

Chapter 10

Adaptive Watershed Management in the South American Highlands: Learning and Teaching on the Fly

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The South American Andes are rife with environmental problems related to human activities within fragile ecosystems. Andean populations are generally among the poorest in South America; they also have only limited access to infrastructure and public services, and are dependent on rain-fed agriculture. These areas are rich in biodiversity yet extremely vulnerable to damage caused by farming. The Andes form the headwaters of many of the great river systems of South America, and runoff and agriculture-related pollution can have consequences far from their sources. Humans are increasingly encroaching in the fragile high plains as population pressures at lower elevations extend the agricultural frontier. This extension creates environmental damage by upsetting pristine areas and leads to runoff, loss of biodiversity, and lower water availability for population centers. Areas where people live just below the high plains are characterized by undulating, steeply sloped topography; this topography and the central importance of water to human and mammal populations make the watershed an obvious focus for solutions to environmental problems.

Solutions in such areas include the usual combinations of tools—regulations, assigning property rights, taxes, and subsidies—but a central component of any sustainable solution is to identify strategies to raise incomes while placing less strain on the environment. These strategies might include more environmentally benign agricultural technologies within the fragile areas, intensification of agricultural production in less fragile areas as a means of reducing pressure on more fragile areas, or strategies to raise income-earning potential through less land-intensive practices such as off-farm employment. Generally, however, efforts to improve natural resource management in agriculture-dependent areas focus on reducing environmental impacts in situ: technologies or public actions to reduce pressure where the damage is occurring.

The watershed approach to natural resource management has been tried in different settings in the highlands of South America with varying degrees of success. The watershed is now widely accepted as the appropriate unit of analysis in cases where water quality is a primary driving concern (Doolette and Magrath 1990) and watershed management is consistent with decentralized governance, which is rapidly gaining favor in Andean countries (Guerra-Garcia and Sample 2007). However, watershed analyses require extensive digitized data and tools that are of limited availability in high mountain areas, and watershed management often requires the cooperation of competing and overlapping levels of local and regional government. Also, ethnic diversity can be significant even in rather small watersheds, and attaining consensus can be a challenge in such

environments. Thus, while watershed approaches to environmental problem-solving show promise, obstacles must be overcome during implementation.

A key element of any watershed approach is to recognize that watershed-level outcomes are a product of individual decisions about land use on fields spread across the catchment area. These decisions are results of livelihood strategies adopted by farmers and others who allocate their physical, human, natural, and other tangible and intangible assets to earn a living, increase their wellbeing, and manage the multiple risks they face (Siegel and Alwang 1999). Individual decisions such as management of a maize field have aggregate effects based on the physical characteristics (e.g., soil type, slopes, rainfall, natural and manmade barriers) and the decisions of others. Interdependence of decisions and their impact on aggregate economic and environmental outcomes result from a complex mosaic of economic, social, and physical networks that characterize all watersheds. The cross-scale spillovers from these different networks imply that solutions found at a single system level are not sufficient. However, the driving factor and the one most directly affected by watershed management is human decision making. This depends on policies and regulations, cultural and social factors, and individual objectives. Effective management must identify mechanisms for effecting change in human activities and options to raise incomes while reducing negative environmental consequences.

The literature shows that livelihood adoption depends on multiple objectives of the decision maker, his or her asset allocation, and the physical, economic, and institutional environment. Linkages across systems transmit signals to actors. For example, decisions at the policy level get transmitted through institutions to households. Household actions depend on field and watershed conditions. Within the household, decision making is shared by men and women (Hamilton 1998), and activities within a livelihood can be shared or differentiated. Concerns for income growth, risk management, food security, and system sustainability all influence household decisions (Reardon and Vosti 1995; Moser 1998; Rakodi 1999). Economic factors such as relative prices and profitability of alternatives drive adoption of new varieties and crop management practices, create incentives to begin new activities on and off the farm, invest in soil conservation, and generally alter land-use decisions (Winters et al. 2004; Coxhead and Demeke 2005). When combined with the interconnectedness of decisions within the watershed, these factors mean that modeling household decisions as a deterministic linear process will inadequately describe them. Yet typical watershed modeling approaches model household decisions as a linear process. (Dario-Estrada and Posner [1999] provide an overview of watershed modeling in the Andean region.) Approaches to watershed management rarely recognize that asset bases and livelihood strategies are fluid and that a successful management plan should introduce alternatives that contribute to higher incomes. Multiple feedback loops and interdependencies at different system levels complicate modeling and decision analysis, and building stakeholder acceptance under such complexity is also a challenge.

The purpose of this chapter is to describe an effort to manage the complex systems in the watersheds of Bolívar Province, Ecuador, that was part of the United States Agency for International Development-funded Sustainable Agriculture and Natural Resource Management (SANREM) Collaborative Research Support Program (OURED 2008). We begin by describing the ecosystem context, then discuss the conceptual framework and our empirical plan. We present selected results showing that ethnic and agroecologic diversity in the watershed mean that technical interventions must be tailored to local conditions and that the process of moving knowledge to action is highly context specific.

Background on Study Site

The Chimbo watershed of Bolivar Province, Ecuador, on the western slopes of the Andes includes the cantons of Guaranda, Chimbo, San Miguel, and Chillanes. It provides 30% to 40% of the water of the Guayas River, the most important river system in western Ecuador. The watersheds make up three distinct ecological regions (páramo, Andean plain, subtropical regions) and four distinct Holdridge zones (subtropical humid forest, low temperate mountain, temperate mountain, boreal). They range from 300 to 4,500 m (980 to 14,760 feet) in elevation and receive between 250 and 2,500 mm (10 and 100 inches) of annual rainfall.

People in the watershed are highly dependent on agricultural incomes, yet small holdings, low productivity, and environmental degradation are associated with the highest rates of poverty in Ecuador. As a result of the central importance of the Chimbo River (figure 1), the government of Bolivar Province has expressed interest in a watershed approach to land-use planning. Together with the Comisión de Estudios para el Desarrollo de la Cuenca del Río Guayas (Commission for the study of development in the Guayas River watershed), the government in 2007 approved local funds for three environmental projects based on the watershed approach. One of these involves identifying alternatives for high-plain agricultural activities; the second provides incentives for reforestation and other soil conservation measures; the third funds environmental education in school curricula. Several local and international nongovernmental organizations work in the area and are using the watershed approach to natural resource management.

The Chimbo area is being buffeted by forces that change the way people live, probably permanently. Like many areas in South America, the region is becoming closely integrated with the



Figure 1. Cattle graze beside a cornfield along a tributary of Ecuador's Chimbo River, the country's most significant watershed.

national and global economy, a result of more open trading regimes, dollarization of the economy in 2000, and better transportation, communication, and information about markets elsewhere. Market integration places competitive stresses on traditional production systems but also provides opportunities for higher local capture of value added through post-production processing. Many stakeholders recognize potential opportunities but express frustration about small scales of production, access to markets and information, and perceived inability to compete in a globalized economy (Barrera et al. 2005). Stakeholders also recognize that environmental degradation is widespread and includes erosion and loss of productivity, loss of biodiversity and natural areas, and declining water quality and quantity. This degradation is perceived to be reducing agricultural competitiveness, although historical evidence on farm yields is not available. Many note that global climate change is reducing access to water and express the need to promote more sustainable use of scarce water resources.

Cross-Systems Management Approach

Programs to enhance environmental management in fragile areas must recognize two features of household decisions within complex systems: tradeoffs between actions at the extensive and intensive agricultural margin, and tradeoffs between on- and off-farm income earning activities. These decisions have implications across the systems. Extensification such as agricultural activities in the Andean high plains can create environmental damage such as increased erosion from sod-busting, long-term loss of soil fertility, agri-chemical pollution, loss of biodiversity, and diminished water availability due to more intensive water use and declining water tables. Pressure on these fragile lands is stimulated by low productivity, progressively smaller holdings, and limited income-earning opportunities at lower elevations. Thus, interactions occur across scales as household decisions at higher elevations imply changes at the field scale that eventually have impact at the watershed and larger scales.

Agricultural intensification can be associated with similar environmental problems, but because resource-conserving technologies are more readily available in intensively farmed areas and because productivity is usually higher in these areas (Southgate 1998), technology can be designed to raise incomes while maintaining or improving environmental quality. Higher incomes in intensive agriculture can stimulate investments in land- and soil-saving technologies and create “economic space” necessary to address environmental problems; they also can reduce pressure on fragile uplands. Cross-scale interactions are obvious.

Land-use patterns help determine the environmental effects of human activities, but the relationship between land use and wellbeing outcomes is fluid and can be affected by research-induced changes in the opportunity set. Nonfarm employment such as processing and adding value to agricultural products may be constrained by technical or market limitations; these limitations can be addressed through focused research and subsequent policy change. Such activities can be associated with increased income and, because their footprint on the landscape is small, minimal environmental degradation.

Our approach to watershed management in Bolivar Province combines a livelihood approach with scientific research to change the livelihood opportunity set. The adaptive management approach is used to integrate the research with planning decisions and promulgate policy to promote land uses consistent with environmental quality.

The adaptive watershed management approach involves several steps. First, we use science and local knowledge to evaluate economic, social, and environmental problems in the watershed.

Second, we engage stakeholders in a process of participatory goal setting based on our evaluation of problems and capabilities. Third, we build capacity to use science-based information to effect institutional change and influence land-use decisions. Fourth, we create the capacity and infrastructure necessary to monitor outcomes, identify the need for new alternatives, and alter the process as appropriate. Concurrent with capacity building, primary research was needed to identify economic, social, political, and environmental conditions in the watersheds and understand the determinants of these conditions; generate and validate environmentally sustainable alternatives to improve production systems and enhance income generation; and create a means of evaluating the effects of alternative actions, policies, and interventions.

Conceptual Framework

The adaptive management framework is well known (Salafsky et al. 2001). It begins with an assessment of conditions and identification of problems, and the community is engaged in a goal-setting exercise. Research findings are then used to produce watershed plans, which are implemented and monitored. Monitoring could lead to changes in plans over time, and the adaptive cycle begins again. We introduce two innovations to this standard framework: Plans are adapted on a regular basis as the research base and understanding of it grows, and the land-use plans include consideration of household decision making and how these decisions create impact across multiple systems.

The conceptual framework includes a focus on the household decision process, and cross-system interactions across the field, watershed, and larger system levels mean that household decisions have wide implications. The household decision process reflects livelihood choices. A livelihood refers to the capabilities, assets, and activities required for a means of living (Chambers and Conway 1992) or how labor, land, and other assets are distributed among productive and reproductive activities. The decision to adopt a livelihood (figure 2) is partly determined by the household asset base; available alternatives; institutional, policy, and social environments; exposure to risks and access to information; and the natural environment. Households allocate assets among activities to meet objectives such as utility maximization and food security. Decisions have effects on household wellbeing, the ability to save and invest (affecting the future asset position), and the natural environment. For example, adoption of a modern maize technology affects labor and land allocations, income, and risk exposure; and may affect erosion, runoff, and future soil quality. Changes in a household's wellbeing and its asset position emerge following adoption, and impacts are seen on soil quality and quantity, biodiversity, runoff and water quality. The latter effects will be felt at the field and farm levels, but through the geographic interlinkages within the watershed, impacts are aggregated to the watershed, ecosystem, and market levels. Some local actions have environmental impact on a larger scale, such as atmospheric carbon emissions.

A physical watershed model is used to reflect cross-systems linkages—how human activity leads to field-scale changes in land use and how these affect watershed outcomes such as total runoff, erosion, and river-water quality. This physical model is a central component of our framework: The assessment and problem identification stage generates information to populate the model. Model runs are used to create and evaluate community land-use management plans. Acceptance of model findings requires the buy-in and active participation of local decision makers in the research. Goals are set, and institutional changes to achieve goals are explored as a part of this research. This participation is attained by involving stakeholders in field research, development, and validation of the watershed and economic models, and selection of alternative management

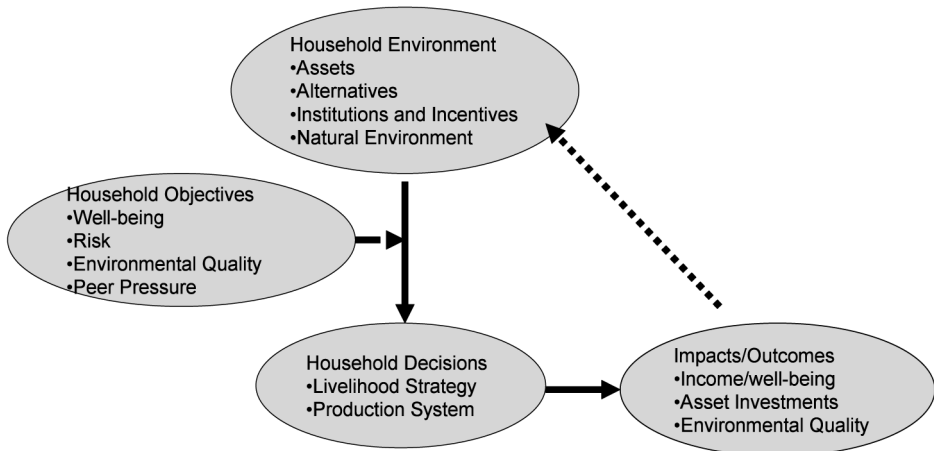


Figure 2. Conceptual framework: Household decision processes.

scenarios; all this engagement is essential to adaptive management (Salafsky et al. 2001). The process should produce agreed-upon land use plans that have wide acceptance in the watershed.

Methods

Project activities include data and information generation, research into determinants of and impacts on wellbeing of livelihood adoption, research to identify new income-generating alternatives inside and outside agriculture, modeling biophysical and social-economic processes in the watershed, and engagement of stakeholders. Stakeholders provide information, define objectives, evaluate results, create and implement plans, and monitor outcomes.

We began by describing the watershed's economic, social, and physical characteristics. These data were used to evaluate current conditions, create an information baseline for monitoring changes over time, and as input into our three basic models. These were models of physical production (soil and environmental attributes, productivity); models of household decisions; and models of physical impacts of individual and aggregate decisions (the watershed model). The data were also used as input into the community goal-setting exercise—to enable assessment of current conditions and to create a vision of where the community wanted to go. This goal-setting exercise, which consisted of several meetings over three months, led to the first adaptation: Instead of focusing primarily on water quality, the community identified three interrelated goals: water quality, availability, and improved soil resources.

The research to identify alternatives includes information on improved production practices (new varieties, management practices), the relationship between improved practices and outcomes (income, soil loss, productivity), alternative production and livelihood activities, market evaluation and market-chain analysis, and obstacles to adoption of new activities. Information on these alternatives is incorporated into the household models to simulate how livelihood changes will result from changes in policy and incentives.

The watershed models create the linkage across scales, from field- and farm-level activities to watershed outcomes such as water quantity and quality, soil loss, and sedimentation. They take information on the spatial distribution of natural conditions, rainfall, human decisions, prices,

institutions, and incentives; relate it to aggregate outcomes; and subsequently use it to simulate the aggregate impacts of alternative policies.

Engagement is a critical component. Early experience indicated substantial doubt about the approach among stakeholders. This skepticism is fueled by two factors: their experience with development programs that provide resources and stimulate rent-seeking, and skepticism that mathematical and computer models would provide useful information for everyday decisions. While the first objection could be reduced only by interacting with the community over time, the second led to increased stakeholder involvement in tools testing and scenario development.

We began our process of involvement in research by engaging local youth to monitor rainfall and stream flows—essential inputs into the watershed modeling effort. We tested differences between hand-collected rainfall information and data from automated weather stations. The experience showed a reasonable correspondence, which helped create confidence in our data collection methods. Maps of land use and soil erosivity were generated using data from our initial assessments, satellite imagery, and other digitized data. These maps were presented at meetings in the watershed; feedback from the community helped us with our estimates and also built ownership among stakeholders, who began to recognize the relationship between land use and environmental outcomes. Our most dramatic experience with respect to skepticism and ownership came when community members insisted on more transparent modeling of land use and outcomes, which led us to rely much less heavily on the Soil and Water Assessment Tool (SWAT; see <http://www.brc.tamus.edu/swat/>) and more heavily on less complex tools such as simple maps showing flows of runoff and areas where erosion potential was most acute. These maps were generated using field-level estimates of erosion and runoff (from our experimental plots) that were aggregated to the watershed scale using knowledge of the slopes and land uses across the watershed.

Central Issues in the Chimbo Watershed

Because of the watershed's size, the project team decided to conduct activities in two sub-watersheds of the Chimbo—the Illangama and Alumbre river watersheds. These were selected because of differences in agroecological and social conditions (table 1), which allowed us to test the adaptive management framework in two environments. Our research partner, the Autonomous National Agricultural Research Institute (INIAP), had ample experience working with farmers and local governments in the upper Illangama watershed but virtually no history of interactions in the lower-elevation Alumbre. The difference in experience in interactions with INIAP allowed us to test different models of bringing knowledge to action, for engagement in Illangama was immediate, while introductions and confidence building were necessary in Alumbre. Agricultural activities predominate in both watersheds, with the cooler, higher-elevation Illangama comprising mainly a potato-pasture system and the warmer, higher-rainfall Alumbre being more diversified with maize-bean associations, other row crops, and some perennials (table 1).

The survey found that remittances and repatriation of funds earned during seasonal migration are important sources of income in both watersheds but more important in the lower watershed. A baseline household survey was conducted in September–November 2006. A random sample of farms was constructed based on farm census data provided by the Ministry of Agriculture, from census data from a national nongovernmental organization, and information from local authorities. Of the 700 farms in the lower watershed, 169 were included in the sample, and 117 of the 500 farms in the upper watershed were included. One representative of each farm was interviewed; about 70% of interviewees were men. Main challenges to income earning include low productivity

Table 1. Principal income-generating activities in the subwatersheds of the Chimbo River watershed, Bolivar province, Ecuador (SANREM participatory assessment and baseline survey).

Subwatershed	Environmental conditions	Principal income-generating activities
Illangama	<p>Region: Páramo and Andean Plain</p> <p>Holdridge life zones: Sub-alpine, mountain, low mountain</p> <p>Soils: Inceptisol 39%, Entisol 28% and Mollisoles and rock 33%.</p> <p>Average temperature: 7°C–13°C</p> <p>Elevation: 2800–5000 m</p> <p>Precipitation: 500–1300 mm per year.</p>	Agriculture (potatoes, pasture, cereals), livestock (cattle, sheep, pigs, others), tourism, small-scale commerce, handicrafts
Alumbre	<p>Region: Andean Plain and Sub-tropical</p> <p>Holdridge life zones: Low mountain and pre-mountain</p> <p>Soils: Inceptisol 13.9%, Inceptisol and Entisol 32.7%, and Mollisol and Inceptisol 52.5%.</p> <p>Average temperature: 15°C–19°C</p> <p>Elevation: 2000–2800 m</p> <p>Precipitation: 750–1400 mm per year</p>	Agriculture (maize, beans, peas), livestock, agro-industry (including medicinal plants, cacao and organic coffee), tourism, small-scale commerce

in agriculture, declining quality of the natural resource base, inadequate access to final markets, low local capture of value added, and inadequate diversification of income-earning inside and outside agriculture.

Stark differences are evident across the two watersheds. The social structure is quite distinct: In the Illangama watershed, all households are indigenous, compared with 38% in Alumbre (table 2). About 12% of households are headed by women in Illangama, compared with 17% in the lower watershed. Conditions faced by women differed from those faced by men; while overall levels of education are similar in the watersheds, adult women are far less likely to be educated compared with males, with the mean education of male adults being about 6 years compared with 4.8 years for women. In the Illangama watershed, female adults averaged less than 3.9 years of education compared with 5.3 years in Alumbre. Households in both watersheds expressed concern about retention of youths, and our survey indicated that 53% of households in Illangama send migrants out either temporarily or permanently, compared with 40% in Alumbre. However, far higher percentages of migrants from Illangama went to Quito; Alumbre households are far more likely to send migrants to coastal areas and abroad. Differences in migration patterns reflect ethnicity. Due to language and other barriers, indigenous migrants have fewer destinations and generally travel to highland destinations. None of the indigenous households in the lower Alumbre watershed sent migrants to non-highland destinations. Migration destinations have important implications for income; households from the lower watershed, despite participating relatively less in migration, receive greater shares of income from migration.

In both areas, farmers and other community members face decisions between livelihood strategies that exploit the extensive and intensive agricultural margins, and decisions about investments in on- versus off-farm productive assets. The settlements are relatively young; the upper watershed was populated by resettled indigenous groups in the early 1980s, while many parts of the Alumbre were unpopulated until the early 1990s. Population pressure in lowlands induced migration into the area. New settlement places obvious pressure on the natural environment. Environmental degradation is evident through obvious erosion on steeply sloped hillsides, absence of soil conservation measures, limited undisturbed natural areas, and turbidity in waterways. Both areas

Table 2. Description of survey households (SANREM baseline survey of households).

	Alumbre	Illangama
Male-headed (percentage)	82.8%	87.2%
Household size	4.7	5.8
Dependency ratio	0.47	0.50
Years education (head)	4.3	4.5
Highest educated family member (years)		
Male	6.2	5.9
Female	5.3	3.9
Percent indigenous	34.9%	100%
Percent with migrants	40.2%	53.0%
Percent migrants to Quito	67.4%	87.1%
Percent migrants other Ecuador	13.2%	12.9%
Percent migrants international	19.1%	0%

Note: N = 286.

remain largely dependent on agricultural livelihoods, but families are increasingly seeking off-farm opportunities. Off-farm income makes up about 57% of income for families in Alumbre compared with 27% for those in Illangama.

Households in Alumbre are more integrated into labor markets, more frequently rely on migration income, and are less reliant on livestock income than those in Illangama. Overall means mask important differences across livelihood strategies. For example, although income from self-owned business and migration make up only 7.4% and 10% respectively of total income in Alumbre, they account for 36.7% and 42.4% of income for those households engaged in these activities. Likewise, all households in both watersheds rely on agriculture to some extent, but income sources are clearly diversified. For example, in Illangama, for the 51% of households who participated in off-farm wage employment, this employment contributed to an average of 30% of household income. Agriculture is also much more diversified in Alumbre (table 3). The Illangama watershed is almost entirely composed of a potato-pasture rotation—95% have pasture, and 100% plant potatoes—with a small number of farms planting maize and chocho (*Lupinus mutabilis*, a local legume). Alumbre farm households plant small grains, maize and beans, and some perennials and Andean fruits.

To better understand how livelihood strategies differ, nine distinct livelihood clusters were identified using a cluster analysis (see the appendix), five in Illangama and four in Alumbre. These livelihood clusters reflect how people use their assets to earn a living. For example, the Illangama clusters include dairy, pasture, and potato production, while grains and legumes dominate in Alumbre. Households in the wealthiest clusters, however, had more diversified income sources, with on-farm activities being complemented with off-farm and often nonagricultural incomes. Households in the poorest clusters tended to be dependent on agricultural wages or agricultural income with small land holdings.

During the participatory assessment and later during meetings in the area, farmers, artisans, and other community members noted that limited access to productive assets constrains their economic possibilities. When discussing assets, farmers generally focused on land and other physical assets such as agricultural equipment. Land holding is unequal in the Chimbo; Gini coefficients, a

Table 3. Household income sources and their distribution by subwatershed (SANREM baseline survey of households).

Income source	Alumbre		Illangama	
	Percent total household income from each source	Percent household income coming from this source for those with income source (percent households receiving income from source)	Percent total household income from each source	Percent household income coming from this source for those with income source (percent households receiving income from source)
Agricultural production	36.1	36.1 (100)	57.8	57.8 (100)
Livestock	6.8	16.4 (41.4)	15.1	17.9 (84.6)
Self-owned business	7.4	36.7 (20.1)	4.8	22.6 (21.4)
Off-farm agriculture wage	21.9	42.6 (51.5)	4.2	25.6 (16.2)
Off-farm wage	17.0	42.1 (40.2)	14.9	29.0 (51.3)
Migration	10.0	42.4 (23.7)	1.9	24.6 (7.7)
Transfers	0.8	20.5 (4.1)	1.3	9.2 (13.7)
Total	100.0		100.0	

Note: N = 286.

measure of inequality, for landownership, were 0.62 and 0.65 in the upper and lower watersheds, respectively. Gini coefficients for land holding in South America are generally in a range of 0.5 to 0.85.) Land access among small-scale farmers is somewhat more equal, with households in the upper Illangama watershed generally having less access (1.2 to 4.2 hectares interquartile range with a mean of 3.5 in Illangama compared with 1.4 to 6.4 with a mean of 5.8 in Alumbre) and lower-productivity lands. About 70% of all land in Bolivar Province is titled, but in our survey 84% of the land was titled, and 12% was rented and may or may not be titled. In Illangama, common management of community woodlands is frequent, and about 38% of households report having access to irrigation, compared with only 9% in Alumbre. Most households with access to irrigation noted that irrigation water was inadequate even when the distribution infrastructure was in place.

As noted, the poorest livelihood clusters in both watersheds have not been able to diversify into nonagricultural businesses, receive most of their wellbeing from meager on-farm earnings, and participate in daily labor markets. An econometric analysis of the determinants of entry into each livelihood using a multinomial logit model showed that location, access to markets, proximity to water sources, and basic human assets such as education, experience, and family structure all affect livelihood decisions (Andrade 2008). Access to assets such as irrigation and credit were also powerful determinants of livelihood choice. For example, credit access was associated with more frequent entry into market-linked livelihoods and the formation of nonfarm businesses. Model results were combined with our geographic information system to reflect the spatial spread of livelihoods and how this spread is affected by changes in policies. This combination is being used to help guide political decisions in the watershed as part of the adaptive watershed management program. See table 4.

Environmental Challenges

Farmers and other members of the community recognize that environmental degradation represents a major challenge to improved wellbeing. The primary environmental problems affecting both subwatersheds are water contamination from agrochemical runoff; loss of soil moisture storage capacity due to erosion and loss of soil organic matter; loss of soil fertility from erosion and lack of adequate fertilization; and loss of biodiversity reflected through a decline in populations of native animal and plant species. Human waste-related pollution of waterways (sewage, garbage) and sedimentation were also viewed as important, especially by women and children in the lower watershed, who collect water for drinking, cooking, washing clothes, and for animal consumption. Surveys and administrative data showed substantial evidence of health problems, particularly gastrointestinal infections, due to poor quality water. This information confirmed the perceptions of the women and children.

Land degradation and deforestation are recognized as serious problems by roughly 90% of the people who responded to our survey; and soil moisture-holding capacity and risk of drought by about 85% (a more common problem in Alumbre). Despite widespread recognition by farm families of the role of soil erosion in reducing agricultural productivity, fewer than 5% of respondents take actions to conserve soils, and many claim they are unaware of soil conservation practices. A similar discord between stated concerns for natural resource quality and use of conservation practices exists with regard to quality of the páramo—the high Andean plain. More than 80% of the farmers in Illangama state that the páramo is threatened by human activity, and respondents recognize the link between its degradation and water quantity and quality at lower elevations. However, only 31% of these same people refrain from using the páramo for productive activities; 61%, 6%, and 3% of farmers, respectively, use the fragile páramo for wood and firewood, cultivation, and pasture land.

Table 4. Agricultural lands and crops planted by subwatershed (SANREM baseline survey of households).

	Alumbre		Illangama	
	Percent of farmers planting	Percent of total area in ...	Percent of farmers planting	Percent of total area in ...
Leguminous (peas, beans, faba beans, chocho, lentils)	35	20	17	6
Grains (corn, wheat, barley, quinoa)	76	42	12	7
Grains and leguminous (corn/beans)	27	34	0	0
Roots (potatoes, mashua, melloco, oca)	5	1	100	84
Andean Fruits (tree tomato, blackberry)	7	3	0	0
Others (onions, sugarcane, carrots, tomatoes, sambo, squash)	2	0	6	2
Pasture	46	n.a.	95	n.a.

Note: N = 286.

Due to stated concerns about biodiversity, an assessment was conducted during the first project year by SANREM partner ECOCIENIA (Calles and Pena 2007). This assessment, which focused on animals (birds, mammals, amphibians) and plants (mainly tree species), identified a rich biodiversity. In particular, several endangered bird and mammal species and important reserves of native tree species are found in both watersheds. Amphibian populations are limited, and competition between induced exotics and native tree species threaten biodiversity. Fragmentation of remnant wooded areas threatens mammal and bird species. Follow-up research will investigate the relationship between fragmentation and viability, a research area identified through community meetings where results of the assessment were presented.

Research was designed with community input to address environmental issues and rectify the apparent conflict between human activities and attitudes with respect to the environment. Activities were prioritized during consultations with beneficiaries who recognize environmental concerns but are familiar with few alternatives to preserve the environment. Intensive engagement of stakeholders was required to build confidence that environmental quality and long-term income generation are not competing objectives, but the close focus on environmental quality (other than water quality) was a product of adaptive management. Sites were identified to monitor weather events and stream flows, analyses of soil nutrient and water-holding capacity were undertaken, and a protocol was established to measure water quality and aquatic biodiversity. Local youth were engaged in monitoring efforts, and close connections between the study team and stakeholders helped stimulate interest. Several study plots were established to analyze the relationship between field management practices and soil erosion; they were set up in a repeated block design to enable statistical comparisons. Local youth and undergraduate students monitored the experiments and collected runoff for measurement as needed. All these practices, products of the adaptive management process, build ownership by local decision makers in the research results and increase the likelihood that findings will be incorporated into actions.

Decision Making and Gender

Anecdotal evidence points toward gender-based biases in decision making. For example, INIAP reports that few women participate in training activities and community meetings, despite the fact that women in Bolivar are generally quite active in agriculture and other income-generating activities. Our survey data show that women are commonly excluded from participating in household decisions and are far less likely to participate in formal training than are men (table 5). Men are also more likely to market products and may, as a result, exercise economic power over women. Decisions about crop sales, chemical use, and household expenditures are predominantly made by men, although women in many households provide input into the decision process. In a similar vein, men are more likely to participate in meetings, elect authorities, and serve as authorities in community organizations. Because adaptive watershed management requires buy-in of stakeholders, particularly those making decisions, we needed to investigate the role of women in decision making and identify means of integrating them into the adaptive watershed process.

Gender roles are differentiated by watershed. Women in Illangama are more likely to haul water and firewood, participate in crop harvests, and care for livestock than women in Alumbre, suggesting that their participation in productive activities is greater. Women in Illangama, however, are much less likely to participate in household decision making such as chemical use on the farm, who participates in training, product sales, and the household budget. They are less engaged in marketing and unlikely to supply labor off the farm. While they are less likely than women from

Table 5. Participation in and responsibility for common activities by gender (%) (SANREM baseline survey of households).

Activity	Alumbre		Illangama	
	Women and men together	Women alone	Women and men together	Women alone
Carries water	15.9	73.2	13.0	83.3
Harvests crops	55.4	16.9	74.1	9.5
Cares for livestock	45.3	36.0	57.9	39.2
Sells products	11.8	29.0	21.2	12.1
Decides about				
Crop sales	19.9	19.9	25.5	13.6
Chemical use	6.6	15.2	0.0	12.8
General decisions	21.1	33.3	12.4	25.7
Expenditures	23.5	21.0	20.9	14.8
Who receives training	11.0	25.6	18.9	8.9
Participates in meetings	25.8	24.7	36.5	11.5
Elects authorities	28.1	25.0	47.9	8.2
Is a community authority	0.0	25.9	0.0	12.7

Note: N = 286.

the Alumbre watershed to serve as a community authority, they are equally likely to elect authorities and participate in meetings.

These observations, consistent with findings presented in table 2 about lower levels of education for women, paint a troubling picture of prospects for engaging women in participatory watershed management. Engaging women is important not only for equity but also to improve project efficiency and generate positive impacts. While we emphasize gender-based inequities, it is also important to note that a large minority of women are decision makers in relevant domains. Women make or participate in making general budgetary decisions in 54% of households in the Alumbre watershed and in 38% of households in the Illangama watershed. Women are heavily involved in decisions regarding crop sales and in marketing crops. Yet INIAP reports far lower levels of female participation in workshops regardless of the purpose. Special efforts have been designed to broaden participation: direct involvement of female professionals in the project, increased funding for female students, and aggressive efforts to stimulate participation by women in project activities.

Constraints to Livelihood Diversification

As we engaged farmers and other villagers in discussions, they quickly identified potential livelihood alternatives and asked for additional research to be conducted. Research was conducted on appropriate crop varieties, recommendations for fertilization, soil conservation measures, integrated pest management, and other areas. Existing crops were included in the research program, with a specific focus on alternative crops in the lower watershed. Stakeholders participated in all field-level research. Economic and social research also identified off-farm alternatives to raise

incomes and increase local value added. Many activities are directly linked to agricultural production, so multipliers are likely to be large.

Discussions during the participatory assessment indicated that market access was an obstacle to increased incomes and retention of value added, particularly in the dairy market. Small-scale milk production is widespread in Illangama, and while most output is consumed in the household, sales of surplus milk and cheese in Guaranda and other markets is common. Producers rely on intermediaries, and information indicates that exercise of market power by intermediaries was slowing income growth in this market.

SANREM undertook a comprehensive analysis of the dairy marketing chain and identified factors constraining growth in the dairy market and livelihood diversification. Growth in dairy is constrained by low productivity; spatial dispersion, which increases costs of transport; and rudimentary cheese production facilities, which lead to waste and lower-quality products. These constraints help to limit possibilities for increased competition in transport and markets because volumes are low and, due to the nature of the product, margins are slim. The area around Illangama is served by a small number of cheese intermediaries who live in the communities of Patococha and Cuatro Esquinas, most of whom have a long family history in the business. Growth in dairy is also constrained by marketing institutions. Cost differentials between prices paid to producers and those received in the Guaranda market were high, but costs of transport are high and technologies are relatively primitive.

Adaptive Management Process and Transdisciplinary Articulation

Previous engagement with stakeholders is an important consideration in building confidence in the process. While the INIAP team had credibility in the domain of agricultural technology, this credibility was confined to the Illangama watershed and did not extend to areas of watershed modeling, environmental issues, and governance. Careful steps were taken to familiarize regional and local authorities with the research team and gradually build ownership in the process. The team also confronted an extremely narrow focus on the part of institutions and unwillingness to view problems as being interdependent. The transdisciplinary and trans-scale nature of the adaptive watershed management process contributed to problems of language and conflicts across decision domains that were difficult to overcome.

Parallel to establishment of the participatory research program, the team worked with provincial governments, which have substantial interest in the watershed approach. A key challenge, however, was to devolve this interest to localities: Changes in land uses, the main means by which environmental conditions can improve, depend on local actions. Beyond efforts at education and use of moral suasion, decisions made at the provincial level have only minimal impacts on land use at local levels. Further, each subwatershed comprises a number of local jurisdictions, and cross-locality cooperation has historically been minimal. Building mutual respect for joint interests and other bases for collaborative decision making became a focus.

The watershed modeling effort requires data of limited availability, including information on land use, soil properties, rainfall and climate, and stream flows. Data collection was designed to maximize community participation, and continued feedback among community members and the research team induces modifications. Less reliance on SWAT is one product of these interactions. Community data collection induced stakeholder interest and stimulated curiosity about data use. This interest further builds engagement in technical modeling.

A major goal is to integrate social sciences with engineering and agronomic research to strengthen the adaptive watershed management process. The watershed model requires informa-

tion on the spatial distribution of land uses before and after a policy change or other intervention, and we used integrated transdisciplinary methods to “simulate” these changes in land use. This approach represents an important departure from previous efforts at adaptive watershed management. For instance, past efforts relied on deterministic and rather highly aggregated programming models to simulate household land-use decisions (Dario-Estrada and Posner 1999). These models calculate a maximized household objective function such as profits from use of household resources, subject to resource constraints such as the amount of land or labor available to the household. Modeling household decisions in such a fashion abstracts from social and cultural forces, the spatial distribution of transportation infrastructure, other factors affecting returns to specific activities in different locations, and household responses to risks, among others.

Our use of mixed and transparent research methods allows us to better understand the factors affecting land-use patterns and how policy change affects these patterns. This process requires close collaboration of researchers from multiple disciplines and also affords local farmers and other community members’ opportunities to evaluate and suggest improvements to our land-use management plan. The qualitative inputs rely heavily on local knowledge of conditions in the watersheds, information on topography and land-use patterns, history of production practices and producer groups, and suitability of lands for different uses. We are also able to incorporate some non-quantifiable determinants of livelihoods and land use, such as the role of family history and experience, the importance of access to markets, and how social networks contribute to livelihood diversification.

The team also found, at the local level compared with the regional level, limited capacity to use project-related information, fewer resources to focus on efforts to influence land-use decisions, but, paradoxically, more interest in research to enhance income generation and improve livelihoods. This interest is a product of the dependency of watershed households on land-based incomes, some experience with farmer field days and other training events, and the immediacy of economic and environmental problems felt by the population. Limited local capacity requires the research team, particularly those presenting information from conceptual and analytical models, to tailor their interactions to generate interest and stimulate feedback from stakeholders. Capacity was particularly a problem in the lower watershed, where familiarity with INIAP was limited and decision making was less a part of community custom. In contrast to the lower watershed, in Illangama a history of interaction with INIAP led to ownership of research findings and incorporation of many of them into the watershed management plan.

Discussion

The watershed approach to natural resource management has been tried in several settings in the South American highlands with varying degrees of success. Watershed analyses require extensive digitized data and tools that are of limited availability in high mountain areas, and watershed management often requires the cooperation of competing and overlapping local and regional governments. Ethnic and social differences may inhibit participation, and stakeholder buy-in is a critical determinant of success. While watershed approaches to environmental problem solving show promise, a number of obstacles must be overcome during their implementation.

Engagement in research facilitates adaptive management in two ways: It enhances the quality of and builds confidence in research results, and it allows adjustments to research as findings are evaluated with local farmers and community members. For example, early participation in research prioritization induced us to devote more resources to research on soil conservation

practices within existing crops; we had planned to look almost exclusively at new opportunities. Engagement also helped convince local authorities that the adaptive management process would require them to develop new capacities. In the past, they had thought of watershed management as focused exclusively on creation of land-use plans, but they now understand that, because of linkages between land use and economic activities, effective management would require them to become engaged in market regulation, in particular, the dairy market. Effective management requires a transfunctional approach to decision making in government.

Our model depends critically on participation of stakeholders as a means of gaining acceptance of the results and as a means of making the results more reflective of local realities. A track record of working in the upper Illangama watershed combined with the strong tradition of community decision making in the highly indigenous area enhanced engagement and ensured success. Early on, participation in assessment and goal formulation exercises led to substantial modifications of the research program. These changes helped make the research more relevant to stakeholder needs. While stakeholders in Illangama showed skepticism about many of the technical details, they were receptive and willing to learn. They eventually assumed ownership, which facilitated quick uptake of recommendations, creation of a community watershed plan, and active engagement in monitoring. Less familiarity with the research team and a more heterogeneous social structure slowed progress in Alumbre and required far more efforts to obtain stakeholder buy-in.

In both areas, economic, social, and geographic conditions limited livelihood options before engagement. Low incomes bounded the “economic space” necessary to permit investments in resource-conserving technologies, and knowledge about environmentally compatible alternatives was not widespread. Our research has created options and demonstrated to decision makers that environmental enhancement does not always imply short-term costs, for we helped to identify means of improving productivity, diversifying livelihoods, and introducing strategies to raise incomes while protecting the natural environment.

Social and physical heterogeneity in the watersheds makes the area a good test case for adaptive watershed management. This effort integrates several forms of social analysis with biophysical modeling to create a more nuanced picture of the relationships among policy and other interventions, land-use patterns, and environmental consequences. The eclectic approach also stimulates stakeholder engagement throughout the process, which increases the likelihood that recommendations are adopted.

Several benefits are apparent in approaching management from a watershed perspective. The watershed is a natural unit whose residents express a shared vision. Water quality and quantity, biodiversity, and other watershed-scale outcomes depend on joint decisions of residents. The effects of one’s actions on others are immediately evident when a cross-scale perspective is introduced. This awareness stimulates uptake of recommendations.

Appendix: Livelihood Clusters in the Two Watersheds

Cluster analysis was used to uncover nine livelihood clusters across the two watersheds. Important differences in livelihood strategies were noted across the watershed.

Alumbre Clusters

Cluster 1: Agricultural activities and remittances dependent

This cluster has a relatively low level of household income, \$2,590 a year, with most of it coming from agriculture but an important share from off-farm wages and migration. This group migrates seasonally to the coastal region to work during harvest. Households own an average of three head of cattle, which provide no measureable income; residents consume the milk products and use the animals to cope with risk. They mainly plant grains and legumes on an average of 5.9 hectares.

Cluster 2: Off-farm agricultural wage dependent

This cluster has the lowest income, \$1,450 a year, even though the farm area is close to the sample average (4.5 hectares). Residents' main income source is off-farm agricultural wages, and they spend more time working on other farms than on their own. They are sensitive to risky events, for their main source of income is linked to farming, and they have few assets to manage this risk. They primarily grow grains and legumes.

Cluster 3: Own-business dependent with more land

This cluster has the highest income in the region, \$8,460 a year, and most of it comes from resident-owned businesses. Agriculture and off-farm activities are secondary sources. Residents hold small amounts of cattle as a resource in case of emergencies. They own the largest amounts of land (10.2 hectares on average) in the watershed.

Cluster 4: Agricultural activities and social-help dependent

This cluster is similar to Cluster 2 but with lower levels of income. This group diversifies its activities among several alternatives. Members depend on agricultural income, off-farm agricultural wage, and social help, each representing similar shares of total income. This group also participates in off-farm wage and migration, but income amounts from these sources are minor. Residents own very small extensions of land and few cattle.

Illangama Clusters

Cluster 1: Agriculture and off-farm wage dependent

Income is near the sample average of \$3,520 a year. The main source of income is agriculture followed by off-farm wages and livestock income. This group has more livestock (eight head per household) than the sample average and produces raw cheese with traditional technology. Livestock activities account for a relatively low share of income but provide a constant source through the year. Average farms in this cluster are 3.9 hectares, and they produce pasture, potatoes, and minor crops.

Cluster 2: Strongly dependent on agriculture

This cluster has the lowest income in the upper watershed. Members depend on agricultural activities, off-farm agricultural wages, and very small shares of livestock income. Members of this group are sensitive to risky events because their incomes are so closely linked to agriculture. Households own an average of four head of cattle, which provide a modest but regular source of income. Farms in this cluster are small (1.8 hectares), and they are planted mainly in potatoes.

Cluster 3: Own-business dependent with less land

This group has the highest income in the watershed, about \$8,650 per year. Half their income is from their own businesses, with farming and livestock activities as secondary sources. On average, households raise 11 head of cattle, producing raw cheese sold mainly to intermediaries. Average land holdings are 5.6 hectares, used for pasture and to grow potatoes and some legumes.

Cluster 4: Agriculture and migration dependent

This group is relatively poor, with an average income of \$2,380 a year. Sources of income are agricultural activities and migration. Members migrate seasonally to Quito and other Andean cities. They reinvest migration income to grow potatoes and other minor crops. Migration represents almost half their income. They own small numbers of cattle and have extremely small land holdings (1.3 hectares), renting most of their cropland. They grow mainly potatoes.

Cluster 5: Agriculture dependent

This cluster has relatively low income, \$2,660 a year, and depends mainly on agriculture (64%). Livestock, off-farm wages, and social help are secondary sources of income. Households own an average of four head of cattle and about 2.4 hectares. On these relatively small lands, they grow pasture and potatoes.

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