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Land-use/land-cover dynamics in the Taquina Watershed Cochabamba Bolivia 1968-2001

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LAND-USE/LAND-COVER DYNAMICS IN THE TAQUIÑA WATERSHED, COCHABAMBA, BOLIVIA: 1968-2001

by

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This paper looks at trends in land-use/cover change in the Taquiña Watershed in the Cochabamba Department of Bolivia from 1968 to 2001 and discusses some of the factors contributing to change. Observations and discussion are based on land-use/cover maps created using GIS that were produced using aerial photographs from 1968, 1993, and 1998, with a 2001 map created based on field observations. Vegetation transects, analysis of physical soil properties, and semi-structured interviews with local residents were also conducted to better understand the physical nature and human perception of change in the watershed. Decreases in agriculture, brush land, native forest, and silvopasture were observed between 1968 and 1993, with increases seen in pasture and eroded land. Land-use/cover change trends were observed beginning in 1993, with increases in agriculture, brush land, and silvopasture and decreases in pasture and eroded land. A slight increase in native forest took place after 1998.

Factors that contributed to land-use/cover dynamics in the watershed include colonialism, agrarian reform, the establishment of Tunari National Park, drought, political and economic variables, conservation activities, and alternative livelihood strategies. It is believed that much of the reversal in land-use/cover change trends is due to a combination of conservation activities initiated by The Program for Integrated Watershed Management (PROMIC) and alternative livelihood opportunities and strategies. Although the changes observed in the watershed likely reduce runoff and erosion, the expansion of agricultural land, possibly an unforeseen byproduct of PROMIC's management activities, poses potential environmental problems for the future.

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Chapter I
INTRODUCTION

The dynamics of land-use/cover change, human livelihood strategies, and their effects on the environment are of increasing concern around the world. Terms such as deforestation, global warming, and biodiversity have not only generated a multitude of studies but entered into our common vernacular. The more we learn about the causes and effects associated with the interface between the human and natural world, the more we wish to know. Recently, the Moscow Conference on Global Changes and the International Geographical Union (IGU) both recommended broadening research activities that focus upon global environmental change (IGU, 1998). In particular, the dynamics of social and environmental change in mountain regions have gained focus in recognition of the International Year of the Mountains (2002), and have helped to raise awareness of the importance of mountains in a broader global context.

Mountain regions around the world have experienced increased environmental change and land conversion generated from deforestation, population growth, agricultural expansion, overgrazing, mining, and hydro-electric development, and other activities (Price, 1981; Goudie, 2000; Bewket, 2002). The importance of mitigating the adverse effects of these land changes is not merely for the protection or preservation of the local environment, but downstream effects of soil erosion, flooding, and sedimentation (White and Maldonado, 1991; Harden, 1993; Sharma and Minhas, 1993; Braud et al., 2001; Estrada and Posner, 2001; Hug and Baccini, 2002). For example, Sharma and Minhas (1993) discuss the effects of increasing population upon the degradation of agriculture, pasture, and forest resources, as well as upon the local and downstream quality of life for people in Himachal Pradesh, India. In the Blue Nile Basin of Ethiopia, Bewket (2002) discusses the implications of land-cover dynamics on the hydrological balance of the Chemoga Watershed and problems of flooding, sedimentation, and the "burying" of valuable grazing land.

In the Andes region of South America, these issues have been addressed in a number of studies. Harden (1993) suggests that patterns of land-use are an important consideration in looking at problems of increased sedimentation in the reservoir of the Amaluza dam in Ecuador as experiments with rainfall simulators show that erosion initiating runoff from pasture, abandoned land, and *Eucalyptus* plantations exceeds that of cultivated fields where rainfall more readily infiltrates the soil. In 1996, Harden again documented high rates of runoff and soil erosion, as well as significantly ($p=.01$) less total carbon on abandoned, non-managed fields in high slope areas than all other cover types in the Paute Watershed of Ecuador. Grazing on abandoned fields, considered a common property resource, further perpetuates the extraction of carbon from the soil and increases runoff through compaction (Harden, 1996). Allan et al. (2002) carried out a comparative analysis of watersheds in the Venezuelan Andes focusing on the impacts of human settlement on deforestation and discussed implications of deforestation, and increased water and sediment yields on river ecosystems. The study showed that there was a positive correlation ($R^2=0.67$) between percent disturbed land and road density, building density, and footpaths (Allan et al., 2002). In the Andean foothills near Mendoza, Argentina, problems of flash floods and sedimentation spurred a study by Braud et al. (2001) that tested the ability of the Areal Non-Point Source Watershed Environment Response Simulation (ANSWERS) model to predict the influence of vegetation on runoff and sedimentation. Another study by Vanacker et al. (2002) in some of the high watersheds of Ecuador showed that the susceptibility to slope movement is highly dependent on recent land-use change, and the authors used land-use change models with Geographic Information Systems (GIS) to predict future slope movement.

The conservation community, government, and residents of Bolivia share concerns for the effects of land-cover change on the environment. In some places, degradation is linked to historical events. In the Tarija area, grazing pressures by goats and cattle introduced by the Spanish initiated such severe erosion that reduced grazing pressure now has little or no effect on local rates of erosion, and erosion is now driven by natural geomorphic processes (Coppus et al., 2002). In the Cochabamba region, the Agrarian Reform of 1953 is thought to have contributed to degradation in mountain watersheds owing to the distribution of small widely-dispersed plots to peasant farmers, which impeded the effective use of labor and land management (Ellis-Jones and Mason, 1999).

The potential of further land-use/cover and degradation remains a concern in Bolivia (Zimmerer, 1993). In some cases however, land-use/cover change may be linked to improved environmental conditions. In the Camacho Valley of southern Bolivia, changing livelihood strategies that have resulted in out-migration of residents, reduced numbers of livestock, and changing grazing strategies, has also facilitated widespread vegetation regeneration (Preston et al., 1997).

In the Cordillera del Tunari in Cochabamba, Bolivia, upland land degradation in the Central Valley has resulted in reduced water for irrigation and domestic uses during the dry season and increased flooding, sedimentation, damage to crops and property

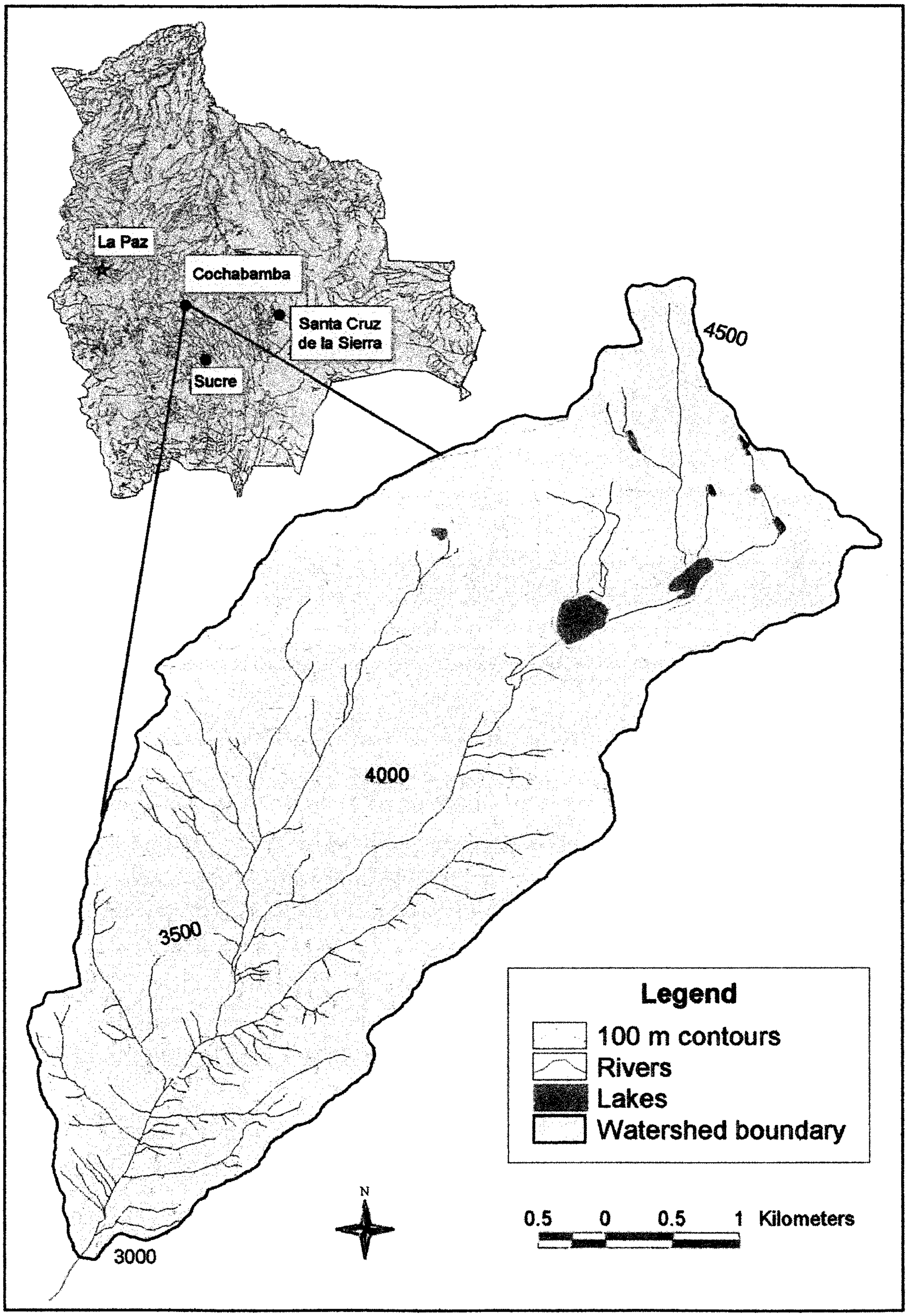


Figure 1. Location of Taquiña Watershed in Bolivia

during the summer rains, and a recognized need for conservation (Richards, 1997; Parque Naciónal Del Tunari, 1998). Colonization, agrarian reform, population fluctuation, industry, and a range of economic factors played a role in land-use/cover changes in the Cochabamba area (Zimmerer, 1993; Lagos, 1994; Larson, 1998; Painter, 1998). These factors have facilitated land-use/cover changes that in turn have led to a degradation of soil, water, and vegetation resources through deforestation, overgrazing, and poor agricultural practices (Preston, 1969; Ellenberg, 1979; Price, 1981; Zimmerer, 1993; Parque Nacional Del Tunari, 1998).

In the Taquiña Watershed of the Cordillera del Tunari (Figure 1), the historical picture is no different. Land-use/cover change, as documented by aerial photography in 1968 and 1993, shows increases in eroded land, decreases in forested land, and an expansion of grazing land. However, further documentation of land-use/cover change in subsequent aerial photographs taken in 1998 shows a reversal in these trends (Vera Zapata, 2001).

Background

Early Settlement

Early settlement (pre-Incan) in the Cochabamba Valley was by native Andean Aymara people. The Aymara originated in the cold, dry *puna* highlands, where they cultivated a variety of tuber crops and quinoa, and herded llama and alpaca- a livelihood well adapted to the harsh climatic conditions of the region (Larson, 1998). What attracted the Aymara to the Cochabamba Valley from the western *puna* were the rich soils and warm climate that made it possible to cultivate some of the more exotic crops of the day, such as maize, squash, and *ahi* (chili peppers) to compliment their normal staples (Larson, 1998). Without large-scale public works to terrace hillsides, valley agriculture remained small-scale, dispersed, and secondary to highland subsistence agriculture (Larson, 1998). In the Cochabamba Valley where the flanking mountains rise up to 5000 meters, both highland and lowland agriculture was practiced in close proximity.

The Aymara were also attracted to this region because they valued a dependable sources of subsistence through the cultivation of a number of ecological tiers (Larson, 1998). By cultivating maize on several scattered, irrigated parcels and storing the produce in communal silos, they were able to provide themselves with a safeguard against famine in the event that harsh weather compromised their harvest of tubers or quinoa in the more temperate *puna* highlands (Larson, 1998). The cultivation of maize had great cultural value; it was often consumed during festivals in the form of chicha (a local brew still consumed today) and was considered a food of the gods (Larson, 1998).

Colonization

Changing land-use patterns ensued with two distinct waves of colonialism that swept the area. The first took place during the expansion of the Inca Empire (1471-1527) (Larson, 1998). During this period, many of the groups that occupied the valleys of the Cochabamba region were relocated to what had become the Incan frontier, further east, to guard against possible low-land aggressors (Larson, 1998). They were replaced with a variety of ethnic groups, both sedentary and seasonal, from the *puna* and other faraway lands. The Inca brought these groups in to perform a variety of tasks for the empire, among which were the cultivation of maize (along with other crops, including fruits) and tending of the royal herds of llama (Larson, 1998). This agrarian transformation turned the Valle Bajo (low valley) of Cochabamba into one of the empire's principal cereal-producing regions and radically changed the local landscape (Larson, 1998)- both in the valley and the adjacent highland areas, where increasing numbers of transplanted ethnic groups continued to cultivate traditional crops.

The second wave of colonization and subsequent land-cover change took place in Cochabamba with the Spanish Conquest of the Incan Empire in 1539 (Larson, 1998). At this time, the fertile valleys of Cochabamba were a battleground. The royal maize fields and irrigation systems were destroyed, and the croplands flooded (Larson, 1998). While some of the native Andean people remained after the Inca were driven out, pursuing subsistence livelihoods in rustic areas of the surrounding valleys and lowlands, most displaced ethnic groups returned, at least temporarily, to their highland places of origin (Larson, 1998). Without the labor force gathered under Inca rule, the once bountiful fields remained unproductive for some time (Larson, 1998).

Once power shifted and the Spanish *encomenderos* began collecting tribute from local ethnic groups, the land-use patterns and practices that developed in the fertile Cochabamba Valley were quite different from that established under Inca rule. Although there were still communal Indian lands, the introduction of European cultivated plants, domestic animals, and agricultural practices greatly changed local environmental conditions (Ellenberg, 1979). With the collapse of the Incan Empire and related social order went certain conservation practices and agricultural know-how that kept agricultural lands productive and the local ecology intact (Eckholm, 1975). The shift from native camelid herds with their softer, nail covered digital pads to European sheep, goats, cattle, donkeys, and horses with their hard, sharp hooves also contributed to land degradation effect (White and Maldonado, 1991; Baied and Wheeler, 1993). Even though human populations had declined, overgrazing of highland pastures accelerated soil erosion owing to compaction and disruption of native ground-cover species (Larson, 1998). The selective grazing habits of these exotic browsers also left behind a thorny, toxic, and less palatable flora that altered the local environment in many areas (Preston, 1969; Ellenberg, 1979; White and Maldonado, 1991).

Post Colonial Period

European colonialism affected the Cochabamba landscape in many ways. For the next few hundred years, people from local ethnic groups migrated away from their own villages to settle in other villages, in towns, or on *haciendas*, or they became integrated into the *mestizo* ethnic category (Lagos, 1994). By the eighteenth century, no purely Indian communities existed on the valley floor, and *haciendas*, populated with landless Indians and *mestizos*, had taken possession of much of the land formerly belonging to highland communities (Lagos, 1994). This pattern persisted despite Bolivia's declaration of independence from Spain on August 6, 1825 (Lagos, 1994). In some respects, land distribution problems became worse following the reforms of the 1880s that abolished Indian communal lands in an attempt to "modernize" the nation and its agrarian structure (Lagos, 1994).

Bolivia entered the global market as a major tin producer in the late 1800s (Lagos, 1994). Mining led to out-migration by lower "caste" Indians from the Cochabamba area to work in the mines and provided opportunities for capitalist ventures that pushed economic frontiers eastward into the tropics (Lagos, 1994). For example, completion of a road between Cochabamba and the Yungas (present-day Chapare) permitted Indians and mestizos to develop important resources, specifically coca and wood, which were in high demand by the miners (Lagos, 1994). With these new opportunities, landless Indians who no longer had to pay tribute to land-owning *hacendados*, were able to accumulate wealth in the early 1900s (Lagos, 1994). This led to a social restructuring that involved both an emergent merchant class and an ability to acquire land (Lagos, 1994).

The mining-driven economic boom ended with the global depression in the late 1920s (Lagos, 1994). Agriculture expanded rapidly as unemployed miners returned home to farm. Without the demand side of the market in place, the economy stagnated, and political unrest ensued (Lagos, 1994). At this time Bolivia declared war on Paraguay over land in the Chaco- a war which they decisively lost and which plunged them further into economic dysfunction and political unrest (Lagos, 1994).

Agrarian Reform

The National Revolution of 1952 set the stage for massive agrarian reform in Bolivia. Landless peasants organized in armed rural militias seized *hacienda* lands, declaring their rights to the land through lineage and because of the years that they had spent working the land (Lagos, 1994). They arrested and terrorized *hacendados* and anyone else opposed to the revolution, asserting that they were no longer dependant on any authority imposed upon them and that they could act on their own free will (Lagos, 1994).

On August 2, 1953, agrarian reform was enacted (Lagos, 1994). By law, this gave farmers the right to occupy *hacienda* lands provided that they worked the land (Lagos, 1994). If the land was not under production, it was to be turned over to the state (Lagos, 1994). The law also forbade unpaid labor on these lands, as well as sharecropping (Lagos, 1994). In effect, only small-to-medium sized family farms, communal properties, and agricultural enterprises with paid laborers were allowed (Preston, 1969). Under the reform, large, rural holdings based on antiquated labor-intensive methods and feudal oppression was prohibited (Heath et al., 1969).

The extent of land under production grew considerably with this incentive, and overall pressure on the land increased. Land that had previously been allocated as prime-grazing land was converted to the cultivation of annual crops (Preston, 1969). Grazing was pushed onto more marginal lands, and while livestock data are not available, intensified grazing on small private lands after the reform accelerated soil erosion (Preston et al., 1997). The collection of fuel wood also increased around newly settled areas, leading to the degradation of native forest (Preston, 1969). The use of fire to clear land for cultivation, as well as to rejuvenate pasture land, caused a decrease in the ability of woody perennials to propagate, thus turning silvopastural land, or brush land, to grassland. While social aspects of the reform may have been positive, environmental implications were not (Price, 1981).

The Taquiña Brewery

Industry has affected land-use in the Taquiña Watershed. The Taquiña brewery was established at the mouth of the Taquiña Watershed on February 6, 1893 to utilize water from the watershed (Anonymous, 1995). The Taquiña Brewery is now one of the largest breweries in Bolivia.

The Taquiña Brewery has influenced land-use/cover in the watershed by encouraging farmers to implement erosion-control measures on their farms, by planting trees in the lower watershed, and by introducing gabion structures to certain reaches of channel to reduce erosion (Mario Rojas, pers. comm., 2002). Since the initiation of a pilot management project by Program for the Integrated Management of Watersheds (PROMIC) in 1991, the Taquiña Brewery's conservation efforts in the watershed have been primarily to maintain roads they established with aid from the Cochabamba Regional Corporation for Development (CORDECO), and PROMIC (Ivan Vargas, pers. comm., 2002).

Tunari National Park

The initial steps toward the creation of a park to protect the natural resources of the Cordillera de Tunari were actually taken in 1939, when a supreme decree was published prohibiting burning in forested areas and the cutting of trees, and promoting reforestation (Parque Naciónal Tunari, 1998). It is unknown how effective the decree was in controlling these activities at the time, but as late as 1958 (following the Agrarian Reform), there are reports that these activities continued despite the drafting of a subsequent decree in 1954 and the creation of the Forest and Hunting Service (Parque

Naciónal Tunari, 1998). Tunari National Park was formally established in 1962 to reduce deforestation and erosion, and to protect the city of Cochabamba and the Cochabamba Valley from inundation by floodwaters and sedimentation (Parque Naciónal Tunari, 1998).

PROMIC

Program for the Integrated Management of Watersheds (PROMIC) began its operations in the Cordillera Tunari with a pilot project in the Taquiña Watershed in 1991 through a bilateral agreement between the Swiss and Bolivian Governments. The project was jointly administered and funded in cooperation by the Municipal Government of Cochabamba and the Swiss Agency for Development, COSUDE (PROMIC, 1996). Today, Belgian Technical Cooperation (BTC) has taken over much of COSUDE's responsibility in the project.

The goal of PROMIC's work in the Taquiña Watershed, as well as other watersheds in the Cordillera Tunari, is to promote productive rural development and improved living conditions through erosion control processes, to increase agricultural productivity without agricultural expansion, to facilitate ground water recharge, to reduce or prevent flood hazards, and to contribute to an "ecological balance" in the watersheds (PROMIC, dates unknown). To achieve these objectives, PROMIC has sought to: 1) control flooding through structural modification of channels; 2) restore degraded areas through revegetation and structural control of surface erosion; 3) establish on-farm soil management and conservation through the use of agroforesrty techniques, slow-forming terraces, and improved farming techniques; and 4) provide extension activities in rural communities (PROMIC, dates unknown). PROMIC has also supported basic health, rural electrification, animal vaccination, and the construction of secondary roads, among other things (PROMIC, dates unknown). Although PROMIC does have specific objectives to meet their goals, they do not specify how they will achieve or measure "ecological balance". Ecology, as pointed out by Botkin (1990), is likely to be in a perpetual state of dynamic disequilibrium, and therefore cannot be "balanced" or stabilized, particularly in dynamic mountain environments.

PROMIC's primary years of development activity in the Taquiña Watershed were from 1991 to 1994 (Program for the Integrated Management of Watersheds, 1996; Ivan Vargas, pers. comm., 2002). From 1994 to 1996, PROMIC's principal concern in the watershed was monitoring (PROMIC, 1996; Ivan Vargas, pers. comm., 2002). Beginning in 1991 and continuing today, PROMIC has carried out research in the Taquiña Watershed on a variety of subjects including the effects of their conservation practices (Ivan Vargas, pers. comm., 2002). This activity has resulted in ongoing contact with residents of the watershed and to an extent has continued the monitoring process. The continued contact has also perpetuated more resident-managed conservation activities in the watershed (Ivan Vargas, pers. comm., 2002).

Roads

Two roads were constructed into the Taquiña Watershed in the early 1990s. In 1991 PROMIC and CORDECO constructed the first road in the lower watershed, approximately two kilometers upstream from the mouth of the watershed (Ivan Vargas, pers. comm., 2002). PROMIC, CORDECO, and the Taquiña Brewery constructed the second road in the upper watershed in 1994 to access a small dam project at Lake Taquiña to increase its holding capacity (Ivan Vargas, pers. comm., 2002). The maintenance of both roads is the responsibility of the brewery (Ivan Vargas, pers. comm., 2002).

Study Objectives

The objective of this study is to analyze and discuss factors that may have influenced land-use/cover change trends in the Taquiña Watershed from 1968 to 2001. I discuss trends in land-use/cover changes in relation to a variety of factors that began before the initiation of the study period in 1968 and continue today. I also analyze land-use/cover changes with regard to their effects on watershed function, the socio-economic impact upon the people living in the watershed, and local ecology.

Chapter II
METHODS

Site Description

The Taquiña Watershed (66° 07' 36" to 66° 11' 10" longitude west and 17° 15' 24" to 17° 19' 25" latitude south) is a tributary of the Central Cochabamba Valley, four kilometers north of the city of Cochabamba. The watershed covers an area of approximately 20 km^2 and ranges from 2887 to 4560 meters above sea level (masl).

Geologically, the watershed is composed of upper Ordovician quartzite, siltstone, shale, and sandstone that experienced a progression of orogenic uplift, primarily reverse faulting and folding, between the Silurian and late Cretaceous/early Tertiary (Claure, 1995). This basement material has since been draped in Quaternary deposits of poorly consolidated drift and moraine material, with colluvial and alluvial deposits interspersed throughout the watershed (Claure, 1995). Soils in the watershed are weakly developed and consist primarily of Entisols and Inceptisols (Amurrio et al., 1993).

Following the Thornthwaite classification system, the Taquiña Watershed lies within a semiarid, mesothermal climatic zone with a mean annual daily temperature of 8.6°C, a median relative humidity of 60.32 percent, and average precipitation of 747 mm/yr, 90 percent of which falls in the summer, or rainy season, between November and March (Vera Zapata, 2001). Winds are generally from the northeast.

Physiographically, the watershed can be divided into three regions. The upper zone, ranging in elevation from approximately 4000 to 4500 masl, is a cold, alpine tundra zone, whose flora consists mostly of small, hearty grasses and mosses (Personal observation). This area is shaped by glacial erosion and consists of cirques, tarn lakes and U-shaped valleys. In the upper watershed, grazing is the only feasible agrarian activity.

The middle elevation of the watershed, 3500 to 4000 masl, is a cold to temperate native grassland containing interspersed brush and tree species in sheltered areas which have more available moisture. Geomorphologically this area is dominated by hummocky glacial depositional features including moraines and till that have been incised by second, third, and fourth-order streams. Periglacial remnants are prominent, as well as evidence of colluvial and alluvial deposits (Personal observation). In this zone, cultivation of some hearty annuals, including potato (*Solanum tuberosum L)*, oca (*Oxalis tuberosa)*, tarhui (*Lupinus mutabilis*), fava beans *(Vicia Faba L.)*, wheat *(Triticum spp.)*, and oats *(Avena L. spp.)* is possible. However, most of the land area is used for grazing.

The lower elevations of the watershed, less than 3500 masl, lie in a more temperate zone. Here the vegetation exhibits more structural complexity and height and a much higher frequency of tree and brush species, as well as succulents. Colluvial and alluvial processes dominate this part of the watershed. In this zone, agriculture is the primary activity, with the additional cultivation of corn, peas, green beans, and flowers occurring simultaneously with grazing on more marginal lands.

Research Methods

Geographical Information System (GIS)

The principle sources of data for this study are GIS themes generated from aerial photographs for the years 1968, 1993, and 1998, and an updated 2001 theme created a field update of the 1998 theme (Vera Zapata, 2001). Vera Zapata (2001) delineated land-use/cover types into seven units, including (i) *pasture:* area dominated by native or non-native grasses, with continual or seasonal grazing by livestock; (ii) *silvopasture:* area where vegetative cover consists of grasses, native tree species, and brush in similar proportions and is regularly used for pastoral activity; (iii) *intensive agriculture:* agricultural land that is used almost perpetually for the cultivation of annuals with a permanent water source; (iv) *moderate agriculture:* area where the regular cultivation of annuals is restricted by elevation, soil depth, available (usually rain-fed) water and few inputs; (v) *native forest:* area dominated by native tree species with grasses and bushes; (vi) *brush land:* area under various grades of cover by brush species, generally not exceeding two meters in height, that may experience occasional pastoral activity; and (vii) *eroded land:* is an area dominated by various processes of erosion and a distinct absence of vegetation.

Because areas of intensive and moderate agriculture delineated by Vera Zapata (2001) would sometimes alternate from one year of coverage to the next, I reclassified these two land-cover units into one unit referred to as *agriculture*. Therefore, only six land-use/cover units were used in the analysis of land-cover dynamics.

The first step in land-use/cover change study of the Taquiña Watershed consisted of a basic analysis of GIS themes produced for the years 1968, 1993, 1998, and 2001 by Vera Zapata (2001). I created queries of the tables attached to these land-use themes for the various years to reveal information related to changes in overall land-use area as well as some of the dynamics of change.

To illustrate changes in total land-use area, percent cover, and percent change for each land-use type (positive or negative), I calculated how each changed between 1968 and 1993, 1993 and 1998, and 1998 and 2001 (Table 1). To illustrate a progression of change dynamics between years of available coverage, the number of polygons in each GIS theme that represent an individual land-use type were summarized, and the average area of land-use types was calculated. This was done to reveal fragmentation and changes in the mean sizes of land-use polygons. The standard deviation of the area for each land-use type was also calculated (Table 2).

Before the reclassification of *intensive agriculture* and *moderately intensive agriculture* land-cover units to *agriculture*, I selected five specific types of land-use/cover change that occurred between 1993 and 2001 using the GIS for a detailed soil and vegetation study. I chose land-use/cover change types that represented the largest surface areas in the watershed based on Vera Zapata's (2001) original classification. I assessed land-use/cover changes by comparing 1993 and 2001 data using ArcView 3.2 GIS. I integrated the two spatial data sets while preserving only those features falling within the spatial extent common to both themes through intersection. In this case, the newly created polygons represent specific land-use/cover change types. Because there is a higher likelihood of discovering observable change in both soils and vegetation over time, only polygons or portions of polygons that had changed by 1998 were chosen for intersection. By using only polygons that had changed by 1998, at least four years would have elapsed between the change and its current field status.

Significant land-use/cover change types under the original classification include change from moderate agriculture to pasture, pasture to moderate agriculture, intensive agriculture to moderate agriculture, pasture to silvopasture, and intensive agriculture to silvopasture. Because on-the-ground observations revealed cover types to be more heterogeneous than indicated in the GIS (e.g. GIS mapped agricultural land may consist of cultivated or fallow fields in a matrix of pastoral or silvopastoral land), I classified land-cover units for soils and vegetation field data as (i) *agricultural land*: land either currently under cultivation, or recently harvested; (ii) *fallow land:* agricultural land that had been fallow for approximately a year or more; (iii) *pasture:* as stated above; and (iv) *silvopasture*: as stated above.

Soils

I analyzed soils in the field and in the laboratory. In the field, I excavated fifteen pits- three pits in each of the five study areas to a depth that revealed the C-horizon (usually about a meter in depth). I recorded texture, color, and presence of rocks, roots, and visible organisms (such as worms or grubs) for each horizon, as well as its depth. Three samples were then extracted from each profile for laboratory analysis. I extracted two undisturbed samples using capped rings from depths of approximately 20 and 40 cm., or what corresponded to the A and B horizon, which were analyzed for porosity (%), bulk density, specific density, and text. I also took a disturbed sample of the upper 2.5 cm of mineral topsoil, which was analyzed for texture. Physical soil analysis was conducted on these samples by technicians at the University of San Simón in Cochabamba. Sites for soil analysis were chosen randomly within an area of previously defined land-use/cover change type.

Vegetation

I surveyed vegetation in the watershed by establishing nineteen 50 m with readings taken at 50 cm intercepts. Transects were established at random within previously selected areas of land-cover change At each intercept, I recorded vegetation (alive or dead) or bare ground to obtain the degree of vegetative cover (%) over the transect, and species to gain an idea of floral biodiversity. If species identification in the field was not possible, I collected a voucher specimen for identification in the PROMIC herbarium.

Sites for vegetative analysis were chosen randomly within an area of previously defined land-use/cover change type. Transects were run perpendicular to the elevational contour. From the end of the transect, a distance of 50 or 100 meters (depending upon the size and shape of the overall area) was measured parallel to the contour. From the end of that measured distance, the next 50 m transect was taken, again perpendicular to the contour. This method was repeated for the selection of each transect. Between three and five transects were taken for each land use/cover change area depending on the size and distribution of the sample area.

I compare the results of soil and vegetative analysis with other studies conducted in the watershed when a specific land area was under a different (or recently changed) use/cover regime.

Interviews

I gathered additional information regarding changes that had taken place in the watershed by interviewing 10 local residents, representing approximately one-fourth of the families living in the watershed. The interviews were conducted with the help of an interpreter who translated from Spanish to Quechua. Nine males and one female, all of whom were household heads were interviewed.

I conducted a semi-structured interview focusing on agriculture, pastoralism, the flora and fauna, water quality, and perceptions of PROMIC (Appendix 3). Specifically, I questioned each person regarding present-day conditions, how things differed in the past (when the interviewee was a child), and what he/she could remember of stories that were told regarding the past (prior to his/her birth).

The respondents reside over the full elevational range of the watershed but were selected because they could be located and were available to be interviewed, thus they do not represent a random sample of the population.

Chapter III
RESULTS

Land-Use/Cover Change

Land-use/cover change between 1968 and 2001 exhibited great variability. Land-use/cover change trends that were established between 1968 and 1993 were reversed from 1993 to 2001 (Figures 2, 3, 4, and 5). The number of land-use/cover type parcels increased over the study period for 67% of the cover types, while the average size of land-use/cover parcels decreased for all cover types leading to a more fragmented landscape (Figures 2, 3, 4, and 5). The relative change in area between agriculture, pasture, silvopasture, brush land, native forest, and eroded land-cover types over time is represented in Figure 6.

The total area under agricultural land cover, which includes both intensive and extensive agricultural systems, fluctuated during the study period. In 1968, the total area under agricultural cover was 158 ha. Between 1968 and 1993, agriculture declined 7% to 147 ha, from 1993 to 1998 it increased 8.5% to 159 ha, and between 1998 and 2001 the area in agricultural use increased 24.7% to 199 ha (Table 1, Figure 7). The number of agriculture parcels increased from 15 in 1968 to 17 in 1993, to 30 in 1998 and to 38 by 2001. At the same time, the average size of agricultural plots decreased from 10.5 ha in 1968 to 8.7 ha in 1993, to 5.3 ha in 1998, and 5.2 ha in 2001 (Table 2, Figures 8 and 9).

In 1968, the area under pasture totaled 904 ha. Between 1968 and 1993, the area of pasture increased 10.3% to 997 ha, between 1993 and 1998 it declined 7.8% to 919 ha, and between 1998 and 2001 it declined 7.7% further to 848 ha (Table 1, Figure 7). The number of parcels in pasture fluctuated between two and three over the study period. The average area of these parcels also fluctuated from 451.9 ha in 1968, to 332.3 ha in 1993, 459.5 ha in 1998, and back down to 282.6 ha in 2001 (Table 2, Figures 8 and 9).

In 1968, the area of land under silvopasture was 231 ha. Between 1968 and 1993 it declined 24.4% to 175 ha, between 1993 and 1998 it increased 49.4% to 261 ha, and between 1998 and 2001 it increased 5.4% to 275 ha (Tables 1, Figure 7). The number of parcels in silvopasture fluctuated from 10 in 1968, to 9 in 1993, to 13 in 1998, and 19 by 2001. The average area of silvopastoral parcels changed from 23 ha in 1968 to 19 ha in 1993, to 20 ha in 1998 before dropping to 15 ha in 2001 (Table 2, Figures 8 and 9).

The area of land under brush in 1968 was 78 ha. Between 1968 and 1993, brush land declined 73.7% to 21 ha, between 1993 and 1998 area remained the same, and between 1998 and 2001 brush land increased by 163.4% to 54 ha (Tables 1, Figure 7). This was the largest percent increase of any land-cover type during the period 1993-2001. From 1968 to 1993, the number of brush land parcels fell from nine to two, while the average area of brush land parcels increased from nine to ten hectares. Conditions did not change from 1993 to 1998, but between 1998 and 2001 the number of brush land parcels increased to eight, while their average area dropped to seven hectares (Table 2, Figures 8 and 9).

The land area in native forest was relatively stable in comparison to other land-cover types. In 1968, the area under forest cover was at its highest with 249 ha. Between 1968 and 1993 native forest cover declined by 19.3% to 201 ha, between 1993 and 1998 it decreased 7.2% to 187 ha, and from 1998 to 2001 native forest increased 1.1% to 189 ha (Tables 1, Figure 7). The number of parcels under native forest cover increased, while the average area of these parcels continued to decrease over the study period. In 1968, there was one continuous native forest totaling 249 ha. In 1993, native forest was fragmented into 5 distinct parcels averaging 40 ha each. By 1998, native forest was fragmented into six parcels averaging 31 ha each and by 2001, the number of native forest parcels increased to eight averaging 24 ha (Table 2, Figures 8 and 9).

Eroded land showed the largest changes in terms of percent change of total area. Between 1968 and 1993, eroded land increased 294% from 7 ha to 27 ha. From 1993 to 1998, the area of eroded land declined 23.5% to 20 ha. Between 1998 and 2001, the area of eroded land declined a further 89% to a mere 2 hectares (Tables 1-4, Figure 7). The number of eroded parcels increased from 4 in 1968 to 8 in 1993, then decreased to 7 in 1998, and finally to 2 in 2001. The average area of eroded parcels in 1968 was 1.7 ha. In 1993 the average area grew to 3.3 ha, then declined to 2.9 ha in 1998, and 1.1 ha by 2001 (Table 2, Figures 8 and 9).

Soils

Soil analysis performed on agricultural land revealed the A-horizon to have a clay loam texture, with a bulk density of 1.3 g/cc, a particle density of 2.5 g/cc, and a porosity of 48.2 %. The B-horizon had silt loam texture, with a bulk density of 1.3 g/cc, a particle density of 2.4 g/cc, and a porosity of 45.6 % (Appendix 1).

Fallow fields had topsoil textures of silt loam, loam/silt loam, and sand loam. A-horizon textures included loam, silt loam, and sandy loam/loam, with bulk densities ranging from 0.7 to 1.7 g/cc, particle densities ranging from 2.0 to 2.8 g/cc, and porosities ranging from 34.6% to 67.3%. B-horizon textures included loams and silt loams, with bulk densities ranging from 1.1 to 1.6 g/cc, particle densities ranging from 2.1 to 2.8 g/cc, and porosities ranging from 35.4% to 52.5% (Appendix 1).

Pasture had a loamy topsoil texture. A-horizon textures included clay and loam, with bulk densities ranging from 0.9 to 1.7 g/cc, particle densities ranging from 2.6 to 2.6 g/cc, and porosities of 34.2% and 64.1%. The B-horizon had a clay texture, with a bulk density of 1.5 g/cc, a particle density of 2.7 g/cc, and a porosity of 45.0% (Appendix 1).

Silvopasture had topsoil textures of loam, clay loam, and loam/silt loam. A-horizon textures included loam, clay loam, silt loam, and sandy loam, with bulk densities ranging from 0.9 to 1.4 g/cc, particle densities ranging from 2.3 to 2.6 g/cc, and porosity ranging from 44.2% to 61.4%. B-horizon textures included loam, silt loam, and clay loams, with bulk densities ranging from 1.0 to 1.6 g/cc, particle densities ranging from 2.4 to 2.6 g/cc, and porosity ranging from 40.6% to 60.7% (Appendix 1).

Vegetation

Ground cover in agricultural land averaged 47%, 76% in fallow fields, 78% in silvopasture, 69% in pasture. Species diversity on agricultural land was lowest, consisting of only 15 recorded species, mostly herbaceous and grass species. Species included herbaceous, grass, and brush in fallow fields; herbaceous, grass, tree, and brush species in silvopastoral land; and herbaceous and grass species in pasture land (Appendix 2).

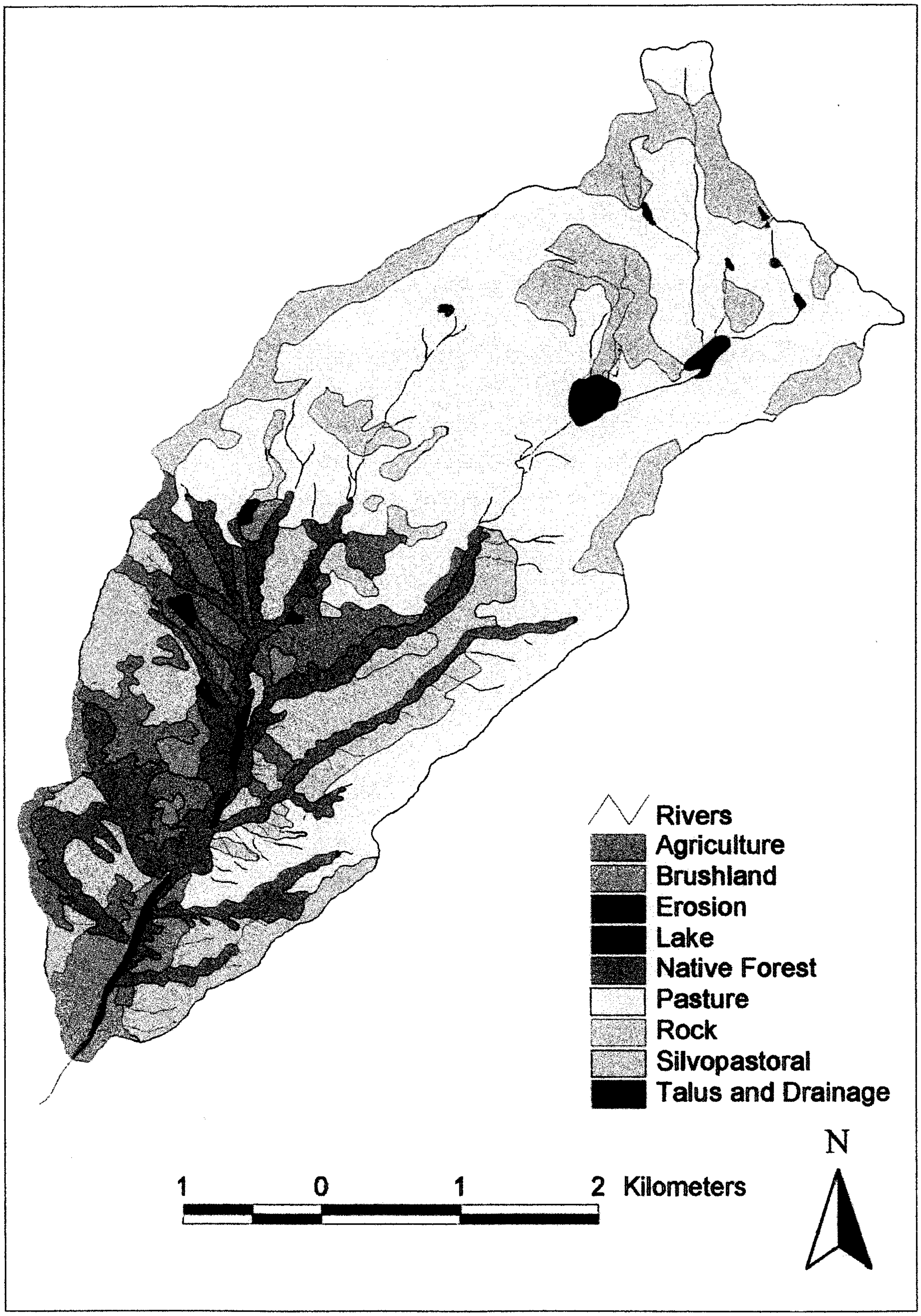


Figure 2. Land-Use, 1968: Taquina Watershed

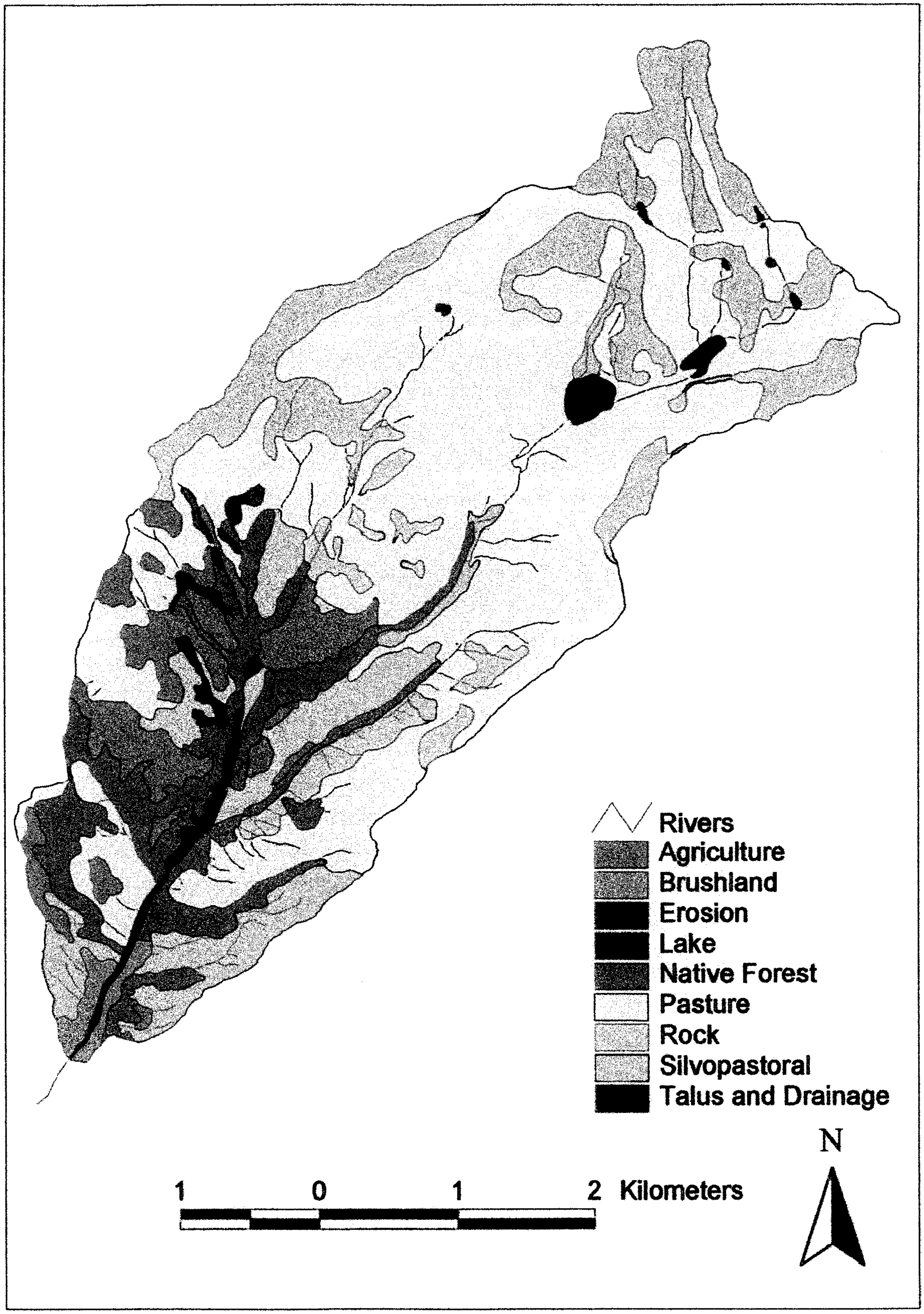


Figure 3. Land-Use, 1993: Taquina Watershed

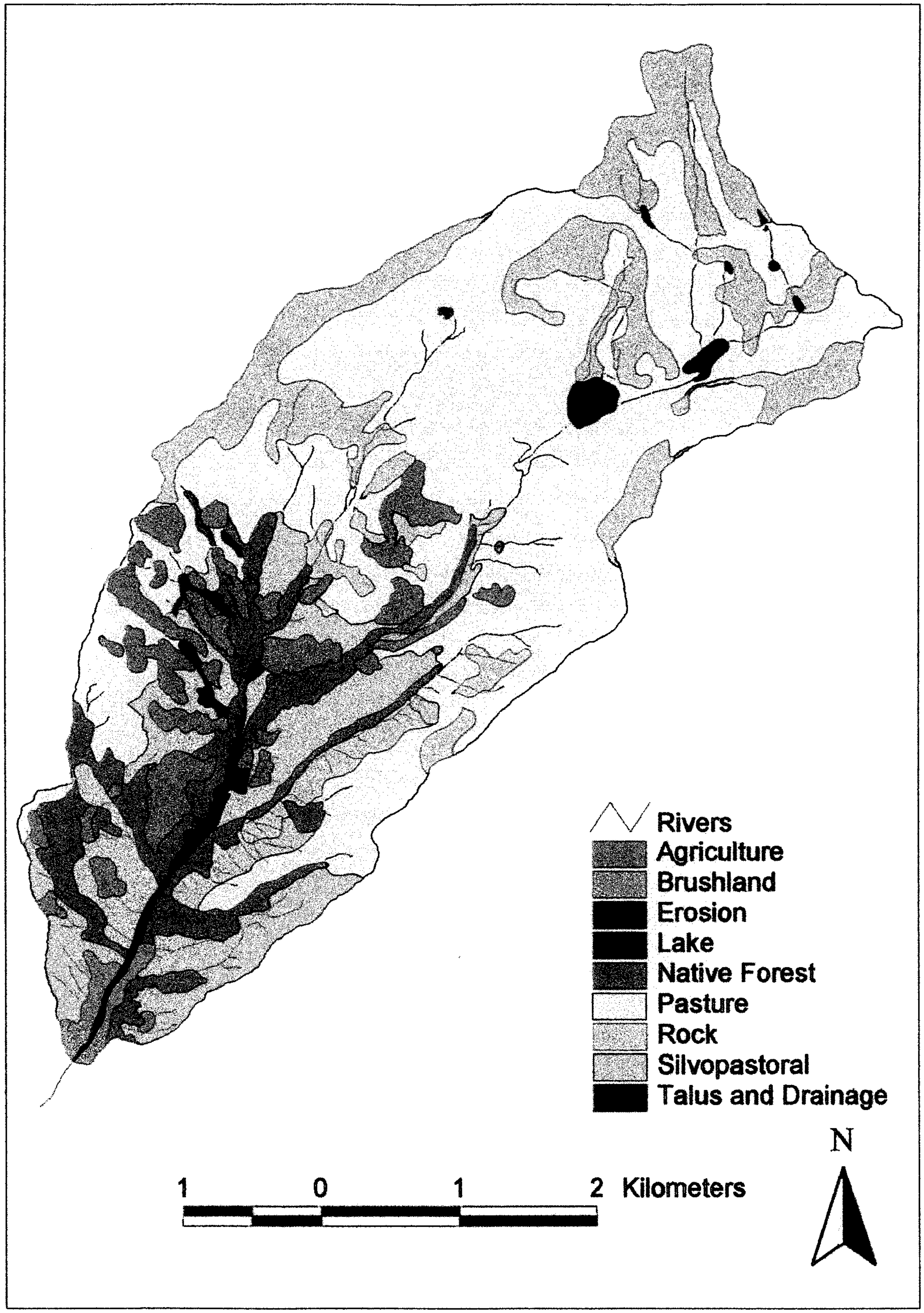


Figure 4. Land-Use, 1998: Taquina Watershed

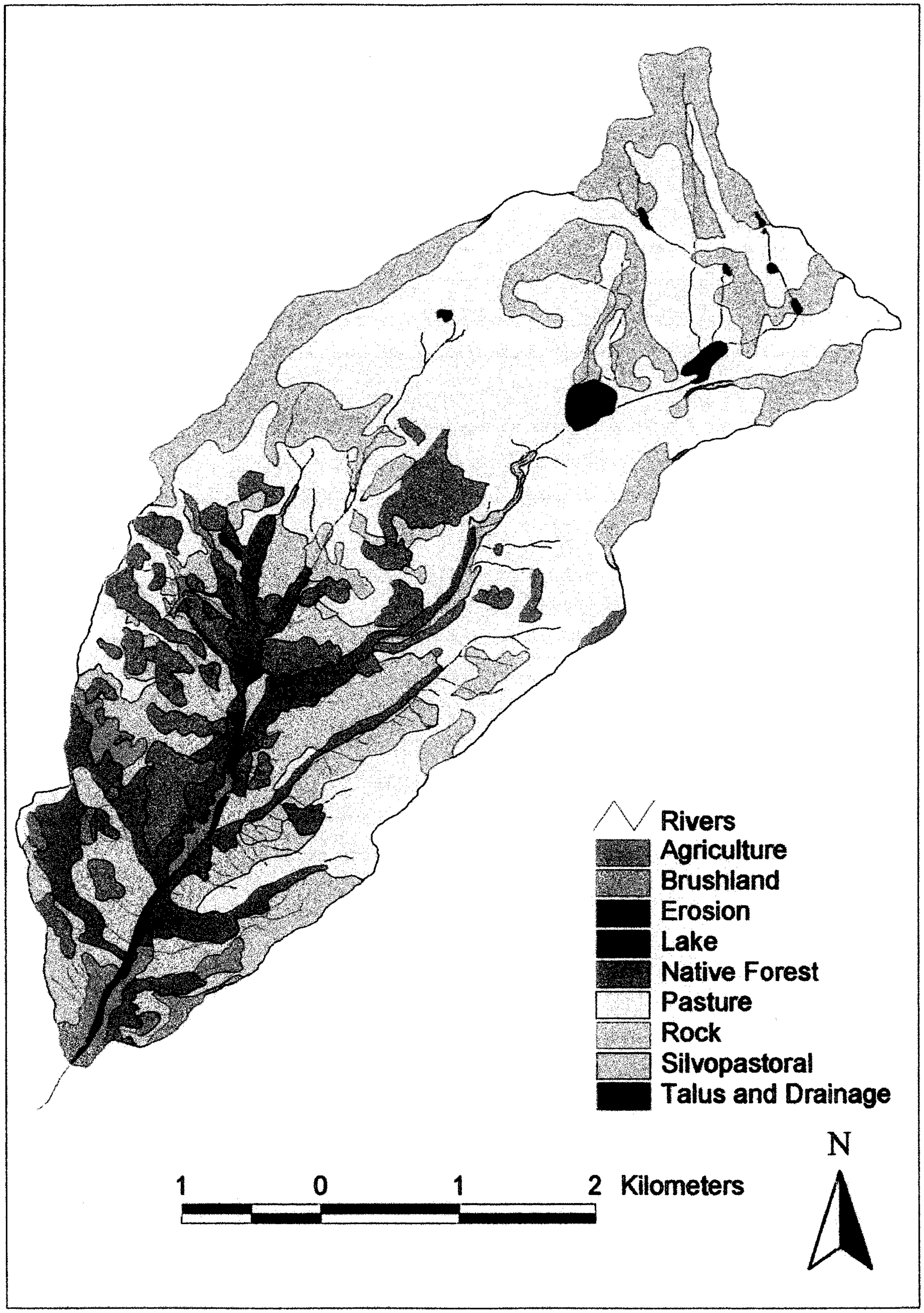


Figure 5. Land-Use, 2001: Taquina Watershed

Figure 6. Relative Change in Area of Land-Use/Cover Types: 1968-2001

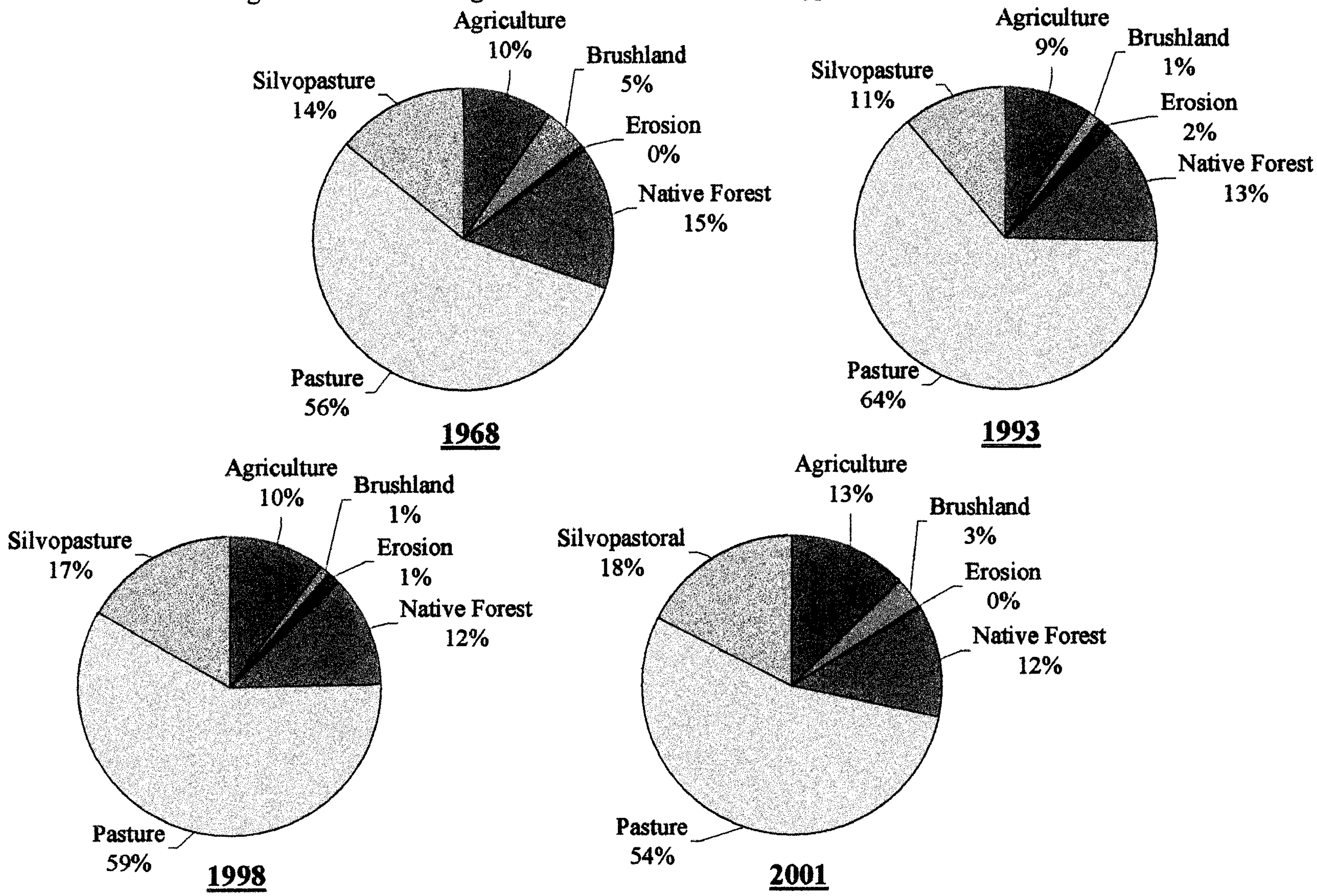


Table 1. Total Area, Percent Cover, and Percent Change in Land-Use/Cover Types: 1968 to 2001

Vegetation Type	1968		1993				1998				2001			
	Area (ha)	Cover %	Area (ha)	Cover %	Change (ha)	Change %	Area (ha)	Cover %	Change (ha)	Change %	Area (ha)	Cover %	Change (ha)	Change %
Agriculture	158	8.0%	147	7.5%	-11	-7%	160	8.1%	13	9%	199	10.1%	39	25%
Brushland	78	4.0%	21	1.0%	-57	-74%	21	1.0%	0	0%	54	2.7%	34	163%
Erosion	7	0.3%	27	1.4%	20	294%	20	1.0%	-6	-24%	2	0.1%	-18	-89%
Native Forest	249	12.6%	201	10.2%	-48	-19%	186	9.5%	-14	-7%	189	9.6%	2	1%
Pasture	904	45.9%	997	50.6%	93	10%	919	46.6%	-78	-8%	848	43.0%	-71	8%
Silvopastoral	231	11.7%	175	8.9%	-57	-24%	261	13.3%	86	49%	275	14.0%	14	5%

Table 2. Number of Plots, Average Area, and Standard Deviation of Land-Use/Cover Types: 1968 to 2001

Vegetation Type	1968			1993			1998			2001		
	Plots #	Avg. Area (ha)	Std. Dev.	Plots #	Avg. Area (ha)	Std. Dev.	Plots #	Avg. Area (ha)	Std. Dev.	Plots #	Avg. Area (ha)	Std . Dev.
Agriculture	15	10.	+/-9.7	17	8.	+/-10.3	30	5.3	+/-5.5	38	5.2	+/-6.7
Brushland	9	8.	+/-9.0	2	10.	+/-2.1	2	10.3	+/-2.1	8	6.8	+/-3.8
Erosion	4	1.	+/-0.8	8	3.	+/-2.4	7	2.9	+/-2.6	2	1.1	+/-1.0
Native Forest	1	249.	+/-0.0	5	40.	+/-42.4	6	31.1	+/-24.0	8	23.6	+/-24.6
Pasture	2	451.	+/-615.5	3	332.	+/-542.6	2	459.5	+/-643.0	3	282.6	+/-483.5
Silvopastoral	10	23.	+/-22.8	9	19.	+/-19.6	13	20.1	+/-17.8	19	14.5	+/-15.0

Figure 7. Total Area of Land-Use/CoverTypes: 1968-2001

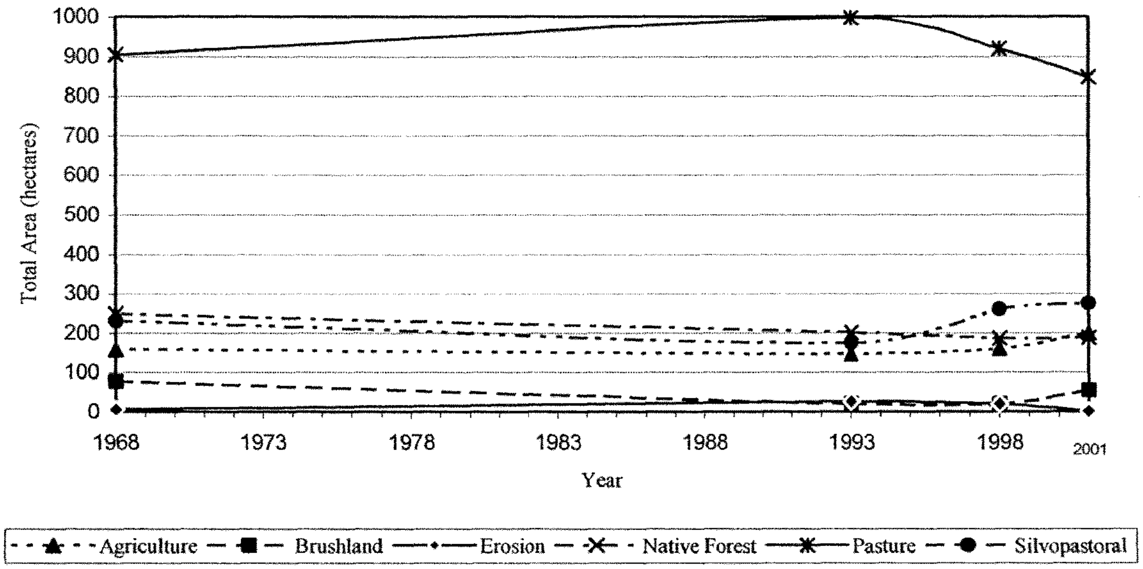


Figure 8. Number of Land_Use/Cover Parcels: 1968-2001

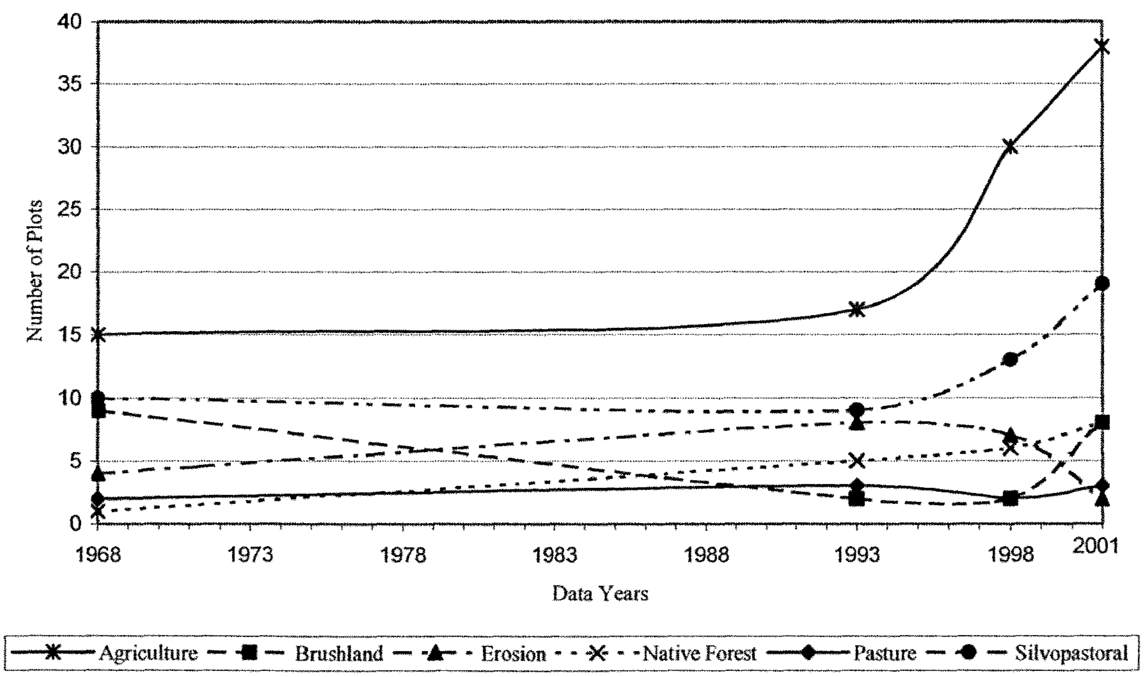


Figure 8a. Average Area of Land-Use/Cover Types: 1968-2001

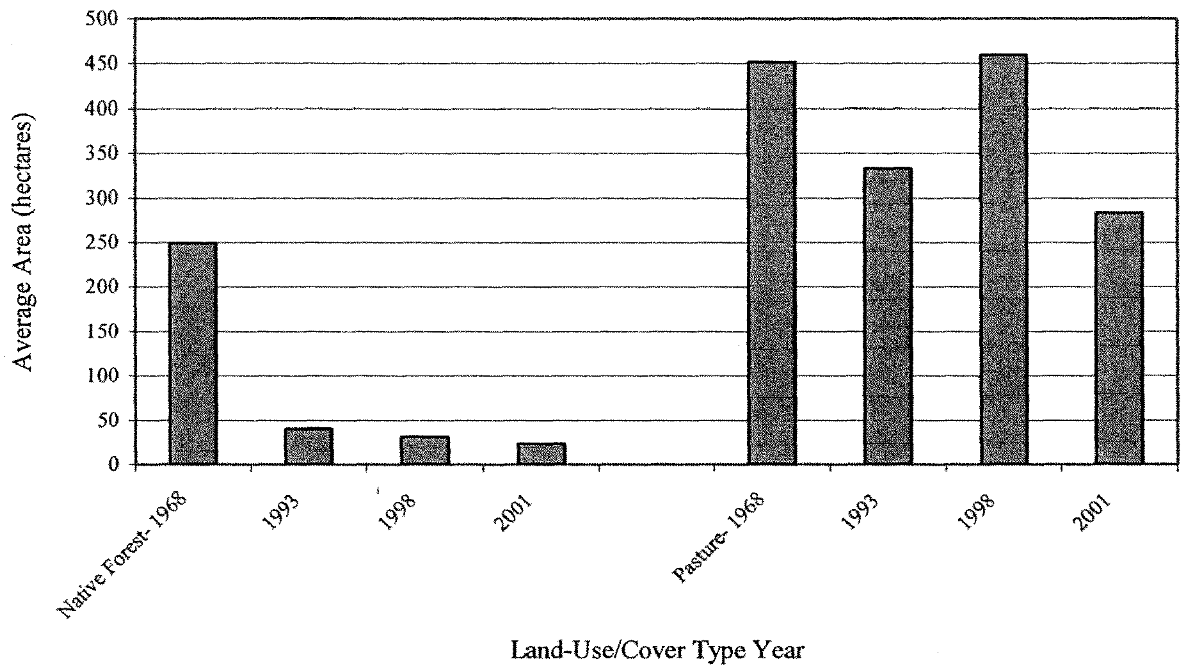
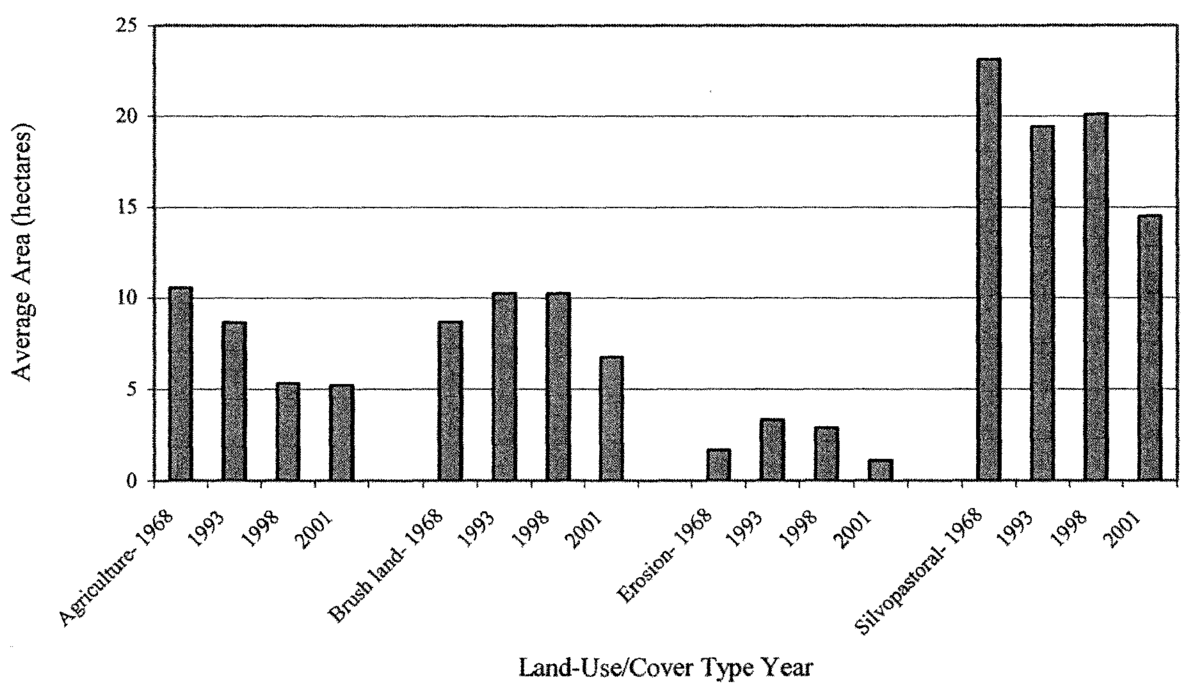


Figure 8b. Average Area of Land_Use/Cover Types: 1968-2001



Chapter IV
DISCUSSION

Several factors likely contributed to land-use/cover change in the Taquiña Watershed between 1968 and 2001. The most important factors include colonialization, agrarian reform, the creation of Tunari National Park, drought, economic and political instability, population fluctuation, alternative employment opportunities, and the effects of initiatives undertaken by a conservation-oriented non-governmental organization, PROMIC.

Pre-1968

Colonization, agrarian reform, and the creation of Tunari National Park all that contributed to the established land-cover in the watershed at the beginning of the study period. Land-cover prior to 1968 is undocumented in the Taquiña Watershed.

Colonialization

Colonization, particularly by the Spanish, laid the foundation on which many of the factors that contributed to land-cover change in the Taquiña Watershed are based. In some cases, Spanish hacienda owners brought families into the area to work who would go on to inhabit and cultivate the watershed (Interviews, pers. Comm., 2002). Even following independence they had a heavy influence on politics and the economy, (Larson, 1998), and they established land tenure patterns and class distinctions that led to the revolution of 1952 and subsequent agrarian reform (Lagos, 1994). The Spanish also left an indelible mark on local agrarian practices by introducing annual species such as wheat, barley, and oats (Larson, 1998) that would be cultivated in the Taquiña Watershed during the period of agricultural expansion to sell in local markets. They also introduced exotic livestock such as sheep, goats, and cattle that have selective grazing habits and hooved feet (White and Maldonado, 1991; Baied and Wheeler, 1993). These animals contributed to land degradation, the expansion of pasture and eroded land, and the contraction of silvopasture and brush land between 1968 and 1993.

Agrarian Reform

The Agrarian Reform of 1953 affected population and land-use/cover in the watershed through massive redistribution of land. The largest effects occurred in the mid- to late 1950s, when population in the watershed increased dramatically and land was converted to agriculture, burning of pasture land and grazing increased, and widespread cutting of fuelwood occurred (Parque Naciónal Tunari, 1998, Interviews, pers. comm., 2002). This period laid the foundation for land-use/cover analysis beginning in 1968. By having introduced the population to the Taquiña Watershed that would put the land to "good use", the Agrarian Reform affects land cover in the watershed to this day. Although land pressure in the watershed did increase owing to the effects of agrarian reform, degradation of natural resources and increased erosion cannot be directly attributed to population pressure alone (Zimmerer, 1993). In many cases densely populated rural areas exhibit a higher degree of conservation and sustainable land use practices due to increased land value and labor availability for conservation farming efforts (Blaike and Brookfield, 1987).

Tunari National Park

In 1962, the entire area of the Taquiña Watershed was incorporated into Tunari National Park, and regulations were enacted to support conservation efforts. One of the most important regulations was to "grandfather" residential rights in the park. People who were born or married into families that already lived in the park were allowed to continue to live, farm, and graze their animals inside the park, but no new in-migration was allowed into the park highlands. (Parque Naciónal Tunari, 1998). While this regulation limited population influx into the watershed, the number of families with rights to reside locally increased over the generations. Interviewed residents (2002) stated that an increasing population with rights to land contributed to decreasing agricultural output potential per family as space became more limited. This, in part, led to an increase in the number and fragmentation of parcels under agricultural cover over the years.

Initially, besides limiting population growth, the effect of designating the Taquiña Watershed as part of Tunari National Park seems to have been rather small. Very few trees, if any, were planted in the watershed between 1968 and 1993, so forest cover continued to be lost to shifting agriculture, cutting of fuelwood, and the practice of burning pasture was still widespread (Parque Naciónal Tunari, 1998). Watershed residents validated these past land-use practices in interviews (2002). The lack of road access not only hampered reforestation efforts throughout the park, it limited the enforcement of laws pertaining to the conservation of resources and the mitigation of hazards associated with increased runoff and erosion.

1968-1993

Colonization, agrarian reform, and the establishment of Tunari National Park continued to affect land-cover between 1968 and 1993, but new factors such as drought, as well as new (and some continued) political and economic variables emerged to affect land-cover change.

Drought

The specific effects of the drought that began in 1983 on natural vegetation in the Taquiña Watershed are unknown. The viability of rain-fed agriculture in much of the Cochabamba region, however, was greatly reduced and in some places eliminated (Painter, 1998). The drought may have forced some families from their agricultural plots to search for alternative livelihoods during this time. This change would have affected the amount of land under cultivation. Those people that did not leave the watershed may have found some security by increasing their investment in pastoral activities. Of those interviewed (2002), 100% said that they had more livestock in the past than they do today. The increase in grazing that took place in the watershed beginning in the 1970s and continuing through the 1980s (Vera Zapata, 2001) was accompanied by the regular burning of pasture (Parque Naciónal Tunari, 1998) and may have been connected to the drought. While burning was thought to help regenerate grasses, it hindered the growth of woody perennials. Thus there was an expansion of pasture land and a corresponding decrease in silvopastoral and brush land during this time. The conversion of silvopasture to pasture between 1968 and 1993 is particularly evidenced in the western side of the watershed (Figures 2 and 3). Drought, combined with increased burning and grazing pressure may also be responsible for an increased distribution of rock on some of the upper parts of the watershed in 1993 (Figure 3).

Increased erosion accompanied land-cover conversion to pasture on the western side of the watershed and a redistribution of agricultural land during this period. Erosion may have increased due to a decrease in infiltration capacity of soils caused by compaction by grazing animals, the creation of hydrophobic soils due to increased burning, and destabilization of soils associated with shifting cultivation and deforestation. Forty percent of residents interviewed (2002) stated that problems with erosion and landsliding contributed to sedimentation in waterways in the past. The greatest effects of the drought on land-cover in the Taquiña Watershed however, were probably in amplifying the effects of economic depression and political instability.

Economy and Politics

Economic and political factors at the national level likely contributed the most to land-cover change between 1968 and 1993. Important economic and political changes included: 1) the disruption of transport routes and the distribution of food to urban areas (Painter, 1998); 2) the 1985 collapse of tin mining owing to the expropriation and reorganization of the mines (Jordan and Warhurst, 1992); 3) economic assistance from the United States that nurtured an economic elite through the development of agroindustry in the tropical lowlands (Zimmerer, 1993) and a group of politically powerful allies (Painter, 1998); 4) a massive resettlement plan that brought people from the highlands to the lowlands, including to the Chapare for the development of agriculture (Painter, 1998); 5) a depression of agricultural prices due to overproduction (Zimmerer, 1993); 6) hyperinflation followed by radical economic restructuring through the adoption of a range of neoliberal policies by the government (Zimmerer, 1993); and 7) an emergent cocaine industry that eventually employed between seven and 20 % of the country's work force and replaced the tin industry as Bolivia's most important export commodity (Zimmerer, 1993; Painter, 1998).

The cumulative effects of the these economic and political developments caused many of the highland locals, who had inherited rights to pursue a livelihood in the Taquiña following its designation as a national park, to migrate out of the watershed- at least on a seasonal basis. Many left to seek supplemental economic and agricultural opportunities in the humid lowlands of the Chapare (Zimmerer, 1993; Ivan Vargas and Constantine Vilca, pers. comm., 2002). These agricultural ventures included the production of bananas, citrus, cotton, and rice, among other crops, but were mostly centered around the cultivation of coca (Ivan Vargas, pers. comm., 2002) and likely included work in some phase of the production of cocaine.

Out-migration was a probable cause for the decrease in the amount of land under cultivation from 1968 to 1993. It was also partly responsible for the decrease in average parcel size. Mothers and daughters would often travel to the city to work as domestic servants (Zimmerer, 1993), while in other cases, fathers and older children would leave to seek alternative income sources, leaving behind wives and young children (Constantine Vilca, pers. comm., 2002). With a smaller family unit in place, and little incentive to participate in the agricultural economy (Painter, 1998), there was less demand on the land for agricultural production, possibly leading to decreased parcel sizes. Because even young children can tend livestock, and because animals are considered a source of economic security (Mario Rojas, pers. comm., 2002), grazing may have come as a more viable local livelihood strategy at this time, thus adding to the expansion of pasture land.

Out-migration caused by economic and political factors may have also affected land-cover in the watershed from 1968 to 1993 by expanding eroded land. According to Zimmerer (1993), a shortage of local labor due to increased time spent by residents in external wage labor activities decreases the investments in local conservation practices in a study of the nearby Calicanto Watershed in Cochabamba. Also, fields that are abandoned without soil conservation measures are more susceptible to erosion (Harden, 1996). It is likely that out-migration from the Taquiña Watershed affected conservation activities similarly.

Land degradation associated with the fragmentation of all land-use/cover types, the expansion of pasture and eroded land, and the reduction of forest, silvopasture and brush land during this period may have affected both water resources and wildlife in the watershed. Residents of the watershed reported that in the past, before PROMIC initiated conservation activities, there were more problems with flooding, erosion, and sedimentation than exist today (Interviews, pers. comm., 2002.). They also reported that native fauna were more plentiful during the days of their ancestors before increased population, hunting, and agropastoral activity threatened their numbers and habitat (Interviews, pers. comm., 2002).

1993-2001

From 1993 to 2001 new trends in land-cover took place in the Taquiña Watershed that began to reverse much of the change observed between 1968 and 1993. Net area increases occurred in agriculture, brush land, and silvopasture land-cover types, while net area decreases occurred in areas of erosion, native forest, and pasture. There was an increase in the number of parcels in agricultural, brush land, native forest, and silvopastoral land-use, while the number of erosion and pasture parcels decreased and remained the same respectively. The average areas of parcels representing all cover types during this period decreased, and the fragmentation of land-cover continued. Pasture was replaced by agricultural land that expanded into the higher reaches of the watershed, as well as silvopasture and brush land, and abandoned agricultural land was replaced by pasture, silvopasture, brush land, and even native forest in some isolated areas.

A new set of factors began influencing land-use/cover dynamics in the watershed during this period including the initiation of an integrated watershed management project by PROMIC, the construction of new roads into the watershed, and the emergence of new local employment opportunities.

PROMIC

PROMIC approached development and conservation in the Taquiña Watershed on many levels including direct intervention in small to large public works utilizing local labor, revegetation of denuded hillsides, structural stabilization and revegetation of gullies, and the placement of gabions in major channels to operate as check dams for floodwaters. The direct effect of these actions in terms of land-cover change in the watershed can be seen in a progressive decrease in the amount of erosion between 1993 and 2001, especially along waterways. The transition of land-cover to brush land and silvopasture in some places can also be partly attributed to the direct planting of trees and shrubs, especially in lower portions of the watershed (Figures 2-5). Today, residents of the watershed consider the work initiated by PROMIC and subsequent land-cover transitions to be positive (Interviews, pers. comm., 2002).

PROMIC also sought to encourage more intensive cultivation through incentives programs. PROMIC assisted farmers who wanted to improve production by helping build water catchments, cement irrigation systems, and sprinkler systems, provided that the farmers implement soil-conservation practices on their land. Erosion control practices included terraces, agroforestry systems, and improved watering systems. Initiatives to improve production included instruction in how to make and use low-cost, effective, organic fertilizers and pesticides, improved varieties of seed, and an increased variety of annual species, such as flowers for sale in local markets. This helped to make agriculture more viable (Constantine Vilca, pers. comm., 2002).

Although one of the objectives of PROMIC was to increase production *without* increasing agricultural land, these activities and incentives may have been partially responsible for the increase in total area under agricultural cover from 1993 to 2001. It is likely that residents wanted to expand on the economic possibilities provided by improved systems of agriculture, and either cleared new land, or rehabilitated fallow areas for this purpose (Constantine Vilca, pers. comm., 2002). The clearing or rehabilitating of old parcels may also partially explain the increased fragmentation of agricultural land, especially between 1993 and 1998, when the number of parcels jumped from 17 to 30. The decrease in average parcel size over this period of time may also partly be a product of the intensification of agricultural systems promoted by PROMIC.

The conversion to agricultural land that took place between 1993 and 2001 was largely concentrated in areas that were previously under pasture. Vegetation transects conducted in the two areas showed that agricultural fields have less ground cover (47%) than pasture (69%). The relatively large amount of exposed ground in these areas increases erosion potential if erosion control measures are not implemented. However, good ground cover (76%) was found on transects taken in fallow fields. The majorities of these fields had been stabilized with terraces or were on slopes of less than 10^{o}. Fallow fields where erosion control measures were not implemented showed extensive laminar and rill erosion and poor ground cover (Personal observation, 2001-2002). Stabilized fallow fields also had higher plant diversity than agriculture and pasture cover types (Appendix 2).

The degree to which PROMIC directly influenced changes to pasture from 1993 to 2001 is uncertain. A component of their outreach promoted "ecological balance," including discouraging pasture burning, but their involvement with livestock and pastoral practices was largely limited to the vaccination of animals. The combined effects of decreased burning and conservation activities, such as the planting of tree and shrub species, allowed for the proliferation of woody perennials. This may also have helped improve on-site conditions by providing shelter and increased soil moisture, which encourages the natural regeneration of native brush and tree species. All of this may have contributed to the transition from pasture to silvopasture and brush land seen in the southern and west-central part of the watershed (Figure 5).

Another factor that may have contributed to the transition from pasture to silvopasture and brush land, and possibly the overall distribution and number of livestock in the watershed, was the threat that animals pose to agricultural fields. Grazers that allow their browsing stock to wander into cultivated fields are obliged to compensate the farmer for his/her losses (Mario Rojas, pers. comm., 2002). Therefore, livestock are generally kept away from cultivated areas. In some places, agricultural land forms a barrier to grazing. Decreased grazing pressure may have facilitated the transition to silvopasture. This relationship can be seen in the west-central portion of the watershed (Figure 5) where the largest transition from pasture to silvopastoral land occurs in areas adjacent to agricultural land.

The transition from pasture to silvopasture in the watershed can be considered a positive change due to the increased ground cover and plant diversity. Vegetation surveys carried out in areas of pasture and silvopasture showed silvopasture to have a ground cover of 78% and pasture to have a ground cover of 69% in the dry season (Appendix 2). Increased ground cover in silvopasture offers more resistance to erosion than in pasture lands. This is true as well for transitions made to silvopasture from agricultural land. The relatively low bulk density of silvopasture soils also suggests a greater infiltration capacity than in areas of pasture and agriculture (Appendix 1). Increased plant diversity in areas of silvopasture also creates greater vegetation structural complexity and height, which may provide habitat for native fauna.

Even in areas of pasture where no land-cover change took place, it appears as though improvements in local conditions occurred. It is not possible to make direct comparisons between the results of this study and the results of vegetation surveys conducted on pasture lands in 1993 by Ruben Camacho (1994) owing to methodological uncertainties, but differences appear to exist. In his assessment of dry season pastoral conditions in the watershed, he recorded a ground cover of 58% in the Thuru Ichu region of the watershed (found in the center of the watershed, above the upper limit of agriculture in (Figure 6). In this study, the same region had a ground cover of 69% in the dry season of 2002- an increase of 11%. In fact, part of the region has since been converted to silvopastoral land, with even greater ground cover. This change may be attributed to decreased burning and grazing as discussed above.

Roads

One component of PROMIC's holistic plan for conservation and the improvement of living conditions for residents of the Taquiña Watershed, was to build roads into the basin. This component of their development strategy had an important effect on land-use/cover change in the watershed after 1993 in a variety of ways. Probably the most profound effect was by facilitating transportation of produce to markets. Nearly everyone interviewed commented on how roads have improved living standards through increased market access. Roads, combined with an increase in the number of cash crops, were a significant factor in increasing the viability of agriculture as a livelihood (Interviews, pers. comm., 2002) and may have contributed to the expansion and fragmentation of agricultural land between 1993 and 2001. The expansion and fragmentation of agricultural land due to roads may have also precipitated other land-cover changes in the watershed such as the reduction in pasture and the associated expansion of silvopasture and brush land.

Road construction and the facilitation of access to the watershed potentially had a dual effect on land-cover and natural resources. On one hand, it facilitated management and conservation activities, which broadly impacted land-cover by allowing PROMIC extensionists, managers from the brewery, and Tunari National Park officials access to previously remote areas. On the other hand, it also provided access to forest resources by outside residents, which potentially contributed to a decrease in native forest between 1993 and 1998. It is also possible that the large stretch of eroded land in the south-central portion of the watershed is directly related to road construction (Figures 3 and 4). The construction of this road, may have either destabilized the hillslope and caused landsliding, or been built subsequent to sliding. By 2001, the eroded land in this area was converted to brush land through the direct planting of Retama (a Broom species) and other native brush species by PROMIC (Figure 5). However, in 2002, I noted recent landslides of lesser magnitude associated with road cuts.

To gain perspective on what local residents feel about PROMIC's work, those interviewed were asked to comment on their efforts in the watershed. They unanimously responded that PROMIC's work in the watershed was good. Seventy percent indicated that roads had improved their lives, while 30% said improved farming and erosion control practices had improved their lives. Furthermore, everyone stated that vegetation has increased in the watershed since PROMIC began operations. Of those surveyed, 80% said that all vegetation types had increased, while 20% said that vegetative cover by non-native species had increased, while native cover had decreased. Of those species introduced to the watershed, most of those interviewed (70%) use and appreciate introduced species as they serve multiple purposes (i.e. firewood, building material, medicine, erosion control, green manure, and tool handles).

Residents were also asked about animal populations to better qualify changes in ecological conditions. All respondents reported a decrease in the overall number of animals, both domestic and wild, although 20% indicated that the number of Tinamou (a native bird species) increased as a result of decreased burning.

When questioned about water quality and quantity, 50% of those interviewed reported that they had seen no change in water since PROMIC began working in the watershed, while 30% responded that less water existed than before. Twenty percent of those interviewed reported that water was cleaner, more abundant in irrigation, and that there were fewer floods since PROMIC's work began. These responses may have been influenced by where people live. I observed that those living at or below the mouth of the watershed commented positively about changes in water quality and flooding.

Alternative Livelihood Strategies

Rural livelihoods in Bolivia make use of multiple resources in various localities (Preston et al., 1997). In the Taquiña Watershed, alternative livelihood opportunities that emerged may have affected land-use/cover dynamics. With the initiation of public works for conservation in the watershed by PROMIC, local employment/economic opportunities for residents developed. In addition to construction laborers, the need for road maintenance continues to provide alternative economic opportunities.

The Taquiña Brewery draws local labor from all over the watershed and includes farmers and grazers alike (Mario Rojas, pers. comm., 2002). Compensation for a day's work is the same for all, but the complementary nature of a laborer's primary livelihood activity with supplemental work creates advantages for certain livelihoods. People whose primary livelihood is the cultivation of annuals can leave fields untended while working another job. Grazers cannot leave their livestock unattended for an entire day. For some, a shift from itinerant pastoral activities to more sedentary, less time-demanding agricultural activities occurred for this reason (Interviews, pers. comm., 2002). Of those interviewed, all who were primarily grazers in the past have now expanded their agricultural output and decreased their number of livestock. This conversion was made to allow more time for work at the brewery (Interviews, pers. comm., 2002).

The decrease in the number of livestock and extent of pasture (Figures 3-5) may have helped to facilitate "positive" changes not only with the expansion of silvopasture and brush land, but also by reducing erosion. Preston et al. (1997) correlates decreases in overall numbers of livestock and changes in preference for more easily managed livestock with decreases in erosion in the Tarija area of southern Bolivia.

The majority of families living in the Taquiña Watershed participate in both grazing and farming to varying degrees. Farmers primarily cultivate annual crops, but have small holdings of livestock. Grazers live in the higher reaches of the watershed and tend livestock as their primary activity, while also cultivating small parcels. Because of a northward/upland expansion and fragmentation of agricultural land, I believe that shifts in livelihood strategy from grazing to farming and working with the brewery may have affected land-cover change in this area. It is unknown if all grazers made similar shifts in livelihood strategy.

Constantine Vilca (pers. comm., 2002), a resident of the watershed, claims that shifts in livelihood from pastoral to agricultural activities also occur due to increased earning potential through the cultivation of improved varieties of annuals, especially flowers, and an increased access to markets with roads.

A diversification of livelihood strategies for increased financial security is another factor in the expansion and fragmentation of agricultural land and corresponding decrease in pastureland in the Taquiña Watershed and Cochabamba region (Ellis-Jones and Mason, 1999). Subsistence strategies that employ a range of resources are common to highland communities (Brush, 1976; Preston et al., 1997). Given Bolivia's extensive history of economic instability, it is possible that grazers placed new land under cultivation to provide themselves with extra provisions, as well as additional earning made available by road access to markets.

It is likely that population dynamics also played a roll in land-use/cover change. There are no reliable data on population changes in the watershed itself, though the approximate number of families increased from 35 to 45 from 1991 to 2001 (Mario Rojas, pers. comm., 2002). The extent, however, of seasonal or permanent out-migration is unknown. An increase in the total area under cultivation, as well as in the number of parcels, could be partially explained by an increase in population. This increased population may also result from decreasing opportunities in the coca industry due to the U.S.-led coca eradication program in the Chapare and the related increase in violence directed toward campesinos. According to Constantive Vilca (2002), some migratory workers did return to the area to pursue a more sedentary livelihood of farming in the watershed for these reasons. The incentive to return may also have been enhanced by

PROMIC's agricultural programs, combined with access to markets as facilitated by the roads built in the upper and lower portions of the watershed.

After 1996, PROMIC's work in the Taquiña Watershed was limited to general investigations and research, so the extent of their influence is questionable. However, the agricultural and conservation practices they introduced continue. To what degree these practices are applied to newly broken ground as the agricultural frontier expands is uncertain. In some areas, newly cultivated lands include soil conservation measures characteristic of intensive agricultural systems, and in others they do not. The reasons for this difference in agricultural practices in newly expanded areas are variable.

Chapter V
CONCLUSION

Land-use/cover change in the Taquiña Watershed was influenced by a broad range of factors between 1968 and 2001, some of which began before the initiation of the study period. However, in 1993, there was a distinct shift in the trend of land-cover change. The most important of these changes were an increase of silvopasture and brush land and a large decrease in eroded land and thus reduced risk of erosion, soil loss, and sedimentation. Other land-cover changes such as agricultural expansion and decreased pasture may have helped to drive change in these areas and provides insight into possible changes that may take place in the future, both locally and regionally.

The reasons for these changes in land-use/cover are multifaceted. In some cases, the changes may have directly resulted from conservation initiatives undertaken by PROMIC. In the case of the eroded land being converted to brush land or silvopasture through a variety of structural soil-conservation methods and revegetation, this is particularly likely. This type of intervention may also be partially responsible for the conversion of portions of pasture to silvopasture and brush land. However, the overall area that underwent change owing to PROMIC's direct intervention is relatively small. Changes in the Taquiña Watershed following 1993 likely occurred due to a combination of extension and conservation activity by PROMIC, increased economic opportunities facilitated by crop diversification and improved varieties of seed, increased access to markets through the construction of roads, alternative livelihood opportunities at the local level, an internal shift of livelihood strategies, and increased population resulting from decreased out-migration to the Chapare for coca cultivation.

Although the reasons for land-use/cover change are multidimensional, after 1993 it can be concluded that the effect of PROMIC on land-cover change in the watershed is substantial. Besides their direct influence on soil, water, and vegetation conservation through revegetation and the use of structural controls, they were instrumental in implementing soil conservation practices on local farms through incentives programs, providing improved and diversified varieties of seed, building roads that linked rural families to markets (which now provided employment for their maintenance through the brewery), and offering direct employment opportunities to residents during periods of road and gabion building. While these efforts improved the potential for economic development for people living in the watershed, they may have compromised other management goals.

Where PROMIC's efforts may have fostered contrary results was in agriculture. In their effort to limit the expansion of agricultural lands and improve livelihood viability through intensification via soil conservation techniques, improved seed, natural inputs, and improved watering systems, it is likely that incentives directly linked to agricultural production were at least partly responsible for agricultural expansion and fragmentation. The increase in area under agriculture occurred relatively quickly, there was a great deal of fragmentation, and the agricultural frontier pushed higher into the watershed into previously uncultivated areas.

If the expansion of agriculture in the upper Taquiña Watershed occurred as a result of a diversification of livelihood strategies among residents involved in off-farm employment and/or pastoral activities, there is a risk that investments in conservation measures will not be made due to time constraints (Zimmerer, 1993). Also, much of the highland agricultural expansion occurred on very steep slopes. These lands are often of more marginal quality, unable to sustain long-term intensive agriculture, and therefore do not warrant the investment in conservation initiatives by rural farmers (Harden, 1996). Such trends may lead to increased erosion, flood hazard, and sedimentation in the future if left unchecked (Ellis-Jones and Mason, 1999). Furthermore, expansion and dispersion of agricultural land will also lead to further fragmentation of adjoining land-cover units.

The Taquiña watershed shares biophysical and historical similarities with other watersheds in the Tunari Range, and a majority of these watersheds are currently being managed by PROMIC. Thus, land-cover changes and the range of causal factors in the Taquiña Watershed may be applicable to other watersheds in the region. While differences between watersheds do exist, such as the unique livelihood opportunities provided by the brewery in the Taquiña Watershed, differences in transportation routes, settlement patterns and livelihood strategies, many of the basic results and recommendations of this study could apply elsewhere.

Environmentally speaking, the land-cover changes that occurred in the Taquiña Watershed were largely advantageous in that ground cover increased, and erosion and sedimentation decreased. However, expanding agricultural land may adversely affect the environmental integrity of adjacent land cover types and down-stream conditions (Ravnborg and Westermann, 2002). Although agricultural expansion is likely to continue, it might be possible to slow the rate of expansion and mitigate some of the adverse effects through additional outreach efforts in the watershed. These efforts should include additional on-farm soil-conservation and the promotion of agroforestry activities in newly converted areas, as well as general environmental and watershed health education, highlighting the local successes achieved thus far.

Further study focusing on the effects of conservation and changing land-cover patterns on local and adjacent ecosystems would also be useful. Limitations in viable habitat and truncated migration corridors due to land-cover fragmentation can negatively affect faunal populations, and ecologic function. An understanding of these relationships could play a crucial role in informing future management strategies, particularly for the national park.

A thorough soil survey of the watershed and creation of a soils GIS layer would also be useful in understanding the distribution of land-cover types. Furthermore, this database would provide a baseline for future conservation assessment and monitoring activities in the watershed.

Appendix 1. Physical Soil Analysis

Sample Area	Sample Depth	Humidity %	Sand %	Silt %	Clay %	Texture	Particle Density (g/cc)	Bulk Density (g/cc)	Porosity %
Agriculture	20 cm	61.1	27	35	38	Clay Loam	2.5	1.3	48.2
	50 cm	51.2	39	53	8	Silt Loam	2.4	1.3	45.6
Fallow	41 cm	50.0	25	51	24	Silt Loam	2.2	1.4	34.6
	71 cm	36.0	27	47	26	Loam	2.5	1.6	35.4
Fallow	Topsoil		30	53	17	Silt Loam			
	26 cm	25.9	22	62	16	Silt Loam	2.2	0.7	67.3
	52 cm	10.3	34	48	18	Loam	2.1	1.4	31.6
Fallow	Topsoil		34	50	16	Loam-Silt Loam			
	24 cm	20.4	34	46	20	Loam	2.0	1.2	42.0
	41 cm	9.8	45	35	20	Loam	2.7	1.6	42.6
Fallow	Topsoil		36	50	14	Loam-Silt Loam			
	24 cm	20.7	28	42	30	Clay Loam	2.5	1.2	51.2
	41 cm	9.9	40	34	26	Loam	2.8	1.5	48.4
Fallow	Topsoil		38	50	12	Loam-Silt Loam			
	36 cm	8.2	26	57	17	Silt Loam	2.8	1.7	40.4
	59 cm	21.8	25	60	15	Silt Loam	2.4	1.1	52.5
Fallow	Topsoil		54	34	12	Sandy Loam			
	23 cm	30.6	52	37	11	Sandy Loam-Loam	2.3	1.0	58.5
	40 cm	15.1	42	45	13	Loam	2.6	1.4	46.3
Pasture	22 cm	27.4	9	27	64	Clay	2.6	1.7	34.2
	51 cm	57.1	13	25	62	Clay	2.7	1.5	45.0
Pasture	Topsoil		42	42	16	Loam			
	21 cm	18.9	46	44	10	Loam	2.6	0.9	64.1
Silvopasture	Topsoil		37	33	30	Clay Loam			
	20 cm	51.8	33	35	32	Clay Loam	2.6	1.2	51.8
	34 cm	55.6	27	37	36	Clay Loam	2.6	1.2	55.6
Silvopasture	Topsoil		39	39	22	Loam			
	30 cm	61.4	25	57	18	Silt Loam	2.3	0.9	61.4
	53 cm	40.6	43	25	32	Clay Loam	2.6	1.6	40.6
Silvopasture	Topsoil		41	50	9	Loam-Silt Loam			
	18 cm	52.9	25	35	40	Clay Loam	2.6	1.2	52.9
	34 cm	60.7	27	53	20	Silt Loam	2.4	1.0	60.7
Silvopasture	Topsoil		41	39	20	Loam			
	20 cm	8.0	67	23	10	Sandy Loam	2.5	1.4	44.2
	32 cm	12.1	49	31	20	Loam	2.6	1.4	47.9
Silvopasture	Topsoil		40	41	19	Loam			
	31 cm	4.9	64	20	16	Sandy Loam	2.6	1.3	48.5
	54 cm	5.1	47	31	22	Loam	2.6	1.5	44.1
Silvopasture	Topsoil		43	39	18	Loam			
	25 cm	11.9	45	29	26	Loam	2.6	1.4	48.1
	38 cm	6.7	43	37	20	Loam	2.5	1.3	46.2

Appendix 2. Vegetation and Percent Ground Cover

Herb Species	Agriculture	Fallow	Silvopasture	Pasture
Alcamille pinnata		3	5	16
Bidens andicola			1	
B. pseudocosmos				
Eryngium paniculatum			9	
Gamochaeta americana		1		1
Geranium fiebrigianum			12	
Gnaphalium badium				3
G. cheirantifolium		2	7	
G. versatile		1	9	
Hiercium mandonii	2	2		
Hypochoeris elete			1	
Lupinus altimontanus	2			
L. mutabilis	1	1		
Orthrosanthus chimboracensis				1
Relbunium affciliatum			1	
R. hypocarpium			1	
Senecio humillimus			1	
Valaeriana cephalanta				1
Werneria strigosissima			2	
Annual 1		1		
Bromliaceae flia, Puya sp.			3	
Carnation sp.	8			
Clover sp.				3
Crop Residue	11			
Dead Annual-D5				1
Dead Annual-D7				1
Dead Annual-M1			2	
Dead Annual-M4			1	
Dead Annual-M7			1	
Dead Native Annual		1	1	4
Unidentified Annual-Planta Roja	17	45	29	1
Unidentified Annual-Weed 2		1		

Grass, Forbe, and Sedge Species				
Bothriochoa barbinodis			1	
Calamagrostis eminens			19	66
C. iagurus			1	
C. mandoniana		2	20	18
C. trichophylla		1	8	
Carex ecuadorica			6	7
Eragrostis montufari			9	
Festuca dolichophylla	1	7	12	
F. fiebrigii	4	2		
F. hicronymi			1	
Hordeum (Graminae)			1	
Muhlenbergia peruviana		1	3	
Nasella inconspicua				
Piptochaetium montevidense		4	66	

Poa buchtienii	1	1		
P. candamoana			2	
P. perligulata	6	17	32	
P. scaberula		3	14	50
Schizachyrium cirratus			1	
Stipa ichu	1	39	175	155
S. inconspicua		1	6	
Phalaris	1			

Tree Species

Baccharis alpina	2	5	1	
B. incarum			5	
B. obtusifolia			1	
Buddleja coricea			2	
Eupatorium azangaroense			6	
Plazia daphnoides			3	
Polylepis besseri		1	28	1
Schinus andinus			1	

Bush Species

Baccharis dracunculifolia		1	5	
Berberis rariflora			3	
Calceolaria parvifolia		3	1	
Gynoxys sp.			2	
Lepechinia meyenii		9	10	
Muehlenbeckia volcanica		5	3	
Satureja boliviana	1	1	2	
S. parvifolia		3		
Viguiera procumbus		5	11	

Other

Cheilanthes myriophyllum			11	
Opuntia erytrophilus			3	
Cactus sp.			2	
Moss or Lichen sp.	3	11	165	50
Thistle sp.		1		

Unknown

C2			6	
C8		1		
D11				1
D3~=S2				3
D4				1
Escursionera				4
L7			2	
M2			2	
M5			5	
M6		3	3	
M8			1	
S5=S8			2	

S7			1	
T12			1	
T2			2	

Exposed Ground

Mineral soil	69	51	134	106
Rock	1	9	79	67

Vegetation	61	185	753	388
Exposed Ground	70	60	213	173
Total	131	245	966	561
Percent Cover	47%	76%	78%	69%

Appendix 3.
Questionnaire Used for Interview of Residents

Background
Name:

Married/Single

Number of Children:

Number of family members living here:

Number of years have you lived in the watershed:

Number of generations your family lived in the Taquiña Watershed:

If you relocated, where did you come from?

What are your principle activities in the watershed?

Have you always participated in these activities, or have you changed over time?

Agriculture
1) What crops do you/ did you/ did your ancestors cultivate? In what cycles?
Currently:

In the past:

Ancestors:

2) What types of livestock do you/ did you/ did your ancestors raise? Approximately how many?
Currently:

In the past:

Ancestors:

3) Do you/ did you/ did your ancestors sell livestock or crops? What livestock or crops are/ were sold?
Currently:

In the past:

Ancestors:

4) Do you/ did you/ did your ancestors consume your/ their livestock and crops? Which ones? Approximately what percentage?
Currently:

In the past:

Ancestors:

5) If there has been a change over time in what you sell and consume, why was there a change?

Ecology
1) What types of wild animals live/ lived in the watershed?
Currently:

In the past:

Ancestors:

2) What differences have you seen/ heard about in wild animal populations (type/numbers) in the watershed?
Currently:

In the past:

Ancestors:

3) Why was there a change?

4) Do you/ did you/ did your ancestors hunt? What animals? Is/was it for food? What percentage of the diet is/was game?
Currently:

In the past:

Ancestors:

5) If there is a change in the types or numbers of animals hunted, why?

6) Where did the animals go?

Native Plants
1) Do you/ did you/ did your ancestors use plants? For what?
Currently:

In the past:

Ancestors:

2) Are there plants that you used in the past that you do not use today? Which? Why?

3) Are there plants that you use today that you did not use before? Which? Why?

4) Are there shamans or medicine men/women who work with medicinal plants?

5) Do these people have students?

6) Can you describe differences in the vegetation between the past and present and when your ancestors were alive?

Water

1) What do you/ did you/ did your ancestors use water for?
Currently:

In the past:

Ancestors:

2) How is/ was the water in quantity and quality?
Currently:

In the past:

Ancestors:

3) Are/ were there aquatic organisms living in the water?
Currently:

In the past:

Ancestors:

4) Are/ were there problems with water such as floods, disease, etc.?
Currently:

In the past:

Ancestors:

PROMIC

1) What do you think of PROMIC and its work?
2) In the eleven years since PROMIC has worked here, has your life changed? How?
3) Have you seen changes in the local ecology since PROMIC started working here?
4) Have you seen changes in crops since PROMIC started working here?
5) Have you seen changes in livestock since PROMIC started working here?
6) Have you seen changes in water since PROMIC started working here?
7) Can you use the plants that PROMIC uses to control erosion and for reforestation for more than one purpose?
8) Would more plants of multiple use interest you?
9) Do you think that everyone in the watershed has benefited equally from PROMIC's work?
10) Are there ways in which PROMIC can help more?

Appendix 4.
Summary of Results From Interviews

Agricultural Products in the Taquiña Watershed			
Crop	Current	Past	Ancestors
Potato (*Solanum tuberosum L)*	100%	100%	80%
Papa Liza (*Ullucus tuberosum)*	60%	80%	40%
Papa Luki (*Solanum curtilobum)*	-	-	20%
Oca (*Oxalis tuberosa)*	90%	80%	50%
Fava Bean *(Vicia Faba L.)*	10%	10%	-
Tarhui (*Lupinus mutabilis)*	60%	50%	10%
Peas *(Pisum Sativum L.)*	-	10%	-
Wheat *(Triticum spp.)*	70%	80%	40%
Barley (*Hordeum vulgare L.*)	10%		-
Oats *(Avena L. spp.*	10%	10%	10%
Corn *(Zea Mays L.)*	10%	10%	10%
Flowers (undifferentiated)	20%	-	-
Lived outside watershed	-	-	10%

Domestic Animals in the Taquiña Watershed			
Animal	Current	Past	Ancestors
Cows	40%	90%	40%
Steers for plowing	20%	10%	10%
Llamas	40%	90%	70%
Sheep	40%	100%	80%
Donkeys	30%	10%	10%
Horses	10%	20%	-
Mules	-	-	10%
Chickens	10%	10%	-
Pigs	10%	10%	10%
No animals	30%	-	-
Lived outside watershed	-	-	10%

Produce and Animals Raised for Market			
Market Resource	Current	Past	Ancestors
Produce	90%	100%	60% * 10% bartered
Animals	40%	90%	80%
Lived outside watershed	-	-	10%

Types of Native Fauna Living in the Watershed			
Native Fauna	Current	Past	Ancestors
Mammals			
Fox	100%	100%	100%
Andean Mountain Cats	10%	10%	10%
Puma	-	30%	60%
Deer	-	10%	10%
Vicuña	-	40%	70%
Alpaca	-	-	10%
Goats	-	20%	50%
Anteater	-	-	10%
Guinea Pigs	30%	30%	30%
Rats/mice	10%	10%	10%
Viscacha	80%	80%	80%
Skunk	10%	10%	10%
Marsupials			
Large American Opposum (10%)	-	-	10%
Mouse-opossum (shrew)	20%	20%	20%
Reptiles and Amphibians			
Snakes	20%	20%	20%
Lizards	10%	10%	10%
Frogs	10%	10%	10%
Birds			
Condor	50%	50%	50%
Eagles	60%	60%	60%
Falcon	10%	10%	10%
Hawks	10%	10%	10%
Tinamou	90%	90%	90%
Doves	20%	20%	20%
Ducks (10%)	-	10%	10%
Undifferentiated song birds	30%	30%	30%
Lived outside watershed	-	-	10%

Animals Hunted			
Reason for Hunt	Current	Past	Ancestors
For food	40%	70%	40%
For sport	0%	10%	0%
Did not know	-	-	10%
Lived outside watershed	-	-	10%

Uses for Native Plants			
Use	Current	Past	Ancestors
Fuelwood	100%	100%	90%
Medicine	90%	90%	90%
Construction	100%	100%	90%
Tools	60%	60%	50%
Food	10%	10%	10%
Lived outside watershed	-	-	10%

Uses for Water			
Use	Current	Past	Ancestors
Drinking	100%	100%	(90%)
Washing	50%	50%	(40%)
Animals	80%	80%	(70%)
Cooking	80%	80%	(70%)
Irrigation	80%	60%	(10%)
Fishing	10%	10%	(10%)
Lived outside watershed	-	-	(10%)

Aquatic Organisms			
Organism	Current	Past	Ancestors
Trout	40%	20%	20%
Frogs	50%	70%	70%
Toads	10%	10%	10%
Ducks	20%	20%	20%
Worms	10%	10%	10%

(%)- Percent of those surveyed who responded affirmatively to use or presence

BIBLIOGRAPHY

Allan, J. D., A. J. Brenner, J. Erazo, A. S. Fernandez, A. S. Flecker, D. L. Karwan, S. Segnini, and D. C. Taphorn, 2002. *Land Use in Watersheds of the Venezuelan Andes: A Comparative Analysis.* Conservation Biology, Vol. 16, No. 2, pp. 527-538.

Amurrio, J., F. Coca, J. Bellott, E. Espinoza 1993. *Clasificacion de Tierras Segun Su Capacidad De Uso A Nivel Semidetallado De La Cuenca Taquiña.* Programma de Manejo Integral de Cuencas- PROMIC, Cochabamba, Bolivia, pp. 209.

Anonymous, 1995. Cochabamba en imagines. Cultural Centanario, Cochabamba: Cerveceria Taquiña, pp.82.

Baied, C., and J. C. Wheeler, 1993. *Evolution of High Andean Puna Ecosystems: Environment, Climate, and Culture Change Over the Last 12,000 Years in the Central Andes.* Mountain Research and Development, Vol. 13, No. 2, pp. 145-156.

Bewket, W., 2002. *Land Cover Dynamics Since the 1950s in Chemoga Watershed, Blue Nile Basin, Ethiopia.* Mountain Research and Development, Vol. 22, No. 3, pp. 263-269.

Blaike, P., H. Brookfield, 1987. *Land Degradation and Society.* Methuen: New York

Botkin, D. B., 1990. *Discordant Harmonies: A New Ecology for the 21st Century.* Oxford University Press: New York, pp.241.

Braud, I., A. I. J. Vich, J. Zuluaga, L. Fornero, A. Pedrani, 2001. *Vegetation influence on runoff and Sediment Yield in the Andes Region: Observation and Modelling.* Journal of Hydrology, 254, pp. 124-144.

Brush, S. B., 1976. *Man's Use of an Andean Ecosystem.* Human Ecology, Vol. 4, No. 2, pp. 147-166.

Camacho, R., 1994. Evaluación Agrostofitosociologica, Manejo y Caracterización de la Flora Nativa en la Subcuenca Taquiña. Universidad Mayor de San Simon, AGRUCO. Pp.90.

Claure, B., 1995. Informe Geologico Regional de la Cordillera del Tunari. PROMIC, CORDECO-COTESU, pp.15.

Coppus, R., A. C. Imeson, J. Sevink, 2002. *Identification, Distribution and Characteristics of Erosion Sensitive Areas in Three Different Central Andean Ecosystems.* CATENA, 725, Article in press, pp 1-14.

Eckholm, E. P., 1975. *The Deterioration of Mountain Environments.* Science, 189, pp. 764-770.

Ellenberg, H., 1979. *Man's Influence on Tropical Mountain Ecosystems in South America.* Journal of Ecology, 67, pp. 401-416.

Ellis-Jones, J., T. Mason, 1999. *Livelihood Strategies and Assets of Small Farmers in the Evaluation of Soil and Water Management Practices in the Temperate Inter-Andean Valleys of Bolivia.* Mountain Research and Development, Vol. 19, No. 3, pp. 221-234.

Estrada, R. D., J. Posner, 2001. *The Watershed as an Organizing Principle for Research and Development: An Evaluation of Experience in the Andean Ecosystem.* Mountain Research and Development, Vol. 21, No. 2, pp. 123-127.

Goudie, A., 2000. The Human Impact On The Natural Environment (Fifth Addition). The MIT Press, Cambridge, Massachusetts, pp. 511.

Harden, C. P., 1993. *Land Use, Soil Erosion, and Reservoir Sedimentation in an Andean Drainage Basin in Ecuador.* Mountain Research and Development, Vol 13, No. 2, pp. 177-184.

----------, 1996. *Interrelationships Between Land Abandonment and Land Degradation: A Case from the Ecuadorian Andes.* Mountain Research and Development, Vol 16, No. 3, pp. 274-280.

Heath, D. B., C. J. Erasmus, and H. C. Buechler, 1969. *Land Reform and Social Revolution in Bolivia.* Praeger Publishers, New York.

Hug, F., P. Baccini, 2002. *Physiological Interactions Between Highland and Lowland Regions in the Context of Long-Term Resource Management.* Mountain Research and Development, Vol 22, No. 2, pp. 168-176.

IGU [International Geographical Union], 1998. *Land Use/Cover Change.* Land Use Policy, 15 (1), pp. 165-166.

Jordan, R., A. Warhurst, 1992. *The Bolivian Mining Crisis.* Resource Policy, Vol 18, Issue 1, pp. 9-20.

Lagos, M., 1994. *Autonomy and Power- The Dynamics of Class and Culture in Rural Bolivia.* University of Pennsylvania Press, Philadelphia.

Larson, B., 1998. *Cochabamba, 1550-1900. Colonialism and Agrarian Transformation in Bolivia.* Duke University Press, Durham and London.

Painter, M. D., 1998. *Economic Development and the Origins of the Bolivian Cocaine Industry.* In "The Third Wave of Colonialism in Latin America." SR Books, Wilmington, Delaware.

Parque National Tunari, 1998. *Criterios Tecnico- Legales para Abordar la Problematica del Parque Nacional Tunari.* Convenio Interinstituticional: Ministerio de Desarrollo Sostenible y Planificacion, Superintendencia Agraria, Prefectura de Cochabamba, Honorable Municipalidad de Cochabamba, pp. 90.

Preston, D. A., 1969. *The Revolutionary Landscape of Highland Bolivia.* The Geographical Journal, Vol. 135, Part 1, pp. 1-16.

Preston, D., M. Macklin, J. Warburton, 1997. *Fewer People, Less Erosion: The twentieth Century in Southern Bolivia.* The Geographical Journal, Vol. 163, No. 2, pp. 198-206.

Price, L. W., 1981. Mountains and Man. University of California Press, Berkeley/ Los Angeles/ London, pp. 506.

Program for the Integrated Management of Watersheds, 1996. PROMIC- Program for the Integrated Management of Watersheds, Informational pamphlet

----------, date unknown a. Program: Integrated Rural Development of Watershed in the Tunari Mountain Range, Cochabamba, Bolivia, PROMIC.

----------, date unknown b. General program information, PROMIC.

Ravnborg, H. M., O. Westermann, 2002. *Understanding Interdependencies: Stakeholder Identification and Negotiation for Collective Natural Resource Management.* Agricultural Systems, 73, pp. 41-56.

Richards, M., 1997. *The Potential for Economic Valuation of Watershed Protection in Mountainous Areas: A Case Study from Bolivia.* Mountain Research and Development, Vol. 17, No. 1, pp. 19-30.

Sharma, P.D., R. S. Minhas, 1993. *Land use and the Biophysical Environment Of Kinnaur District, Himachal Pradesh, India.* Mountain Research and Development, Vol. 13, No. 1, pp. 41-60.

Vanacker, V., M. Vanderschaeghe, G. Govers, E. Willems, J. Poesen, J. Deckers, B. De Bievre, 2002. *Linking Hydrological, Infinite Slope Stability and Land-Use Change Models Through GIS for Assessing the Impact of Deforestation on Slope Stability in High Andean Watersheds.* Geomorphology 1276.

Vera Zapata, R.E., 2001. *Clasificación de Tierras Según su capacidad de Uso Mayor en la Cuenca Taquiña "Método T.C. Sheng, Empleando SIG".* Prefectura-COSUDE, Cochabamba, Bolivia, pp. 109.

White, S., and F. Maldonado, 1991. *The Use and Conservation of Natural Resources in the Andes of Southern Ecuador.* Mountain Research and Development, Vol. 11, No. 1, pp. 37-55.

Zimmerer, K. S., 1993. *Soil Erosion and Labor Shortages in the Andes with Special Reference to Bolivia, 1953-91: Implications for "Conservation-with-Development".* World Development, Vol. 21, No. 10, pp. 1659-1675.