Title

Preliminary GIS analysis of the agricultural landscape of Cuyo Cuyo, Department of Puno, Peru

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PRELIMINARY GIS ANALYSIS OF THE AGRICULURAL LANDSCAPE OF CUYO CUYO, DEPARTMENT OF PUNO, PERU

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ABSTRACT

Computerized analysis of a geographic database (GIS) for Cuyo Cuyo, (Dept. Puno, Peru) is used to correlate the agricultural production zones of two adjacent communities to altitude, slope, aspect and other geomorphological features of the high-altitude eastern escarpment landscape. The techniques exemplified will allow ecological anthropologists to analyze spatial patterns at regional scales with much greater control over the data.

INTRODUCTION

The Production, Storage and Exchange (PSE) research project was initiated with NSF support in 1984.[1] The goal was to investigate questions of agricultural ecology and economics in two communities located on the upper slopes of the eastern escarpment of the Peruvian Andes. The more specific problem was this: How do peasant agriculturalists in a marginal high-altitude environment mitigate production risk? In seeking answers to this question we identified three possible risk-reduction mechanisms available to Andean households: i) decisions to disperse fields and to inter-crop multiple cultigen varieties; ii) decisions to process and store a portion of the annual crop; and, iii) decisions to exchange labor and produce among households or communities.

Our hypotheses relied on the observation that each of these mechanisms has an efficacy which depends on cost and structural constraints (e.g., seasonal scheduling), and on the spatial and temporal nature of the risk factors. For instance, field dispersion is a viable mechanism if the factors affecting production -- frost, drought, and pests, predominantly -- are highly localized. If that is the case, dispersed fields will even out micro-climatic or pathogenic conditions (Winterhalder 1990b). Analysis of these hypotheses requires that we characterize the environment of Cuyo Cuyo in terms of its dynamic temporal properties (e.g., climate patterns and their predictability) and its spatial heterogeneity (e.g., habitat patchiness). This type of environmental characterization is part of an effort to develop more general models of processes of ecological adaptation (see Winterhalder 1980; Halstead and O'Shea 1989).

Investigation of the problem has taken the form of a multi-disciplinary project with an emphasis on quantitative methodologies.[2] The core of the information is three datasets gathered continuously

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[2]2Among the participants are a geomorphologist (D. Alexander), geographer (S. McRae), pedologist (J. Sandor) and plant ecologist (B. Bennett). The anthropologists included representatives of several subdisciplinary specialties: economic (J. Recharte), ecological (B. Winterhalder), nutritional (P. Graham), archaeological (C. Goland) and medical (A. Larme).

for a period of two years. Ten households in each of two communities were the sample. Although the communities are located nearby one another, and thus were simultaneously accessible to one research team, their territories span differing sets of ecological zones on the escarpment. Similar in socio-cultural features, the sample communities offered us a controlled ecological comparison. The data consist of i) weekly diaries of household expenditures and income; ii) a time allocation study using a spot check methodology of all individuals in the twenty families; and, iii) a field dispersion study which gathered extensive information on each of the 675 fields planted by these households over the two seasons.

In addition, we have collected ancillary data on climate in the central Andean region, primarily to document the temporal dimension of risk (Winterhalder 1990a). Archaeology (Goland 1988), geomorphology and soils have received preliminary analysis, as has vegetation ecology. We have surveyed terrace distribution, use and maintenance and have mapped these features on airphotos. One completed dissertation focused on the inter-relationships of agriculture and seasonal migration of males to mine gold (Recharte 1988, 1990). Dissertations in progress will examine field dispersion as a risk-reduction mechanism (Goland), healing and the relationships of work to health (Larme), and household nutrition and food management (Graham). Most of these datasets have focused on the same sample of 20 households and they overlap in time. This has generated a multi-disciplinary record of information unique in being derived from the same, long-term sample.

GIS AND SPATIAL ANALYSIS IN ANDEAN ECOLOGY

By virtue of rugged topography and steep altitudinal gradients, the Andes present sharp contrasts of environmental conditions within short distances (Winterhalder and Thomas 1982; Gomez Molina and Little 1981). Strong vertical zonation of environment, complicated by the effects of local topography, slope and exposure, has figured prominently in andean life. Whatever their social organization, from the very earliest prehistoric period the peoples in the Andes have attempted to mobilize this micro-environmental diversity to insure an adequate and reliable livelihood (Murra 1984). Transhumant hunter-gatherers (Lynch 1973) moved up and down the slopes following seasonal resource opportunities. With the domestication of plants and animals and the evolution of kingdom and state level polities, similar integration of diverse zones was accomplished through various forms of centrally organized colonization, exchange and trade (Browman 1981, 1984). In the contemporary period, markets partially have supplanted zonal integration achieved earlier by household and community-level exchange. The rich archaeological, ethnohistorical and ethnographic documentation available in the Andes have made the region a focus for studies of history and ecology, and their relationships (Orlove and Guillet 1985).

Drawing on ethnohistoric study of the Lupaqa, a small 16th century kingdom located on the north end of Lake Titicaca, the anthropologist John Murra (1968, 1981) has characterized this organizational form by an *archipelago*, or *verticality*, model (Brush 1976; Orlove 1977). Typically, andean polities had their main populations and administrative locus in the high altitude plateaus, but they developed forms of economic organization that insured access to dissimilar production zones extending down the vertical gradients of both the western and eastern slopes of the mountains. In some cases, these were isolated "islands" of production, not geographically contiguous with the centralized territory.

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Based on this brief introduction, we can identify three considerations that have encouraged attention to the spatial dimension in the PSE analyses: i) we are attempting to conceptualize ecological adaptation at a generalized level of temporal and spatial processes; ii) the Andean environment forces attention to the micro-ecological scale of unique landscape elements; and iii) we know in general terms that andean economies from the earliest to the present have succeeded through their ability to integrate this environmental diversity. Understanding those economies in ecological terms requires methodologies that can facilitate complex spatial analyses.

GOALS OF PAPER

This paper will present results of our use of ArcInfo,[3] a geographic information system (GIS), to assist in this research. We focus primarily on the three-dimensional TIN (Triangulated Irregular Network) module. We will illustrate our uses of GIS, discuss problems we have encountered and describe analytical protocols to circumvent them.

Project history dictates that the results are preliminary. Although the PSE group anticipated using GIS and remote sensing as early as 1982, in the early phases of the project we were able only to digitize the relevant portions of 9 (1:25,000) topographic maps.[4] This year Winterhalder and Evans were able to resume the GIS portions of the analysis.[5] The work has proceeded more slowly than we anticipated, due to a series of technical difficulties. Indeed it will be a subtext of this presentation that whatever the original research questions one should approach GIS in an exploratory and skeptical frame of mind. However attractive for analysis and display of large, spatially-referenced datasets, at this point in its development the methodology itself can become a significant part of the research effort.

MAP COVERAGES AND ANALYSES

The bulk of our coverages (or map layers) derive directly or indirectly from portions of the nine 1:25,000 (7.5' UTM Projection) topographic maps that cover some part of our study area.[6] The nine

[3]ArcInfo is a vector-based GIS, produced by Environmental Systems Research Institute, Redlands, CA.
[4]This work was done by our collaborating geographer (Stephen McRae), then at UC Riverside.
[5]Supported by an NSF, Anthropology Program, Quantitative Methodology Training Grant (BNS# 8901823).
[6]They are:

Scale	Name	Index
1:25,000	Ananea	30X-1-SE
1:25,000	Ancolala	29Y-III-SO
1:25,000	Cuyo Cuyo	29X-II-SE
1:25,000	Huarachani	30X-I-SO
1:25,000	Janccocala	30X-I-NE
1:25,000	La Rinconada	30Y-IV-NO
1:25,000	Punalaquequi	29X-II-SO
1:25,000	Sorraccocha	30X-I-NO
1:25,000	--	30Y-IV-SO
1:100,000	Limbani	29X
1:100,000	Putina	30X
1:100,000	La Rinconada	30Y

These maps were copied onto mylar and digitized from that more stable medium. Portions of the 1:100,000 map series were redrawn at a larger scale (Kargl projection unit) to produce contour lines for small areas missing from the 1:25,000 maps. Corner tics were derived from the US Army technical Manual (TM - 5-241-11) and interpolated from the nearest labeled UTM grid intersection.

quadrangles total 1,675 km^2. From this, we have boxed off and digitized a study region of 1,046.7 km^2 (62.5% of the original quadrangles). This study region surrounds the District of Cuyo Cuyo which along with the communities of Huancasayani and Nacoreque makes up a core research sample of 430.25 km^2 (Figure 1). PSE has focused intensive analysis on two of the peasant communities located

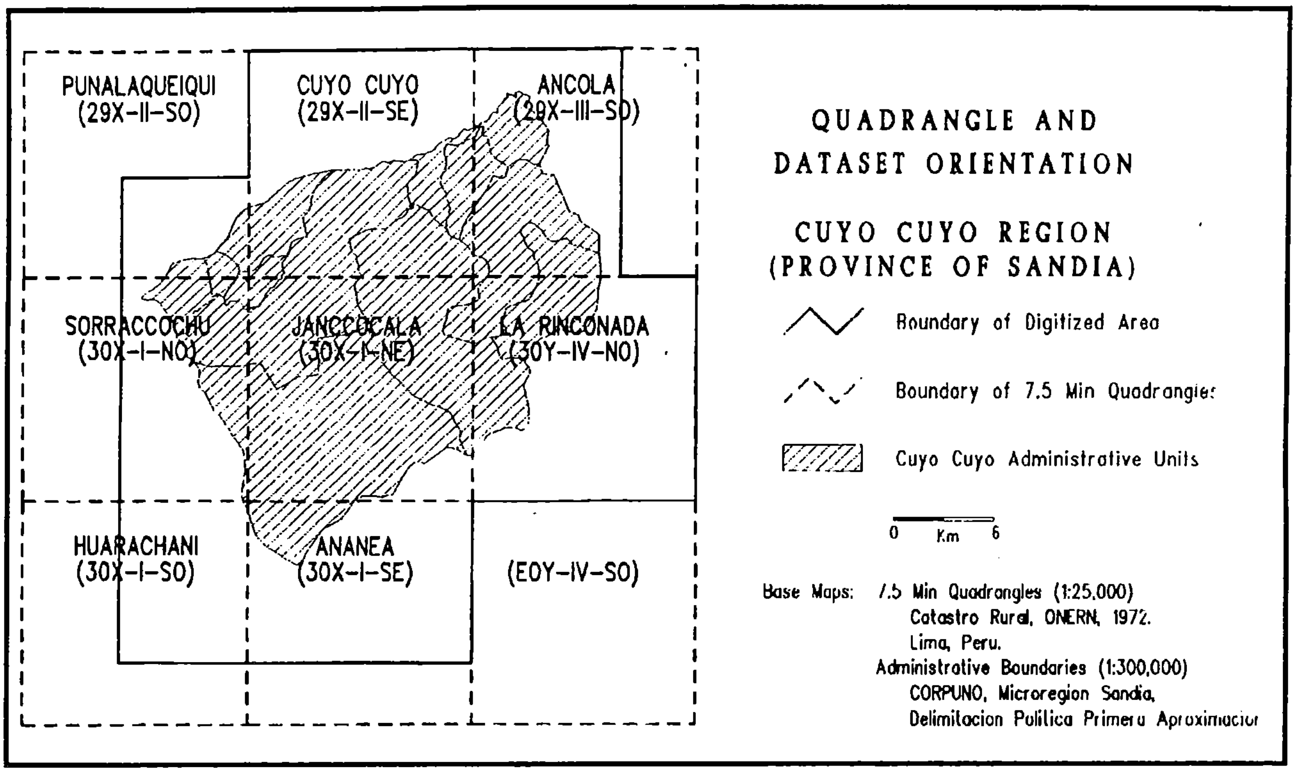


Figure 1. Quadrangle and Data Set Orientation.

within the District, Puna Ayllu (79.16 km^2) and Ura Ayllu (21.09 km^2).[7]

A description of the main, single-theme coverages is given in Table 1. Existing coverages include those derived directly from quadrangle maps (Adminplus/Adminall, Circulation, Contours/100msamp, & Vegezones), those based on field mapping by PSE personnel (Archeo, Sites), and those derived indirectly from contour lines using the TIN module (Aspectsmp, Distin08T, & Slopesmp). In the near future we plan to add coverages from field work (Fldsmp, PlantCom, & GeomphSmp), and from analysis of a Landsat TM image (LndSatSmp).

[7]Digitizing was done with a Calcomp 9100 digitizing tablet, using the ArcInfo Automated Digitizing System. Subsequent editing was done in ArcEdit using a Tektronix 4109 Color terminal. This was a lengthy and occasionally frustrating, labor-intensive process performed mostly by work-study students at UC-Riverside. The digitizing of the 100m contours, which define elevation provinces and from which slope and aspect are derived, required most of the effort. Administrative boundaries, transportation networks and general land use or cover features required less time. Translating the quadrangle maps to a computer format required reconciliation of numerous small errors and inconsistencies in the horizontal positioning of elevation information (for instance, contours occasionally did not meet precisely when we attempted to edge-match the original quadrangles to produce a composite map).

Table 1. PSE-GIS coverages (or map layers) and their source(s).[1]

Coverage Name for: Region	Sample	Source[2]	Description
EXISTING:			
Adminplus	Adminall	Base maps	Political boundaries of the District, comunidades & anexos
Archeo	--	Field Records	Archaeological Survey area (see Goland 1988)
--	Aspectsmp	TIN/contours	Aspect, in 45 deg increments (N, NW,W,SW,S,SE,E,NE)
Circulation	--	Base maps	Roads and trails
Contours	100msamp	Base maps	100 meter contour intervals
--	Distin08T	TIN/contours	Tin-derived coverage with aspect, slope and surface area, by district
Sites	--	Field Records	Position and area of located archaeological sites (Goland 1988)
--	Slopesmp	TIN/contours	Slope, in graduated increments
Vegezones	Vgznsmp	Base maps	Altitude-delimited vegetation zones identified by Camino et al., 1981)
Rivers	Riversmp	Base maps	Rivers & major streams
Water	Watersmp	Base maps	Lakes
PLANNED:			
--	Fldsmp	Field Records	All plots from the field dispersion study
--	PlantCom	Field Records	Distribution of plant communities.
--	Geomphsmp	Field Records	Map of geomorphological features
--	LndSatSmp	EOSAT	Digital (TM) satellite image

[1]Not listed are individual quadrangle boundaries, various combinations of administrative boundaries, or composite maps made by unioning together these individual coverages.
[2]*Base maps* = derived directly from existing quadrangles; *Field records* = derived from maps drawn by project members on base maps, supplemented with 1:40,000 and 1: 10,000 airphotos; *TIN/ contours* = TIN-produced coverages, deriving ultimately from base map contour lines.

Landscape

We will now turn to some analytical issues using the database and graphics potential of GIS. For geographical orientation, the contour coverage of the study region is shown in Fig. 2. Moving from southwest to northeast, one crosses the high plains of the Ananea plateau toward the peaks of the cordillera. This area is typical of the more elevated portions of the andean Altiplano; the drainage is toward Lake Titicaca and the interior of the basin. The mountains, here the Carabaya and Apolobamba ranges, dissect the coverage on a southeast to northwest axis. The glaciated peaks of these mountains reach above 5300m and the passes through them are around 4400m. Their northeast flanks form the headwaters of drainages that begin the precipitous descent of the eastern escarpment toward the Amazon basin. The Awi Awi, Cuyo Cuyo and Huancasayani rivers converge near the northern margin of the coverage[8] to form the Rio Sandia, which becomes the Rio Wari Wari, then Inambari and eventually Madre de Dios. The lowest point on the coverage occurs near its northeaster corner at 2600m. Figures 4 and 5 present a three-dimensional view of the central portion of this landscape that we are studying intensively (corresponding to the cross-hatched, "Administrative Units" portion of Figure 1).

Tightly compressed production zones characterize the steep andean slopes. Extended use of this "vertical" landscape is typical of household and community economic organization. Even a simple description of the resource potential of community lands requires a quantitative assessment of their distribution by altitude. A cross-tabulation of elevation by community with cell entries representing area provides this analysis (Table 2; Graph 1). The lower of our two study communities, Ura Ayllu (elevation, 3400m; total area, 21.09 km sq; population, 856) has lands extending from 2600m to 4300m [range, 1800m]. This represents a fairly even distribution of 130 to 180 hectares of land at each of the 100m elevation intervals between 3300m and 4200m. The larger community of Puna Ayllu (elevation, 3800m; area, 79.16 km sq; population, 1776), has lands extending from 3400m to 4800m [range, 1500m]. However, 89% of its territory is at elevations of 4100m or higher, above the limits of horticultural production. By comparison, 80% of Ura Ayllu's territory is below 4100 m in elevation. In the research sample as a whole, over 82% of the 430.25 km^2 lies at or above 4100m.

There are 208 lakes in the study area, all located between 4000 and 4700m, with nearly 90% of the water surface at 4300m. Lakes cover 20% of the map area at this altitude (Table 3). Most of these lakes are very small (135 are less than one hectare in extent); the largest ones (see Figure 4) are 4.41 km^2 and 2.43 km^2.

Archaeological Survey

Working in such a rugged and physiologically difficult terrain, our archaeological team was especially concerned to know the relative extent and representativeness by altitude of the area that they were able to survey. Table 4 shows the altitude distribution of the survey area relative to the total area of the research sample. The archaeologists examined slightly more than 10% (44.18 km sq) of the study area (430.25 km sq). Lands above 4700m (= 15,416 feet) were not sampled, those between 4400 and 4600 m were sampled but not in proportion to their extent, and from 2800 to 4300m, an even 20 to 30% of each 100 meter interval was surveyed.

[8]These drain the three headwaters in the coverage, from northwest to southeast, respectively (see also Figure 3).

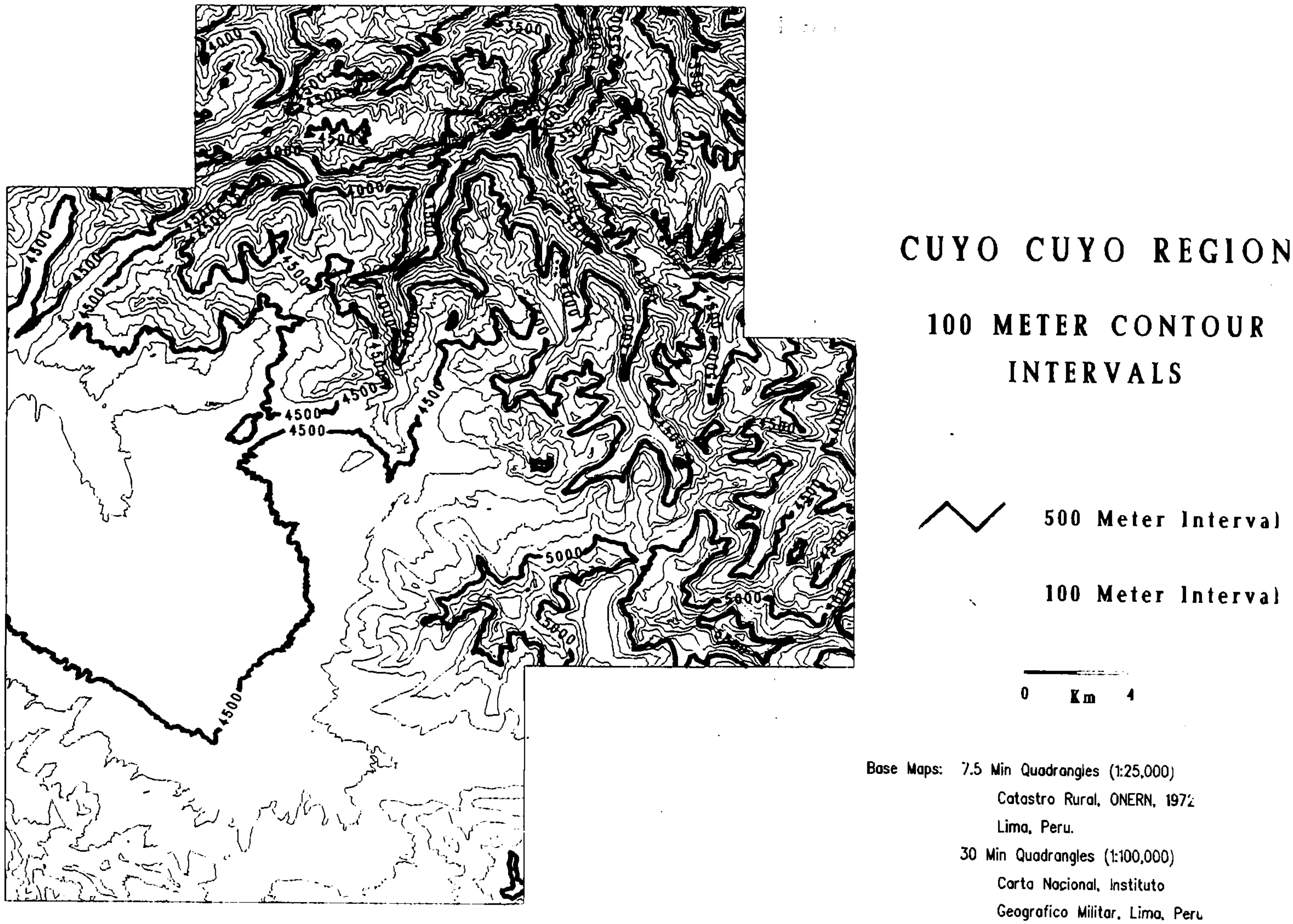


Figure 2. Cuyo Cuyo Region: 100m Contour Intervals.

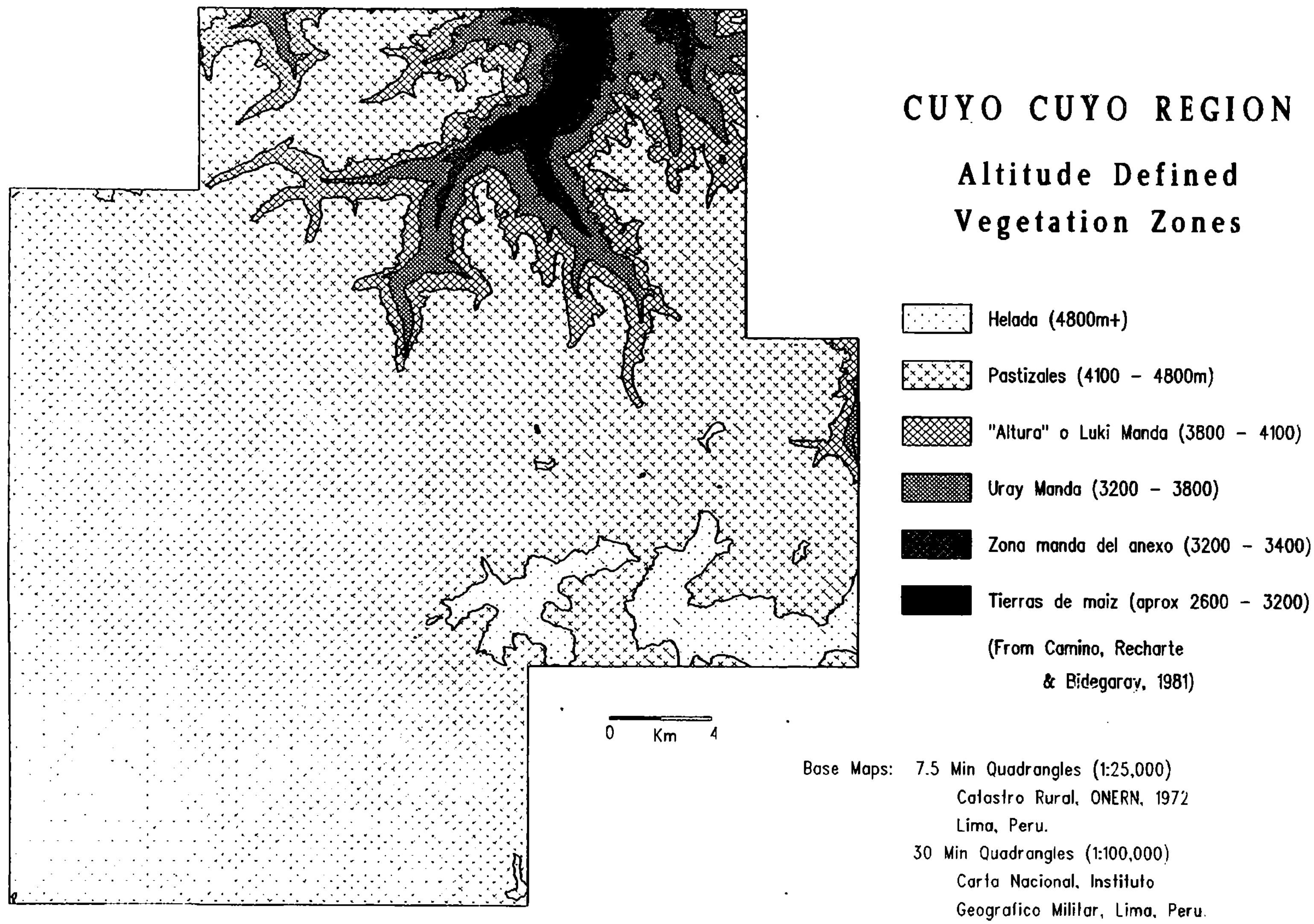


Figure 3. Cuyo Cuyo Region: Altitude-Defined Vegetation Zones.

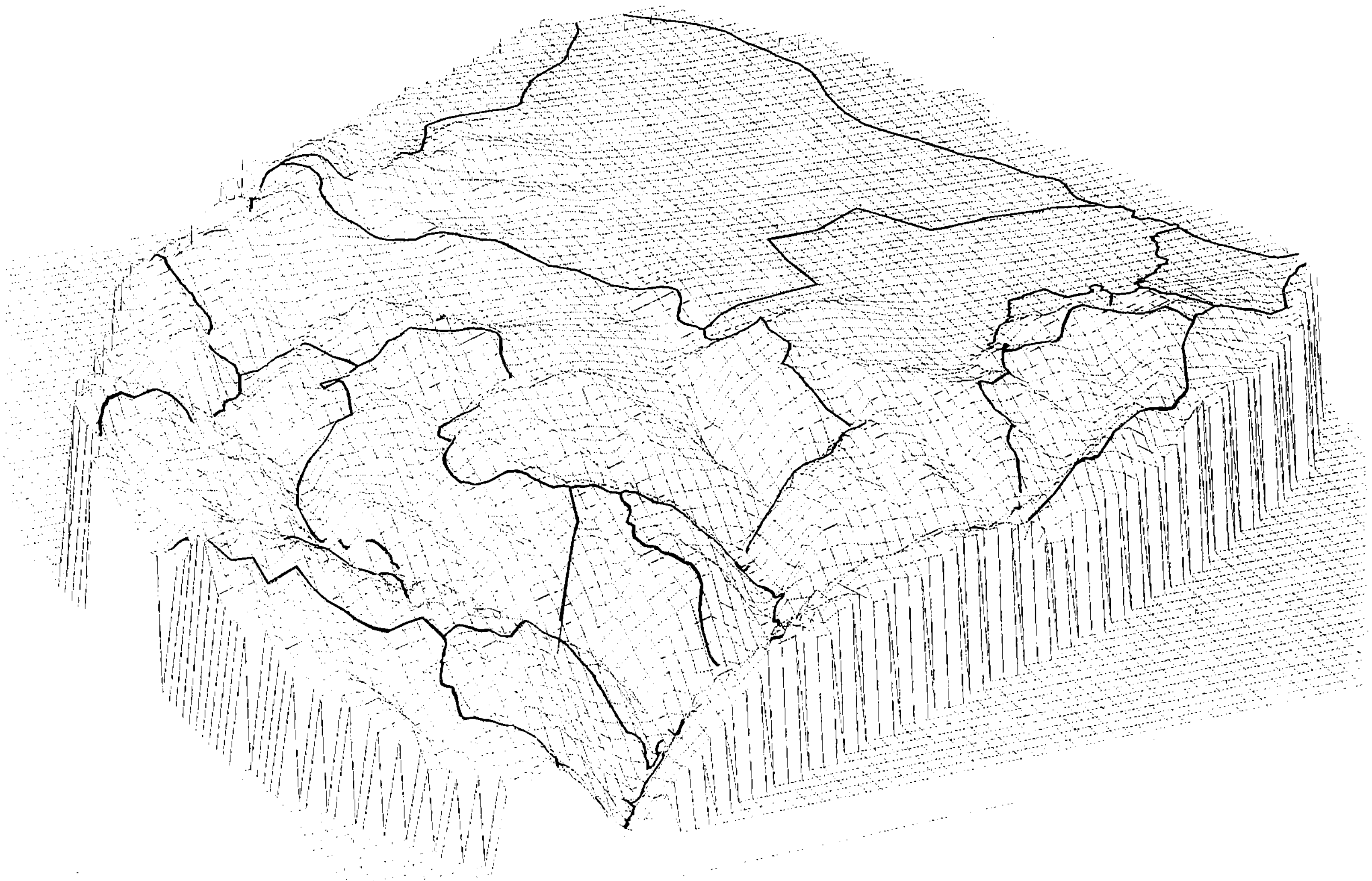


Figure 4. Three-Dimensional View of the Study Sample, from Northeast, with Administrative Boundaries

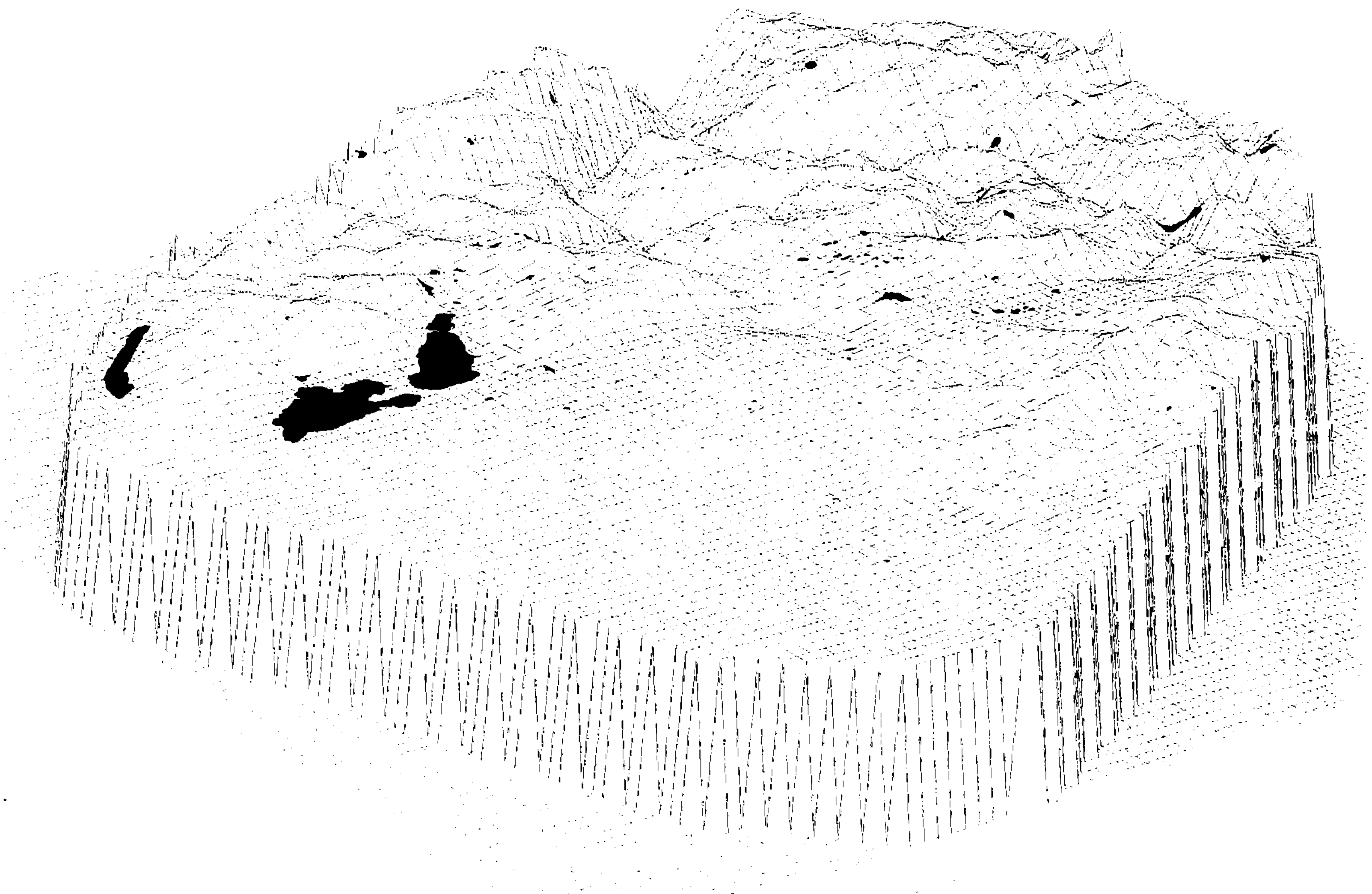


Figure 5. Three-Dimensional View of Study Sample, from Southwest, with Lakes.

Table 2. Elevation by Area for Study Communities.

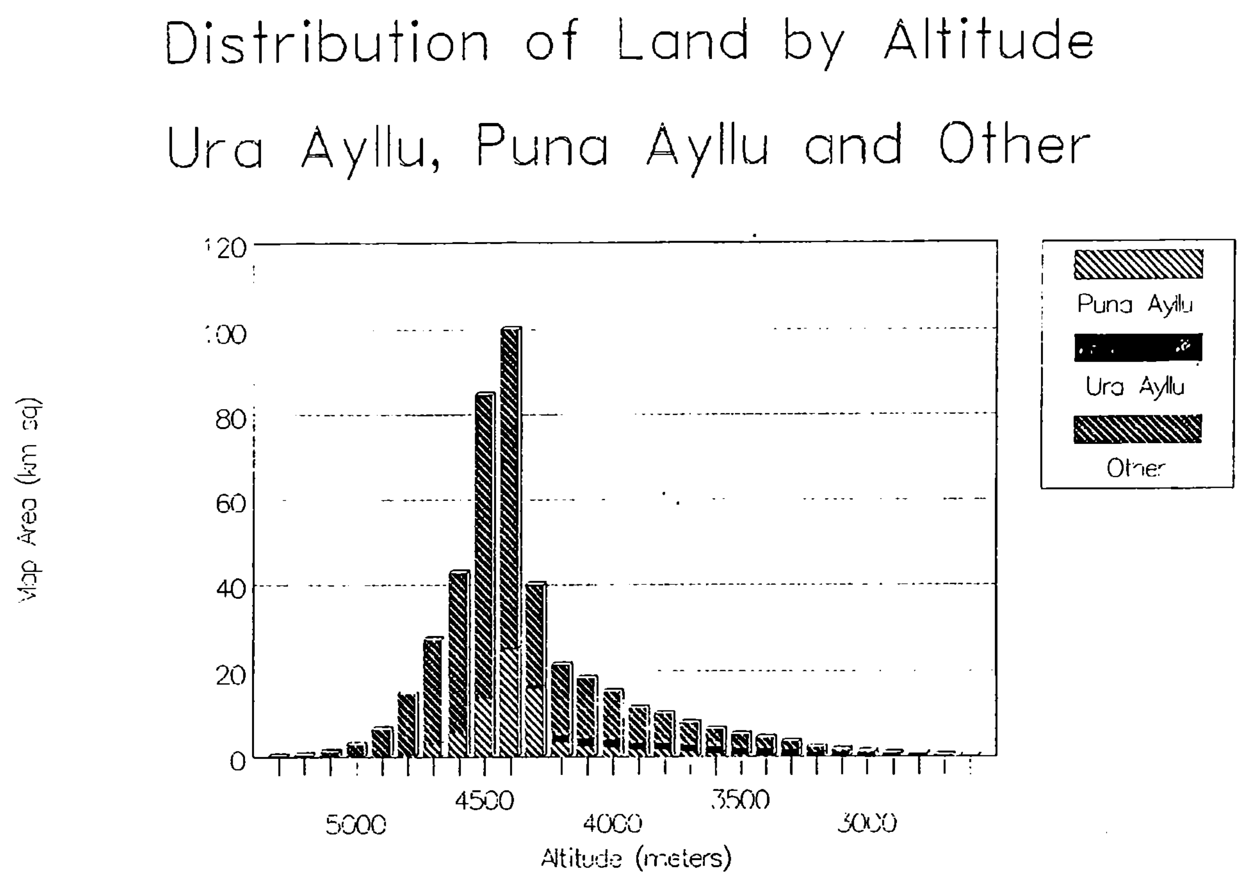
Elev	Other		Puna Ayllu		Ura Ayllu		Total	
m	km sq	Col%	km sq	Col%	km sq	Col%	km sq	Col%
5300	0.07	0					0.07	0
5200	0.43	0					0.43	0
5100	1.20	0					1.20	0
5000	2.89	1					2.89	1
4900	6.44	2	0.01	0			6.45	1
4800	14.15	4	0.51	1			14.66	3
4700	24.10	7	3.14	4			27.24	6
4600	36.75	11	5.94	8			42.69	10
4500	70.86	21	13.74	17	0.01	0	84.61	20
4400	74.64	23	25.22	32	0.10	0	99.96	23
4300	23.24	7	16.01	20	0.70	3	39.95	9
4200	16.29	5	3.43	4	1.66	8	21.38	5
4100	13.96	4	2.52	3	1.83	9	18.31	4
4000	11.04	3	2.11	3	1.92	9	15.07	4
3900	8.06	2	1.81	2	1.41	7	11.28	3
3800	6.73	2	1.73	2	1.39	7	9.85	2
3700	5.19	2	1.29	2	1.37	6	7.85	2
3600	4.03	1	0.94	1	1.38	7	6.35	1
3500	3.29	1	0.61	1	1.31	6	5.21	1
3400	2.59	1	0.15	0	1.75	8	4.49	1
3300	1.81	1			1.69	8	3.50	1
3200	1.17	0			0.96	5	2.13	0
3100	0.60	0			1.03	5	1.63	0
3000	0.31	0			0.86	4	1.17	0
2900	0.15	0			0.71	3	0.86	0
2800	0.04	0			0.60	3	0.64	0
2700	0.00				0.30	1	0.30	0
2600	0.00				0.11	1	0.11	0
TOTAL	**330.03**	**100**	**79.16**	**100**	**21.09**	**100**	**430.28**	**100**

Table 3. Elevation by Area for Lakes.

Elev	Terrestrial		Lakes		Total	
m	km sq	Col%	km sq	Col%	km sq	Col%
5300	0.07	0			0.07	0
5200	0.43	0			0.43	0
5100	1.20	0			1.20	0
5000	2.89	1			2.89	1
4900	6.45	2			6.45	1
4800	14.65	3	0.01	0	14.66	3
4700	27.08	6	0.16	2	27.24	6
4600	42.61	10	0.08	1	42.69	10
4500	84.23	20	0.38	4	84.61	20
4400	99.74	24	0.22	2	99.96	23
4300	32.02	8	7.93	89	39.95	9
4200	21.30	5	0.08	1	21.38	5
4100	18.27	4	0.04	0	18.31	4
4000	15.02	4	0.04	0	15.06	4
3900	11.27	3			11.27	3
3800	9.84	2			9.84	2
3700	7.84	2			7.84	2
3600	6.34	2			6.34	1
3500	5.21	1			5.21	1
3400	4.49	1			4.49	1
3300	3.50	1			3.50	1
3200	2.13	1			2.13	0
3100	1.63	0			1.63	0
3000	1.18	0			1.18	0
2900	0.86	0			0.86	0
2800	0.63	0			0.63	0
2700	0.30	0			0.30	0
2600	0.11	0			0.11	0
TOTAL	**421.29**	**100**	**8.94**	**100**	**430.23**	**100**

Table 4. Elevation by Area for Archaeological Survey

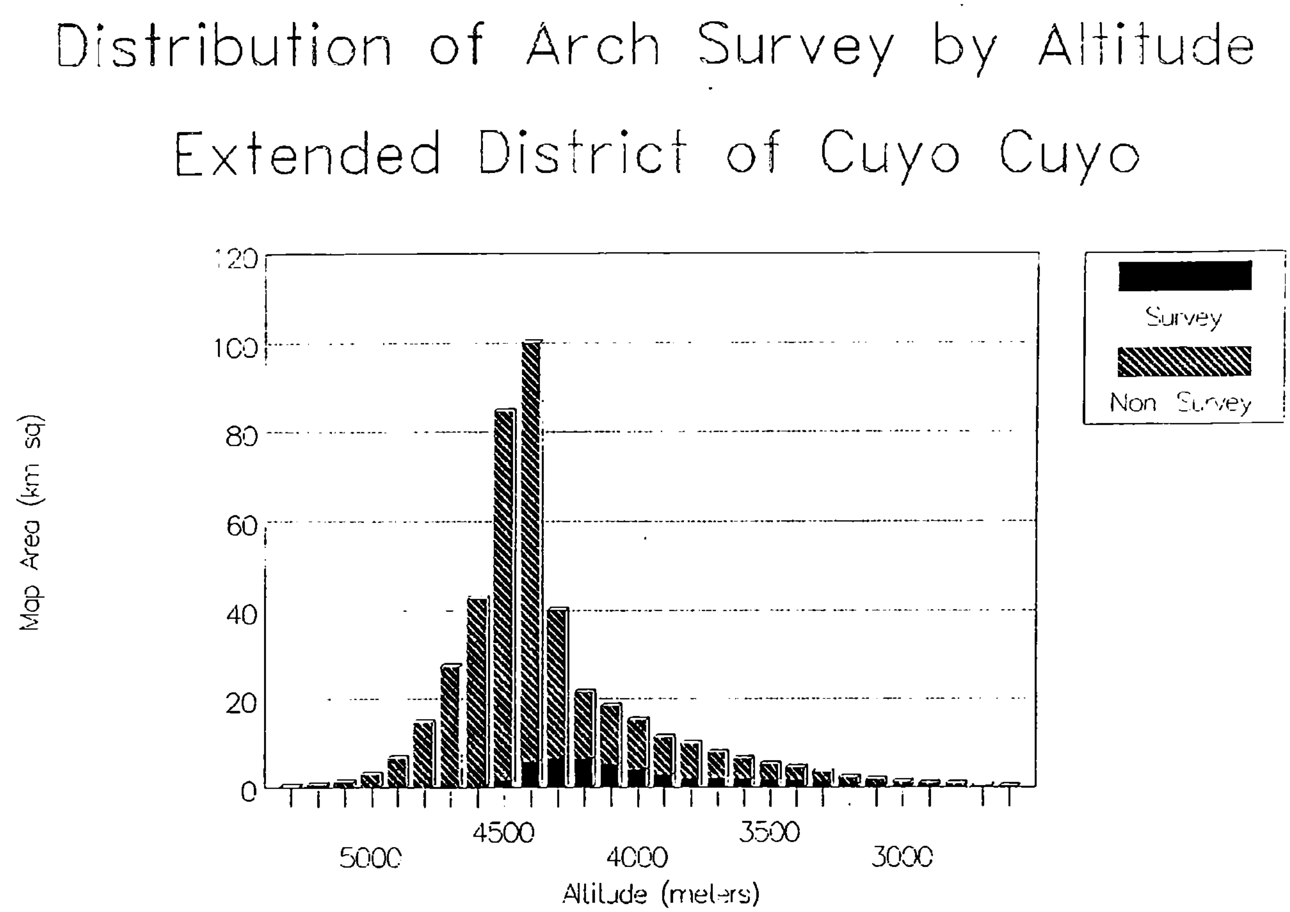
Elev m	Non-Survey km sq	Non-Survey Col%	Survey km sq	Survey Col%	Total km sq	Total Col%
5300	0.07	0			0.07	0
5200	0.43	0			0.43	0
5100	1.20	0			1.20	0
5000	2.89	1			2.89	1
4900	6.45	2			6.45	1
4800	14.66	4			14.66	3
4700	27.24	7			27.24	6
4600	42.66	11	0.03	0	42.69	10
4500	83.03	22	1.59	4	84.62	20
4400	94.23	24	5.73	13	99.96	23
4300	33.46	9	6.49	15	39.95	9
4200	15.03	4	6.35	14	21.38	5
4100	13.20	3	5.11	12	18.31	4
4000	11.07	3	3.99	9	15.06	4
3900	8.38	2	2.89	7	11.27	3
3800	7.79	2	2.05	5	9.84	2
3700	5.80	2	2.04	5	7.84	2
3600	4.46	1	1.89	4	6.35	1
3500	3.60	1	1.61	4	5.21	1
3400	3.00	1	1.49	3	4.49	1
3300	2.32	1	1.18	3	3.50	1
3200	1.56	0	0.57	1	2.13	0
3100	1.21	0	0.42	1	1.63	0
3000	0.83	0	0.35	1	1.18	0
2900	0.61	0	0.25	1	0.86	0
2800	0.48	0	0.15	0	0.63	0
2700	0.29	0	0.00		0.29	0
2600	0.11	0	0.00		0.11	0
TOTAL	**386.06**	**100**	**44.18**	**100**	**430.24**	**100**



Graph 1. Distribution of Land by Altitude

A total of eight sites were located (Goland 1988). They fall between 3400 m and 4400 m, but the majority of them and the larger part of the area covered are in the upper end of this range, at or above 4100m (areas given in hectares):

Site name:		CC-2	CC-3	CC-4	CC-5	CC-6	CC-7	CC-8	CC-9	TOTAL
Elev (m)	4400	2.11				0.05		4.66		6.81
	4300		0.02			0.53	5.04			5.58
	4200		5.76		0.35		4.30			10.42
	4100				1.71					1.71
	4000									
	3900									
	3800			1.35						1.35
	3700			0.79						0.79
	3600									
	3500								1.82	1.82
	3400								0.01	0.01
Total		2.11	5.78	2.14	2.06	0.58	9.34	4.66	1.83	28.49



Graph 2. Distribution of Archeological Survey by Altitude

Land Use Zones

In 1981 Camino et al. surveyed the Cuyo Cuyo region and identified key agricultural zones. Because their zonal boundaries were defined by elevation a GIS coverage of these features is a reclassification by altitude. By combining (unioning) the vegetation zone coverage with that for political boundaries we can calculate the distribution of these zones by community (Table 5). The results confirm and refine our impression of basic ecological differences between the two study communities. Puna Ayllu has 89% of its territory in the high altitude pasture zones, another 7% in the production zone suitable only for frost-hardy bitter potatoes, and only 4% of its area (2.99 km sq) in the main tuber and habas zone of the valley. Puna Ayllu has no territory in the lower tuber or maize zones. In contrast, the production zones of Ura Ayllu are more diverse and evenly represented. Ura Ayllu has 20% of its territory in the pasture region, 22%, 28% and 13% in the upper, middle and lower tuber production zones, respectively, and an additional 17% located at altitudes suitable for cultivation of maize.

Table 5. Agricultural Zone by Area for Study Communities.

Zone*	Other		Puna Ayllu		Ura Ayllu		Total	
	km sq	Col %	km sq	Col %	km sq	Col %	km sq	Col %
H	4.59	1	.00	0	.00	0	4.59	1
A	280.40	85	70.52	89	4.29	20	355.21	83
B	25.82	8	5.65	7	4.71	22	36.18	8
C	15.09	5	2.99	0	5.80	28	23.88	6
D	2.99	1	0.01	0	2.65	13	5.65	1
E	1.10	0	.00	0	3.61	17	4.71	1
TOTAL	**329.99**	**100**	**79.17**	**100**	**21.06**	**100**	**430.22**	**100**

*H = (Helada), glaciers & snowcaps, 4800m+; A = (Pastizales), pasture lands, 4100-4800m; B = (Luki Manda, Altura), bitter potato zone, 3800m-4100m; C = (Uray Manda), tuber production zone, 3400-3800m; D = (Zona Manda del Annexo), lower tuber production zone, 3200-3400m; E = (Tierra de maíz), maize production zone, 2600m-3200m.

TIN ANALYSES[9]

We have reproduced as Appendix I the TIN protocol used to create the 3d views and analyses which

[9]The TIN module of ArcInfo produces a three dimensional representation of a map which has at least one spatial attribute (x,y coordinates) and an associated vertical scale (z). In our case these are Cartesian points taken from contours lines, and their associated elevations, respectively. The irregular topography of a landscape is approximated by fitting it with a surface of continguous triangles. Each triangle is a polygon, defined by its corner points, perimeter, area, elevation, slope angle and slope aspect. This method of surface representation is economic for a digital computer to store and analyze, and it allows one to produce profiles and three-dimensional views, along with network and various kinds of three-dimensional analyses.

In practice the TIN module requires a large number of steps, each one subject to experimentation and the occasional pitfall (Appendix I). One must start with a larger coverage than ultimately is desired (as margins shrink during processing), manually add to the contour map points representing peaks, swales, saddles and other topographic inflection points, convert the coverage to a TIN, transform the TIN to a lattice, apply various filters to smooth and augment different aspects of relief, apply an algorithm that uses generally known topographic relationships to further enhance the geographical realism of the surface, then reconvert the lattice to a TIN (for 3d views, which can be "draped" with other coverages), convert the TIN to a polygon coverage, clip the polygon coverage to the desired boundary, and dissolve on the continuous slope and aspect variables to create coverages which represent those features categorically. If analyses are desired, the Info files of these coverages must be exported from ArcInfo. They then can be reformattred and imported into a database or statistical package such as SAS. This can be a difficult and time-consuming procedure.

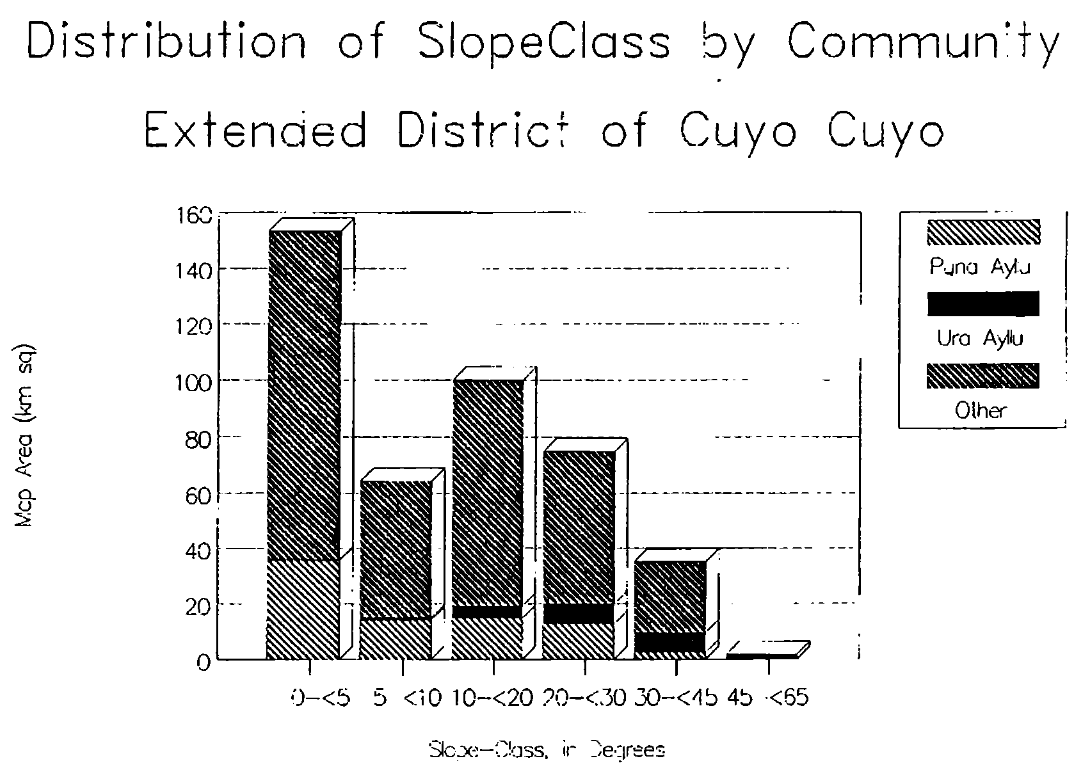
are presented in this section. It describes the sequence of steps, the commands used and the parameters which we adopted, sometimes after considerable experimentation. It also provides some analytical guidelines, draws attention to unanticipated difficulties and describes our solutions.

Slope, Aspect and Surface Area

The TIN module of ArcInfo allows one to create coverages representing slope angle, slope aspect and elevation. These can be unioned with other coverages to produce more specific, cross-tabular analyses. In Table 6 (Graph 3) we show the distribution of slope classes by community. Note that the lands of

Table 6. Slope-Class by Area for Study Communities.

Slope (deg)	Other km sq	Other Col%	Puna Ayllu km sq	Puna Ayllu Col%	Ura Ayllu km sq	Ura Ayllu Col%	Total km sq	Total Col%
0= <5	117.30	36	35.66	45	0.36	02	153.32	36
5=<10	49.35	15	14.22	18	0.76	04	64.33	15
10=<20	80.97	25	14.74	18	4.37	22	100.08	23
20=<30	54.85	17	12.71	16	7.32	37	74.88	17
30=<45	25.61	8	2.41	3	7.11	36	35.13	8
45=<65	1.54	0	0.07	0	0.10	0	1.71	0
TOTAL	**329.62**	**100**	**79.81**	**100**	**20.02**	**100**	**429.45**	**100**



Graph 3. Distribution of Slope-Class by Community

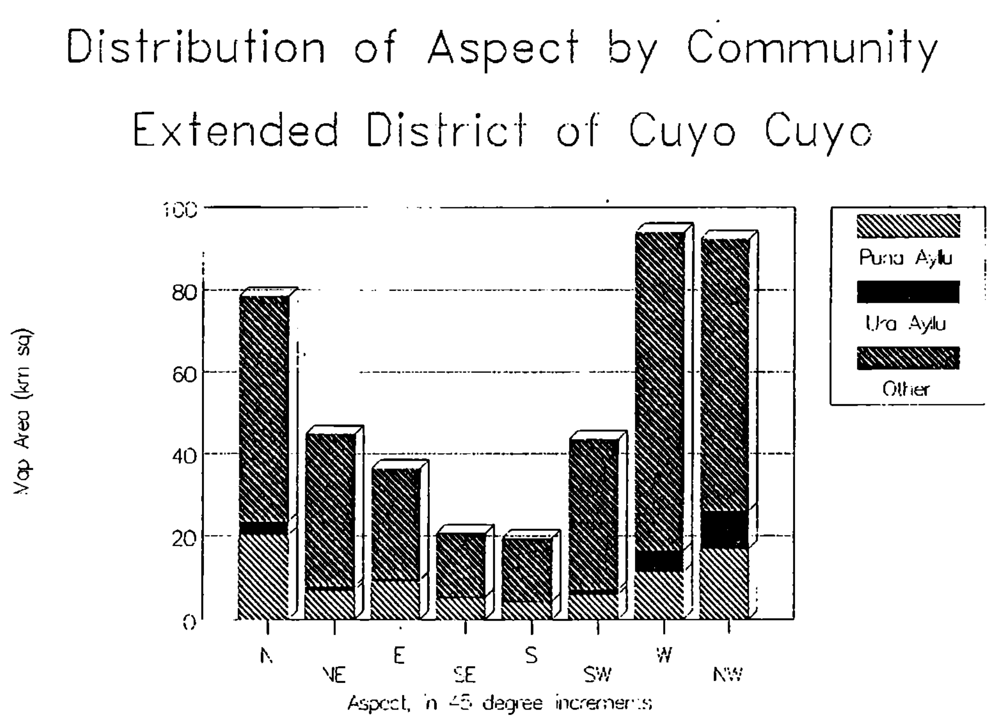
Puna Ayllu are distributed among the lower slope angles (45% less than 5 degrees; 81 percent less than 20 degrees). This is consistent with their location on a high plain with heavily weathered hills. By contrast, the lands of Ura Ayllu are concentrated at the steeper angles (73% at an angle of 20 degrees or more). They occupy the steep canyonsides and narrow valley bottoms of the heavily dissected headwaters of the eastern escarpment.

Table 7 (Graph 4) depicts aspect for the study sample (in 45 degree increments). Puna Ayllu lands

Table 7. Aspect-Class by Area for Study Communities.

Aspect*	Other km sq	Other Col%	Puna Ayllu km sq	Puna Ayllu Col%	Ura Ayllu km sq	Ura Ayllu Col%	Total km sq	Total Col%
N	55.01	17	20.20	25	3.25	16	78.46	18
NE	36.89	11	6.96	9	0.92	5	44.77	10
E	26.75	8	9.14	11	0.42	2	36.31	8
SE	15.19	5	5.20	7	0.18	1	20.57	5
S	15.05	5	4.29	5	0.05	0	19.39	5
SW	36.53	11	5.89	7	1.10	6	43.52	10
W	77.75	24	11.30	14	4.99	25	94.04	22
NW	66.38	20	16.83	21	9.08	45	92.29	21
	329.55	**100**	**79.81**	**100**	**19.99**	**100**	**429.35**	**100**

**In 45 degree increments.*



Graph 4. Distribution of aspect by Community

are distributed across slopes facing in all compass directions, with slight biases to the W, NW and N. Nearly all (86%) of the land of Ura Ayllu faces these three directions, that is toward the northwest quadrant. Although Ura Ayllu lands are steep (Table 6), their aspect is advantageous. In this southern hemisphere location, crops facing toward the north receive extra solar radiation. And those on slopes with a northwestern orientation do not suffer the shock of strong early morning sunlight on frosted plants (as would occur if they faced toward the NE quadrant).

Anyone who has spent much time in mountain environments knows that steep-slope habitats defy two-dimensional maps. This has a physiological element that can be felt in the calves and lungs. It has a perceptual element, as it takes great skill to create and manipulate a complex three-dimensional image using a flat topographic map. Of greater importance, it has an analytical element. Among the more important measures of human-environment relations are those routinely calculated with reference to area (population density, crop production statistics, etc.). Yet it virtually never is specified if the denominator value used in these calculations is the map area (the area a slope projects onto a horizontal plane) or the *actual surface area on the ground.* Our facile reference to the "areas" of Puna and Ura Ayllu in Tables 1 through 5 (actually map rather than surface area) is an example. The possible degree of error produced by this oversight is easily calculated for a plane of uniform angle:

Degree slope	**Percent increase of surface relative to map area**
10	1.5%
20	6.4%
30	15.5%
40	30.5%
50	55.6%
60	100.0%

Uncertainty of this magnitude surely will complicate precise analysis of relationships among slope,population and agricultural productivity in mountain environments.

On the andean escarpment it is unexceptional to find fields on steep slopes, whether they are terraced or not. Calculations based on map and surface areas will produce significant differences. In Table 8 we describe the relationship between surface area and horizontal or map area for the Cuyo Cuyo study communities. The results are based on our TIN analysis (see Appendix I). The ratio ranges from a low of 1.01:1 for Churura, a small annexo on the high plain above Cuyo Cuyo, to 1.13:1 for the study community of Ura Ayllu. To illustrate the potential biases of ignoring the surface/map area distinction, note that potato production on the average Ura Ayllu slope (8535 kg/ha,

Table 8. Relationship of Map to Surface Area, Cuyo Cuyo Districts.

Community or Annex	**Map km sq**	**Surface km sq**	**Ratio Surface/Map**
Calpapata	28.89	32.38	1.12:1
Churura	117.06	118.46	1.01:1
Cojene-Rotojoni	85.55	91.65	1.07:1
Huacchani	10.46	10.64	1.02:1
Huancasayani	44.78	48.93	1.09:1
Huanomoco	18.09	19.20	1.06:1
Nacoreque	13.72	15.09	1.10:1
Puna Ayllu	79.33	81.74	1.03:1
Pacneria	3.88	4.04	1.04:1
Soracchocha	6.63	6.88	1.04:1
Ura Ayllu	19.25	21.70	1.13:1
TOTAL	**427.64**	**450.71**	**1.05:1**

surface area) would jump to 9,621 kg/ha, if calculated by map area.[10] The Ura Ayllu population density of 41.3 individuals/km sq (map area) would fall to 36.6 individuals/km sq if calculated by surface area.

In summary, Puna Ayllu lands are characterized by low-slope and diverse aspects. They are predominantly high altitude plains located above the margin of agriculture, with limited extensions into the upper, frost-hardy potato zones. The community of Ura Ayllu is much smaller and steeper, with territory spread fairly evenly from the highest tuber producing zones to altitudes low enough to permit maize cultivation. Nearly all of the Puna Ayllu land faces onto the northwestern quadrant.

PLANNED ANALYSES

As demonstrated, GIS can be used to generate the base-line data necessary to analyze the relationships between peasant ecology and economics. Our planned studies build on this base to address more directly questions of production and risk.

Field Distribution

A key component of our research effort is analysis of field distribution as a potential risk-reduction mechanism. We have adopted a micro-economic model developed by the economic historian Donald McCloskey and originally applied in studies of field dispersion in medieval England (McCloskey 1976). At its simplest, the model assesses the trade-off between a benefit (reduced harvest variability and thus diminished likelihood of an unwelcome shortfall, as greater numbers of dispersed and independently varying fields are added to the crop inventory), and a cost (the diminished average net productivity of each field as travel time and transportation costs grow). Because both the benefits and costs are a function of the number of fields, a simple optimization model allows one to examine this relationship quantitatively (Winterhalder 1990b).

However, the anlaytical demands of the model are enormous. It is something entirely different to handle the spatial dimension, multiple variables and sample sized necessasry to make a careful quantitative analysis of this question. McCloskey used impressive historical skills and analytical ingenuity in deriving parameter estimates from the documentary sources available to him. In the Andean case, we have been able to measure many of the relevant variables directly. Over the two years of our sample, we have gathered approximately 80 pieces of information on each of 675 fields (488 unique plots, allowing for those planted in both of the consecutive years of our sample). These fields are small (average size is 240m^2). Families disperse their agricultural efforts into an average of 17 plots/year. Using surface area, production ranges from 8535 kg/ha for potatoes to 1162 kg/ha for habas. Other turber crops are intermediate in productivity: oca = 8269 kg/ha; illaco = 5836 kg/ha; isano = 6892 kg/ha.

We currently are digitizing these field locations. Making them a coverage in our GIS will give us analytical control over relationships between crop distribution and production, and geographical factors such as elevation, slope and aspect. It gives us visual tools for analyzing the movement of fields and cultigens among valley-wide units of the sectorial fallow rotation. And, it gives us efficac-

[10]This calculation is hypothetical, as much of Ura Ayllu's potato production occurs on the more gentle incline of terrace surfaces.

ious means of calculating travel and transportation costs (using the NETWORK module of ArcInfo) important in our model. These studies are pending, but we are optimistic about their potential.

Terrace Distribution, Use and Abandonment

The stone-faced terraces that dominate the agricultural landscape of Cuyo Cuyo apparently are the product of a massive, technologically proficient and highly organized human effort. Our archaeological survey suggests that they are anywhere from 900 to 1500 years old (Goland 1988). Examination of partial cross-sections produced by slides reveals they have a standardized and complex wall form and internal structure. Ground survey of maintained and collapsed areas suggests that they once were even more extensive than they are today.

Terrace use, maintenance, and reclamation have become practical issues throughout the Andes, but little is known about their distribution, functions or productivity. There may be a million hectares of terraces in Peru, 75% of which currently are abandoned. This is a sizeable figure when compared to the 2.6 million hectares of land under cultivation in this land-scarce country (Denevan 1987). As part of the PSE project, one of us (BW) has mapped the distribution of maintained and abandoned terraces in the Cuyo Cuyo area on small-scale (1:10,000) air photos. We expect to digitize this information as a GIS coverage and then to use the spatial sampling capacities of ArcInfo to determine if terrace location is systematically affected by altitude, slope, exposure, distance from settlement, or other factors. It is easy to imagine hypotheses about these relationships, but without the systematic and quantitative capacities of GIS, it will be impossible to rigorously test them.

Micro-Climate and Remote Sensing

Two more envisioned projects will conclude this prospectus of GIS applications in Cuyo Cuyo. First, our analyses are demonstrating high correlations between some measures of climate (e.g., monthly rainfall predictability) and geographic variables like altitude (see Winterhalder 1990a). We hope eventually to use GIS to translate these relationships into climatic maps with much greater accuracy and at a much smaller scale than presently is possible in a heterogeneous region like the Andes. Prediction of the effects of climate change on agricultural production and peasant livelihood will depend on such capacities. Second, we anticipate a much more sophisticated analysis of vegetation cover and land use as we are able to incorporate landsat TM data into our coverages. We are just beginning to work with a landsat scene of Cuyo Cuyo from March 1987, toward the end of the growing season and coincident with the second year of our detailed field studies.

CONCLUSIONS

It has been the genius of Andean peoples to adapt an inhospitable environment to human purposes. Pre-Columbian agriculturalists pushed the upper limits of crop production and pastoralism with andean domesticates to above 4000m. They used the cold to advantage by freeze-drying tubers for storage as a hedge against risk. They developed complex political and administrative systems in order to integrate and pool the resources of diverse, complementary micro-environmental zones (Murra 1984). Our attempts to understand and in some cases recover that knowledge, to preserve it, and to apply it for the benefit of current and future andean peoples will depend on our achieving similar levels of environmental sophistication. GIS and remote sensing will be useful tools in that process.

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The Remote Sensing/GIS Laboratory at UNC Chapel Hill is equipped with a Digital Microvax II with five Tektronix 4209 graphics terminals. The primary software packages on the Microvax are ERDAS, a raster-based image processing package, and ARC/INFO, a vector-based GIS package. The lab also has a Sun workstation for ERDAS image processing with a separate ArcInfo site license. Processing in this lab is aided by the campus-wide VAX 6330, which also has an ARC/INFO site license, and a Compaq work station with ERDAS and an ArcInfo live-link connection. Communication is possible between all of these processors through the campus Ethernet and inter-lab Telnet connections. Hardcopy devices include a Tektronix 4693 four color printer and a Calcomp 1025 for large-format plots.

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APPENDIX I
Steps in a TIN Analysis

The following protocol describes the specific steps that we have used to create the PSE TIN analyses. By overlooking some of the details specific to our coverage, it also can be read as a general guide to procedures, problems and solutions.

1. CLIP a wide-margin, *line* coverage from the contours coverage, using adminwmar as the clip boundary.

[This creates a line coverage of the 100m contour intervals as the basis for the TIN. It is clipped with boundaries (adminwmar) slightly larger than and encompassing the desired slope/aspect analysis area (equivalent to adminall coverage), to allow for margin shrinkage during filtering and for later removal of anomalous edge effects].

2. Add points (n = 41) for peaks, swales and for any boundary points that would be concave on the basis of end points of adjacent contour lines. TIN procedures work best on coverages with a convex hull. This creates coverage DISTIN00, which is the basis of all subsequent TIN manipulations.

[The elevations of the marginal points were interpolated from the quadrangle maps, using a temporary union of contours with adminplusb (a union of adminwmar and the map boundaries) to aid in correctly positioning the elevation estimates. Note that the La Rinconada quadrangle was not available so none of its peaks were added as points to the DISTIN00].

3. Arctin DISTIN00 to create DISTIN01. Command sequence: ARCTIN DISTIN00 DISTIN01 ALL ELEV 50 50.

[This creates a coverage with 23,728 nodes; 50 hull nodes; 47404 triangles, and minimum and maximum elevations of 2600m and 5376m respectively].

4. Tinlattice DISTIN01 to create DISTIN02. Command sequence: TINLATTICE DISTIN01 DISTIN02 SMOOTH.

[Select 296 x-axis and 315 y-axis points, to yield a d_x = 100m and a d_y = 100m. This gives a lattice of 93,536 points].

5. Filter DISTIN02 to create DISTIN03. Command sequence: FILTER DISTIN02.LAT DISTIN03 LOW 1.

[Low filtering smooths jagged edges introduced by earlier TIN procedures].

6. Vip DISTIN03 to create DISTIN04. Command sequence: VIP DISTIN03.LAT DISTIN04 45.

[This will recreate the lattice using an algorithm that selects the topographically most significant points. The 45% selection finds 43,929 points (of an estimated 42,091), using the DISTIN03 lattice (which itself has 93,536 points)].

7. Arctin DISTIN04 to create DISTIN05. Command sequence: ARCTIN DISTIN04 DISTIN05 POINT SPOT 125 125.

[This creates a TIN coverage with 11570 nodes, 73 hull nodes and 23065 triangles; minimum z is 2614m; maximum z is 5367m].

8. Tinarc DISTIN05 to create DISTIN06. Command sequence: TINARC DISTIN05 DISTIN06 POLY DEGREE #.

[This creates a polygon coverage which has slope (in degrees) and aspect variables (variables are called "items" in ArcInfo). There are 23,066 polygons, i.e., the 23065 of the TIN coverage plus the global polygon created by the perimeter. The area is 626.98 km sq].

9. Clip DISTIN06 with ADMINALL to create DISTIN07. Command sequence: CLIP DISTIN06 ADMINALL DISTIN07 POLY 100.

[This clips the slope/aspect polygon coverage to the margins of the political units that comprise the sample for analysis. In effect, at this point we excise the marginal regions introduced by using adminwmar in the original clip (see step 1). DISTIN07 contains 15,669 polygons and has an area of 430.67 km sq. It contains variables for slope ("DEGREE_SLOPE"), aspect ("ASPECT") and surface area ("SAREA"). In anticipation of later procedures, the item names SLOPE-CLASS and ASPECT-CLASS should be added to this coverage].

10a. Union DISTIN07 with ADMINALL to create DISTIN08. Command sequence: UNION DISTIN07 ADMINALL DISTIN08 100 JOIN.

[This joins the administrative boundaries with the slope/aspect polygon coverage, so that later analyses can be done by community. DISTIN08 has 15369 polygons, an area of 429.26 km sq and, in addition to the variables mentioned immediately above, now has an item for DISTRICT. Use repeat DROPITEMS to get rid of unnecessary variables ADMINALL-ID, ADMINALL#, DISTIN07-ID, and DISTIN07#. DISTIN08 will be used mainly to calculate the **surface area** of the landscape available in different administrative units within the District].

10b. Export INFO portion of DISTIN08, for file transfer and analysis. Command sequence: EXPORT INFO DISTIN08.PAT DISTSFAR NONE.

[This will export the info (database) portion of the DISTIN08 coverage into an uncompressed, ascii file with the name DISTSFAR.E00. After editing to remove header and footer materials, and to insure column alignment and excision of unwanted variables, it is translated to a SAS data file. Note that procedures for transfer, editing and translation will depend on local hardware and software options].

11a. Create lookup tables, to dissolve the DEGREE_SLOPE and ASPECT variables into categories of SLOPE-CLASS and ASPECT-CLASS.

[The look-up tables are constructed according to the intervals and item conventions given in the tables immediately below. Note that for the **slope** classification the intervals are not uniform in width, but increase as slope grows steeper in the following sequence: 5, 5, 10, 10, 15, 20, and 25 degrees.

For **aspect** the 360 degrees of the circle have been divided into eight equal quadrants centered on the 0, 45, 90, 135, etc., degree axes].

SLOPETBLA

Slope Interval (degrees)	Degree_Slope	Slope-Class	Symbol
0 <= x < 5	5.0	1	0
5 <= x < 10	10.0	2	1
10 <= x < 20	20.0	3	2
20 <= x < 30	30.0	4	3
30 <= x < 45	45.0	5	5
45 <= x < 65	65.0	6	7
65 <= x < 90	90.0	7	9

ASPECTBL

Aspect description	Aspect	Aspect-class	Symbol
North	22.5	1	0
Northeast	67.5	2	1
East	112.5	3	2
Southeast	157.5	4	3
South	202.5	5	4
Southwest	247.5	6	5
West	292.5	7	6
Northwest	337.5	8	7
North	360.0	1	0

11b. Within INFO, select DISTIN07 and use the relate command to create an item with the proper degree-slope and aspect value for each record. This is done with commands as follows:

```
SELECT DISTIN07.PAT
RELATE SLOPETBLA BY DEGREE_SLOPE WITH TABLE NUMERIC
CALCULATE SLOPE-CLASS = $1SLOPE-CLASS
```

```
SELECT DISTIN07.PAT
RELATE ASPECTBL BY ASPECT WITH TABLE NUMERIC
CALCULATE ASPECT-CLASS = $1ASPECT-CLASS
```

11c. Use the dissolve command to create a slope class coverage and an aspect class coverage. The command sequence is as follows:

DISSOLVE DISTIN07 SLOPECOV SLOPE-CLASS POLY

DISSOLVE DISTIN07 ASPECTCOV ASPECT-CLASS POLY

[Before running these procedures, assign the global polygon an arbitrary SLOPE-CLASS and ASPECT-CLASS value (e.g., 15) that is not represented among the values for these variables in the slope or aspect lookup tables. The world polygon must have a dissolve item value different from any of the values for the interior polygons. This circumvents a software bug in the dissolve procedure, in which the global polygon is confused with other polygons with which it shares a border].

12a. Union slopecov, aspectcov, adminall, and 100msamp to create a file named U03. Command sequences:

```
UNION SLOPECOV ASPECTCOV U01 50 JOIN
UNION U01 ADMINALL U02 50 JOIN
UNION U02 100MSAMP U03 50 JOIN
CLEAN U03
```

12b. Export the Info (database) portion of U03 for analysis with SAS (see 10b).

[Prior to export, use INFO commands (Reselect, List) to check all items (variables) for values that are missing, out of range, or illogical in context (e.g., larger values for the surface than map (the horizontal projection) area of a sloped polygon). In our experience, one can count on a small number of such anomalies, especially along the margins of a TIN-generated coverage. Some of these can be fixed with INFO procedures (such as eliminate, to take care of sliver polygons) or by use of arcedit to locate and manually supply or correct the values].

SOME ADDITIONAL TIN PROBLEMS, WITH SOLUTIONS

Problem: When using processes that require a fuzzy tolerance, the default values often yields strange results. The anomalous coverages have arcs that are clipped together at odd points and often the shape and area of the polygons are changed in inappropriate ways. These results are particularly problematic for closely spaced contour lines (steep slopes).

SOLUTION: To preserve the integrity of the original coverage, we have started routinely using a very small value (e.g., 10m for the UTM coordinate system) for the fuzzy tolerance option.

Problem: When the TIN coverage is clipped with an attribute coverage, illogical values appear for area and surface area (e.g., area > surface area, negative values, values out of range). Apparently this is due to a difference in the number of digits for the x and y coordinates (UTM system). Because y coordinates had one more digit, precision errors occur in the calculation of area.

SOLUTION: To resolve this problem, the coverages were transformed into a new coordinate system, with one digit removed from the y coordinate. The steps are as follows:

1. Copy <old coverage> <new coverage>
2. Within INFO, select the <new coverage> .TIC file
3. CALCULATE YTIC = YTIC - 8000000
4. Within ARC: Transform <old coverage> <new coverage>. Do this to both the TIN coverage and the clip coverage, then subsequent clips yield logical values.

Problem: When the TIN coverage was unioned with one of the attribute coverages, surface area values no longer are correct relative to area. Whenever an attribute coverage overlaps (e.g., bisects) a TIN polygon, the union procedure creates two new polygons. The area variable in each polygon produced by the split is corrected, but the surface area variable of the original TIN polygon is carried over into both of the new, derived polygons [i.e., The union process makes the proportionate adjustments to area, but treats surface area value as it would any other item in the attribute table: it assigns it unchanged to both of the new polygons].

SOLUTION: To resolve this problem, new polygons had to be related to the originals, in order to re-calculate the correct values for surface area.

1. Within ARC: Additem <tin coverage>.PAT <tin coverage>.PAT NEWSAREA 4 12 F 3
2. Within INFO select <tin coverage>.PAT
3. CALCULATE IDSAVE = $RECNO (This command gives each record a unique identifier that is carried over with the surface area value).
4. Within ARC: Union <tin coverage> <attribute coverage> <new coverage> 10
5. Within INFO: Select <new coverage>.PAT
6. Relate <tin coverage> by IDSAVE
7. CALCULATE NEWSAREA = SAREA* (AREA/$1AREA)

NEWSAREA now is the correct value in those polygons split as a result of the union procedure. A good way to check which surface area values have changed is to compare the NEWSAREA and SAREA values. If they are the same, then that is a polygon that wasn't split. If they are different, verify that they represent the same proportion as AREA to $1AREA.

A TIN FLOWCHART
(numbers keyed to accompanying text)