EXPLORATIONS OF PARTICIPATORY GIS IN THE PERUVIAN ANDES

by

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ABSTRACT

A community-based natural resource management project in Peru utilized GIS in its attempt to "socialize" information for the rural inhabitants of three semi-arid Andean watersheds. Named *Procesos y Productos*, the two-year pilot project provided funding and technical assistance to three local non-governmental organizations with no previous GIS experience. The NGOs organized watershed stakeholders to inventory natural resources, identify development priorities, and create proposals for potential external investors. This thesis study examines the impacts and impediments of GIS in each of these three cases. Analysis is based upon project reports, interviews, and direct observations by a graduate student working as a consultant to the NGOs.

In this project, local farmers used aerial photographs and GPS to inventory resources at the village level, and NGOs used existing datasets to produce intervention maps at the watershed level. Stakeholder committees were organized at both the village and watershed level to define mapping themes. GIS products sparked participant interest in the project and helped both the NGOs and committees to set development priorities. At the same time, data constraints, barriers to participation, and a lack of external assistance limited the depth of GIS impacts. As these watersheds and their stakeholders represent many mainstream physical, social, and institutional challenges, this project provides a useful case study for first-time applications of GIS to community-based resource management in a lesser-developed country.

INTRODUCTION

Strategies for rural development and resource management worldwide, and particularly in the Americas, have been influenced in recent years by two significant political trends: a slow but significant shift towards decentralization of state government, and increased efforts to democratize local politics. Decentralization allows sub-national authorities the freedom and resources to tailor development actions to local needs, and democratization gives more decision-making power to the citizens most affected by development policy (OAS 2001). As a result, natural resource development efforts are shifting significantly away from high capital, technically prescribed projects, and towards more human-scale, interactive *processes* emphasizing adaptive management and community participation.

At the same time, the world is experiencing an information and communications revolution, facilitated by rapid advances in digital data processing and multi-media technologies. The Internet is, of course, a major component. However, natural resource management requires geographic analysis of spatially explicit data – a process undertaken through the technology of Geographic Information Systems (GIS).

Like the Internet, the components of GIS by themselves are simply tools. While increasingly user-friendly, they are usually managed by specialists or consultants. If GIS is to be applied within the before-mentioned framework of localized information management and decision-making, the technology must be transferred – at least partially – to local professionals. Further dissemination of GIS tools or products to the public at large can have a democratizing influence and provide a new means to communicate stakeholders' knowledge and concerns. Such efforts to deliver georeferenced data and spatial analysis tools to the local level can be described as "participatory" GIS.

Making GIS participatory in this way presents many challenges, particularly in lesser-developed countries. Applications to natural resource management at the local level must overcome the scarcity of quality spatial datasets, limited experience of managers of the technology, and the need to develop the necessary social processes of participatory development. Case studies offer a means to examine the impediments to participatory GIS and its impact for both communities and institutions.

This thesis study examines the use of GIS technologies and public participation methodologies to promote community-based natural resource management as part of a case study in the Peruvian Andes. The setting is a pilot project for natural resources planning in three small mountain watersheds. Three local NGOs combined methods of Participatory Rural Appraisal (PRA) with tools of GIS to facilitate collective natural resources management by watershed inhabitants. Stakeholders prioritized development goals at both the village and watershed scale, and with GIS attempted to generate spatial products that quantify resource potential and influence development decisions.

The project, named "*Procesos y Productos*", was financed for two years by the Ford Foundation and administered through the International Potato Center in Peru. It differs from many development efforts in that, as opposed to responding to an acute problem, here stakeholders were encouraged to address longer-term resource issues of their choice. No funding was promised for development projects that are proposed; instead, stakeholder organization and GIS maps products were anticipated to help earn funding from elsewhere. A simple methodological guide, limited GIS training, and occasional support was provided, but for the most part NGOs are expected to create their own geospatial products.

Chapter I reviews a collection of recent literature on participatory GIS theory and applications. Chapter II presents the GIS methods of the project and examines impediments to GIS applications. Chapter III introduces methods of social organization in this project and examines how outcomes were influenced by the introduction of GIS. A concluding chapter reviews results and offers recommendations for future projects operating under similar circumstances.

CHAPTER I: Literature Review

GIS and public participation in natural resource management

INTRODUCTION

A new and rapidly growing collection of literature proposes that the careful integration of GIS into community-based natural resource management strategies has a potential to enhance outcomes for both the targeted populations and development actors alike. Research, however, highlights multiple factors that inhibit successful adoption of GIS by both communities and institutions, and projects often demonstrate only modest impacts of GIS on stakeholders. In this review of participatory GIS literature, we examine the application of GIS to community-based resource management in the developing world by exploring some commonly raised theoretical concerns and reviewing the results of several recent case studies.

The chapter begins with an introduction to the concept of participatory GIS and its potential benefits in diverse settings – particularly in socially and economically marginalized regions of the developing world. A theoretical review follows outlining various impediments to participatory GIS in these regions, and possible approaches to overcoming them. Finally, further research needs illustrated by the *Procesos y Productos* project are outlined. Observations from case studies are cited throughout the review, as empirical evidence offers the most effective means to evaluate this subject.

GIS in participatory resource management

With GIS technology now highly advanced and increasingly standardized, many natural resource management professionals are willing and able to adopt it in their respective fields. Yet a newer concept of GIS is being developed in recent years, in which products are created not only by practitioners of the technology, but also by the populations who have a stake in the issues these products represent. This concept – that by participating in the GIS *process*, stakeholders can greatly contribute to the success of resource management strategies – is rapidly gaining recognition among GIS and development experts (Abbot, Chambers et al. 1998; Craig, Harris et al. 2002; Kyem 2002a).

Definitions for this more socially integrated practice of GIS vary, but generally include the words "community" or "participation". Public Participation GIS (PPGIS) is a title first conceptualized in 1996 by the US National Center for Geographic Information Analysis as a means to "facilitate a more inclusive spatial decision-making processes….constructed with community participation and incorporating non-conventional knowledge types" (NCGIA 1996). PPGIS is now the topic of multiple publications and an annual conference (URISA 2002). It is defined as a combination of a technology and a social movement (Craig, Harris et al. 2002), incorporating not only hardware and software, but a process in which people and data are integral components as well (Jordan 2002).

Others provide more cautious definitions. Abbot and Cambers et al (1998) offers the term "GIS in participatory research" to distinguish that GIS is simply a tool to be applied to preexisting forms of social investigation. "Community-integrated GIS" (Harris and Weiner 2002) is another term indicating a procedure that is agency-driven, but values community perspectives of their landscape. Regardless of the chosen title, proponents agree that success requires both an external component of GIS expertise and conventional data, and the internal knowledge and perspectives of the target population. This combination of "local" and "expert" knowledge (Harris and Weiner 2002), or "indigenous knowledge" and "Western" technology (Laituri 2002), is commonly referred to in the referenced literature as *participatory GIS*.

Examples of Participatory GIS

To better articulate the concept of participatory GIS just introduced, we review two examples of its application – in both a data-rich and a data-poor setting. The first is the community of Verona, a rapidly urbanizing area in Dane County in the state of Wisconsin, USA. Ventura and Niemann et al. (2002) are studying a pilot project that uses geospatial information technologies to gain citizen input regarding future growth of the community. The project applies GIS software and products to public forums, publications, and an interactive website to solicit public input for preferred land use planning strategies. With ample funding, high citizen interest, and public understanding of the technology, project planners have succeeded in obtaining evidence of the future growth patterns preferred by developers, farmers, environmentalists, and other demographic groups in the community. Citizens demonstrated GIS-literacy in their comprehension of spatial analysis and in their preference for complex multi-layer map products. At the same time, they benefited by learning more about

development issues in their community, and by making their viewpoints known to planners (Ventura, Niemann et al. 2002).

In the much different setting of Mpumalanga province, South Africa, Harris and Weiner (2002) used GIS in community workshops to facilitate participant mapping of land use potential, natural resource access, and the locations of forced removals of blacks by the past apartheid government. Communities provided more detailed knowledge of land use potential than is available in the limited governmental database, identifying small zones of higher productivity within the defined "lower" productivity regions. Such data improvements could potentially influence the implementation of government land reform. In the case of forced removal, the participatory mapping exercise created a local data product that simply did not exist in the expert government or private GIS databases. The exercises also revealed stark differences in perceptions between blacks and whites regarding historical relocation and current access to natural resources. Many blacks that had not previously been asked to share their perceptions on the politics of local natural resource access welcomed the exercises. Conversely, white commercial farm owners were much less willing to discuss power relationships in a spatial context (Harris and Weiner 2002).

The initial success of each of these cases demonstrates a potential for participatory GIS in both data-rich and data-compromised environments. Despite a disparity in resources, GIS helped to generate citizen awareness and create improved information products in each project. Further study is now needed to determine how GIS ultimately influenced outcomes. The project in Verona is now evaluating whether each interest group ultimately feels that the use of GIS in the planning process has worked to their advantage (Ventura, Niemann et al. 2002). Likewise, the study in Mpumalanga province would benefit from an examination of the social impacts that may occur now that GIS has helped articulate past injustices and current conflicts in land claims.

Comparing these two studies also illustrates unique challenges to participatory GIS outside a developed country such as the United States. The Internet, for example, was a key tool in Verona for facilitating citizen discourse, voting, and GIS access (Ventura, Niemann et al. 2002). An Internet-based GIS was also established for the project in Mpumalanga province, but access to this tool by the general population is quite limited (Harris and Weiner 2002). In general, social facilitation and technical support are particularly necessary in regions where infrastructure is limited, and the daily struggle of the population to meet basic needs limits their ability to engage in longer-term planning exercises (Harris and Weiner 2002).

Growing applications of participatory GIS in the developing world

Reports of participatory GIS success (Craig, Harris et al. 2002; Sieber 2002) are most common in countries such as the US, which enjoy advantages of modern computer resources, existing political empowerment, and highly educated citizens. However, recent technological and political trends are improving the prospects for success of participatory GIS applications elsewhere in the world.

The incredible advances made in computer technology in recent years have indeed been slower to reach the developing world (Craig, Harris et al. 2002). However, the lower cost and increased performance of computers is making GIS more accessible to many small communities and organizations (Kyem 2002a). There remains a great need to further improve the performance and economy of GIS tools for users worldwide; but in making GIS participatory, the issues of technical performance have become secondary to issues of participation and social empowerment (Jordan 2002).

Since the 1992 United Nations Earth Summit, nearly all major development organizations are promoting community participation in their efforts (Rhoades 1998). Development philosophy now stresses the scientific validity of local knowledge and the need to include local input in development planning (Chambers 1994; Hinchcliffe, Thompson et al. 1999). The International Agricultural Research Centers (IARCs), for example, have evolved in their definition of participatory research from one in which farmers simply provide labor and feedback to a more collaborative and adaptive framework in which farmers share knowledge and ideas both among themselves and with outside researchers (Fujisaka 1994). Participatory Rural Appraisal (PRA) is a principle tool in this strategy (Freudenberger 1994), and many practitioners recognize a potential for GIS to enhance PRA methodologies (Abbot, Chambers et al. 1998; Mbile 2002).

Development policy is evolving incrementally away from centralized control of resource management and budget allocation (OAS 2001). Colombia and Peru, for example, now allocate substantial federal funds to the discretion of regional governments. The new constitution of Thailand delegates natural resource management powers to each *Tambon*, or sub-district (Hoare, Maneeratana et al. 2001). Worldwide, the IARCs have transferred much of their applied research responsibilities to smaller national research centers (Fujisaka 1994). International donors and development agencies also look increasingly towards regional government and especially local NGOs to provide innovative solutions to chronic resource management problems (Ashby, Sanz et al. 1999; Bebbington 1999). These smaller institutions must therefore balance the macro-level priorities of their donors, and the micro-level demands of the rural population they were created to serve (Pearce 1997). Hence, the need for communication tools such as GIS to link top-down and bottom-up strategies.

In this more decentralized and democratized setting, GIS is seen as a practical tool for spatially linking national databases with local issues to promote cooperation, facilitate planning, and earn funding for prioritized projects (Ashby, Sanz et al. 1999). Given the changes in technology, policy, and development philosophy described above, the potential for success for participatory GIS in the development world is growing.

Advantages of participatory GIS

Participatory GIS in natural resource management can have a constructive impact at multiple political levels. At the community level, visualization through maps has proven effective in including input from otherwise marginalized stakeholders. Mapping of communal forest resources over aerial photographs by Forest User Groups (FUGs) in Nepal's Parbat district permitted greater participation of traditionally underrepresented groups – particularly women

and the non-literate (Mather 2000). Development projects in northern Thailand have helped villagers create three-dimensional topographic models that speak a "common language" for land use evaluation and planning among hill tribes (Srimongkontip 2000; Hoare, Maneeratana et al. 2001; Puginier 2002). Herdspeople of the highland community Aarsal in Lebanon contributed their knowledge of soil, climate, and vegetation for input into a GIS land capability map that defines threats by the expansion of orchards into marginal lands (Zurayk, el-Awar et al. 2001).

Beyond simply collecting single layers of information, analysis of multiple data sets in GIS can also assist communities in decision-making regarding the allocation of resources. In the community of Kofiase in southern Ghana, a GIS map of forest suitability helped address conflicts between local logging and preservation interests by integrating decision criteria from both groups (Kyem 2002b). The community of Nuevo San Juan Parangaricutiro in central Mexico coupled national topographic and soil data with local knowledge to develop a forest management plan (Bocco, Rosete et al. 2001). In these cases, substantial external input in the form of GIS training or analysis was necessary. Given this assistance, however, communities that are organized can use GIS as a tool to help them reach consensus and articulate their concerns in an effective, geographical context (Shultz, Saenz et al. 1998).

In linking communities to institutions, GIS can translate spatially explicit, locally-derived information into a form more readily recognized outside the community (Mohamed and Ventura 2000). The Nuevo San Juan forest plan, for example, earned certification by the Forest Stewardship Council (Bocco, Rosete et al. 2001). In Mae Hong Son province of

Thailand, the natural resource mapping and classification served as a "mediator" between farmers and government agencies and allowed for the quantification of land areas according to potential for five types of farming and forestry practices (Puginier 2002). The maps of Nepali FUGs mentioned earlier provided the District Forest Office with authentic, georeferenced information at lower cost and greater speed than traditional survey methods (Mather 2000). Similar benefits were indicated in exercises with FUGs elsewhere in Nepal, also allowing communities greater negotiation power with forest officials (Jordan 2002).

Additionally, the external actors facilitating participatory GIS projects stand to gain through the process of information exchange with communities and between institutions. Spatially based information obtained from local populations can help donors better direct project resources (Craig, Harris et al. 2002). For example, researchers obtained farm size, ownership, and production data from farmers in the Pacuare watershed of Costa Rica with the use of aerial photos, topographic and cadastral maps, and GPS. By combining these data in GIS with previous studies on land suitability, they identified relationships between farm size and land degradation that will help direct future soil conservation projects, as well as monitor long-term progress (Shultz, Saenz et al. 1998).

These examples demonstrate a potential of participatory GIS to articulate knowledge and concerns of the less privileged, and to advance their interests to the agenda of regional and national organizations (Kyem 2002a). Kyem emphasizes, however, that despite good intentions, the celebrated goals of participatory GIS are rarely fully attained in practice. There remain many important technical, social, and institutional challenges.

IMPEDIMENTS TO IMPLEMENTATION

Successful implementation of participatory GIS in marginalized communities requires not just the adoption of the technology, but also the identification of an appropriate geographic scale, the acquisition of quality spatial data, the inclusion of local input, and the protection of stakeholders' interests. Researchers provide a wealth of theoretical debate on these issues, and some recommended courses of action to address them.

Accessing quality spatial data

While GIS itself becomes less an expert system and more a common office tool, access to useful data is often a more limiting factor than is the operation of GIS tools themselves (Sieber 2002). Natural resource information can be divided into two "tiers" of geographic scale: landscape-level variables such as climate, topography, or soils; and community-specific information such as hunting grounds, income sources, or irrigation rights (Laituri 2002). Data for the former are often publicly available and systematic in format. For the latter, they are generally unique to the local population and require Participatory Rural Appraisal (PRA) or related methods for acquisition. Each presents its own challenges in acquisition, integration, and quality control of data.

Biophysical data sets of topography, climate, soils, and vegetation are among the most commonly used secondary data sets for natural resource management. Although straightforward in theory, in less-developed countries the data are often inadequate, practitioners are inexperienced, and computer resources are limited. In the Negril watershed in Jamaica, for example, many national data sets are unavailable in digital format, improperly photocopied, out of date, or prohibitively expensive (Rybaczuk 2001). Current land cover information can usually be derived from satellite imagery, but often the only available soils and topographic data is out of date or at scales as coarse as 1:250,000. Furthermore, while several studies demonstrate success in digitally analyzing existing biophysical data sets, few outline procedures for data acquisition and integration. Though often assumed as routine, such preliminary steps can inhibit the progress of first-time GIS applications.

Socio-economic data is not commonly georeferenced with accuracy. National census tracks are usually tallied within municipalities or other political districts and do not necessarily correspond to watershed or agro-ecological boundaries (Shultz, Saenz et al. 1998). Household data is available only through specialized studies, and must still be linked with household locations in order to map poverty or other variables. In the Carchi province of Ecuador, rural cadastral maps ranking poverty by individual household parcels have been used to create watershed-level poverty maps (Arellano, Poats et al. 2000), but such data are not necessarily available elsewhere. As a result, many studies focus on biophysical variables while citing a remaining need to incorporate social data (Shultz, Saenz et al. 1998; Zurayk, el-Awar et al. 2001).

Secondary data can be expensive to acquire and time consuming to integrate, particularly when not performed systematically. Having such operations managed under a centralized infrastructure can relieve small organizations from individually performing these tasks (Onsrud and Rushton 1995). Such consolidation of data management, though perhaps in conflict with recent trends towards decentralization, could produce more reliable and standardized data sets complete with *metadata*, which describe dataset parameters such as source, scale, projection, and attributes (Alspach 1999). An example of this is a CD-ROM of mostly biophysical geographic information covering all of Honduras, created by the Hillsides Program of the International Center for Tropical Agriculture (CIAT) (Ashby, Sanz et al. 1999).

In contrast, primary data collection generally remains the responsibility of the local organizations that work closest with stakeholders. Aerial photographs provide a means for stakeholders to directly measure spatial features such as forest boundaries, irrigation networks, or land use, while simultaneously engaging a greater number of community members in dialogue. Known as participatory photo-mapping, this strategy has been successful in mapping general land use and common property boundaries (Mather 2000; Jordan 2002; Kyem 2002b). Airphoto analysis requires that photos be acquired, digitized, and orthorectified. Though well tested from a technical standpoint, this process is quite challenging to local development organizations and is seldom addressed in the participatory GIS literature.

Selecting the appropriate scale

In a given project, the scale of the spatial data used will influence the form and degree of public participation (Rybaczuk 2001). Ideally all stakeholders will be represented, but GIS offers challenges in linking the concerns and knowledge of farmers with those of watershed planners.

The gap between problem solving at the community scale versus the landscape scale is demonstrated by CIAT's Hillsides Project in the 7000 ha Cabuyal watershed in Colombia. A GIS study of hydrology was used by the Cabuyal watershed association, drawing credit for its management of water resource conflicts between upper and mid watershed inhabitants (Ashby, Sanz et al. 1999). Yet a survey indicates that representation in the association had been biased towards specific interest groups and a majority of watershed inhabitants were unaware that the association existed (Ravnborg and Guerrero 1998). Communities objected to some watershed planning actions, such as the conversion of land they farmed into vegetated buffers to protect springs. CIAT therefore shifted attention to a finer scale, first organizing inhabitants of sub-watersheds no larger than 200 hectares to address local issues before proposing projects at the watershed level (Ravnborg and Guerrero 1998).

In this example, GIS was used to delineate the sub-watersheds boundaries in which to direct community organizing, but it has not been applied to integrate community needs to the watershed scale. Indeed, few participatory GIS studies achieve scale integration. Studies that focus on individual communities or user groups (Mather 2000; Hoare, Maneeratana et al.

2001; Jordan 2002; Kyem 2002b) have used aerial photography or topography from 1:10,000 scale to 1:50,000 scale to supplement highly participatory surveys, sketches, and group activities. Studies intended to map entire watersheds (Shultz, Saenz et al. 1998; Ashby, Sanz et al. 1999) use existing spatial data generally from 1:50,000 scale to 1:200,000 scale, involving few if any watershed representatives for interpretation or planning. Linking the public participation benefits of large-scale mapping with the wide spatial coverage of small-scale mapping is therefore a remaining challenge of participatory GIS.

While mixing scales in GIS in technically possible, it is not necessarily recommended. Bitter (1999), for example, warns against combining data sets of 1:10,000 and 1:100,000 scales. The resource access study in Mpumalanga used land-cover data ranging from 1:10,000 to 1:250,000 scale, but does not explain the process or address issues of scale integration (Harris and Weiner 2002). Either detailed data will be rendered insignificant at the smaller-scale, or coarse data will under-represent variability at a larger-scale.

"Scaling-up" organizationally from the village level to the watershed level has proven to be a successful strategy for community-based resource management efforts, particularly in northern Thailand (Srimongkontip 2000). Success in spatial analysis has been slower, but such efforts can begin with individual villages using photo-mapping strategies to capture local input and then reference this to secondary data at the watershed level. This spatial codification of local knowledge, however, presents its own challenges.

Codifying local knowledge for use in GIS

Community-based natural resource management must pursue the similarities between traditional and modern scientific knowledge while also respecting their differences. This challenge is well illustrated in the study of soils. Existing soil surveys can potentially be improved with site-specific soil knowledge of local farmers. In the mountains of Lebanon, Zurayk et al. (2001) found, however, that local knowledge of soil types did not conform to finite polygons, making it difficult to integrate with Lebanon national soil surveys in GIS. An interdisciplinary study of indigenous soil knowledge in the Colca valley of Peru found that with the exception of some similarity in soil texture, the soil lexicon of this region does not generally match the rigid categories of Western taxonomy (Sandor and Furbee 1996).

This uniqueness of indigenous natural resource knowledge also offers potential advantages. It is known that farmers' understanding of soils is in many cases based on production and conservation impacts, while the commonly used international soil classification systems derive their taxonomy from soil genesis. In the highlands of Bolivia's Cochabamba department, for example, local classification systems recognize degrees of land degradation and could therefore serve as an effective means for monitoring of soil erosion (Zimmerer 1994).

The challenge for GIS analysis is to translate this knowledge into a spatially georeferenced format. As an alternative to direct measurement, social and biophysical indicators offer a potential means to gain the local knowledge of the environment. Zurayk (2001) acquired

farmer knowledge of frost and snow frequency and indicator plant species to derive climate data where no meteorological measuring stations exist. Socio-economic indicators are equally important as biophysical indicators, yet fewer cases are cited of their successful implementation in participatory GIS studies.

Once obtained, local input must be considered in the context of the social and political environment. For example, in participatory exercises with three-dimensional topographic models, hill tribes in Thailand deliberately misrepresented the extent of their forest use under a concern that the information would lead to confiscation of their land by the state forestry department (Puginier 2002).

Furthermore, there remain many types of local knowledge that simply cannot be represented spatially (Harris and Weiner 2002; Zimmerer 2002). For example, much of the information obtained by Harris and Weiner (2002) in Mpumalanga province of South Africa is in the form of oral histories, and impossible to integrate with GIS. Salas (1994) found that indigenous farmers in highland Peru may describe potato varieties using myths and metaphors that become ambiguous under scientific classification. Multi-media has been proposed as a means to incorporate stories, songs, or photographs into a GIS database (NCGIA 1996; Craig, Harris et al. 2002; Harris and Weiner 2002; Jordan 2002); yet these methods usually depend on web or electronic technologies that are not available to most indigenous people.

Finally, it is important to emphasize that local knowledge cannot be considered as homogenous, but is instead socially differentiated among stakeholders from varied ethnic groups or socioeconomic settings. By separating stakeholders into groups of men, women, and village leaders in Mpumalanga province, Harris and Weiner (2002) were better able to capture specific knowledge. Understanding not only actions but also motives of all interest groups requires open-ended questions, open-ended expectations, and a diversity of data-gathering methods such as those available through PRA practices (Freudenberger 1994).

Limitations to participation and empowerment

Many researchers propose that GIS products can get a community or group "on the map", legitimizing their solicitations for public services or infrastructure (Abbot, Chambers et al. 1998) and enabling a breakthrough of community concerns to regional or national attention (Aitken 2002). They also agree that GIS without participation can restrict stakeholders' power of influence by separating the planning process from the affected people (Jordan 2002). Kyem (2002a) poses an important question, however, of whether stakeholder participation automatically translates into their true empowerment.

Within a community, those who embrace spatial data and GIS jargon are in a position to monopolize the technology to their own advantage (Laituri 2002), thereby gaining disproportionate influence over resulting GIS products. Also, the filtering of external spatial information through foreign GIS experts, even with the best of intentions, can obscure its meaning to participants (Kyem 2002a). Furthermore, once the information is taken away

from its originators, participants are dependent upon outsiders to represent them accurately (Jordan 2002). Once digitized, control of information can be difficult, and communities put themselves at risk of manipulation by their own government or other interests (Mohamed and Ventura 2000).

A strategy for limiting these potentially negative effects is to intentionally omit some details in the data (Peluso 1995). To protect communities from external interests, an economic development project in Northland, New Zealand mapped culturally sensitive sites within buffer zones such that their exact locations could not be identified on maps. Now developers must consult with representative village elders before proposing any project inside the buffer zones (Laituri 2002). Alcorn (Alcorn 2000) proposes mapping only communal boundaries to resource access, thus avoiding internal conflicts that may result from public disclosure of individual ownership or access boundaries. This strategy has proven to be effective for communally managed forest resources, as seen in Nepal (Jordan 2002).

Because GIS remains an expert tool and an expensive endeavor, its application can reinforce top-down development planning (Abbot, Chambers et al. 1998). In general, frequent opportunities for community feedback regarding externally-derived GIS products will inspire confidence and transparency among participants (Alcorn 2000). Community monitoring groups can facilitate this need at the local level, and at the national level safeguards should be in place to prevent manipulation by outside interests (Mohamed and Ventura 2000).

EMERGING OPPORTUNITIES FOR RESEARCH

Researchers have expressed a need for further in-field testing of participatory GIS methodologies (Abbot, Chambers et al. 1998; Alspach 1999; Barndt 2002). Participatory GIS theory cannot practically be tested in controlled experiments; therefore researchers examine multiple case studies of its use in diverse settings (Ventura, Niemann et al. 2002). Among the documented applications of participatory GIS in developing countries, however, not all settings are equally represented. Case studies predominantly involve forest management (Bocco and Toledo 1997; Mather 2000; Srimongkontip 2000; Jordan 2002; Laituri 2002; Puginier 2002; Kyem 2002b), as opposed to agriculture or livestock management. Many of these forest communities have traditions of communal resource management as opposed to individual property ownership. Furthermore, participatory GIS studies are often inspired by broader mandates for conservation, such as the requirement for communal forest management plans in Mexico, or the national watershed classification system of Thailand.

A prerequisite to successful participatory GIS is social organization. In South Africa tribal lands, the diverse and traditional population provides a social environment that encourages dialogue and consensus with the inclusion of minority groups (Harris and Weiner 2002). In Nuevo San Juan in Mexico, strong social organization and concern for sustainable resource management enabled successful GIS adoption, given a substantial external investment in technical resources and training (Bocco, Rosete et al. 2001). These cases achieved results; however, participatory GIS methodologies need to also be applied in communities that are less organized and less supported.

Likewise, more descriptive evaluations of technical procedures for data integration, analysis, and presentation will be helpful to local NGOs attempting to use GIS technology. The technical process of georeferencing primary data and integrating secondary data into GIS can be particularly challenging to local organizations lacking GIS training or advanced hardware and software. Case studies of first-time GIS applications using local technicians, locally available data, and existing computer resources provide valuable examples for future efforts.

Participatory GIS is now beginning to move into the mainstream of international rural development. To add a unique case study to this growing body of literature, *Procesos y Productos* is reviewed to examine whether its methodologies could be managed by stakeholders, and be of use to decision-makers. The following two chapters evaluate the successes and failures of GIS applications in the context of this project. Citing results from each of three project watersheds and their respective participating NGOs, four general questions are addressed:

1) Can existing secondary data sets be successfully integrated and analyzed in GIS by existing NGO staff using existing resources?

2) Can unique, georeferenced primary data sets be created by local NGOs with legitimate participation of the watershed communities?

3) Can practical GIS data products be created that communicate both the watershed environment and stakeholder-defined development priorities to institutions at the regional or national level?

4) Does the introduction of GIS to the participatory process actually strengthen local involvement in natural resource management?

CHAPTER II: Applications of GIS for Natural Resource Management

Impediments to GIS adoption in the *Procesos y Productos* project

INTRODUCTION

This chapter examines GIS applications to a pilot project for community-based natural resource management in the Peruvian Andes, carried out in three semi-arid mountain watersheds by three local non-governmental development organizations. The focus of this chapter is primarily technical, examining methods of data collection and analysis and the impediments encountered in this process. The use of GIS is evaluated at both the watershed level and the community level, and three fundamental questions are explored: (1) can secondary data sets be incorporated into GIS by the NGOs? (2) can primary GIS data sets be created jointly by local NGOs and watershed inhabitants? (3) with these data, what practical GIS data products can be created to facilitate a participatory development process?

Procesos y Productos: Socializando la Información para la Acción operated between May 2000 and May 2002 as a pilot project to assist both communities and organizations in the creation of information products for natural resource management. The objective was to organize stakeholders around resource issues and identify development priorities that raise their standard of living while sustaining the natural resources base. A hypothesis of the project was that GIS tools can enhance the participatory process of collecting, processing, and communicating information. The project assembled existing secondary data held by government and private institutions and generated primary data through the participating NGOs and watershed stakeholders (CONDESAN 2000).

The project was administered by the *Consorcio para el Desarrollo Sostenible de la Ecoregión Andina* (CONDESAN), a sustainable development program connected with the International Potato Center (CIP) in Lima, Peru. Three Peruvian NGOs were invited to each select a watershed in which to implement the project. The NGOs are representative of non-profit, non-governmental natural resource development and conservation organizations of the Andean region. Staffs range from 5 to 40 professional Peruvian nationals, many with degrees in agronomy or engineering. Though their objectives are diverse, each NGO works directly with subsistence farmers to address fundamental resource management challenges with practical solutions. All have competence in the use of computers, but none had utilized GIS prior to this project. Two of the organizations are based in the northern city of Cajamarca, and another operates in the southern city of Puno. A more detailed profile of each NGOs is provided in the Appendix I.

Two of the three project watersheds lie in the upper Jequetepeque basin of the northern Peruvian Andes (figure 1), in the department of Cajamarca. This region is home to a high degree of biodiversity, extremely steep topography, shallow soils, and a six-month dry season that necessitates irrigation for agriculture. A high level of poverty, poor services, and limited access add to the development challenges in this region.

The 8515 hectare Asunción river watershed ranges from 1550 masl to 4150 masl. It includes the ecological zones *yunga*, *quechua*, and *jalca*, as defined by increasing elevation. Production systems are diverse and defined primarily by elevation. They include sugarcane and fruit in the yunga, grains and tubers in the quechua, and pasture in the jalca (ASPADERUC 2002).

The contiguous Cardón and Cuzcudén river watersheds comprise the second project site in the upper Jequetepeque. This site contains 4240 hectares including yunga and quechua zones ranging from 1200 masl to 3200 masl. This pair of watersheds shares many of the socioeconomic and biophysical characteristics of the Asunción watershed. (CEDEPAS 2002).

The third and largest project site is the 27,000 hectare Conavari watershed in the southern highland department of Puno, near lake Titicaca. Rising above 3800 masl, this catchment contains two ecological zones: the flat and arable *suni*, and the surrounding mountainous *puna*. The project works only within the 5000 hectare suni zone of this watershed, where most agricultural production takes place. Poverty is equally if not more pronounced here than in northern Peru (CIRNMA 2002).

This project intended to attract national governmental agencies, international development organizations, and private interests to invest in its watersheds once stakeholders were identified and development priorities were articulated using GIS. The primary intended client of GIS products was the *Proyecto Nacional de Manejo de Cuencas Hidrográficas y Conservacion de Suelos* (PRONAMACHCS) – a program of the Peruvian government administering soil and water conservation projects in the rural hillsides. A profile of this agency is provided in Appendix I.

METHODS

Simple, low-cost GIS procedures were applied to create georeferenced map products addressing development priorities at both the village and watershed scale. Each level of analysis required distinct methods for data collection and analysis.

GIS at the watershed scale

For analysis across watersheds, the project adopted a simple procedure previously developed by the GIS lab at CIP. The "Minimum Data Set" methodology was designed in conjunction with PRONAMACHCS to map soil and water conservation priorities in the 16,000 hectare Encañada watershed, located in the Cajamarca River basin. With a relatively modest input of time and data, existing biophysical data layers at 1:25,000 scale were used to create a georeferenced map of proposed conservation actions (figure 2). Though of limited value in directing efforts within individual villages, the product can guide resource management decisions across a watershed (Posner, Bussink et al. 2002). Similar methods of processing GIS data have been implemented in mountain watersheds worldwide, proving valuable for integrating and managing data from different sources (Bitter 1999).

Each of the NGOs was introduced to this methodology to guide GIS applications in their respective watersheds. Using social organization and planning methods outlined in Chapter 3, they gained input from watershed stakeholders to define natural resource management issues of local importance. With assistance from CONDESAN, the NGOs were responsible for secondary data collection and GIS analysis. The resulting thematic maps are intended to gain outside support for development proposals, and to build a sense of collective resource management among watershed inhabitants themselves.

GIS at the community scale

In addition to the Minimum Data Set method at the watershed scale, NGOs have experimented with means of geospatial data collection and analysis at the village scale. A potential entry point for GIS applications at this level of detail is through participatory resource mapping (PRM), commonly practiced throughout the world (Abbot, Chambers et al. 1998). In these exercises, stakeholders sketch spatial features of their environment and provide relevant descriptive information. PRM is used in Participatory Rural Appraisal (PRA) methodology as a means to encourage wider participation and transcend language barriers. GIS provides an opportunity to put PRM results into a storable and retrievable format that can be integrated with other spatial data (Mbile, DeGrande et al. 2003).

Large-scale aerial photographs provide a means for linking GIS and PRM, as demonstrated by research with "participatory photo-mapping" for community forestry in Nepal (Mather 2000; Jordan 2002). Stakeholders draw features of their communities over enlargements of georeferenced aerial photographs, and the results are digitized to create a spatial database. The information is similar to that acquired through PRM, but can be integrated and analyzed with other spatial data in GIS. In addition, the alluring visual perspective offered by aerial

photography can encourage input from underrepresented stakeholders and inspire community dialogue (Alcorn 2000).

Forest management is a common resource theme addressed in the photo-mapping literature. Forest boundaries, for example, can be delineated in aerial photographs, imported into a vector GIS layer, and linked to a table of attributes for forest uses and users. Soil mapping also depends on aerial photography, and can potentially be done with local participation. Olivares (Olivares, Muñoz et al. 2001) engaged farmers in La Encañada watershed to map soils by qualitative assessment using local taxonomy. Small-scale airphotos of the watershed assisted this process, and by rectifying and digitizing the soil units this "indigenous" information could potentially be made GIS-ready.

Deriving spatial information from airphotos requires the complicated procedure of orthorectification, which corrects for geometric distortions caused by the camera lens, camera angle, and variations in topography. Orthorectification requires two additional sets of data covering the area of the photograph: a raster image of topography known as a digital elevation model (DEM); and roughly six to twelve precise *x*, *y*, and *z* coordinates of distinct features on the ground, known as control points. DEMs and control points are particularly challenging to obtain with accuracy in mountainous environments (Heywood, Price et al. 1994). This technical challenge to photo-mapping is often not addressed in the participatory GIS literature.

Another tool for georeferencing features at the village level is the increasingly accurate and inexpensive technology of Global Positioning Systems (GPS). With a handheld GPS receiver, stakeholders can directly record geographic coordinates for village landmarks, boundaries, irrigation canals, and other geographic features that are difficult to display with spatial accuracy in community sketch-mapping exercises. These data can then be instantly uploaded into a spatial database. GPS is often used to supplement, but not replace, aerial photographs as a tool for participatory mapping.

IMPLEMENTATION

GIS computational resources and training

Project funds provided each of the three NGOs with a full-time license to Idrisi, a raster-based geographic modeling and image processing software package (Clark Labs 2003). Idrisi was chosen because of its affordable price to international non-profit organizations, and because it includes extensive raster and vector functionality in a single program. The software interface is available in Spanish, but the help system and manuals were available only in English at the time of the project.

No new computer hardware was provided for the project. All NGOs already possessed or soon acquired computers with Pentium processors fully capable of running the Idrisi software. None possessed scanners or printers larger than A4 standard letter format.

Each NGO assigned GIS operations to an existing engineer or agronomist with previous computer experience, but no particular knowledge of GIS. These professionals were expected to absorb GIS duties into their existing responsibilities. At the onset of the project in October 2000, CIP provided a three-day in-house GIS training workshop in Lima. Two professionals from each NGO were introduced to GIS theory and practice using Idrisi and data from their respective project watersheds. In 2001 a mid-term three-day GIS workshop was also provided for the two NGOs in Cajamarca. Throughout the two years of the project, a full-time GIS expert from CIP made multiple visits to each of the NGOs to provide technical support. The three NGOs' GIS technicians also communicated informally among themselves to share experiences. In addition, two graduate students provided full-time GIS assistance to the NGOs – one in Cajamarca for a period of nine months, and the other in Puno for three months.

Secondary data acquisition and integration

Data acquisition began with biophysical data sets similar in type and scale to those used with the Minimum Data Set methodology in Encañada. NGOs acquired hardcopy topographic maps from the Peruvian National Geographic Institute (ING) at 1:25,000 scale. These maps were inconsistent in date of origin, but all contained elevation contour lines at 25 meter intervals. CIRNMA also acquired topographic maps with five meter contours of the suni region from the Special Project for Lake Titicaca (PELT). Secondary data are summarized in Table 1. Lacking large format scanners, the NGOs resorted to scanning topographic sheets in sections, digitally rejoining them into a single digital topographic image, and then digitizing the contours on-screen using AutoCAD (figure 3).

ASPADERUC already possessed both a soil survey and a land use survey at 1:25,000 scale from a 1998 study of La Asunción watershed. CEDEPAS contracted its own such study for the Cardón/Cuzcudén watersheds in 2000. These studies use a soil taxonomy of the Food and Agriculture Organization "Soil Map of the World" (FAO 1974), including data for the eight soil parameters shown in Table 2. CIRNMA acquired a soil survey at 1:150,000 scale from the National Office for Evaluation of Natural Resources (ONERN), covering only two-thirds of the Conavari watershed in which only four soil units are represented. The aerial photographs used in these surveys were manually rectified using a stereoscope, but without differential rectification to correct for distortion due to topography.

Complementing each soil survey is a land cover survey, created at the same time and scale. Vegetation types surveyed are specific to each watershed; the most common are identified in Table 2. Where a variable is heterogeneous in a given unit, values are listed as associations – for example, one soil unit in La Asunción lists pH as a range of 6.5 to 7.3; and a land cover unit of the Cardón/Cuzcudén shows 50% wheat and 50% natural pasture.

With project funds, the two Cajamarca NGOs purchased original panchromatic black and white aerial photographs of their watersheds from the Peruvian land titling program (PETT). Included are fifteen photos covering most of the Cardón/Cuzcudén watershed, and twelve of the more populated half of the Asunción watershed, all with approximately 70% overlap.

Due to the varied elevation across the coverage area, the scale of these contact prints is not uniform, but average scale of acquisition is estimated to be approximately 1:15,000.

Data from climate measuring stations is available from the Peruvian military; however only one measuring station exists within each watershed, and data collection for these stations dates back between only 4 and 20 years. These climate data were not acquired, as they are costly and are not useful for generalizing across the great elevation ranges of these watersheds.

Lastly, NGOs located socio-economic data from a 1992 national agricultural census. As census data are reported within each municipality, cropping and livestock information is not necessarily related to watershed or ecological boundaries.

Development of intermediate products from secondary data

With secondary data collected and georeferenced in GIS, NGOs began to create thematic data layers. Each began by creating a digital elevation model (DEM) from the digitized topographic contours. The digitized elevation contour lines were imported into Idrisi from AutoCAD, converted to raster, and interpolated to create a 15m resolution DEM raster grid for each watershed (figure 4).

Three themes were derived from the DEMs using Idrisi. First, watershed boundaries were delineated from the DEM by selecting watershed outlets digitized from topographic maps.

DEM was reclassified within the watershed into elevation zones, and these zones were ;ned the climate and vegetation characteristics of L.R. Holdridge's "World Plant ıations" (Holdridge 1947). This produced a map of agro-ecological zones defining es of temperature, rainfall, and humidity, as well as common plant genera (figure 5). rage slope values were also calculated for each raster cell in the DEM, and the resulting grid was reclassified and smoothed to create an image of selected slope ranges (figure

ıents of the soil survey and land cover survey data were simplified by reclassification. associations were reclassified to the most dominant soil characteristic for that unit (for ıple, a soil unit with drainage defined as 70% "moderate" and 30% "severe" becomes 6 "moderate"). This created discrete-value units that can be analyzed with other atic layers in GIS, but also generalized these attributes within soil units. Through this ss, thematic layers were created for soil pH, texture, depth, drainage, and salinity (table Much of the land cover data are also heterogeneous within land use units. These data generalized into the six predominant classes, also shown in Table 2.

dditional component of the soil surveys that required adjustment is the land capability ification (LCC) system created by the US Natural Resource Conservation Service ns 1992). Given the thin soils and steep slopes of the Andes, few soil units in these rsheds qualify as arable land (classes I-IV of eight) under this system. Recognizing that ers in La Asunción watershed have little choice but to farm much of the land area for h cultivation is not recommended (class V and above), ASPADERUC created a "sensible soil map" that rescales and renames the first seven LCC classes into three classes of high, medium, and low agricultural suitability, with class VIII committed to full-time protection (figure 7). This reclassification of the LCC expands the area permissible for farming, but is increasingly restrictive for more vulnerable soils.

Three airphotos of Cardón/Cuzcudén and one from La Asunción were scanned and orthorectified. The graduate student in Cajamarca obtained the ArcView script OrthoRec from the Environmental Systems Research Institute webpage (ESRI 2000), and used ArcView software at the regional PRONAMACHCS office. The previously derived DEM provided elevation data, and ground control points were taken from features on the topographic maps or with a GPS receiver in the field when possible.

Primary data collection

In each watershed, NGOs established spatial data collection methods of their own design. Airphotos covering three caseríos of La Asunción were reprinted at a scale of approximately 1:3000, covered with transparent plastic lamination, and introduced at meetings of the village irrigation committees. Participants were invited to draw features such as farm and village boundaries, springs and irrigation canals, and village landmarks over the images (figure 8). Agronomists from ASPADERUC attended three to four monthly committee meetings in each caserío to facilitate this procedure.

CEDEPAS introduced similar exercises in the Capellanía caserío. These were integrated with PRA activities rather than being the focus of the meetings themselves, as in La Asunción. Farmers inventoried soil types of their caserío using the local soil taxonomy, and then were asked to delineate these soil types on the airphoto (figure 9). They were also encouraged to delineate other features such as the caserío boundary, irrigation canals, and landmarks.

GPS was used in ten Cardón/Cuzcudén watershed villages to delineate groundwater springs and irrigation canals. Village farmers accompanied the CEDEPAS agronomist in this activity. The data were uploaded into GIS and coupled with a database of canal names, users, and flowrates measured with a bucket and stopwatch, simultaneously with the GPS data collection (figure 10). GPS was also used to delineate all caserío boundaries that could not be identified from topographic maps.

No aerial photography exists for the Conavari watershed; however, CIRNMA delineated boundaries of pastures in three villages using a hand-held GPS receiver and community input. Two foreign students facilitated the process; one managed the GPS while another inventoried vegetation species and measured dry biomass for each delineated pasture type. The data were then used to quantify the extent of grasslands of different quality in order to determine sustainable grazing densities and the potential benefit of irrigation within each delineated pasture zone.

These are the "*procesos*" used in this project to acquire and analyze spatial data both across watersheds and within communities. The following section examines the "*productos*" created at both the watershed and community levels, and the potential for linking these two scales of data.

RESULTS and DISCUSSION

Secondary data integration at the watershed level

The integration of previously collected spatial data into GIS was largely successful, but also proved to be time-consuming and potentially error-prone. Manual digitization of elevation contours became the single most time-consuming step in the integration of existing spatial data. The digitized contours for La Asunción revealed a horizontal displacement of as much as 60 meters at the union of two topographic maps. Errors elsewhere have been attributed to differences in neighboring topographic maps (Rybaczuk 2001), however in this case it is not known whether displacement results from errors in the piecemeal process of scanning and rejoining topographic map sections in AutoCAD, or discrepancies in the original maps themselves.

Although the DEMs were created at 15 meter resolution, derivations of slope are likely to be inaccurate within an individual pixel. Using transects, Zurayk et al. (2001) found 35% error in the slope values calculated from a DEM derived from 50m contours at 1:100,000 scale. The 1:25,000 DEMs derived from 25m contour lines should be much more precise, likely correct in directing attention to areas of several tens of hectares. However these products have not been verified by in-field measurements. A more efficient alternative may be to acquire DEMs directly; for example, 30 meter resolution DEM data from the 2000 Shuttle Radar Topography Mission at 16m vertical accuracy will soon be available (JPL 2003a), and 10 meter DEMs can be derived from ASTER satellite imagery accurate at 1:50,000 scale, given adequate ground control (JPL 2003b).

Soil survey data, derived with the use of non-rectified aerial photography, was presented from surveyors with no account given as to how soil unit boundaries were digitized. Therefore, overlays of soil survey data with other spatial data layers should be assumed to carry geometric errors. Placed over an orthophoto, soil survey unit boundaries of Cardón/Cuzcudén appear over-generalized and displaced from their apparent true delineation in the image (figure11). For La Asunción, an overlay of soil survey and land use data layers shows a maximum offset of over 100 meters. The 1:25,000 survey data is further limited by the high edaphic variability and small farm sizes of the Andes. Within a given soil or land cover unit, smaller areas with entirely different values are likely to exist (Poma 2001).

The soil survey, land use survey, and digital elevation model were the most important secondary data sets for GIS applications at the watershed level. Thematic maps for soil conservation, agroforestry, and pasture potential all use these sources exclusively. Such maps serve to direct decisions to particular villages or regions within watersheds, at which point thematic map are best set aside in favor of in-field observation and farmer knowledge of the landscape.

Use of topographic data and soil surveys is widespread among watershed-scale soil conservation research efforts. With substantial funding over several years, other studies have also analyzed land ownership and production data to relate farm size to soil degradation (Shultz, Saenz et al. 1998), interpreted aerial photography to outline units of forest quality (1998; Bocco, Rosete et al. 2001), acquired farmer soil and vegetation knowledge to delineate agro-ecologic zones (Zurayk, el-Awar et al. 2001), or used hydrologic modeling to estimate the relative distribution of waters supply among tributaries (Ashby, Sanz et al. 1999). By comparison, this project performed relatively simple GIS analysis due a limited availability of data, a strong dependence on local technicians to carry out spatial analysis, and the emphasis by the Minimum Data Set methodology on simple data input.

Primary data acquisition and use at the community level

Given the limited detail of secondary data layers for resource investigations and planning at the village level, NGOs were motivated to collect and analyze spatial data at a larger scale and with greater involvement by watershed inhabitants. Experimentation with participatory GIS methodologies grew from the NGOs' natural inclination to work directly with community members, and their interest in data collection and quantitative analysis. The foreign graduate students assisting the NGOs also encouraged and assisted the application of GIS at the community level. NGO professionals proved willing and able to utilize GPS technology and aerial photographs to collect primary spatial data.

Well-distributed control points for orthorectification of airphotos were challenging to acquire from either digitized topographic maps or in-field GPS measurements. Topographic maps of Peru are decades out of date, are sometimes faded or marked over, and share few distinct features with recent airphotos. GPS provides a precise means to measure ground control points specific to the airphotos, but these features are often far from roads, deep in valleys, or atop mountains; and they are difficult or impossible to access on the ground. Also, specific hardware and a high-performance computer are needed. OrthoRec functioned correctly only on processors of at least 500 MHz, which were not accessible to NGOs until later in the project.

Despite these challenges, three airphotos of the Cardón/Cuzcudén watersheds and one of La Asunción were successfully orthorectified. Topographic maps had already been obtained, scanned, and oriented in order to create a DEM, and GPS measurements of opportune ground features had been taken simultaneously with other efforts such as the irrigation canal inventory in Cardón/Cuzcudén. Root-mean-square values exceed 15 meters for both interior and exterior orientations, using approximately 10 ground control points for each image. These errors are demonstrated by comparing an orthophoto with the digitized contour lines used to create the DEM (figure 12). Due to delays in acquiring airphotos, a high-performance computer, and ground control, orthorectification could not be accomplished before the scanned airphotos were printed for use in participatory photo-mapping sessions.

As seen in the participatory photo-mapping sessions in Nepal (Mather 2000; Jordan 2002), the exercises in the three targeted caseríos of La Asunción appeared to attract participants

regardless of gender, age, or literacy. The first session in each caserío drew as many as 25 participants, with the number gradually declining over the course of two hours until a core group of two to six active participants remained. Subsequent sessions each attracted 10 to 15 participants initially, with the core group always remaining throughout the entire exercise.

In each caserío, delineation of caserío boundaries, groundwater springs, and irrigation canals was completed within the first mapping session. In subsequent sessions, two of the Asunción caseríos also delineated individual property boundaries and drafted an associated table of land use and irrigation access at each property. This method for data collection proved much more time-efficient than manually walking along the features with a GPS receiver, as was done in the Cardón/Cuzcudén watershed.

The process of manually digitizing information from the laminated airphoto prints promises to be far more time consuming than uploading GPS data into a computer. Lacking a digitizing table or large-format scanner, the immediate option for the NGOs is to on-screen digitize the information intuitively by relating the completed photomaps to an orthophoto image on a computer monitor. One possible alternative to this is monorestitution, successfully applied by local technicians in Mexico to digitize vector data from airphotos (Bocco, Rosete et al. 2001).

ASPADERUC and PRONOMACHCS considered introducing the participatory soil study methods they implemented in Encañada (Olivares, Muñoz et al. 2001) to the Asunción watershed, and integrating results into GIS. Should a mosaic of referenced aerial photography be produced, it would greatly facilitate the integration of participatory survey results with the spatial datasets already produced for the watershed.

Production of unique thematic maps

Despite the observed limits in data accuracy, NGOs were generally successful at applying the Minimum Data Set methodology to create useful GIS maps at the watershed scale. As with the soil conservation map for Encañada, their maps used biophysical but not social or economic data. Using soil survey, land use, and elevation data layers, ASPADERUC produced a conservation intervention map for the Asunción watershed. Terraces, infiltration ditches, extractive forests, or protection forests are recommended for all land area under seasonal cultivation, using input parameters of slope and soil depth (figure 2a and figure 13). This map was intended to attract funding from PRONAMACHS for the proposed conservation actions.

It was anticipated that governmental agencies - particularly PRONAMACHCS - might request customized GIS products and provide decision-making criteria to NGOs. The agency had earmarked funds for over 100 small watersheds in the country, and GIS analysis of secondary data was seen as a means to systematize the prioritization of watersheds according to conservation needs. However, due to political uncertainly at the national level during the course of this project, no funding or direction was offered by the agency.

ASPADERUC also created suitability maps of La Asunción for three marketable tree species: avocado (*Persea americana*) and chirimoya (*Annona cherimola Mill*) (figure 17b), and taya (*Caesalpinia spinosa*). These maps were created using soil survey and elevation data and suitability criteria determined through bibliographic research by the NGO. The taya map, for example, classifies watershed suitability the species according to its preferred elevation range, soil texture, and soil pH (figure 14). Taya is a nitrogen-fixing tree with a resin useful for dyes, cosmetics, and leather tanning, and is native to La Asunción watershed. The Peruvian Export Promotion Commission (PROMPEX) has conducted feasibility studies of this species for export to European markets, but as of yet no investments for taya have been proposed in La Asunción watershed.

Choosing where to maintain taya involves additional factors not considered in the suitability map. Within a given field, one may consider slope for purposes of soil conservation, or complementary species for nutrient cycling. Likewise, as the input data layers for soil texture and pH are generalized across soil survey units, more detailed information at the farm level is needed before decisions are made. Therefore, the taya suitability map serves to direct attention to specific regions of the watershed, provided that in-field observations and the input of farmer knowledge are then used at a finer scale.

CIRNMA created a 1:150,000 scale thematic map of the potential for pasture improvement in the Conavari watershed based upon slope and soil pH, salinity, and drainage (figure 15). This theme was selected because of the region's dependence on livestock, the impending arrival of a large irrigation canal to the region, and current problems with poor drainage where irrigation is already practiced. All areas with less than 15% slope are considered feasible for gravity irrigation, and therefore have higher potential for improvement. Using vegetation association data from the land cover survey, CIRNMA also created watershed maps of pasture suitability for each of cattle, sheep, and alpacas (figure 16)

The National Social Development Fund (FONCODES) of Peru offers micro-loans to some small farmers in the Conavari watershed for investments in livestock; however, the agency does not actively seek technical criteria to spatially prioritize its operations. CIRNMA has not yet succeeded in gaining the attention of this agency with its GIS thematic maps of soil and vegetation suitability for pasture improvement.

In the Cardón/Cuzcudén watersheds, suitability maps for potential development projects were created by CEDEPAS with input from the watershed association. Due to the growing shortage of firewood and building material, stakeholders identified forest resources as a development priority. Suitability maps were created for pine (*Pinus radiata*), alder (*Alnus sp.*), and eucalyptus (*Eucalyptus globulus*), considering only elevation in determining suitable ranges (figure 17a). The watershed association intends to build tree nurseries at different elevations of the watersheds, and will use these maps to plan their distribution in the watershed.

The only unique GIS products created at the village level were pasture improvement maps for the three focus communities in the Conavari watershed. CIRNMA combined results of an in-field vegetation survey with farmer knowledge of livestock diets and GPS delineations of

pasture area. The result is a georeferenced thematic map of pasture potential, useful in determining the optimal livestock density of each pasture parcel and its potential to be improved with the introduction of irrigation to these communities (figure 18).

These village-level pasture improvement maps provide geographic coordinates to land cover information that is similar to that previously articulated through PRA sketch mapping (figure 19). While this case is not a true integration of PRA an GIS, it does indicate a potential to meet the objectives of GIS-based Participatory Resource Mapping expressed by Abbott and Chambers et al. (1998). All other actual GIS products utilized only the existing secondary data sets obtained from external sources.

CONCLUSIONS

With a modest investment of mostly informal training, local professionals learned the concepts of geospatial analysis and acquired the skills necessary to operate GIS. In adopting this technology, the primary limitations facing stakeholders involve a lack of standardized databases, competing demands for the time required to manage spatial data, and a limited demand for data products.

The GIS products created in this project can best be described as indicative maps – useful in focusing development efforts towards general areas at the watershed level, but not necessarily reliable as a basis for decision-making at the village or especially the farm level.

Products such as the taya suitability map meet the objectives of the minimum data set methodology by quantifying land areas suitable for specific conservation or development actions. Decision-making beyond the scale of 1:25,000, however, must revert to in-field observations, but can be enhanced by the use of finer-scale spatial data tools such as aerial photographs.

A single institution such as CIP could acquire and process secondary data more efficiently than several inexperienced local NGOs. Freeing NGOs of the lengthy process of secondary data preparation would leave them more time to conduct social research and collect primary data in the field, and to create custom GIS products. At a minimum, presenting NGOs with ready-made elevation data would offer a good starting point GIS data management.

NGO efforts and stakeholder interest for the collection of primary data demonstrates a potential for GIS applications at a larger scale. Drawing such features over airphotos proved much faster than walking boundaries and canals in the field with a GPS, and allowed for input from a greater number of community members. Assembling a watershed mosaic of orthorectified aerial photography may be unrealistic for the scope of this project; however, the impediments to photo-mapping appear to have resulted more from a need to better incorporate PRA methodology in multiple watershed villages simultaneously.

Although primary data were never spatially linked with the watershed-scale thematic maps, there is a benefit to coordinating efforts at both the village and watershed scales. For example, a watershed-scale product such as the taya map of La Asunción directs attention to

general regions within a caserío, at which point farmers can use a village-level product such as an aerial photograph to guide the selection of sites for planting trees. Airphotos, even if not integrated into GIS, can serve as a starting point for management at the scale where the thematic maps produced from secondary data are no longer helpful.

Had some formal process of GIS needs assessment been implemented as a preliminary step to *Procesos y Productos*, the project might have achieved results with more consistency and efficiency. The process of formal and comprehensive user needs assessment can help to identify the goals and the scope of GIS in a project. Without such planning, NGOs depended on potential clients to define the needed products; and when such clients did not emerge, GIS was applied without clear objectives or requirements. The project did succeed in creating unique thematic maps addressing local development priorities. However, with better defined procedures and GIS product criteria matching the needs and abilities of local technicians, NGOs could likely create more concise thematic maps in a shorter period of time.

Table 1: Secondary data integration for each watershed

Watershed	Data type	Source	Scale	Integration procedure	Intermediate GIS product
Asunción and Cardón/Cuzcudén	*Topography*	ING [1]	1:25,000	Maps scanned, contours digitized	DEM, slope, ecologic zones
	Soil survey	Contracted professionals	1:25,000	unknown	Individual soil parameters
	Land cover survey	Contracted professionals	1:25,000	Unknown	Individual vegetation types
	Airphotos	PETT [2]	≈1:15,000	Scanning, orthorectification	Orthophotos
	Census	INEI [5]	-	-	-
Conavari	*Topography*	PELT [3]	1:10,000	Maps scanned, contours digitized	DEM and slope
	Soil survey	ONERN [4]	1:150,000	Scanned and digitized	Individual soil parameters
	Land cover survey	ONERN [4]	1:150,000	Scanned and digitized	Individual vegetation types
	Census	INEI [5]	-	-	-

[1] *Instituto Nacional de Geografia*
[2] *Programa Especial de Titulación de Tierra*
[3] *Proyecto Especial de Lago Titicaca*
[4] *Oficina Nacional de Evaluación de Recursos Naturales*
[5] *Instituto Nacional de Estadistica y Informática*

Table 2: Variables for soils and land use surveys

Data type	**Variables in original survey**		**Variable in GIS thematic layers**
Soil survey	Texture Parent Material Drainage pH Salinity	Useful depth Erosion class Stoniness Land use potential (NRCS)	Texture Useful Depth pH Salinity Drainage
Land cover survey	Natural forest Other forest Natural pasture Cultivated pasture Fallow Bare soil / rock	<u>Crops</u> corn, wheat, barley, lentil, potato, bean, pea, fruit, sugarcane	Grains Tubers Cultivated pasture Natural pasture Forest Degraded area

CHAPTER III: GIS Impacts on Stakeholder Organization and Action

Evaluation at the community, watershed, and institutional levels

INTRODUCTION

The previous chapter introduced methodologies for spatial data collection and analysis and examined impediments to their adoption by partner NGOs in the three project watersheds. Three questions were addressed regarding the collection of primary data, the assemblage of secondary data, and the products created with these data. This chapter examines the framework of stakeholder organization within which GIS was introduced, and evaluates how GIS appears to have influenced the impacts of these activities on project participants.

The original *Procesos y Productos* proposal defines the goal of developing "a proactive sense of watershed commonwealth among local residents". This is accomplished by working at two levels:

- *At the level of the* caserio *or sector, where residents (20 - 50 households) will address local environmental issues (e.g. pesticide use, wastewater management, drinking water quality, fire control); and,*
- *At the level of the municipality or* micro-cuenca *(5,000 - 20,000 ha), where stakeholders will prioritize soil and water management interventions, as well as develop a portfolio of productive projects.*

The power that comes from information will not be held by outside facilitators, but rather by the local watershed association.

(CONDESAN 2000)

There are four general steps in this process: (1) enable a customized and informed decision-making process for resource management in each community (*caserío)*; (2) connect all caseríos in a given watershed (*micro-cuenca*) together into an association capable of planning interventions at a watershed scale; (3) link each watershed association with the political system at the municipality or district level; and (4) through this process, achieve results that will encourage the adoption of this project's methodologies by other institutions working elsewhere in the region (CONDESAN 2000). The goal is to empower grassroots organizations, NGOs, and municipal authorities with data and information management tools, allowing them to have a direct impact on resource management decisions and attract funding for projects that they themselves prioritize. The project views GIS as a potentially useful tool in realizing these objectives.

Each NGO's methodology for stakeholder organization and resource assessment is reviewed, followed by a summary of achievements made in resource management planning and the impact of applying GIS at each the community, watershed, and institutional levels.

METHODS

The investigator for this study worked in Cajamarca as a consultant to two of the participating NGOs for 9 months between September 2000 and May 2001, and returned in August of 2002 for five weeks to evaluate project results. Information was gathered by personal observation, document review, and interviews. The investigator conducted individual semi-structured interviews with the director, GIS technician, and social scientist of each NGO. The NGOs also presented the investigator to local stakeholders in each watershed for informal, conversational interviews. Interview subjects include eight farmers, three local political authorities, and one governmental agency representative. Mid-term and final project reports from each of the NGOs provide background of watershed profiles, methods, results, and GIS products. In addition, the investigator used personal notes and memory of field visits, meetings, and general involvement in the project.

Methods for identifying interest groups and promoting collective natural resource management in the three project watersheds are outlined in a guide published by the International Center for Tropical Agriculture (CIAT) (Westermann, Guerrero et al. 1999). This document offers practical exercises based on the Participatory Rural Appraisal (PRA) theory developed Robert (1994) and other development researchers (Thrupp, Cabarle et al. 1994). Each NGO was provided the CIAT guide at the onset of the project, with the expectation that they would adapt the methodology to their individual experience and needs.

The CIAT methodology engages resource users at villages of approximately 100 - 300 hectares by identifying all interests groups – or stakeholders – who may have conflicting views about how best to manage natural resources within their region. In each community, a first meeting of stakeholders promotes collective action for resource management and explores participant interest; semi-structured interviews better identify management conflicts and interest groups; and a second meeting discusses conflicts among the interest groups. Stakeholders are then encouraged to negotiate, reach agreement, and draft concrete proposals for improving communal management of natural resources. It is important that the process

not create false expectations among stakeholders by proposing unrealistic solutions, nor should it simply illustrate challenges without identifying practical means to address them (Westermann, Guerrero et al. 1999). This procedure was intended to take place throughout the first year of the project.

Strategic planning across watersheds of 5,000 to 20,000 hectares was to follow stakeholder identification and continue for approximately three years. In this process, representatives of the village committees join to form a watershed association. Through a series of meetings facilitated by an NGO, they identify themes common among the village committees and develop strategic plans for specific projects across the watershed. Ideally, the associations and NGOs outline alternative development scenarios and their expected impact on the landscape. The minimum data set GIS methodology – explained in Chapter 2 – is then applied by NGOs to represent spatial dimensions of these prioritized projects. Economic and soil erosion modeling could be applied, but the minimum expectation is that the associations draft proposals that can be used to earn funding from counterparts such as the municipality or governmental agencies (CONDESAN 2000). GIS is intended primarily for applications at the watershed level, where existing data sets - often at 1:25,000 scale - are adequate to identify land areas suitable for selected conservation or development initiatives.

IMPLEMENTATION

In each watershed, the process of stakeholder organization and development planning was applied according to the social and biophysical characteristics of the site and the capabilities and preferences of the NGO facilitators.

Stakeholder organization at the community level

Stakeholder organization was conducted in seven communities in the Conavari watershed. All components of the CIAT methodology were applied, including interest group identification, participatory resource inventory, and group reflection on potential conflicts. The CIRNMA sociologist made adjustments from conventional PRA procedures by extending the process throughout several shorter meetings instead of conducting all activities within only two or three longer sessions. In addition, training activities not specified in the CIAT methodology were added. Outside specialists provided occasional training for issues specified by community members during the PRA process, such as cheese making and artificial insemination of cattle.

Two adjacent watersheds in the San Pablo district of Cajamarca were chosen by CEDEPAS as their project site. The Cardón and Cuzcudén catchments total 4240 hectares of highly variable topography. The NGO had previously been working in nearby communities, but this project was its first experience in these particular watersheds. A facilitator from CEDEPAS initiated PRA activities in all 14 of the watersheds' caseríos, but later focused on

only the three that expressed the greatest interest in the project. Each participated in a natural resource inventory combining the CIAT methodology with Rapid Rural Appraisal (RRA) techniques known to the facilitator, with occasional assistance by a foreign PRA and agricultural specialist.

In La Asunción watershed, ASPADERUC selected three caseríos, each representing a specific ecology: the middle *yunga* (≈ 1900 masl), upper *yunga* (≈ 2100 masl), and lower *quechua* (≈ 2400 masl). These communities were chosen due to their participation in a previous district-level development planning project, and their proximity to the only reliable road in the watershed. In each caserío a natural resource management committee was formed. Two facilitators from ASPADERUC led resource inventory activities including biological transects, agricultural calendars, Venn institutions diagrams, and gender role analysis. Training exercises known as *Escuelas de Campo* ("field schools") were later initiated, as funding and training had been provided to ASPADERUC from a United Nations Food and Agriculture Organization (FAO) program. This method was used as a means to provide resource committee members with more tangible and immediate benefits for their participation. The training activities addressed themes such as crop rotation for pest control and composting for organic fertilizer.

Strategic planning at the watershed level

Once several communities were organized, a watershed association was formed by representatives from each of the community natural resource committees. The purpose of the association is to define development priorities at the scale of the watershed, develop planning strategies for new projects, and then seek funding for these development proposals. It is through this ground-up approach of organizing community resource committees, forming watershed associations, and presenting proposals to external institutions that the project attempts to connect all potential stakeholders in a region.

In the Conavari watershed, the seven communities that participated in PRA exercises all nominated representatives to serve on a regional committee. The communities all lie within the watershed's 5000 hectares of *suni* – the flat, arable plain of the Lake Titicaca basin. The remaining 22,000 hectares is *puna* – the less productive mountainous region. Livestock is the major agricultural investment in the watershed, making pasture quality a primary stakeholder concern. The Conavari suni is soon to be connected to a major regional irrigation infrastructure project, which will create new management issues regarding water distribution and poor soil drainage. CIRNMA considers the current level of organization among irrigation users to be inadequate to properly manage this new resource.

In the Cardón and Cuzcudén watersheds, a watershed association was formed including members from all 14 caseríos. CEDEPAS facilitated multiple meetings with the association, local political authorities, and area representatives of state organizations. The CEDEPAS facilitator led strategic planning exercises to define development priorities, and a one-day forestry training session with direction from a representative of the Peruvian Natural Resources Institute (INRENA). Prior to the formation of a watershed association there was no formal organization between the upper and lower regions of these watersheds.

Between 1998 to 2000 ASPADERUC had participated in a development planning project for the municipal district of Asunción, which includes nearly the entire La Asunción watershed. A committee (COMUDIA) was created at the level of the municipality to represent political, public, and private institutions in the application of a district development plan. As an alternative to creating a new watershed association, ASPADERUC chose to attempt to integrate project goals with the activities of COMUDIA while working in its three selected caseríos.

RESULTS and DISCUSSION

Community level

Different means for engaging stakeholders at the village level were applied by each NGO as they adapted the original methodologies to match their specific experiences and challenges. CEDEPAS, having the smallest project site, chose to work in all communities of its watersheds and create a true watershed association; ASPADERUC focused exclusively on only three communities, and converted its focus from planning to training to match the experience of its facilitator; and CIRNMA made the greatest commitment to social research by dedicating a full-time PRA professional to seven communities of its watershed (table 3). Given the small size and relative inexperience of these NGOs versus the demands of organizing stakeholders across watersheds of thousands of hectares, such pragmatic adaptations to the original methodology were a necessity.

Led by the CIRNMA sociologist, seven Conavari watershed communities completed the PRA process and three went on to identify development priorities. These are:

- Canllacollo: pasture management through the identification of optimal land for irrigation based on soil characteristics, vegetation diversity, and access to irrigation.
- Huancarani: integrated control of *gorgojo* (a potato pest), through collectively planned rotation of the timing and varieties of potato planted.
- Chancarani: soil erosion control through reducing the intensity of agriculture on steeply sloped lands.

In the Canllacollo cooperative, local farmers guided a GPS delineation of their pastures according to vegetation quality, and the resulting boundaries were integrated with a vegetation study conducted by CIRNMA. By coupling pasture area with measurements of vegetation density and diversity and farmers' knowledge of livestock diets, CIRNMA was able to determine the optimal grazing density and the potential of each pasture parcel to be improved with the introduction of irrigation (figure 18). This same type of study was also carried out in the other two communities.

Three caseríos in the Cardón/Cuzcudén watershed identified development priorities, but none were ultimately articulated as geospatial products. Capellanía claimed mechanized sprinkler irrigation technology as a priority, Cuzcudén prioritized the production and sale of pottery, and El Lloque identified both reforestation and irrigation storage as priorities. In response to El Lloque's solicitation, CEDEPAS did find funding to build a micro-reservoir in the caserío,

however GIS played no role in the process. CEDEPAS also collected an extensive GPS inventory of caserío boundaries, irrigation canals, and springs throughout the two watersheds, led by local farmers. These data have been integrated into GIS, but not yet applied to analysis.

Through PRA activities, each of the three caseríos in La Asunción identified a similar list of production challenges: limited irrigation supply, largely due to poor management of the canal system; low soil fertility; and crop pests, particularly those that damage high value fruit crops. The *Escuelas de Campo* provided farmers with hands-on agricultural training, allowing for collective experimentation of newly introduced methods for insect pest control and the production of compost fertilizer. No spatial analysis was involved in these activities.

Airphoto interpretation exercises were introduced in the three La Asunción communities, and generated high initial interest among participants. The large-format laminated airphoto prints were introduced at monthly irrigation committee meetings, and participants were quickly able to locate and trace caserío boundaries, trails, rivers, areas of high erosion, and the spatial reach or irrigation supply over the images. These features have not been digitized nor has a definitive use of this information yet been identified. The airphoto maps remain with committee members in the caseríos.

Indeed, not all community-identified development priorities may require enough detail of spatial information to justify the use of GIS. However, efforts to support the planning process with GIS, and in particular aerial photography, were hampered by a lack of any specific social research methodology to complement primary data collection and analysis. Sketch mapping had been performed earlier in these communities, but results were not connected to the photo-mapping exercises that were conducted later. The only community-level GIS maps created in this project – the three pasture quality maps for communities in Conavari watershed – were produced by the NGO with the least GIS expertise, but the greatest commitment to the PRA methodology. This result may indicate that success in GIS applications is limited at least as much by the need for social organization and clear project goals as by the technical demands of the technology. This reinforces the claim by Mbile (Mbile, DeGrande et al. 2003) that integrating sketch mapping with spatial analysis requires more expertise in PRA than in GIS.

Even with adequate facilitation of the social process, communities can lose faith and memory of the project when problem identification and planning are not followed up with tangible results. The NGOs therefore recognized a need to follow planning with action, taking their own initiative to provide shorter-term results such as training for cheese manufacturing in Canllacollo, and fruit fly control in the caseríos of La Asunción. Interviews indicate that these are the first activities recalled by farmers. In Cardón/Cuzcudén, where few training activities were provided, CEDEPAS found it difficult to maintain the interest of selected caseríos throughout the length of the project. Similarly, the mayors of Mañazo and Asunción municipalities were initially supportive of the project, but later lost interest when it became apparent that no physical benefits would result within their two-year terms of office. These results emphasize the need to show stakeholders measurable results on the ground in addition to long-range community development plans articulated by GIS.

Watershed level

The associations, GIS maps, and anticipated donors for each watershed are outlined in Table 4. Each of the seven participating communities in the Conavari watershed elected a representative to serve on a regional association. Representing only the lower watershed, the association is not truly a watershed group. More accurately, it represents an ecological region that shares a harsh climate, limited water supply, and wide plains on which livestock are grazed. The Conavari association meets monthly, with the stated goal of acquiring funds for prioritized projects. Currently the group is working to acquire legal status to enable them to accept funds from donors. Targeted projects focus on improvements in livestock and pasture quality; however no specific funding sources have yet been identified.

CIRNMA has produced a 1:150,000 map of pasture improvement potential across the watershed (figure 15). A small loan-granting agency of the national government (FONCODES) offers direct agricultural investment funds to small farmers in the region, with only a small percentage of these loans ending in default. However, CIRNMA has not succeeded in gaining the attention of this agency with either the watershed or community maps of pasture improvement potential.

The watershed association of the Cuzcudén/Cardón watersheds is also seeking legalization so that they may seek loans for selected projects, but no specific donors are yet identified. CEDEPAS helped the association elaborate five profiles of potential projects:

- Forest plantations for firewood, construction material, and soil conservation (figure 17a)
- Expanded avocado production for export
- Expansion of *taya* (*Caesalpinia spinosa)* – a native nitrogen-fixing tree with commercial value
- Conservation of soils on steeper slopes
- Better pasture and livestock management to increase milk production.

These priorities are each represented in simple GIS thematic maps and an outline of the intended beneficiaries, estimated costs, and targeted institutions are outlined in project profiles. The association is coordinating with the San Pablo district sub-prefect for governmental assistance, and with the municipality for land on which to build tree nurseries. Two governmental agencies (INRENA and PRONAMACHCS) are interested in working with the watershed group. Also, the emergence of a watershed vision among inhabitants was indicated when the association organized a watershed soccer championship, drawing teams from seven of the 14 caseríos

No watershed-level association was formed in the La Ásunción watershed. COMUDIA dissolved, and ASPADERUC failed to revive the organization as a substitute for a watershed association. The NGO elaborated its own watershed maps intended for soil conservation and agroforestry (figures 13 and 14), and now looks to a recently formed regional anti-poverty institutional consortium (the *Mesa de Concertación para la Lucha Contra la Pobreza*) for support in project implementation. Watershed maps and new institutional alliances have

strengthened the NGO's solicitation for World Bank funds to develop an agroforestry project in the same watershed.

In terms of tangible impact, it is not yet apparent that GIS provided a significant contribution at the watershed level. Due to delays in preparing secondary data, GIS products were not introduced until rather late in the project, generally after watershed development priorities were set. Furthermore, the content of these products were heavily influenced by the NGOs. The native taya, for example, is an attractive theme for professional agronomists, but local farmers did not appear to share the same optimism for the tree's economic potential, instead emphasizing more proven assets such as livestock and the chirimoya fruit. Most importantly, no investors have requested any specific spatial information products, thus limiting the motive of already busy NGOs to experiment with GIS, and the confidence of watershed inhabitants in the usefulness of GIS products.

Institutional level

Due to factors at the institutional level, further success at GIS implementation may not have substantially improved project results. PRONAMACHCS was plagued with uncertainty and personnel turnover as the Peruvian government passed through three presidential administrations throughout the duration of the project. The primary foreign investor in the Cajamarca region, INCALAC (a private dairy processor), was already averse to funding projects in Asunción due to the lack of access roads into the watersheds principle dairy producing areas. FONCODES does not require technical proposals for its loans and therefore has expressed no interest in using spatial analysis to direct its investments in the Conavari watershed.

The NGOs themselves enjoyed some of the more tangible benefits from using GIS in the project. All three cite improved methodologies in participatory planning and new skills in geographical data management as results of their participation. They are using their newly acquired GIS skills and data to strengthen requests for new project funding, thus keeping open the possibility for continued work in their watersheds.

NGOs are generally more experienced in providing technical assistance to individual farmers than in longer-term watershed development planning; however, their performance in this project demonstrates a potential to work at wider scales provided that adequate project resources are available. They possess a valuable combination of social research skills coupled with an ability to acquire a degree of GIS expertise, making them worthy candidates to integrate capacity-building on the ground with big-picture planning through GIS – a promising combination for sustainable resource management.

CONCLUSIONS

At the village level, an immediate impact of using georeferenced spatial information is to motivate participation of stakeholders across boundaries of age, gender, literacy, or income. However, primary data collection in this project was often applied without a clear definition of goals, leading to a false raising of stakeholder expectations and an unnecessary investment

in data collection. GPS and especially aerial photography should therefore be accompanied by Participatory Rural Appraisal or other proven social research methodologies as a means for guidance.

In building a resource management "vision" at the watershed level, among the first actions to be undertaken should be the production of simple and straightforward GIS maps for stakeholders. These products need not involve actual GIS analysis nor propose specific actions, but can simply portray the watershed boundary and any relevant social or biophysical variables. Such products serve to promote the watershed as a planning unit where this concept has not been previously applied.

As the planning advances, however, concise criteria for analysis are needed for the production of unique thematic maps. NGOs were given few demands regarding the content of GIS products, and therefore developed maps slowly and somewhat redundantly. More precise product demands coupled with a promise of support for watershed proposals would serve to motivate technicians and stakeholders alike to prioritize development projects and create thematic maps.

Potential investors such as PRONAMACHCS are more likely to fund projects that reach beyond individual communities, and development efforts are more likely to see long-term success when resource management issues common to several communities can be linked to secondary data sets and analyzed across a landscape unit such as a watershed. The existing data sets for soil surveys, elevation and land cover at 1:25,000 scale are too coarse to be of much use within villages of 300 hectares, but they can serve to direct actions within a watershed of a few thousand hectares.

Nonetheless, farmers will continue to focus on solving the problems closest to home. The watershed "vision" takes time to build, and can only be established with continuity in project design and real results at the local level. Stakeholders must see the use of information result in action; therefore, by offering results incrementally beginning at the village level, confidence and organization within the watershed my advance and longer-term goals at broader scales can begin to gain importance.

Table 3: Village level stakeholder organization

NGO activities	W A T E R S H E D S		
	Asunción	***Cardón / Cuscuden***	***Conavari***
Communities initially engaged	Three caseríos in lower and middle watershed	All 14 caseríos in both watersheds	Seven communities in lower watershed
Communities prioritized	Same three caseríos as above	Three of the above caseríos, in lower and middle watershed	Three of the above communities
Participatory activities conducted	Committee formed: Resources inventoried; Field training provided	Committees formed or individuals selected; Resources inventoried; Issues prioritized	Committees formed; Resources inventoried; Issues prioritized; Field training provided

Table 4: Prioritized projects as the watershed level

NGO activities	WATERSHEDS		
	Asunción	***Cardón / Cuscuden***	***Conavari***
Watershed association	None formed	Formed in April 2002	Formed in Feb. 2001
Representation	Deferred to district's ***Mesa de Concertación***	All 14 caseríos	Seven caseríos in lower watershed
Legalization	-	In process	In process
Primary proposal	Agroforestry (proposed by NGO itself)	Tree nurseries and forestation	Pasture improvement
Potential donors	World Bank	PRONAMACHCS, INRENA	European governments
Data sources	Topographic maps, Soil and vegetation survey, Airphotos, Hydrologic survey	Topographic maps, Soil and vegetation survey, Airphotos	Topographic maps, Soil and vegetation survey
Maps in GIS	DEM and slopes, "Sensible soils map", Soil conservation plan, Agroforestry suitability	DEM and slopes, Irrigation inventory, Agroforestry suitability	DEM and slopes, Pasture improvement potential

CONCLUSIONS

The accomplishments of this project begin at the community level, where NGOs began to organize resource users around relevant management themes in twenty-four villages. Results were most favorable when Participatory Rural Appraisal (PRA) methods were fully applied, or where technical training was provided. Working within existing organizations such as an irrigation committee proved more effective than creating new ones. However, without continued NGO facilitation, nor any imminent prospect for external assistance beyond organization and planning, village resource management committees have begun to dissolve.

In two of the three project watersheds, community representatives are maintaining watershed management associations with minimal assistance from NGOs. The organizations are seeking legal status to allow them to independently seek funding. Through the process of strategic planning with these associations, NGOs have strengthened their presence in the watershed communities and created alliances with some governmental institutions working in these regions.

The production of GIS thematic maps using secondary data has proven to be a realistic goal. With limited training and support, NGO technicians succeeded in creating basic maps of slope, ecological zones, soil conservation potential, agroforestry potential, and pasture improvement potential for their watersheds. Creating the preliminary data layers for elevation, soil characteristics, and land use proved time consuming, and the original input data included significant geographic error. However, the products can be used to calculate the spatial extent of proposed development actions within a watershed, and NGOs can continue to use their databases for future planning activities.

At the village level, airphotos proved powerful in drawing stakeholders' attention and facilitating community dialogue for resource management. Participants were efficient in delineating village boundaries and landmarks, irrigation canals, and individual farm boundaries, and the process encouraged involvement across age and gender boundaries. However, the photomaps have not been used outside these communities, and the effects of this activity on stakeholder empowerment therefore has not been analyzed.

The greatest beneficiaries of the project may be the NGOs themselves, as they acquired GIS management skills, created spatial databases for their watersheds, and enhanced their skills in PRA methodologies. The participating NGO are in perhaps the best position to integrate social research with the technology of GIS. They are trusted by local stakeholders, while they also maintain good relations with centralized institutions. Each NGO in this project has used these benefits to enhance their solicitations for future project grants. Results of these applications are pending.

Beyond the technological barriers of GIS adoption are the limitations in data and institutional resources. NGOs generally were limited in the time they could dedicate to GIS training and database development. Project funding provided software and some secondary data, but

further efforts will require additional funding. The scale and detail of soil and vegetation surveys and the coverage of topographic maps and airphotos present inherent limitations. Primary data collection can improve existing data sets, opening opportunities for participation but also demanding an extensive investment of time and learning by both NGOs and stakeholders.

Perhaps the greatest disappointment in the project was the lack of any offers for investment in the watersheds as a result of management planning and its articulation through GIS products. The Peruvian soil conservation agency – the project's first anticipated client – suspended all new development plans during the political turnover that stretched through the duration of the project, and private investors were few in these isolated areas of the Andes. Potential opportunities have arisen with the recent regionalization of the Peruvian government and the creation of an inter-institutional anti-poverty program; however, real money for proposals has yet to filter down to the project watersheds.

The monetary cost to stakeholders for GIS operation in this project was not great, as the NGOs were provided funds for data, software, training, and at least one full-time salary for project implementation. However, the development of data input and GIS products is inevitably time-consuming, especially for NGO personnel who had no former experience with the activities. The demands of truly participatory development through PRA methodology, particularly with the added task of collecting primary georeferenced data, is substantial and requires more personnel and more time than were available in this project.

It is noteworthy that the only communities for whom specific GIS products were developed had the benefit of a full-time PRA facilitator plus occasional technical training exercises, yet the NGO working with this area had the least GIS expertise of the three. This result may indicate that success in GIS application is limited less by technical demands of the tool and more by the need for social organization and continued community support of project goals.

The disparity in results between the watershed versus the village level demonstrates the relative ease of managing GIS products at the smaller scale. However, NGOs were driven to work with spatial data at the community level as well. There arose a difference in strategy between NGOs who prefer to work on the ground within individual communities, and donors or agencies that tend to address larger areas with less detail and thus prefer watershed maps over community maps. Mapping individual communities may be too demanding an activity to repeat across all villages in a watershed; however, those communities that are selected for PRA exercises may make better use of watershed-scale products if these can be supplemented with village-scale georeferenced data. Watershed maps created from secondary data are far more efficient to produce, but these products have been sometimes disputed by farmers' in-field observations (Posner, Bussink et al. 2002). Participatory photo-mapping can provide farmers with a means to express their knowledge in a format compatible to the smaller-scale maps produced by GIS technicians.

As concluded by Mbile (2003), attempts to integrate GIS with community sketch mapping require a basic understanding of GIS, but also a mastery of Participatory Resource Mapping methodology. In this project, PRM occurred before airphotos had been acquired, and photo-mapping exercises did not relate to the earlier PRM activities. As a result, participants were not clear of the objectives of the exercises, and the information obtained was rather arbitrary. Airphotos are indeed a powerful tool, but future photo-mapping efforts must treat them as simply an improved medium over which to conduct disciplined PRM methodology.

The difficulty in orthorectifying airphotos has inhibited the translation of photo-mapping data into GIS, but a greater limitation is a lack of clearly identified goals for the integration of primary and secondary data. Therefore, a participatory GIS methodology should also include a process of needs assessment, whether formal or directed by the NGOs themselves, as a means to better define project objectives.

An additional shortfall in this project was the simple limitation of time. Watershed-level maps were not available at the initial community meetings, thus delaying the promotion of a watershed "vision" among stakeholders. Data collection at the village level fell behind PRA activities. Independent funding could not be secured before project funds expired. With only 24 months, limited funds, and no prior GIS experience, *Procesos y Productos* was not likely to achieve results comparable to those from much larger studies frequently cited in participatory GIS literature. The best achievements of this project may still come as the participating NGOs apply their newly acquired skills to future efforts.

The assemblage of existing data in GIS can be accelerated through centralization of the process. In Peru, as in many developing countries, acquisition of geospatial data can be time consuming and often requires special contacts in particular institutions. All three NGOs conducted a parallel process of data acquisition and integration, which could have been more efficiently executed through contractors or centralized technical assistance. This investment would then leave NGOs more time for primary data collection or product creation. Though introducing a "top-down" component to an otherwise decentralized process, secondary data integration is already a rather generic and pre-defined procedure that should not be significantly changed by systematization.

In order to maintain stakeholder interest for the duration of the project, NGOs recognized the need to link planning with action. On their own initiative, they conducted technical training programs and offered some small physical rewards to participants. Results from PRA activities demonstrate that stakeholders do indeed value long-term solutions such as reforestation and soil conservation; however, in interviews farmers first reflected on immediate products such as improved seeds or pest control workshops. Small but tangible results in the short-term can have a great impact in maintaining stakeholder interest and confidence in a project.

Even if no GIS analysis has yet been applied, secondary data layers should be given maximum exposure to stakeholders. The simplest of maps can be the most useful in the initial stages of planning, as indicated by municipal authorities that showed more interest in the input data layers for soil or elevation than in final thematic maps. Community events such as the soccer tournament held by the Cardón/Cuzcudén watershed association present an excellent opportunity to utilize the power of GIS to produce attractive, straightforward maps that command people's attention.

Nonetheless, without requests from investors for specific products, map production by the NGOs became mostly an academic exercise, motivated primarily by a need to demonstrate GIS proficiency for internal project evaluation. The process of technological adoption, innovation, and independent management by GIS technicians may have been accelerated by the definition of concise, funding-dependent criteria for GIS product development.

The above results indicate that the use of GIS in this project may have ultimately been a "hammer looking for a nail" (Posner 2001). This may be attributable in part to the fact that the project was designed to address long-term resource management issues, whereas most participatory GIS applications are initiated in response to more acute social conflicts or competition for resources. The impediments to GIS application addressed in this study – more so than the complexity of the technology itself – must first be overcome to make participatory GIS a truly effective process in settings such as this that offer limited physical, informational, and institutional resources.

APPENDIX I: NGO and Watershed Profiles

Non-profit organizations

The *Asociación para el Desarrollo Rural de Cajamarca* (ASPADERUC) is an independent, non-profit organization created in 1978 and based in the city of Cajamarca. Its mission is to improve the economic, social, and environmental conditions of the rural population in the department of Cajamarca through the promotion of sustainable development and gender equity. ASPADERUC promotes soil and water conservation, strategic planning with local governments, management and commercialization of diverse Andean agricultural products, agroforestry, irrigation, pest management, and agro-tourism. In reaching these goals, ASPADERUC has produced soil conservation structures, tree nurseries, seed storage structures, rural libraries, demonstration farms, water supply systems, in-field training programs, agricultural production assistance, district-wide strategic plans, and health education. Funding for ASPADERUC comes from foreign governments and international and private organizations.

ASPADERUC maintains an average of ten employees, most of whom have a university education in engineering, agronomy, or forestry. For *Procesos y Productos*, it has assigned an agronomist and a forester for in-field participatory work, and a civil engineer with computer design experience for creating mapping products.

The *Centro Ecuménico de Promoción y Acción Social* (CEDEPAS) is a private, non-profit institution working since 1992 in the departments of Cajamarca and La Libertad in northern Peru. Funding for current projects comes from several sources including foreign embassies and international organizations, while thirty percent of total income is generated internally. The mission of CEDEPAS is threefold: to promote sustainable development of natural resources, to enable competitiveness among small farmers and entrepreneurs, and to strengthen democratic institutions in Peru. The division of CEDEPAS responsible for the first of these goals, *Área de Gestión de los Recursos Naturales* (ARENA), was given responsibility for carrying out *Procesos y Productos*. ARENA provides organization, training, information, and infrastructure to rural communities, primarily for potable water and irrigation systems and agricultural production. The entrepreneurial division of CEDEPAS is also working in the study area to promote marketable bean and fruit crops through farmer training in production, pest control, and commercialization.

Overall CEDEPAS has over 40 employees, seven of whom manage ARENA with degrees in civil engineering, agronomy, and sociology. Among them, three have worked in *Procesos y Productos*: an agronomist working with communities, and two civil engineers: one with computer management and design experience for operating GIS, and one with administrative experience for overall project management.

The *Centro de Investigación de Recursos Naturales y Medio Ambiente* (CIRNMA) is a non-profit created in 1992 to assist small farmers in agricultural production research, technology transfer, agro-industry, small business organization, training, and credit. Projects include

irrigation and pasture management, conservation and commercialization of Andean grain and tuber varieties, and production of wool clothing for export. Funding comes from international and national organizations, including the private sector, plus income generate by commercial activities. CIRNMA is based in the city of Puno in southern Peru and works in the *altiplano*, a high altitude plateau with characteristics much different than the steep eastern Andean slopes of Cajamarca.

In contrast to the NGOs in Cajamarca, CIRNMA has dedicated a sociologist to work full time with the communities selected for *Procesos y Productos*. Data management and GIS responsibilities were given to an agronomist with some experience in database management, but none in the use of GIS.

PRONAMACHCS

The project's primary intended client for GIS products was the *Proyecto Nacional de Manejo de Cuencas Hidrográficas y Conservacion de Suelos* (PRONAMACHCS) – a program of the Peruvian government administering soil and water conservation projects in the rural hillsides. PRONAMACHCS suffered severe political manipulation in the 1990s by the Fujimori administration, leaving a reputation for top-down strategies dependent on prescriptive physical infrastructure and direct incentives to farmers.

The agency is now seeking a new identity under the current Toledo administration. Recently the agency has attempted to redirect itself by serving more as a "second-floor" organization to administer funds and direction for conservation projects, leaving implementation to private organizations and communities (Posner 2001). CONDESAN viewed PRONAMACHCS as a potential client for information products created through *Procesos y Productos*; however, little of the promised progress had been seen in the agency since a turnover in administration in 2001.

Project watersheds

ASPADERUC has selected the watershed of the Asunción River in the upper Jequetepeque basin for the *Procesos y Productos* project. This 8515 hectare watershed lies entirely within the district of Asunción, in the province of Cajamarca, and comprises just over half the district's area. The range of elevation in this watershed is extreme and includes the ecological zones *yunga* (1500m - 2250m), *quechua* (2250m - 3400), and *jalca* (> 3400m). Agriculture is equally diverse, and is defined primarily by elevation. Production systems include sugarcane and fruit in the yunga, grains and tubers in the quechua, and grazing in the jalca. The watershed is home to a high level of biodiversity, with 117 plant species identified. However, the extremely steep topography (50% of the watershed with slope > 20 degrees), shallow soils, and six-month dry season of the region provide great challenges to agriculture.

ASPADERUC had experience in the Asunción watershed prior to its work in *Procesos y Productos*. Between 1998 and 2000, it worked with CARE and CONDESAN in developing the *"Strategic Plan for the Development of the District of Asunción"*. This project produced

some biophysical and socio-economic data, and organized acting authorities and organizations into a planning group (*Comité Multisectorial para el Desarrollo Integral de la Asunción* – COMUDIA) to execute the strategic plan for the district (ASPADERUC 2002).

CEDEPAS has selected a pair of watersheds within the districts of San Pablo, San Luis, and Tumbadén, also in the department of Cajamarca and the upper Jequetepeque river basin. The adjacent catchments of the rivers Cardón and Cuzcudén comprise the 4240 hectare study area, including yunga and quechua zones. The lower region enjoys biophysical conditions favorable to the production of several marketable agricultural products; however, transport and commercialization challenges have so far limited this potential. The middle region suffers a lack of access to irrigation and few forest resources. Much of the upper region is productive for livestock, but access is extremely limited, especially in the wet season. CEDEPAS has been working in these districts since 1998, but *Procesos y Productos* is its first experience in these particular watersheds (CEDEPAS 2002).

The CEDEPAS and ASPADERUC watersheds share many characteristics common to the upper Jequetepeque basin. Each area experiences the same wet and dry seasons, and a similar variation in temperature and rainfall according to altitude. In both watersheds, shallow soils and extremely steep slopes predominate, and nearly all agricultural production is for self-consumption. Poverty is extreme in both areas, demonstrated by limited education, health care, and infrastructure, though the relation of poverty to factors such as elevation, access, and organization is not well studied. Both NGOs identify limited availability of water, low soil fertility, and a lack of organization among the challenges to development in these watersheds.

The watershed selected by CIRNMA lies mostly within the district of Mañazo, department of Puno, in the southern highlands (*altiplano*) of Peru. This region differs from the upper Jequetepeque in many respects. As with the eastern slopes of the Andes to the north, this region experiences distinct wet and dry seasons. However, at altitudes above 3800m, climate often supercedes water or other biophysical factors as the limiting factor for agriculture. Risks include frost, drought, and in the wide plains (*suni*) of the Lake Titicaca basin, poor drainage. In the surrounding highlands (*puna*), the climate is harsher and soils less fertile, allowing for little more than grazing of cameloid species.

The 27,000 hectare Conavari river watershed selected by CIRNMA is much larger than those of the Cajamarcan NGOs, and includes a great deal of sparsely populated and inaccessible puna. CIRNMA has therefore elected to work only within a subset of this watershed, a region of mostly suni within the Mañazo district boundary. This area was selected primarily because of a large irrigation project currently under construction. Three thousand hectares of this area are programmed to receive out-of-basin irrigation water through the Lagunillas project, and this, more than location within the watershed, is seen as a unifying issue for development. The bi-national *Programa Especial del Lago Titicaca* (PELT), financier of the project, works only in constructing the infrastructure, leaving the beneficiaries with no training in managing their new resource. CIRNMA has been working to organize and train producers for the arrival of water in the canals (CIRNMA 2002).

In northern Peru, the smallest unit of rural political administration is the *caserío*, consisting of dispersed individual farms and a centralized school, church, and communal meeting area. Caseríos in the two northern watersheds average approximately 40 – 80 households distributed and an area 200 – 400 hectares. In the southern highlands, administration is less uniform and a community may be defined as an association of producers, a business cooperative, or simply a campesino community.

Table 5: Profile of project watersheds

NGO	*Asunción*	*Cardón / Cuzcudén*	*Conavari*
District and department:	Asunción, Cajamarca	San Pablo, Cajamarca	Mañazo, Puno
Region	Upper Jequetepeque	Upper Jequetepeque	*Altiplano*
Watershed size	8515 ha	4240 ha	27,000 ha
Elevation (m)	1570 - 4150	1220 - 3280	3860 - 4850
Ecological zones	25 % yunga 60 % quechua 15 % jalca	40 % yunga 60 % quechua	35 % suni 65 % puna
Topography	very steep	very steep	flat (suni); steep (puna)
Soil	shallow	very shallow	saline (suni); shallow (puna)
Vegetation	crops: 56 % pasture: 33 % forest: 0 % barren: 11 %	crops: 58 % pasture: 12 % forest: 0.5 % barren: 30 %	crops: 8 % pasture: 47 % bare: 12 % no data: 33 %
Rainfall (mm/yr)	500 - 1000	360 - 920	275 - 980
Avg. temp (°C)	16 – 4	18 - 9	16 - 1
No. families	1300	730	1700

Table 6: Profile of partner NGOs

NGO	*ASPADERUC*	*CEDEPAS*	*CIRNMA*
Mission	Rural economy, Society, and Environment	Democracy, Environment, and Small enterprise	Research and development for production systems
Year of creation	1978	1992 (in Cajamarca)	1992
Department	Cajamarca	Cajamarca, La Libertad	Puno
Previous experience	Resource conservation, Environmental education, Agricultural production	Water supply, Agricultural production, Commercialization	Technology transfer, Agro-industry, Business development
# employees	10 (10% women)	40 (25% women)	5 (no women)
Average education	University degree	University degree	University degree

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FIGURES

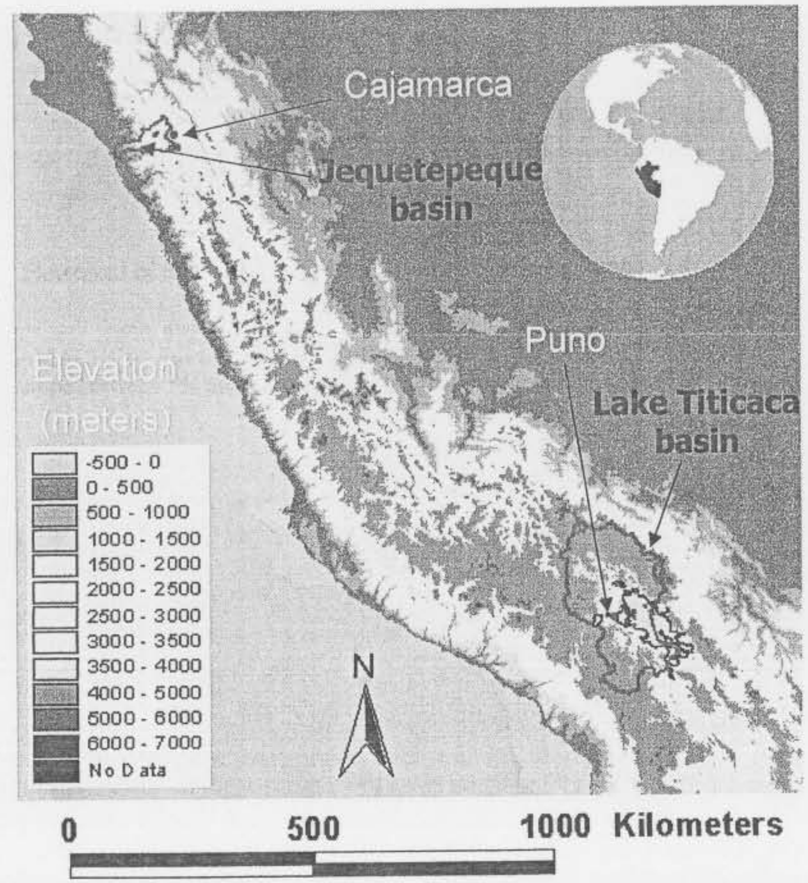


Figure 1: Project watershed sites

Asunción, Cardón/Cuzcudén, and Conavari watersheds are colored in yellow; their respective basins are outlined in blue.

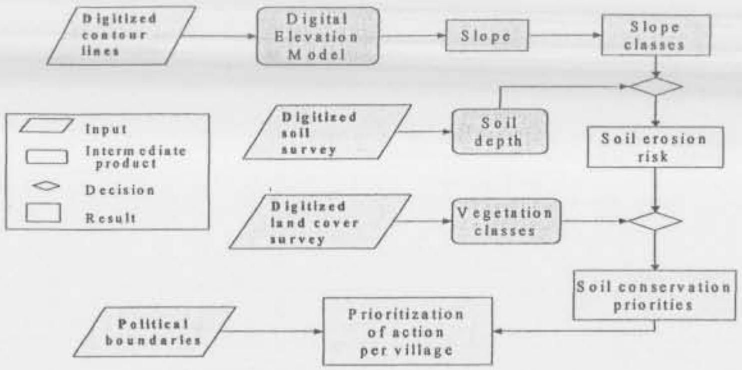


Figure 2a: Flowchart of Encañada soil and water conservation map

Input for slope, soil depth, and general land use are analyzed using soil conservation criteria from PRONAMACHCS. For example, infiltration ditches are recommended in cultivated areas with a slope between 5% and 15% and topsoil depth between 30cm and 60cm.

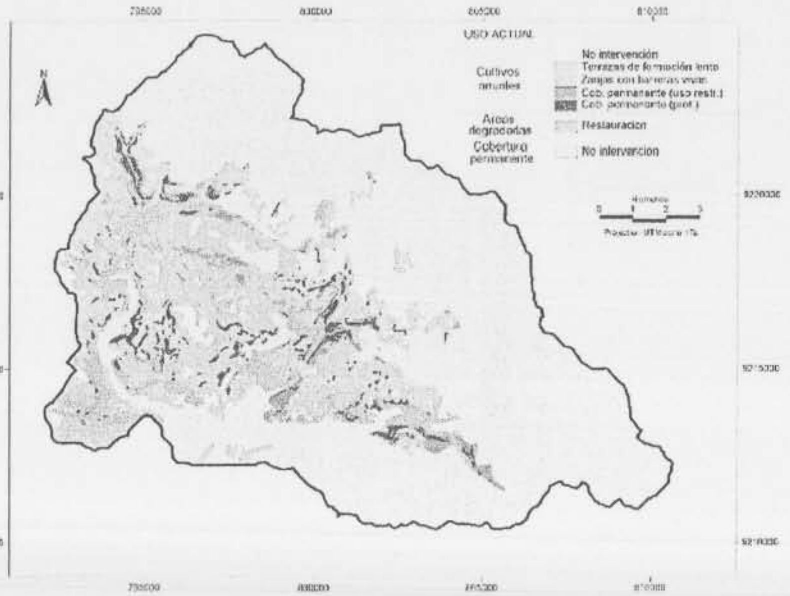


Figure 2b: La Encañada soil conservation map

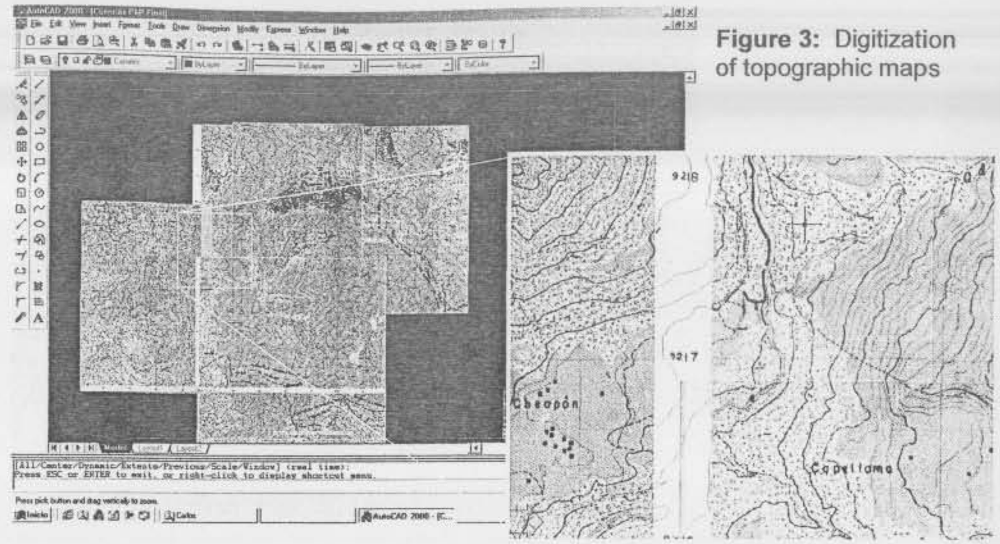


Figure 3: Digitization of topographic maps

Scanning and digital re-joining of topographic maps, and digitization of contour lines, performed in AutoCAD

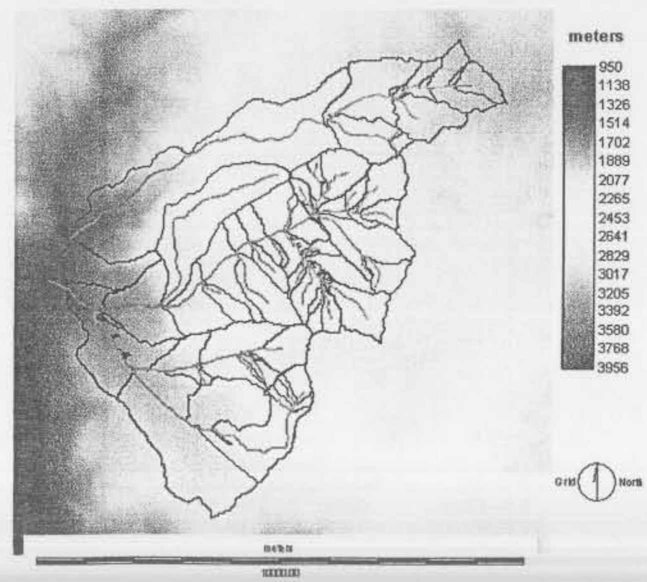


Figure 4: Digital elevation model (DEM)

DEM for 4240 hectare Cardón / Cuzcudén watershed, with digitized rivers and calculated watershed boundaries

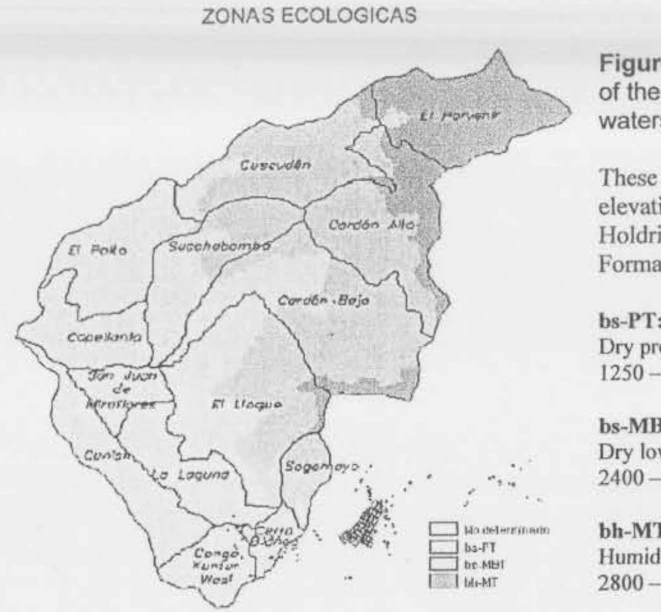


Figure 5: Ecological zones of the Cardón / Cuscudén watersheds

These zones are derived from elevation, according to the Holdridge 1947 World Plant Formations:

bs-PT:
Dry pre-montane tropical forest
1250 – 2400 masl

bs-MBT:
Dry low mountain tropical forest
2400 – 2800 masl

bh-MT:
Humid mountain tropical forest
2800 – 3300 masl

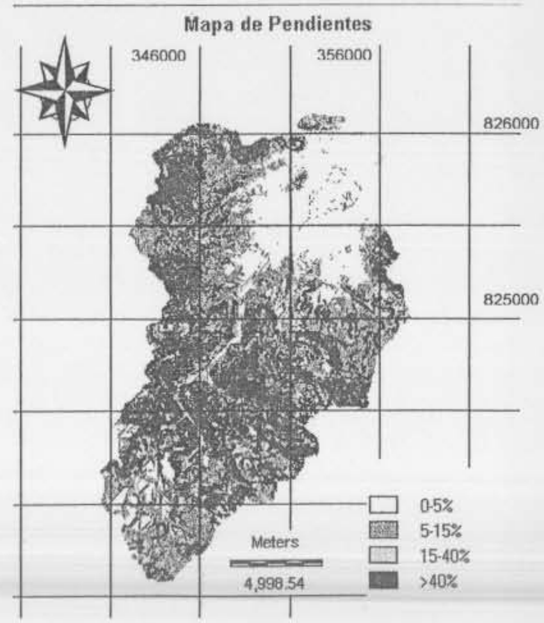


Figure 6: Slope map for the Conavari watershed region

This area is not a true watershed. In lower regions, boundaries are defined by political borders instead of topography

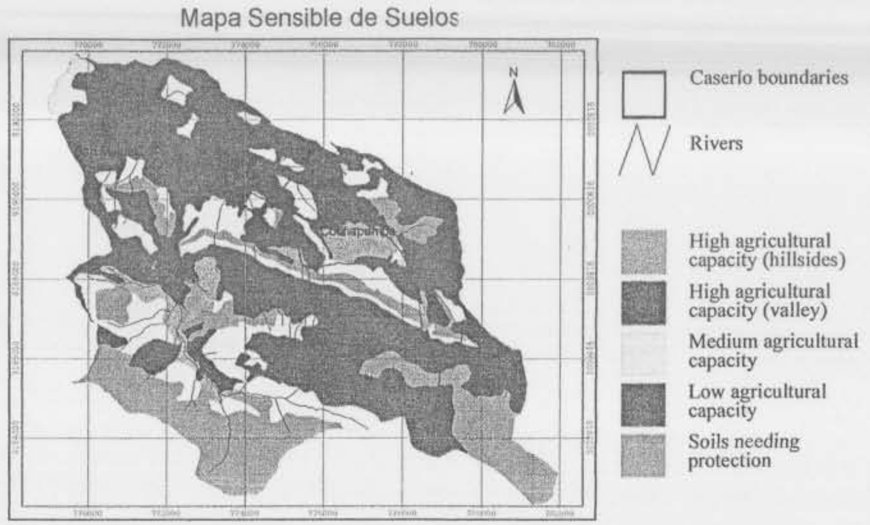


Figure 7: "Sensible soil map" for La Asunción watershed

Figure 8: Participatory photo-mapping in La Asunción

Figure 9: Participatory photo-mapping in Cardón / Cuzcudén

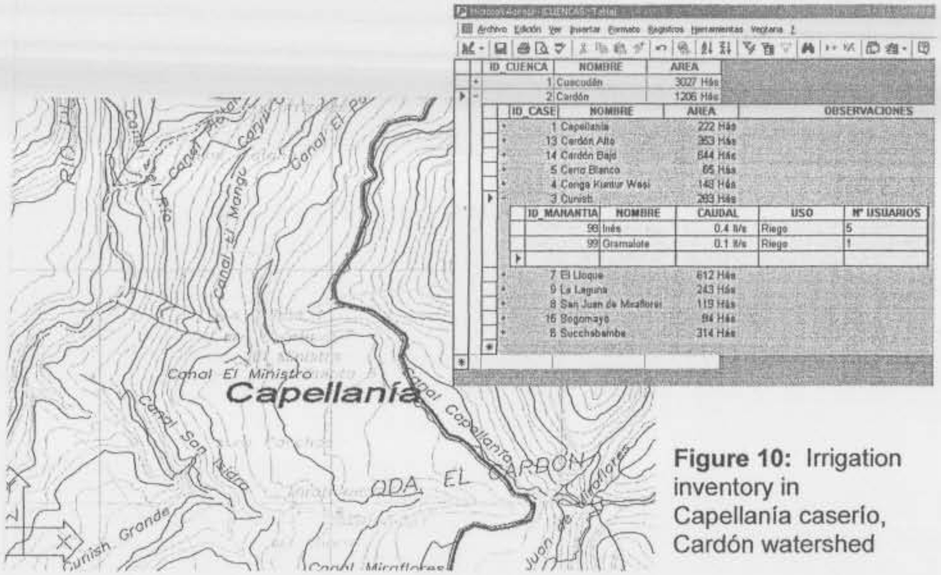


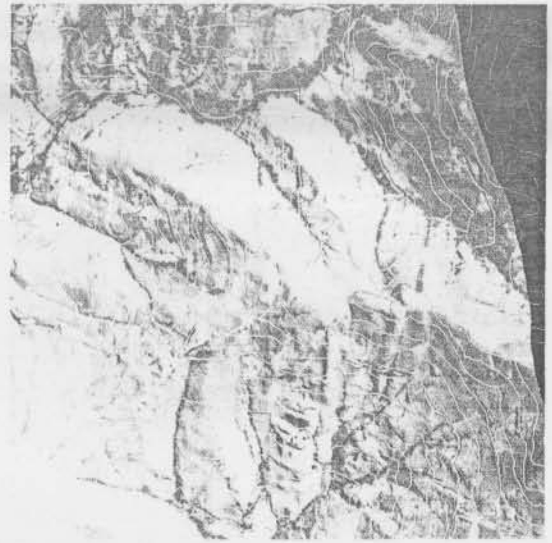
Figure 10: Irrigation inventory in Capellanía caserío, Cardón watershed

Figure 11: Year 2000 Orthophoto covering part of Cuzcudén caserío

Yellow lines represent soil survey unit boundaries derived from older airphotos that are not differentially rectified; blue lines represent irrigation canals measured with a 12-channel GPS receiver

Figure 12: Year 2000 Orthophoto underlying digitized contour lines

This orthophoto of Cardón / Cuzcudén was derived with input from a DEM that was created by these contour lines



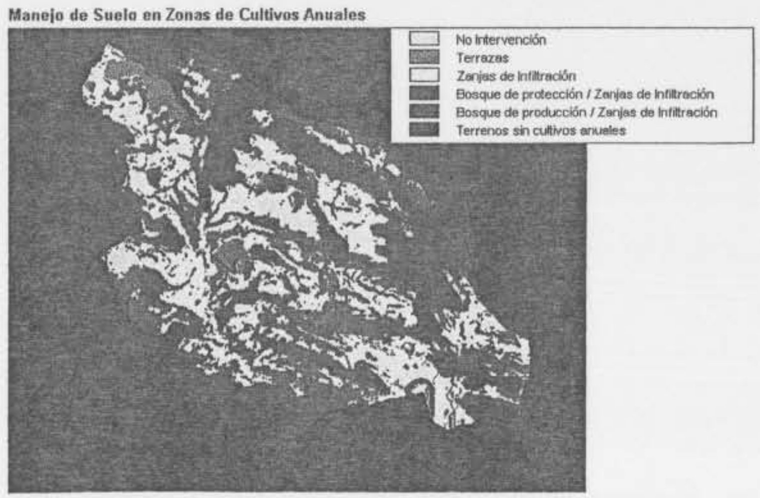
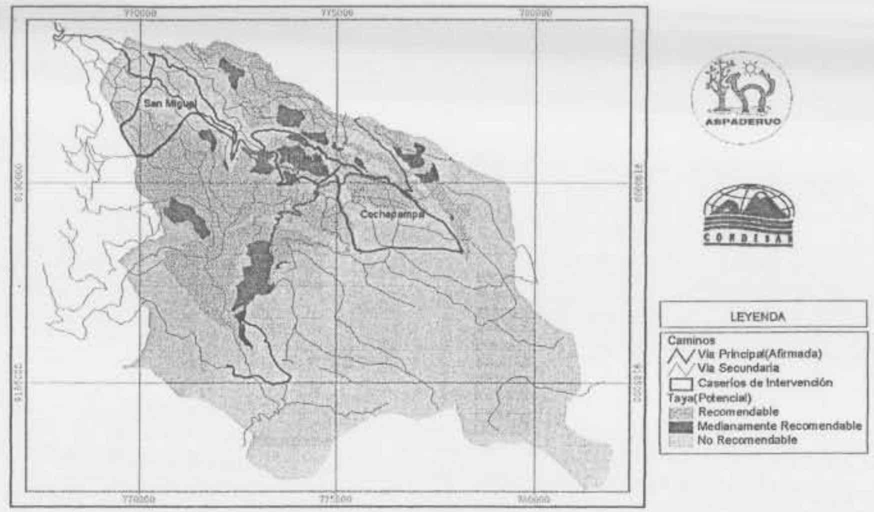
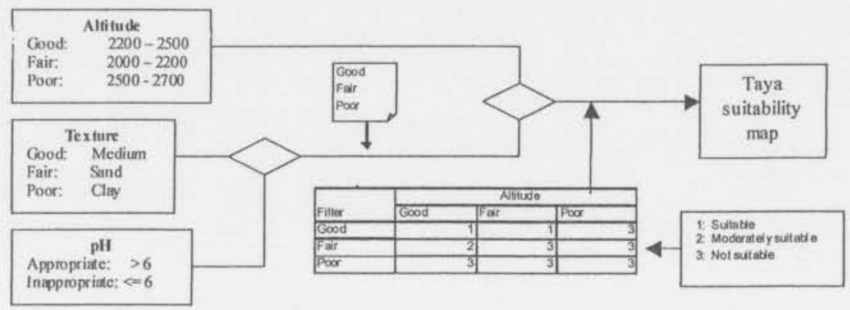


Figure 13: Soil conservation map for La Asunción watershed

Proposal	San Miguel	Huabal	Cochapampa	Watershed
No intervention	0	0	0	4811
Terraces	91	27	9	153
Infiltration ditches	94	79	190	1158
Production forest	56	8	59	1013
Protection forest	3	0	0	9
Uncultivated areas	67	50	132	1354
Total area	312	165	390	8498

Regiones Potenciales para Taya Microcuenca La Asunción





Potential for Taya	Area (ha)	Area (%)
Suitable	2145.00	25.2
Moderately suitable	376.00	4.4
Not suitable	5994.00	70.4

Figure 14: Potential for *taya* (*Caesalpinia spinosa*) in La Asunción watershed

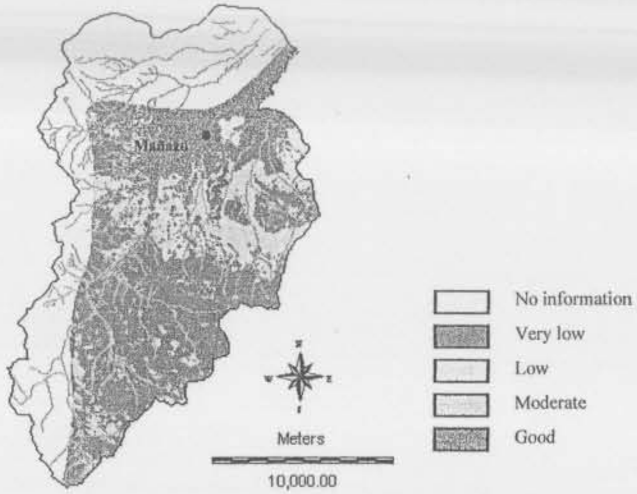


Figure 15: Pasture improvement potential in Conavari watershed

A 1:150,000 scale thematic map covers the two-thirds of the Conavari watershed that is covered by secondary data.
For slopes less than 15%, gravity-fed irrigation is considered feasible, and drainage is therefore added as a parameter.

Potential	Good	Moderate	Low	Very low	Total
Watershed area (ha)	3,300	2,500	3,855	8,425	18,080
Watershed area (%)	18.1	13.8	21.4	46.7	100

				Potential for pasture improvement
Irrigation possible (slope <15%)	Good natural drainage	No salinity limitation	neutral to alkaline	Good
			slightly acidic	Good
			acidic	Moderate
		Salinity limitation	neutral to alkaline	Moderate
			slightly acidic	Moderate
			acidic	Low
	Poor drainage	No salinity limitation	neutral to alkaline	Low
			slightly acidic	Low
			acidic	Very low
		Salinity limitation	neutral to alkaline	Very low
			slightly acidic	Very low
			acidic	Very low
Irrigation impossible (slope >15%)	pH	neutral to alkaline		Low
		slightly acidic		Low
		acidic		Very low

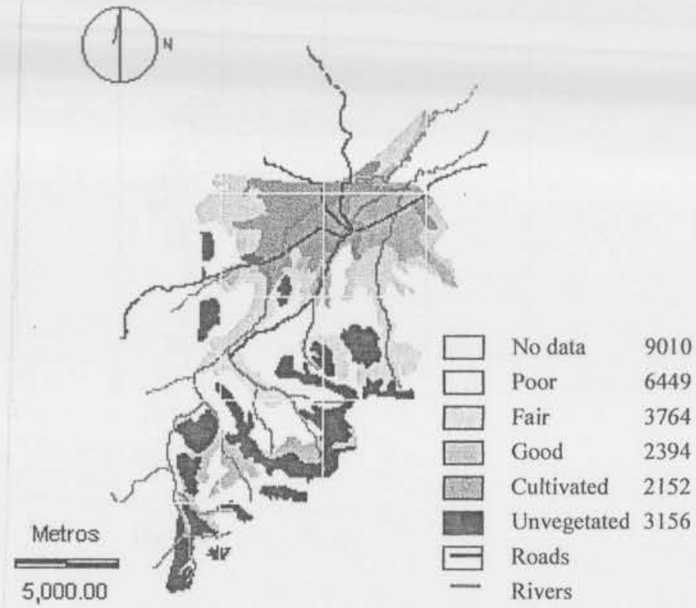


Figure 16: Vegetation potential for sheep and goats in Conavari watershed

Vegetation association	code	cow	llama	sheep	alpaca
Festuchetum - muhlenbergetum	Fe-Mu	3	3	3	2
Calamagrosetum I	Cacu	3	3	3	2
Stipetum	St	2	2	2	2
Festuchetum I	Fedi	1	1	1	1
Festuchetum III	Feri	2	2	3	3
Calagrosetum II	Cavi	2	3	3	2
Pycnophylletum	Py	1	1	1	1
Muhlenbergetum - distichlietum	Mu-Di	1	1	2	3
Parastrephetum	Pale	1	1	1	1
Distichetum	Dimu	1	1	1	3
No vegetation	SV	0	0	0	0
Cultivated areas	AC	0	0	0	0

1 = Poor
2 = Fair
3 = Good

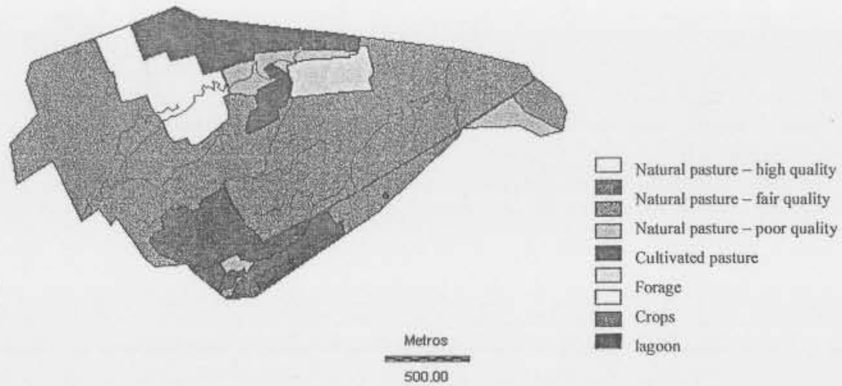


Figure 18: Pasture typology for Canllacollo cooperative, Conavari watershed

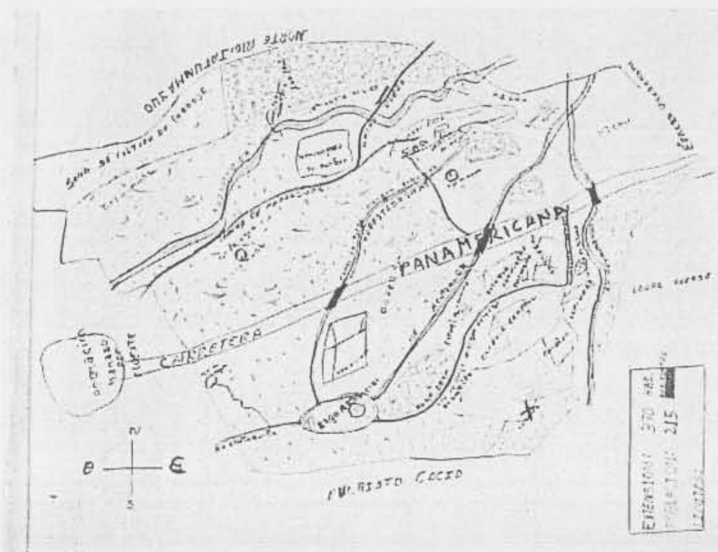


Figure 19: Canllacollo community sketch map of natural resources