Defining ecosystem-based adaptation strategies for hydropower production: stakeholders' participation in developing and evaluating alternative land use scenarios and the strategies to achieve desired goals

Definición de estrategias de adaptación basadas en los ecosistemas para la producción de energía hidroeléctrica: la participación de actores en el desarrollo y la evaluación de escenarios alternativos de uso de la tierra y estrategias para lograr los objetivos deseados

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Abstract

Hydropower production is a development priority for Costa Rica. The life-span of hydropower dams depends on the provision of adequate Soil Regulation Services (SRS) from upstream areas. In this paper we consider the case of the Reventazon watershed, which has been prioritized by the National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) for being an important development region highly vulnerable to climate change. Indeed, current degradation of SRS is determined by inadequate soil management in agricultural upstream areas such as the case of the Birris watershed. Moreover, the observed frequency and intensity of extreme precipitation events in the region have made it prone to more erosion. Climate change is expected to maintain or increase these trends calling for urgent action to protect SRS provision. Erosion affects two main sectors in the watershed. Upstream, it affects farmers by reducing soil productivity over time and, downstream, it affects hydropower dams by increasing the costs for companies to prolongue the life span of their dams. In such a context, there is a potential for joint gains for both actors although this might not have been highlighted so far. Scenario planning and discussion is a tool for promoting discussions among stakeholders on possible futures to outline strategies to protect SRS provision. Through an interdisciplinary approach, we combine methods from decision analysis and modelling to systematize value-based information from stakeholders and territorial data from modelling of erosion outcomes from different soil management options. We present some preliminary results from the stakeholders' discussions on scenarios.

Keywords: adaptation, ecosystem services, analysis of scenarios, soil management

Resumen

La producción de energía hidroeléctrica es una prioridad de desarrollo para Costa Rica. La vida útil de las represas hidroeléctricas depende del suministro adecuado de los Servicios de Regulación del Suelo (SRS) de las zonas río arriba. En este artículo consideramos el caso de la cuenca del Río Reventazón, la cual fue catalogada como prioritaria por la Comunicación Nacional a la Convención Marco de las Naciones Unidas sobre el Cambio Climático (CMNUCC), por ser una región de desarrollo altamente vulnerable al cambio climático. De hecho, la degradación actual de los SRS está determinada por la gestión inadecuada del suelo agrícola en las zonas río arriba, como en el caso de la cuenca del Birrís. Además, la frecuencia e intensidad observadas de eventos extremos de precipitación en la región la han hecho más propensa a la erosión. Se espera que el cambio climático mantenga o aumente estas tendencias, por lo que es necesario tomar acciones urgentes para proteger la provisión de SRS. La erosión afecta a dos sectores principales de la cuenca. Río arriba, afecta a los agricultores mediante la reducción de la productividad del suelo con el tiempo. Río abajo, afecta a las represas hidroeléctricas al aumentar los costos en los que incurren las empresas para prolongar la vida útil de sus represas. En este contexto, existen beneficios comunes potenciales para ambos actores, aunque esto no se ha puesto en evidencia todavía. La planificación y discusión de escenarios es una herramienta para promover conversaciones entre los actores acerca de posibles futuros para delinear estrategias que protejan la provisión de SRS. Mediante un enfoque interdisciplinario, combinamos métodos de análisis de la toma decisiones y de modelaje, para sistematizar la información basada en el valor de los actores, y datos territoriales resultados del modelaje de la erosión producto de diferentes opciones de manejo del suelo. Se presentan algunos resultados preliminares de las discusiones de los actores acerca de los escenarios.

Palabras clave: adaptación, análisis de escenarios, manejo de suelos, servicios ecosistémicos

1. Introduction

The Reventazon watershed of Costa Rica is the most important for national hydroelectricity production (ICE 1999). The life-span of hydropower dams depends on the quality of water reaching them, which is determined by sediment loads flowing down the watershed. Each year, up to one and a half million tons of sediments are removed from the dams to ensure largest possible life-span. More than two million US dollars are spent to partially remove these sediments and to produce energy by alternative sources during this operation (Rodriguez 2001).

The quantity of sediments reaching the dams is influenced by four factors: the distribution, frequency and intensity of extreme precipitation events and the upstream soil management. Indeed, the Reventazon watershed was established as a priority area in the first National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) (IMN 2000) due to its vulnerability to precipitation extremes and its relevance for national development. Furthermore, the watershed management plan has outlined that erosion in upstream areas is an important factor in siltation of dams and three sub-watersheds were identified as priority areas for targeting soil conservation efforts. One of these is the Birris sub-watershed. The presence of a small hydropower dam and of high rate of land use conflicts makes this sub-watershed an interesting learning case for the National Electricity Company (ICE). For the establishment of efficient soil conservation programs in this watershed, we need to consider the potential changes that may affect two important stakeholder groups, farmers and hydropower generators. These actors are affected by the degradation of Soil Regulation Services (MEA 2005) and are, therefore, interested in the identification of adequate responses. Neither of these two stakeholders have experience with possible outcomes of available responses although activities to foster soil conservation actions are being undertaken in the Birris watershed.

The aim of this paper is to illustrate how the use of multiple tools like modeling, decision analysis and negotiations can support decisions on adaptation of both upstream farmers and downstream hydropower actors. The underlying idea of our approach is that improving understanding of i) how erosion is affected by both land management and climate extremes, ii) what are possible outcomes to be expected and iii) what aspects matter in the implementation of such responses, can start the definition of ecosystem-based adaptation strategies. We achieved our objectives through a process of scenarios-construction and structured consultations with these actors. We strove for identifying both the existing potential for joint gains in a soil conservation program and the unwanted outcomes of implementing alternative responses to SRS degradation.

2. Description of the case study

The Birris is a sub-watershed of the Reventazon River (Figure 1). It has an extension of 4800 ha and is under the influence of the Atlantic climate, with 2325 mm average rainfall, 82.8% of which is concentrated in the May-December period. Extreme rainfall events have increased in number in the last forty years (Aguilar et al. 2005) thus increasing erosivity of precipitation. Topography is characterized by slopes reaching 70% especially in the upper part of the watershed. The population, the majority locally-born, has a density of 161 inhabitants per square kilometer, above the national average (INEC 2002). Most of it (61%) is dedicated to market-oriented agriculture and has been conducting its current productive activity for the last forty years (ICE 1999).

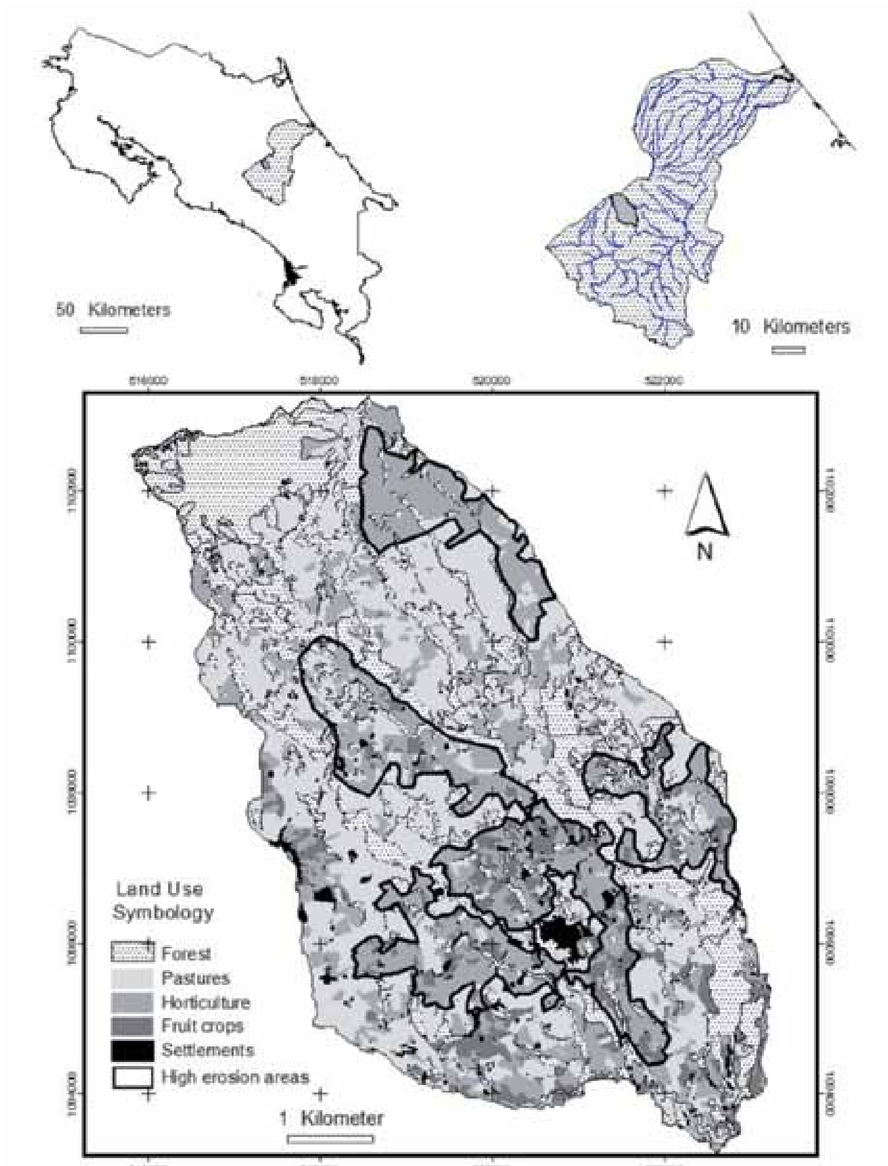

Figure 1: Birris sub-watershed location, land uses and the delineation of high erosion areas.

The resulting intense process of forest fragmentation and intensive agricultural production[1] makes this sub-watershed one of the largest sediment-producers of the country (Sanchez-Azofeifa et al. 2002). Average erosion rates increased from 12 ton/ha/yr prior to 1978, when only 15% of the watershed was under horticulture, to 42 ton/ha/yr in the 90's when crops occupied more than 30% of total watershed area (Abreu 1994; Marchamalo 2004). However, the effect of such high level of erosion is only visible in some areas because the majority of the watershed is sloping down from the Turrialba volcano where deep *andosols* are largely common (Lutz et al. 1994; Rodriguez 2001).

2.1 Rational and strategy for mainstreaming Ecosystem Services into adaptation decisions: use of scenarios in the Birris sub-watershed

The Reventazon watershed management plan identified the Birris sub-watershed as an important producer of sediment reaching ICE's dams. In this sub-watershed, ICE and JASEC (both local power companies) have implemented soil conservation activities in conjunction with the agricultural extension office, targeting individual producers or their associations.

However, questions like what are the effects at watershed level of the promoted practices, what alternative investments are possible to change the way soil is managed, and finally what is the perspective of different actors on these alternatives have not been explored. By using an inter-disciplinary approach, we first look at what factors matter to each of these two stakeholders in the provision and use of SRS. Then, we use GIS modeling to simulate different soil cover and management options following stakeholders' perspectives. Finally, we use the scenarios as inputs for stakeholders' consultations to assess their concerns over potential landscape management options. Scenarios consist of the description of equally possible futures that play a provocative role in the design of possible actions to counter an undesirable existing trend of environmental degradation (Selin 2006). We build on existing methods for developing scenarios (Patel et al. 2007) where selected stakeholders take part in the process of identifying relevant variables. This has the potential to make scenarios relevant to stakeholders and useful for informed discussion of possible futures (i.e. as consequences of alternative pathways of soil management in the watershed). An ecosystem services approach is used to explore the potential for joint gains in contexts where producers and users of SRS have little knowledge of possible alternative soil management options and of their outcomes. This provides opportunity for mainstreaming ecosystems in adaptation responses at the landscape level.

2.2 Selecting the participants

Under the ecosystem-based approach, the identification of relevant actors is guided by the dynamics of supply and provision of ecosystem services and by the decision context in which stakeholders influence their provision and use (Fisher et al. 2009).

The selection of actors to be involved in this research is thus influenced by the specific decision context in which direct supply and use of soil regulation services (SRS) takes place. Upstream, farmers are direct beneficiaries of soil conservation efforts but also contribute to the provision of this service to downstream hydropower plants. These facilities are interested in keeping low sediment loads in the water they use for producing hydropower. Besides those directly involved in the supply and use of SRS, especially those concerned with the design of responses to SRS degradation and in the promotion of soil conservation responses, watershed management committees are also important when alternative soil management scenarios are to be considered as possible responses. We, thus,

1 Agricultural technologies that are applied in few plots in the area include some soil conservation practices such as contour lines and water conservation channels for horticulture. In the case of livestock we find stabled breeding and manure management. Most agricultural systems do not use trees in the productive plot and do not use terracing although slopes are very steep.

included the Watershed Planning Committee for the Reventazon watershed, given its intended supportive role in fostering watershed conservation in the region.

3. Scenario building

We used inter-disciplinary methods in developing scenarios and in structuring consultations with stakeholders to evaluate alternatives. The methods used to develop stakeholders' consultations include value-focused thinking interviews and focus groups (Keeney 1992), and negotiation analysis following the method of Raiffa et al. (2007). Additionally, we used GIS modeling (see text frame) to develop land use scenarios and a sediment-management-cost model for the small hydropower dam. We built our understanding of possible alternatives for soil management[2] using different sources of information (Scholz and Tietje 2002). Thus, alternative soil conservation measures to be represented in the scenarios (reforestation, agroforestry, silvopastoral systems, and soil management practices) were based on stakeholders' consultation, review of previous analysis of soil conservation adoption by farmers, and soil conservation studies developed in the area. The overall methodology then included a sequential approach of structured consultations with stakeholders and modeling (Vignola et al. 2008).

The key aspects to be included in the GIS modeling phase of the alternative scenarios were identified during focus group discussions where farmers indicated desirable and possible practices that conservation programs could be and, partially, are already promoting. On the other side, key criteria for hydropower companies concern the identification of priority areas and the costs and outcomes of supporting soil conservation efforts in these areas. GIS land use models were thus based on information derived from stakeholders (see text box).

Before constructing the final scenarios for consultations we ran focus groups and interviews to identify additional qualitative indicators to measure the performance of implementing alternative soil management responses in the Birris sub-watershed. We used a value-focused thinking approach (Keeney 1992), to discuss information on soil degradation in the watershed, land uses associated to erosion, socioeconomic impacts, as well as alternatives (mechanisms) to face those problems. Through this step, we could i) evaluate the understanding of the GIS-based scenario information, ii) validate the indicators identified in the previous process of consultation, and iii) complement scenarios description with the identification of new indicators.

Finally, evaluation workshops were held with each of the stakeholders. Alternative scenarios were presented to stakeholders through a set of posters that described (using maps, graphics, and photos) general characteristics of each one of the six possible landscape futures (two reference scenarios and four achievable scenarios) and all the quantitative (i.e. GIS-modelled) and qualitative (stakeholders-based) indicators associated to each of them. Then, a plenary discussion on "what are the good and what the bad things in the way the landscape is managed now" was developed. Every participant declared his ideas in a brainstorming session. In these final workshops, stakeholders evaluated four alternative scenarios. Here, we excluded, from the evaluation, the two extreme scenarios "completely covered by forest" and "completely deforested" since these two scenarios were merely representing the extreme limits of the effects of possible extreme vegetation-cover changes in the provision of SRS. For example, while erosion produced under the "complete forest" scenario represents the "natural" base line of erosion production, the extreme "completely deforested" scenario shows the highest possible erosion in the landscape when the last remaining spots of forests are cleaned. Thus, while these two extremes

2 Soil management practices to be simulated in the scenarios were identified using information from the agricultural extension office and other existing programs for soil conservation. These included: use of trees in agricultural plots (i.e. agroforestry and silvopastoral systems); soil and water channels, contour lines cultivation, and terracing.

are deemed "improbable", the other four scenarios include changes in vegetation cover in directions that are considered possible and/or desirable (i.e. based on stakeholders' consultations) and are thus used for evaluation of stakeholder's preferences. Details of these scenarios are shown in Table 1 and, for stakeholders' consultation, are named as follows: 1) current soil use; 2) reforestation of high priority areas for erosion control; 3) adoption of soil conservation practices only in high priority areas for erosion control y; 4) adoption of soil conservation practices in the whole basin.

GIS modeling for quantitative analysis of scenario SRS performance

As two extreme scenarios we take the full forest cover (scenario 1, as a "natural baseline" production of sediment) and full deforestation (scenario 3) as boundary of the actual scenario (2). Land use changes could be achieved by soil conservation programs. Potential implementation of soil management activities and the change in erosion-control-relevant areas were identified based on existing practices (Marchamalo, 2004). CALSITE platform (Bradbury, 1995) was used to estimate total laminar erosion in the watershed using the RUSLE model (Wischmeier and Smith, 1978):

$$A=(R,C,K,LS,CP)$$

Where A is the resulting field sediment calculation (ton/ha/yr), R is the erosivity of precipitation based on data from 32 meteorological station in the Reventazón watershed, C is vegetation cover factor, K is the soil erosivity, SL is the slope length and CP is a factor accounting for soil management practices. Most of these factors were estimated in previous studies in the area (Elizondo 1979; Bermudez, 1980; Gutierrez, 1987; Mora, 1987; Forsythe, 1991; Cervantes and Vharson, 1992; Arroyo and Madriz, 1994; Portilla, 1994; MAG-FAO, 1996; Gomez, 2002; CATIE, 2003; Gomez, 2004; Arroyo *et al*., 2006).

In the model, each of the conservation practices induces changes in parameters that are relevant for erosion control as promoted or already used by local farmers (Cubero, 1996). For factor C and K in the model additional field data were collected in the watershed (Lianes *et al*., Submitted). Moreover, to account for possible increases in frequency and intensity of precipitation extremes as the increasing trend observed for the region (Aguilar *et al*., 2005), we simulated an increase in R considering 4 hypothetical projections of increase in erosivity of precipitation (i.e. current, +1%, +5% and +10%) as a proxy of increase in frequency of extreme precipitation. LS was accounted for by estimating how some conservation practices might reduce the length of slope (LS) run by water along the slope. CP was included using existing literature data.

The CALSITE simulation allows the identification of erosion risk areas where to focus actual and potential future conservation efforts. Priority areas (i.e. where erosion is higher) were identified based on criteria that were identified in consultations with hydropower actors. According to this criterion, in different scenarios risk class is calculated weighting pixels also by their connection to the hydrographic network in the watershed. Pixels that were closer to a water stream, other variables being constant, were weighted higher. Erosion produced by different watershed areas and finally the annual total sediment output of the watershed were calculated with CALSITE. Since the scenarios were referring to a temporal horizon of 15 years, we did not include effects of climate change on factors such as vegetation under the assumption that in this time horizon, the effect of increasing temperature is not so relevant for currently cultivated crops. Similarly the reduction of soil organic matter as a result of surface erosion was not included.

3.1 Description of scenarios

Indicators to describe scenarios included both quantitative and qualitative indicators (Table 1). Many qualitative indicators reflected expected trends as suggested by literature, experts and stakeholders. Together with this information we used photos, maps and easy-to-understand graphs to complement scenarios presentation to stakeholders. Thus, photos of typical soil conservation practices in the watershed were visually representing the main characteristics of the correspondent scenario. For example, in the scenario "soil conservation practices in high priority areas for erosion control" the picture captured soil and water conservation contour-line cultivation in Birris areas where slope is high and closeness to the river is small.

The average education level of farmers required efforts to ensure adequate understanding of map graphics and other information presented. We started by training individuals on the identification of key points of their territory inside the map (i.e., infrastructure, rivers, their own production plots) and of the legend used. A compendium of graphic material used in scenario analysis complemented this information (Figure 2).

Table 1: Details of indicators (relative magnitude and direction) used in scenarios of land use management for Birrís river sub-watershed.

Indicators	Scenarios *			
	1	2	3	4
Water quality	Low	High	High	High
Forest cover	Low (35%)	High (60%)	Low (35%)	Medium (35%)
Presence of plant and animal species	Low	High	Medium	Medium
Quantity of top-soil lost (mm/year)[5]	Medium (5)	Very low (0.14)	Very low (0.17)	Very low (0.06)
Cost of promoting agreements between stakeholders to foster community actions	Low	Very low	High	Very high
Dependence of agricultural inputs	High	-	Low	Low
Available area for agriculture	Medium (32%)	Very low (<5%)	Medium (32%)	Medium (32%)
Electric energy cost	Medium	Very low	Low	Low
Diversification of income opportunities	Low	Low	Medium	Medium
Cost of implementation of soil conservation practices	Low	Medium	High	Very high
Cost of soil nutrients reposition lost by erosion (colones/ha/year)	Medium (11,000)	Very low (312)	Very low (316)	Very low (121)
Risk level of infrastructure damage	Very high	Very low	Medium	Very low
Extension of high risk areas in the watershed	Medium	Low	Low	Low

** **Scenarios: 1.** current soil use; **2.** reforestation in high priority areas for erosion control; **3.** adoption of soil conservation practices only in high priority areas for erosion control; **4.** adoption of soil conservation practices in the whole basin*

3 We translated the value of RUSLE (i.e. in ton/ha/yr) to quantity of top-soil lost per year to facilitate understanding of this measure to farmers. Indeed, we found that visualizing this phenomenon in terms of top-soil lost (i.e. the most important productive part of the soil) is closer to farmers' perspective as an indicator.

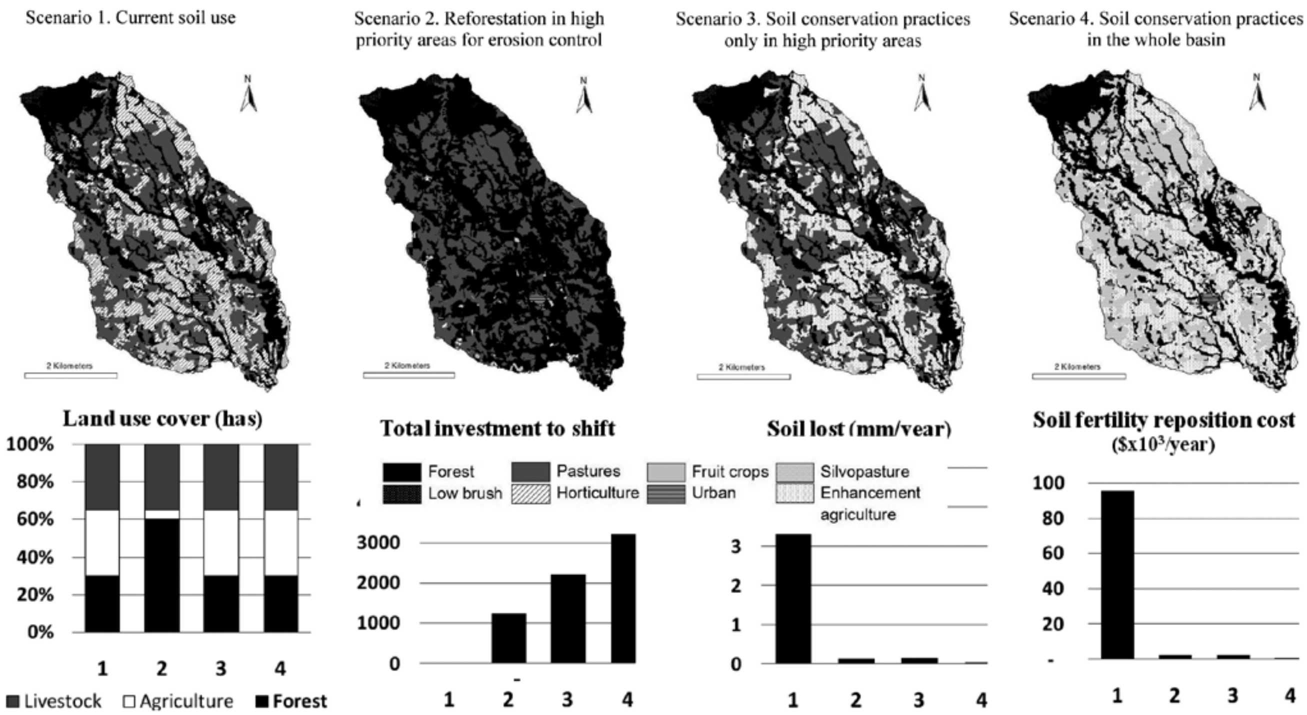

Figure 2. Land use scenarios of the Birris River sub-watershed: Maps picturing the respective land use management and graphics with values of quantitative indicators for each scenario (1 to 4).

4. Stakeholders' perspectives

As we discussed in Section 3.1, evaluation of stakeholders' preferences was focused on three groups of actors: farmers, hydropower companies, and the watershed committee. Differences in stakeholders' preferences were consistent with how their group is interested in specific aspects of the SRS provision (Table 3). A strong point resulting from this evaluation exercise is a general rejection of status-quo degradation of SRS and willingness to change for more environmentally friendly landscape management. Reasons declared to justify the non preference for status quo (scenario 1) were different for each group of stakeholders; however, there were agreements on some issues.

Hydropower companies expressed concerns with erosion reduction for its long-term impacts on dams. Watershed committee's representatives agreed with those reasons, and added concerns over biodiversity loss and impacts on water quality and pollution by agrochemicals. Farmers, in addition to the previous reasons, referred to the negative impact of soil erosion on agriculture and livestock production in the future.

For scenario 2 (i.e. "reforestation in high priority areas"), participants showed concern over potential social conflicts from conversion of agricultural activities to forest cover in these areas. Indeed, here farmers are smallholders highly dependent on market-oriented agricultural production for whom "losing" farm soil to forest cover represents a very high opportunity cost. JASEC did not prefer this scenario.

From the perspective of stakeholders, scenario 3 and 4 represented a balance between agricultural activity and conservation of soils and water, income generation, and the reduction of vulnerability to extreme precipitation (mentioned by farmers as positive externalities of these soil use scenarios). The main difference in concerns among stakeholders was related to the higher cost of achieving scenario 4 (i.e. soil conservation promoted all over the sub-watershed) compared to scenario 3 (only in priority areas).

Table 2: Reasons attached to most and least preferred land use scenarios expressed by farmers and hydropower company.

	Non preferred		Preferred		
	Scenario 1	Scenario 2*	Scenario 2*	Scenario 3	Scenario 4
Electric Company	More erosion, risk and vulnerability Higher maintenance costs More expensive in long term Harmful for all the actors, because affects everybody's welfare			Viable and sustainable in the future Cost is manageable	Lower erosion Risk and vulnerability reduction Benefits area spread to more actors in the watershed Sustainable production Costs are reduced in a long term
FARMERS	Deforestation Erosion Impacts in water quality Impacts in future production Higher costs of health, services, infrastructure	Lack of employment Migration	Soil and services enhancement Employment is available More achievable	Agriculture is allowed Lower erosion Water quality is maintained Opportunities for higher incomes All sectors are involved	Lower erosion Higher income Harmony with nature
Watershed Committee	High erosion Poor water quality Pollution by agrochemicals Biodiversity lost Incapable to resolve socioeconomic problems Higher costs of energy production	Productive land is needed. Otherwise, social conflict may arise	Erosion and high risk areas are reduced Foster of a "conservation of nature" culture Less pollution Lower costs of energy production	Balance situation between production and environment Soil conservation Possibility of experience's replication	Agriculture is allowed Lower erosion and pollution Improvement of water quality and quantity

*In the case of the hydropower company, scenario 2 was neither the most nor the least preferred scenario.

5. On the use of scenarios

Scenarios are a tool for informing policies on consequences of current behaviors and fostering discussion of potential preventive solutions. Complex systems, such as the case of provision of SRS in vulnerable watersheds, are characterized by large uncertainties and are hard to model, especially in data-scarce regions. In this respect three main aspects need to be considered. First, elaborating highly complex models to build history of the future would require huge data sets with long time series capturing trends from the past. Second, even if data was not a limitant factor, the outcomes of models would still hide the huge uncertainties that characterize the provision of ES under climate change and future land use change and management (Hulme 2005). Third, when modelling scenarios with stakeholders to inform policy-making processes, there are important issues to be considered such as trust in scenario building, clear understanding of the scenario building process and of the uncertainties attached to it (Selin 2006). This aspect is particularly important given the preformed judgments that stakeholders might have towards a given problem. Indeed, the final aim of scenario building is achieving change in the behaviour of actors so that accepted solutions to an unwanted status-quo situation can be envisaged (Berkhout et al. 2001).

In previous research on the preferences of stakeholders for the Birris (Marchamalo and Romero 2007), participants were asked to rate alternative land use planning priorities presented as general concepts such as "farmers' income", "water quantity and availability", "erosion control" and "water quality". Results from this exercise do not differ substantially from our findings. However, using scenarios in open discussions with stakeholders has the potential to broaden their perspective on a variety of objectives and issues to be considered under the design of a land use plan. It can, additionally, leverage new perspectives on joint gains among actors that were unthought-of before.

In the experience presented in this paper, stakeholders were involved from the very start of the scenario building process. This has helped building trust between model facilitators and stakeholders. Moreover, in the trade-off between precision and stakeholder involvement, we were driven by simplicity of modelling and putting efforts in stakeholders' involvement. Farmers' associations participating in the final scenario evaluation workshop asked for more of these exercises on the basis of their "utility in stimulating creative knowledge". They found the exercise very useful especially for younger generations of farmers who might embrace more soil conservation behaviour in the face of changing climate conditions.

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