Explorations of Participatory GIS in Three Andean Watersheds

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INTRODUCTION

GIS for Rural Development in the Andes

An information revolution brought on by rapidly advancing digital data processing technologies is now influencing rural development in isolated regions of the world. Geographic Information Systems (GIS) provide a potentially useful tool for spatial analysis of natural resource management in developing nations; however, this evolving technology must blend with current social changes. Development philosophies worldwide now stress the need to incorporate the knowledge and perspectives of local stakeholders (Chambers 1994; Rhoades 1998; Hinchcliffe, Thompson et al. 1999). Politically, the Americas have seen movements toward decentralization of state governments and democratization of local politics, allowing sub-national authorities some freedom to tailor development actions to local needs (OAS 2001). In this setting, GIS is seen as a practical tool for spatially linking national databases with local perspectives to promote awareness, facilitate planning, and earn funding for prioritized projects (Ashby, Sanz et al. 1999).

In response to these trends, new GIS methodologies are emerging that involve not only practitioners of the technology, but also the populations who stand to be affected by spatial information products. Emerging concepts include "community-integrated GIS," which remains agency-driven but incorporates stakeholders' perspectives of their landscape (Harris and Weiner 2002); and "GIS in participatory research," which considers GIS as a tool to integrate with pre-existing forms of social investigation (Abbot, Chambers et al. 1998). An underlying assumption in these definitions is that by participating in the process of GIS application, stakeholders can significantly contribute to the success of resource management efforts (Craig, Harris et al. 2002; Kyem 2002a). Such strategies for delivering georeferenced data and spatial analysis tools to the local level are commonly defined as *participatory GIS*.

Many case studies of participatory GIS in developing countries involve communal forest management (Bocco and Toledo 1997; Mather 2000; Jordan 2002; Puginier 2002; Kyem 2002b), and are often supported by organized stakeholders, governmental mandates, and formal GIS training and services. Fewer studies involve individual landowners engaged in agriculture or livestock management, or small organizations receiving minimal external assistance. Participatory GIS theorists and practitioners recognize a continued need for in-field testing of methodologies (Abbot, Chambers et al. 1998; Barndt 2002), as additional case studies in challenging settings can illustrate likely impediments and potential impacts of GIS applications for both community and institutional stakeholders.

This paper examines the application of GIS to a community-based natural resource management project in three small watersheds of the Peruvian Andes. Named "*Procesos y Productos*," this pilot project was administered between May 2000 and May 2002 by the *Consorcio para el Desarrollo Sostenible de la Ecoregión Andina* (CONDESAN),a sustainable development consortium within the International Potato Center (CIP) in Lima, Peru. Three local non-governmental organizations (NGOs) applied Participatory Rural Appraisal (PRA) methods to help stakeholders prioritize development goals at both the village and watershed scale. The NGOs collected secondary data and created georeferenced maps of proposed soil and water conservation actions in their respective watersheds. The resulting thematic maps are intended to guide management decisions, gain outside support for development proposals, and build a sense of collective resource management among watershed inhabitants.

The use of GIS is evaluated here at both the watershed level and the community level to explore three fundamental questions: (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) And, with these data, what practical GIS data products can be created to facilitate a participatory development process? Results should be of interest to small NGOs seeking empirical evidence of GIS performance in rural participatory resource management, particularly in developing countries limited in educational, administrative, communications, and spatial data infrastructure.

Study Site and Actors:

Two of the three project watersheds — San Pablo and La Asunción — lie in the upper Jequetepeque basin of northern Peru (Figure 1 and Table 1). This region is home to multiple ecological zones, extremely steep topography, and shallow soils. Agricultural production is diverse and strongly dependent upon irrigation during a six-month dry season. Severe poverty, poor services, and physical isolation add to the development challenges in this region (ASPADERUC 2002; CEDEPAS 2002).

The third and largest project site — Mañazo — lies in the southern highland department of Puno, near Lake Titicaca. The wide plains of this *altiplano* region endure frequent frosts and occasional drought. The population depends heavily upon livestock and forage crop production. Poverty is equally if not more pronounced here than in northern Peru (CIRNMA 2002).

Table 1: Watershed study sites

Study Site	Asunción	San Pablo	Mañazo
District and department	Asunción, Cajamarca	San Pablo, Cajamarca	Mañazo, Puno
Watershed size	8515 ha	4240 ha	26,915 ha
Elevation	1570–4150 m	1220–3280 m	3860–4850 m
Avg. annual rainfall	500–1000 mm	360–920 mm	280–980 mm
Avg. temperature	4–16 C	9–18 C	1–16 C
Number of households	1300	730	1700
Participating NGO	ASPADERUC [1]	CEDEPAS [2]	CIRNMA [3]

[1] *Asociación para el Desarrollo Rural de Cajamarca*
[2] *Centro Ecuménico de Promoción y Acción Social*
[3] *Centro de Investigación de Recursos Naturales y Medio Ambiente*

The three local NGOs working in these watersheds are representative of non-profit natural resource development and conservation organizations of the Andean region. They are staffed by Peruvian nationals—primarily engineers or agronomists— and they work closely with stakeholders in search of sustainable and practical solutions to fundamental resource management challenges. Few have been formally trained in PRA methodologies, and while most are adept with computers, none had used GIS prior to this project.

An 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. Historically the agency has built prescriptive physical infrastructure such as terraces, and gained farmer participation through food-for-work and other direct incentives. These practices have helped to create an environment of paternalism in rural Peru; however, the agency is redirecting itself as an administrator of funds for conservation projects, leaving implementation to private organizations and stakeholders.

METHODS

Secondary Spatial Data Integration:

Project funds provided each NGO with a full-time license to the geographic modeling and image processing software package Idrisi32 (Clark Labs 2000). Each NGO assigned GIS operations to a staff engineer or agronomist with previous computer experience, but no particular knowledge of GIS. A consultant from CIP provided three-day GIS training workshops to NGO staff at the beginning and mid-point of the project, and visited the NGOs frequently. Two visiting graduate students provided direct assistance to NGOs during periods of the project.

The NGOs acquired hard copy topographic maps, soil surveys, and land use data at the finest scale available for their watersheds (Table 2). Lacking large format scanners, they scanned topographic sheets in sections, digitally rejoined them into a single image, and then digitized the contours on-screen using AutoCAD. They then used Idrisi to interpolate the contours into a 15-meter resolution Digital Elevation Model (DEM). Three themes were derived from each DEM. Watershed boundaries were delineated, with outlets digitized from topographic maps. Within the watershed, elevation was classified into agro-ecological zones defining average temperature, rainfall, humidity, and common plant genera as defined by Holdridge (1947). Average slope values were also calculated from the DEM, and the resulting slope grid was reclassified and filtered to create an image of selected slope ranges.

As an improvement over the national soil and vegetation data sets, the NGOs contracted finer-scale surveys of the Asunción and San Pablo watersheds using 1972 stereo aerial photography and field observations. To create uniformity within survey units, soil associations were reclassified to the most dominant soil characteristic for that unit. This action creates discrete-value units that can be analyzed with other thematic layers in GIS, but also generalizes attributes within soil units. Both soil survey and land cover data were simplified in this way to create thematic layers of individual characteristics (Table 2).

Table 2: Secondary biophysical data sets

Data type	Source	Scale	GIS layers created
Topography	ING [1]	1:25,000	DEM, Slope, Ecological Zones
	PELT [2]	1:10,000	
Soil Survey	by contract	1:25,000	Texture, pH, Useful Depth, Salinity, Drainage
	ONERN [3]	1:150,000	
Land Cover Survey	by contract	1:25,000	Grains, Tubers, Forest, Cultivated Pasture, Natural Pasture, Degraded Area
	ONERN	1:150,000	
Airphotos	PETT [4]	≈ 1:15,000	Digital Orthophotos

[1] *Instituto Nacional de Geografía*
[2] *Proyecto Especial de Lago Titicaca*
[3] *Oficina Nacional de Evaluación de Recursos Naturales*
[4] *Programa Especial de Titulacion de Tierra*

These GIS layers of soils, land cover, and topography, all originating from existing institutions, provide the minimum necessary data sets for biophysical analysis across watersheds (Posner, Bussink et al. 2002). The NGOs, however, also chose to explore the use of geospatial data at the village scale, where they were already applying Participatory Rural Appraisal (PRA) or related methods of social research.

Primary Spatial Data Collection:

A potential entry point for GIS applications at this level of detail is through participatory resource mapping (PRM), a component of PRA commonly practiced throughout the world (Abbot, Chambers et al. 1998). Also known as community sketch mapping, PRM can transcend language barriers and encourage wider participation among stakeholders. 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. In addition, the alluring visual perspective offered by aerial photography can encourage input from underrepresented stakeholders and stimulate community dialogue (Alcorn 2000).

The NGOs acquired original black and white overlapping aerial photographs from 1998 and 2000 covering the majority of the Asunción and San Pablo watersheds. Due to highly variable topography the scale of the airphotos is not uniform, but average scale of acquisition is estimated to be approximately 1:15,000. The NGOs produced laminated airphoto enlargements at approximately 1:3,000 scale for presentation at village meetings. Four of the airphotos were orthorectified with ArcView and the OrthoRec script (ESRI 2000), using the DEM and ground control points taken from topographic maps or measured in-field with a Global Positioning Systems (GPS) receiver when possible.

Where aerial photography did not exist or had not yet been acquired, GPS was used to create digital spatial databases. Each NGO acquired a hand-held 12-channel GPS receiver. In collaboration with local farmers, they recorded coordinates for irrigation systems, village boundaries, or vegetation coverage. These data were uploaded into GIS and linked with associated attribute data, such as irrigation users and pasture quality.

Social Organization and Planning

The application of spatial data to *Procesos y Productos* fulfills part of a broader overall project goal: to empower grassroots organizations, NGOs, and municipal authorities with information that directly guides resource management decisions and attracts funding for locally prioritized development proposals.

The methodologies of Participatory Rural Appraisal (PRA) (Chambers 1994; Thrupp, Cabarle et al. 1994) provide the basis for social organization in this project. Each NGO was given a guide from the International Center for Tropical Agriculture (CIAT) for identifying interest groups and promoting collective natural resource management. This methodology begins at villages of approximately 100–300 hectares with NGO-facilitated meetings, activities, and semi-structured interviews. Stakeholders are encouraged to address conflicts and create proposals for meeting the resource management needs they identify (Westermann, Guerrero et al. 1999).

The NGOs sought to involve villages that represent the ecological diversity of each watershed, though ease of access and prior organization also influenced selection. In each village a natural resource management committee was formed, or this charge was added to an existing irrigation committee. Throughout the three watersheds, stakeholders were organized in thirteen communities.

Each NGO adapted the methodology to its individual experience and the needs of local communities. Facilitators extended the PRA process throughout several shorter meetings instead of only two or three longer sessions as originally prescribed. To maintain participant interest, technical training on topics such as cheese production and integrated pest management was offered in response to stakeholder demand. The NGOs also took the initiative to introduce aerial photographs or GPS receivers in resource inventory exercises with village farmers.

Scaling up from stakeholder organization within villages, NGOs facilitated strategic planning across project watersheds. Village representatives joined into watershed associations to articulate development priorities. NGOs then applied the available secondary data in GIS to create thematic maps representing locally proposed actions for soil and water conservation. Ultimately, the project anticipated that these spatial information products could help watersheds associations to attract funding for their development proposals (CONDESAN 2000).

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 their influence on resource management in these watersheds.

RESULTS and DISCUSSION

Secondary data analysis

Despite obstacles in procuring available data and maintaining data accuracy, the NGOs were generally successful at creating useful GIS maps at the watershed scale. ASPADERUC successfully combined data for soil depth and slope to create a 1:25,000 scale soil conservation map recommending terraces, infiltration ditches, extractive forests, or protection forests for all land area under seasonal cultivation in the Asunción watershed. This map incorporated conservation design criteria from PRONAMACHS in an attempt to attract agency funds and better direct implementation across the watershed.

CIRNMA created a 1:150,000 scale thematic map of the potential for pasture improvement in the Mañazo watershed, using slope and soil pH, salinity, and drainage as input. This product addresses management issues likely to arise with the completion of a large irrigation canal in the poorly drained plains of this watershed. The NGO also created watershed maps of pasture suitability for cattle, sheep, and alpacas according to vegetation associations of the land cover survey.

A growing need for firewood, building material, and soil conservation led the San Pablo watershed association to identify forest plantations as a priority project. ASPADERUC used input of soil texture and pH to create a suitability map for marketable tree species within appropriate agro-ecological zones of the Asunción watershed. One example is the leguminous species *taya* (*Caesalpinia spinosa*), a native tree that produces a potentially marketable resin (Figure 2).

The integration of previously collected spatial data into GIS had successes, but also proved to be time-consuming and error-prone. NGO technicians could not easily afford the time needed for on-screen digitization of 25-meter elevation contours. The resulting vector file of contours for the Asunción watershed reveals a variable horizontal displacement of as much as 60 meters where topographic sheets join, possibly a result of the piecemeal process of scanning and digitizing these data. Furthermore, the 1:25,000 scale DEMs were not verified by in-field measurements; therefore, slope and other layers derived form DEMs could be used only to generalize across areas of at least several tens of hectares.

Substantial discrepancies are also found in overlaying soil survey and land use data layers with the DEM. The airphotos used to create these surveys were not differentially rectified, and the manner in which survey data were digitized is not provided. Soil and vegetation surveys are further limited by the high edaphic variability and small farm sizes of the Andes, where a given survey unit is likely to contain smaller areas with entirely different characteristics (Poma 2001).

The process of orthorectifying recent airphotos also proved to be challenging. Computer hardware capable of running the software was not available to NGOs until the second year of the project. Well-distributed ground control was difficult to acquire from out-of-date 1:25,000 topographic maps, or by GPS in isolated terrain. Ultimately, four aerial photographs were individually orthorectified using the DEM and approximately 10 control points per image. Root-mean-square values averaged 15 meters for both interior and exterior orientations.

Primary data collection

The NGOs facilitated two or three photo-mapping sessions in each of four villages. Each exercise attracted between ten and twenty participants of mixed age, gender, and literacy, and ended with a smaller number of enthusiasts who returned for subsequent sessions. Participants delineated village boundaries, landmarks, irrigation canals, and springs in the first two mapping sessions (Figure 3). One village in San Pablo watershed also incorporated a PRA inventory of local soil taxonomy. In two Asunción watershed villages, farmers independently delineated individual property boundaries and drafted an associated table of crop types and irrigation frequency at each field. Due to the delays in the creation of orthophotos, these photo-mapping exercises used copies of the original airphotos without geometric correction.

NGOs also appreciated the ability of GPS receivers to efficiently record and upload coordinate data into a digital database. In the San Pablo watershed, local farmers accompanied NGO agronomists to delineate village boundaries and irrigation springs and canals. The data were coupled with a database of canal names, users, and flowrates. In the Mañazo watershed, ranchers in three villages directed a GPS delineation of pasture types in conjunction with an NGO-led inventory of vegetation species and biomass, and farmer knowledge of livestock diets. This activity produced the project's only unique village-level GIS products: georeferenced thematic maps of pasture potential for three Mañazo communities, useful in determining the optimal livestock density of each pasture parcel (Figure 4). It is noteworthy that these are also the only communities of the project that enjoyed the assistance of a full-time professional PRA facilitator, whereas the other NGOs had assigned to agronomists the task of PRA facilitation in addition to their existing duties.

Delineation of features over airphotos proved to be much more time-efficient than walking along the features with a GPS receiver; however, digitizing information from aerial photographs promises to be far more challenging than uploading GPS data. As the aerial images used in the participatory photo-mapping exercises are not orthorectified, NGOs must redraw results over digital orthophotos on a computer screen or digitizing table before they can be used in GIS.

Integrating secondary and primary data

GIS proved to be most practical in this project 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. These GIS products can best be described as indicative maps — useful in focusing development efforts toward general areas at the watershed level, but not necessarily reliable as a basis for decision-making at the village or especially the farm level. The watershed map for *taya* suitability in Asunción provides an example. This product meets the objectives of using existing secondary data to quantify land areas suitable for the chosen action; however, the input layers for soil texture and pH are generalized across soil survey units and more detailed information at the farm level is needed before planting sites are selected. Such a product serves to direct attention to specific regions of the watershed, at which point in-field observations and farmer knowledge becomes more useful at a finer scale. Similar results were found in a previous application of GIS to the Encañada watershed in northern Peru, where a watershed map created from secondary data was efficiently produced, but results were sometimes disputed by farmers' in-field observations (Posner, Bussink et al. 2002). In these instances, aerial photography offers a means for stakeholders to communicate their spatial knowledge.

CONCLUSIONS

Significant barriers remain for the successful application of GIS by existing institutions in a setting such as the Peruvian Andes. Secondary data are often limited in scale, coverage, and quality; preparation of preliminary data layers is time consuming for first-time GIS users; and mountain environments involve highly variable characteristics that are particularly challenging to map with accuracy. Nonetheless, the creation of GIS products by local NGOs using secondary data has proven to be a realistic goal. The thematic maps created in this project offer stakeholders a means to visualize and quantify development priorities, thereby enhancing the decision making process and strengthening proposals for external investment.

Within villages of a few hundred hectares, however, thematic maps of the watershed must be supplemented by direct observation and local knowledge of the landscape. Mapping exercises at the village level allow stakeholders to make such knowledge spatially explicit, while stimulating interest and fostering community dialogue for collective resource management. Primary data can guide development actions even if not actually linked to a GIS thematic map of, for example, the potential for agroforestry or pasture improvement. In such cases, aerial photographs and GPS receivers can help stakeholders select sites for actions such as planting trees or building terraces on appropriate soils and slopes.

GIS could be more efficiently used in this setting if secondary data management were more systematized. All three NGOs conducted a parallel process of acquisition, digitization, and integration of the available data sets. If a single institution were to provide ready-to-use products such as DEMs and orthophotos, NGOs could dedicate more time to conducting social research, collecting primary data, or experimenting with more advanced GIS functions. Although this introduces a top-down component to an otherwise decentralized process, secondary data integration is a rather generic and pre-defined procedure that should only become more effective by systematization.

Additional impediments arise from the scarce resources of local institutions in the Peruvian Andes. The NGOs' technicians needed to balance GIS duties with existing responsibilities and generally were limited in the time they could dedicate to self-training and database development. Project funding provided software and some secondary data, but no further funding for additional needs. However, use of GIS in this setting should become more feasible as computer software advances, hardware becomes more affordable, and descriptive accounts of technical procedures for data integration, analysis, and presentation are disseminated to small organizations attempting to use GIS technology for the first time. Overall, local professionals proved capable of adopting GIS technology, given sufficient time and encouragement for experimentation.

The experience of this project illustrates that the ultimate impact of GIS applications is influenced no more by technical constraints than by the social and political context in which the technology is applied. Spatial data applied at the village level has the immediate impact of engaging stakeholders across cultural boundaries and generating unique primary information. However, aerial photographs and GPS receivers encourage data collection before clear objectives for their use are established, potentially leading to false expectations and wasted effort by stakeholders. Spatial analysis tools should therefore be used in conjunction with Participatory Rural Appraisal or other proven social research methodologies to better insure their appropriate application.

In building a vision for resource management across a watershed, initial spatial information products need not necessarily involve GIS analysis or modeling. Secondary data products portraying the watershed and common reference points are valuable in promoting collective watershed planning to a broad audience, and can be introduced relatively early in the process of stakeholder organization. As planning advances, however, detailed criteria for analysis are needed to produce GIS maps for specific actions. Concise, funding-dependent information objectives are the best means to motivate local technicians to create innovative GIS products.

Unfortunately, few such demands for GIS products were ultimately offered. The transition of political power in Peru through three presidential administrations during the course of this project severely limited the potential for rural investment, particularly from the anticipated client PRONAMACHCS. Without requests from investors for specific products, map production by the NGOs became a somewhat academic exercise, motivated primarily by a need to demonstrate GIS proficiency for internal project evaluation. Nonetheless, NGOs benefited by adopting GIS methodologies, building spatial databases, and enhancing their skills in stakeholder organization.

GIS applications in this project may be appropriately described as “a hammer looking for a nail” (Posner 2001), attempting to supply information products before a specific demand has been demonstrated. The use of GIS is nonetheless valuable in efforts to address long-term resource management issues as opposed to simply responding to immediate social conflicts over resource access. Organizations such as the three in this project are in a strategic position to integrate social research with GIS technology, as they enjoy the trust of both local stakeholders and centralized institutions while proving capable of acquiring the skills necessary to operate GIS. The impediments addressed in this study—both social and technical—must first be overcome to make participatory GIS a truly effective process in settings that offer limited physical, informational, and institutional resources.

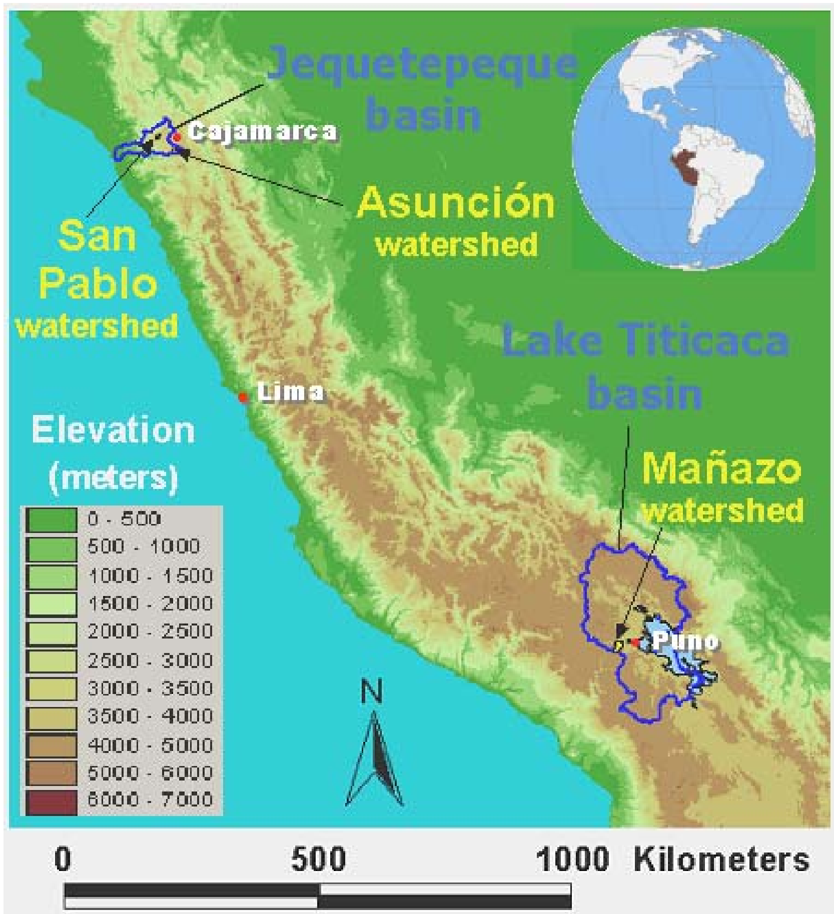
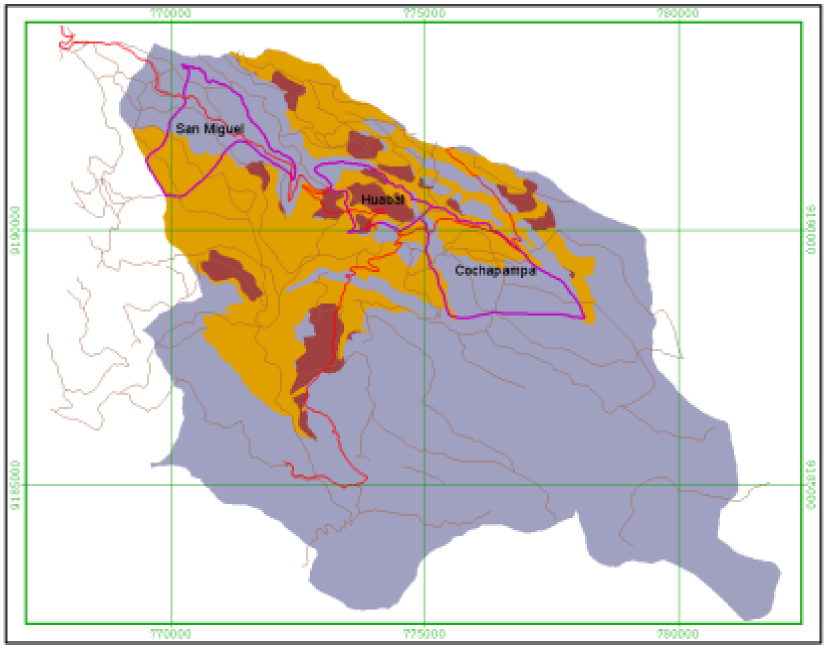
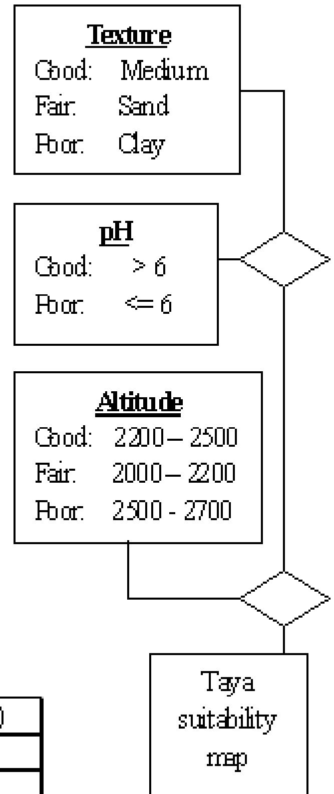


Figure 1: Project watershed sites





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

Figure 2: Taya (*Caesalpinia spinosa*) potential map for the Asunción watershed (ASPADERUC 2002)

Figure 3: Photo-mapping exercise in Capellanía community, San Pablo

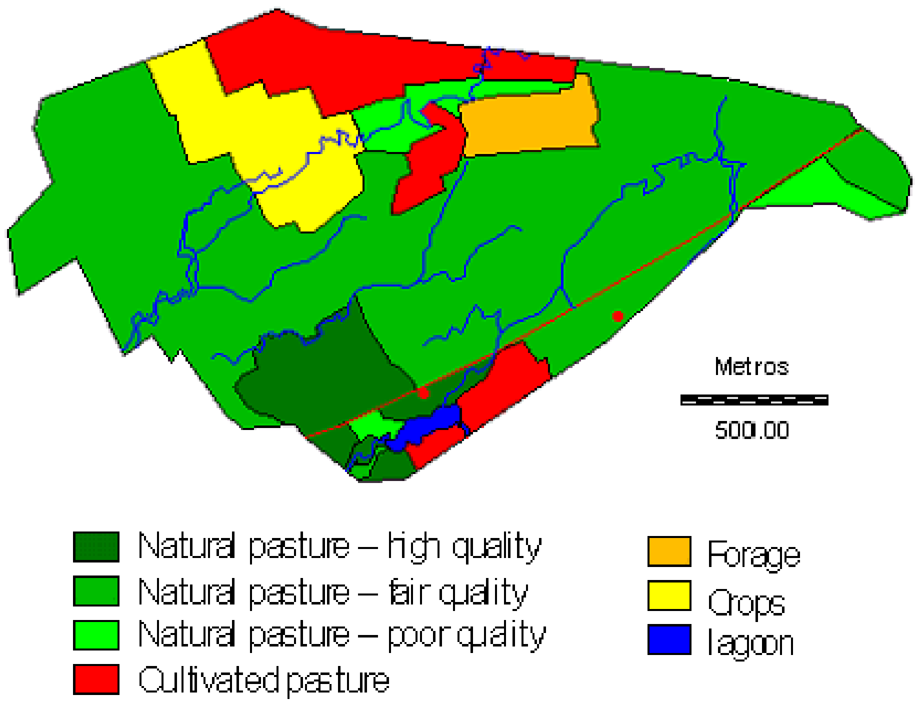


Figure 4: GPS-derived pasture potential map for the Canllacollo cooperative, Mañazo (CIRNMA 2002)

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