Putting Natural Resource Management on the Map: Using GIS as a Tool for Soil Conservation Planning in Two Small Andean Watersheds

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The paper describes a practical approach to developing a georeferenced natural resource database that is locally constructed and managed. With the new GIS (geographic information system) software and hardware available today, various types of natural resource information can be collected and combined to allow local users to visualize new relationships in GIS output maps. The maps can be prepared and modified according to specific criteria. This capacity helps operationalize the concept of the watershed for use in development planning. The data collected for this study were used to create maps for two watersheds that show zones for alternative soil conservation interventions. This work was a collaborative effort by the Cajamarca office of the Peruvian Proyecto Nacional de Manejo de Cuencas Hidrográficas y Conservación de Suelos (PRONAMACHCS), the non-governmental organization Asociación para el Desarrollo Rural de Cajamarca (ASPADERUC), municipal authorities of La Encañada and Asunción, and the International Potato Center (CIP). CONDESAN (Consortium for the Sustainable Development of the Andean Ecoregion) sponsored the project.

Steep topography, abrupt changes in ecology due to elevation, the importance of irrigation, and a new emphasis on environmental management are all factors that make watersheds an often-used unit for rural development and natural resource management projects in the Andes (Rhoades, 1998). In addition, the desire to develop more participatory approaches to rural development has given impetus to focusing on micro-watersheds (5000–20,000 ha), where the inhabitants are neighbors who are members of the same irrigation committees and often serve together on municipal councils.

One challenge to this approach is operationalizing the concept of watershed. For many municipal and project officials it is difficult to move beyond site-specific interventions (such as promoting a new crop or constructing terraces) to a watershed perspective, or to use a watershed vision to set priorities for site-specific activities (Farrington and Lobo, 1997). In order to address this issue, a team of CIP/CONDESAN scientists, agronomists from the non-governmental organization (NGO) ASPADERUC (Asociación para el Desarrollo Rural de Cajamarca), and municipal officials, worked together to develop a methodology to incorporate different types of local information (topography, hydrology, political limits, etc.) into a Geographic Information System (GIS).

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matrix. Then, in collaboration with the Peruvian national soil and water conservation agency PRO-NAMACHCS (Proyecto Nacional de Manejo de Cuencas Hidrográficas y Conservacion de Suelos), algorithms were defined that permitted a simplification of the information and the identification of zones for soil conservation interventions.

The overall goal of this activity is to develop a cost-effective and robust methodology that will enrich the local debate on natural resource management with information that is collected and processed locally. We initiated the work in northern Peru in the Cajamarca Department, first with a watershed within the municipality of La Encañada (15,700 ha), and then in Asunción (8100 ha) (Figure 1).

Materials and Methods

Data management

Data managed in a GIS can be used for a variety of purposes. The goal of this activity would be to develop a solid database for different types of community planning. The first output were maps and a zonification system for soil conservation interventions that could be used by PRO-NAMACHCS, the national soil and water conservation agency. It was assumed that slope, ground cover, soil type, and rainfall intensity would be the most important factors in the zonification. Figure 2 summarizes the flow of information in developing the maps. First, contour lines were digitized and interpolated, resulting in elevation models. These were used to subdivide the watershed into catchments and to make a slope map. Ground cover and soils maps (approximately 1:25,000) were then drawn using aerial photos and existing soil maps, ‘walking the landscape’, and digging soil pits. Based on this work, slope classes, ground cover classes, and soil depth units were defined. Political boundaries between communities, roads and paths, and local reference points (clinics, schools, and churches) were also georeferenced and included in the GIS database. The GIS work for La Encañada was completed at the International Potato Center using existing databases developed for other projects (De la Cruz et al., 1999). For Asunción, ASPADERUC scanned the maps for importing into Autocad, a mapping program, where the features of the map were digitized on screen. Additional landmarks were georeferenced with a global positioning system (GPS). Data were imported into IDRISI (IDRISI software (http://www.clarklabs.org/)) for processing.

Developing interventions

After the data collection phase, algorithms were devised following the flow diagram in Figure 2 to divide the watershed into soil conservation zones. In collaboration with the PRO-NAMACHCS team and published tables (PRO-NAMACHCS, 1998), a set of rules was established to identify potential soil conservation interventions (no intervention, sloping terraces, infiltration ditches, and reforestation) on cropped land (Table 1).

There was a consensus that soil conservation measures were not of great importance for slopes of less than 5% and that no interventions other than vegetation restoration and forest plantations were possible on slopes of more than 40%. The main interventions would focus on the intermediate slope types, which were categorized into two groups: 5-15% (terracing possible) and 16-40% (infiltration ditches, terracing only possible if the soils are deep).

The six ground cover classes originally used in the data collection phase were simplified to three, based on ‘permanency’ of ground cover: zones of permanent vegetation (grasslands, forest), zones of annual disturbance (annual crops plus associated short-term fallow), and degraded zones where little vegetative cover remained. With respect to crop type, cereal (maize, wheat, barley, oats), tuber (potato, oca, ollucu), and legume (peas,
lentils, lupins) crops were all collapsed into an ‘annual cropping’ category. The reason is that in this region of Peru there is only one rainy season (November-March, 500-800 mm/year) resulting in similar growth patterns for each of these different food crops. When funds are limited, soil conservation in areas with permanent cover (pastures, forests) is not a priority nor is the rehabilitation of seriously degraded areas. Therefore, the focus of the interventions would be on areas in annual crops and their associated fallows.
Areas in annual crops were crossed with four slope classes to create an erosion risk table for annual cropping: low risk on slopes of less than 5%; medium risk on slopes of 6–15%; high risk on slopes from 16–40%; very high risk on slopes of more than 40%.

According to the soil classification used, there were 209 different units in La Encañada (Jiménez, 1996) and 114 units in Asunción (Jiménez, 1998). But because decisions on soil conservation interventions (terraces, ditches, and reforestation) with these non-volcanic soils would be based primarily on soil depth rather than on such characteristics as soil texture or internal drainage, it was considered appropriate to simplify the soil categorization into just two categories: less than 60 cm deep, and more than 60 cm deep.

Few small watersheds in the Peruvian Andes have rainfall stations that measure both total rainfall and maximum 30-minute rainfall intensities. Because both of

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<th>Table 1</th>
<th>Decision rules for soil conservation interventions in annual cropping areas.</th>
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<tr>
<td>Soil depth</td>
<td>Erosion potential</td>
</tr>
<tr>
<td>Shallow&lt; 60 cm</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
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<tr>
<td></td>
<td>High</td>
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<td>Very high</td>
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<tr>
<td>Deep&gt; 60 cm</td>
<td>Low</td>
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the project micro-watersheds have one station, neither has two, it is difficult to identify differences in rainfall within the watershed. As a result, although daily rainfall data were collected and used in subsequent crop (DSSAT) and watershed models (SWAT), it was not possible to use variations in rainfall amount and intensity within the watershed as a factor in this typology.

Once the rules were agreed upon, the maps were drawn, and the classification was ground checked. At that point, the relative areas for each type of intervention were calculated for the watershed, by catchment, and by community. Maps of several communities were enlarged to 1:2000 and used to initiate participatory discussions about potential conservation interventions.

Results and Discussion

In spite of the generally steep topography in the Andes and the relatively small size of the watersheds (8000–15,000 ha), we found that working at a scale of 1:25,000 with contour lines at intervals of 25 m was acceptable for our objectives. At this scale we were able to identify important differences on the landscape and in sufficient detail for conservation planning.

The two watersheds selected are fairly typical of agricultural zones in the Andes. High elevation native pastures, primarily of Calamagrostis, Festuca, and Bromus grasses (Sánchez, 1995; 1999), predominate in La Encañada (45%), but constitute only 15% of the lower Asunción watershed. Nevertheless, both watersheds are dominated by steep slopes (> 15%), and cropped land plus its associated fallow make up 33–45% of the watershed area. On less steeply sloping land, planted pastures are common, mostly consisting of ryegrass (Lolium perenne) and clover (Trifolium repens).

La Encañada has greater expanses of flat land (slope 0–5%) used for annual cropping than does Asunción (23% vs. 4%). In Asunción, nearly half of the annual cropping is conducted on slopes of more than 40%. In contrast, in La Encañada only 12% of the cropped land is on slopes that steep. This suggests that the sustainability of production systems in Asunción is in greater jeopardy than it is in La Encañada, and rather than soil conservation interventions, alternative production systems (such as improved pastures, more fruit trees or forestry) must be a high priority for municipal authorities.

Figure 3A and 3B are maps of soil conservation intervention zones by watershed. At each site, the no-intervention zone covers the largest area (63% in La Encañada, 54% in Asunción); these are the areas that are either in permanent cover or in annual cropping but on mild slopes. Zones suitable for sloping terraces, infiltration ditches, and reforestation are the next largest areas (30% in La Encañada, 44% in Asunción). Terracing and creating infiltration ditches on cropped lands will result in better soil and water management and should improve crop yields. On the other hand, reforestation will mean taking land out of annual cropping so the trade-off must be examined. The third major category is rehabilitation, which implies rebuilding soil and vegetative cover in zones that have been degraded, primarily by man’s activities (La Encañada 7%, Asunción 2%).

When the interventions map is superimposed on the community boundaries map, critical areas, those with high priority for soil conservation, can be identified. For example, both La Torre community in La Encañada (highlighted with parallel lines in Figure 3A) and Shirac in Asunción (highlighted with parallel lines in Figure 3B) are high priority areas. In both, nearly one hundred percent of the area is in cropland and 81% in the former and 96% in the latter would need terracing, infiltration ditches, or should be put into permanent cover according to these algorithms.
Figure 3A. La Encañada soil conservation zonification with community boundaries.

Figure 3B. Asuncion soil conservation zonification with community boundaries.
An additional step in this process was to take the results of the zonification exercise to individual communities to see if they would be a useful aid in local soil and water conservation planning. A blow-up (1:2000) of a portion of the watershed map covering the single community of La Torre in La Encañada was taken into the field to do a participatory zonification exercise. An evaluation of this exercise with the PRONAMACHCS officials led to two main conclusions. First, the map showing the zonification of interventions was helpful in enriching the conversation, because the map did not coincide exactly with the local vision of natural resource management. And second, having a georeferenced base map was useful to agency technicians because they could accurately locate and inventory existing structures (terraces, waterways) and plan new interventions.

Not surprisingly, the change in scale from a 15,700 ha watershed to a 220 ha community resulted in some locally ‘unacceptable’ generalities. Based on further community-level discussions, the team added three components to the program.

• With the help of farmers, project agronomists are making community land-use maps based on local criteria (Olivares et al., 2000).
• Recent aerial photographs (approximately 1:15,000) are being blown up to 1:3000 and used as the basis of natural resource discussions in the community.
• The team is redoubling its efforts to focus on irrigation and potable water issues (Delgado, 1998; Soto, 1996).

With these additions to the flow diagram shown in Figure 2, the process and database are now serving the needs of district (watershed authorities) and community leaders. For example, the database and mapping capabilities are being used to draw land-use maps based on local definitions, to identify irrigation canal catchment basins, to map all the springs potentially useful for drinking water, and to identify zones for orchard expansion.

Conclusions
Digitizing existing maps and georeferencing some additional field measurements can result in useful databases for natural resource management. What is equally important is that more and more local organizations (government agencies, NGOs, university laboratories) are acquiring the software and experience necessary to apply and improve the methodology. At the level of a watershed like La Encañada or Asunción, the methodology allows municipal and agency personal to identify soil conservation intervention zones or zones suitable for new production systems. At the local community level, the system is being adapted to help envision and solve local problems, especially around water issues.

References


