of people’s valuation attitudes and possible behaviour. Several case studies demonstrate, in different ways that is possible to utilize survey techniques to solicit quantitative willingness to pay (WTP), or willingness to accept (WTA) information simultaneously with qualitative information permitting interpretation of motives and attitudes underlying people’s WTP or WTA statements. Thus it is suggested that CV enquiry process can be understood not just as a way to obtain information about people’s preferences quantified in “commodity” terms of price for given good/service, but more profoundly as a reciprocal learning process where both the researchers and the interviewees might come to appreciate more about the range of perspectives that may be brought to bear on the valuation problem (O’Connor 2000). In addition to, CV methods can comprehensibly describe and approximate values for a complex ecosystems process. Also, collection of valuation data through surveys allow to simultaneously elicit beliefs and opinions that underline preferences that determine values (Pattanayak and Kramer 2001).

Finally, while CV methods have been refined since it was first applied to environmental valuation four decades ago, many questions remain. Nevertheless, CV and related methods remain important tools for environmental economist because of their advantage in valuation of nonuse benefits and cases where observed market behaviour is not available (Young 2004).

Table 4 Main types of nonmarket water valuation methods, their characteristics and uses.

Valuation method	Description of method and data sources	Useful for valuing water as
Inductive Methods		
1.- Observation of water market transactions	Observed prices from transactions for short-term leases or permanent sales of rights to water.	Actual at-source or at-site WTP manifested by transactions within or between agricultural, industrial, municipal and environmental uses.
2.- Econometric estimation of production and cost functions	Primary or secondary data on industrial and agricultural inputs and outputs analyzed with statistical (usually regression) techniques.	Producer's (agricultural or industrial) at-site valuations.
3.- Econometric estimation of municipal water demand functions	Primary or secondary municipal data analyzed with statistical methods.	At-site demands for municipal sector (including residential, commercial, and government) deliveries.
4.- Travel cost method (TCM)	Revealed preference approach using econometric analysis to infer the value of recreational site attributes from the varying expenditures incurred by consumers to travel to the site.	Valuation of recreational services and derived at-source valuations for changes in water supply.
5.- Hedonic property value method (HPM)	Revealed preference approach using econometric analysis of data on real property transactions with varying availability of water supply or quality.	At-source demands for changes in water quantity or quality revealed by actors in residential or farm properties.
6.- Defensive behaviour method	Revealed preference method using reductions in the costs of actions taken to mitigate or avoid incurring an external cost as a partial measure of the benefits of policies from reducing the externality.	Valuation of reduced water pollution from biological or chemical contaminants.
7.- Damage cost method	Maximum willingness to pay given as monetary value of damages avoided.	Valuation of reduced water pollution or flood damages.
8.- Contingent valuation method (CVM)	Expressed preference method using statistical techniques for analyzing responses to survey questions asking for monetary valuation of proposed changes in environmental goods or services.	At-source valuations of environmental (e.g. instream) water supplies. Also at-site valuations of changes in residential water supplies.
9.- Choice modeling (CM)	Expressed preference method using statistical techniques to infer WTP for goods or services from survey questions asking a sample of respondents to make choices among alternative proposed policies.	At-source valuations of environmental (e.g. instream) water supplies. Also at-site valuations of changes in residential water supplies.
10.- Benefit transfer	Benefits estimates for one or more sites or policy proposals employed to assign benefits or value to other sites or policy proposal.	Adaptable in principle for any case: producers' or consumer' goods; and collective environmental goods including nonuse values.
11.- Benefit function transfer/ meta-analysis	Statistical synthesis of the results of previously reported studies of the same phenomenon or relationship to distill generalizations.	Potential bases benefit transfer in all producers' and consumers' valuation contexts. Also valuable for assessing role of methodological assumptions in research results.

Source: Young 2004

Table 4^{a} Main types of nonmarket water valuation methods, their characteristics, and uses.

Valuation method	Description of method and data sources	Useful for valuing water as
Deductive Methods		
1.- Basic Residual methods	Constructed models for deriving point estimate of net producers' incomes or rents attributable to water via budget or spreadsheet analysis.	At-site or at-source estimates for offstream intermediate goods (agriculture, industry) for single-product case.
2.- Change in net rents	Constructed residual models for deriving interval estimate of net producers' income or rents attributable to increment of water via budget or spreadsheet analysis.	At-site or at-source estimates for offstream intermediate goods (agriculture, industry) for multiple-products, multiple-technology cases.
3.- Mathematical programming	Constructed residual models for deriving net producers' rents or marginal costs attributable to water via (usually) fixed-price optimization models.	At-site or at-source estimates for offstream intermediate goods (agriculture, industry) for multiple-products, multiple-technology cases
4.- Value-added	Constructed models of net producers' income or rents attributable to water via value-added measure from input-output models.	Seriously biased (overestimate) method that has been used mainly in offstream intermediate goods (agriculture and industry).
5.- Computable general equilibrium models (CGE)	Constructed models for deriving net producers' income or rents attributable to water via price-endogenous optimization models.	Recently adapted method used mainly for offstream intermediate goods (agriculture and industry).
6.- Alternative cost	Value attributable to cost savings from next best alternative source of service (e.g. electricity transportation)	At-site or at-source valuation of intermediate goods offstream (agriculture, industry) and instream (hydropower transportation). Also for water as private and collective consumption good by households.

Source: Young 2004

Disadvantages

Even within the confines of the information obtainable through a CV survey format, a researcher who adhered rigidly to a schema of analysis and interpretation based on the neo-classical axioms of optimal producer and consumer choice would be missing a lot of relevant information (O'Connor 2000). In CV surveys people could give false opinions on fictitious issues, because of the pressure to answer which is created by the form in which the questions are asked and the manner in which the "don't know" responses are handled by the interviewer. Additionally, people can be more easily pressured into giving an opinion on a fictitious issue when the topic seems familiar to them. The more the person knows about a subject, the less likely he or she is to make such a "mistake". In contrast, less well informed people may thus be more likely to offer opinions on fictitious issues. The less knowledgeable a person is about a given subject, the more easily she or he can be confused and pressured to give an opinion about it. A strategy to avoid the problem mentioned above could be not to pressure people to give options when they show ignorance about the topic, and give respondents an explicit opportunity to say they have "no opinion" of the subject (Bishop *et al.,* 1986).

Another contingent valuation anomaly is the “embedding effect”. This “effect” is the tendency of willingness to pay responses to be highly similar across the different surveys even where theory suggests that the responses be very different. An example of embedding would be the willingness to pay to clean up one lake roughly equal to cleaning five lakes, including the one asked individually. The embedding effect usually arises from the nonexistence of individual preferences for the public good in question and from the failure of survey respondents, in the hypothetical circumstances of the survey, to consider the effect of their budget constraints. Because of these embedding effects, different surveys can obtain widely variable stated willingness to pay amounts for the same public good, with no straightforward way for selecting one particular method as the appropriate one (Diamond and Hausman 1994). As an example, Schkade and Payne in 1993 developed a verbal protocol analysis in which individuals were asked to “think aloud” about their willingness to pay to protect migratory waterfowl from drowning in uncovered wastewater holding ponds from oil and gas operations. Everything the subjects said was recorded on audio tapes, and information was transcribed and coded. Transcripts showed the inherent difficulty in selecting a willingness to pay response and the extent to which people refer to elements that ought to be irrelevant to evaluating their own preferences. About one-fourth of the sample mentioned the idea that if everyone did his part then each household would not have to give all that much. About one-sixth of the sample made comparisons with donations to charities. About one-fifth of the sample said they just made up a number or guessed an answer. Many respondents seemed to wish to signal concern for a larger environmental issue. This pattern may reflect the unfamiliarity of the task the respondent faced. Finally, these findings strongly suggested that people are not easily in touch with underlying preferences about the type of commodity asked about, and findings did not lend support to the hypothesis that respondents are an attempt to measure and express personal preferences.

Additionally, Diamond and Hausman (1994) concluded that; contingent valuation (CV) is a deeply flawed methodology for measuring nonuse values. The absence of direct markets parallels affects both the ability to judge the quality of CV responses and the ability to calibrate responses to have usable numbers. It is precisely the lack of experience both in markets for environmental commodities and in the consequences of such decisions that makes CV questions so hard to answer and the responses suspect. In addition to, they argued that internal consistency tests are required to measure the reliability and validity of such surveys. There is a history of anomalous results in CV surveys that seems closely tied to the embedding problem. Although this problem has been recognized by the literature for over a decade, it has not been solved. CV methods should not be used for damage assessment or for benefit costs analysis. Finally authors said that, it is impossible to conclude that surveys with new methods will not pass internal consistency tests. Yet they do not see much hope for such success. This scepticism comes from the belief that internal consistency problems come from an absence of preferences, not a flaw in survey methodology. That is, authors don’t think that people generally hold views about individual environmental sites (many of which they never heard of) or that; within the confines of the time available for survey instruments, people will focus successfully on the identification of preferences, to the exclusion of other bases for answering survey questions. This absence of preferences shows up as inconsistency in responses across surveys and implies that the surveys responses are not satisfactory bases for policy.

The pervasive influence of citizen preferences has posed a theoretical problem for CV research. The problem arises in establishing the relevance of WTP, insofar as it measures individual welfare, to citizen preferences, which by goods and goals other than individuals typically pursue through civic and political association, not through actual or hypothetical market transactions. In addition, the ambiguity of the term "satisfaction" suggests a second way of dealing with the problem of citizen preferences. For example: when citizens say that they are willing to pay for the existence of visibility over the Grand Canyon, whether they will visit or not, what do they think they are buying? Is it clean air or physic satisfaction? Surveys that investigate non use values never ask how much individuals would pay for the psychic satisfaction or "warm glow" they expect to experience as a result of various policies (Sagoff 1998).

Another technical problem that vexes CV surveys has to do with the ambiguity of survey data with respect to preferences. This problem arises because preferences are not observable objects. Researchers might think of them as private mental states, or more accurately, as conceptual constructs of microeconomic theory. Preference must be inferred from behaviour. Yet behaviour is not self-describing; rather, a person's motions or actions have to be interpreted. To interpret these motions or actions as a choice, researchers must already ascribe a preference to the agent. Without the ascription of such a motive, the bodily motions would make no sense (Sagoff 1998).

A major concern in CV design is whether respondents are truly able to understand and place in context the questions they are being asked and, consequently, whether they can accurately value the good in question. Issues relating to the valuation of the supply of much publicity provided goods are complex and highly contextual. Hypothetical questions and meaning can be thought of as problems of specifying exactly what the good in question is. Understanding the good, or the policies that produces, it is difficult for respondents because they often are not familiar with either. Attitudes are unlikely to correspond to the behaviour that occurs if the project were actually implemented when respondents are presented with questions about goods or projects that they really do not understand. When a project (or the good itself) has multiple attributes, these all need to be explained to respondents (Boardman *et al*., 2001).

As CV deals with increasingly controversial and complex topics, the neutrality of the CV questionnaire becomes an increasingly important issue. Neutrality has come to the fore as litigants in (especially environment) curt cases have conducted their own CV surveys. Meaning and neutrality issues often intersect in ways that are extremely difficult to disentangle. Unfortunately, there are no simple answers to the neutrality problem. But an inevitable conclusion is that one has to be especially cautious in interpreting the results of CV surveys that have been prepared by either party to litigation or advocacy groups (Boardman *et al.,* 2001).

Although it is reasonable to assume that individuals can make rational judgments about their valuations of goods in most market situations, evidence suggests that in certain circumstances they may not be able to do so readily. This is even more likely to occur in the context of CV surveys because judgments rather than decision making is involved, and because there are not opportunities to learn from "mistakes". These decision-making errors can be thought of as a type of market failure. In the context of CV, the term judgment bias rather than decision-making bias is applicable because the respondent is not actually purchasing the good in question. In addition, it is well recognized in the marketing literature that respondents to surveys tend to overstate their willingness to purchase a product that is described to them. This may be a strategic response but can also be thought of as a form of anchoring bias in a context which potential consumers do not engage in any learning. It is likely to be quite unconscious. The bias can flourish, because the respondent does not actually have to commit money (Boardman *et al.,* 2001).

The concept of the willingness to pay is used by the water demand researches to mean willingness to pay and ability to pay; the separate concepts are rolled up in one. Unfortunately, this opens the real possibility that some respondents will understand willingness to pay as inclusive of affordability, and others to take it as exclusive. So their responses become ambiguous, the researchers don't know quite what they mean (Merrett 2002). Finally, hypothetical bias means the hypothetical nature of the expressed preference format yields systematically higher bids than would bids requiring actual purchase of the commodity. One of the basic critiques of CV methods is summarized in the phrase "ask a hypothetical question; get a hypothetical answer" (Young 2004).

5.3.3.1.3. Contingent Valuation calibration

The following suggestions were presented by Merrett (2002). First, the design and development of water and sanitation projects in a local area need to be based upon a good understanding of the existing local markets for these services. The water demand school has made a great contribution to comprehend these hydrosocial processes from the point of abstraction to the moment of water purchase by the household. This now needs to be complemented by an attempt to grasp how much water is used by the family, by whom and to what purpose. Without this baseline behavioural groundwork, projects in the scenario year are exposed to a great risk of failure. Second, researchers understanding of future household behaviour require semi-structured interviews primarily with families' female adults. It is women who play the primary role in the collection and purchase of water, as well as its internal use in cooking, washing and cleaning. For this reason alone, the professional team should include a female sociologist or socio-economist. In large surveys the bulk of the data collection will be done by trained enumerators (ideally women). But the professionals in the research team should play the central part in at least a sub-sample of the interviews. This also calls for a national professional to form part of the research team. Surveys where enumeration is the sole responsibility of local secondary school graduates, but where data analysis and report writing are preserved only for international staff, should be strictly avoided. Furthermore, respondents should be recognized not as objects sourcing numerical signs but as intelligent, purposive, reflexive subjects, rich in their textual accounts of their neighborhood and their region. The researcher should also appreciate that respondents are made up of persons with a variety of private agendas – cynics, strategists, diplomats and idealist. Third, the scenario project option(s) can be developed prior to the survey or, with the sampled population, by the research team itself. In either case the expressed preferences of the targeted groups are vital, as the "new paradigm" insists so eloquently. The project option should be cost in terms of capital investment as well as ongoing outlays. The use of wtp_{max} (maximum willingness to pay) in the survey questionnaire and the employment of anchor prices would cease, to be replaced by a question of type. For example; we have explained our work and described the proposed project, including the means that households would pay for it. To cover its full costs the project would require a price of *x* naira/gallon. Can you now tell us whether your family would be willing to pay and able to afford *x* naira per gallon?

Several experts in CV have suggested overall criteria for evaluating CV instruments. They suggested five criteria for evaluating instruments. First, respondents should understand and be familiar with the good that is being valued. Second, respondents should have, or be given, experience in both valuation and the choice procedure. Third, there should be as little uncertainty as possible about the details of the project. All three of these concerns can best be addressed by attempting to reduce uncertainty, for example, by employing quality ladder, by stressing realistically and concretely the substitution possibilities, and by presenting gains (benefits) in percentage terms as well as in absolute terms. Fourth, WTP rather WTA should be used for valuation purposes. Finally, attempts should be made to avoid anchoring and starting point bias (Cummings *et al.,* 1986).

Some surveys were designed to permit a distinction to be made between "zero bid", "don't know" and "refusal" responses. In the past, it has been common to discard zero and "very high" bids for purposes of statistical analysis. However, the question of defining invalid or illegitimate responses is not simple to resolve. Individuals can be reluctant to pay if, for example, they believe that wildlife ecosystems "should" be maintained or that they, as citizens have, or should have, rights to the goods or services. Zero bids in a WTP context, if taken at face value, can misstate the intensity of some people's environmental preferences (i.e. some people may bid "zero", not because they don't care but because their view is that protection of the environmental feature in question "should" be assured). Reliance on "revealed" monetary WTP bids as a method for appraising the value that people attach to the environmental feature may thus be controversial from both epistemological and normative points of view. In a study developed in the UK related wet fens, only 5% of the sample presented "refusals" answers. This suggested that most of the interviewees did accept the survey purposes as meaningful and legitimate. Nonetheless, the analysis of the significance of attitudinal and "rights" variables in accounting for the level of bids for wet fens shows that many people are motivated by deontological concerns (that is moral beliefs, principles of good or right action, etc.) that are not adequately captured by the criterion of a Pareto-efficient resource use (O'Connor 2000).

The National Oceanic and Atmospheric Administration (NOAA) with the advice of the Nobel Laureates in Economics Kenneth Arrow and Robert Solow, developed a panel of experts with the objective to assess the reliability of Contingent Valuation Method. Their main conclusion was that "CV studies can produce estimates reliable enough to be the starting point of a judicial process of damage assessment, including lost passive use values". However, the panel members recommended a guideline for future applications of CV. The six most important of these guidelines are noted below (Arrow *et al.,* 1993; Portney 1994):

- CV methods should rely on the discrete choice format. Respondents should, in other words, be questioned on how they would vote ("yes" or "no") if offered a choice regarding a program that would involve higher taxes or payments but yield a specific environmental benefit. The yes/no decision is similar to that frequently experienced in actual purchase decisions or in voting for public programs, and responses to discrete choice questions are closer to actual valuations.

- Personal interviews are preferable to telephone surveys, which in turn are better than mailed questionnaires.
- CV applications should contain a scenario that accurately and clearly describes the expected effects of the policy or program being valued.
- Questionnaires should include reminders that any expressed WTP for the policy in question would reduce the amount available for other goods and services.
- CV applications must include reminders of the substitutes available for the improved good or service in question. For example, if asked to vote on a proposal to improve reservoir recreation, the respondent should be reminded of existing reservoirs being created independent of the proposal in question.
- Surveys should include follow-up questions that ensure that respondents comprehend the decision they are asked to make and help the analysts understand the basis for their responses.

5.3.3.1.4. Contingent Valuation study cases

A Contingent Valuation (CV) study was developed in Denver, Colorado, US, with the objective to determine residents Willingness to Pay (WTP) a higher bill to reduce heavy pollution in the South Platte River. The river has been modified by diversions, adjacent land use and pollution to the point where the river's ecosystem, including its fishes, are severely imperiled. In addition, the river is operated as a plumbing system with about 500 irrigation ditches and 70% of water withdrawals for agriculture. Much of the river's remaining flows are irrigation return flows, with additional inflows from the sewage treatment plant in Denver. Due in part to the lack of riparian vegetation to filter irrigation returns flows and feedlot run-off, the South Platte ranks first in contamination by ammonia and second among the US's 20 major rivers in contamination by phosphorus. In addition to polluted water, erosion of streambanks, irrigation return flows, and reduction of stream water by agriculture use has greatly diminished the natural ecosystem of the South Platte River. Finally, as the result of these changes in flow regime, habitat, and water quality, six of the remaining native fish species are at risk and are being considered for the endangered species list. Peoples' behaviour was measured with a statistical model, and the model included the following variables; a) Bid (specifies the increase in water bill the person was asked to pay); b) Unlimited water (Do you agree or disagree with the statement, farmers should be allowed to use as much water as they are entitled to even if it temporarily dries up portions of streams?); c) Government purchase (Do you agree or disagree with the statement, Government purchase of land along the South Platte river to increase fish and wildlife is something I would support?); d) Environmentalist (Are you a member of a conservation or environmental organization?); e) Average water bill (the average indoor use monthly water bill for each community). Regression results indicated that, in USD (US dollars), the amount of WTP was negative (-0.144) and statistically significant ($p< 0.01$). This implied that the higher the dollar amount the respondents were asked to pay, the lower the probability that the respondents would vote for restoration of ecosystem services. In the case of unlimited water question, WTP was negative (-1.485 at $p< 0.05$) indicating those that agreed with the right of farmers to use their entire water right even if it dries up the stream, were less likely to agree to pay for restoration of ecosystem services. In the question of Government purchase, respondents were more likely to vote for a higher water bill to carry out such a program (1.846 at $p< 0.05$). In the environmental group question, respondents were more likely to agree to pay the higher water bill (3.383 at $p< 0.01$). Finally, in the case of the average water bill question, respondents voted against an increase in their water bill for project implementation (-0.063 at $p< 0.05$). WTP results indicate that, households were willing to pay 21.00 USD per month with a 95% confidence interval of 20.50 – 21.65 USD, for the increase in ecosystem services on this 45-mile stretch of the South Platte River. Applying this WTP (21.00 USD per month) in 26% of the households in the zone (73,381), the amount collected per year would be 18.54 million USD. This takes into account that land rent cost is 12.3 million USD (40.00 USD/acre x 300,000 acres). It is possible to assume that the household WTP could cover the land rent costs, and 6.24 USD million per year could be spent for on-site restoration with native vegetation, riparian improvements and fencing (Loomis *et al.,* 2000).

In eastern Indonesia, a study was developed to estimate the local economic values of ecological services provided by protection of forest watersheds in Ruteng Park. It is necessary to mention that authors modified the contingent valuation (CV) method on two counts. First, willingness to pay (WTP) was modeled in terms of producer surplus measures in contrast to most environmental valuations that are derived from consumer welfare theory. Second, two models of behaviour, perceptions and adjustment, were proposed to capture how households respond to the CV questions. CV surveys were introduced with a standard description of park institutions and management to ensure that respondents received homogenous information. This was followed by several opinion questions designed to remind respondents about their environmental constraints and substitution possibilities. Drought mitigation was described in the survey as “drought control services, which is to decrease the drought conditions for your crops and improve a supply of dry season water”. These services were described to result “from several planned activities by Ruteng Park including protecting existing forest, planting trees in degraded watersheds and teaching the farmers new soil conservation measures”. However, the amount of increased baseflow was not specified. Authors hypothesized that household responses to the CV questions were based on their own perceptions of the service. Results indicated that responses to leading questions in the CV section on the survey revealed that households were keenly aware of, and interested in their environmental conditions. Ninety-nine percent of respondents agreed that “the amount of water in the springs and rivers depended on the forest”; 47% believed that “dry season water shortages” have increased in the Manggarai region over the last 10 years; 80% agreed that by “spending money on irrigation systems farmers could successfully reduce drought conditions for their crops during the dry season”; and 66% felt that “plants, birds, monkeys, and other animals in the region need special protection”. The annual fees for drought control varied from 0.48 to 6.42 USD (27,000 USD in total, evaluated by multiplying mean WTP of 2 USD by number of affected households). But, response patterns to the fees were confounded by physiographic and socio-demographic differences at the household level. For example, households that expected increases in profits through higher rice revenues, because rice is a water-demanding crop, were willing to pay more than households that had coffee plantations.

Also, the coefficient on the wealth index indicated that wealthier households were willing to pay more, and more educated households mark up their preference benefits. Finally, the coefficient on forest cover indicated that households living in watersheds with higher levels of forest cover may feel that there is no need for forest protection because they are not exposed to droughts. For similar reasons, residents in watersheds with greater rainfall were willing to pay less. In conclusion, when applying the CV method to a hitherto unmeasured ecological service in a developing country setting, the risk of commodity and context misspecification is high; that is despite the interviewer training, focus groups, and survey pre-test (Pattanayak and Kramer 2001).

In northern Nicaragua a study assessed the potential local economic benefits and costs associated with taking an environmental service approach to addressing problems of potable water availability in a microwatershed. A decline in water quality and quantity was identified by the community of San Dionisio as the most important consequence of resource degradation in the microwatershed. Since the principal use of water in the watershed was domestic consumption, the contingent valuation method (CVM) was used to estimate the value of restoring local water supplies. Several land use management options have been proposed as part of a strategy for improving hydrologic function in the watershed. The possible costs of these options were assessed in light of the value of the benefits from the CVM analysis. Additionally, a community-based natural resource management approach was developed to structure devolution of authority and to understand and support local organization and negotiation processes among socially and economically different stakeholders. CVM results indicated that San Dionisio households were willing to pay (WTP) 3.94 córdobas (0.38 USD) per month for improved water supplies. Among the communities, the average WTP ranged from 11 córdobas in Cobano to 0.21 córdobas in Zapote. Zapote has significant problems with water availability including rationing of potable water supplies 6 months a year on average. The low WTP for this community probably reflects strategic bias since there is significant opposition in the community to increasing water rates to solve water problems. In economics terms, CVM study results showed that the value of improving existing water resources in San Dionisio is relatively modest, equivalent to 0.61% of the rural household annual income. Community-based natural resource management approach results mentioned that 80% of the respondents felt that San Dionisio’s water problems should be solved via better land management rather than the construction of new water projects (i.e. deep wells). In addition, the socioeconomic analysis showed that the major determinant of water source protection is whether or not the households feel that the water source belongs to them. Water sources that belong to the household are significantly more likely to be protected than public sources or sources that belong to other households. In conclusion, CVM results showed that, it is necessary to implement an integrated approach to natural resource management that would likely yield a range of benefits beyond potential impacts on water, and local communities could play an important role in designing and implementing solutions (Johnson and Baltonado 2004).

In 2004, in Florida, USA, Alavalapati *et al.*, used a stated preference based choice experiment approach to assess the value of environmental services associated with silvopasture. The study was conducted because levels of phosphorus in Lake Okeechobee have more than doubled in the last century, and resulted in eutrophication and damages to aquatic life (Harvey and Havens 1999).It was assumed that silvopasture has the potential to reduce phosphorus runoff, sequester additional carbon dioxide, and improved the wildlife habitat in the Lake Okeechobee watershed (Stainback *et al.,* 2004). Silvopasture was compatible with the traditional ranching practices in the watershed and information about public demand for environmental services was critical to formulating incentive schemes. The theoretical construct of a stated preference choice experiment (CE) approach stems from a discrete choice analysis of consumer preferences, and considers each of the environmental attributes of silvopasture in the watershed as an alternative to a choice set. The authors estimated household WTP for environmental services with a random parameter logit (RPL) model. A survey of households who potentially benefit from silvopasture practices in Lake Okeechobee was conducted. In designing the survey, each of three environmental attributes (water quality, carbon sequestration, and biodiversity) was identified and described at three levels (see Table 5 for examples).

Table 5 An example of a choice set presented to the household to elicit the value of environmental change.

a) Please vote for the plan that you prefer:

Environmental response	Option A	Option B	Option C Current condition
Water quality improvement (reduction of phosphorus runoff)	31 – 60 %	61 – 90 %	No change
Air quality improvement (Absorption of CO_2)	No change	high	No change
Wild life habitat improvement (better habitat for wildlife)	Moderate	No change	No change
Annual tax increases (per year for 5 years)	\$ 40.00	\$ 120.00	\$ 0

b) If the above plans are in a referendum, which one would you vote for?
Option 1 ____ Option 2 ____ Option 3 ____
c) Please circle one number to indicate how certain you are with the choice you have just made:
Not certain Very certain
1 2 3 4 5 Thank you.

Research results indicated that the average WTP per household for a moderate level of improvement in all three environmental attributes was 137.00 USD per year for five years. With 1.3 million households in the watershed, the total WTP for the environmental service would be \$924.40 million USD. This value reflects the households' total demand for environmental services associated with silvopasture in the Lake Okeechobee watershed. However, to complete the equation it is necessary to determine ranchers' willingness to adopt silvopasture practices and which policy incentives would be more effective? Researchers investigated Florida ranchers' willingness to adopt silvopasture practices. Specifically, they assessed the effect of premium beef prices and direct payment for the adoption of silvopasture using a dichotomous choice CV approach. Results showed that the variable representing incentive payment offers had a positive and significant effect on the probability of adoption. Willingness to accept (WTA) silvopastoral systems had a price premium of 0.15 USD/lb of beef or a direct payment of 9.32 USD/acre/year. Information showed that, on the one hand, with 2.4 million hectares of grasslands, the direct payment policy would cost about $56 million annually. On the other hand with 482.84 million of pounds of beef/year, the price policy would cost about 72.43 million USD annually. It is clear that the total amount of households' WTP is enough to cover the environmental service offered by the farmers. Authors concluded that phosphorus runoff taxes alone did not induce a desire to change ranch land management practices. Payments for sequestering carbon along with a pollution tax were found to be more effective in bringing about desired changes. Furthermore, results indicated that a direct payment policy was less costly in comparison with price premiums. Finally, it is important to note that each policy may be unique in achieving the set objective and in bringing about desirable and undesirable effects. Policies must induce landowners to search for land use innovations that reduce the cost of pollution and/or increase profitability. In addition, it is necessary to take into account social, administrative and institutional feasibility when designing a policy (Alavalapati *et al.,* 2004).

5.3.3.2. Opportunity Costs

Opportunity Cost (OC) is a concept where the definition has two core notions: (i) the notion of a foregone opportunity, meaning that an investment, activity, or use of a resource prevents an alternative investment, activity or use of the resource; and (ii) the notion of a cost, meaning that the foregone opportunity would have provided benefits. Some argue that the word "opportunity" is redundant, but useful in remembering that in economics "*the cost of using a resource arises from the value of what it could be used for instead*" (Concise Encyclopedia of Economics). Therefore, the sum of both costs assesses the true cost of any course of action. In the case of forest conservation, the accounting cost is limited to operational costs (primarily security guard salaries), but the conservation might prevent people from generating value from agriculture. The concept of opportunity cost is based on scarcity and exclusiveness, because one course of action prevents another one. Forest conservation could take place alongside other land uses in a world without land scarcity, thus suppressing opportunity costs. But scarcity usually translates into exclusiveness when two activities or land uses cannot take place simultaneously (Pirard 2008).

To take the most valuable alternative as the opportunity forgone, assumes un-limited rationality where the presence of barriers would not prevent its realization. But the real opportunity cost might better rely on the alternative option with the highest probability. This distinction finds an important application with "avoided deforestation", where the opportunity foregone is identified with the business-as-usual scenario (what would happen with deforestation?) (Pirard 2008).

Increasingly of interest are measures of opportunity costs of water resources. When evaluating tradeoffs of proposed reallocations, the economist needs a measure of the benefits of the proposed new use as well as the reduction of benefits associated with reduced water use in the sector currently benefiting. Hence, opportunity costs are the reverse of incremental benefits (Young 2004).

5.3.3.2.1. Opportunity costs study cases

An *ex-ante* analysis was developed in the Dominican Republic to measure, based on farmers' point of view, the financial feasibility of implementing soil-conserving land uses in the uplands of the watershed that supplies water to the Valdesia hydroelectric dam. Based on current prices for agricultural products, a wage of 3.50 USD/day (which is equal to the minimum wage), and the budgets for soil-conserving agricultural activities, Net Present Values (NPV) was estimated for a 25 year planning interval. Results indicated that, whereas applying better land management practices without altering land use seems to yield positive returns for at least some farmers, changing land use in order to meet soil conservation goals does not appear to be remunerative for many individuals. NPV estimated in several slope classes (B= 20 – 35%; C= 36 – 50%, and D= >50%), showed that neither devoting land to a reforestation effort nor converting land from agriculture to agroforestry benefits the typical working farmer. It is necessary to mention that, the precision of the results in this study is limited because information about *status quo* and soil conserving agriculture in this particular watershed is imperfect. Nevertheless, those results constitute evidence in support of two hypotheses. First, where the soil conservation goals can be met merely by improving land management practices, farmers will experience low or possibly negative costs in order to reduce erosion. Second, the conversion of land from traditional agriculture to a more soil-conserving use does not seem to be in the private interest of many groups of farmers (Veloz *et al.,* 1985).

Research estimated the OC of biodiversity conservation in Kenya from the potential net returns of agricultural and livestock production, and compared them with the net returns from tourism, forestry and other conservation activities. Authors adopted a financial and partial equilibrium approach for a single year (1989) in which they compared OC with net benefits from tourism and forestry. They define net benefits (NB) of biodiversity conservation to be $\text{NB}_{\text{Conservation}} = \text{NB}_{\text{Direct use}} + \text{NB}_{\text{indirect use}} + \text{NB}_{\text{Non-use}} - \text{OC}_{\text{Conservation}}$. Where direct uses are tourism and forestry, indirect uses could be soil and watershed protection, pharmaceuticals, biodiversity and carbon sequestration. The non-uses represented such things as existence values, whereas $\text{OC}_{\text{Conservation}}$ represented the opportunity cost from setting the Parks, Reserves and Forest land (PRF) aside for conservation. The value of agricultural and livestock production were calculated utilizing a land potential and socioeconomic approach, and included a total of 515,450 km^2. Results indicated that Kenyan parks, reserves and forests could potentially support 4.2 million Kenyans, 5.8 million livestock and 0.8 million hectares of cultivation, and generate gross revenues of 565 million USD/year, and net returns of 203 million USD/year. In contrast, the net returns of wild life tourism sector were 27.20 million USD/year and the net returns of use and non-use of forestry resources were 14.8 million USD/year. When the authors compared the potential net return of the land conversion (203 million USD/year) with the net returns of the direct, indirect, and non use of the PRF (42 million USD/year), they found that, under the current socieconomic and political conditions, the net revenues from wildlife tourism and forestry are unlikely to meet the opportunity costs of the land set aside in PRF. In fact, the Kenyan government is subsidizing these conservation activities to the amount of 161 million USD every year, a benefit to the rest of the world by the continued existence of the flora, fauna and undisturbed habitats. Finally researchers mentioned that if the developed world expects a country like Kenya to continue with its conservation politics, then it must be prepared to contribute substantially to cover these costs (Northon-Griffiths and Southey 1995).

Research developed in the rural community of Jesús de Otoro, Honduras, calculated the opportunity cost of the environmental services generated by the ecosystems located in a groundwater recharge zone, and compared them with the amount offered by a local scheme of payment for hydrological environmental services (PHES). Opportunity costs were computed using the current productive activities located in the recharge area (forest, livestock, traditional agriculture, and coffee). Results indicated that the groundwater recharge zone extended over 2,500 hectares, but only 73.85 hectares were under the PHES scheme. Seventy-six percent of water users in the area lived under poor conditions, and drinking water users paid 0.005 USD per month per family, for a total of 1,269 families. The opportunity cost of the land was 1,145.91 USD ha/year, whereas the amount received by the areas under the PHES scheme was 12.45 USD ha/year. Authors concluded that the amount offered by the PHES scheme was too low to cover the opportunity cost of the land and was not attractive to the farmers. Second, fresh water users didn't have the economic capacity to pay more for the environmental service. Third, land use conversion from productive activities to conservation could generate food scarcity and employment reduction. Finally, the PHES developed in the Jesús de Otoro community, under the current socioeconomic and political conditions, is an unsuccessful strategy of sustainable development (Martínez 2005).

In 1973, the Mbaracayu Forest Biosphere Reserve in eastern Paraguay was 90% forested. However, by 2004 only 56% of the reserve remained forested and, with the exception of a core area of the reserve and several forests on adjacent private lands, was becoming highly fragmented. As of 2004 there were three dominant land uses in the region: smallholder agriculture (12% of land surface), large-scale cattle ranching (14%), and soybean production (2.4%). The OC of these activities were calculated using a multinomial logistic regression analysis model that included biophysical conditions, human infrastructure, land tenure, soil type, discount rates and property size variables. Results indicated that mapping the average spatial net rents over the three dominant land uses (smallholder agriculture, cattle ranching, and soybean farming) showed a high degree of spatial heterogeneity in estimated land values for the Biosphere Reserve. Most of the high-value land was concentrated in the extreme east of the reserve. Forested land in this area is highly likely to be converted to soybean plantations (the most economically valuable land use) because it is at the edge of an extensive soybean belt that overlays the fertile soils shared by some of the most productive parts of Paraguay, Brazil, and Argentina. Most of the remaining land is of substantially lower economic value but variability in price is still apparent. Large "blocks" of similar economic value, such as the indigenous reserve directly south of the core protected area, reflect the strong effects of land tenure on land price. As a consequence of this spatial heterogeneity the OC ranged from 0 to 927 USD/ha. Authors concluded that integrating economic costs within algorithms of the reserve could lead to greater applicability to real-world problems. In contrast to many approaches that require extremely detailed biological information, basic cost estimates are relatively easy to obtain and have significant real-world value in that they translate the economic costs involved in potential conservation plans in a way that is universally understood (i.e., through their monetary value). Including such costs up front in conservation planning should streamline the design process, allowing decision makers the ability to immediately understand the costs of various proposals rather than having to estimate such values in a *post hoc*, separate process. Nonetheless, spatial cost-benefit analyses of ecosystem goods and services remain difficult for two reasons. First, although many nonmarket valuation exercises show that the economic values of ecosystem goods and services can be high, they are usually not "capturable" at a scale relevant to local agents of land-cover change. In other words, although the global or regional value of ecosystem goods and services can be significant, often no mechanisms exist for local agents of land-cover change to benefit from this value, so it does not enter into their decision-making process. Second, the state of the art in nonmarket valuation and mapping of ecosystem goods and services is still developing and needs further investigation to allow modeling of economic values at spatial scales that are fine enough to be used in spatially explicit landscape models of habitat conversion (Naidoo and Adamowicz 2006).

In the Tapalpa watershed in Jalisco State, México researchers generated information that could help in the creation of a market of PHES. Specific objectives were to determine the water use value using contingent valuation and the opportunity cost of the natural forest located in the watershed highlands. The watershed has an area of 21,000 ha and half of it is forested. The demand analysis indicated that the hydraulic resource (HR) used is about 23,171,885 m^3/year. Ninety-three percent of this total is used in the agricultural sector, mainly for vegetable production (50%) and basic crops (23%). When compared to other sectors, the calculated WTP value for the HR is higher in the service sector (76.7% of the interviewers said to be well disposed). However, the biggest contribution to the total WTP was given by the domestic sector (46.5%) with $3,064,301 Mexican pesos/year. Additionally, a direct relationship between the study level and WTP for HR was determined. Age showed an inverse relationship with WTP. The estimated total WTP value resulted was smaller than the estimated opportunity cost to conserve forest in the watershed, resulting in an annual deficit of $ 27,201,313 Mexican pesos/year. The total WTP represents only 10% of the opportunity cost. In addition, if the associate costs for recovering forest areas currently in other use (areas in conflict) were added, the annual deficit would increase to $ 45,130,988 Mexican pesos/year and the WTP would be reduced to 6% of the total opportunity cost. In conclusion, water user WTP is not enough to cover land use opportunity cost ($ 4,158.00 Mexican pesos/ha/year), and in the case where a PHES market is created, government subsidies would likely be necessary. Unfortunately, federal government subsidies are only around $ 300 Mexican pesos/ha/year (López *et al.,* 2007).

In a study developed in Indonesia, researchers calculated the opportunity costs of the pulp industry that was developed in native forest zones. However, several factors such as the heterogeneity of the pulp industry or the availability of non-forest lands to displace activities complicated the analysis. To face this situation, the author used a new method called the "Flexible stepwise approach". This method is flexible in the sense that it derives formulae that suit key characteristics of each case. The following operational definition is proposed: "*The social opportunity cost of avoided deforestation is the financial loss for a country when one hectare of forest prevents another land use as determined by the business as-usual scenario. This financial loss also considers the most obvious alternatives for investors and impacts on downstream industries*". A flexible stepwise approach requires simplicity for being operational while guaranteeing fair and credible cost estimations. This trade-off translates into the necessity to be context-specific and inclusive of the most significant side effects (e.g. downstream industries) of avoided deforestation, while not using costly and time-consuming methods (e.g. exhaustive cost-benefit analyses). Moreover, cost estimations are likely to be more useful in classifying high/low costs rather than refining estimations. Precise estimations are indeed most justified for determining individual compensations to land users (e.g. *private* opportunity costs). Therefore, this approach merely intends to orient the calculation in the right direction in order that decision-makers do not miss the real low cost strategies for reducing deforestation. Once a direction is chosen, the choice of assumptions like discount rates and time horizons is as debatable as for any other opportunity cost calculation. Results indicated that OC values ranged from zero to one thousand dollars per hectare per year, and concluded that stepwise approach was applied to the pulp sector in Indonesia with interesting results. Indeed it showed that opportunity costs could be calculated in different ways with contrasted values. This supports the view that negotiations between host countries and other stakeholders, in particular those who fund activities to reduce deforestation, would gain in credibility with the use of a similar framework. To do so could help to allocate financial resources to developing countries in a fairer way. It could allow contributors to wisely use their resources and to prevent ultimate beneficiaries from being inappropriately compensated. Yet, as for any other method, transparency is a requirement in order to ensure that the right assumptions are applied (Pirard 2008).

A study developed in the United Kingdom showed that the relationship between land heterogeneity and incentive compatibility is a problem for the design of agri-environmental schemes. This point is supported because land is heterogeneous, both in terms of agricultural value and in terms of environmental value. From the policy perspective ‘local’ can indicate a region where the payments for providing the same environmental goods and services are uniform across the region. However, even within such a region, land productivity will vary both within and between farms. Moreover, each farm was characterized by the proportion of each of these land types which it comprised. As a consequence, each farmer would respond to the introduction of compulsory set-aside by setting aside their lowest quality land, whilst farms with an overall higher quality of land would experience the largest decreases in production income. In other words, the lower the quality of the land on a farm, the lower the marginal (or opportunity) cost of diverting land to environmental purposes, and the greater the area of land which will be diverted for any given payment. Contrary to that the higher the land quality, the lower the area diverted for payment. Authors concluded that under the point of view of this analysis it is clear that any flat rate payment scheme for environmental care will generate suboptimal provision when either or both the opportunity costs of provision and the social values of the environment are heterogeneous. Furthermore, the more different the costs and values of environmental provision are between different areas (within or between regions), the greater the misallocation is likely to be, to the extent that the total costs of any flat rate scheme can exceed the benefits (Fraser 2009).

5.3.3.3. Participatory Approach

The participatory approach is recognised world-wide as a desirable approach for the success of research and development projects in the field of land management and conservation. This approach is promising in improving farmers' awareness of environmental problems and solutions, as well as in linking local and scientific knowledge (Hoang Fagerström *et al.,* 2003). Participation by farmers is essential for the planning of sustainable management of land and water resources. Farmers are closer to the real local problems, and therefore they are aware of factors that experts often do not consider, and their objectives are more realistic for economic development (Stockin 1996).

Human development is the process of enlarging the capabilities, choices and opportunities of people, especially the rural and the poor, to lead a long, healthy and fulfilling life. This process includes the expansion of people's capacity and skills to gain access to and control over factors that affect the basic needs essential to their lives. These needs include freedom from poverty, food security and availability of safe drinking water and improved sanitation. In addition, human development puts people's empowerment at the centre of development. It aims to enable people to use their capabilities and resources to the fullest without destroying the richness of their cultural and natural environment. Unfortunately, one of the major problems that have slowed human development is the lack of people's participation in the design and implementation of policies and programs that affect their lives. Unless people become the protagonist of their own development, no amount of investment or provision of technology will improve standards of living in a sustainable way The problem, however, is that the rural and the poor who need to become active actors in their development to enable them to improve their livelihood are often beyond easy reach (Anyaegbunam *et al.,* 2004).

Many rural development projects fail because the so-called beneficiaries do not truly participate in the assessment of needs and identification of problems to be addressed by such efforts. Rural people's perceptions of problems and solutions are often overlooked, while their storehouse of information, experience and analysis is usually neglected. Rural people are thus regarded as mere recipients, rather than as the actual creators of change and progress. This results in incomplete and inaccurate analysis of problems, and incomplete and inaccurate identification of solutions, frequently leading to poor programme planning and formulation. Target beneficiaries frequently refuse to participate in the implementation of such programmes because they are not perceived as relevant to their felt needs (Anyaegbunam *et al.,* 2004).

Communication for development is the systematic design and use of participatory activities, communication approaches, methods and media to share information and knowledge among all stakeholders in a rural development process in order to ensure mutual understanding and consensus leading to action. The aim is to facilitate people's participation at all levels of the development effort to identify and implement appropriate policies, programmes and technologies in order to improve the environmental management in a sustainable way. Communication for development uses activities, media and materials to empower people to articulate and share their own opinions, needs, problems and abilities both among themselves and with outside development agencies. This enables the people to influence the decision-making processes of formulating and implementing projects and programmes intended to satisfy their needs and solve their problems. Communication for development uses communication research, approaches, methods, traditional and modern media and materials to improve dialogue between rural people and development agencies in order for all parties to reach mutual understanding and jointly decide on problems, needs, solutions as well as on new and appropriate technologies and practices. Such decisions often marry local capabilities with outsiders' knowledge and skills for more effective problem solving. Jointly identified solutions are often more acceptable to the people because they are seen as relevant to their needs. Dialogue ensures that the people's culture, attitudes, capabilities and skills, as well as their views and opinions form the basis for the planning and formulation of effective and relevant development projects and programmes (Anyaegbunam *et al.,* 2004).

Participatory approach in watershed development is fundamentally about the creation of new opportunities, in an institutional and ecological sense. The ultimate indicators of success are the ability of communities to take advantage of new opportunities and to what extent these benefits are sustained in the post project phase. The nature of the relationship between private and common pool resources is dynamic and highly site specific. Where the link is strong, communities are likely to be more willing to invest time and resources in the rehabilitation of common resources. In such a context, common pool resources provide a focal activity around communities that enable them to organize themselves. It is now widely accepted that within the realm of participatory management, if the productivity of natural resources is to be enhanced in a sustainable fashion, the communities must participate in plans for rehabilitation and management. Their participation will generate a stake in the process and enhance the prospects of both institutional and ecological sustainability (Kaushik *et al.,* 2007).

5.3.3.3.1. Participatory Approach study cases

A study was developed in the Doon Valley, located in the Lesser Himalaya, Uttar Pradesh, India where the principal objective was to arrest, and as far as possible reverse the on-going degradation of the Doon Valley environment. Since people have been the agent of change in the process of degradation; they were placed centrally to the project's objectives and strategy. Subsidiary objectives were: a) Involve the local population in all stages of planning, implementation, and management of project activities, and b) improve the quality of life of rural people so as to enable them to remain in the rural areas and to be positively involved in the management of the environment. People living in the valley are the focus of the project strategy. It is assumed that if the living standards of the people are raised, their dependence on natural resources will decrease and that, with education, their awareness of environmental issues will increase. To achieve sustainability of improved production systems, a major part of the strategy was to evolve suitable village organizations so that, after the end of the project, the villagers would manage, on a self-reliant and sustainable basis, the created and/or improved assets would. This was further encouraged by introducing reciprocal obligations by villagers for project interventions, so that the beneficiaries would perceive them as their own and thus worth maintaining. Emphasis was placed, therefore, on strengthening the capabilities of communities, to encourage *innovation*, and to move away from *intensification* through outside inputs. Moreover, the strategy aimed at integrated development using the village as the basic unit and involving the communities in planning, implementation, monitoring, and evaluation, leading to post-project maintenance. Results indicated that, though the primary aim of the project is eco-restoration, the villagers' priorities differ greatly. Village plans reveal that irrigation, animal husbandry, agriculture, and sometimes physical infrastructures (e.g. roads, hospitals) are priorities, whereas environmental concerns are rated low. Villagers are more interested in social infrastructure, non-farm livelihood activities, and individual immediate gains in farm production, than in community management of natural resources. Eco-degradation is appreciated but initially is not perceived as a threat. In the Doon Valley, for instance, fodder and fuel supplies are not yet seen by villagers to be critical. Perhaps, opportunities for community action in natural resource management are greater if there is a perceived deficiency in a vital resource. Moreover, as villagers had become used to receiving subsidies from the government, a major attitude change was required for them to accept the principle of reciprocal inputs. Ultimately, the women were the most receptive to this change. Attempts were made with the villagers to link project investment in their priorities, such as income-generating activities, with reciprocal activities by villagers to achieve environment-related goals, such as forest protection. Their initial reluctance to protect common property resources resulted from: a) The absence of any example to show how profitably such natural resources can be managed on a sustainable basis for community benefit, b) concern over the future rights of access by villagers to the protected resources, and c) popular belief that there are still sufficient forest resources to meet local demand. Contrary to that, Bio-gas plants proved to be popular with villagers, and they combined benefits for women and the environment. These plants saved 323 kg/firewood/day and 54.3 hours/day in firewood collection. Authors concluded that several lessons emerge from the Doon Valley Project, some specifically related to watershed management procedures in mountainous areas, whereas others are more widely applicable to participatory rural development programs in general: a) the project demonstrates that a government agency can work in a participatory manner. This required time for attitudinal changes and team-building through training and exposure visits, combined with encouragement of similar reorientation among the beneficiary communities, b) women proved to be more responsive to project intervention than men. This probably partly reflects their roles as the true managers of the natural resources in the hills but also the fact that, un-like the men, they are less exposed to outside influences, c) adopting "village watersheds" as the basic planning unit, in preference to conventional physical watersheds, proved to be practical in terms of involving people, d) encouragement of village-level organizations often proved difficult due to the ethnic complexity of the villages. Groups need to be focused on a common interest and different models need to be applied, and d) the *innovation* component of the development process has so far had greater impact, through attitudinal, behavioral, and institutional changes at the village level, than the *intensification* component, through outside capital investments or technologies (Datta and Virgo 1998).

In the Chemoga watershed, Blue Nile, Ethiopia, a study investigated the extent of farmers' participation in current Soil and Water Conservation (SWC) undertakings. The specific objectives were to: 1) Verify whether farmers' participation in the SWC activities was due to their own conviction, and 2) identify and describe major factors influencing farmers' willingness to participate in the SWC activities. The study specifically focused on the SWC works that were underway by the time of the fieldwork (1999–2000). The results indicate that the majority of the farmers participated in the SWC against their will. The most important factor discouraging them from participating freely was the perceived ineffectiveness of the structures under construction. Awareness about soil erosion as a problem, labour shortage and land tenure insecurity were found to be less important in providing an explanation for the disinterest shown by most of the farmers towards the SWC activities. Therefore, the important factors that needed immediate consideration for SWC efforts in the study area or the region at large were: 1) SWC structures had to be carefully designed and constructed taking into account ground realities, and 2) participation of the farmers had to be through their own conviction regarding the effectiveness and efficiency of the technologies (Bewket and Sterk 2002).

Other research developed in West Bengal, India, analysed a participatory approach that is used to improve water conservation by rainwater harvesting on a watershed basis. The Government of India's commitment to Participatory Irrigation Management (PIM) and the encouragement of water management being undertaken with the help of Water Users Associations (WUAs) are apparent from a perusal of its National Water Policy. Participatory integrated watershed development refers to conservation and regeneration of natural resources like soil, water and plants through vegetative measures including forestation, horticulture and pasture development, and engineering measures such as contour bounding, trenching, terracing, nala bunds, gully plugs and check dams through active participation of the local people. West Bengal is endowed with remarkable variations in physiographic resources. From the soil and water conservation point of view, the most vulnerable areas are gravelly and lateritic tracts of the western districts (Purulia, Bankura, Birbhum, the western part of Burdwan and West Midnapur), the hilly areas of the Darjeeling district and coastal saline zone mainly comprised of 24-Parganas (South) and 24-Parganas (North) districts. *In situ* water harvesting techniques, such as contour trenches (SCTs), continuous contour trenches (CCTs), and contour bounding have been introduced in the region on a micro-watershed basis to improve the soil moisture regime in their lands and to address the mid season moisture stress conditions of crops grown in uplands and midlands, namely staggered. These measures have demonstrated their ability in conserving the rainwater received during the monsoon season. They help in maintaining better soil moisture regimes, stabilizing crop yields and providing an appropriated environment to protect the severely eroded soils under the cover of vegetation and grasses. These *in situ* rainwater harvesting measures are now widely acclaimed as successful soil and water conservation measures in the region. The coastal area of West Bengal is earmarked by near surface shallow aquifers with saline/brackish water, which is therefore unfit for irrigation purposes. On the other hand, the groundwater suitable for irrigation is found at greater depths (300 – 400 m) and its exploitation is expensive and hence not feasible. In most of the coastal areas of West Bengal, no perennial canal with water suitable for irrigation is present. During monsoons, excess water is present, causing water logging and submergence of crops so no crop is cultivated during rabi and summer seasons due to a lack of good quality irrigation water. The only alternative left is excavation of farm ponds in individual fields (considering the rest of the field as a catchment/watershed of the pond) for storing excess rain water during the monsoon period and reusing it for life saving protective irrigation to the crops during the post-monsoon period in addition to practicing fish-farming. The ponds are generally located at the lowest point of the field and the runoff water is collected by gravitational flow. In conclusion, PIM involves a redefinition and refocusing (not a mere reduction or downsizing) of government's role in irrigation so as to lead to a genuine partnership or joint management between the government and WUAs. Therefore, PIM involves an approach based upon integrated and joint management of irrigation with the community (in the form of the WUA) and government agencies working together for equitable, rational, timely, and convenient allocation of water. PIM increases efficiencies both in canal management and on-field water application. PIM legislation should specify that regardless of whether the source is lift irrigation (from rivers or from community tube wells) tank system or a conventional irrigation system based upon storage and water distribution, wherever water is distributed between 30 or more farmers, the PIM and WUA approach should be mandatory (Mazumdar 2007).

A participatory approach (PA) study was developed with the objective to investigate vulnerability and adaptive capacity to climate variability and water stress in the Lakhwar watershed in Uttarakhand State, India. The study combined watershed modelling with a PA. Water balance modelling for Lakhwar watershed was carried out using SWAT and MODFLOW models. Areas that would be most affected due to changes in flows and water stresses were identified, and two villages were selected for community-level interactions. Group discussions were held in each village during May–July 2005 to elicit community perceptions about climatic changes and learn about factors impacting agricultural livelihoods over time. Stratified random sampling was, and semi-structured interviews were, conducted with different types of households to elicit information on their agricultural practices and non-agricultural responses in the face of water scarcity. Key person interviews were carried out with village elders and leaders. Time budgeting exercises were carried out with women. The community in each of the two villages was brought together for group discussions and timeline exercises, separately with men and women. Water availability maps developed in the watershed modelling exercise were shared with the community to stimulate brainstorming on a possible pool of options that would enhance the adaptive capacity of vulnerable households in the long run. A timeline was developed by the community of key developments in the village, including the changing water stress situation, extending into future scenarios for water stress and possible interventions. Socioeconomic results showed that villages suffer the lack of basic services such as electricity, drinking water, toilets, health centre, road connectivity, telephone and education beyond the primary school level. Houses are made of mud, stone, and wood, and indoor air quality is poor due to the use of traditional stoves. There is no collective or cooperative society in the village, which could help to reduce vulnerability. And the migration from the villages to the cities is massive. In the case of people's perception about climate variability and water stress, results indicated that almost all the households interviewed in the two villages felt that rainfall has declined in quantity and that they could no longer rely on the timely onset of the monsoon. Respondents noted a decrease in scattered light rainfall useful for percolation, and an increase in intense rainfall which destroys crops and runs off. There was concern that rainfall is lost to surface runoff, streams and springs are drying up, and soil moisture has declined. In the case of gender information, women bear the major burden of performing agricultural operations and gathering supplies for household needs. Time accounting exercises showed that they spend 14 h/day working in the fields, and gathering fodder and firewood, preparing manure, collecting drinking water, rope-making, haymaking, etc. The strategies proposed by households to confront water scarcity were; a) improving their access to available water (e.g. makeshift storages, digging deeper tube-wells, exchanging irrigation timeshares, buying groundwater, and engaging in water theft), b) reducing their demand for water (e.g. switching to less water consumptive crops, adopting more efficient irrigation practices, and altering dates for agricultural operations), c) coping with the adverse impacts of periodic drought (e.g. credit, sale of valuables and livestock, use of stored seeds and food-grains), and d) diversifying their sources of livelihood (e.g. alternative employment opportunities, migration). Authors concluded that the interactions with communities acutely highlighted the mismatch between top-down policy recommendations and ground-level needs and aspirations. It is difficult to reconcile a situation where there is severe lack of water and near abandonment of farming as a livelihood, with the National Water Policy which lays emphasis on the sale of water, and the right of the government to sell excess water. The replication and refinement of the study methodology can help develop a programme of 58participatory research on adaptation responses to water stress that are evolved by the affected communities themselves. Such a programme can help policy-makers effectively target resources to minimize the adverse effects of current and future water scarcity (Kelkar *et al.,* 2008).

5.3.4. Watershed ecosystem services market

The emergence of a market for watershed services has not been associated with significant competition in supply or demand. Because watershed services benefit groups of individuals and are characterized by threshold effects, cooperation in demand and supply is a key aspect. Market development depends on strengthening cooperative and hierarchical arrangements to allow beneficiaries and providers to come together to formulate group payment strategies and to tackle free riding. At the same time where cooperative or hierarchical arrangements exist, but have come under strain due to inequitable benefit-sharing and high costs, markets are being introduced to ease tensions and facilitate financial and in kind transfers. At least six questions need to be considered in the development of markets for Environmental Services (ES) (Landell-Mills and Porras 2002).

1) *What form do markets take?* Markets vary tremendously between locations and services sold. This review considers seven key features to help describe market form: the commodities, the characteristics of participants, the level of competition, payment mechanisms, the geographical extent of trading, the level of maturity and the degree to which markets are embedded in broader institutional contexts.
2) *Why do markets evolve?* Markets evolve in response to changing demand and supply conditions. Understanding what is driving changes in demand and supply is a critical first step in developing strategies in market creation.
3) *How do markets evolve?* Institutional development tends to be slow, iterative and path dependent. It is closely intertwined with shifting power relations and changing incentive structures. Understanding the complex processes through which change occurs is essential for those wishing to foster market development.
4) *What does market development mean for human welfare?* With market development driven by certain individuals and/or groups, there can be no presumption that markets will improve social welfare. Economic, social and environmental impacts need to be measured. Transaction costs associated with establishing and running market mechanisms must also be considered.

5) *What do markets mean for poor people?* Impacts on poor people are of particular concern. To help guide this assessment the review considered how markets are impacting on assets (including financial, human, social, physical, natural and political) held by these groups.
6) *What are the key constraints to market development?* Lessons on constraints to market development need to be drawn out from answers to the above questions. Ultimately this is critical as a basis for identifying prerequisites for welfare-enhancing markets.

Market structures vary between locations and goods. Economists concerned with efficiency have traditionally been preoccupied with the degree of market competition. However, markets are dynamic, involve varied participation and that are embedded in a wider institutional framework, it is important for decision-makers to examine an array of features. Seven features are used to distinguish between different market forms (Landell-Mills and Porras 2002).

- *The commodity*. The key ingredient in any market is the commodity that is being bought and sold.
- *Characteristics of participants*. Participants include those demanding environmental services, those supplying services and intermediaries involved in facilitating transactions. Participants may include the private sector, the public sector, non-government sector, civil society or a combination.
- *Level of competition*. The level of competition determines the extent to which individual market players can influence prices, often referred to as market power. Conventionally we measure competitiveness by the number of players in a market: the fewer the players (e.g. in the case of monopolies), the greater each participant's market power and the less competitive the market. Competitive markets involve several participants. However, it is critical to distinguish between explicit and effective competition. Even where markets are highly concentrated, if there is a credible threat of entry by competitors the market may be competitive.
- *Payment mechanism*. Several options exist for transferring funds from buyers to sellers, including direct negotiation, broker-based markets, auction systems, and exchange-based markets.
- *Geographical extent of trading*. Trades may be local, national, regional or international depending on the market and its location *vis a vis* political boundaries.
- *Level of maturity.* Market maturity may be defined in a number of ways. Four useful criteria include: the time period since transactions were first initiated (i.e. the age of the market), the degree of price discovery attained to date, market participation and liquidity, and the level of sophistication in the payment mechanism employed.
- *Nested nature*. Markets evolve in a context. Not only may markets replace existing institutional arrangements, but they build on institutional arrangements which will influence the form they take. It is important to understand this context and the nature of inter-institutional relationships.

5.3.4.1. Payment for Hydrological Ecosystem Services

Payments for environmental services (PES) are part of a new and more direct conservation paradigm, explicitly recognizing the need to bridge the interests of landowners and outsiders. Eloquent theoretical assessments have praised the absolute advantages of PES over traditional conservation approaches. Some pilot PES exists in the tropics, but many field practitioners and prospective service buyers and sellers remain skeptical about the concept (Wunder 2007). Following Wunder (2005) a PES could be defined as:

1. A *voluntary* transaction where
2. A *well-defined Environmental Service* (ES) (or a land-use likely to secure that service)
3. Is being 'bought' by a (minimum one) ES *buyer*
4. From a (minimum one) ES *provider*
5. If and only if the ES provider secures ES provision (*conditionality*)

First, PES is a voluntary, negotiated framework, which distinguishes it from command-and control measures. This presupposes that potential ES providers have real land-use choices. Secondly, what is bought needs to be well defined. It can be a directly measurable service (e.g. additional tons of carbon stored) or land-use caps that are likely to help in providing that service (e.g. "forest conservation provides clean water"). In fact, here the word "likely" hides important scientific insecurities and popular perceptions. Especially hydrological services are often based on beliefs rather than scientific proofs (e.g. "forest cover always increases water availability") (Kaimowitz 2005). Also, external factors can interfere; Nature is not always 'well-behaved'. For instance, even if forest conservation indeed increases the likelihood of clean local water provision, this increase may be subordinate if the general frequency of tropical storms and flooding is high, thus dominating water-quality outcomes. Payments that build on scientifically unlikely relationships, on likely relationship being unlikely to affect significantly the desired outcome, or on what has outright been proven to be a myth, might persist over a long time. In many cases, we lack the knowledge base to classify objectively which ES provision cases are real and which ones are 'imaginary'. However, authors assumed that a poor underpinning of ES will tend to decrease PES robustness and sustainability. In other words, the less realistic the scientific basis of a PES scheme, the more exposed it is to the risk of buyers questioning its rationale and abandoning payments. In any PES, there should be resources going from at least one ES buyer (criterion 3) to at least one provider (criterion 4), though the transfer often occurs through an intermediary. Last but not least, in a PES scheme user payments need to be truly contingent upon the service being continuously provided (criterion 5). The basic logic of PES mechanisms is shown in Figure 9. Ecosystem managers, whether they are farmers, loggers, or protected area managers, often receive few benefits from land uses such as, for example, forest conservation. These benefits are frequently less than the benefits they would receive from alternative land uses, such as conversion to cropland or pasture. But deforestation can impose costs on downstream populations, who no longer receive the benefits of services such as water filtration, and on the global community, because of reductions in biodiversity and carbon storage (the actual impacts will, of course, vary from case to case). Payments by the service users can help make conservation the more attractive option for ecosystem managers, thus inducing them to adopt it (or, in the case of protected area managers, giving them the resources to do so) (Engel *et al.,* 2008). PES thus seeks to internalize what would otherwise be an externality (Pagiola and Platais 2007).

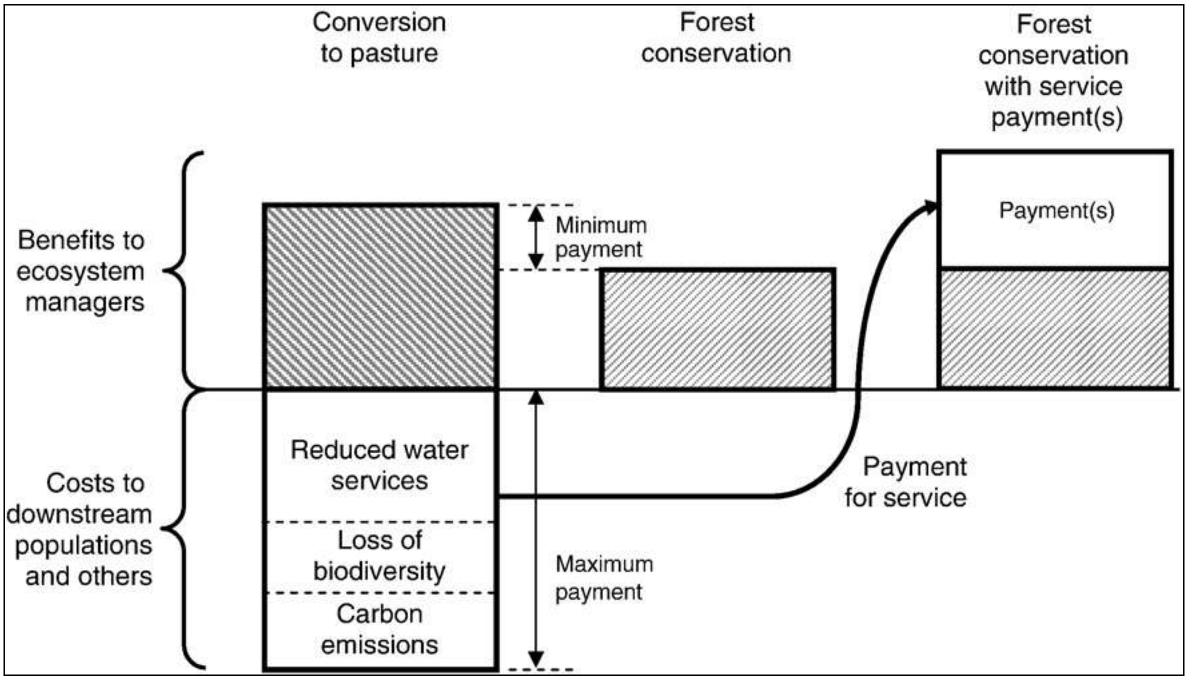

Figure 9 The logic of payment for environmental services. Adapted from Pagiola and Platais 2007.

5.3.4.2 Study cases of Payment for Hydrological Ecosystem Services

Around the world, schemes of Payment for Hydrological Ecosystem Services (PHES) are supported by the fact that forests generate several hydrological services, for example: a) water flow regulation: maintenance of dry season flows and flood control, b) water quality maintenance: sediment load control, c) nutrient load control (e.g. phosphorous and nitrogen), chemical load control, and salinity control, d) erosion and sedimentation control, e) land salinization reduction/water table regulation, and f) maintenance of aquatic habitats (e.g. maintaining water temperature, shading rivers/streams, ensuring adequate woody debris in water). Unfortunately, scientific information to support these assumptions is scarce and landscape variability (soil type, hydrogeology, type of forest, slope grade, and weather conditions, among others) difficult that results obtained in a microwatershed could be used in another place (Landell-Mills and Porras 2002; Kaimowitz 2005). Several examples of these schemes of PHES are shown in the following paragraphs.

In 2002, Landell-Mills and Porras developed an interesting recompilation of experiences about schemes of payment for ecosystem services (PES) including hydrological ES that were implemented around the world. In total, authors reviewed 61 study cases related to schemes of Payment for Hydrological Ecosystem Services (PHES) (Table 6). Authors indicated that forests are associated with a range of services delivered at a watershed level. Unfortunately, these assumptions are supported by scarce scientific evidence that concluded that forests do not offer a panacea for the loss of watershed services. In fact, forests contributions depend on a range of site-specific factors, including climate, terrain, soil composition, and forest management. In most cases, forests will add greater value when they are incorporated into a broader watershed protection strategy involving other land uses and physical protection measures such as contour bonding, terracing and check dams. Finally, authors generated the following conclusions: a) given the large number of stakeholders involved in watershed protection, payments tend to be channelled through intermediaries, allowing buyers and sellers to contract out the negotiation and conclusion of deals, overseeing implementation and enforcing contracts. Intermediaries are also valuable mechanisms for pooling funds from a group of beneficiaries and/or collecting user fees. In more advanced countries, over-the-counter trading using pre-packaged commodities is being promoted, in some cases alongside clearing-house systems, b) For the most part, markets have emerged as a result of a growing willingness to pay the beneficiaries. This is often the result of improved understanding of the benefits provided by watersheds and the growing threats they are facing. In more developed countries, new government regulations for improved water quality have been the major force behind investment. Due to the difficulties of excluding non-payers from watershed services, suppliers have generally lacked leverage for demanding payments. Yet, as commodities and payment mechanisms become increasingly sophisticated, supply-driven markets are no longer unthinkable, c) Amidst the flurry of activity to promote payments for watershed protection, little attention has been given to impacts.

Table 6 Summary of the watershed services and their commodities analyzed by Landell-Mills and Porras in 2002.

Service	Commodity	Number of Cases
Water quality	Watershed protection/ best management practice contracts	6
	Water quality credits	4
	Land acquisitions	4
	Conservation easements	2
Water table regulation	Salinity credits	1
	Transpiration credits	1
	Salinity-friendly products	1
	Stream flow reduction licenses	1
Aquatic habitat protection	Best management practice contracts	3
	Salmon Safe products	1
	Land leases	1
	Salmon habitat restoration contract	1
	Salmon habitat credits	1
	Water rights	1
	Land acquisition	1
Soil contaminant control	Ecolotree plantings	1
Water quality and regulation	Watershed protection contracts	20
	Protected area	10
	Land acquisition	4
	Water rights	2
	Watershed lease	1

Questions need to be asked as to whether the market provides a preferable mechanism for delivering watershed services to tried and tested regulatory systems. The literature provides little insight on this issue. For the most part, studies offer superficial reviews of economic, social and environmental benefits with virtually no assessment of costs. Moreover, the literature fails to convince that markets offer the optimal way of achieving improved watersheds. The lack of attention to equity impacts of emerging payment schemes raises a number of concerns, d) concerns over equity impacts are reinforced by the analysis of constraints to market development. Even where the gains from trade are significant, the significant transaction costs involved introduce serious barriers to entry for anyone lacking financial resources, managerial and coordination skills, technical knowledge and political connections. Moreover, the costs of participating in emerging markets raises the number of individuals living in a watershed, weakens the government's regulatory capacity, decreases hydrological data reliability, and lessens property rights security. While developing countries face severe hurdles in establishing markets for watershed protection, it is the poorest groups in these countries that risk marginalisation. Governments have a critical role to play in ensuring markets work for the benefit of all sections of society, not just the most powerful (Landell-Mills and Porras 2002).

In 2002, Martha Echavarria presented an analysis on FONAG (Fondo del Agua) in Ecuador. The target of this institution is to finance the management and conservation of watersheds that surround Quito city. This city has a population over 1.5 million. It is located in an Andean valley at 2,800 meters above sea level. In total the city consumes around 7 m^3 of water per second. Drinking water is provided by a public municipal company, Quito Metropolitan Area Sewage and Potable Water (EMAAP-Q), and supplies over 260,000 homes. About 80 per cent of Quito's drinking water comes from two protected areas, the Cayambe Coca Ecological Reserve and the Antisana Ecological Reserve. These reserves cover 520,000 hectares. Their natural ecosystems are "Páramos" (high-altitude Andean grasslands), and cloud forest. Although natural reserves are formally protected for conservation, they face a number of threats. More than 7,000 people live within Cayambe Coca. They require water for their crops and have ancestral rights to use grasslands for livestock. Additionally, over 20,000 people live in communities and agricultural cooperatives surrounding the reserves. Their principal activities are diary production and the sale of timber. People believe that these practices affect the "Páramos" hydrology behavior. However no hydrological studies have been developed. The solutions to face these threats have been watershed valuation, land purchase or economic compensation, controlling illegal logging, hunting, fishing, burning, overgrazing, and trash disposal, targeted land management, and implementing sustainable production systems. In 2000 FONAG stepped in as the institution that connects highland farmers with Quito city water users. In the beginning FONAG received funding from EMAAP-Q, USAID, and The Nature Conservancy. The endowment is not expended, only the financial returns are used. Unfortunately, financial performance was reduced by Ecuador financial crisis and fund revenues were lower than expected. Also, FONAG is particularly vulnerable to unexpected reductions in payments because its revenues depended on EMAAP-Q. Thus, the long-term contracts would be difficult to support. Finally, taking into consideration that FONAG is still very new, a few lessons are beginning to emerge; a) Political leadership, b) water user's support, c) concentration of power in EMAAP-Q, d) water pricing increases, and e) scientific knowledge (Echavarria 2002).

Research was developed in Balian a *barangay* (or village) in the Municipality of Pangil, Province of Laguna, Philippines. It is located approximately 90 km south of Manila, and Laguna is one of four provinces that are being advertised as alternative industrial centres to Manila. The municipality is located in the north-eastern part of the province, with the Sierra Madre mountain range bordering both the east and the west. There are approximately 500 families living in Balian. Farming is their main source of livelihood. Farms owned through inheritance are mostly planted with fruit-bearing trees, while the smaller farms are planted mostly with rice. Labour wages are around 2 USD per day. Most of the land can be bought and sold. In the past, these farmlands were subdivided into small lots and were given tax certificates. These in turn were used to issue land titles to the owners. In 1925, long before it became fashionable for people to organize themselves to fight for environmental issues, the people of Balian mobilized themselves to tap water from upland streams and rivers for their domestic water supply. They formed a group called "Samahan ng Bailan Para Sa Pagpapauwi ng Tubig Inumin" (SBPTI), which literally means Organization of Balian for Providing Drinking Water. The group took care of building and maintaining their crude water pipes carved out of bamboo poles which ran from an identified water source upstream, and ensured that water reached every household within its jurisdiction. It is based on the principle of self-help and is purely voluntary. All residents of the community are automatic members, and any project that concerns water should be coordinated with them. Part of the upstream area surrounding Pangil and Balian was logged in the 1960s and 1970s, and later divided into upland agricultural plots. Interwood (International Hardwood and Veneer Company) owned the logging concession. After the logging concession denuded the forest of hardwood trees, small-scale loggers and charcoal-makers continued cutting secondary-growth trees. Slash-and-burn farmers encroached into the area through the years. Carabao grazers grew in number, contributing to soil erosion and siltation. All of these contributed to the denudation of the Balian watershed. There was nothing in the literature that suggested that the organization protested the presence of the logging concessionaire in their area. Most probably, this was because during that time, water supply was constant and water quality did not deteriorate. During the late 1980s, however, local residents started noticing that the water was less abundant. Whereas before this period, water had flowed continuously for 24 hours a day, they started noticing that water would not be available during certain times of the day, particularly during the summer months. Furthermore, during the rainy season, the Dakil River, located in the lower portion of Balian, began to flood more often, and floodwaters were muddier than before. Landslides started to occur, and the climate was not as cool as before the time that the watershed began to lose its trees. Finally, the waterfalls in the area were not as large as they had been previously. Thus, in the late 1980s there was a resurgence of initiative among the SBPTI members. Along with some local and national government officials, SBPTI started discussing how they could solve their dwindling water-supply problem. They took matters into their own hands and passed a resolution asking the municipal government to declare a 50-metre radius from all water sources as protected. DENR went further and suggested that they increase the boundary to a 100m radius around the water source. The provincial government finally declared a 100m radius around all water sources as protected. Much remains to be done. The group "Lingap Kalikasan" (LK) or Care for Nature an extension of SBPTI, claims they have only covered roughly 40 per cent of the total land area surrounding their two existing water sources. They must negotiate with other landowners to complete their program to establish buffer zones and reforest their watershed. At present the LK relies on its good relations with the incumbent officials and on its own track record. It has no legal mandate to serve as the manager of the watershed, which its members intend to correct with the pending resolution declaring LK as the legal management body of the watershed. The SBPTI continues to exist as part of the LK, with its main responsibility limited to maintaining the water supply system of Balian. Some of the bamboo pipes have been replaced with rubber ones over the years. However, there are still portions of the water supply system that rely on bamboo. Carabao grazing and increased population in the upland areas have periodically caused these pipes to break, thus affecting the water supply of residents below. In order to ensure the continuous supply for all residents, SBPTI continually conducts monitoring and rehabilitation activities, the latter usually involving replacement of cracked or worn-out water pipes. Furthermore, SBPTI regularly conducts cleaning activities for the intake tanks, which are located near the water source. Such activities entail raw material costs. To pay for the material used to maintain the system, the SBPTI now charges PhP15 per household per month as water-supply fees. Fees were originally adopted in the 1990s, at a low rate of PhP5 per household per month. The fee, however, is only to cover the cost of raw materials and is not a payment for the water. Still, the revenue generated is insufficient to cover all material expenses, and the organization depends on donations from the municipal and *barangay* government units as well as from wealthy landowners in the area. Labour for planting, water-system repairs and maintenance is free, as members of the SBPTI maintain the water system themselves. Researchers concluded that the formation of both the SBPTI and the LK was initiated by the community residents themselves. Government had nothing to do with setting them up. NGOs who have worked in the area likewise attest to the pure or unadulterated characteristic of these organizations, such that their growth was purely determined by internal dynamics, and was not forced upon them by outside influence. Thus, residents have always ‘owned’ the organizations, and have always felt they had a major stake in the organizations’ programs and projects. Because of this sense of ownership, commitment to their activities is very high, further ensuring the success and growth of the organizations (Rosales 2003).

An analysis of a local scheme of Payment for Environmental Services (PES) for Birds and Watershed protection was implemented in the Los Negros Valley, Bolivia. In the last 25 years, farmers in the town of Los Negros claim that dry-season water flows have been reduced by fifty percent. Although downstream landowners blame upland deforestation, the growing scarcity is probably a combined result of factors such as land-use changes, higher water off-take from irrigators upstream (due to increased population and more intense cropping), and losses during water distribution. In the Los Negros Valley, a recently initiated PES scheme involves the simultaneous purchase of two environmental services. The US Fish and Wildlife Service is paying for habitat protection for migratory bird species, while downstream irrigators through the Municipality of Pampa Grande are paying to conserve the same upland forest and “puna” native central Andean alpine grassland vegetation that likely helps maintain dry-season water supplies. The service buyers are jointly compensating individual upstream landowners through the provision of benefits such as beehives, apicultural training, and barbed wire. Transfers are made each year, conditional upon approval by a local monitoring and enforcement committee that verifies that the native vegetation has indeed been protected. This scheme, the first in this country, was developed in 2003 by Fundación Natura Bolivia. To develop this scheme several situations were taken in account. First, only 1,328 people lived in the upper part of the watershed, centered on the community of Santa Rosa, which facilitated discussions and negotiations. Second, in Los Negros town, irrigators constituted a potential long-term "service demander" group who perceived an increasing water-scarcity problem. Third, a clear local perception of forest and water links existed. Above the upstream forests clouds were almost permanently present and downstream farmers had a strong belief, albeit unsubstantiated scientifically, that forest protection and the maintenance of water supplies were linked. Finally, the short linear distance from Santa Rosa to Los Negros town made stakeholder coordination more tractable. All upper watershed landowners have been invited to voluntarily enter the PES program. Basically, service sellers choose to participate in the contingent conservation scheme at the established PES rates, decide what plot to enroll, and determine the time period of their contract. Building trust and confidence in the scheme among service providers has been a slow but positive process. Five farmers initially participated in the program in 2003, protecting 592 ha. They were joined in 2004 by seven more that protected an additional 252 ha, and by 2005 a total of 21 landowners were protecting 1,111 ha. As of August 2007, 46 land owners were protecting 2,774 ha of native vegetation, of which approximately 1,335 ha were cloud forest. One noteworthy implementation feature of the scheme is the non-cash mode of payment. During the negotiation phase (November 2003–January 2004), the environment committees of Santa Rosa and Los Negros met and after some iteration agreed on the annual payment of one artificial beehive for every 10 ha of forest protected for a year (a cash equivalent of 3 USD/ha/year), plus the value of accompanying apicultural training. However, three main obstacles were identified; a) A lack of a credible downstream institution that could ensure service buyers will contribute equitably to the scheme, b) a lack of trust by downstream farmers that payment to upstream farmers would actually lead to more conservation, c) a fear among upstream farmers that the initiative is designed to appropriate their land. An additional problem was that a base line in water flow and bird species diversity was not determined. Also, the lack of hydrological data meant that many basic dynamic relationships remain unknown. For example, it is not clear how much of the observed reduction in downstream dry-season water stream flow is due to increased competition from upstream irrigator demand, rather than reduced supply. Nor is it known how much of reduced water supply would be due to factors other than local land-use changes, for example, regional climate change. Even if PES implementers are correct to assume that loss of cloud-forest cover has and will continue to cause reductions in dry-season stream flow, other important unknowns include the magnitude of that forest–water relationship (i.e. how many liters/second of dry-season stream flow will be saved by the protection of one additional hectare?) and whether there are threshold effects (i.e. reduced marginal water gains, once a minimum of hectares have been protected/deforested). Finally, authors concluded that this local scheme provided lessons that could help others decision-makers in the application of PES policies. For example; a) intensive data collection before policy implementation, b) current payment amount is enough to protect marginal lands with low productivity and if the objective is to increase the protected area the payment needs to cover the land use opportunity cost, c) to support the policy payment only with municipal and international NGO's funds is an unsustainable strategy, lowland water users need to pay for their water consumption (Asquit *et al.,* 2008).

Additional research was developed in Mexico, with the target to analyze the policy of Payment for Hydrological Environmental Services (PHES) implemented throughout the country by the National Forest Commission (CONAFOR) since 2003. The Program of Payment for Hydrological Environmental Services of Forests (Pago de Servicios Ambientales Hidrológicos-PSAH) was conceived as playing a key role in those areas of hydrological importance where other policies have proven ineffective. It provides economic incentives to avoid deforestation in areas where severe water problems are linked to deforestation, but where commercial forestry cannot compete against agriculture or ranching. PSAH consists of direct payments to landowners with primary forest cover (forests in a good state of conservation). Part of the PSAH's innovative approach is that it is funded through an earmarked portion of federal fiscal revenues from water fees, creating a link between those who benefit from the environmental services and those who provide them. The policy was also motivated by fairness. Without PES, Mexico would face a dilemma in many areas where forest owners are poor: effectively applying regulations that prohibit land use change would reduce deforestation rates, but eliminate income generating opportunities. Mexico thus faced real trade-offs between poverty reduction and environmental protection, between local and global benefits, and between the welfare of present and future generations. The objective of paying for forests' environmental services is to avoid these tradeoffs, and protect natural capital. The Mexican government invests 27.3 million USD/year, in the payment of hydrological ecosystem services, which comes from citizens' water use taxes (rivers, lakes, lagoons and groundwater). Unfortunately, the hydrological information to support the relationship between forests and water indicated that the creation of a hydrological ecosystem service respond to site-specific situations and not due to the presence of the forest itself. Despite the uncertainty of a true forest-water relationship the policy decision was to go forward with the program for two reasons. The first invoked the precautionary principle (OECD 2001), given the uncertainty of forest-water connections, it was better to err on the side of caution. Moreover, some officials considered avoiding deforestation worthwhile purely for biodiversity conservation. The second reason was that many deforested areas fulfill the conditions for a damaging impact of deforestation on watersheds; for example, most pastures are overgrazed and their soil is compacted, while only a handful of dams have infrastructure to reduce siltation. The PSAH was focused in critical recharge areas, protected areas, mountains and zones with a high level of poverty. Economic theory indicated that PES needs to be based either on their value to consumers or on the opportunity cost of providing them. However, there was so little information about the value of environmental services in México that a fixed-price program with only two tiers was decided on beforehand. These tiers are differentiated only by forest type, with cloud forests in the upper tier. Under a fixed payment system, two circumstances deserve special attention. The first circumstance is when the opportunity costs of preserving forests are zero. This occurs when agriculture and grazing are not profitable, or when they are less profitable than forest activities. In this case, forests would be preserved even without the PSAH program. Owners of such land would clearly be interested in participating in the PSAH program, since they would receive payments without actually sacrificing anything. On the other hand, when opportunity costs are higher than the payment offered by the program, owners of forests that would yield a higher income as agriculture, livestock, industrial, or urban projects would choose not to participate in the program. If these benefits are higher than the environmental benefits that would be generated, then society is better off if such forests remain outside the program.

However, if the environmental benefits are higher than both the opportunity costs and the amount offered, then the single price has effectively prevented a welfare-improving transaction (Pagiola *et al.,* 2002). After long negotiations the payment was established at 36.4 USD/year/ha of Cloud Forest and 27.3 USD/year/ha for the other forest types. Results indicated that from 2003 to 2005, 480,100 hectares were selected to participate in the PSAH. In fact, there were not enough resources to cover the total amount of solicitudes. Finally, authors commented that PSAH in México generated some lessons. For example; a) The nature of the public good of water services made the Mexican government opt for a system in which it would act as intermediary between service providers and users, instead of creating a framework for private transactions between them, b) the Mexican government created a nation-wide program, instead of a series of local ones, because financing was obtained by earmarking a federal water fee. It has the benefit of attending large scale watersheds or aquifers but at the cost of having a program not perfectly tailored to local needs and conditions, and not linking directly contributions by users and payments to the forest owners that provide most of their environmental services, c) the CONAFOR-PSAH is not a market. The Mexican government is acting as a monopolistic buyer on behalf of water users. It establishes a price and waits to be offered forests to set aside for conservation, d) PES programs are not a panacea for deforestation or for water or biodiversity problems, but they certainly are a valuable addition to the set of policies available to solve them. They have the potential of correcting market failures in a straightforward way, defining some property rights over the environmental services in favor of the forests owners, characteristics that can improve equity while producing a more efficient allocation of resources (Muñoz-Piña *et al.,* 2008).

In 2008, Stefano Pagiola developed an analysis of the “Pago por Servicios Ambientales” (PSA) program that was implemented in Costa Rica since 1997. This scheme is supported by the Forest Law No.7575 that recognized four environmental services provided by forest ecosystems: a) mitigation of greenhouse gas emissions; b) hydrological services, including provision of water for human consumption, irrigation, and energy production; c) biodiversity conservation; and d) provision of scenic beauty for recreation and ecotourism. The law provides the regulatory basis to contract landowners for the services provided by their lands, and establishes the National Fund for Forest Financing (Fondo Nacional de Financiamento Forestal, FONAFIFO). Over the years, the PSA program has evolved considerably. In 2000, the array of instruments was simplified to only two: timber plantations and forest conservation. An agroforestry contract was introduced in 2004, and a natural regeneration contract is currently being introduced. Initially completely untargeted, the PSA program is moving towards a greater degree of targeting. On the demand side, FONAFIFO has secured agreements with many water users to pay for watershed conservation, and developed streamlined instruments to facilitate this. It was an early entrant in the global carbon market. Funds to support the PSA in Costa Rica come from several sources with FONAFIFO receiving 3.5% of its revenues from a fossil fuel sales tax (about 10 million USD per year). From 2001 to 2006, the PSA program was supported by a loan from the World Bank and a grant from the Global Environment Facility (GEF) through the Ecomarkets Project. A new project, Mainstreaming Market Based Instruments for Environmental Management (MMBIEM), will continue supporting the program from 2007. The PSA Program has also received a grant from the German aid agency KfW through the Huetar Norte Forest Program. Efforts have also been made to charge various service users for the services they are receiving. In the case of Hydrological Services, FONAFIFO has dedicated substantial efforts in negotiations with water users for them to pay for the water services they receive and has reached a number of agreements. In total, eleven agreements were developed with the objective to protect an area of 18,772 hectares. However, only 9,861 hectares were enrolled in 2004. In addition, the payments to the landlords to provide the ecosystem service were variable (from 15 to 45 USD/ha/year during the five years). In 2005, Costa Rica expanded the use of water payments by revising its water tariff (which previously charged water users near-zero nominal fees) and introduced a conservation fee earmarked for watershed conservation. This new tariff was instituted by Presidential decree, and will be embedded in a new Water Law which is under consideration in the National Assembly. The water tariff represents a shift from voluntary agreements to compulsory ones. It will result in a rapid and substantial increase in the amount of funding available for conservation. After five years of efforts, voluntary agreements generated about 0.5 million USD annually. Over a similar period, the water tariff is likely to generate ten times the amount of the previous program. The move to compulsory payments has an important downside. In addition to funds, payments made under voluntary agreements also generate information, on which areas are important for water supply, and on what kinds of services need to be protected. Voluntary agreements also contain an explicit feedback loop, as water users can withhold payment if they do not receive the desired services. Neither of these desirable characteristics is present in the case of compulsory payments such as those mandated by the new water tariff. As fees are uniform nationwide (for a given type of user), prioritization must depend on FONAFIFO undertaking its own studies of conservation needs and getting them right. When fee payment are compulsory, water users have no leverage to request changes if the program fails to improve water services. PES programs can suffer from various kinds of inefficiency: a) offering payments that are insufficient to induce adoption of socially-desirable land uses, thus causing socially undesirable land uses to remain in use, b) inducing the adoption of socially-undesirable land uses, that supply environmental services, but at a cost higher than the value of the services, and c) paying for adoption of practices that would have been adopted anyway. In addition, the author commented that the type and size of payments provided by a PES program affect the likelihood of these problems arising. Costa Rica's PSA program offers a relatively low, undifferentiated, and mostly un-targeted payment. Thus it will only tend to attract participants whose opportunity cost of participation is low, or negative. Such a program is very likely to experience the first type of problem, in which socially-desirable land use practices are not adopted because the payment offered is insufficient. The extent of the impacts of the PES program to successfully generate environmental services is unfortunately impossible to determine. Although the PSA program has established a strong system to monitor land user compliance with payment contracts, the program remains weak in monitoring its effectiveness in generating the desired services. Also, water service agreements indicate that the PSA program is often fails to conserve areas that could potentially generate environmental services. Finally, the author concluded that Costa Rica's PSA program has been one of the conservation success stories of the last decade. Its approach has been widely studied, and to an increasing degree imitated. FONAFIFO has hosted dozens of official delegations from countries throughout the world who have come to study the PSA program. However, the PSA program has many weaknesses, and it is as important to learn from its mistakes as it is to learn from its successes. The other major weakness in the PSA program is its lack of data on the extent to which its activities are, in fact, generating environmental services. The efficiency and long-term sustainability of the program demands an understanding of how different land use practices contribute to generating the environmental services (Pagiola 2008).

A study developed in Ecuador analysed a local scheme of Payment for Hydrological Environmental Services (PHES) located in the Municipality of Pimampiro. This municipality of 12,915 inhabitants consumes fresh water supplied by the upper Palaurco River watershed. The target recipients of the PES system were 27 households who owned 638 hectares (ha) in the Nueva América Cooperative, located 32 km from Pimampiro. Nueva América occupied the right back of the Palaurco River. Further downstream, part of the river's flow was piped to the Pimampiro urban area, providing a water flow of 60 l/s. Ten percent of Nueva América's forests and 18% of its páramos (native Andean alpine grasslands) had progressively been converted to annual crops and pasture. The PES system was designed to halt and reverse this incremental agricultural frontier expansion. Currently, 19 Nueva América families (70%) participate in PHES, with 550 ha enrolled (87% of total area). PHES contracts initially lasted for five years, but at the end of 2005 they were renewed for an indefinite period. Each household receives 6 USD/year/ha of intervened forest or páramo, 8 USD/year/ha of mature secondary forest, and 12 USD/year/ha of primary forest or páramo. This was financed by a 20% water consumption surcharge on the 1,350 families in Pimampiro with water meters (Echavarría *et al.,* 2004), plus the interests generated by a water fund (donated by the Ecuadorean Corporation for the Development and Renewable Resources: CEDERENA), which initially held 15,000 USD (about 500 USD annually). In the case of biophysical information to support this scheme, the author commented that available baseline information referred exclusively to land use, not to service provision itself. How different water services (annual flow, dry season flow, water quality) were affected by potential land-use changes in Nueva América have not been studied (site-specific hydrological analysis of water-retention capacity and runoff rates in natural páramos and forests compared to deforested areas). The promotion of natural vegetation cover by PES was largely based on the precautionary observation that these vegetation types had provided a satisfactory water service in the past, while the hydrological effects of conversion remained widely uncertain. Rather than directly guaranteeing improvements in water quality or quantity, PES-induced conservation functions were used as an insurance against certain environmental risks and fluctuations. Authors concluded that this PHES was a successful strategy to protect watershed highlands, and a feasible proposal to replicate in other parts of Ecuador. However, it is important to underline that in this study case, some site specific situations influenced its success, for example: a) Highlands have low opportunity costs, b) people in the highlands live under extreme poverty, c) a decrease in livestock activity profitability, and d) a Federal Forest Law that forbade cutting forest or burning páramos in this altitudes (Wunder and Albán 2008).

5.3.4.3 Recommendations to improve schemes of PHES

An electronic workshop developed by FAO in 2002 generated several recommendations for the design of policies of payment for hydrological environmental services. The workshop was developed around three main questions; a) What are the biophysical impacts of upstream land uses on downstream water resources in rural watersheds?, b) How can these impacts be valued in terms of benefit and costs to downstream people?, and c) Which mechanisms can be identified to share these benefits and costs among upstream and downstream land use water users? Some comments and recommendations were:

1) The knowledge of natural processes relative to the impact of anthropogenic land use change is critical for development of effective and appropriate response strategies.
2) Watershed management is understood to include livelihood concerns, including both socioeconomic as well as biophysical components.
3) Impacts and responses in land use activities on hydrological and sediment-related processes need to be considered at the appropriate scale. Efforts to change land use practices and to implement mechanisms for sharing of benefits and costs will be most successful in response to measurable problems in small basins.
4) Site-specific process models should be developed that allow local conditions to be considered in the design of interventions.
5) Assessment of land use impacts on water resources should include examination of governance and institutional arrangements that determine the distribution of benefits and costs among stakeholders, including those associated with uncertainty.
6) Due to the complexity of landscape processes and the long time lag between cause and effect, uncertainty is inherent in any scientific findings and assumptions about land–water interactions. This uncertainty needs to be made very explicit to avoid the emergence of new myths.
7) To value costs and benefits of changes in specific land use practices, the ideal is to be able to identify how those changes will affect the availability of specific resources of concern, and their value to users. This can be made more manageable by dividing the watershed into hydrological sub-units based on uniform agro-climatic conditions.
8) Economic instruments are likely to be more effective if they are combined with education and awareness building activities, and participation by affected people, for example through watershed organizations. Successful mechanisms have evolved from a narrow to a broad focus or from management of a water body to the whole catchment area.
9) The development of stakeholder associations with decision-making autonomy should be promoted starting at the smallest scales, to ensure that local interests are represented in negotiations over larger-scale problems, and to reduce transaction costs. NGO^{s} can play an important role in this institution-building process.

10) Establishment or recognition of property rights should not overlook customary tenure arrangements that may otherwise be put at a disadvantage in formal land titling projects.
11) For benefit-sharing arrangements to be successful, stakeholders must at least have a common understanding and agreement about the nature of expected impacts, the approximate magnitude of costs and benefits, and also about areas of uncertainty. This is best achieved at smaller scales, where anthropogenic impacts can be verified and distinguished from natural processes. At such scales, people will be more likely to be willing to make the necessary commitments for resolving interest conflicts and reaching agreements.

5.3.4. Conclusions

Literature review underline that, ecosystem services faced a paradoxical situation. On the one hand, ecosystems produced several services that are used by society, and in the special case of the hydrological ecosystem services, they are necessary to support basic human requirements. Unfortunately, notwithstanding the relevance of these ecosystems services, they continued to be under human pressure. In answer to that, governments implemented “Command and Control” approaches with the objective to protect and to regulate ecosystem services use. Unfortunately, this strategy sometimes failed due to lack of legal regulation, inadequate budget, exhaustive bureaucracy, and corruption. The development of environmental services markets appeared like an answer to protect fragile ecosystems with the participation of the society. However, one problem that policymakers need to face is to calculate the value of the ecosystem to protect. The Contingent Valuation methodology was used widely to determine, under the demand point of view, which is the willingness to pay to protect an ecosystem service. Unfortunately, in developing countries the use of this method was questioned due to the socioeconomic characteristics of the citizens, and the lack of knowledge about ecosystems functions. Another option to calculate the value of an ecosystem is to calculate its opportunity cost (OC). In this method, the value of an ecosystem is the net income of a feasible productive activity that could be developed in the area occupied by the ecosystem, and in theory, the amount calculated will be the amount to pay at the landlords to protect the ecosystem, and to avoid natural land use conversion. Finally, Participatory Approach was implemented in rural communities, with the objective to value natural resources. This method involves communities in their decision making processes, and takes into account citizens point of view and their proposals to confront the problem. In conclusion, there are several methods to calculate the value of an ecosystem; all of them have advantages and disadvantages, and the decision of which method will be implemented need to consider several aspects, for example: citizens environmental culture, socioeconomic situation, land tenure rights, ecosystem fragility, legal framework, biophysical information, among others. When the value of an ecosystem is calculated the next step could be to use this information to design a policy of Payment for Hydrological Ecosystem Services (PHES). However, literature review indicated that the OC of the land is rarely considered in the PHES polices implemented in developing countries (i.e. PSA in Costa Rica or PSAH in México). Perhaps this situation is developed due to the fact that the OC of the land could change enormously from one site to other. Contrary to that, information about the OC of the land could be used more appropriately in local schemes of PHES that consider small watershed (< 10 km^2).

6 References

Alavalapati, JRR; Shrestha, RK; Stainback, GA; Matta, JR. 2004. Agroforestry development: An environmental economic perspective. *Agroforestry Systems* 61: 299–310

Anyaegbunam, C; Mefalopulos, P; Moetsabi, T. 2004. Participatory rural communication appraisal: Starting with the people. A handbook (2^d Ed.). FAO. Rome. 160 p.

Aylward, B. 2002. Land-use, hydrological function and economic valuation. Proceedings of the UNESCO symposium: Forest-Water-People in the humid tropics. Kuala Lumpur, Malaysia. 47 p.

Arnell N.W. 1999. Climate change and global water resources. *Global Environmental Change* 9: S31-S49

Arrow, K; Solow, R; Potney, PR; Leamer, EE; Radner, R; Schuman, H. 1993. Report of the NOAA panel on Contingent Valuation. The National Oceanic and Atmospheric Administration. 67 p.

Asquith, NM; Vargas, MT; Wunder S. 2008. Selling two environmental services: In-kind payments for bird habitat and watershed protection in los Negros, Bolivia. *Ecological Economics* 65: 675 – 684.

Ataroff, M; Rada, F. 2000. Deforestation impact on water dynamics in a Venezuelan Andean cloud forest. *Ambio* 29 (7): 440 -444

Barraza L; Pineda J. 2003. How young people see forest in México: a comparison of two rural communities. *Unasylva*: 213 (54): 10 - 17

Bary, F; Wood, MK; Murray, L. 1993. Livestock grazing impacts on infiltration rates in a temperate range of Pakistan. *Journal of Range Management*. 46(4): 367-372

Berbel, J; Goméz-Limón, JA. 2000. The impact of water-pricing policy in Spain. An analysis of three irrigated areas. *Agriculture Water Management*: 43(2): 219 - 238

Bewket, W; Sterk, G. 2002. Farmers' participation in soil and water conservation activities in the Chemogawa watershed Blue Nile basin, Ethiopia. *Land Degradation and Development* 13: 189 – 200.

Bishop GF; Tuchfarber, AJ; Oldendick RW. 1986. Opinions on fictitious issues: the pressure to answer survey questions. *The Public Opinion Quarterly* 50 (2): 240 –250.

Bishop, J; Landell-Mills, N. 2002. Forest Environmental Services: An overview. *In*: Selling forest environmental services: Market-based mechanism for conservation and development. (Pagiola, Bishop and Landell-Mills. Eds). EARTHSCAN. London. 15 – 35 p

Boardman, AE; Greenberg, DH; Vining, AR; Weimer, DL. 2001. Cost-benefit analysis: Concepts and practice. 2^d edition. Prentice Hall, Inc. New Jersey, USA. 526 p.

Bockstael, NE; Freeman III, AM; Koop RJ; Portney, PR; Smith, VK. 2000. On measuring Economic Values for Nature. Environmental Science & Technology. 34(8): 1384 – 1389.

Bolaños, JD. 2004. Programa de recuperación y conservación de microcuencas (PROCUENCAS) en la provincia de Heredia, Costa Rica. In: In: Electronic Forum on Payment Schemes for Environmental Services in Watersheds. FAO, REDLACH. Santiago de Chile. 10 p.

Bosch JM; Hewlett JD. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology*, 55: 3 - 23

Brady, NC; Weil, RR. 2002. The nature and properties of soils. (13th ed.). Prentice Hall (eds). New Jersey, USA. 960 p.

Bruijnzeel, L.A. 1986. Environmental impacts of (de)forestation in the humid tropics: a watershed perspective. *Wallaceana* 46: 3 – 13

Bruijnzeel, LA. 1990. Hydrology of moist tropical forest and effects of conversion: a state of knowledge review. National Committee of the Netherlands for the International Hydrological Programme-UNESCO, International Institute of Aerospace Survey and Earth Sciences. Amsterdam, the Netherlands. 230 p.

Buckhouse, JC; Gifford, GF. 1976. Sediment production and infiltration rates as affected by grazing and debris burning on chained and seeded Pinyon-Juniper. *Journal of Range Management.* 29(1): 83 – 85

Burgess, PF. 1971. The effect of logging on hill *Dipterocarp* forests. Malayan Nature Journal 24: 231-237. *In*: Bruijnzeel, LA. 1990. Hydrology of moist tropical forest and effects of conversion: a state of knowledge review. National Committee of the Netherlands for the International Hydrological Programme-UNESCO, International Institute of Aerospace Survey and Earth Sciences. Amsterdam, the Netherlands. 230 p.

Campos, JJ; Alpízar, F; Louman, B; Parrotta, J; Porras, IT. 2005. An integrated approach to forest ecosystems services. Global Forum, Forest in the global balance, Changing paradigms. 98 –116.

Carbon, BA; Roberts, FJ; Farrington, P; Beresford, JD. 1982. Deep drainage and water use of forests and pastures grown on deep sands in a Mediterranean environment. *Journal of Hydrology*, 55: 53-64

Comisión Nacional del Agua (CNA). 2008. Estadísticas del Agua en México. CNA. México D.F. 233 p.

CONAPO (Consejo Nacional de Población) 2006. Consulted March 12th 2006. On line: http://www.conapo.gob.mx/00cifras/00indicadores/00.xls

Cornes, R; Sandler, T. 1996. The Theory of Externalities, Public Goods and Club Goods (Second Edition). Cambridge: Cambridge University Press. 590 pp. *In*: Landell-Mills, N; Porras, IT. 2002. "Silver bullet or fools' gold? A global review of markets for forest environmental services and their impact on the poor". Instruments for sustainable private sector forestry series. IIED, London, UK. 272 p.

Chagoya F,JL; Iglesias G.L. 2009. Esquema de pago por servicios ambientales de la Comisión Nacional Forestal, México. *In*: Políticas y sistemas de incentivos para el fomento y la adopción de buenas prácticas agrícolas: como una medida de adaptación al cambio climático en América Central (Sepúlveda and Ibrahim Eds.). CATIE. Serie Técnica. Informe Técnico No. 377: 189 – 204 p.

Cummings, R; Brookshire, D; Schulze, W. 1986. Valuing environmental goods: An assessment of the contingent valuation method. 288 p. *In*: Boardman, AE; Greenberg, DH; Vining, AR; Weimer, DL. 2001. Cost-benefit analysis: Concepts and practice. 2^{d} edition. Prentice Hall, Inc. New Jersey, USA. 526 p.

Datta, SK; Virgo, KJ. 1998. Towards Sustainable Watershed Development through People's Participation: Lessons from the Lesser Himalaya, Uttar Pradesh, India. *Mountain Research and Development* 18 (3): 213 – 233.

De Graaf, NR. 1986. A Silvicultural System for Natural Regeneration of Tropical Rainforest in Suriname. PhD thesis, Agricultural University, Wageningen, 250 pp. *In*: Bruijnzeel, LA. 1990. Hydrology of moist tropical forest and effects of conversion: a state of knowledge review. National Committee of the Netherlands for the International Hydrological Programme-UNESCO, International Institute of Aerospace Survey and Earth Sciences. Amsterdam, the Netherlands. 230 p.

Diamond, PA; Hausman, JA. 1994. Contingent valuation: is some number better than non number? *The Journal of Economic Perspectives* 8 (4): 45 – 64.

Echavarria, M. 2002. Financing watershed conservation: The FONAG water found in Quito, Ecuador. *In*: Selling forest environmental services: Market-based mechanism for conservation and development. (Pagiola, Bishop and Landell-Mills. Eds). EARTHSCAN. London. 91 – 101 p.

Echavarria, M. 2004. Algunas lecciones sobre la aplicación de pagos por la protección del agua con base en experiencias en Colombia y Ecuador. In: Electronic Forum on Payment Schemes for Environmental Services in Watersheds. FAO, REDLACH. Santiago de Chile. 10 p.

Emmerich, WE; Heitschmidt, RK. 2002. Drought and grazing: II. Effects on runoff and water quality. *Journal of Range Management*. (55): 229 – 234

Engel, S; Pagiola, S; Wunder, S. 2008. Designing payments for environmental services in theory and practice: An overview of the issues. *Ecological Economics* 65: 663 – 674.

Food and Agriculture Organization of the United Nations (FAO). 2000. Land-Water linkages in rural watersheds. *Land and Water bulletin* 9. Rome, Italy. 90 p.

Food and Agriculture Organization of the United Nations (FAO). 2004. Payment schemes for environmental services in watersheds. Regional forum Arequipa, Peru. *Land and Water Discussion Paper* 3. Rome, Italy.

Fraser, R. 2009. Land heterogeneity, agricultural income forgone and environmental benefit: An assessment of incentive compatibility problems in environmental stewardship schemes. *Journal of Agricultural Economics* 60 (1): 190 – 201.

Freeman III, A,M. 2003. The measurement of environmental and resources values: theory and methods (2^d ed). Resources of the future. Washington D.C. 491 p.

Fundación Gonzalo Río Arronte; Fundación Javier Barros Sierra. 2004. Prospectiva de la demanda de agua en México, 2000 – 2030. México. D.F. 105 p.

Hamblin, AP. 1985. The influence of soil structure on water movement, crop root growth and water uptake. *Advances in agronomy*. 38: 95-158 *In*: Shaxson, F; Barber, R. 2003. Optimizing soil moisture for plant production: the significance of soil porosity. Rome. FAO. *Soils Bulletin* 79. 107 p.

Hanemann, WM. 1994. Valuing the environment through contingent valuation. *The journal of economic perspectives* 8 (4): 19 –43.

Harvey, R; Havens, H. 1999. Lake Okeechobee Action Plan. Lake Okeechobee Issue Team for the South Florida Ecosystem Restoration Working Group, South Florida Water Management District, West Palm Beach, Florida, 43 pp. *In*: Alavalapaty, JRR; Shrestha, RK; Stainback, GA; Matta, JR. 2004. Agroforestry development: an environmental economic perspective. *Agroforestry Systems* 61: 299 – 310.

Hoang Fagerström, MH; Messign, I; Wen, ZM. 2003. A participatory approach for integrated conservation planning in a small catchment in Loess Plateau, China Part I. Approach and Methods. *Catena* 54: 255 – 269.

Hofmann, L; Ries, RE; Gilley, JE. 1983. Relationship of runoff and soil loss to ground cover of native and reclaimed grazing land. *Agronomy Journal* 75(4): 599 - 602

Horne, R; Gwalter, J. 1982. The recovery of rainforest overstorey following logging. 1. Subtropical rainforest. Australian Forest Research 13: 29-44. *In*: Bruijnzeel, LA. 1990. Hydrology of moist tropical forest and effects of conversion: a state of knowledge review. National Committee of the Netherlands for the International Hydrological Programme-UNESCO, International Institute of Aerospace Survey and Earth Sciences. Amsterdam, the Netherlands. 230 p.

Instituto Nacional de Estadística Geografía é Informática (INEGI). 1960. VIII Censo General de Población y Vivienda. Localidades de la República Mexicana por entidades Federativas y Municipios. 627 y 690 p.

Instituto Nacional de Estadística Geografía é Informática (INEGI). 2005. Anuario Estadístico, Veracruz de Ignacio de la Llave, Tomos I y II. México, D.F.

Instituto Nacional de Estadística Geografía é Informática (INEGI). Carta de Vegetación. F 14-9. México D.F. INEGI. 1:250,000. A colores.

IUCN – The World Conservation Union; The Nature Conservancy; The World Bank. 2004. How Much is an ecosystems worth? Assessing the economic value of conservation. Washington D.C. USA 60 p.

Jensen, ME; Burman, RD; Allen, RG. 1990. Evapotranspiration and irrigation water requirements American Society of Civil Engineers, New York, 332 p. *In*: Ward, AD; Trimble, SW. 2004. Environmental Hydrology (2^d ed.). Lewis Publishers. Florida, USA. 475 p.

Jipp, PH; Nepsta, DC; Cassel, DK; de Carvalhol, C. 1998. Deep soil moisture storage and transpiration in forests and pastures of seasonally dry Amazonia. *Climatic Change* 39: 395 – 412

Joffre, R; Rambal, S. 1993. How tree cover influences the water balance of Mediterranean rangelands. *Ecology* 74 (2): 570 – 582

Johnson, NL; Baltodano, ME. 2004. The economics of community watershed management: some evidence from Nicaragua. *Ecological Economics* 49: 57 – 71.

Kaimowitz, D. 2005. Useful myths and intractable truths: the politic of the link between forest and water in Central America, in: Forest, Water and People in the Humid Tropics: Past, Present and Future Hydrological Research for Integrated Land and Water Management (Bonell and Bruijnzeel eds) Cambridge University Press. 86 – 98.

Kaushik, PK; Pandey, BK; Tripathi, YC. 2007. Participatory approach to watershed management in India. *Indian Forester* 133 (12): 1659 – 1668.

Kelkar, U; Kumar N,K; Prakash S, V; Chandna, U. 2008. Vulnerability and adaptation to climate variability and water stress in Uttarakhand State, India. *Global Environmental Change* 18: 564 – 574.

Kramer, PJ. 1983. Water relations of plants. Academic Press Inc. Orlando, Florida 489 p. *In*: Ward, AD; Trimble, SW. 2004. Environmental Hydrology (2^{d} ed.). Lewis Publishers. Florida, USA. 475 p.

Lal, R; Elliot, W. 1994. Erodibility and Erosivity. *In*: Soil erosion: research methods. (Lal, R. ed.). Soil water and soil conservation society. Ankeny. IA. 340 p.

Landell-Mills, N; Porras, IT. 2002. “Silver bullet or fools’ gold? A global review of markets for forest environmental services and their impact on the poor”. Instruments for sustainable private sector forestry series. International Institute for Environment and Development, London, UK. 272 p.

Loomis A,J; Kent B,P; Strange C, L; Fausch C, K; , Covich, A. 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. *Ecological Economics* 33: 103 – 117.

López P, C; González G, M de J; Valdez L, JR; de los Santos P, HM. 2007. Demanda, disponibilidad de pago y costo de oportunidad hídrica en la cuenca Tapalpa, Jalisco. *Madera y Bosques* 13 (1): 3 – 23.

Lusby, GC. 1970. Hydrologic and biotic effects of grazing versus no grazing near Grand Junction, Colorado. *Journal of Range Management*. (23): 256 – 260.

Madrigal B, R; Alpízar R, F. 2008. Diseño y gestión adaptativa de un programa de pagos por servicios ecosistémicos en Copán Ruinas, Honduras. *Investigación Agraria: Sistemas y Recursos Forestales* 17(1): 79 – 90.

MAG/FAO/Holanda GCP/COS/012/NET. 1996. Producción y conservación de suelos y aguas en áreas ganaderas. Informe Técnico No. 16. 63 p.

Martínez T, M. 2005. ¿Mercado ó Ilusión? Esquema de pago por servicios ambientales -PSA- en Jesús de Otoro, Honduras. Tesis Doctoral. Universidad Autónoma de Barcelona. 147 p.

Mazumdar, A. 2007. Participatory approaches to sustainable rural water resources development and management: Indian perspective. *Journal of Developments in Sustainable Agriculture* 2: 59 – 65.

McDonald, MA; Healey, JR; Stevens, PA. 2002. The effects of secondary forest clearance and subsequent land-use on erosion losses and soil properties in the Blue Mountains of Jamaica. *Agriculture, Ecosystems and Environment* 92(1): 1-19

McGinty, WA; Smeins, FE; Merril, LB. 1979. Influence of soil, vegetation, and grazing management on infiltration rate and sediment production of Edwards Plateau rangeland. *Journal of Range Management* 32(1): 33 - 37

MEA. 2005. Millennium Ecosystem Assessment, Ecosystems and Human Well-being: Synthesis. Island Press, Washington DC. 137 p.

Meadows, DH; Meadows, DL; Randers, J; Behrens, WW. 1972. The limits to growth. A report for The Club of Rome's project on the predicament of mankind. Universe Books. New York, USA. 205 p.

Meadows, D; Randers, J; Meadows, D. 2004. Limits to growth: the 30 year update. Chelsea Green (eds). 338 p.

Meeuwig, RO. 1970. Infiltration and soil erosion as influenced by vegetation and soil in Northern Utah. *Journal of Range Management* 23(39: 185 – 188

Merret, S. 2002. Deconstructing households' willingness-to-pay for water in low-income countries. *Water Policy* 4: 157 – 172.

Molle, F. 2001. Water pricing in Thailand: theory and practice. Research Report No. 7. DORAS Project. Bangkok: Kasetsart University. 79 p.

Morgan, RPC. 1995. Soil erosion and conservation. (2^d ed). Longman Group limited. Harlow Essex, England . 198 p.

Muñoz-Piña, C; Guevara, A; Torres, JM; Braña, J. Paying for the hydrological services of Mexico's forests: Analysis, negotiations and results. *Ecological Economics* 65: 725 – 736.

Mwendera, EJ; Mohamed Saleem, MA. 1997. Hydrologic response to cattle grazing in the Ethiopian highlands. *Agriculture, Ecosystems and Environment* 64: 33-41

Naidoo, R; Adamowicz, WL. 2006. Modeling opportunity costs of conservation in transitional landscapes. *Conservation Biology* 20 (2): 490 – 500.

Northon-Griffiths, M; Southey, C. 1995. The opportunity cost of biodiversity conservation in Kenya. *Ecological Economics* 12: 125 – 139 p.

O'connor, M. 1998. The VALSE (Valuation for Sustainable Environments) Project. Centre d'Economie et d'Ethique pour I'Environnement et le Développement, Paris, France. 49 p.

O'Connor, M. 2000. Pathways for environmental valuation: a walk in the (Hanging) Gardens of Babylon. *Ecological Economics* 34: 175 – 193.

Pagiola, S. 2002. Paying for water services in Central America: Learning from Costa Rica. *In*: Selling forest environmental services: Market-based mechanism for conservation and development. (Pagiola, Bishop and Landell-Mills. Eds). EARTHSCAN. London. 37 – 61.

Pagiola, S; Landell-Mills, N; Bishop, J. 2002. Market-based mechanism for forest conservation and development. *In:* Selling forest environmental services: Market-based mechanism for conservation and development. (Pagiola, Bishop and Landell-Mills. Eds). EARTHSCAN. London. 1 – 13 p.

Pagiola, S; von Ritter, K; Bishop, J. 2004. Assessing the economic value of ecosystem conservation The World Bank Environment Department. Environment Department Paper No. 101. 60 p.

Pagiola, S; Platais, G. 2007. Payments for Environmental Services: From Theory to Practice. World Bank, Washington. In: Engel, S; Pagiola, S; Wunder, S. 2008. Designing payments for environmental services in theory and practice: An overview of the issues. *Ecological Economics* 65: 663 – 674.

Pagiola, S. 2008. Payments for Environmental Services in Costa Rica. *Ecological Economics* 65: 712 – 724

Papendick, RI; Campbell, GS. 1988. Concepts and management strategies for water conservation in dryland farming. In: Challenges in Dryland Agriculture: A global perspective. Proceedings of the International Conference on Dryland Farming. Texas, USA. 119 – 127 p.

Pattanayak, SK; Kramer, RA. 2001. Pricing ecological services: willingness to pay for drought mitigation from watershed protection in eastern Indonesia. *Water Resources Research* 37 (3): 771 – 778.

Pérez, CJ. 2009. Pagos por Servicios Ambientales en el Municipio de San Pedro del Norte, Nicaragua y su contribución a la adaptación del cambio climático. In: (Ibrahim, Sepúlveda Eds.) CATIE. Serie Técnica. Informe Técnico No. 377. 245 – 259 p.

Pirard, R. 2008. Estimating opportunity costs of Avoided Deforestation (REDD): application of a flexible stepwise approach to the Indonesian pulp sector. *International Forestry Review* 10 (3): 512 – 522.

Rauzi, F; Hanson, CL. 1966. Water intake and runoff as affected by intensity of grazing. *Journal of Range Management*. (19): 351- 356

Porras, I; Grieg-Gran, M; Neves, N. 2008. All that glitters: A review of payments for watershed services in developing countries. Natural Resources Issues No. 11. International Institute for Environment and Development. London, UK. 129 p.

Portney PR. 1994. The contingent valuation debate; why economist should care. *The Journal of Economic Perspectives* 8 (4): 3 – 17.

Rhoades, EP; Locke, LF; Taylor, HM; McIlvain. 1964. Water intake on a Sandy Range as Affected by 20 years of differential cattle stocking rate. *Journal of Range Management* (17):185-109

Rickards G, J; Piguerón W, C. 2009. Financiamiento de Programas para conservación de ecosistemas templados de montaña. Instituto Nacional de Ecología. Consulted *On line*: 16/02/2009 http://www.ine.gob.mx/ueajei/publicaciones/libros/395/rickards.html

Riera, P. 1994. Manual de Evaluación Contingente. Instituto de Estudios Fiscales. Universidad Autónoma de Barcelona. 112 p.

Robin, C. 1976. El vulcanismo de las planicies de la Huasteca (Este de México). Datos Geoquímicos y petrográficos. *Boletín del Instituto de Geología Num. 96: 55 – 92* p. UNAM

Rosales, RMP. 2003. Developing pro-poor markets for environmental services in the Philippines. Environmental Economics Programme. International Institute for Environment and development (IIED). 99 p.

Rosegrant, MW; Cai, X; Cline, SA. 2002a. Global water outlook to 2025: Averting an impending crisis. International Food Policy Research Institute. Washington, D.C. USA and International Water Management Institute. Colombo Sri Lanka. 26 p.

Rosegrant, MW; Cai, X; Cline, SA. 2002b. World Water and Food to 2025: dealing with scarcity. International Food Policy Research Institute. Washington. D.C. 322 p.

Rostagno, CM. 1989. Infiltration and sediment production as affected by soil surface conditions in a Shrubland of Patagonia, Argentina. *Journal of Range Management* 45(5): 382 - 385

Russell, JR; Betteridge, K; Costall, DA; Mackay, AD. 2001. Cattle treading effects on sediment loss and water infiltration. *Journal of Range Management* 54(2): 184-190

Sagoff, M. 1998. Aggregation and deliberation in valuing environmental public goods: A look beyond contingent pricing. *Ecological Economics* 24: 213–230.

Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). 2008. Reglas de Operación del Programa Pro-Árbol de la Comisión Nacional Forestal. Diario Oficial de la Federación. Miércoles 31 de Diciembre del 2008. 112 p.

Shaxson, F; Barber, R. 2003. Optimizing soil moisture for plant production: the significance of soil porosity. Rome. FAO. *Soils Bulletin* 79. 107 p.

Schkade, DA; Payne, JW. 1993. "Where do the numbers come from? How people responds to contingent valuation questions. In: Hausman (*eds.*) Contingent Valuation: A critical assessment. Amsterdam, North Holland press 271 – 304.

Stadtmüler, T. 1994. Impacto hidrológico del manejo forestal de bosques naturales tropicales: medidas para mitigarlo. Una revisión bibliográfica. Turrialba, CR. CATIE- COSUDE. *Serie técnica. Informe técnico* No. 240. 62 p.

Stainback, GA; Alavalapati, JRR; Shrestha, RR; Larkin, S; Wong, G. 2004. Environmental economic valuation of silvopasture: a dynamic optimization approach. *Journal of Agricultural and Applied Economics* 36 (2): 481 – 489.

Stockin, M., 1996. Land management for sustainable development: farmers' participation. *In:* Uitto, J.I., Ono, A. (Eds.), Population, Land Management, and Environmental Change. The United Nations University, Tokyo, pp. 13–27.

Stocking, M.A. 1994. Assessing vegetative cover and management effects. *In*: Soil erosion: research methods. (Lal, R. ed.). Soil water and soil conservation society. Ankeny. IA. 340 p

Stocking, MA; Murnaghan, N. 2001. Handbook for the field assessment of land degradation. Earthscan Publications Ltd. London, UK. 169 p.

Suárez de Castro, F. 1982. Conservación de Suelos. (3 ed). San José, Costa Rica. IICA. 315 p.

Taddese, G; Mohamed Saleem, MA; Abyie, A; Wagnew, A. 2002. Impact of grazing on Plant species richness, plant biomass, plant attribute, and soil physical and hydrological properties of Vertisol in East African Highlands. *Environmental Management* 29(2): 279-289

Takar, AA; Dobrowolski, JP; Thurow, TL. 1990. Influence of grazing, vegetation life-form, and soil type on infiltration rates and interrill erosion on a Somalion rangeland. *Journal of Range Management* 43(6) 486- 490

Thurow, TL; Blackburn, WH; Taylor Jr, CA. 1986. Hydrologic characteristics of vegetation types as affected by livestock grazing systems, Edward Plateau, Texas. *Journal of Range Management* 39(6) 505-509

Thurow, TL; Blackburn, WH; Warren, SD; Taylor Jr, CA. 1987. Rainfall interception by midgrass, shortgrass, and live oak mottes. *Journal of Range Management* 40(5) 455-460

Thurow, TL; Blackburn, WH; Taylor Jr, CA. 1988. Infiltration and interrill erosion responses to selected livestock grazing strategies, Edward Plateau, Texas. *Journal of Range Management* 41(4) 296-302

Tromble, JM; Renard, KG; Thatcher, AP. 1974. Infiltration for three rangeland soil-vegetation complex. *Journal of Range Management* 27(4) 318 - 321

United Nations (UN). 2005. The millennium development goals Report 2005. New York, USA. 48 p.

UNEP (United Nations Environmental Programme) .2006. Consulted March 11th 2006. On line: http://www.unep.org/Documents.multilingual/Default.asp?DocumentID=97&ArticleID=1503

UNESCO (United Nations Educational Scientific and Cultural Organization). 2006. Water a shared responsibility: The United Nations World Water Development Report 2. Executive summary UNESCO, Paris, France. 52 p.

Van Lill, WS; Kruger, FJ; Van Wyk, DB. 1980. The effect of afforestation with *Eucalyptus grandis* hill. ex maiden. and *Pinus patula* schlecht. et cham. on streamflow from experimental catchments at Mokobulaan, Transvaal. *Journal of Hydrology*, 48: 107--118

Veloz, A; Southgate, D; Hitzhusen; McGregor, R. 1985. The economics of erosion in a subtropical watershed: a Dominican case. *Land economics* 61 (2): 145 – 155

Villón B, M. 2002. Hidrología. ITCR - CRRH. Cartago, Costa Rica, CA. 436 p.

Ward, AD; Trimble, SW. 2004. Environmental Hydrology (2d ed.). Lewis Publishers. Florida, USA. 475 p.

Warren, SD; Blackburn, WH; Taylor jr, CA. 1986a. Effects of season and stage of rotation cycle on hydrologic condition of rangeland under intensive rotation grazing. *Journal of Range Management* 39(6) 486 - 3491

Warren, SD; Blackburn, WH; Taylor jr, CA. 1986b. Soil hydrologic response to number of pastures and stocking density under intensive rotation grazing. *Journal of Range Management* 39(6) 500 - 504

Warren, SD; Thurow, TL; Blackburn, WH; Garza, NE. 1986c. The influence of livestock trampling under intensive rotation grazing on soil hydrologic characteristics. *Journal of Range Management* 39(6) 491 - 495

Waterloo MJ; Bruijnzeel LA; Vugts HF; Rawaqa, TT. 1999. Evaporation from *Pinus caribaea* plantations on former grasslands soils under maritime tropical conditions. *Water Resources Research* 35 (7): 2133 – 2144

Weerts, GJ. 1991. Soil hydraulic conductivity on two tropical soil types under forest and a 25 year old pasture: field measurement and data application. Atlantic Zone Programme. Report 4. CATIE- MAG- AUW. Turrialba, Costa Rica. 60 p.

Winter, TC; Harvey, JW; Lehn Franke, O; Alley, WM. 1998. Ground water and surface water: a single source. U.S. Geological survey. Circular: 1139. U.S. department of the interior. Denver, Colorado. 87 p.

Wunder, S. 2005. Payment for environmental services: some nuts and bolts. Occasional paper No. 42. Center for International Forestry Research (CIFOR). 24 p.

Wunder, S. 2007. The efficiency of payments for environmental services in tropical conservation. *Conservation Biology* 21(1): 48 – 58.

Wunder S; Albán, M. 2008. Decentralized payments for environmental services: The cases of Pimampiro and PROFAFOR in Ecuador. *Ecological Economics* 65: 685 – 698.

WWC (World Water Council); CNA (National Water Commission of Mexico). 2006. 4th Water World Forum, Final Report: Local Actions for a global change. México, D.F. 257 p.

Yates, CJ; Norton, DA; Hobbs, RJ. 2000. Grazing effects on plant cover, soil and microclimate in fragmented woodlands in South-Western Australia: implications for restoration. Austral Ecology 25: 36-47

Young, A. 1987. The potential of Agroforestry for soil conservation and sustainable land use. *In*: Seminar on Land and Water Resources Management. World Bank. Washington D.C. 303-317 pp.

Young, RA. 2004. Determining the economic value of water: concepts and methods. Resources for the future (eds). Washington, D.C. USA. 356 p.

First Chapter

Generation of hydrological information as a first step to design a local policy of payment for hydrological ecosystem services in northern Veracruz, México

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ABSTRACT

Protection of ecosystem services generated by natural ecosystems is an issue at the forefront of the contemporary environmental agenda. Hydrological services have significant importance in countries with water scarcity problems. Part of this problem is attributed to the lack of relatedness between ecosystems service suppliers and users, and schemes of payment for hydrological ecosystem services (PHES) are emerging as a strategy to connect them. However, in the development of a scheme of PHES, one critical point is to determine if the protective land uses are adequately generating the service to sell. This study was developed to determine the hydrologic behaviour of land uses located in a hydrological recharge area. The land uses were secondary regeneration forest (SRF), African star grasslands (GWT), African star grasslands with shrubs (GS), disturbed *Quercus oleoides* forest (QF) and natural grasslands (NG). Indicators were precipitation, throughfall, runoff, soil moisture changes, evapotranspiration and percolation. Hydrological balances showed that percolation was higher in GWT (1,608 mm), GS (1,744 mm) and NG

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(1,314 mm), than in SRF (1,119 mm) and QF (974 mm). The findings indicate that data used in support of PHES must be adequately quantified at the local level, rather than making intuitive judgments about the ecological services provided by different land uses.

Key words: **compaction, evapotranspiration, hydrological balance, infiltration, runoff.**

1. Introduction

Humans and all other living beings depend on water for life and health. Yet the World Health Organization reports that about 80 percent of the world's people live in places where the only available water is unsafe. Water-related problems such as overuse, scarcity, pollution, floods and drought are an increasingly important challenge to sustainable development, as the United Nations recognized in declaring 2005-2015 the "Water for Life" Decade (FAO 2007). Additionally, growing populations, global climatic change, soil erosion, and societal expectations are factors that have reduced the availability of fresh and clean drinking water. More than one billion people across the globe do not have available safe water in sufficient quantities to meet the minimum levels of health and income (Rosegrant *et al.,* 2002; World Bank 2004). Safe drinking water supply is a serious problem in México because of increases in water demand due to population growth (from 25.8 million of people in 1950 to 103.4 millions in 2005), and income *per capita* increases (1.9% per year) (Meadows *et al.,* 2004; CNA 2008). Political conflicts between Tamaulipas and Nuevo León, and Guanajuato and Jalisco States, originated by boundary rivers water distribution, provided clear evidence that water scarcity is a serious problem. Additionally, the National Water Commission (CNA) predict that due to the current population growth (1.02% period 2000-2005) and water management, the water scarcity problem will be more critical in coming years (CNA 2008). Veracruz State is located in the Gulf of México, and due to its size is divided into three regions; north, central and south. The northern region has an average precipitation of 1,675 mm, with evaporation more than 70%. Following the FAO ranking for pressure on hydrologic resources, an indicator that considers the amount of water available and water used, climatic conditions and population size (4.94 million), this region generates a medium pressure on water availability (10-20%) (Fundación Gonzalo Río Arronte, and Fundación Javier Barros Sierra 2004, CNA 2008).

To tackle water scarcity is not an easy task because the problem originates not only with the protection of hydrological ecosystem services, but also with water extraction, transport, storage, use and contamination (World Bank 2004; CNA 2006; UNESCO 2006). Due to this complexity, this study is focused on the first part of the problem. Globally, one action proposed to protect the areas that generate water is the Payment for Hydrological Ecosystem Services (PHES) (FAO 2004b). This strategy was designed with the objective to connect water users with the ecosystem service suppliers through economic compensation for the hydrological service provided (Pagiola and Platais 2002). In general, PHES improves natural forest conservation (Pagiola *et al.,* 2006). However, these schemes are based on hydrologic “Cause-Effect” suppositions, creating a situation that could generate false expectations and social conflicts (Landell-Mills and Porras 2002; Kaimowitz 2004; FAO 2004b). Whilst it is acknowledged that biophysical information is necessary to support PHES schemes (FAO 2004), there are few instances where hydrological information is intrinsic to the decision-making (UNESCO 2006). Consequently, the generation of site specific information is strongly recommended as a first step in the construction of local PHES and policies (FAO 2004b).

An isolated volcanic mountain named “Otontepec Sierra” is located in the northern of Veracruz. This mountain generates drinking water for around 122,000 people, distributed throughout the municipalities of Tepetzintla, Tancoco, Tantima, Tamalin, Chinampa de Goroztiza, Naranjos-Amatlan, Ixcatepec, Chontla and Citlaltepetl (INEGI 2005). Water is transported from the highlands to the lowlands (where the cities are located) by a network of pipes and containers. The natural ecosystems in the highlands are sub-humid deciduous forest and oak forests. However, the forest is changing to other land uses, such as livestock and traditional agriculture, which generate more income for landowners. And, it is perceived by lowland water users’, who suffer water scarcities in the dry season, that this problem is generated by mountain deforestation. To confront this problem, the Tepetzintla Municipality plans to implement a scheme of PHES, with the aim of protecting the highland forest and thereby increasing water supply (Personal communication, Ing. Jesús Zeníl Méndez, Tepetzintla Municipal President Period 2005–2007). Unfortunately biophysical information to support this assumption is not available, and under the politician point of view, to propose a local policy of PHES without cause-effect information could generate sociopolitical problems with the communities that pay an ecosystem service. Therefore the study objective was to determine the hydrological behaviour of natural forests and grasslands located in an Otontepec mountain highlands catchment, with the intent that the information will be used to generate an accurate local PHES scheme.

2. Methods

2.1. Study area

The study was conducted in northern Veracruz; Gulf of México in the Tepetzintla Municipality, in a catchment located on “Otontepec Sierra” an isolated volcanic mountain. This mountain is located between 97°58’30’’ and 97°48’00’’ West, and 21°19’19’’ and 21°09’34'' North. The climate is $A(w^2)$ sub-humid tropical (Köppen classification) with a dry season from March to June and a wet season from July to February. The average precipitation in the zone is around 1,552 mm y^{-1} (CNA 2008). Altitude ranges from 350 to 900 meters above sea level (m.a.s.l.). Geology is extrusive basaltic igneous rocks, and sedimentary and volcanic-sedimentary rocks, all from the Miocene period (INEGI Geology Map Tamiahua F 14-9). Topography is complex with sharp ridges, gullies and colluvial processes. Soils are inceptisols and alfisols. Natural vegetation is semi-deciduous tropical forest, with zones of *Quercus oleoides* Cham & Schlecht forest in the upland areas (INEGI Vegetation Map Tamiahua F 14-9). A 68 hectares (ha) catchment in the Otontepec Sierra highlands was selected for the study. The altitude raises from 650 to 900 m.a.s.l. with an irregular topography (from 5% to 50% slope grade) and colluvial processes. The catchment was divided in two subzones, the highlands and the lowlands. In the highlands, land uses selected were secondary regeneration forest (SRF), African Star grasslands (*Cynodon nlemfuensis* Vanderyst var. *nlemfuensis*) without trees (GWT), and African Star grasslands (*C. nlemfluensis*) with shrubs of *Conostegia xalapensis* (Bonpl.) D. Don ex DC) (GS). In the lowlands, land uses selected were disturbed *Quercus oleoides* Cham. & Schlecht forest (QF) and *Paspalum notatum* Flüggé grasslands without trees (NG). Land use characteristics were determined following the methodology used by Chacon *et al* 2007. SRF was located at 848 m.a.s.l. with a slope of 40% and a complex topography.

Interviews with forest owners indicated that primary forest was cut and burned in 1980, because a Government policy that promoted forest conversion to agriculture. Maize was cultivated for two years and after that land was abandoned to regeneration. The forest shows three strata; trees, shrubs and weeds, and soil covered by a thick litter layer. The number of trees per hectare was 546 with a basal area of 745 m^2 ha^{-1}, the average tree height was 8.3 m, and the total canopy area occupied 12,212 m^2 ha^{-1}. The more common species were *Heliocarpus donnell-smithii* Rose ex Donn.Sm. (19%); *Persea* spp. (16.2%); *Muntingia calabura* L. (13.4%); *Inga spuria* Humb. & Bonpl. ex Willd. (12.7%); and *Croton draco* Schltdl. & Cham. (9.9%). The number of shrubs per hectare was 2,133 with the more common species being *Turpinia insignis* (H. B. & K.) Tul. (23.9%), and *C. xalapensis* (9.9%). GWT were located at 825 m.a.s.l. with a slope of 29% and complex topography. Interviews with the two grasslands owners indicated that the grasslands are more than 30 years old, dating from when the forest was cut and burned and Guinea grass seeds (*Panicum maximum* Jacq) were spread to establish pastures. However, this grass was replaced within the last 15 years with *C. nlemfluensis*. Stocking rate was 0.90 Animal Unit (AU) ha^{-1}, and had a slow rotational grazing management system (30 days grazing, 60 days released). GS were located at 815 m.a.s.l. with a slope of 55% and complex topography. *C. xalapensis* shrubs were common in disturbed forest areas, had well developed trunks and dense canopy, and were not grazed by livestock. The number of shrubs per hectare in the Silvopastoral System (SPS) was 516, and their canopy area occupied 3,637 m^2 (36.3%). Shrubs control was manual without agrochemical use. Stocking rates were 0.45 AU/ha, with slow rotational grazing management. QF was located at 715 m.a.s.l., with a slope of 32%, and complex topography. Forest characteristics were; 131 trees per hectare, average height 15.1 m, basal area 277 m^2 ha^{-1}, and only one canopy stratum. Interviews with forest owners indicated that this forest was more than 50 years old. From the farmers' points of view these trees were a problem, because they are very difficult to produce beneath the canopy and they have a slow growth rate. With opportunistic cutting or wind damage, the opportunity is taken to introduce grasslands and secondary regeneration is controlled with agrochemicals. Oak wood was in high demand in local markets for fence poles, firewood, and timber. Finally, NG was located at 713 m.a.s.l. with a slope of 36% and irregular topography. Grassland owners mentioned that this grass “appears” in this area when it is overgrazed, and is very difficult to eradicate. This grassland was under continuous grazing by cattle and horses and the stocking rate was calculated as 1.5 AU/ha.

2.2. Experimental design

Due to the sources variability in the recharge area such as geology, slope grade, land use, colluvial processes and soil type, the catchment was divided into two subsections, highlands and lowlands. In each area, several land uses were selected and each one was considered as a case study. Highlands land uses were SRF (24 years old), GWT (>30 years old) and GS (>30 years old). Lowlands land uses were QF (>50 years old) and NG (>15 years old). Variables measured were bulk density, rainfall, throughfall, infiltration rate, surface runoff, and changes in soil moisture. Variables calculated were evapotranspiration, canopy interception, and percolation. The hydrological balance in each land use was estimated by:

$$^{1}\boldsymbol{R = ET + I + P + R^{*} + \Delta S}$$

Where:

R = Rainfall (mm), R^{*} = Runoff (mm),

ET = Evapotranspiration (mm), I = Canopy interception (mm),

P = Percolation (mm), ΔS = Change in water storage within the soil profile (mm).

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[1] Adapted from Pilbeam *et al* 1995

2.2.1. Precipitation and Throughfall

Three rustic pluviometers and a standard pluviometer were located near the land uses selected. In the case of QF and SRF, throughfall was measured near the runoff plots with eight horizontal pluviometers of 1 m length (from Ford and Deans 1978; Bruijnzeel 1990; Pilbeam *et al.,* 1995; Wallace *et al*., 1995; Ward and Elliot 1995; Hafkenscheid 2000).

2.2.2. Runoff

Runoff was measured in each land use with the use of runoff plots. However, due to the sources of variability in the field work area (i.e. colluvial processes, slope grade, land use and amount of rock) and the runoff plot size (10 x 20 m), was decided to install one runoff plot in each land use selected. Runoff plot was established in middle of the slope of each land use type (downslope) (from McDonald *et al.,* 2002). In order to stabilize the soil after runoff plot installation, plots were installed one year in advance (May – July 2006). Runoff was then recorded from August 2007 to July 2008. Runoff plots installed in grasslands without trees and grasslands with shrubs were grazed year round at the same stocking rate and at the same rotation time that the farmers use in all their grasslands. The objective of this decision was not to change the existing system management (personal communication, L.A. Bruijnzeel 2004). In grasslands, runoff plots were frequently damaged due to disturbance of cattle, however they were repaired immediately. In order to stop most rain splash in or out of the plot, runoff plots were bounded with zinc sheeting dug into the soil at 7.5 cm depth and protruding above the soil at 7.5 cm height. Each plot was drained to one corner where there was 10 cm diameter drainpipe. The drainpipe was connected to a series of specially adapted and calibrated plastic drums. Trenches connecting drums were covered to prevent direct rainfall input (adapted from Acharya *et al*., 2007, 2008). On September 25, 2006, a rainstorm was recorded to have precipitated 200 mm of rain in 24 hours. Taking this storm into account, the field equipment was designed with three drums and a multi-slot collection system. The first drum had a capacity of 250 litres and passed one eighth of the runoff to the next drum. The second drum had a capacity of 1,600 litres and passed one tenth of the runoff to the next drum. Finally, the third drum had a capacity of 20,000 litres. This system was designed to record a maximum of 21,850 litres or 110 mm of runoff per rainstorm event (adapted from Acharya *et al.,* 2007, 2008).

2.2.3. Infiltration

Infiltration rates were measured using the double ring method (Anderson and Ingram 1993; Ward and Elliot 1995; Henríquez and Cabalceta 1999) in areas near the runoff plots when soil was at field capacity (wet season: July – December). However, the irregular microtopography in the slope difficult double ring installation (lack of wide level surface areas in the slope), and was necessary to use small rings (20 and 30 cm diameter, inner and outer rings, respectively). Five sites were randomly selected and the infiltration rate was calculated in each land use with the Kostiakow equation ($I = at^b$), where I= accumulated infiltration, t = accumulated time, a = intercept and b = slope (Henríquez and Cabalceta 1999). In GS, infiltration tests were developed under the shrub canopy and in open areas (four tests in each area).

2.2.4. Bulk density

The open bag method was used to determine soil bulk density due to the high content and size of rocks and gravel (USDA 1999). Twenty replicate samples were taken in each land use, except grasslands and shrubs where 15 samples each were collected under canopy and in open areas.

2.2.5. Evapotranspiration and Percolation

Evaporation (ET) and Percolation (P) was measured using a field method based exclusively in soil water content measurements at several depths, and includes an estimation of the unsaturated hydraulic conductivity (Klaij and Vachaud 1992). This method was selected because was no feasible to obtain appropriate soil samples, due to the stoniness of the soil, and to calculate the unsaturated hydraulic conductivity in the laboratory. In addition, due to the amount of rock in the soils it was not possible to install vertical soil moisture sensors (ECH_2O – Decagon$^{©}$). Therefore, soil pits were excavated and the sensors were installed horizontally in a small hole in the pit wall at three depths; 15, 45 and 75 cm. Each hole was carefully filled after the soil moisture sensors installation. Soil moisture was measured every 2 hours and information was stored in a datalogger (ECH_2O Decagon$^{©}$). Changes in soil moisture profile were calculated every 24 hrs. Figures 1, 2, 3, 4 and 5 show a sample of the curves developed with the information recorded during the highest intensity rainfall season (August – December 2007). Evapotranspiration and percolation were calculated from changes in soil moisture content with the following equations (adapted from Klaij and Vachaud 1992):

Dry season (from March to July)

$ET = S_{om(t)} - S_{om(t+\Delta t)}$

Wet season (from August to February)

$ET = Pr - R - I + S_{om(t)} - S_{om(t+\Delta t)} - K(\theta_a)\,\Delta t$

Percolation

$P = S_{rm(t)} - S_{rm(t+\Delta t)}$

Where:

ET = Evapotranspiration,

$S_{om(t)}$ = Water stored in soil profile from surface *o* to the maximum root depth *m* in a period of time Δ*t,*

Pr = Precipitation,

R = Runoff,

I = Canopy interception,

P= Percolation,

$K(\theta_a)\,\Delta t$ = Unsaturated hydraulic conductivity,

$S_{rm(t)}$ =Moisture stored in the layer from the maximum rooting depth *m* to the maximum depth of soil moisture measurements *r* in a period of time Δ*t.*

2.2.6 Statistical analyses

Bulk density and infiltration rate results were analyzed by a paired *t*-test using the software InfoStat Version 1 (InfoStat 2004).

3. Results and Discussion

3.1. Soil characteristics

Previous studies on the genesis of the Otontepec Sierra (Robin, 1976) indicated that the mountain was formed by volcanic processes. The mountain base, like the entire coastal valley, is located at 220 m.a.s.l. and was formed by the rise of the continental tectonic plate during the Oligocene period (35 – 23 millions of years). This was confirmed by the presence of ocean fossils in the catchment lowlands. Subsequently, during the Miocene period (7.5 – 6.6 millions of years), extrusive alkaline-basaltic rock was deposited by more than twelve lava fluidal processes, some of them more than several hundred meters wide, uplifting the mountain to 1,000 m.a.s.l. The field work zone was located in the mountain highlands from 700 to 850 m.a.s.l. and soil profile descriptions were developed following FAO (1990) methodology. The summary of the soil profile descriptions, bulk density and double ring infiltration tests are shown in tables 1a and 1b.

The groundwater recharge zone parent material is extrusive alkaline-basaltic lava (Robin 1976). This point is relevant because, during cooling process for this type of lava, deep fissures develop in the rock, a situation that improves rock weathering and porosity and hence water infiltration. Therefore, it is likely the subsoil bedrock in the field work area is porous and permeable which could prevent soil saturation and generate fast drainage (Smith 2004, UNESCO 2006). In fact, basalt aquifers tend to generate low runoff in rainfall events, either in low-intensity long-duration winter storms, or short-duration high-intensity summer thunderstorms (Stephenson and Zuzel 1981). Additionally, underground runoff is common in volcanic soils with steep slopes and colluvial processes (Weiler *et al*., 2005). Bulk density results indicated that, soils under grasslands without trees showed statistical difference ($p<0.050$) in comparison with soils under forest or grasslands and shrubs; 1.18^d, 1.17^c, 0.97^a, 0.99^b, and 0.99^b g cm^{-3} for GWT, NG, SRF, QF and GS respectively. These results show a similar tendency at the results mentioned by McGinty *et al*., 1979; Weerts 1991; Yates *et al*., 2000 and Taddese *et al*., 2002. Infiltration results indicated statistical difference ($p<0.050$) between grasslands without trees, and forest and grasslands and shrubs; 0.99^c, 0.56^c, 11.15^a, 14.1^a, 7.82^b, cm h^{-1} by GWT, NG, SRF, GS, and QF, respectively. This tendency is similar to data reported by Yates *et al*., 2000; Schultz *et al*., 2004 and Zimmermann *et al*., 2006. The large differences between SRF, GS, QF and GWT, NG were likely due to a higher percentage of rocks throughout the soil profile (Farvolden 1963), and the presence of deep roots from trees and shrubs (Bergkamp 1998).

3.2. Rainfall

Rainfall was recorded from March 2006 until December 2008. Total annual rainfall was 1,309 mm in 2006, 2,120 mm in 2007, and 1,675 mm in 2008. Historically (1971 – 2000) mean rainfall in the study zone is 1,675 mm (CNA 2008). However, in 2007 the impact of hurricanes “Dean” (date: 22/08/2007, Saffir/Simpson rank: 2, total rain: 301 mm in 25 hours, and maximum rain rate: 450 mm/h) and “Lorenzo” (date: 27/09/2007, Saffir/Simpson rank: 1, total rain: 182 mm in 26 hours, and maximum rain rate: 180 mm/h) and tropical storms Number 28 (date: 02/09/2007, total rain: 69 mm in 22 hrs, and maximum rain rate 140 mm/h) and Number 29 (date 03/09/2007, total rain: 102 mm in 14 hours, and maximum rain rate 120 mm/h) generated an irregular rainfall season with high precipitation in August and September 2007.

3.3 Soil moisture

The different land uses exhibited similar soil moisture performance as shown in figure 1a-d. For example, soil moisture at 15 cm depth had greater variability than at 45 and 75 cm depths, possibly due to the behavior caused by roots uptake and evaporation. The most stable soil moisture was observed at 75 cm depth, likely due to the fact that plant roots seldom reached this depth. Additionally, in all the cases and at all depths excess soil moisture drained over a short-time (24 hrs), even after high intensity storms. This means that soils under study showed an extraordinary capacity to transport water through the soil profile, regardless of the land use.

3.5. Hydrological Balance

The information recorded and calculated was used to calculate hydrological balances for the August 2007 – July 2008 period (Table 2a, b).

The hydrological balances indicated that runoff was scarce in all land uses, 21.6, 41.4, 9.2, 6.5 and 6.9 mm in SRF, GWT, GS, QF and NG, respectively. These results are similar to the findings reported in two sites with volcanic soils, one in Oaxaca, México by Martínez *et al*., 2001, and the other in the Blue Mountains of Jamaica by McDonald *et al*., 2002. Scarce runoff was probably generated due to interactions among soil cover, vegetation roots, microtopography, soil characteristics, and the presence of soil macropores (Bergkamp 1998, Scherrer and Naef 2003, Weiler and Naef 2003). Evapotranspiration was higher in SRF, QF and NG, than GS and GWT, 488, 578, 581, 342 and 400 mm, respectively. These results showed a similar tendency to the information reported by Carbon *et al.,* 1982; Hodnett *et al*., 1995; Jipp *et al*., 1998, Waterloo *et al*., 1999, Calder

2007 and Calder *et al* 2007. Finally, balances showed that forests percolated less water than grasslands, 1119, 974, 1314, 1608 and 1744 by SRF, QF, NG, GWT and GS, respectively. These results showed a similar tendency to the information reported by Bosch and Hewlett 1982, Carbon *et al.,* 1982. Bruijnzeel 1990, Waterloo *et al*., 1999, Kaimowitz 2005, Van der Salm *et al*., 2006 and Calder *et al*., 2007.

4. Conclusions - hydrological information to design a local scheme of PHES

The hydrological data presented generates information that need to be taken into account in the construction of a local scheme of PHES in the study catchment. The results are counter-intuitive in several respects. For example, under the supply point of view, it is not feasible to propose an increase in the aquifer base flow by changing grasslands to forest. In other words, the land uses located in the groundwater recharge zone during the period of study generated appropriate hydrological ecosystem services. These findings can potentially generate conflict in the development of a local policy of PHES because the hydrological information is in disagreement with one of the stated requirements for implementation of a PHES scheme, namely that the PHES scheme compensates suppliers for increasing the quality and the quantity of ecosystem service generated (FAO 2004). To address this conflict we propose that forest conservation needs to be supported, but not as the ecosystem that percolates more water, but as the land use most likely to maintain appropriate and stable hydrological services over the long term (Echavarria 2004; van Dijk and Keenan 2007), because grassland management is more vulnerable to rapid change in response to changes in farmers' socioeconomic situations, and is more difficult to monitor (Stocking 1994). Under the demand point of view, water available needs to be regulated and distributed more efficiently, rather than relying on increasing availability. Lastly, the implementation of a local PHES policy is part of a more complex plan to confront the water supply problem reported by the communities. This strategy needs to consider several actions, such as: protection of the groundwater recharge zone, construction of efficient hydraulic infrastructure, improvement of local organization, and population growth control.

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References

Acharya, G.P., McDonald, M.A., Tripathi, B.P., Gardner, R.M. and Mawdesley, K.J. 2007. Nutrient losses from rain-fed bench terraced cultivation systems in high rainfall areas of the mid-hills of Nepal. Land Degradation and Development 18, 486-499.

Acharya, G.P., Tripathi, B.P., Gardner, R.M., Mawdesley, K.J. and McDonald, M.A. 2008. Sustainability of sloping land cultivation systems in the mid-hills of Nepal. Land Degradation and Development 19, 530-541.

Anderson, J.M., Ingram, J.S.I. (eds). 1993. Tropical Soil biology and fertility: a handbook of methods. 2 ed. CAB international. Wallingford, Oxon, UK. 221 pp.

Bergkamp, G. 1998. A hieralical view of the interactions of runoff and infiltration with vegetation and microtopography in semiarid shrublands. Catena 33, 201 – 220.

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

Bruijnzeel, L,A. 1990. Hydrology of moist tropical forest and effects of conversion: a state of knowledge review. National Committee of the Netherlands for the International Hydrological Programme-UNESCO, International Institute of Aerospace Survey and Earth Sciences. Amsterdam, the Netherlands. 230 pp.

Calder, I.R. 2007. Forests and water -Ensuring forest benefits outweigh water costs. Forest Ecology and Management 251, 110-120.

Calder, I.R., Hofer, T., Vermont, S., Warren, P. 2007. Towards a new understanding of forests and water. Unasylva 229, 3 -10.

Carbon, B.A., Roberts, F.J., Farrington, P., Beresford, J.D. 1982. Deep drainage and water use of forests and pastures grown on deep sands in a Mediterranean environment. Journal of Hydrology 55, 53 – 64.

Comisión Nacional del Agua (CNA). 2006. La Gestión del Agua en México. Avances y retos. México D.F. 249 pp.

Comisión Nacional del Agua (CNA). 2008. Estadísticas de Agua en México. México, D.F. 233 pp.

Chacón L,M; Harvey, CA; Delgado, D. 2007. Diversidad arbórea y almacenamiento de carbono en un paisaje fragmentado del bosque húmedo de la zona atlántica de Costa Rica. Recursos Naturales y Ambiente 51-52, 19 – 32

Echavarria, M. 2004. Algunas lecciones sobre la aplicación de pagos para la protección del agua con base en experiencias en Colombia y Ecuador. In: Regional Forum: Payment schemes for environmental services in catchments, FAO. Land and Water discussion paper 3, 74 pp.

Farvolden, RN. 1963. Geologic controls on ground-water storage and base flow. Journal of Hydrology 1: 219 – 249.

Food and Agriculture Organization of the United Nations (FAO). 1990. Guidelines for soil profile description, Rome 3rd Edition 30 pp.

Food and Agriculture Organization of the United Nations (FAO). 2004a. Electronic forum on payments schemes for environmental services in catchments. Final Report. Santiago, Chile. 27 pp.

Food and Agriculture Organization of the United Nations (FAO). 2004b. Payment schemes for environmental services in catchments. Regional Forum. Arequipa, Peru. 95 pp.

Food and Agriculture Organization of the United Nations (FAO). 2007. Forest and Water. Unasylva 229, 73 pp.

Ford, E.D., Deans, J.D. 1978. The effects of canopy structure on stemflow, throughfall and interception loss in a young Sitka Spruce plantation. Journal of Applied Ecology 15, 905 – 917.

Fundación Gonzalo Río Arronte; Fundación Javier Barros Sierra. 2004. Prospectiva de la demanda de agua en México, 2000 – 2030. México. D.F. 105 pp.

Hafkenscheid, R.L.L.J. 2000. Hydrology and biogeochemistry of tropical montane rain forest of contrasting stature in the Blue Mountains, Jamaica. Ph.D. Thesis. Vrije Universiteit te Amsterdam. 302 pp.

Henríquez, C., Cabalceta. 1999. Guía práctica para el estudio introductorio de los suelos con enfoque agrícola. Universidad de Costa Rica. 122 pp.

Hodnett, M.G., Pimentel da Silva, L., da Rocha, H.R., Cruz Senna, R. 1995. Seasonal soil water storage changes beneath central Amazonian rainforest and pasture. Journal of Hydrology 170, 233 – 254

Instituto Nacional de Estadística Geografía é Informática (INEGI). 2005. Anuario Estadístico, Veracruz de Ignacio de la Llave, Tomos I y II. México, D.F.

Instituto Nacional de Estadística Geografía é Informática (INEGI). Carta Geológica. México D.F. INEGI. 1:250,000. A colores.

Instituto Nacional de Estadística Geografía é Informática (INEGI). Carta de Vegetación. México D.F. INEGI. 1:250,000. A colores.

Jipp, P.H., Nepsta, D.C., Cassel, D.K., de Carvalhol, C. 1998. Deep soil moisture storage and transpiration in forests and pastures of seasonally dry Amazonia. Climatic Change 39, 395 – 412.

Kaimowitz, D. 2005. Useful myths and intractable truths: the politic of the link between forest and water in Central America, in: Forest, Water and People in the Humid Tropics: Past, Present and Future Hydrological Research for Integrated Land and Water Management (Bonell and Bruijnzeel eds) Cambridge University Press. 86–98.

Klaij, M.C., Vachaud, G. 1992. Seasonal water balance of a sandy soil in Niger cropped with pearl millet, based on profile moisture measurements. Agricultural Water Management 21, 313 – 330.

Landell-Mills, N., Porras, I.T. 2002. Silver bullet of fools' gold? A global review of markets for forest environmental services and their impact on the poor. Instruments for sustainable private sector forestry series. International Institute for Environment and Development, London. 272 pp.

Martínez, M.R., López M.R., López L, C. 2001. Caracterización geográfica y escalamiento de cuencas en zonas de ladera de Oaxaca. Memoria: XI Congreso Nacional de Irrigación. Guanajuato, Guanajuato, México.

McDonald, M.A., Healey, J.R., Stevens, P.A. 2002. The effects of secondary forest clearance and subsequent land-use on erosion losses and soil properties in the Blue Mountains of Jamaica. Agriculture, Ecosystems and Environment 92, 1 – 19.

McGinty, W.A., Smeins, F.E., Merril, L.B. 1979. Influence of soil, vegetation, and grazing management on infiltration rate and sediment production of Edwards Plateau rangeland. Journal of Range Management 32, 33 – 37.

Meadows, D., Randers, J., Meadows, D. 2004. Limits to growth: the 30 year update. Chelsea Green 338 pp.

Pagiola, S., Platais, G. 2002. Payments for Environmental Services. The Environment Strategy Notes 3. 4 pp.

Pagiola, S., Bishop, J., Landell-Mills, N. 2006. La venta de servicios ambientales forestales. (2ª Edición) INE-SEMARNAT, México D.F. 464 pp.

Pilbeam, C.J., Daamen, C.C., Simmonds, L.P. 1995. Analysis of water budgets in semi-arid lands from soil water records. Experimental Agriculture 31, 131 – 149.

Robin, C. 1976. El vulcanismo de las planicies de la Huasteca (Este de México). Datos Geoquímicos y Petrográficos. Boletín del Instituto de Geología UNAM 96: 55 – 92.

Rosegrant, M.W., Cai, X., Cline, S.A. 2002. World Water and Food to 2025: dealing with scarcity. International Food Policy Research Institute. Washington. D.C. 322 pp.

Scherrer, S; Naef, F. 2003. A decision scheme to indicate domain hydrologic flow process on temperate grasslands. Hydrological Processes 17: 391 – 401.

Schultz, R.C., Isenhart, T.M., Simpkins, W.W., Colletti, J.P. 2004. Riparian forest buffers in agroecosystems – lessons learned from the Bear Creek Catchment, central Iowa, USA. Agroforestry systems 61, 35-50.

Smith, R.P. 2004. Geologic Setting of the Snake River Plain Aquifer and Vadose Zone. Vadose zone Journal 3, 47 – 58.

Stephenson, G.R., Zuzel, J.F. 1981. Ground water recharge characteristics in a semi-arid environment of Southwest Idaho. Journal of Hydrology 53, 213 – 227.

Stocking, M.A. 1994. Assessing vegetative cover and management effects. In: Soil erosion: research methods. (Lal, R. ed.). Soil water and soil conservation society. Ankeny. IA. 340 pp.

Taddese, G., Mohamed Saleem, M.A., Abyie, A., Wagnew, A. 2002. Impact of grazing on plant species richness, plant biomass, plant attribute, and soil physical and hydrological properties of Vertisol in East African Highlands. Environmental Management 29, 279-289.

United Nations Educational, Scientific and Cultural Organization (UNESCO). 2006. Water a shared responsibility: The United Nations World Water Development Report 2. Paris, France. 601 pp.

United States Department of Agriculture. 1998. Keys to Soil Taxonomy. Eighth Edition. 328 pp.

United States Department of Agriculture. 1999. Guía para la evaluación de la calidad y salud del suelo. 88 pp.

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

van Dijk, A., Keenan, R.J. 2007. Planted forest and water in perspective. Forest Ecology and Management. 251, 1-9.

Wallace, J.S., Jackson, N.A., Ong, C.K. 1995. Water balance of agroforestry systems on hillslopes. Final report to the ODA Forestry Research Programme. Overseas Development Administration (ODA), Institute of Hydrology (IH). International Centre for Research in Agroforestry (ICRAF). Nairobi, Kenya. 39 pp.

Ward, A.D., Elliot, W.J. 1995. Environmental Hydrology. Lewis Publishers. Florida, USA. 462 pp.

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

Weerts, G.J. 1991. Soil hydraulic conductivity on two tropical soil types under forest and a 25 year old pasture: field measurement and data application. Atlantic Zone Programme. Report 4. CATIE- MAG- AUW. Turrialba, Costa Rica. 60 pp.

Weiler, M; Naef, F. 2003. An experimental tracer study of the role of macropores in infiltration in grasslands soils. Hydrological Processes 17, 477 – 493.

Weiler, M., McDonnell, J.J., Meerveld, I.T., Uchida, T. 2005. Subsurface Stormflow. Encyclopedia of Hydrological Sciences. (Anderson and McDonell eds). Pp. 1 – 14. Wiley & Sons Ltd.

World Bank. 2004. Water Resources Sector Strategy. Strategic directions for World Bank engagement. USA, Washington DC. 78 pp.

Yates, C.J., Norton, D.A., Hobbs, R.J. 2000. Grazing effects on plant cover, soil and microclimate in fragmented woodlands in South-Western Australia: implications for restoration. Austral Ecology 25, 36-47.

Zimmermann, B., Elsenbeer, H., De Morales, J.M. 2006. The influence of land-use changes on soil hydraulic properties: Implications for runoff generation. Forest Ecology and Management 222, 29 – 38.

Table 1a

Soil profile description, bulk density and infiltration rate in three land uses located in a hydrological recharge zone in the highlands of Otontepec Sierra, Northern Veracruz, México, 2008

	Land Use		
	Secondary Regeneration forest	**Grasslands without trees**	**Grasslands + *C. xalapensis* shrubs**
Elevation m.a.s.l.	848	805	779
Slope at the site %	40 (complex)	29 (complex)	55 (complex)
Vegetation cover %	> 80 (leaves, mulch)	> 80 (grass)	> 80 (shrubs, grass)
Parent material	Colluvial deposits of Basaltic lava	Colluvial deposits of Basaltic lava	Colluvial deposits of Basaltic lava
Soil type (USDA 1998)	Inceptisol	Inceptisol	Inceptisol
Evidence of Erosion	None	None	None
Effective soil depth (cm)	> 100	> 100	> 90
Drainage class	Well drained	Well drained	Well drained
Horizon A characteristics			
Depth (cm)	35	40	30
Colour (Munsell)	7.5YR2.5/3	7.5YR4/4	5YR3/2
Texture	Clay Loam	Clay loam	Sandy Clay loam
Sand %	37.84	39.84	47.84
Clay %	28.16	32.16	28.16
Silt %	34.00	28.00	24.0

pH	6.29	6.74	6.23
Organic Mater %	3.8	5.09	5.56
Presence rock fragments %	- 40	15 – 40	15 – 40
Soil structure	Sub angular blocky	Sub angular blocky	Sub angular blocky.
Consistency when moist	Very Friable	Friable	Very Friable
Interstitial voids	Common	Common	Common
Abundance of roots	Common	Many	Common
Soil tests			
Bulk Density (g cm^{3})	0.97^{a}	1.18^{d}	0.99^{b}
Infiltration rate (cm h^{-1})	11.15^{a}	0.99^{c}	14.1^{a}

Table 1b

Soil profile description, bulk density and infiltration rate in two land uses located in a groundwater recharge zone in the lowlands of Otontepec Sierra, Northern Veracruz, México, 2008

	Land Use	
	Disturbed *Quercus oleoides* forest	***Paspalum* spp grasslands without trees**
Elevation m.a.s.l.	715	713
Slope at the site %	32 complex	36 straight
Vegetation cover %	> 80	> 90
Parent material	Colluvial deposits, basaltic lava	Basaltic Lava
Soil Type (USDA 1998)	Inceptisol	Alfisol
Evidence or Erosion	None	None
Effective soil depth (cm)	> 95	> 95
Drainage class	Well drained	Well drained
Horizon A characteristics		
Depth (cm)	30	30
Colour (Munsell)	7.5YR2.5/2	7.5 YR3/3
Texture	Sandy Clay Loam	Sandy Clay Loam
Sand %	47.84	45.84
Clay %	26.16	32.16
Silt %	26.0	22.0
pH	6.74	6.49
Organic Mater %	4.21	4.55

Presence rock fragments %	40 - 80	2 – 5
Soil structure	Granular and Sub angular blocky	Granular and Sub angular blocky
Consistency when moist	Friable	Friable
Interstitial voids	Common	Common
Abundance of roots	Common	Common
Soil tests		
Bulk Density (g cm^{3})	0.99^{b}	1.17^{c}
Infiltration rate (cm h^{-1})	7.82^{b}	0.56^{c}

Table 2a

Hydrological balances of three land uses located in a highland groundwater recharge zone (August 2007 – July 2008). Otontepec Sierra, Northern Veracruz, México, 2008.

	Land Use		
	Secondary Regeneration Forest	**Grasslands without trees**	**Grasslands + *C. xalapensis* Shrubs**
Total rain (mm)	2,422	2,416	2,417
Canopy interception (mm)	403	n/d	n/d
Net rain (mm)	2,019	2,416	2,417
Runoff (mm)	21	41	9
ET (mm)	448	400	342
Change in soil moisture storage *ΔS* (mm)	431	368	320
Percolation (mm)	1,119	1,608	1,744

Table 2b

Hydrological Balances of two land uses located in a lowland groundwater recharge zone (August 2007 – July 2008). Otontepec Sierra, Northern Veracruz, México, 2008.

	Land Use	
	Disturbed *Quercus oleoides* Forest	***Paspalum* spp grasslands without trees**
Total rain (mm)	2,301	2,388
Canopy interception (mm)	180	n/d
Net rain (mm)	2,121	2,388
Runoff (mm)	6.5	7
ET (mm)	578	581
Change in soil moisture storage *ΔS* (mm)	563	487
Percolation (mm)	974	1,314

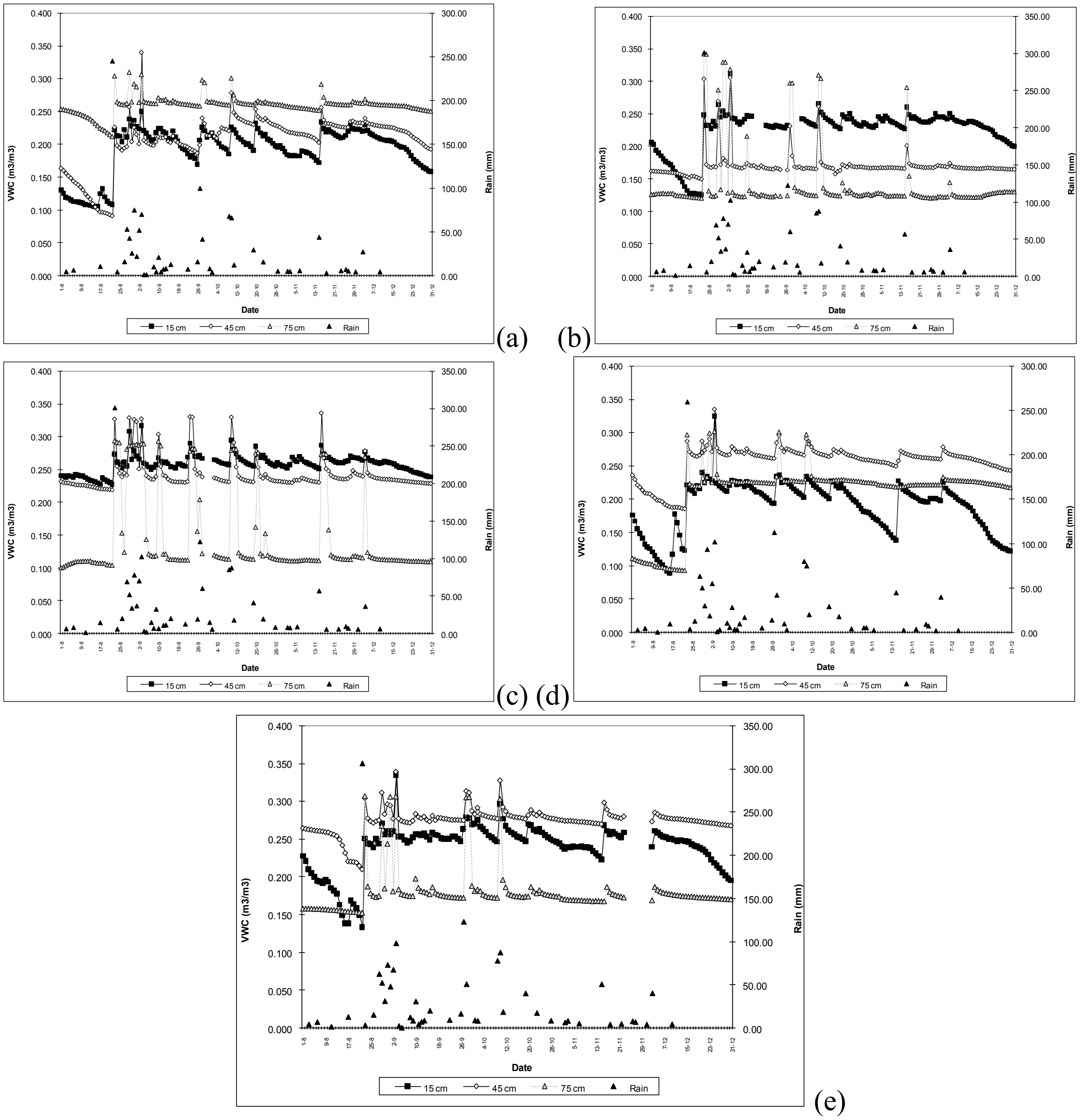

Figure 1. Soil moisture behaviour at three depths (15, 45 and 75 cm) in soil under a) secondary regeneration forest (24 years old) b) African Star grass (*Cynodon nlemfuensis* Vanderyst var**.** *Nlemfuensis*) without trees (+30 years old) c) a silvopastoral system [African Star grass (*Cynodon nlemfuensis* Vanderyst var**.** *Nlemfuensis*) + *Conostegia xalapensis* (Bonpl. D. Don ex DC) shrubs] (+30 years old) d) *Quercus oleoides* Cham. & Schlecht forest (+50 years old) e) native grass (*Paspalum notatum* Flüggé) (15 years old). August – December 2007, Otontepec Sierra, Northern Veracruz, México.

Exploring the feasibility of a payment for hydrological ecosystem service generated by three natural forests with different levels of intervention in a groundwater recharging area in northern Veracruz, Mexico.

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ABSTRACT

Natural forests provide hydrological ecosystems services (HES). However, forests continue to be changed to other production land uses that are mostly managed in an unsustainable way resulting in the alteration of HES. Payments for Hydrological Ecosystems Services (PHES) appear as an instrument of environmental policy directed to connect HES users and suppliers. However, one question that needs to be answered is; how much is necessary to pay for the provision of HES? Study objectives were to determine the opportunity cost of three natural forests located in a groundwater recharge area, and to show this information to lowland water users to obtain their point of view. The amount that every family needed to pay was 7.03 USD/year. When this information was showed to HES users, a consensus was reached to pay the tariff. Additionally, the communities generated several comments regarding tariff rate, for example; people with other activity that consumes more water should pay more as opposed to people that only have a domestic water use. In this case, if a policy of PHES is implemented, it would first be necessary to develop an index of water payment, in agreement with the communities or install hydraulic infrastructure to measure the water consumption.

Key words: cash flow analysis, opportunity cost, participatory approach

1. Introduction

Natural forests as well as other land use types (i.e. agroforestry systems) provide several ecosystems services (ES) to humans such as; scenic beauty, greenhouse gases reduction, habitat for biodiversity conservation, watershed protection, water flow regulation, and soil erosion control, among others (Bruijnzeel 1988; MacDonald *et al.,* 1996; Aylward 2002; Johnson *et al.,* 2002; Izac 2003; Murgueitio 2003; Teixeira *et al.,* 2003; Alavalapati *et al.,* 2004). Around the world, however, natural forests are continually changed to other land use types that generate more income for landowners. Unfortunately, these land use changes are managed under unsustainable practices, resulting in the alteration or elimination of ecosystem services that could affect societal wellbeing (Bruijnzeel and Critchley 1994; FAO 2000; Aylward 2002). In fact, a change in the generation of HES in the mountain highlands could affect, in several ways, other ecosystems and people in the lowlands (FAO 2000). For example, an infiltration rate decrement in a groundwater recharge zone soils could decrease the productive life of hydropower infrastructure, fresh water scarcity, fresh water pollution and loss of biodiversity, among others (Aylward 2002). Several strategies have been developed and implemented around the world to reduce the loss of natural forests, including the establishment of protected areas and ecological corridors, and the enactment of conservation regulations and policies directed to control the use of natural resources. Unfortunately, these strategies have not been successful protecting natural forests, and deforestation rates continue to be high, particularly in developing countries (FAO 2000; Pagiola *et al.,* 2002; Murgueitio 2003; FAO 2007). One reason natural forests are converted to other more profitable land uses is that positive externalities generated by these ecosystems are not considered by the market, and consequently are absent in the landowners cash flow (Bishop and Landell-Mills 2002; Habb and McConnell 2002; Freeman III 2003). A new approach to overcome this market failure is to implement a payment scheme for ecosystem services (PES). A PES consists of a payment or direct compensation by the users of the service for the maintenance or provision of an environmental service to the providers of the service (Wunder 2005). The aim of a PES is to generate funds that can be used either: (i) to increase the private benefits of conservation to individual forest managers, and so change their incentives; or (ii) to generate resources that can be used to finance conservation efforts by public or private conservation groups (Pagiola *et al.,* 2002). Payment schemes for Ecosystem Services are flexible mechanisms that can be adapted to different conditions. They consist of a payment or direct compensation by the users of the service for the maintenance or provision of an environmental service to the providers of the service. PES in watersheds usually relates to water supply, availability and/or quality and is called Payment for Hydrological Ecosystems Services (PHES). The successful application of PHES depends on various factors, such as the proper identification of suppliers and users, as well as the relationship between land use and service supply. Therefore, not every resource management problem at the watershed level can be solved with the application of a PHES scheme. Local PHES systems have a greater impact in the attainment of short term goals than schemes with a national or global scope. PHES can be sustainable in the long term if they are funded by local resources to solve specific problems of the population. However, there is a risk of PHES exacerbating economic dependence when based on external resources. PHES can contribute to conflict solving processes by providing platforms for negotiations (Echavarría

2002). One of the most important limitations of PHES policies is high transaction cost during their design and implementation (e.g. biophysical studies, assessment and system installation) (FAO 2004). In 2002 Landell-Mills and Porras developed a global research about markets of PHES implemented around the word (in total 61 study cases were considered). Authors reported that the majority of markets were in an emerging phase and few studies provided a comprehensive socioeconomic valuation. In addition, the Opportunity Cost (OC) associated with forgone land uses was rarely mentioned, and not all users' fees were introduced in a consultative manner. Fees were often imposed by water-based enterprises, NGO's and government agencies. Developing a policy of PHES with these flaws could result in non-participation by landlords, because the payment could be lower than their land OC. In addition if the tariff is imposed, households could evade payment because the amount is not in agreement with their socioeconomic situations and culture (Pagiola *et al.,* 2002). In Latin America, nationwide schemes of PHES were developed with these methodological flaws, for example, FONAFIFO in Costa Rica (Pagiola 2002; Redondo and Welsh 2006) and PSAH in México (SEMARNAT 2007; Chagoya and Iglesias 2009). A more feasible approach for developing successful local schemes of PHES is to consider land use OC and water users' points of view for establishing payment levels, such as the procedure followed by PASOLAC in Central America (Obando 2007).

México is a country that encompasses 1,964,375 km^2 and is located between coordinates 118°42' and 86°42' Longitude West, and 14°32' and 32°43' Latitude North. The north and central zones of the country are arid and semiarid climates whereas the southeast is humid. The population quadrupled between 1950 and 2005 from 25.8 to 103.48 million inhabitants, and changed from rural (57.4%) to urban (76.5%). México is a country with a high-medium water stress level; since fresh water availability was reduced from 18,035

m^3/inhabitant/year in 1950 to 4,312 m^3/inhabitant/year in 2007. The problem is severe in the northern and central zones because these regions generate 87% of the gross domestic product (GDP), encompass 70% of the population and only 30% of the hydrologic resource (CNA 2008). Veracruz State in the Gulf of México encompasses 71,820 km^2 and has a population of 7.25 million inhabitants (INEGI 2005). Due to its long form, this state is divided into three zones, South, Central and North, and has different climate zones ranging from humid tropic in the south, moist and cold in the central mountains, and sub-humid tropic in the north (INEGI 2005, CNA 2008). Otontepec Sierra, an isolated volcanic mountain, located in northern Veracruz and consists of approximately 15,150.00 hectares (Gazeta Oficial de Veracruz 2005). Due to its geological origin (Robin 1976), Otontepec Sierra supplies fresh water for approximately 122,000 people distributed throughout nine municipalities (Tepetzintla, Chontla, Tamalin, Tantima, Tancoco, Ixcatepec, Naranjos-Amatlan, Citlaltepetl and Chinampa de Gorostiza) (INEGI 2005). Natural vegetations in the Sierra consist of deciduous sub-humid forest and *Quercus oleoides* cham. & schlecht. forest (INEGI land vegetation map F 14-9). During the last years, natural forests in the Sierra are being altered to other productive land uses such as agriculture and livestock. Unfortunately, this problem has being ongoing since 1934, when several “Ejidos” (rural common use property in México) were established and occupied approximately 3,101.5 hectares of the mountain (San Juan Otontepec, Tancoco 1, Tancoco 2, San Juan-Nicolasillo, La Campechana, Copaltitla, Citlaltepetl, Apachicruz 1, Apachicruz 2, and Adolfo Lopez Mateos) (Gazeta Oficial de Veracruz 2005). Since then, private landowners and “Ejidarios” (citizens that have “Ejidal” land) began to change natural forest to other land used directed to shelf-consumption and for selling in local markets. In addition, from 1970 to 1976 the National Deforestation Program improved livestock and agriculture development initiatives in forested areas generating more pressure in forest remnants (Castañeda 2006). In 2005, the Veracruz Government decreed Otontepec Sierra a Natural Protected Area (Gazeta Oficial de Veracruz 2005). The decree recognized that Otontepec mountain generates an important hydrological ecosystem service and mentioned that the PHES is one alternative to improve forest conservation. In 2005, it was reported that three communities “El Humo”, “Tezitlal-Tepetzintla” and “Tezitlal-Chontla” denounced a reduction in productivity of mountain springs due to land use changes induced by highland landowners, resulting in home water shortages (Personal communication, Ing. Jesús Zeníl Méndez, Tepetzintla Municipal President, Period 2005 – 2007). As a means to resolve this conflict, a PHES aimed at protecting natural forests located in the highlands has been proposed. However, two pieces of information are needed to design a viable payment initiative: one piece is to assess natural forests’ opportunity costs, and the other is to appraise the point of view of lowland water users regarding the implementation of a payment to protect natural forests in the recharging area.

The objectives of this research were to calculate the opportunity cost of highlands forest conservation, and to explore water users’ point of view regarding payment for the hydrological service. Information generated in this study will help to build a more efficient PHES and local polices directed at forest conservation.

2. Methodology

2.1 Study Area

The study was developed in northern Veracruz, Mexico, in a microwatershed located in Otontepec Sierra, an isolated volcanic mountain (Map 1). This mountain is positioned between coordinates 97°58’30’’ and 97°48’00’’ West, and 21°19’19’’ and

21°09'34'' North . The climate is A(w^2) Sub-humid tropic (Köppen classification), with a dry season (from March to June) and a wet season (from July to December). Average precipitation in the zone is around 1,552 mm y^{-1} (CNA 2008). The altitude of the mountain ranges from 350 to 1,000 meters above sea level (m.a.s.l.). Soils are Inceptisols and Alfisols. Geology in the highlands is extrusive basaltic igneous rocks, and in the lowlands are sedimentary volcanic rocks, all from the Pliocene and Miocene periods (INEGI Geology Map Tamiahua F 14-9). The natural vegetation is sub-humid deciduous tropical forest with zones of *Quercus oleoides* forest (INEGI Vegetation Map Tamiahua F 14-9).

Using satellite images the springs that supply fresh water to communities were located and their recharging area delimited. Using Software ArcView 3.3© and a Satellite Image of IKONOS (0.6 m x 0.6 m pixel), the catchment area was calculated at 68 hectares. This area ranged from 650 to 900 m.a.s.l in altitude, had an irregular topography (from 5% to 100% slope grade), and exhibited colluvial processes. Main land uses identified were *Q. oleoides* cham. & schlecht. forests, secondary regeneration forests, grasslands without trees, and grasslands (*Cynodon nlemfuensis* Vanderyst var. *nlemfuensis*) with shrubs (*Conostegia xalapensis* (Bonpl.) D. Don ex DC). In the lowlands, three rural communities use the water provided by this microwatershed, “El Humo”, “Tezitlal-Tepetzintla” and “Tezitlal-Chontla”, with 1,828, 87 and 157 inhabitants, respectively (405 families in total). Each community have a water committee that reports monthly activities such as problems with water infrastructure, finance balances and water payment status, among others. In the case of water payments, “El Humo” has a tariff of 0.35 USD/month/family (1 USD = 13.5 Mexican pesos), independent of the level of water consumption. The other two communities do not have a water payment, when they need to carry out an initiative related to water use, such as building hydraulic infrastructure; they either pay a tariff or help with labour to do so.

2.1 Opportunity cost calculation

Natural forests in the selected catchment generate hydrologic ecosystem service. However, this positive externality is not valued by the market and is absent in landowners cash flow. In other words, if forest landowners obtain an economic input through the sale of this ecosystem service equal to the net income generated by an alternative productive activity, then perhaps they will avoid cutting the forest to implement grasslands or agriculture (Wunder 2007). However the question remains; how much should be paid to cover the opportunity cost of the alternative land use? In theory, the OC are the benefits forgone when a scarce resource is used for one purpose instead of the next best alternative (Young 2004). The OC of two natural forests and one silvopastoral system was calculated based on the methodology proposed by Norton-Griffiths and Southey (1995), and was considered that the alternative land use in the catchment was dual purpose livestock (milk and beef) in grasslands without trees. This activity was selected because is the most common productive activity in the Otontepec Sierra and in the microwatershed selected.

Scenarios were built utilizing several sources of information, for example: veterinary medicine suppliers helped with the cost of several products that are used by livestock farmers (i.e. vaccines, antibiotics, hormones, agrochemicals, among other products). Local livestock farmers helped with information about the control of livestock diseases, grassland management (i.e. costs of weeds control), livestock management (i.e. internal and external parasite control) and milk and beef production. Experts in livestock and grasslands management of the INIFAP (National Institute of Agricultural, Livestock and Forestry Research) helped with information about the benefits of a rotational grasslands management system in comparison with extensive grassing. Also, with information about the productive and reproductive characteristics of the dual purpose livestock, for example: milk production, beef production, genetic and reproductive parameters. Catchment landowners gave their point of view about the feasibility to implement a livestock activity in the groundwater recharge area (advantages and disadvantages), and their point of view about the conflict between forest conservation and livestock activity. Finally, authors information about the hydrologic behaviour of the land uses in the recharge area (i.e. infiltration rate, bulk density), and the characteristics of the secondary regeneration forest and *Quercus oleoides* forest (i.e. basal area, number of trees, canopy area), were used to support the scenarios.

2.1.1. Land uses characteristics

2.1.1.1 Scenario 1 "Livestock opportunity cost in a zone with *Quercus oleoides* forest (QF)"

Natural QF was located at 715 m.a.s.l., at a slope of 32% with complex topography and 131 trees/ha recorded with an average high of 15.1 m, a basal area of 277 m^2/ha, and one canopy stratum. Soil was covered by dead leaves and aboveground vegetation was scarce. Interviews with forest owners indicated that these forests are more than 50 years old and have not had any silvicultural management. According to the farmer's point of view, the trees are a problem because it is very difficult to produce something under their canopy and *Q. oleoides* (Oak) trees have a slow growth rate. When farmers cut a tree or the wind breaks a tree, farmers use the opportunity to introduce grasslands, controlling secondary regeneration with agrochemicals. In addition, market demand at the local market of Oak timber is high, with tree stump prices close to 76 USD/tree.

2.1.1.2 Scenario 2 “Livestock opportunity cost in a zone with Secondary Regeneration Forest (SRF)”

The SRF was located at 848 m.a.s.l., at a slope of 60% with complex topography. Interviews with forest owners indicated that primary forest was cut and burned in 1975 because a government policy encouraged forest conversion to agriculture (Castañeda 2006). Maize was cultivated on the deforested land for two years and then left to secondary regeneration because native wildlife damages the maize plants and crop production was low in the second year. This forest contained three stratums; trees, shrubs and weeds, with dead leaves covering the soil. The number of trees per hectare was 546 with a basal area of 745 m^2/ha, an average tree height of 8.3 m, and a total canopy area of 12,212 m^2 per hectare, indicating some overlapping of trees in the canopy. The more common species were *Heliocarpus donnell-smithii* Rose ex Donn.Sm. (19%); *Persea* spp. (16.2%); *Muntingia calabura* L. (13.4%); *Inga spuria* Humb. & Bonpl. ex Willd. (12.7%); and *Croton draco* Schltdl. & Cham. (9.95%). Additionally, the number of shrubs per hectare was 2,133 with the more common species being *Turpinia insignis* (H. B. & K.) Tul. (23.95%), and *C. xalapensis* (Bonpl.) D. Don ex DC. (9.9%). It is necessary to mention that these trees are used for firewood, but due to the long distance to the SRF, residents of the nearest rural community of “San Juan Otontepec” avoided their use. Adjacent land use to the forest was used for livestock.

2.1.3 Scenario 3 “Opportunity cost of “liberating” for natural regeneration an area with silvopastoral system (grassland + shrubs) (GS)”

The silvopastoral system was located at 815 m.a.s.l., at a slope of 55% with complex topography. *C. xalapensis* shrubs were common in the forest’s disturbed areas, with strong trunks and a dense canopy, and were not grassed. Livestock avoided walking through the shrubs and preferred to walk around the shrub canopy area. Hydrologic information indicated that shrubs were important under the hydrological point of view because bulk density showed statistical difference ($P<0.001$) under the canopy than in open areas (0.70^a *vs.* 1.26^b g/cm^3, respectively), and the infiltration rate (Kostiakow equation, Henríquez and Cabalceta 1999) showed statistical difference under the shrubs canopy than in open areas (26.9^a *vs*. 1.51^b cm/h, respectively). In other words, shrubs were important under the hydrological point of view because they acted like buffer zones with higher infiltration rates under their canopy than in open grassland areas. However, according to the livestock farmers' points of view these shrubs were a problem because shrubs are not grassed for the livestock and grasslands growth under shrubs canopy was scarce, and shrubs canopy occupied 36% of the grassland area.

2.1.2. Opportunity cost calculation

To calculate the OC a single year budget (2008) was constructed with the objective that the Net Benefit (NB) of the livestock activity was considered similar to the forest OC. To calculate Oak forest OC and Secondary Regeneration Forest OC, equation 1 was used. To calculate the Silvopastoral System OC, equation 2 was used (Norton-Griffiths and Southey 1995). Furthermore, in each scenario two sensibility analyses were developed, one with changes in agrochemicals and veterinary medicine costs and the other with changes in milk prices.

Equation 1

$$OC_{\text{Forest Conservation}} = NB_{\text{livestock}}$$

$$NB_{\text{livestock}} = NR_{\text{livestock}} = GR_{\text{livestock}} - C_{\text{livestock}}$$

Equation 2

$$OC_{\text{Silvopastoral System Conservation}} = NB_{\text{(grasslands + shrubs)}} - NB_{\text{grasslands without shrubs}}$$
$$NB_{\text{(grasslands + shrubs)}} = NR_{\text{(grasslands + shrubs)}} = GR_{\text{(grasslands + shrubs)}} - C_{\text{(grasslands + shrubs)}}$$
$$NB_{\text{grasslands without shrubs}} = NR_{\text{grasslands without shrubs}} = GR_{\text{grasslands without shrubs}} - C_{\text{grasslands without shrubs}}$$

Where:

OC = Opportunity Cost
NB = Net Benefits
NR = Net Returns
GR = Gross Revenues
C = Costs

2.1.3 Lowland users' point of view on PHES

Opportunity costs to protect the natural forests and leaving for natural regeneration the area with silvopastoral system (grasslands + shrubs) were presented to three communities (El Humo, Tezitlal-Tepetzintla and Tezitlal-Chontla) at their current meetings following a participatory approach methodology (Geilfus 1998). This approach was employed because water is a volatile topic in this region of Veracruz and several political conflicts about springs concessions were registered in the past (Personal communication 2007, Ing. Clemente J. Leyva, Veracruz State Water Commission-CAEV). In addition, these communities make their decisions by consensus. For the reason, a meeting with members of the local water committees was assembled prior to developing the community meetings. The meeting objective was to introduce researchers to the committee members, to show the project objectives and to solicit their request to present this information in their current communities meetings. With the committee members' permission, researchers participated in six informational gatherings, two for each community. The first meetings were developed in May 2006 with the objectives to; a) introduce researchers to community members and to "break the ice", b) show research objectives, c) explain that this information would not affect their current legal water situation, but would only be used to help them in their decision making processes, d) explain in the simplest way; What is a

Hydrological Ecosystem Service? and Why is it important to protect the highland forests?, and e) request their permission to develop another meeting to show the research results. Additionally, this meeting helped to identify households' points of view about their water supply problems, their perception about payment for the water used, and other problems related to the hydraulic infrastructure. A second round of meetings were developed in September 2007 and their objectives were; a) to explain carefully the socioeconomic and hydrologic information generated, b) to hear their opinions and to answer their questions, c) to explain again; What is a Hydrological Ecosystem Services?, What are the market components?, and What will be their participation?, d) to show, how much each family would need to pay to protect the natural forests and the SPS in the recharge area, and e) to determine if they were in agreement to pay the tariff.

3. Results and Discussion

3.1 Opportunity costs and sensibility analysis

Opportunity costs of the three land uses considered are shown in Table 1. Results indicated that the option of conserving the Quercus forest presented the highest gross margin. This situation was developed because sites located in the *Quercus oleoides* forests had the best characteristics to develop livestock activity. On the other hand, the opportunity cost for abandoning the silvopastoral system for natural regeneration had the lowest gross margin because the site was steeply sloped and presented low grassland cover which was not enough to support a high stocking rate.

Graphs 1 and 2 illustrated the sensitive analysis for the first scenario "Opportunity cost for conserving *Quercus oleoides* forest (QF)". Results showed that livestock activity continued to be profitable with an increase in supply costs up to 80% and with milk price decreases of 0.10 USD/litre. These results indicated that livestock is an attractive activity to Oak forest landlords.

Graphs 3 and 4 illustrated the sensibility analysis for the second scenario “Opportunity cost for conserving the secondary regeneration forest (SRF)”. The analysis indicated that livestock continued to be profitable with significant reductions in milk price and increments in supplies. It is evident that livestock is an economic activity that can support severe changes in its main components and perhaps is one reason that helps to explain the current land use change process.

Graphs 5 and 6 showed that livestock activity under the third scenario conditions has a low profitability and is sensitive to changes in supply costs and milk price. In this case the PHES would be an interesting option to convert the silvopastoral system to secondary regeneration forest. In fact, the amount paid by the National Forest Commission (CONAFOR) to protect Agroforestry Systems (26.4 USD) is enough to cover the third scenario OC (15.4 USD). Unfortunately, land use conversion from silvopastoral systems to secondary regeneration forest is not included in this policy. However, CONAFOR had a new policy, “Concurrent Founds”, were CONAFOR would match one peso for each peso that water users pay (SEMARNAT 2008). In this case, the responsibility to support the payment is shared by CONAFOR and the water users. If this agreement could be realized, it would be possible to pay the second scenario OC. But, this option implies an intensive community’ organization and an interesting question arises; Who will support the community organization costs? It is clear that the implementation of a local policy of PHES needs to be accompanied by institutional support (Government, Universities, NGO’s, among others) (Porras *et al.,* 2008).

Table 2 indicated that the total cost to protect the forest remnants and to release the area under silvopastoral system in the recharging area is around 2,850 USD/year. This amount divided among the number of families indicated that each family needs to pay 7.03 USD/year.

3.2- Lowland water user point of view

Three rural communities use the water released by the recharge zone. The first, "El Humo" is located in Tepetzintla Municipality at 280 m.a.s.l., with a population of 1,828 people (866 women and 962 men) distributed among 378 homes with the following characteristics: water service 91%, soil floor (without cement) 91%, no sewage drainage system 83%, T.V. 74.3%, and refrigerator 31.5%. The second community, "Tezitlal-Tepetzintla" is located at 300 m.a.s.l., with a population of 87 people (40 women and 47 men) distributed among 22 homes with the following characteristics: water service 100%, cement floor 72%, no sewage drainage system 50%, T.V. 95%, and refrigerator 82%. The third community, "Tezitlal-Chontla" is located in the municipality of Chontla at 280 m.a.s.l., with a population of 157 people (78 women and 79 men) distributed among 39 homes with the following characteristics: water service 95%, soil floor (without cement) 72%, no sewage drainage system 84%, T.V. 77%, and refrigerator 59% (INEGI 2005).

A gathering was developed in May 2006 with the members of the local water committees (13 citizens). Project information was shown and the request to present this information to their communities was accepted by all the members. Additionally, this event helped to understand the level of organization of the communities. Unfortunately, coordination among communities is scarce, and each community faces its water supply problems independently. However, it is important to underline that they consume the same water from the same catchment. Three meetings were developed, one in each community. The first assembly was conducted in “El Humo” with the participation of 72 households. During this meeting the project proposal was shown and the concept of hydrological ecosystem services (HES) was explained. In addition, authors explained that this research would not affect the communities current legal situation regarding springs concessions, and the only target was to help them in their decision making process. The last point was important because in 2005 another neighboring community “Tierra Blanca” tried to “take” one spring that was used by “El Humo” with the argument that this spring had enough production to supply both communities. However, “El Humo” citizens avoided the takeover of the spring by “Tierra Blanca” citizens by measuring its flow. Fresh water is difficult to obtain in this region; therefore it was very important to visit the spring’s zone to delimitate its recharging area, identify the main land uses and calculate the OC of the productive activities. For this reason, the request to visit spring zone and recharge area was solicited carefully. Fortunately, the request was accepted by a partial consensus (66% yes and 34% no). Citizens explained that they have severe water supply problems in the dry season months and they attribute this to deforestation processes in mountain highlands. However, the water committee manager mentioned that the hydraulic infrastructure was built 20 years ago, and the water deposits overflow during the night. This last point indicated that perhaps the fresh water supply problem in this community was caused by an obsolete hydraulic infrastructure and not by a reduction in springs flow. The meeting was ended with the agreement to return in one year with the socioeconomic information generated. The first assembly in Tezitlal-Tepetzintla was convened with the participation of 32 people. This small community showed a high interest in the project proposal and households agreed (100%) to permit a visit of the spring’s zone. Households commented that they do not have severe water supply problems in the dry season, but they are nervous about the increase in the “El Humo” population. They felt that water supply would be a problem in the future when this community demands more water. It is important to mention that during the meetings local leaders controlled opinions. The meeting was ended with the agreement to return with the information generated. The gathering in “Tezitlal-Chontla” was conducted with a participation of 35 households. This community showed less interest in the project in comparison with the last community. Households heard project proposal and were in a partial agreement to permit the spring zone visit (54% yes and 46% no). Additionally, they commented that they have water supply problems only in years with a long dry season or when the hydraulic infrastructure is damaged. The meeting was ended with the agreement to return with the information recorded.

The second meetings were developed in September 2007. The “El Humo” gathering was conducted with 68 households. It is necessary to mention that participating households in the second meeting were not the same households that participated in the first meeting. The concept of PHES and research results were explained carefully. The socioeconomic information was explained and supported with hydrologic information generated by the authors in their springs recharge area (see Chapter One). Hydrologic information suggested that land uses in the recharge area (Oak forest, secondary regeneration forest, grasslands + shrubs, and grasslands without trees) resulted in an appropriate hydrologic behaviour and it was not feasible to propose an increase in catchment flow with a land use change from grasslands to forest. The proposal was to protect the natural forest not as an ecosystem that percolates more water but as the safest land use that guarantees HES provision. Contrary to that, grassland hydrologic behaviour recorded could change in short time due to changes in the current grassland management such as increase stocking rate, change to extensive grassing system, use fire to clean grasslands (Stocking 1994) or global climatic changes (Arnell 1999; Arnell 2004). Additionally, the spring zone visit showed that each community built rustic infrastructure to store spring flow and transported the water by a system of pipelines and water deposits. Three community infrastructures were of the same size and at the same level. However spring water is not captured in equal amounts by the infrastructure. For example, flow measurements in the dry season (June 2006) indicated that “El Humo” had 107/litres/inhabitant/day, contrary to that, Tezitlal-Tepetzintla had 307 litres/inhabitant/day and Tezitlal-Chontla had 270 litres/inhabitant/day. These differences in water availability could generate problems in the future, and community organizations could be necessary to resolve this situation without sociopolitical conflicts. El Humo” households were questioned if they were in agreement to pay the OC to protect the natural forests and to release the area under silvopastoral system in the recharging area. They were partially in agreement to pay the OC of the alternative land use to protect natural forests and silvopastoral system (57% yes 43% no). However, households generated several questions that needed to be taken into account before the implementation of a policy of PHES. For example; households asked that if payment to protect the forest is applied, who would collect the payment, who would pay the forests and silvopastoral system landlords, who would monitor the landlords, who would pay the salary of the people that will be working on policy implementation, and what would be the function of the Municipal Government? Comments above indicated that a local policy of PHES should be accompanied by economic support from the Government, NGO’s or other institutions with the communities’ organization, and supervision. The second Tezitlal-Tepetzintla gathering was conducted with 33 persons. Research information was shown and households participated actively. Additionally, they were in agreement to pay the alternative land use OC (100%). Base in the information shown, households reiterated their concerns about future water supply problems. However, they mentioned that community organization would be difficult and that the participation of one institution without political preferences could help in this processes. Finally, the Tezitlal-Chontla second gathering was developed with the presence of 30 households. Citizens were interested in the information generated. When they were questioned about OC payment for the alternative land use in the highlands, they avoided answering directly. Households mentioned that they would be in agreement to pay this amount, if people that had pigs or a rural cheese factory paid more, or people that had a home made with bricks or cement paid more than people that had a home made with rustic materials, or big families with more than 5 persons paid more than small families with 2 or 3 persons. The last comments indicated that a water use tariff is needed before implementation of a PHES policy.

4. Conclusions

Benefit-cost analysis showed that livestock profitability changed in the three scenarios. This variability was developed due to specific site characteristics, for example: livestock activity was more profitable, and its OC was higher, in areas with low slope grade. In contrast, livestock activity showed low profitability in steep slope areas with shrubs. In addition, sensibility analysis indicated that livestock activity continued to be profitable, notwithstanding increments in supplies costs (medicine and agrochemicals) and decrements in milk price.

“El Humo” and “Tezitlal-Tepetzintla” water users were in agreement to pay the opportunity cost of the alternative land use with the objective to protect the natural forests and to release the area under silvopastoral system located in their springs recharge zone. However, feedback comments indicated that other aspects should be considered before the implementation of this policy. For example; a) It is necessary to calculate and to include the transaction costs in the water tariff, and b) Government, NGO’s or other institutions need to help with organization, training, economic support and legal assistance of the implementation and monitoring of this policy.

“Tezitlal-Chontla” water users conditionally agreed to pay the opportunity cost of the alternative land uses. Households mentioned that they would pay this tariff if households with pigs or a rural cheese factory paid more, or households that live in homes made with bricks and cement paid more than people that have homes made with rustic materials, or big families with more than 5 persons paid more than families with 2 or 3 members. These comments indicated that before the implementation of a policy of PHES in these rural communities a basic infrastructure to measure water consumption should be installed and a water use tariff should be developed by communities’ consensus.

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5. References

Alavalapaty, JRR; Shrestha, RK; Stainback, GA; Matta, JR. 2004. Agroforestry development: an environmental economic perspective. *Agroforestry Systems* 61: 299 – 310.

Arnell, N.W. 1990. Climate change and global water resources. *Global Environmental Change.* 9: S31-S49

Arnell, N.W. 2004. Climate change and global water resources: SRES emissions and socio-economic scenarios. *Global Environmental Change* 14: 31 - 52

Asquith, NM; Vargas, MT; Wunder, S. 2008. Selling two environmental services: In-kind payments for bird habitat and watershed protection in los Negros, Bolivia. *Ecological Economics* 65: 675 – 684 p.

Aylward, B. 2002. Land-use, hydrological function and economic valuation. Proceedings of the UNESCO symposium: Forest-Water-People in the humid tropics. Kuala Lumpur, Malaysia. 47 p.

Bishop, J; Landell-Mills, N. 2002. Forest Environmental Services: An overview. *In*: Selling Forest Environmental Services: Market based mechanisms for conservation and development (Pagiola, Bishop and Landell-Mills Eds.). Earthscan Publications Ltd. London, UK. 15 – 35 p.

Bruijnzeel, LA. 1988. (De)forestation and dry season flow in the tropics; a closer look. Journal of Tropical Forest Science 1 (3): 229 – 243.

Bruijnzeel, LA; Critchley, WRS. 1994. Environmental impacts of logging moist tropical forest. UNESCO. IHP Humid Tropics Programme Series. Num. 7. Paris, France. 52 p.

Castañeda R,J. 2006. Las Áreas Naturales Protegidas de México de su origen precoz a su consolidación tardía. *Scripta Nova.* Revista Electrónica de Geografía y Ciencias Sociales. Universidad de Barcelona. Vol. X, núm. 218(13) Consulted *on line* February 9th 2009. http://www.ub.es/geocrit/sn/sn-218-13.htm

Chagoya F,JL; Iglesias G.L. 2009. Esquema de pago por servicios ambientales de la Comisión Nacional Forestal, México. *In*: Políticas y sistemas de incentivos para el fomento y la adopción de buenas prácticas agrícolas: como una medida de adaptación al cambio climático en América Central (Sepúlveda and Ibrahim Eds.). CATIE. Serie Técnica. Informe Técnico No. 377: 189 – 204 p.

Comisión Nacional del Agua (CNA). 2008. Estadísticas Del Agua en México. CNA-SEMARNAT. México D.F. 228 p.

Echavarria, M. 2002. Financing watersheds conservation: The FONAG water found in Quito, Ecuador. *In*: Selling Forest Environmental Services: Market based mechanisms for conservation and development (Pagiola, Bishop and Landell-Mills Eds.). Earthscan Publications Ltd. London, UK. 91 – 101 p.

Food and Agriculture Organization of the United Nations (FAO). 2000. Land-Water linkages in rural watersheds. *Land and Water bulletin* 9. Rome, Italy. 90 p.

Food and Agriculture Organization of the United Nations (FAO). 2004. Electronic Forum on Payment Schemes for Environmental Services in Watersheds. Final Report. Santiago, Chile. 27 p.

Food and Agriculture Organization of the United Nations (FAO). 2007. Situación de los Bosques en el Mundo. Roma, Italy. 157 p.

Fundación Gonzalo Río Arronte; Fundación Javier Barros Sierra. 2004. Prospectiva de la demanda de agua en México, 2000 – 2030. México. D.F. 105 p.

Freeman III, AM. 2003. The measurement of environmental and resource values: theory and methods. Second Edition. Resources of the Future. Washington DC. USA. 491 p.

Gaceta Oficial de Veracruz. 2005. Decreto de Área Natural Protegida a la Sierra de Otontepec en su categoría de Reserva Ecológica. Tomo CLXXII, Núm. 43. Miércoles 2 de Marzo. 40 p.

Geilfus, F. 1998. 80 Herramientas para el desarrollo participativo: Diagnostico, planificación, monitoreo, evaluación. GTZ – IICA. San Salvador 235 p.

Haab, TC; McConnell, KE. 2002. Valuing environmental and natural resources: the econometrics of non-market valuation. Series: New horizons in environmental economics. Edward Elgar Publishing Limited. United Kingdom 326 p.

Henríquez, C; Cabalceta. 1999. Guía práctica para el estudio introductorio de los suelos con enfoque agrícola. Universidad de Costa Rica. 122 p.

Instituto Nacional de Estadística Geografía é Informática (INEGI). 2005. Anuario Estadístico, Veracruz de Ignacio de la Llave, Tomos I y II. México, D.F.

Instituto Nacional de Estadística Geografía é Informática (INEGI). Carta de Vegetación F 14-9. México D.F. INEGI. 1:250,000. A colores.

Instituto Nacional de Estadística Geografía é Informática (INEGI). Carta Geológica F 14-9. México D.F. INEGI. 1:250,000. A colores.

Izac A, MN. 2003. Economic aspects of soil fertility management and agroforestry practices. *In*: Trees, crops and soil fertility (Eds. Schroth G. and Sinclair FL.). CAB publishing. CAB international. Wallingford, Oxon, UK. 437 p.

Johnson, N; White, A; Perrot-Maître, D. 2002. Developing markets for water services from forest: issues and lessons for innovators. Forest Trends, World Resources Institute, The Katoomba group. Washington D.C. USA. 26 p.

Landell-Mills, N; Porras, IT. 2002. Silver bullet of fools´ gold? A global review of markets For forest environmental services and their impact on the poor. International Institute for Environment and Development (IIDE). London. 272 p.

McDonald, MA; Healey, JR; Stevens, PA. 1996. The effects of secondary forest clearance and subsequent land-use on erosion losses and soil properties in the Blue Mountains of Jamaica. *Agriculture, Ecosystems and Environment* 92 (1): 1-19.

Murgueitio, E. 2003. Environmental impact of milk production systems in Colombia and alternative solutions. *Livestock Research for Rural Development* 15 (10). 17 p.

Northon-Griffiths, M; Southey, C. 1995. The opportunity cost of biodiversity conservation in Kenya. *Ecological Economics* 12, 125 – 139 p.

Obando E, M. 2007. Evolución de la experiencia de los PSAH en Nicaragua: El caso de los Caballos, Municipio de San Pedro del Norte, Chinandega. PASOLAC-COSUDE. Documento No.534. Serie Técnica 2/2007. 45 p.

Pagiola, S. 2002. Paying for water services in Central America: Learning from Costa Rica. *In*: Selling Forest Environmental Services: Market based mechanisms for conservation and development (Pagiola, Bishop and Landell-Mills Eds.). Earthscan Publications Ltd. London, UK. 37 – 61 p.

Pagiola, S; Landell-Mills, N; Bishop, J;. 2002. Market-based mechanisms for forest conservation and development. *In*: Selling Forest Environmental Services: Market based mechanisms for conservation and development (Pagiola, Bishop and Landell-Mills Eds.). Earthscan Publications Ltd. London, UK. 1 – 13 p.

Pagiola, E. 2008. Payments for environmental services in Costa Rica. *Ecological Economics* 65, 712 – 724.

Redondo B, A; Welsh, K. 2006. Payment for Hydrological Environmental Services in Costa Rica: The Procuencas study case. *Tropical Resources Bulletin* 25, 19 – 25.

Robin, C. 1976. El vulcanismo de las planicies de la Huasteca (Este de México). Datos Geoquímicos y Petrográficos. *Boletín del Instituto de Geología* UNAM 96: 55 – 92.

Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). 2008. Reglas de Operación del Programa Pro-Árbol de la Comisión Nacional Forestal. Diario Oficial de la Federación. Miércoles 31 de Diciembre del 2008. 112 p.

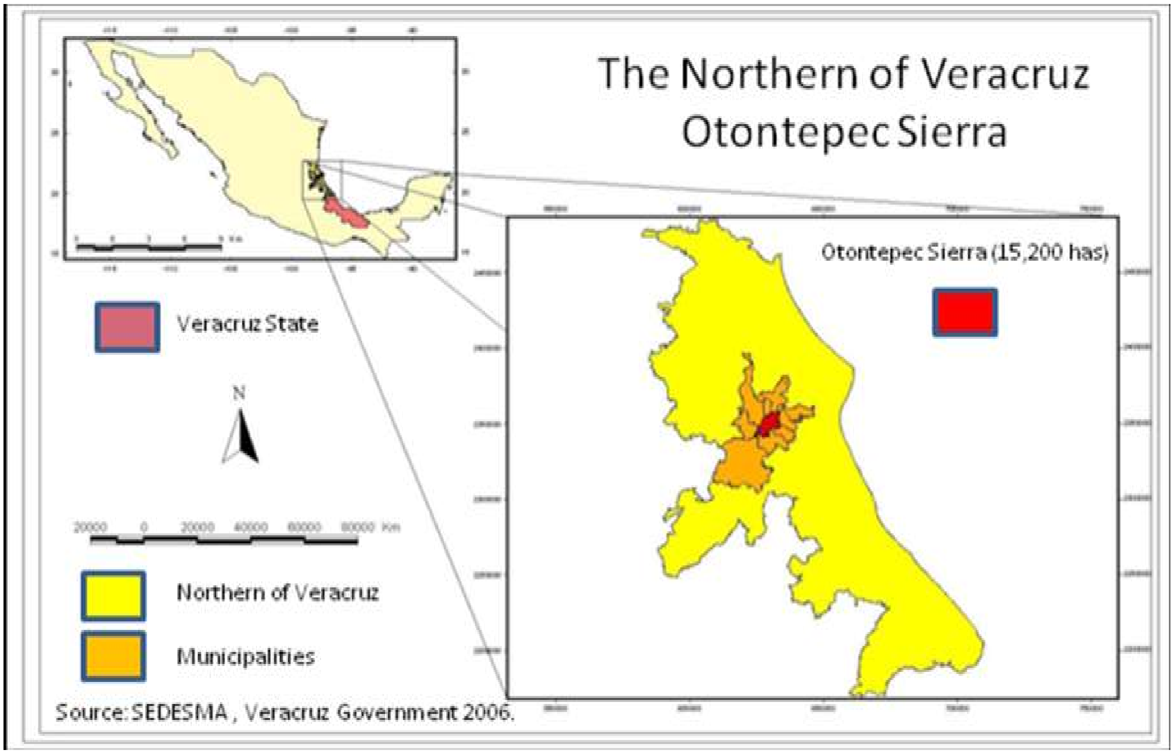
Stocking, M.A. 1994. Assessing vegetative cover and management effects. *In*: Soil erosion: research methods. (Lal, R. ed.). Soil water and soil conservation society. Ankeny. IA. 340 p.

Teixeira, WG; Sinclair, FL; Huwe, B; Schroth, G. 2003. Soil Water *in*: Trees, Crops and Soil Fertility (Schroth and Sinclair *eds*.) CAB international, Wallingford, Oxon, UK. 209 – 232.

Wunder, S. 2005. Payments for environmental services: Some nuts and bolts. Occasional Paper No. 42. Center of International Forestry Research (CIFOR). 32 p.

Wunder, S. 2007. The efficiency of payments for environmental services in tropical conservation. *Conservation Biology* 21(1): 48 – 58.

Young, RA. 2004. Determining the economic value of water: concepts and methods. Resources for the future. Washington, D.C. USA. 356 p.



Map 1. Otontepec Sierra location (Source SEDESMA, Veracruz Government 2006).

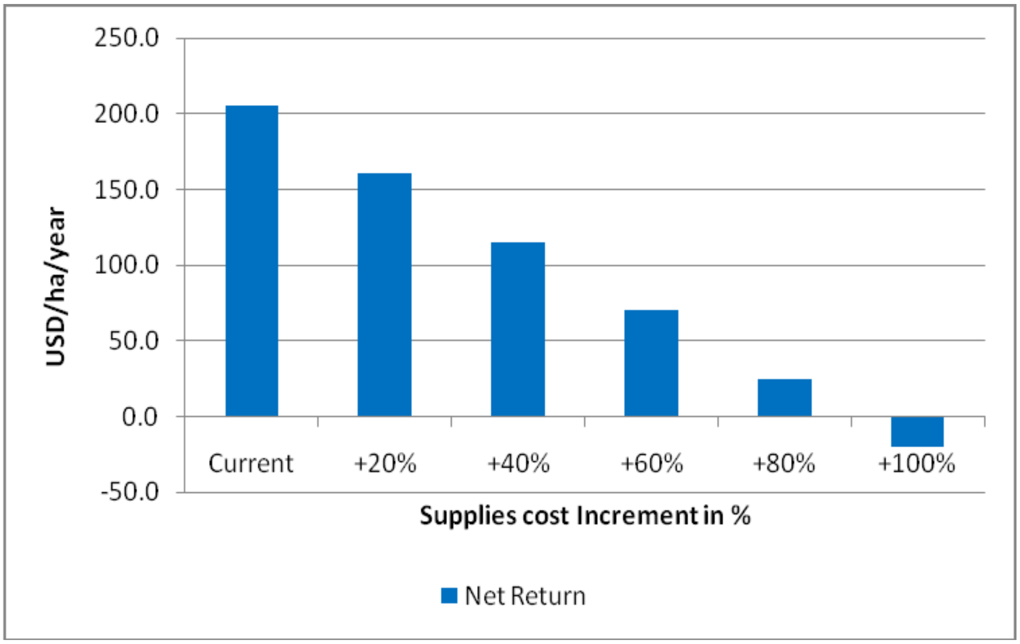
Table 1 Scenarios budget of the three alternative land uses located in a recharge zone of Otontepec Sierra. Northern Veracruz, México (Period January – December 2008).

Concept	**First Scenario*** **(USD/ha)**	**Second Scenario**** **(USD/ha)**	**Third Scenario***** **(USD/ha)**
+Stocking rate (AU/year)	1.0	0.5	0.3
Grasslands maintenance			
Labour	14.81	14.81	5.39
Weed killers	111.11	0	0
Cow maintenance*			
Technical assistance	17.78	8.89	2.16
Labour	90.07	45.04	10.92
Stick control	9.26	4.63	1.12
Internal parasite control	4.80	2.4	0.58
Mineral salt	6.89	3.41	0.84
Grain supplementation	48.67	24.30	5.90
Vaccines	5.0	2.48	0.61
Other medicine	37.04	18.52	4.5
Calf maintenance			
Internal parasite control	2.22	1.1	0.27
Vaccines	0.86	0.43	0.10
Total costs	**348.51**	**126.0**	**32.39**
Incomes			
Milk	480.0	160.0	38.83
Calf sale	74.07	37.04	8.98
Gross revenues	**554.07**	**197.0**	**47.81**
Net Returns	**205.56**	**71.0**	**15.42**

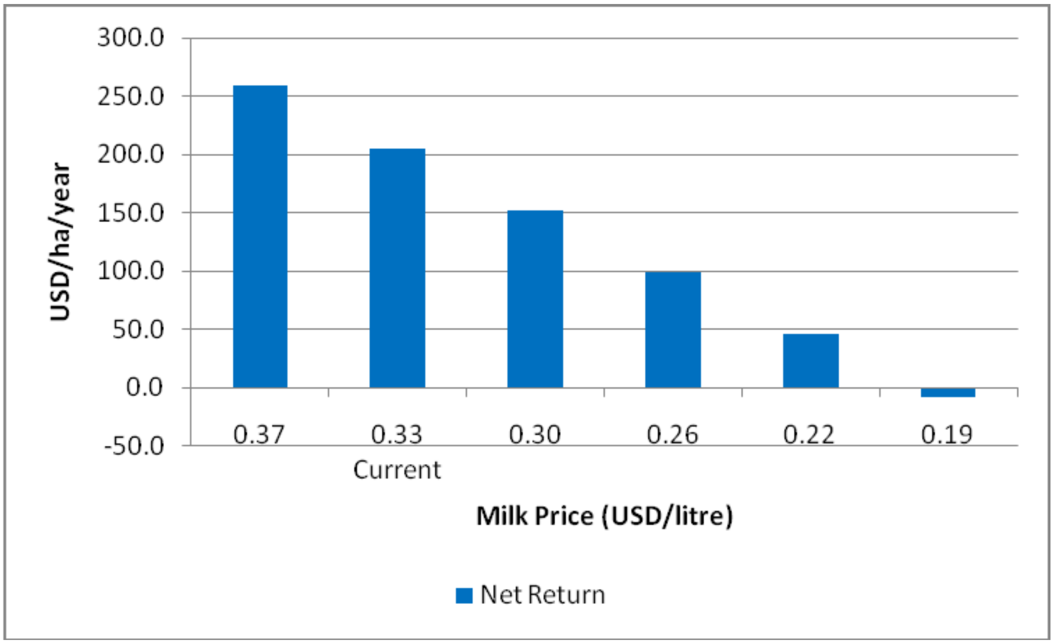
* Scenario 1 "Livestock opportunity cost in a zone with *Quercus oleoides* forest (QF)"

** Scenario 2 "Livestock opportunity cost in a zone with Secondary Regeneration Forest (SRF)"

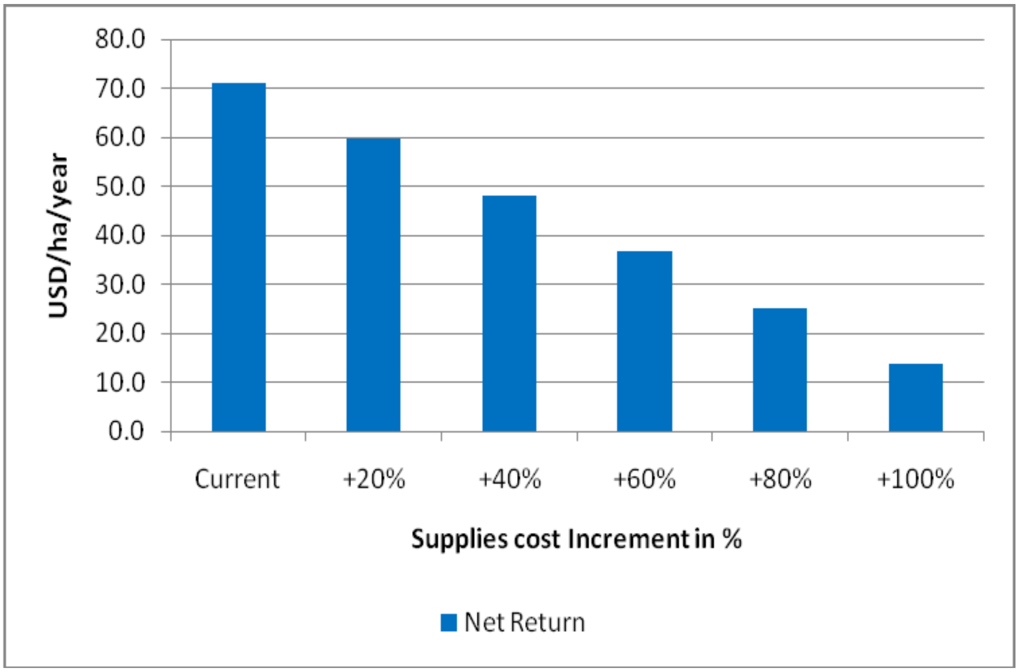
*** Scenario 3 "Livestock in grasslands without shrubs opportunity cost in a zone under a silvopastoral system (grassland + shrubs) (SPS)" Note: All the values are in USD (North America Dollar). 13.5 Mexican pesos = 1 USD +AU = Animal Unit/hectare.



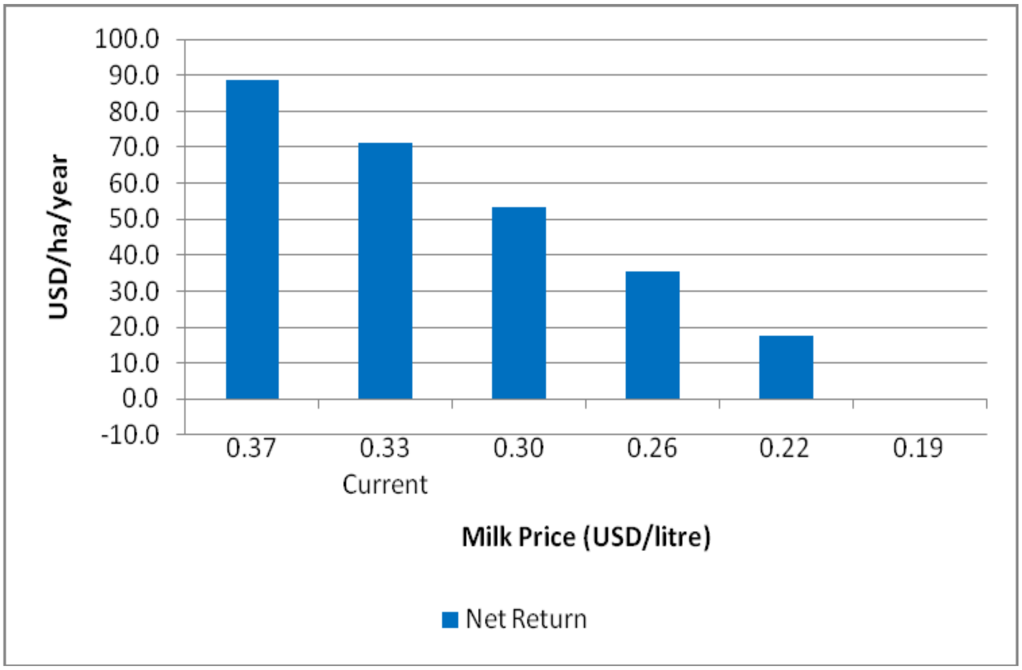
Graph 1 Sensibility analysis of Scenario 1 "Livestock opportunity cost in a zone with *Quercus oleoides* forest (QF)" with increments in the cost of agrochemicals and veterinary supplies, northern Veracruz, Mexico 2008.



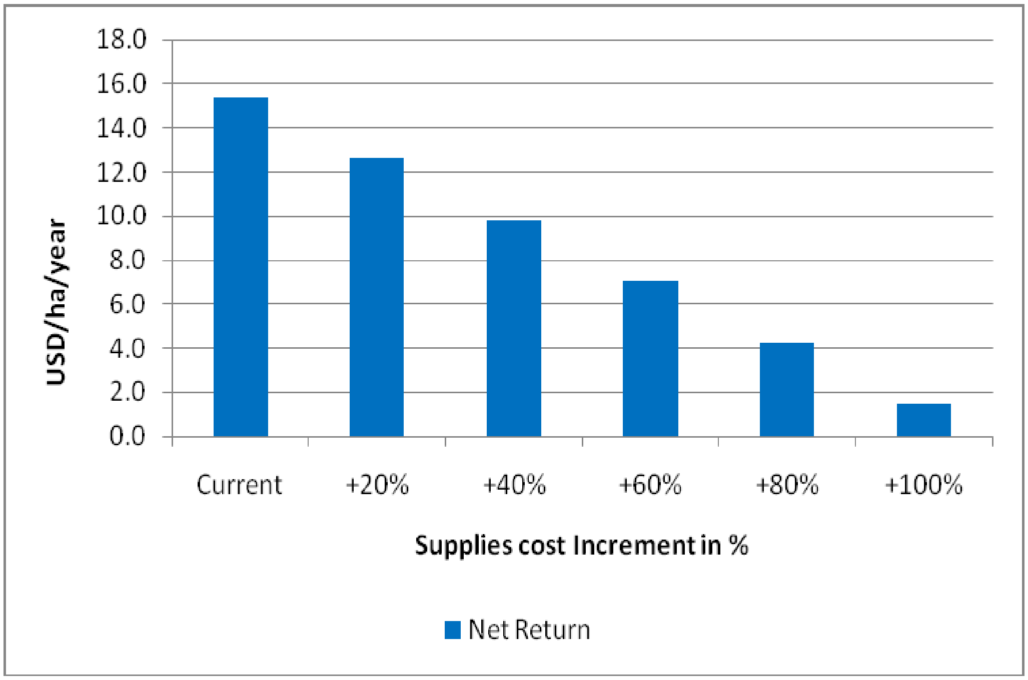
Graph 2 Sensibility analysis of Scenario 1 "Livestock opportunity cost in a zone with *Quercus oleoides* forest (QF)" with changes in milk price, northern Veracruz, Mexico 2008.



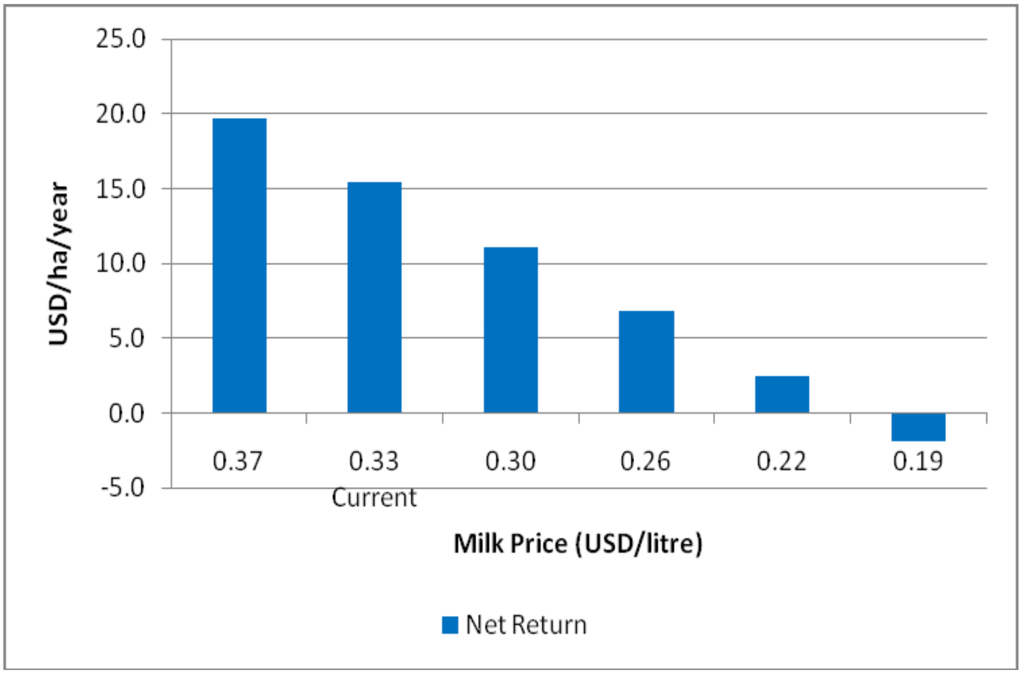
Graph 3 Sensibility analysis of Scenario 2 “Livestock opportunity cost in a zone with Secondary Regeneration Forest (SRF)” with increments in the cost of agrochemicals and veterinarian supplies, northern Veracruz, Mexico 2008.



Graph 4 Sensibility analysis of Scenario 2 “Livestock opportunity cost in a zone with Secondary Regeneration Forest (SRF)” with changes in milk price, northern Veracruz, Mexico 2008.



Graph 5 Sensibility analysis of Scenario 3 "Livestock in grasslands without shrubs opportunity cost in a zone under a silvopastoral system (grassland + shrubs) (SPS)" with increments in the cost of agrochemicals and veterinary supplies, northern Veracruz, Mexico 2008.



Graph 6 Sensibility analysis of Scenario 3 "Livestock in grasslands without shrubs opportunity cost in a zone under a silvopastoral system (grassland + shrubs) (SPS)" with changes in milk price, northern Veracruz, Mexico 2008.

Table 2 Opportunity Cost to preserve two natural forests and one silvopastoral system in a groundwater recharge zone located in Otontepec Sierra highlands, northern Veracruz, Mexico, 2008.

Land Use	**Opportunity Cost USD/ha/year**	**Hectares**	**Total USD/year**
Quercus oleoides Forest	205.56	5.35	1,099.75
Secondary Regeneration Forest	71.0	23.62	1,677.02
Silvopastoral System (*Cynodon nlemfuensis* + *Conostegia xalapensis)*	15.4	4.82	74.22
Total		33.79	**2,850.99**
Number of families with water line		405	
USD/family/year*		**7.03**	

* USD/family/year = is the amount to pay per family per year to protect the natural forests and the silvopastoral system located in their spring groundwater recharge area. 1 USD = 13.5 Mexican pesos.

Methodological approach to design a local scheme for payment of hydrological ecosystem services northern Veracruz, México

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ABSTRACT

In northern Veracruz, México an isolated volcanic mountain, named Otontepec Sierra, generates fresh water for around 122,000 people. However, its natural land uses (Oak forest and subhumid deciduous forest) are changing to other productive activities that generate more incomes for the highland landlords (i.e. livestock). Tepetzintla is one municipality that uses the water released by the mountain. Unfortunately, during the dry season several communities suffer water scarcity problems and they believe that this problem is caused by mountain deforestation. A political proposal to face this problem is the development and implementation of a Payment for Hydrological Environmental Services (PHES) with the target to protect the natural highland forests and to increase springs base flow. However, to propose a local scheme of PHES without basic information could generate false expectations among citizens. The objective of this research was, under a multidisciplinary approach, to propose a method that could help in the construction of a local scheme of PHES. Proposed methodology was as follows: 1) To review the current Federal and State laws that could regulate the implementation of a local scheme of PHES; 2) to identify communities with water supply problems; 3) to locate springs and to delimitate their recharge area (RA); 4) to measure springs base flows; 5) to identify main land uses in the RA and to determine their soils hydrologic behaviour; 6) to calculate

productive activities Opportunity Cost (OC) located in the RA; 7) to identify highland landlords point of view regarding to receive a payment to protect the natural forest, 8) to identify water user points of view regarding payment of land OC; and 9) to establish the feasibility to implement a local scheme of PHES with base in all the information generated. Additionally, the methodological proposal was validated with a study case selected in Tepetzintla Municipality. Results showed that Otontepec Sierra was declared, in 2005, by the Veracruz Government as "Natural Protected Area" and its management plan was in agreement with forest conservation, sustainable productivity and the application of policies of PHES. Tepetzintla Municipality identified three rural communities with water supply problems (El Humo, Tezitlal-Tepetzintla and Tezitlal-Chontla). Diagnostics showed that "El Humo" had serious water supply problems and this was caused by an obsolete hydraulic infrastructure. The RA had an extension of 68 hectares. In 2008 spring base flow was calculated at 4.22 litres/second (364,608 litres/day). This amount divided among water users (2,072 people) indicated that water availability was 176 litres/day/person, this quantity is lower at the 250 litres/day/person indicated by Federal Water Law in México (CNA 2008). In the RA the main land uses identified were *Quercus oleoides* forest, secondary regeneration forest, a silvopastoral system (grasslands + shrubs) and grasslands without trees. Hydrological balances indicated that all land uses soils performed good hydrologic behaviour, which was attributed to their parental material, amount of rock and good soil structure. In community meetings, forest conservation was proposed, under a precautionary principle, as the safest land use to maintain the hydrological ecosystem service, because grasslands management could change drastically due to changes in socioeconomic livestock farmer situation. Socioeconomic results indicated that, highland forest landlords were in agreement to protect their forest if they received the annual compensation calculated. Additionally, OC to maintain natural forests and to release the area under silvopastoral system was calculated as 7.03

USD/family/year, and lowland water users were in agreement to pay for forest protection. However, the agreement was conditional in that if the users had pigs, a rural cheese factory, a house made of bricks and cement, or big families they would be required to pay more for their water. In conclusion, the implementation of a local scheme of PHES is part of the solution to the water scarcity problem reported by Tepetzintla Municipality. PHES policy needs to be complemented with other actions such as, updating the hydraulic infrastructure, organizing the communities, installing the equipment to measure water use, and designating, in consensus with the communities, a water use tariff.

Key words: hydrology, multidisciplinary appraisal, policy, socioeconomics

1. Introduction

Globally, supplying drinking water to an increasing population is a growing problem. Population growth, natural land use alteration, erosion, climatic changes, increases in *per capita* income, water pollution, among other factors decrease the availability of fresh, clean drinking water. In addition, for more than one billion people across the globe, safe water is available in insufficient quantities to meet the minimum levels of health and income (Rosegrant *et al*., 2002). Drinking water availability in quantity and quality is one of the UNESCO Millennium Development Goals (Goal num 7. Ensure environmental sustainability) (UN, 2005; UNESCO, 2006). The United Nations in 2005 mentioned that during the 1990^{s}, access to improved drinking water sources increased substantially. However, over a billion people have yet to benefit, with the lowest coverage in rural areas and urban slums (UN 2005).

The supply of good quality drinking water is also a problem in México. On the one hand, water demand has increased every year due population growth and a rise in *per capita* income. In fact México's population has increased five times during the last century (from 20 to 102 million people) (Meadow *et al.*, 2004) (CNA 2008). On the other hand, water availability does not increase year to year. On the contrary, water stock is affected by pollution, erosion, overdrawing, and salinization among others factors. Political conflicts between Tamaulipas and Nuevo León, and Guanajuato and Jalisco states, gave clear proofs that water scarcity is a serious problem and could result in social conflicts between rural and urban areas (Fundación Gonzalo Río Arronte and Fundación Javier Barros Sierra, 2004).

The northern region of the Gulf of México (National Water Council classification) includes Tamaulipas and northern Veracruz, and has the following socioeconomic characteristics; territorial extension of 127,166 km^2, population of 4.94 million people, population density of 39 inhabitants/km^2, Gross Domestic Product (GDP) of 3.7 %, and 154 municipalities (INEGI 2005, CNA 2008).

"Otontepec Sierra" an isolated volcanic mountain, is located in the northern Gulf of Mexico (Nahuatl dialect, *cotontoc* = cut, *tepetl* = mountain). This mountain generates fresh water for 122,000 citizens distributed throughout nine municipalities (Citlaltepetl, Chinampa, Chontla, Ixcatepec, Naranjos-Amatlan, Tamalin, Tancoco, Tantima and Tepetzintla) (INEGI 2005). Its natural land uses are *Quercus oleoides* Cham & Schlecht forest and Subhumid Deciduous Forest (INEGI, Vegetation Chart F14-9). However, the natural forests have been converted to other land uses which generate on-site benefits such as beef and milk production, and vegetable and perennial crops production (corn, beans, coriander, fruits, citric and coffee). The local downstream communities perceived that a decrease in water supply is associated with the deforestation and adoption of unsustainable agricultural practices in Otontepec Sierra highlands (Ing. Clemente Leyva, Veracruz State Water Commission, 2006, personal information).

As a result of water scarcity, the Tepetzintla Municipal Government (2001 to 2004) faced a social confrontation. Two neighbourhood communities, “El Humo” and “Tierra Blanca”, were interested in tapping water resources from the same mountain spring (named “San Andres I”). However, this spring does not supply enough water to meet the demands of both communities. This conflict generated a difficult political and social situation between these communities and the municipality (Ing. Jesús Zeníl Méndez, Municipal President, period 2005- 2007. Personal information).

In an effort to face the problem mentioned above, Tepetzintla Municipality was interested in implementing a local Scheme of Payment for Hydrological Environmental Services (PHES) with the objective to protect and to restore the natural forest located in the mountain highlands, and to increase fresh water supply. However, implementing a local scheme of PHES without basic information, institutional framework and sustainable mechanisms to generate funds for PHES could generate false expectations and political conflicts. This research proposes a methodology that could help in the design of a local scheme of PHES based in a multidisciplinary appraisal in which hydrologic, socioeconomic and policy information are considered. This approach has several advantages as it includes a participatory approach with the stakeholders to analyze alternatives for providing incentives for conservation of water resources (FAO, 2002); it includes the possibility of considering the tradeoffs between different points of view (Freeman III, 2003); it includes the possibility to determine if this water supply problem can or can’t be resolved with the PHES implementation, and it analyses whether PHES is part of a more complex strategy to confront the problem (Landell-Mills and Porras, 2002).

2. Methods

The study was developed in northern Veracruz, México, in a microwatershed located in the Otontepec Sierra, an isolated volcanic mountain. This mountain is positioned between coordinates 97°58’30’’ and 97°48’00’’ West, and 21°19’19’’ and 21°09’34" North. The climate is A(w^2) Sub-humid tropic (Köppen classification), with a dry season (March to June) and a wet season (July to December). Average precipitation is 1,552 mm y^{-1} (CNA 2008). The mountain range is between 350 to 1,000 meters above sea level (m.a.s.l.). Soils are Inceptisols and Alfisols. Highland geology is extrusive basaltic igneous rocks and sedimentary volcanic rocks in the lowlands, all from the Pliocene and Miocene periods (INEGI Geology Map Tamiahua F 14-9). The natural vegetation is sub-humid deciduous tropical forest with zones of *Quercus oleoides* forest (INEGI Vegetation Map Tamiahua F 14-9).

The methodological proposal consisted of nine steps: First, to review and analyze the current Federal and Veracruz State laws that could regulate the implementation of a local scheme of PHES; Second, to identify communities with water supply problems and possible solutions to the water supply problem; Third, to locate and measure the highland springs groundwater recharge area (RA); Fourth, to locate and to measure springs base flows; Fifth, to identify main land uses in the RA and to determine the soils hydrologic behaviour; Sixth, to calculate the Opportunity Cost (OC) of the productive activities located in the RA; Seventh, to identify highlands landlord’s perception regarding to receive a compensation to protect their natural forest; Eight, to identify the water user’s perception regarding the OC payment for the alternative land uses with the objective to protect the natural forests; and Ninth, to establish the feasibility to implement a local scheme of PHES with a base in all the information generated.

2.1 Policy framework

Federal laws reviewed were a) Federal Constitution of México (1917), b) Agrarian Law (1992), c) Federal Water Law (1992), d) General Law of Sustainable Forest Development (2003), e) Federal Sustainable Development Law (2001), f) Ecological Equilibrium and Environment Protection Law (1988). Veracruz State laws reviewed were; a) Law of sustainable forest development (2006); b) State Law of Ecological Equilibrium and Environment Protection (1990), and c) Decree of “Otontepec Sierra” as Natural Protected Area (2005). These laws were analyzed and discussed with a lawyer (Lic. Oscar Rivera Ortega), that worked in the Bureau of Forestry of Veracruz State Government (SEDARPA), with the objective to identify clauses that could improve or limit the implementation of a local scheme of PHES.

2.2. Communities identification

Tepetzintla Municipality identified three rural communities in the lowlands that reported water supply problems, “El Humo”, “Tezitlal-Tepetzintla” and “Tezitlal-Chontla”, with 1,828, 87 and 157 inhabitants, respectively (405 families in total) (INEGI 2005). All three communities used the same highland springs for fresh water supply. Communities had a strong social organization and all decisions were taken by consensus in an official monthly meeting. Each community had a water committee that every month reported the activities developed, such as problems with water infrastructure, finance balance, and water payment status among others. “El Humo” had a tariff of 0.37 USD/month/family (1 USD = 13.5 Mexican pesos), independent of water consumption. The other two communities do not have a water payment, when they need to carry out an initiative related to water use, such as building hydraulic infrastructure; they either pay a tariff or help with labour. Authors visited the communities during their monthly meetings to explain the project proposal and to solicit their permission to measure the springs’ base flows. This action was necessary because water supply problems in the region are common and information about spring production needs to be used carefully. In addition, it was necessary to inform the citizens that this research did not affect their current water law situation and the only intention was to obtain information to help them in their decision-making processes. Information generated in this step was useful to answer the following questions: Who are the water users? What are the points of view of the communities regarding the water supply problem? Is water scarcity a real problem? Are there other factors that affect water supply?

2.3. Recharge zone identification

The recharge area (RA) provides hydrologic resources to the springs that supply lowland communities and was considered a priority conservation area. RA boundaries and soil characteristics were identified with the help of an expert in soils (Ph.D. Andreas Nieuwenhuyse) from CATIE (Tropical Agricultural Research and Higher Education Center). Several aspects were taken into account such as, spring flow direction, topography, slope direction, slope grade, and colluvial processes. Additionally, soil profile descriptions were developed in 5 pits (1m long, 1m wide and 1m depth) (FAO 1990). Pits that were excavated to install the equipment to measure runoff (6 pits of 3 m long, 2 m wide and 1.5 m depth) were useful to observe soil strata characteristics. In addition, a mountain genesis study was used (Robin 1976). These activities helped to answer the following questions: How much of the critical zone should be protected? What are the geological processes in the RA?

2.4. Springs location and base flow measurement

At the base of the RA, springs that supplied lowland communities were located and rustic infrastructure was built with the objective to measure their base flow during the dry season (March to June) over three years (2006 – 2008). The base flow is the amount of water needed to sustain a streams flow and is supplied almost entirely from groundwater. The base flow, reported in litres/second or cubic meters/second, was calculated by dividing the volumetric flow measured by the time it takes the spring to release a specified amount of water (Equation 1) (Villon 2002). This information was used to answer following questions: What is the recharge area base flow? How much water is available per citizen in the dry season? Is this amount enough to cover their basic necessities?

Equation 1

$$\mathbf{Q} = \frac{V}{T}$$

Where:

Q = Base water flow (litres/second)
V = Volume of water (litres)
t = time (Seconds)

2.5. Hydrology of the main land uses

Land uses identified in the RA were, *Quercus oleoides* Cham. & Schlecht. forest (QF) (7.8%), secondary regeneration forest (SRF) (34.7%), silvopastoral system with grasslands and shrubs (GS) (7.1%), African star grasslands without trees (GWT) (14.7%)

and native grasslands without threes (NG) (4.4%). Other land uses were riparian forest (6.6%), and isolated trees of *Q. oleoides* with different amounts and types of grass, shrubs and weeds (24.7%). Hydrologic indicators measured were precipitation, throughfall, runoff, soil erosion, changes in soil moisture profile, bulk density and infiltration rate. Indicators calculated were evapotranspiration, and percolation. The period of measurement was from August 2007 to July 2008. Additionally, an automatic meteorological station (Vantage Pro2 Plus©) was installed next to the field work area. Information generated was used to identify soils hydrologic characteristics and to determine if soil hydrologic behaviour was affected by land use changes (more information in Chapter One).

2.6. Opportunity Cost and Lowland water user's point of view

Taking into account that alternative land use to natural forests in the RA was livestock activity, a budget was developed for fiscal year 2008 with the objective that the net benefit (NB) of the livestock activity was considered as the forest Opportunity Cost (OC). Due to the different kind of forests and RA characteristics three scenarios were developed with information collected from local suppliers' data, key informants, and local livestock farmers. Scenarios were livestock opportunity cost in a zone with *Quercus oleoides* forest (QF); livestock opportunity cost in a zone with secondary regeneration forest (SRF); livestock in grasslands without shrubs opportunity cost in a zone under a silvopastoral system (grasslands + shrubs) (GS). Equation 2 was utilized to calculate the OC of SRF and QF whereas equation 3 was used to calculate the OC of GS (Norton-Griffiths and Southey 1995). Subsequently, the area occupied by each land use was calculated with ArcView GIS 3.3© software and a high resolution IKONOS© satellite image, dated December 2006 (0.6 m x 0.6 m pixel) (Source: CONAFOR). Each area calculated was multiplied for its OC (i.e. 23.63 hectares under SRF x 71.0 USD/ha (OC) = 1,677

USD/year). The total OC was divided among the families that use water, and the quantity calculated was the amount to be paid per family per year to protect the natural forests remnants and the silvopastoral system in the RA (more information in Chapter Two).

Equation 2

$$OC_{\text{Forest Conservation}} = NB_{\text{livestock}}$$
$$NB_{\text{livestock}} = NR_{\text{livestock}} = GR_{\text{livestock}} - C_{\text{livestock}}$$

Equation 3

$$OC_{\text{Silvopastoral System Conservation}} = NB_{\text{(grasslands + shrubs)}} - NB_{\text{grasslands without shrubs}}$$
$$NB_{\text{(grasslands + shrubs)}} = NR_{\text{(grasslands + shrubs)}} = GR_{\text{(grasslands + shrubs)}} - C_{\text{(grasslands + shrubs)}}$$
$$NB_{\text{grasslands without shrubs}} = NR_{\text{grasslands without shrubs}} = GR_{\text{grasslands without shrubs}} - C_{\text{grasslands without shrubs}}$$

Where

OC = Opportunity Cost
NB = Net Benefits
NR = Net Returns
GR = Gross Revenues
C = Costs

2.7 Highland landlord’s perception

Socioeconomic and biophysical information was showed in January 2009 at the highlands landlords in a meeting developed in San Juan Otontepec, Chontla Municipality through a participatory approach methodology (Geilfus 1998). Hydrologic information and the concept of Hydrological Ecosystem Services (HES) were explained carefully. Also, the relevance of their actions in the quantity and quality of the water released by the springs was underlined, and OC concept and the amount of payment for each kind of forest were explained with detail. Additionally, meeting generated important feedback information such as land tenure situation, landlord’s organization, point of view about the Otontepec Sierra Decree, among other points. This participatory method was selected, because it was the first time that highland landlords heard something about HES and OC concepts.

2.8 Perceptions of local communities in lowlands

Socioeconomic and hydrologic information was analysed for the three communities at six official meetings (two per community) through a participatory approach methodology (Geilfus 1998). Socioeconomic information shown was basic concepts of Environmental Services markets, the land OC concept, and the reasoning for the necessity to protect the RA by the OC payment. Hydrologic information shown was basic concepts of the mountain hydrological cycle, base flow measurements, and hydrological balances and their components (precipitation, runoff, evapotranspiration, canopy interception and percolation). Also, during the meetings important feedback information was obtained such as hydraulic infrastructure problems, population growth problems, and communities' organization among others. All information was shown and explained in a very simple format with the use of diagrams and photos on multimedia equipment and big sheets of paper. The purpose to present information under this method was supported by the following: 1) Water is a difficult topic in this region; several political conflicts regarding springs concessions were registered in the past. 2) It was the first time citizens heard anything about Hydrological Environmental Services and the necessity to protect their springs RA with their economic resources. 3) It was the first occasion households had heard about the mountain's hydrological cycle and were informed about the soils hydrologic behaviour. 4) The opportunity cost concept was explained carefully, because citizens needed to make an informed decision regarding payment of an OC for the alternative landuse in the RA, with the objective to protect two natural forests and one silvopastoral system. 5) These communities make all their decisions by consensus (more information in Chapter Two).

3. Results and discussion

3.1. Legal framework

In February 2005, the Veracruz Government declared “Otontepec Sierra” as a Natural Protected Area (NPA). This decree was a normative document and was supported in the Federal Constitution of the Mexican United States, the General Law of Ecologic Equilibrium and Environment Protection, and the Veracruz State law of Environmental Protection. The NPA has an extension of 15,152 hectares (ha) and was divided into three subzones: a) nucleus area (2,921 ha), b) buffer area (3,251 ha), and c) sustainable development area (9,027 ha). Following the decree, the nucleus area will be located between 750 to 1,000 meters above sea level (m.a.s.l.) and the land use will be restricted to natural forest. Consequently, land use change, timber extraction and hunting will be prohibited. The buffer area will be located between 550 to 750 m.a.s.l. and as suggested in the decree, productive land uses (livestock and agriculture) will need to be replaced by natural vegetation. A sustainably developed area will be located between 350 to 550 m.a.s.l., and will be permit the implementation of livestock and agriculture under sustainable management, promoting silvopastoral systems and agroforestry systems. In the land tenure case, the decree mentioned that Private and Ejidal property would remain intact, and land expropriation was not mentioned. Additionally, economic incentives like payment for environmental services (PES) was recommended to improve forest conservation and land use conversion from agriculture and livestock to natural forest. Based on this information, it is possible to assure that the current legal framework improves forest conservation and the implementation of PHES policies in Otontepec Sierra NPA. However, it is necessary to remember that “Otontepec Mountain NPA Decree” was created recently (2005), and the deforestation problem in the mountain has been reported since 1970 (Castañeda 2006). It means that perhaps local highland landlords are not likely to change their historical livelihoods to a new proposal, which implies release their lands to natural regeneration with the objective to protect an environmental service that is used by lowland people.

3.2. Communities identification

Three rural communities with recurrent water supply problems were identified by Tepetzintla municipality in 2006. These places were "El Humo-Tepetzintla", "Tezitlal-Tepetzintla" and "Tezitlal-Chontla" with 1828, 87 and 157 citizens, respectively (405 families in total). These communities use the water released by the same RA, and spring water is transported by gravity by a network of pipes and containers from the highlands (where springs are located) to the lowlands (where communities are placed). In each location the project presentation was developed and the permission to measure springs base flow was obtained. These meetings revealed that each community had a different water supply problem. "El Humo" is a community with a strong social organization and every month an official meeting reports problems and projects in the community. In this meeting the water committee informs the community about the activities developed and the financial balance. This community has 346 homes with a water line (91.5%) and each family pays 0.37 USD/month for its water consumption (notwithstanding the amount of water used in domestic or other activities). Money was used to repair infrastructure and to pay for labour. In the dry season, this community had water supply problems where households reported that the amount of water in the tanks was insufficient to supply all the citizens during the day. Citizens assumed that this problem was caused by a reduction in spring water production as a consequence of mountain deforestation. Nevertheless, during a field trip the hydraulic infrastructure was visited and it was clear that the infrastructure was obsolete, because it was two decades old and the community population had increased from 1,326 in 1990 to 1,828 citizens in 2005 (INEGI 2005). In addition, the "El Humo" water committee informed that the water deposits overflow during the night (from 10 pm to 6 am). The other two small communities ("Tezitlal-Tepetzintla" and "Tezitlal-Chontla") reported water scarcity problems only in years with a long dry season. In general, water infrastructure in both communities was sound enough to supply all citizens throughout the day. Neither community has a water use tariff; therefore when a water line needs to be fixed or installed, citizens cooperate with labour or in cash. Two points should be considered when developing of a PHES policy for the three communities: first, different water scarcity perceptions exist among the communities. The smaller communities didn't have a water scarcity problem. However, the larger community, due to its size and population growth, will demand more water in the future which in turn will affect the smaller communities. This implies that community organization would be necessary, in order to avoid misunderstandings and social conflicts. Second, the hydraulic infrastructure would need to be modernized, and the construction of water containers that hold all the available water during the night would be the citizen priority.

3.3. Recharge zone identification

The RA had an extension of 68 hectares (ha), and ranging from 650 to 900 m.a.s.l. in altitude, had an irregular topography and slopes ranging from 5% to 85%. Volcanic processes formed the topography (Robin 1976) and parental material was extrusive alkaline basaltic rock (INEGI Geology Map Tamiahua F 14-9). Additionally, several colluvial processes were observed on steep slopes. Due to the RA complexity it was divided into two zones; lowlands and highlands. Soils in the highlands were Inceptisols and in the lowlands were Inceptisols and Alfisols (USDA 1998).

3.4. Springs location and baseflow measurement

Springs that supply communities were identified at 650 m.a.s.l. The mean base flows were 3.25, 3.36, and 4.22 litres/second in 2006, 2007, and 2008 respectively. Spring flow was divided into three parts by rustic infrastructure (one by each community); however, water distribution was not equal. For example, in June 2006 “El Humo-Tepetzintla” received 2.28 litres/second, which was divided among its population of 1,828 people with each citizen receiving 107 litres/inhabitant/day. However, this amount is lower at the 250 litres/inhabitant/day mentioned by the Law of Water in México, to fulfill basic domestic requirements (CNA 2008). In contrast, “Tezitlal-Chontla” received 0.55 litres/second. If this quantity was divided among its population each citizen would have received 301 litres/inhabitant/day (See Table 1). Results indicated that the current infrastructure was inefficient in distributing equal quantities of water released by the springs. To confront this situation the following strategies were proposed: a) Community organization is strongly recommended to develop clear rules of spring water use to help avoid social problems in the future, b) Construction of new infrastructure in the highlands to provide a similar amounts of water per inhabitant per day for each community. The difference in water supply among the communities is a situation that could affect the implementation of a local scheme of PHES.

3.5. Hydrology of the main land uses

The RA was divided into two subzones, highlands and lowlands. In the highlands land uses identified were 23.62 ha (34.7%) of Secondary Regeneration Forest (SRF), 10.1 ha (14.7%) of grasslands (*Cynodon nlemfuensis* Vanderyst var**.** *nlemfuensis*) without trees (GWT), and 4.82 (7.1%) of grasslands with *Conestegia Xalapensis* (Bonpl.) D. Don ex DC shrubs (GS). In the lowlands land uses were 5.32 ha (7.8%) of *Quercus oleoides* forest (QF) and 3 ha (4.4%) of native grasslands (*Paspalum notatum* Flüggé) (NG). Due to the high variability identified in the RA each land use was considered as study case. Profile descriptions indicated that soils showed good structure such as angular and sub-angular blocks, high percentage of organic matter (3.8%, 5.09%, 5.56%, 4.21% and 4.55% by SRF, GWT, GS, QF and NG, respectively), good drainage, presence of voids, and channels. Additionally, bulk density showed statistical difference ($p<0.050$) in the SRF and the grasslands and shrubs than grasslands without trees (1.18^d, 1.17^c, 0.97^a, 0.99^b, and 0.99^b g cm^3 by GWT, NG, SRF, QF and GS, respectively). Infiltration results indicated statistical difference ($p<0.050$) between grasslands without trees, and forests and grasslands and shrubs (0.99^c, 0.56^c, 11.15^a, 14.1^a, 7.82^b, cm h^{-1} by GWT, NG, SRF, GS, and QF, respectively). Precipitation during August 2007 through July 2008 was recorded as 2,416 mm, however 1,387 mm (57%) were registered in three months (586, 525 and 276 mm, in August, September and October, respectively). Hydrological balances (August 2007 – July 2008) showed that percolation in land uses selected were 1744, 1608, 1314, 1119 and 974 mm by GS, GWT, NG, SRF and QF, respectively (more information in Chapter One). In conclusion, due to the geological and hydrological soil characteristics, land uses under grasslands performed a similar hydrologic behaviour than natural forest. Therefore, it is not feasible to propose an increase in the base flow with a land use change from grasslands to forest. In answer to that, forest conservation was proposed under a precautionary principle (Echavarria 2004; Wunder 2005). This principle was proposed in the sense that natural forests could be the safest land use to provide the hydrological ecosystem service if they maintain intact their soils biophysical characteristics. In contrast, grasslands management could change drastically (i.e. from rational grassing to overgrazing), due to changes in socioeconomic livestock farmer’s situation (Stocking

1994). Also, the increasing uncertainty about the effects of climate change is another argument to protect the remnants of natural forest in fragile ecosystems (Arnell 1999).

3.6. Opportunity costs

The OC of the livestock activity in one hectare under QF, SRF and GS were calculated as 205.56, 71.0 and 15.4 USD/ha/year, respectively. When these amounts were multiplied by the area occupied by each land use (5.35, 23.62, 4.82 hectares by QF, SRF, GS, respectively) and divided among the 405 families that use the hydrological environmental services, results indicated that each family would need to pay 7.03 USD/year to protect natural forests and to release the area under silvopastoral system in the RA (more information in Chapter Two). However, if a local scheme of PHES is implemented, the calculated amount should also include the current “El Humo” household water tariff and the amount paid by those that will be working in the PHES implementation and operation (see Table 2).

3.7. Highland forest landlords point of view

23 highland forests landlords participated in the meeting developed in San Juan Otontepec in January 2008. Meeting results indicated that land tenure rights were different among them. For example: 21 landlords mentioned that they had “Ejidal” tenure rights, but not had an official document that supported their land tenure status. Last situation could generate a problem, because the program of PHES implemented by the National Forestry Commission (CONAFOR) in México required an official document to support the land tenure status (SEMARNAT 2008). Additionally, FAO in 2004 mentioned that the lack of land tenure rights difficult the implementation of PHES policies in Latin America. In the

case of the hydrologic information, results generated high interest among landlords, because they did not know the relevance of their land management in the mountain's hydrological cycle. Other results indicated that 65% of the landlords heard something about the Otontepec Sierra Decree in a regional radio station. However, the 100% of the landlords not know the Natural Protected Area (NPA) plan management and the restriction to change the natural forest in the highlands. In answer to that, landlords commented that they need to use their lands to produce something (i.e. milk and beef) with the objective to support their families. The last comment is in agreement with Pagiola *et al.,* 2005. Also, OC concept and the information calculated were explained carefully and landlord's answers showed different point of view, for example: Secondary regeneration forest landlords were in agreement (100%) with the amount to receive per year. In contrast, *Quercus oleoides* (Oak) forest landlords considered that the amount calculated in not enough to cover the forgotten income generated by the wood sale. In addition, Oak forest landlords commented that they preferred to obtain one big payment that considered the total price of the wood, than to receive a small payment every year. Finally, landlords generate several questions that need to be taken in account if a policy of PHES will be implemented. For example: What happen if one year they not receive the payment? Could the payment increase with the time? Who pay them? Who supervise them? Which will be the Municipal Government participation?

3.8. Water users' point of view

Socioeconomic and hydrologic information generated high interest among the community citizens. The results of the hydrologic information were unexpected because the common belief was that the water supply reduction was caused by land use change in the highlands. The proposal was to pay to protect the forest not as the land use that percolate more water, but as the land use that offers the safest option to maintain the hydrological environmental service in the best way (Echavarria 2004; Wunder and Albán 2008), because grasslands management could change in a short time due to socioeconomic factors (Stocking 1994). In all communities people were in agreement to pay for protection of the natural forests. However, the last point should to be taken with caution, because in small communities local leaders influenced other members of the community to be in agreement. Additionally, during the meetings citizens expressed comments that implied more consensus and organization for example, “People that have pigs or a rural cheese factory need to pay more than people that have a domestic use”, or “Big families need to pay more than small families”, or “Households that live in homes made with bricks and cement need to pay more than households that live in homes built with rustic materials (wood, bamboo, and palm among others)”. People also questioned that in the case that the PHES will be implemented: Who will collect the payment? Who will pay the highland landlords? Who will supervise the highland owners? Which municipal government will participate? And who will participate from the INIFAP (National Institute of Forestry Agriculture and Livestock Research) and CONAFOR? Taking into account the households’ opinion in regards to implementing a PHES, it is necessary to develop clear rules of the game in consensus with all lowland water users, and to install the basic equipment to measure water consumption. Additionally, it is necessary to include in the payment the salary of the people that will be working on the PHES implementation and management (Table 2). Finally, it is necessary to determine if government institutions want to participate and how they want to participate if this policy of PHES is implemented (i.e. to help with communities’ organization, to monitor forest protection, to facilitate actor’s communication, to search funds, among other activities).

4. Conclusions

The legal framework of the Otontepec Sierra Natural Protected Area improves the development and implementation of Payment for Hydrological Environmental Services policies. It is necessary to point out that land use change began in 1970 and the Otontepec Sierra was not decreed as a NPA until 2005. It means that landlords could resist to change their current behaviour (transform natural forests to agriculture or livestock), to conserve the forest through a PES policy.

“El Humo-Tepetzintla” has more water supply problems due to an obsolete hydraulic infrastructure and population growth. On the contrary, “Tezitlal-Tepetzintla” and “Tezitlal-Chontla” have not reported water supply problems likely due to their small size and sufficient infrastructure. However, this situation could change if “El Humo” increases their water demand. Community organization is strongly recommended to develop clear water use rules, water use tariffs and to avoid social confrontations.

Based on the groundwater recharge zone geology characteristics and soils hydrological behaviour, it is not feasible to propose an increase in the spring base flow by conversion from grasslands to forest. This indicates that drinking water is a scarce resource that needs to be used carefully by the community’s households. Water use culture needs to be promoted in the community through talks and workshops with schools, focal groups and official gatherings.

Forest conservation was proposed, not as the land use to percolate more water, but as the safest land use and the best way to maintain the HES. Also, forests are easy to monitor by satellite images and field trips. On the contrary, grasslands management practices could change over a short period of time due to changes in the farmers’ socioeconomic situation (i.e. stoking rate increase, grassing system change and cleaning grasslands with fire), and consequently are more difficult to monitor.

Highland landlords not know the Otontepec Sierra NPA Decree and the NPA management plan published in 2005 and 2006, respectively. When they understood the NPA Decree, landlords were in disagreement to release their grasslands to secondary regeneration, because they need to use their lands to produce something to survive. In the case of the OC information, secondary regeneration forest owners were in agreement with the amount calculated. Contrary to that, Oak forest owners indicated that, under their point of view, the payment is not enough to cover the stump price of the Oak trees. In fact, landlords commented that perhaps will be appropriated a big payment that covers the total value of the wood in the first year, than a small payment every year.

Citizens that participated in the community meetings agreed to pay the opportunity cost to protect the natural forests and the silvopastoral system in the groundwater recharge area. However, this point should be taken with caution because manipulation by community leaders was observed and the decision was conditional based on the development of other activities (i.e. community organization to design a water use index and improve infrastructure among others) before the implementation of a PHES policy. Also, it is important to determine the responsibility of municipal and state governments and federal institutions such as INIFAP and CONAFOR during PHES design, implementation and monitoring.

The methodological proposal applied in this research generated key information that indicates that, the implementation of a local scheme of Payment for Hydrological Environmental Services is part of the solution to the water supply problem reported by Tepetzintla, Municipality in “El Humo”, “Tezitlal-Tepetzintla and “Tezitlal-Chontla” communities. In this case study, the PHES policy should be complemented with other activities such as updated hydraulic infrastructure, community organization, water use culture, and government participation.

References

Arnell N.W. 1990. Climate change and global water resources. *Global Environmental Change* 9: S31-S49

Castañeda R,J. 2006. Las Áreas Naturales Protegidas de México de su origen precoz a su consolidación tardía. *Scripta Nova.* Revista Electrónica de Geografía y Ciencias Sociales. Universidad de Barcelona. Vol. X, núm. 218(13) Consulted *on line* February 9th 2009. http://www.ub.es/geocrit/sn/sn-218-13.htm [ISSN: 1138-9788]

Comisión Nacional del Agua (CNA). 2008. Estadísticas del Agua en México. 1ª Edición. CNA. México D.F.233 p.

Constitución Política de los Estados Unidos Mexicanos. 1917. Diario Oficial de la Federación. Publicada el 5 de Febrero de 1917. Ultima Reforma publicada en el DOF el 26 de Septiembre del 2008. 158 p.

Decreto de Área Natural Protegida a la Sierra de Otontepec en su categoría de Reserva Ecológica. 2005. Gaceta Oficial de Veracruz. 33 p.

Echavarría, M. 2004. Some lessons about the application of payment for water protection in Colombia and Ecuador. *In*: Payment schemes for environmental services in watersheds. *Land and Water Discussion Paper* 3. FAO. Rome, Italy. 67 p.

Food and Agriculture Organization of the United Nations (FAO). 1990. Guidelines for soil profile description, Rome 3rd Edition 30 p.

Food and Agriculture Organization of the United Nations (FAO). 2002. Land-Water linkages in rural watersheds. *Land and Water bulletin* 9. Rome, Italy. 90 p.

Food and Agriculture Organization of the United Nations (FAO). 2004. Payment Schemes for environmental services in watersheds. *Land and Water Discussion Paper* 3. Rome, Italy 71 p.

Freeman III, A,M. 2003. The measurement of environmental and resources values: theory and methods (2d ed). Resources of the future. Washington D.C. 491 p.

Fundación Gonzalo Río Arronte; Fundación Javier Barros Sierra. 2004. Prospectiva de la demanda de agua en México, 2000 – 2030. México. D.F. 105 p.

Geilfus, F. 1998. 80 Herramientas para el desarrollo participativo: Diagnostico, planificación, monitoreo, evaluación. GTZ – IICA. San Salvador 235 p.

Instituto Nacional de Estadística Geografía é Informática (INEGI). 2005. Anuario Estadístico, Veracruz de Ignacio de la Llave, Tomos I y II. México, D.F.

Instituto Nacional de Estadística Geografía é Informática (INEGI). Carta de Vegetación. F 14-9. México D.F. INEGI. 1:250,000, a colores.

Instituto Nacional de Estadística Geografía é Informática (INEGI). Carta geológica. F 14-9. México D.F. INEGI. 1:250,000, a colores.

Landell-Mills, N; Porras, IT. 2002. “Silver bullet or fools’ gold? A global review of markets for forest environmental services and their impact on the poor”. Instruments for sustainable private sector forestry series. International Institute for Environment and Development, London, UK. 272 p.

Ley Agraria. 1992. Diario Oficial de la Federación. Publicada el 26 de Febrero de 1992. Ultima Reforma publicada en el DOF el 17 de Abril del 2008. 41 p.

Ley de Aguas Nacionales. 1992. Diario Oficial de la Federación. Publicada el 1º de Dic. de 1992. Ultima Reforma publicada en el DOF el 18 de Abril del 2008. 103 p.

Ley de Desarrollo Rural Sustentable. 2001. Publicada en el Diario Oficial de la Federación el 7 de Diciembre del 2001. Ultima Reforma publicada en el DOF el 02 de Febrero del 2007. 57 p.

Ley Estatal del Equilibrio Ecológico y la Protección al Medio Ambiente. 1990. Honorable Quincuagésima Legislatura del Estado de Veracruz. 03 de Mayo de 1990. 39 p.

Ley General de Desarrollo Forestal Sustentable. 2003. Publicada en el Diario Oficial de la Federación el 25 de Febrero del 2003. Ultima Reforma publicada en el DOF el 26 de Diciembre del 2005. 69 p.

Ley de Desarrollo Forestal Sustentable para el Estado de Veracruz de Ignacio de la Llave. 2006. Publicada en la Gaceta Legislativa. Año II. Número 85. 21 de Junio de 2006. 14 – 41 p.

Ley General de Equilibrio Ecológico y la Protección al Medio Ambiente. 1988. Publicada en el Diario Oficial de la Federación el 28 de Enero de 1988. Ultima Reforma publicada en el DOF el 23 de Febrero del 2005. 79 p.

Meadows, D; Randers, J; Meadows, D. 2004. Limits to growth: the 30 year update. Chelsea Green (eds). 338 p.

Northon-Griffiths, M; Southey, C. 1995. The opportunity cost of biodiversity conservation in Kenya. *Ecological Economics* 12. 125 – 139 p.

Pagiola, S; Arcenas, A; Platais, G. 2005. Can payments for environmental services help reduce poverty? An exploration of the issues and the evidence to date from Latin America. *World Development* 33(2): 237-253 p.

Programa de Manejo de la Reserva Ecológica, Sierra de Otontepec. 2006. Coordinación General del Medio Ambiente, SEDESMA, Gobierno de Veracruz. Serie: “Protejamos Nuestro Medio Ambiente”. Vol. 11. 91 p.

Robin, C. 1976. El vulcanismo de las planicies de la Huasteca (Este de México). Datos Geoquímicos y petrográficos. UNAM. *Boletín del Instituto de Geología Núm. 96: 55 – 92* p.

Rosegrant, MW; Cai, X; Cline, SA. 2002. Global water outlook to 2025: Averting an impending crisis. International Food Policy Research Institute. Washington, D.C. USA and International Water Management Institute. Colombo Sri Lanka. 26 p.

Secretaría de Medio Ambiente y Recursos Naturales. 2008. Reglas de Operación del Programa Pro-Árbol 2009. Diario Oficial, miércoles 31 de Diciembre del 2008. 112 p.

Stocking, M.A. 1994. Assessing vegetative cover and management effects. *In*: Soil erosion: research methods. (Lal, R. Ed.). Soil water and soil conservation society. Ankeny. IA. 340 p.

United Nations (UN). 2005. The millennium development goals Report 2005. New York, USA. 48 p.

UNESCO (United Nations Educational Scientific and Cultural Organization). 2006. Water a shared responsibility: The United Nations World Water Development Report 2. Executive summary UNESCO, Paris, France. 52 p.

USDA (United States Department of Agriculture). 1998. Keys of soil taxonomy. Eighth Edition. Washington, D.C. 328 p.

Villón B, M. 2002. Hidrología. Instituto Tecnológico de Costa Rica - CRRH. Cartago, Costa Rica, CA. 436 p.

Wunder, S. 2005. Payment for environmental services: some nuts and bolts. Occasional paper No. 42. Center for International Forestry Research (CIFOR). 24 p.

Wunder S; Albán, M. 2008. Decentralized payments for environmental services: The cases of Pimampiro and PROFAFOR in Ecuador. *Ecological Economics* 65: 685 – 698 p.

Table 1

Spring baseflow measurement during three years (2006, 2007 and 2008), and its distribution among the rural communities that use the hydrological service. Otontepec Sierra, northern Veracruz, México.

Indicator	Year		
	2006	**2007**	**2008**
Rainfall (mm)	1,470	2,120	1,675
Baseflow (litres/second)	3.25	3.36	4.22
Baseflow in 24 hours (litres)	281,088	289,879	364,200
Distribution among communities (litres/inhabitant/day)			
“El Humo” (1,828 inhabitants)	107.9	90.6	107.2
“Tezintlal-Tepetzintla” (87 inhabitants)	419.8	341.2	633.4
“Tezitlal-Chontla” (157 inhabitants)	301.53	602.8	720.74

Table 2

Water use tariff to apply in the case that a local Scheme of Payment for Hydrological Environmental Services will be implemented in three rural communities. Otontepec Sierra, northern Veracruz, México (2008).

Concept	Communities		
	“El Humo”	**“Tezitlal-Tepetzintla”**	**“Tezitlal-Chontla”**
Current water tariff (USD/family/month)	0.37	0	0
Opportunity Cost of alternative land use (USD/family/month)	0.59	0.59	0.59
Transaction costs* (USD/family/month)	0.28	0.28	0.28
Total tariff (USD/family/month)	**1.24**	**0.87**	**0.87**
Total tariff (USD/family/year)	**14.9**	**10.4**	**10.4**

1 USD = 13.5 Mexican Pesos. * The salary of the people that will be working in the PHES implementation and operation.

10 General Conclusions and Comments

The methodological proposal developed in this research generated relevant information that could help in the design and implementation of a local policy of PHES in the Otontepec Sierra, located in northern Veracruz, México. The multidisciplinary approach helped to understand the complexity of a water supply problem, and helped to develop more appropriated strategies.

In the case of the biophysical information generated, hydrological balances showed that a land use conversion from grasslands to forest does not assure an increment in the amount of percolation. In this study case, the infiltration rate in the land uses under study was regulated more by soil characteristics such as soil genesis, soil structure, macropores, amount of roots and the amount of rocks in the first 30 cm of soil profile, than by the land use *per se*. Superficial runoff was scarce in all land uses. And, underground runoff was observed in the field after a high intensity rainfall. Unfortunately, the equipment installed in the field was not designed to measure underground runoff. Soil moisture sensors indicated that soils in this recharge area reached field capacity in 24 hours, notwithstanding the amount of water received by the storms. However, information mentioned above needed to be taken with caution, because is the result of a single year data. Fortunately, "Fundación Produce Veracruz", approved a grant to continue with this experiment from January 2009 to August 2010.

Hydrological information helped to conclude that; if a local policy of PHES would be implemented in the microwatershed under study, forest protection need to be proposed, not as the land use that percolated more water but as the safest land use to maintain the hydrological characteristics of the soil in the most appropriated conditions ("Precautionary principle"). Additionally, forests can be monitoring by satellite images and field trips. Contrary to that, grasslands could change their management in a short period of time, for example: grasslands could be overgrazed due to a long dry season (i.e. "El Niño" meteorological phenomena), or due to changes in the livestock farmer socioeconomic status (i.e. disease, economic crisis), or due to changes in grasslands management (i.e. from rotational to extensive grassing systems or the use of fire to weeds control).

In the case of the socioeconomic information, Opportunity Cost (OC) of the livestock activity was calculated like an alternative land use for two different kind of forest; Quercus forest (QF), secondary regeneration forest (SRF), and a silvopastoral system with shrubs (GS). The amounts calculated were 205.56, 71.0 and 15.4 USD/ha/year for QF, SRF, and GS, respectively. Also, a sensibility analysis showed that livestock activity is a profitable activity that could support drastic increases in supply costs and reductions in milk price. These results could explain why natural forests in the Otontepec Sierra are changed to livestock activities. In addition, when the OC calculated was compared with the payment amount offered (34.5 USD/ha/year) by the National Forest Commission (CONAFOR) in México it was clear that only the GS OC could be covered. However, CONAFOR has another PHES policy with concurrent funds, where they pay a peso if the ecosystem services user pays the other peso. If this policy was implemented it would be possible to cover the SRF OC. However, the implementation of the last policy will need the creation of a legal institution and a strong organization among communities. The total OC (2,850.99 USD/ha/year) was divided among 405 lowland families that use the water released by the microwatershed. Results indicated that each family needed to pay 7.03 USD/year to cover the land use OC. In theory, the last payment would be implemented if communities received the same amount of water. Unfortunately, water distribution among communities is not equal. For example in July 2008 (dry season), "El Humo" received less water (107 litres/inhabitant/day) than the other two communities (633 and 702 litres/inhabitant/day, to "Tezitlal-Tepetzintla" and "Tezitlal-Chontla", respectively). Last situation indicated a problem that needed to be confronted, with the construction of appropriated hydraulic infrastructure, and communities' organization, before the implementation of a PHES policy.

To consider the point of view of the future hydrological ecosystem service users is a critical step in the construction of a local policy of PHES. For example in this study case, each community answered in a different manner to the question about their willingness to pay the land use OC to protect the remnants of natural forest and the silvopastoral system. For example: “Tezitlal-Tepetzintla” community agreed in a 100% to pay; however two local leaders who have ecological preferences influenced the meeting. In the other case, “Tezitlal-Chontla” citizens were in agreement to pay but on the conditions that a water tariff was developed to differentiate between the number of citizens per home, home characteristics (i.e. made with cement or rustic materials), and other activity outside domestic use (i.e. rural cheese factory or pigs husbandry). Finally, “El Humo” community agreed to pay the land use OC but conditioned their participation with several interesting questions. For example: If the PHES would be implemented, who will collect the water use tariff? Who will pay the highland landlords? Who will monitor the landlords? Who will pay the salary to the people that will be working on the PHES? Which municipality will participate? These questions indicated that several actions needed to be developed before the implementation of a local scheme of PHES. For example, to improve community organization, to create the rules of the game in agreement with the communities, to adjust the tariff with the transaction costs, and to determine the participation of the municipality or other government institution.

A local scheme of PHES is not the solution to the water supply problem reported by Tepetzintla Municipality. A policy of PHES could be part of the solution with the objective to protect the ecosystem that provides the hydrological service, but should be developed at the same time with other activities such as a hydraulic infrastructure update, water use culture, and communities’ organization.

The application of the methodology proposed in this dissertation could help decision-makers in their judgment about whether or not to implement a policy of Payment for Hydrological Ecosystem services in a community with water supply problems. The method proposed could reduce the generation of false expectations among citizens or institutions, and could help in the generation of more feasible strategies to confront the fresh water supply problems.