THE ROLE OF RAINFED FARM PONDS IN SUSTAINING AGRICULTURE AND SOIL CONSERVATION IN THE DRY HIGH VALLEY REGION OF COCHABAMBA, BOLIVIA: DESIGN CONSIDERATIONS AND POST IMPOUNDMENT ANALYSIS

THESIS

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Lack of sufficient water for irrigation is a major problem in and around the valleys surrounding the town of Aiquile, Cochabamba Bolivia. In addition, much of the region is undergoing desertification compounded by drought, deforestation, bad traditional agricultural practices, over grazing and a "torrential" rainfall pattern leading to severe soil erosion and low agricultural production.

Between 1992 and 1994, the author constructed a network of 24 small, mostly rainfed farm ponds to increase agricultural production and alleviate soil erosion and land-use problems by improving cover conditions. A 5-year post-impoundment analysis was carried out in 1998. The analysis examined current pond conditions, design criteria, irrigation water / crop production increases and the alleviation of land-use problems. Current pond conditions fell into four distinct categories with only 25 percent of the ponds being deemed as "functioning well." The project increased irrigation in the region and improved cover conditions in 66 percent of the pond sites.

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CHAPTER I

INTRODUCTION

Lack of water for irrigation is a major problem in and around the valleys surrounding the town of Aiquile, Cochabamba Bolivia. Due to the seasonal nature of precipitation, only four months out of the year, and a drought that has impacted the region intermittently for at least the last ten years, the ability to cultivate crops other than during the rainy season is seriously limited. Wet-season-only farming on a subsistence level accounts for the majority of the agricultural production. As of 1995 an estimated 80% of the agriculturally productive land of the valleys was left vacant during the dry season. Although some irrigation systems do exist in these valleys, their water supplies are grossly inadequate for full utilization by the farmers. Compounding a lack of sufficient irrigation water, the region as a whole is undergoing desertification. This process has been brought about by deforestation, bad traditional agricultural land-use practices and overgrazing. These problems, along with a torrential rainfall pattern, have lead to severe soil erosion and low agricultural production.

As a United States Peace Corps volunteer (PCV) working in Bolivia from 1992-1995, the author was assigned to a non-government organization (NGO) known as INDRI (Institute National Development Rural Integrated). INDRI, although capable of capturing funds from many sources, received the bulk of its funding indirectly through the United

States Agency for International Development (USAID) which channels its available funds through its subcontractors down to the NGOs. INDRI, like many NGOs in the region, works primarily in the transfer of new agricultural technology to the rural areas (campo) and farmers. Although the technical staff at INDRI recognized the lack of irrigation water as a serious problem, it lacked the resources and funding to attempt a solution. It was for this reason that, after discussion with the INDRI staff as well as with USAID contractors, the author proposed a network of approximately 25 small, mostly rainfed farm ponds, "atajados" in Spanish. An equal number of wells were also proposed for the valleys. The project was approved and funded for the author and his host country agency (HCA) through a grant from USAID under the Small Project Assistance (SPA) grants program and totaled $10,000.00. The author's project was only a small part of the overall USAID plan to improve living conditions in the region through expenditures in soil and water conservation and infrastructure improvements. The hope was that with the addition of these new sources of irrigation water, the beneficiaries involved would be able to irrigate more of their land more often, increase agricultural production and rise above subsistence level only farming. Many soil and water conservation benefits would also be attained as the rainfall would be captured where it fell and not contribute to the soil erosion process. Also, the US government stance on this issue was that if economic conditions could be improved in the region the people would have less incentive to seasonally migrate to the coca producing areas of the country and work in the illicit cocaine production process.

CHAPTER II

THESIS OBJECTIVES

A final economic report and Peace Corps Training Manual were developed after excavation of the ponds, and the impact of the wells has already been analyzed in a separate study (Hanrahan, 1993). The objectives of this thesis were: (1) to describe the physical, economic and environmental conditions in the study area that prompted the irrigation project, (2) outline pond construction techniques, and (3) to assess the viability of the pond project from a water resources management and soil conservation perspective and to make recommendations for future projects. Approximately five years have passed since the "completion" of the project, but to date no detailed analysis has been prepared to evaluate its success. In short, did the project increase available water resources to the point that agricultural outputs increased, and were soil erosion and land-use problems alleviated? To obtain the needed data to make an adequate assessment as to the success or failure of the project, the author, along with the help of his former HCA, carried out an in-field survey / post impoundment study in the former project area. It should be noted that numerous irrigation projects, similar to the one studied here are currently being undertaken by various national and international development agencies throughout the region and these agencies (as well as USAID) could benefit from the results of such a study. This thesis describes the study area, reviews relevant literature, outlines pond construction procedures, and documents the methodology and results of a post impoundment analysis in order to evaluate the effectiveness of the author's project in expanding the potential for irrigation based agriculture.

CHAPTER III

TRADITIONS IN WATER HARVESTING

The utilization of rainwater runoff in semiarid and arid regions, primarily for agriculture, includes moisture conservation techniques, the control and channeling of runoff to selected fields (runoff farming) and the actual storage of runoff for use later, also known as water harvesting. When the stored rainwater runoff is used for irrigation and thus crop production, the combination is known as runoff agriculture, although the distinction between this term and runoff farming is a subtle one. Many of the methods associated with these practices are thousands of years old and are still in use today in one form or another.

Moisture conservation techniques include all of the various physical measures that can be taken in order to reduce soil moisture losses by arresting runoff so that sufficient moisture exists in the soil to grow crops (Stern, 1979). In addition to water conservation many of these practices have the extra benefit of added soil conservation. These practices are often utilized on slopes and include the use of stone or earth ridges, the actual furrows in land that has been contour plowed, and the use of terraces, especially on steep, rocky terrain. On gently sloping to almost flat land, runoff can be detained by the construction of basins, a form of shaping the land into mini-catchments (Weber, 1985). Mulching and weeding as well as a number of other in-field agronomic measures also help to minimize soil moisture losses. Many of the moisture retaining techniques mentioned here, especially the use of stone ridges, were practiced by the inhabitants of the Negev Desert, in present day Israel 2000 years ago.

Runoff farming refers to the practice of concentrating surface rainwater runoff for agricultural production in arid and semiarid regions where often other permanent sources for irrigation do not exist (Pacey-Cullis, 1986). An example is water spreading, which involves the diverting of floodwaters within intermittent streams from their natural courses to adjacent floodplains or valley floors. The inundated areas then have sufficient soil moisture to grow crops. Water spreading systems need careful design. The technique is best utilized where an upstream drainage area is guaranteed to supply at least a few water flows each year and where the fields to be cultivated are gently sloping (NAS, 1974). The method is still widely used in many parts of Asia. Another example is the ancient runoff farms of the Negev Desert, in which an elaborate canal system, fed by a catchment of approximately 60 hectares, channeled runoff to numerous farms up to 3 hectares in size within a narrow valley. The system has been reconstructed by the Israeli government and is still functioning today. Still other examples include: the excavation of contour seepage furrows which increase the available water within the river floodplains of Zambia, the use of contour bunds to trap the runoff on the plains to the east of the Nile River in Sudan, microcatchment farming which concentrates the rainfall by creating a mini watershed around an individual plant, and desert strip farming which utilizes a series of terraces to shed water onto an adjacent strip of productive soil.

Of course, all these practices are variations on a common theme but with one goal in mind, to assure an adequate supply of water to mature the crop being grown. Obviously, this goal is tied to the water requirements of the crop and other water conservation techniques being implemented in the general area as well as the annual rainfall and its balance with evaporation during the growing season (Stern, 1989). The choice of what crops are to be grown is critical. In general, perennial crops with deep root systems are better adapted to runoff farming as they can utilize runoff water that has been stored deep in the soil, avoiding evaporation losses (NAS, 1974). Short-lived grains also have been cultivated using runoff farming methods as they mature rapidly and require minimal rainfall.

Rainwater harvesting is simply defined as the gathering and storage of water running off surfaces on which it has fallen (Pacey-Cullis, 1986). When tied into an agricultural context, it is in essence a variation of runoff farming / agriculture but with the distinction that the water is first "harvested" off of the surrounding slopes and then stored for later use. Although primarily used for irrigation, other uses can include water for livestock, aquaculture (fish cultivation) and in some places as a potable water supply, but only after treatment. It has been successfully utilized in regions of the world which receive as little as 100 mm, or slightly less, of annual rainfall (NAS, 1974).

The practice of rainwater harvesting is at least 4000 years old and is thought to have been first developed during the Bronze Age. The most often cited example of an ancient system is that of the Negev Desert, but equally venerable traditions and examples exist worldwide. Some examples include: the earthen dams built by the ancient Egyptians to capture runoff within the Nile floodplain, the small dams placed within intermittent streams by the ancient Indians of Mexico, and the relatively large runoff fed ponds used for rice cultivation in Japan which are still in use today (Chiga, 1997). Of course small scale rainwater harvesting for domestic use has existed for at least as long as it has for agriculture. An example is the monasteries in Mexico, where the monks utilized rainwater runoff to fill cisterns, as springs were lacking (Hasse, 1989).

The ancient Romans were very adept in rainwater harvesting (roof catchments for domestic use) as well as in the construction of reservoirs and are assumed to have learned much of their technical knowledge from the ancient Greeks. In fact, many of their systems appear to have been based upon a sophisticated rainwater harvesting system that was unearthed by archaeologists during the reconstruction of the Palace of Knossos on the island of Crete (Hasse, 1989). The Romans, however, improved upon the basic Greek designs by using closed cisterns which could store greater amounts of water, reduce evaporation losses and prevent the entrance of pollutants into the water. In addition, many of the Roman systems had a shallow pool in the center (atrium) of the house, which served the duel purpose of water for domestic use as well as air conditioning through evaporative cooling. These systems, unlike other ancient systems from other cultures, were designed not for agricultural use but to provide water for the inhabitants of many of the Roman cities around the Mediterranean basin where water resources were often limited. What some refer to as the "Roman rainwater catchment culture" reached its peak between 527 – 565 AD when Caesar Justinian ordered the construction of what is believed to be the world's largest cistern in what is now Istanbul, Turkey. The structure still exists today and measures 140 by 70 meters and was capable of storing 80,000 cubic meters of water. A sophisticated system of filters assured clean water (Hasse, 1989).

In more modern times the use of rainwater harvesting systems, in urban areas for domestic use, has been for the most part abandoned due to the potential of pollution, and has often been supplanted by groundwater developments. An exception to this is the use of artificial catchments on the slopes of some island hillsides, such as in Jamaica, where runoff water constitutes a large percentage of the domestic water supply (Stern, 1989). Rainwater harvesting does still exist in many regions of the world for agriculture and in some cases exclusively for livestock, and to a lesser extent even for household use. One of the largest, most extensive rainwater harvesting systems exists in Western Australia. Within this system several thousand hectares of mostly barren terrain have been compacted and shaped to channel the runoff to in-ground storage tanks. These tanks furnish water for both livestock as well as a number of small towns (NAS, 1974). The performance and water yields are adequate as long as the system is properly maintained. Although some large rainwater harvesting systems exist, they are the exception rather than the rule. Most rainwater harvesting takes place on a small-scale site-by-site basis according to the needs of individual farmers or farms.

In semiarid regions of Africa, particularly in western Sudan and in parts of Ethiopia, the traditional method for collecting rainwater for livestock as well as for other uses is by the use of "hafirs." A "hafir" is an artificially excavated rainwater-catchment pond, properly situated on gently sloping land where rainwater runoff by sheet flow is directed to it off of the surrounding hills by the use of built-up ridges (bunds) that surround the pond and also help to define the catchment area to it. Located in the semiarid Sahel of Africa, they are most often utilized by the pastoralists of the region. The ponds vary in capacity from as little as 1000 to as high as 200,000 cubic meters of total water storage (Pacey-Cullis, 1986). The design of "hafirs" is similar to that of "ahars" used in India for agriculture. However, the water ponded behind the bunds of an "ahar" is slowly siphoned off over the course of the season for various uses, including irrigation, and then completely drained and planted in the desired crop. In this fashion the area within the pond is also utilized for crop production.

A modern day example of where rainwater harvesting has been adopted not only for agriculture but for soil and water conservation as well is in the Siwalik foothills of Northern India. Prior to the middle of the last century the hills were covered in a lush growth of acacias, pines, shrubs and grasses. Due to political turmoil and excessive human pressure, by the middle of this century the region had been gradually transformed into a barren, highly eroded landscape, bearing little resemblance to its former appearance. The haphazard felling of trees, random hill cuttings for sand and gravel, uncontrolled grazing, fires and bad farming practices led in a relatively short time to rapid rainwater runoff, flooding, erosion, sedimentation, the silting in of lakes and the destruction of once fertile farmland (Pant, 1983).

In order to ameliorate the years of environmental degradation that have occurred in this region, a watershed wide reforestation / soil and water conservation plan was proposed in the 1970s and actually implemented in 1980. The main objective of the plan was to improve land utilization, conserve soil, and store and conserve rainwater (Pant, 1983). This was achieved in part by the construction of three large rainwater-runoff fed earthen dams within the project area, each averaging 65,000 cubic meters of water storage. To date, the project has achieved considerable success as documented by: a decrease in siltation within the fields below the dams, greater availability of irrigation water, control of flooding and erosion downstream, greater yields and improved water quality of groundwater in areas adjacent to the impoundments and a change in the microclimate within the general area of the ponds. Additionally, forest cover has increased and better soil moisture retention and less runoff are occurring within the areas influenced by water from the ponds. Although the region will probably never be fully returned to the state it once was in, it will at the very least not be a barren wasteland.

In Bolivia, rainwater harvesting is a relatively new concept, although one that has its roots within some of the water-use practices and traditions of the indigenous people. Within the semiarid mountainous region of the study area, small hand dug ponds, "kochas" in Quechua, have always existed that were utilized to capture at least some of the runoff during the rainy season. These ponds tended to be small, perhaps 200 cubic meters maximum, and were used exclusively for livestock and domestic use during the dry season. For agricultural purposes the farmers always relied directly on the limited seasonal rainfall, but also practiced on a more limited scale, some of the runoff farming techniques such as water spreading discussed earlier. Within other regions of the country, such as in the wooded, seasonally dry Chaco, an extensive network of runoff fed ponds was excavated in the 1940s and 50s in order to expand cattle ranching (Van Dixhoorn, 1996). Beginning in the 1960s, the first rural health and development agencies arrived bringing with them the promise of more water. These agencies concentrated mostly on the development of groundwater resources for "agua potable" by capping springs, constructing wells, and building infiltration galleries within the valley areas of some of the seasonally flowing streams, all in order to supply water to some of the small villages. With the drought that affected the region in the 1980s, emphasis shifted toward the development of adequate supplies of irrigation water. This was accomplished through greater development and utilization of groundwater resources, dam construction, and on a smaller site-by-site basis the development of small-scale irrigation through the construction of rainwater fed farm ponds, or "atajados."

The utilization of rainwater harvesting has grown significantly in Bolivia in the last 20 years. Currently, there exist numerous large and small-scale irrigation projects throughout the country. Many of these projects are placing their emphasis within the still drought stricken high valley region where the need for irrigation is paramount. Within each of these projects a rainwater harvesting component exists which utilizes "atajados." In fact some think, as mentioned earlier, that "atajado fever" has struck this region of the country and that perhaps other approaches to solve the problem should also be considered, especially since the climate and soils are not particularly suited for large-scale agriculture (Verweij, 1997).

CHAPTER IV

STUDY AREA

Bolivia

Bolivia, the fifth largest country in South America, occupies roughly 1,096,000 square kilometers, making it about the size of both Texas and California combined (Figure 1). It is one of the highest, most isolated and poorest of the Latin American republics. It has a population of close to 8 million people and a growth rate of 2.25% (1992 Census). Bolivia is the second poorest country in South America (after Guyana) and the third in the Western hemisphere (Haiti being the poorest) with the real GDP per capita being only $2,600. The average life expectancy is 64 years, 4.1 children are born on average per woman, and infant mortality is high with an average 10% dying within the first year. Ninety-five percent of all Bolivians are Catholic, adult literacy (15 and older) is 80% overall, but 88% for males and 72% for females. Spanish is the official language, but Quechua followed by Aymara, is widely spoken in the highlands and an estimated 25 to 30% of the people, mostly women, speak no Spanish at all. The country, since its 1884 war with Chile, is entirely landlocked but does have free access to the ocean through agreements with many of its neighbors. Of the 8 million or so people, more than 70% live in the western region of the country, mostly within the more hospitable temperate high valley region (Swaney, 1992).

Bolivia is the most "Indian" nation in South America, more than 55% of the people are of pure Indian (Quechua, Aymara or other) stock, while an estimated 35% of the population is mestizo, people of mixed Spanish and Indian blood. The remaining 10% or so of the population is of European descent. People of African heritage most of whom are descended from slaves that were conscripted to work in the mines of Potosi during the eighteenth and nineteenth centuries make up 1% or less of the population. Recent immigrants include Japanese, Chinese, Indians, Arabs, and Platt-Deutsch-speaking Mennonites.

Although the country lies entirely within the tropics, elevation plays more of a role in determining the climate than latitude does, and one can find anything from hot and humid lowlands to cold barren icy peaks. The terrain varies from the rugged Andes Mountains in the west (elevations greater than 21,000 feet), to high plains (altiplano), to hills, to the lowland plains of the Amazon. The country is rich in mineral resources, natural gas and timber, all of which help to contribute to its economy. However, agriculture provides employment for approximately 50 percent of the labor force. In the late 1980s and early 1990s, coca and cocaine production brought between $600 million to 1 billion dollars annually into the country, more than all legal exports combined (Swaney, 1992). This emphasis on a "cocaine economy" has, within the last four to five years, shifted toward a more licit economy, due mainly to efforts by the United States Government along with help and money from USAID. However, much money laundering still takes place, and infrastructures of entire cities have been built or greatly improved (indirectly) through this new found wealth. Currently, a demographic transition is taking place and at last count

60% of the population lived within urban areas. Recent environmental problems and issues include a lack of infrastructure in these fast-growing urban areas, the unregulated clearing of land to expand the agricultural frontier, deforestation of tropical timber, biodiversity loss, soil erosion, overgrazing, desertification and industrial pollution of water supplies (Swaney, 1992).

Physical Characteristics

The valleys of the study area (Tipajara and Uchuchajra) lie at about 2200 meters above mean sea level and are a part of what is known as the dry, high valley region of Cochabamba. Both valleys are situated just north of the town of Aiquile, within the province of Campero which is located in the southeast corner of the Department of Cochabamba (Figures 2 and 2a). They have a semiarid, temperate, Mediterranean type climate, but unlike a true Mediterranean climate receive the bulk of their rainfall (90 %) in the summertime, between November and March in the Southern Hemisphere (Swaney, 1992). These valleys, as well as the entire region in which they are located, lie in the rain shadow of the Serrania (mountainous region) of Cochabamba. Their relatively dry climate of 500 mm of average rainfall per year stands in sharp contrast to the Chapare Region (1500 mm plus) on the Amazonian side of the same mountain range. Potential evapotranspiration in the region is estimated to be 1100 mm, more than twice that of the rainfall. The actual rainfall, while relatively low, is described as being "torrential" with heavy downpours of as much as 50 mm / hour (Garcia, 1992). Flash floods, in the downstream reaches of the region's intermittent streams, are common during the rainy season. Daytime temperatures within the region average around 70 degrees Fahrenheit year round; however, frost (usually at night) is not uncommon during the months of June and July. Cold winds from the south, called "surazos," are also common at this time of the year.

According to the use and definition of ecological life zones (Holdridge, 1987 and Freeman, 1980) the study area can be classified as Thorn Steppe/Woodland (see photo 1). Physiographically, at least three separate land units can be identified, valley, hilly upland and flat to rolling upland (McDowell, 1989). The natural vegetation of this life zone has been extensively impacted by human activity by both irrigated agriculture and overgrazing (Dickinson, 1988). Trees indicative of this zone include Prosopis juliflora, Schinus molle and Acacia macrantha, while thorny xerophytic shrubs include Prosopis kuntzei, Prosopis ferox and various Acacia species. Cactus species include Cereus hankeanus, Roseocereus tephracanthus and Opuntia cochabambensis. Introduced, non-native Eucalyptus tree and shrub species are also common in some areas.

Soils within the study area derive from the weathering of folded Ordovician sandstones and shales and consist mainly of inceptisols but with entisols and aridisols in the valleys (MACA, 1969). Agriculturally, the soils lack high natural fertility and are relatively low in organic matter but tend to be richer within the valleys. The valleys themselves are characterized by being predominately agricultural, but only at, or just above subsistence level.

Economic and Educational Status

One of the most noticeable aspects of the study area is its extreme poverty and underdeveloped economic status compared to agricultural zones closer to Cochabamba City (see photos 2 and 3). Most of the families live below what is considered the poverty level but marginally support themselves through wet-season-only subsistence level farming and livestock. According to a nationwide study, the population of the province of Campero, including the study area, falls within the extreme poverty index with an estimated 93 percent of the population unable to adequately fulfill basic needs (UDAPSO, 1993). Net rural incomes countrywide average less than US $500.00 per capita annually (Banco Central de Bolivia, 1994). Education levels are low within all the valleys, with only 20% of the population attending school through the seventh grade. Illiteracy is approximately 40% for the population of 20 years and older. Moreover, as much as 25% of the female inhabitants receive no formal education whatsoever (CORDEP, 1989). Quechua (the language of the Incas) is the spoken language in all the valleys and often Spanish is only spoken by the male inhabitants who may travel outside the region. This situation has begun to change in recent years as bilingual education, for both genders, is being promoted in the rural areas.

Average family size consists of 6 members, infant mortality is 110/1000 and the average life expectancy in the region is 58 years (CORDECO, 1994). Common diseases and illnesses include a wide variety of gastrointestinal aliments often associated with parasitism, occasional cholera outbreaks and other waterborne diseases and chagas, a disease transmitted by the bite of the chagas beetle which can affect the cardiovascular system to the point of death (Swaney, 1992). An estimated 98% of the population was born within the Department of Cochabamba and 85% within the actual region. The current growth rate is approximately negative 0.3% (INE-BOLIVIA, 1993).

Land ownership

The average farm size is about 5 hectares and over 90 percent of the inhabitants of the study area own their homes. Land ownership, even in this rather isolated area is unequal, with slightly more than half the farmers owning only 21 percent of the cultivable land (CORDEP, 1989). Another aspect of land ownership that is of concern in the region and study area is the steady decrease in farm size through the subdivision of the land as it passes from one generation to the next. With the Agricultural Reform of 1952, many campesinos (peasants) became first-time landowners of the very fields they had been tied to by the patrons (land barons) who controlled them. Large tracts of land were simply divided among the families living on them. Many farms, which originally numbered 20 hectares or more in 1952, have been reduced in size down to as little as 1 to 2 hectares through inheritance and real estate transactions. This translates into less land under cultivation per family in a semiarid region where at least 5 hectares is considered to be the minimum farm size for adequate agricultural production (PDAC, 1989). Additionally, many of these new landowners lacked the skills to rise above subsistence level farming, while others knew very little about land stewardship. Orchards have been cut down, goats and sheep allowed free access to sensitive areas, and some lands have even been abandoned. Although this trend has improved somewhat in recent years, it continues, in part due to fragmentation / subdivision of the land. When the Patron-hacienda system was in place, a privileged few Spanish land barons controlled vast tracts of land and people to work it, both being essentially the property of the patron. No matter what the social / ethical implications of this system, it can at least be said that the resource base (land, soil, trees) was maintained and not degraded to the point of abandonment.

Environmental Problems

Another quite obvious aspect of the study area is that it appears to be undergoing a process of desertification. The principle factors responsible for this situation include the overall low natural fertility, moisture, depth and erosion potential of the soil, inadequate farming and in-field agronomic measures, overgrazing by livestock, deforestation brought about by the harvesting of wood for fuel and inadequate or nonexistent soil and water conservation measures. Of course all these factors are interrelated but in addition, their severity is compounded by a torrential rainfall pattern characterized by spotty, high intensity rains with high "raindrop impact," runoff and flash flooding, all leading to increased erosion (Figure 3). In addition, a drought has intermittently affected the region for approximately the last ten to fifteen years (CORDECO, 1990).

Deforestation of the xerophytic forest cover is occurring within the study area through overgrazing and also by the actions of the inhabitants themselves who rely upon wood as their sole source of fuel, mainly for cooking or in making chicha. (Chicha is a weakly fermented corn beer that is drunk in large quantities during local celebrations.) All wood for domestic use is collected within the valleys and environs mostly from the Chacatea

(Dodonea viscosa) shrub as most of the large trees have already been cut or are in use for grain storage purposes or as shade trees around the homes. Actual forest degradation is difficult to quantify in such an arid area where tree cover was sparse to begin with but estimates run as high as 75 percent forest cover loss (Antezana, 1997). In addition, an average of 7.6 kilograms of wood per day are consumed by each family (Antezana, 1995). Some limited reforestation efforts have been undertaken within the study area, mostly in the form of citrus and peach tree plantings where the area can be fenced off from goats and irrigation is available. Eucalyptus and pine have also been planted with limited success.

Livestock practices within the study area are one of the main factors that contribute to desertification. However, livestock for the local people, represent not only food (meat, milk and cheese) but a source of income as well. Nearly every family owns at least some livestock. A 1991 survey established that within the study area the average family owned 6 cows, 10 sheep, 10 goats, 7 chickens, a pig and a horse (ASAR, 1991). If a farmer lacked adequate farmland for crop production, livestock could always be kept, especially goats, on the more marginal land. Livestock ownership, in addition to carrying a measure of social prestige is a survival strategy for the farmers, a means of providing food or income during times of need. For this reason livestock numbers still remain relatively high within the study area as a higher value, both social and economic, is placed on the quantity of livestock (sheep, goats, cattle etc.) and not the quality of an individual animal (Painter, 1988). The concept of having fewer but well fed animals was not understood.

The farmer knew that he could always add another animal to this herd and allow it to graze on the more marginal lands which had been set aside as common grazing areas.

Actual grazing practices were well established within the study area. In general, within the higher altitude pastures and more hilly parts of the study area, herds of goats and sheep were allowed to graze freely, while on slightly lower, flatter areas cattle and a lesser number of donkeys and horses were allowed to graze (see photo 4). Large numbers of goats and sheep could be seen herded by small children who, along with dogs, herded them in a daily ritual from corral to mountain top to watering hole and then back to the corral for the evening. In some places well-worn paths could be seen as a result of this daily practice. This daily migration has had a negative impact on the vegetation and soil of the study area, especially in the steeper, upper valley areas where groundcover was sparse to begin with. Indeed, livestock pressure has exceeded the carrying capacity in many parts of the study area, bringing along with it deforestation, severe gully erosion, increased stream scouring and sedimentation and a loss of valuable topsoil (Ehrlich, 1988). Evidence of overgrazing could be seen in virtually every area that was not fenced. The farmers, realizing the potential destructiveness of livestock, took great care in guarding what valuable crops they had through fencing. Goats, with their very broad dietary predisposition are of particular concern in preventing the regeneration of natural vegetation (Gow, 1988). They can easily browse in thorny woodland, will eat seeds, young seedlings, bark off of trees and even the roots of trees once they have been dug up. Sheep, a closely related species, are nearly equal in their dietary preferences but not quite as destructive as they will only eat down to the root of a plant and not the actual root.

Desertification within this region has been compounded not only by the torrential rainfall pattern but also by drought. Estimates of the exact year when the current drought started and how long it has been affecting the region vary, but analysis of the average yearly rainfall for approximately the last fifty years points to certain trends in yearly precipitation (Figure 4). The average yearly rainfall for the region is 450 mm; however, the fourteen-year period from 1976 to 1989 was marked by some of the wettest and driest years on record, varying from 730 to 255 mm (CORDECO, 1990). This up and down trend in yearly precipitation continued throughout this time period with great yearly variation occurring during the early to mid 1980s and then a marked decrease in average yearly precipitation, less than 300 mm, occurring in the late 1980s and continuing into the early 1990s. More recently, the region suffered seriously from the affects of El Nino in 1998 with less than 300 mm recorded rainfall, but in 1999 much of this same region has been subjected to flooding problems as a result of too much rainfall. The climate of this region may indeed be changing; however, short-term weather patterns are not always indicative of climate change and should be viewed with caution, as only detailed analysis of the long-term weather record can be utilized to support climate change theories.

The soil, although relatively fertile in the valleys, is highly susceptible to the impact of the torrential rainfall pattern and erosion is common, as exhibited by the many ravines formed along some of the steep slopes (see photo 5). Hillside crop fields commonly show moderate to severe erosion, even gullies (McDowell, 1991). There also exist some highly eroded barren areas completely devoid of vegetation that no doubt have been worsened by the extensive numbers of unsupervised herds of sheep and goats. An estimated 75 percent of the land under cultivation within this sub region of the country exhibits problems either with slope, rockiness, erosion and/or bad drainage; while within the actual study area over 60 percent of the soils have moderate to severe erosion (CORDECO, 1980). Farming takes place on land that is too marginal for cultivation, even with irrigation. Landslides are common in some places as a result of the sparse vegetation, shallow soils and the torrential rainfall pattern.

The key conservation problems (soil, water and crops) identified within the project area include: a lack of adequate fertilizer for good crop yields, low soil moisture, inadequate infiltration of rainwater into the soil and excessive loss of soil nutrients through soil erosion by rainfall impact / rainwater runoff (McDowell, 1989). Many of the farmers recognize at least some of these problems especially as they relate to long-term declines of soil fertility and crop yields. Some conventional conservation practices are followed in the study area, including crop rotations, contour plowing, contour ditches and strip cropping. However, these activities are often counteracted by practices such as the poor alignment or lack of contour furrows, lack of adequate soil protection for fallow or low crop density planted fields, inadequate fallow times and crop rotations and no controls to prevent excessive in-field rainwater runoff (McDowell, 1989). In addition, herbicides and pesticides are sometimes applied in an irrational manner, the science and use of these chemicals being rather new to the farmers. While some measures for watershed management have been implemented in the valleys by various agricultural extension agencies, these measures, although somewhat successful, are not keeping pace with the current land practices and the process of desertification continues.

On sun-dried, clay-rich surfaces, such as in the study area, runoff may begin as soon as a thin surface layer is wetted by capillary absorption (Bloom, 1978). Soil erosion (by water) first starts as a result of raindrop impact in combination with sheet flow, which is water flowing in sheets that has not yet become channelized. "The velocity and mass of sheet flow might not be sufficient to erode and transport soil particles were it not for the violent impact of raindrops and the tendency of sheet flow to develop 'surges' as it forms and breaks minor dams of vegetation and soil (Bloom, 1978)." In addition, a critical length of overland flow is required before sheet flow achieves enough velocity to begin erosion (Horton, 1945). In densely vegetated watersheds with little or no slope, sheet flow can occur for hundreds of meters before becoming channelized into rills. Within the study area this distance has been observed to be quite short, often 10's of feet, as groundcover tends to be sparse, and the soils highly erodable. As rill erosion increases, gullies are soon formed, which in essence only differ from rills by their size and permanence (Bloom, 1978).

This is the established process of soil erosion by water that occurs in the study area, but it is compounded by a torrential rainfall-high raindrop impact pattern. McDowell (1993) states that "It is the intensity of the rain not the quantity of runoff that is the most important factor in determining the quantity of erosion within the zone," (see Table 1) and that actual ground cover plays a greater role in preventing erosion than does runoff. This aspect is illustrated in a summary of research findings which analyzed ground cover conditions, runoff and soil erosion rates on a small 50 meter squared parcel just outside the town of Aiquile for the total rainfall of a five month period, (Table 2 - Garcia, 1992).

As illustrated, soil erosion rates on bare or fallow soil are the highest while erosion rates occurring on natural groundcover are at least 17 times lower. These findings illustrate the relative little importance of runoff in a specific area as compared to the groundcover and subsequent soil erosion. Also, it should be noted that similar results were obtained regardless of slope. These findings further illustrate the importance that crops such as beans, with their relatively dense ground cover, have in controlling erosion. Yearly soil erosion estimates for different ground covers / land-use within the region are summarized in Table 3.

The traditional crops of corn, potatoes, wheat and peanuts are the main crops grown during the rainy season along with onions, tomatoes and garlic at various other times of the year with irrigation. Beginning in the early 1990s some xerophytic crops such as certain types of beans were introduced to the study area by USAID as well as some other crops. Common crop rotations include corn or wheat to potatoes or peanuts, to onions, and onions to potatoes or tomatoes to onions to corn. Good access to major agricultural markets is somewhat limited due to travel time and transportation costs to major urban centers such as Cochabamba and Sucre (Antezana, 1997). Some limited irrigation does exist in the valleys, irrigating less than 20% the arable land, which utilizes water from the major rivers of the region and to a lesser extent, groundwater (CORDEP, 1989). USAID funded a project in one sector of the study area which, through the construction of a filtration gallery, tapped into the shallow unconfined groundwater beneath one of the intermittent streams and channeled the water into an existing irrigation system (Hanrahan, 1992). Shallow wells have also been dug, all within the floodplains of intermittent streams and a number of springs have been capped. These water sources generally yield limited supplies, and pumps as well as gasoline must be purchased. No major water impoundments exist within the sub region or study area. The actual land to be irrigated receives either full or supplemental irrigation, depending upon the time of year. With irrigation, crops may be produced up to three times a year and on average nine different crops grown (Hanrahan, 1992). An estimated 7000 additional hectares in the valleys have potential for irrigation (PDAR, 1990).

Table 1.
Rainfall intensity, runoff and soil loss for a similar climatic zone in Chinchina, Columbia.

Total Rainfall (mm)	Intensity (mm) Five-minute interval	Runoff (mm)	Erosion (tons/ha)
20.6	7.9	6.8	7.35
21.4	5.0	11.1	1.74
18.0	4.5	7.8	1.06
21.8	2.2	4.5	0.47
20.0	1.9	0.8	0.12
22.0	1.0	unknown	0.06

Source : Suares de Castro, 1982

Table 2.
Runoff and erosion under different cover conditions during a five-month period for a small watershed outside the town of Aiquile, Cochabamba, total rainfall equals 265 mm.

Field Condition, Or Crop Grown	Percentage of Maximum Cover	Erosion (tons/ha)	Runoff (mm)
Fallow, Bare Soil	20 %	15.8	75
Wheat	18 %	13.9	72
Linseed	20 %	13.9	78
Green Beans	34 %	11.3	71
Dry Beans	46 %	10.2	71
Native Vegetation	55 %	0.9	15

Source : Garcia, 1993

Table 3.
Yearly soil erosion estimates for land-use within the High Valley Region of Cochabamba, Bolivia.

General Land-Use Category	Erosion (tons/ha/year)
Cultivated	25 tons/ha/year *
Degraded	40 tons/ha/year
Native Shrubland	2 tons/ha/year
Native Woodland	1 tons/ha/year
Fallow, Bare Soil	16 tons/ha/year

* average for all crops

Source : PDAR, 1990

Seasonal Migration

Due to the lack of water in general but specifically during the dry season, and poverty compounded by desertification and drought, there is much seasonal migration that takes place in this region, at least 50 percent of the farmers leave at this time to look for work elsewhere. This is not a new occurrence, seasonal migration of peasant farmers from the high valley region of Cochabamba to other parts of the country is a long established tradition. During the nineteenth century the ancestors of these people were the primary source of labor for the mines in Potosi. At this time the patrons would "lease these people out" to the mine owners, often during the dry season, when farming activities were at a minimum. With the agrarian reform of 1952 many of these now liberated subsistence level peasant farmers found themselves in need of money in order to pay for a variety of household and farming costs which had previously been provided by their patrons (Kay, 1981). With little income generating activities available to them during the dry season these people were forced to look for work, often as wage laborers, outside of their geographic region.

This trend in seasonal migration continues today but has been exacerbated by farm size fragmentation, low agricultural production, unpredictable rainfall and a deteriorating natural resource base, further forcing migration on the farmers (Painter, 1987). Most farmers view migration as a necessity, but with the ultimate goal being to obtain the necessary capital so that sufficient investments can be made in their own properties, such as irrigation development, thus avoiding future migrations (Blanes, 1983). The farmers are thus forced with trying to balance the requirements of agricultural production against the need to earn income elsewhere. In areas where this seasonal migration trend is well established, large numbers of people tend to leave their farms immediately after the harvest, often neglecting the necessary maintenance of their fields and other tasks needed at this time, thus further deteriorating the natural resource base of their lands (Collins, 1987).

Common migratory destinations include the cities of Cochabamba and Santa Cruz where labor is needed in the construction industry and the agricultural regions of Santa Cruz for the sugar cane and cotton harvests. Other destinations include migration to regions outside the country such as Argentina, Chile and Brazil to work in agriculture, or as laborers in major urban centers. Current migration trends include those just mentioned as well as work as seasonal or long-term farm laborers in Australia and Israel. An estimated 100,000 Bolivian citizens live and work within the Washington, D.C. area, of which at least 80 percent are in the country illegally (Los Tiempos, 1999).

As of the early 1990s, at least 55 percent of the male farmers of the high valley region, exact numbers being hard to quantify, were involved in the cocaine production process in the humid, tropical mountainous region of the Chapare on a seasonal basis (USAID, 1992). This work often involved the actual "stomping of the leaves" of the coca plant (Erythroxylum coca) that were mixed with various chemicals such as kerosene until a paste was formed that was then further processed. Many of the high valley farmers viewed the employment opportunities of this region as a mixed blessing as it was located closer to their homes with relatively good pay, but at the same time they risked arrest, physical abuse, imprisonment, disease and sometimes death (Painter, 1987). By 1998 migration to the Chapare coca-producing region, where this illicit process took place had virtually stopped thanks mainly to anti-drug efforts by the Bolivian government along with the help of the USDEA and infrastructure expenditures by USAID (Los Tiempos, 1998). It was due in part to this yearly migration to the Chapare that development efforts were also concentrated in the high valley region, the source of many of the seasonal laborers. The goal was to keep the farmers from migrating by improving the economic conditions where they lived. At least some of these efforts appear to have worked as in 1999 Bolivia was "recertified" by the US government as more coca was decommissioned than the set goal. Large increases in financial assistance have been proposed for the upcoming fiscal year.

Conservation Program

Against this backdrop of coca cultivation, seasonal migration, insufficient family incomes and low agricultural production / resource base deterioration, USAID reprogrammed the Chapare Regional Development Project (CRDP) in the late 1980s. The revised project focused not only on coca eradication and the promotion of alternative crops in the Chapare but also redirected funds through the High Valleys Subcomponent of the project to address the problems of underdevelopment in the high valley region which included the province of the study area, Campero. This province was identified as one of the subregions with the highest rates of poverty and migration to the Chapare, as well as one geographically isolated from the departmental capital and its services. It was therefore included in the regional development plan created for the southern planning district of Cochabamba (Kent, 1987). The hierarchy and funding sources for the project / plan involved a number of governmental and non-governmental organizations and is summarized in Figure 5.

The goal of this revised project / plan was to place more emphasis on infrastructure development and outreach programs in soil and water conservation in the hope that they would positively influence agricultural production, rural employment, investment, income and general economic development within the region. General project areas included the development of groundwater and surface water resources for irrigation purposes, the implementation of soil and water conservation techniques and the promotion of new agricultural technologies such as improved seed, plows, agrochemicals and new crops (Hanrahan, 1992). More specifically, funding was provided for shallow and deep well development, various soil and water conservation techniques, land reclamation, in-field agronomic measures and river defense. For irrigation activities, funding focused on the actual development or improvement of existing sources through the construction of water- intake structures, the improving, lining and extension of irrigation canals, and the construction of farm ponds. The development of irrigation resources was deemed a necessity as it had been observed that there was little migration among farmers that irrigated (Dickinson, 1988). The ultimate success or failure of the project was evaluated in terms of its impact on migration to the Chapare (Gow, 1988).

Within the study area, the ultimate goal of the project was to develop and finance a Soil and Water Conservation Program which along with the promotion of new agricultural technologies could be implemented by governmental and non-governmental organizations working with the farmers (McDowell, 1989). Extensive practical training by USAID contractors was provided for Bolivian technicians, extensionists and farmers. Practices promoted a wide range of soil and water conservation technologies including, continuous and discontinuous bench terraces, in-field rock, earth or live barriers, infiltration ditches, improved contour plowing, a wide range of in-field agronomic measures, gully control structures and water harvesting practices such as farm ponds to capture rainwater runoff. The success of these various techniques was first demonstrated to the farmers through the use of "comparison plots" on small sections of their fields. Once the effectiveness of these various measures had been successfully demonstrated and the confidence of the farmers gained, these practices were fully implemented throughout the study area. Due to these efforts, yields in some parcels increased as much as 300 percent in the first year (Macias, 1998). It was within this context and under the circumstances just explained that the concept of "atajados" was first proposed as a part of the solution to a rather complex problem.

While the utilization of "atajados" within the high valley region and actual study zone of the author's project has many soil and water conservation benefits, "atajados" were actually designed more as a means "to increase agricultural production and expand the agricultural frontier through the management of water" (Macias, 1998). Hydrologic parameters such as rainfall were analyzed prior to excavating the first forty ponds in the province of Campero. The rainfall pattern in this region consists of spotty, high intensity rains with high raindrop impact and runoff, but that can vary greatly in quantity, intensity and duration. Sufficient water is lacking for agriculture and livestock needs for at least eight months out of the year. Macias, 1998, noted that in rainstorms of 10 mm or less, greater than 90 percent of the water enters and is stored in the soil, while in rainstorms of greater than 10 mm at least 80 percent is lost as runoff and never utilized for crop production. How could this lost water be taken advantage of? After discussion with a number of farmers it was further noted that the cultivation of crops took place on both the slopes above the valleys as well as in the more fertile valleys. However, crops grown on the slopes would always produce even during low rainfall years while valley crops would often die from drought. This observation was an impetus for the construction of a network of "atajados" that would capture the rainwater runoff from the up-slope, often more eroded areas and store it in farm ponds above the more fertile valley areas that could be irrigated by gravity flow. The consensus among the USAID contractors and Bolivian counterparts was that a network of small farm ponds in the area would not only have the advantage of increasing available water resources but also help in alleviating land use, farming marginal land, and soil erosion problems. By 1992 more than 500 "atajados" existed within the province of Campero and neighboring zones. Within the actual study area current numbers are difficult to estimate as at least four different projects have been implemented since the author's 1993 project which consisted of 25 ponds, approximately a quarter of the total at the time.

Figure 5 demonstrates the institutional hierarchy, acronyms and funding structure that were in place at the time of the author's project. In administrating and distributing funds, USAID relied upon the existing Bolivian governmental structure, channeling funds down to the level of the author's project. At the top of the hierarchy are the Ministries of

Agriculture and Sustainable Development (strictly administrative agencies) which receive their funding directly from the Bolivian Government but can also receive funds turned over to the Bolivian Government from US tax dollars generated from wheat sales, PL-480. The Vice Ministry of Alternative Development is next in line and, along with FONODAL, directly oversees the operation of PDAR which receives the majority of its funding (channeled through FONODAL) as well as operational support from USAID. The main program within PDAR is CORDEP. CORDEP has a number of components that include the USAID contractors of Development Alternatives Incorporated (DAI), the Bolivian agricultural research agency of (IBTA), the regional highway development program (SNC) and Planning Assistance, under which the NGOs (including INDRI) fall. Planning Assistance was the USAID component in charge of the financial management of the NGOs while DAI provided technical and operational support. The author's project was directly funded by two USAID Small Projects Assistance (SPA) grants made available to Peace Corps Volunteers.

Many of the NGOs in operation at the time of the author's project, while capable of capturing funds from a number of sources, were created for the sole purpose of capturing USAID funds. When USAID pulled out of the High Valley Region in the mid 1990s a number of these NGOs folded, although many still exist in name only. If these NGOs had incorporated some form of user's fees into their programs, they might still be functioning today (Seeley, 1998). The current trend in development within the region relies upon the allocation of funds from the limited National Budget of Bolivia, supplying funds in relation to the population size of a given municipality. The municipality is then responsible for infrastructure improvements including those in the rural areas. In theory, the NGOs can then "fill in the gaps" by obtaining funding from other sources for complementary or additional projects.

Figure 1

Political Map of Bolivia

Figure 2

Department of Cochabamba and Location of Study Area

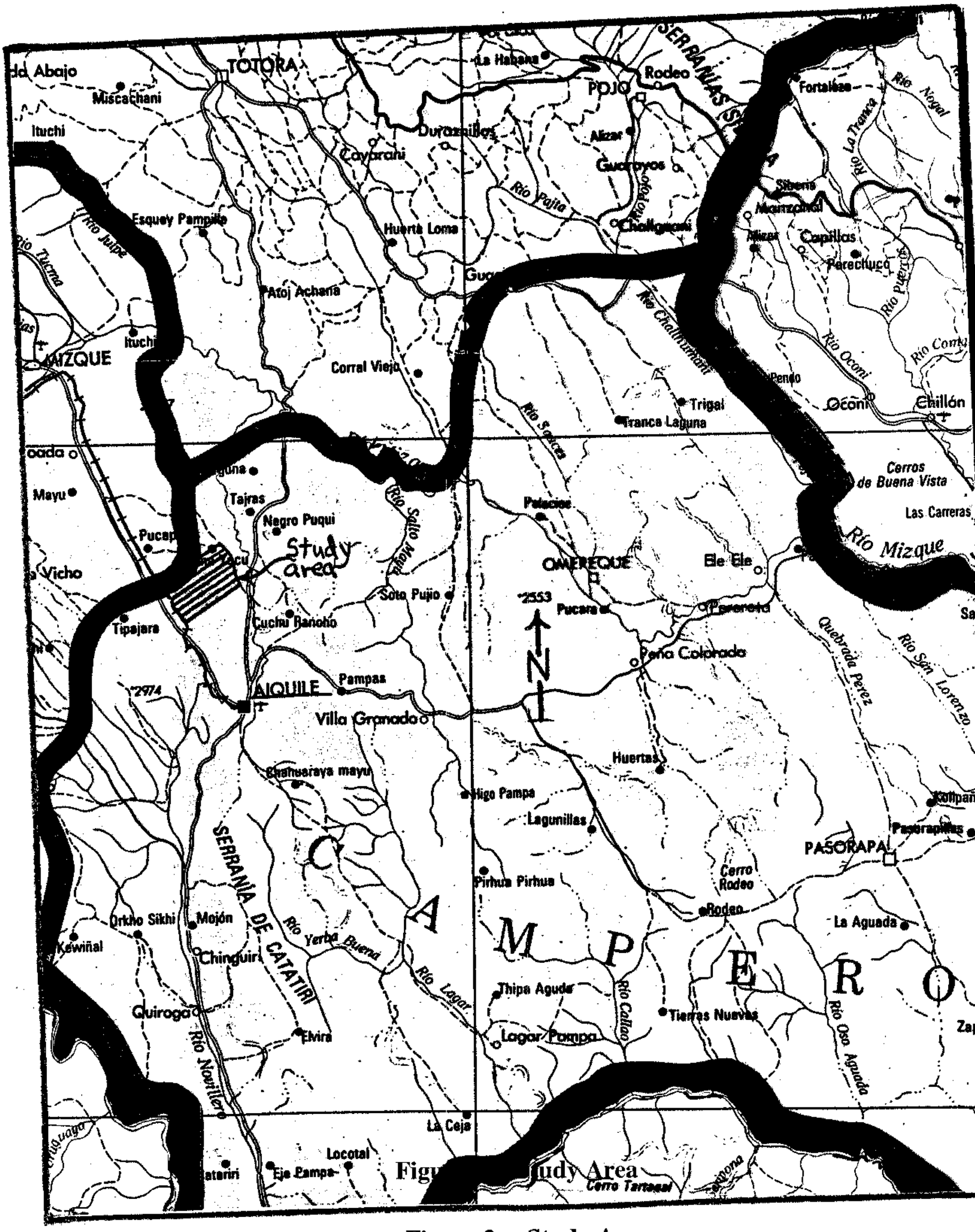
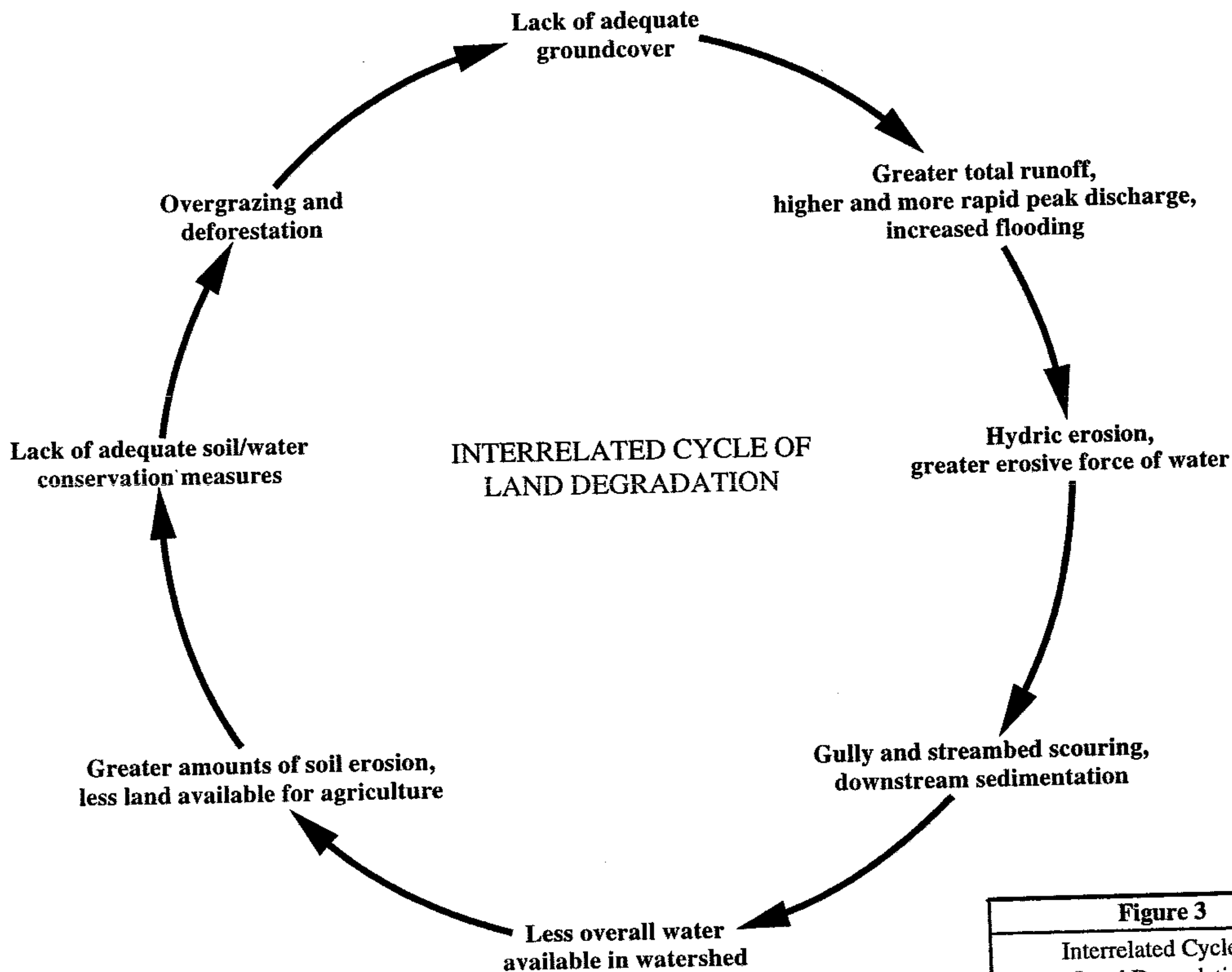


Figure 2a, Study Area



Modified from: Van Dixhoorn, 1996.

Figure 3

Interrelated Cycle of Land Degradation

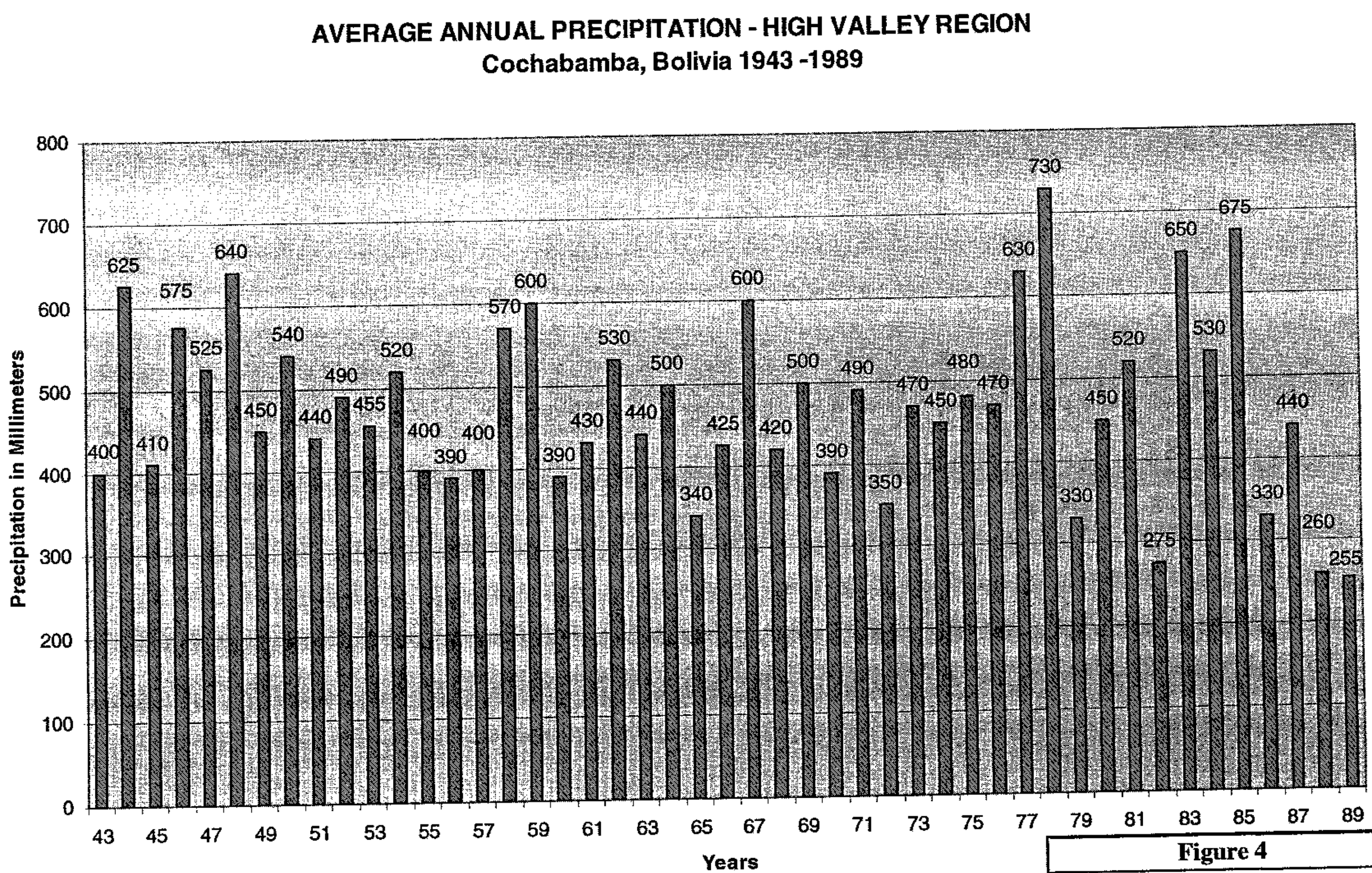


Figure 4

Average Annual Rainfall
Cochabamba, Bolivia

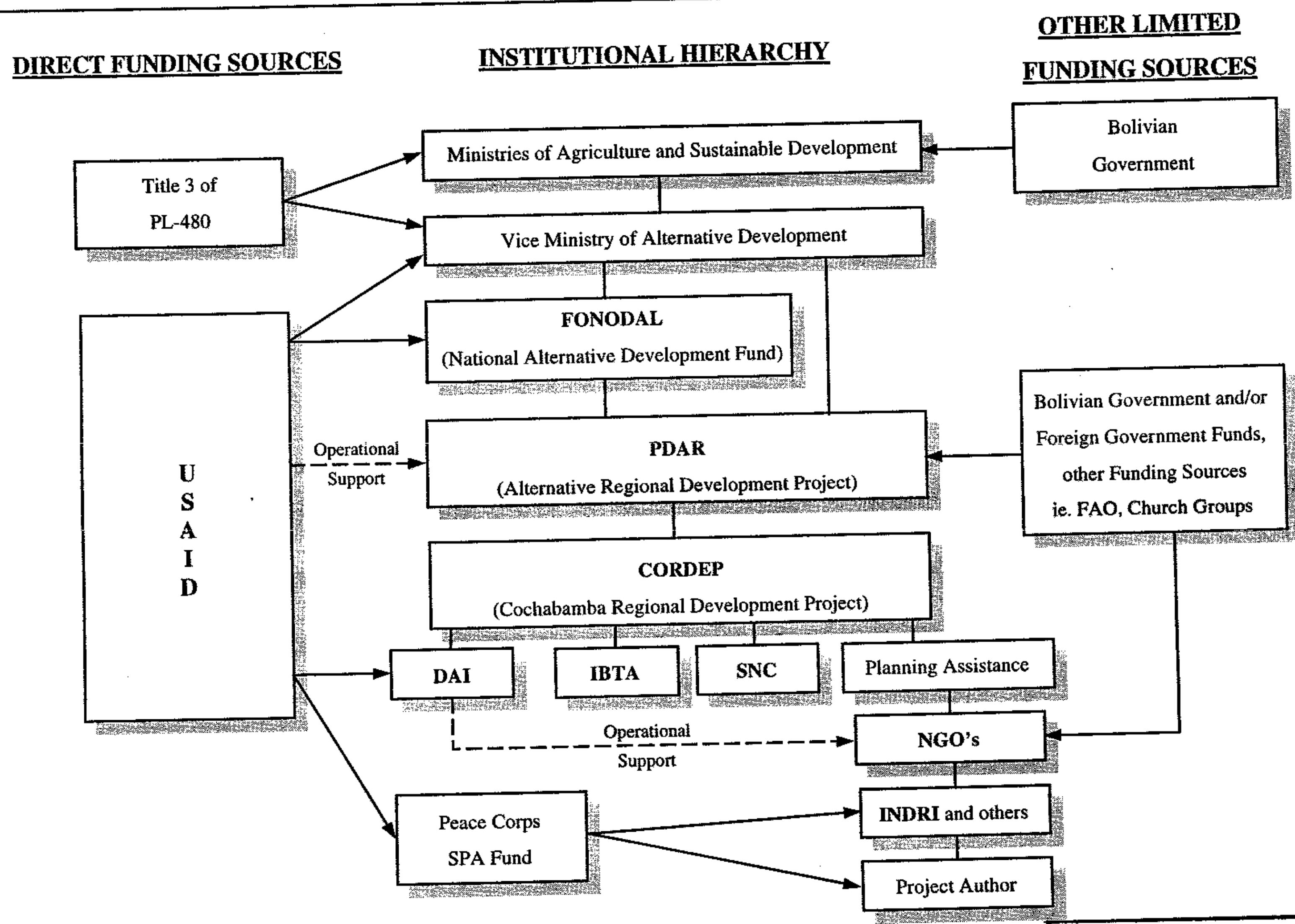


Figure 5
Institutional Hierarchy and Funding Sources

Photo 1. **Relatively Intact Xerophytic Forest Cover.**

Photo 2. **Entrance to Study Area.**

Photo 3. Typical Dwelling of Study Area.

Photo 4. Cows Grazing in Fallow Pasture of Study Area.

Photo 5. Hillside Erosion, With No Measures In Place to Control Further.

CHAPTER V

POND DESIGN, CONSTRUCTION, AND USE

The process of design, construction and actual use of each pond within the author's project followed the seven steps outlined below.

1) **Identify needs** – Find and contact the communities or groups with the greatest need or interest for irrigation and arrange for future meetings/discussions.
2) **Survey** – Identify the exact locations for the ponds, the drainage areas and the fields to be irrigated through discussions with both community leaders and agencies.
3) **Design** – Plan the entire project on paper, including all logistics as in who, what, where, when.
4) **Construction** – Before starting, have the contractor, community leaders, agency and any other parties involved sign a contract that details the construction schedule.
5) **Develop the catchment area** – This is an important aspect of the ponds that should be incorporated into the contract with the users, as it maximizes the runoff that can be harvested from the drainage area, prevents erosion and ensures the maximum long-term usefulness of the ponds.
6) **Use** – Identify the manner in which the water is to be used, how it will be transported to the fields, how often and for how long. Include plans for soil and water conservation.

7) **Maintenance** – A maintenance contract should also be included to ensure ponds are inspected on a regular basis. Pond siltation is a common problem.

Description of a Typical "Atajado"

The word "atajado" is Spanish from the verb atajar, which means to intercept, in this case water. It is a relatively small, excavated farm pond for rainwater harvesting in arid and semiarid regions that can be used for irrigation, watering livestock, aquaculture or a combination of these uses plus others. They also have soil and water conservation benefits if installed and maintained correctly. When constructing an "atajado," the goal is to create a mini drainage basin/canal system that drains and captures stormwater runoff (from sheet flow, rills and gullies) to a small catchment pond above the fields to be irrigated by gravity flow. "Atajados" have been found to be most useful in high semiarid mountainous regions where intermittent streams tend to flow violently and liberally but for only brief periods (Stern, 1989). Water, as in more humid regions, cannot be utilized from permanent sources such as springs or rivers, but can be intercepted from rainwater running off the surrounding mountains and "harvested" in the ponds. These ponds function like a source of extra water that complements or even replaces rainwater to grow crops when the need is the greatest, such as during the dry season. They provide relatively large quantities of water in relation to the given rainfall of these regions and their use is appropriate under conditions where a relatively small supplement to rainfall can make a dramatic improvement in crop production (McDowell, 1989).

A typical "atajado" rainwater catchment system consists of three parts (Figure 6).

These areas are: the drainage area to the "atajado," the "atajado" itself and the areas below it to be irrigated. For the efficient capture and use of rainwater runoff, each of these areas needs to be developed and maintained and their complementary structures constructed.

In the drainage area to the "atajado", canals ideally sloped at 0.5% channel runoff to the pond. Check dams of rock or other suitable material are placed at equal distances in the runoff swale areas to slow down the "time of concentration" of stormwater to the pond. Terraces can also be constructed for this purpose. The drainage area should also include a soil conservation and reforestation or revegetation plan.

USDA/NRCS construction guidelines include the following provisions. The "atajados" outer banks, sloped at 3:1, should be stabilized and protected by a grass cover or other suitable vegetative cover if possible. The recommended interior wall slope of a pond is 2:1. To minimize seepage all ponds should be constructed with a core trench and with well-compacted floors and walls. All plant material should be removed from any soil used to construct the pond and any topsoil should be removed to one side for use later. The crown (top surface) of the dam wall should be 0.5 to 1.0 meters in width. A cement channel, constructed in a way to serve as a silt trap, should be built at the pond's inflow to focus runoff and to prevent erosion and silting (see photo 6). A riprap spillway provides an outlet for excess water, designed according to the catchment area. Although not commonly used in Bolivia, a properly designed and maintained spillway ensures that stormwaters can pass through the dam rather than over it, thus preserving the integrity of the dam walls.

If an "atajado" is to be used as water storage for irrigation, a network of irrigation canals also needs to be built. It is important that technical advice be given to farmers on proper irrigation techniques so that water will be used effectively. Proper soil conservation and soil conditioning practices need to be implemented to ensure the long-term productivity of the land. Fencing ponds is also recommended in some cases to keep livestock from trampling the pond banks or even possibly drowning. Within the study area fencing was achieved through the use of native thorny vegetation, first cut with machete then arranged as fencing where needed. If the "atajado" is to be used for watering livestock, then a water trough should be incorporated into its design away from the pond banks. Additionally, routine maintenance is essential for the proper and continued use of a pond and this responsibility needs to be made clear to the project beneficiaries.

The actual excavation of the ponds in the author's project was achieved by bulldozer-tractor, with a scraper attachment (see photo 7). Although project funds could have been used to pay families to dig their own ponds, digging by hand would have taken weeks. Additionally, the money may have confused the farmers' motivations as paying them to dig ponds on their own land was seen by both the author and his HCA as a "handout." A 50/50 approach was used during the project involving groups of three to five families. Interested groups paid for half of the cost of the construction of the "atajado," thus either doubling the pond's volume, or increasing the number of ponds in the general area. Both the author and his HCA agreed that by taking this approach the project beneficiaries would exhibit greater interest and motivation in completing the necessary tasks to properly develop and maintain their ponds. Additionally, once a bulldozer, was nearby people were more likely to take advantage of its presence. Earth-moving equipment of this type was not common in the study area.

Pond Location

When well situated, "atajados" can check further erosion and gullying and be a prime asset to a farmer. However, when situated poorly and/or not maintained, they can actually increase soil erosion, quickly fill in, and cause local flooding by washing out (Figure 7). There are many factors involved in properly locating an "atajado." Putting the human factors aside (i.e. who owes whom money), these considerations include: soil type, topography, climate, location of fields to be irrigated, groundcover conditions, and the size of the drainage area to the pond. In Bolivia, as in many developing countries, engineering surveys, including soil borings, are usually performed only for large-scale projects, and not to locate small farm ponds. Therefore, when situating an "atajado," one must often rely entirely on field experience and familiarity with the area. If other well functioning excavated ponds already exist nearby, their locations, soil type and design can often be used as an example in helping to locate other potential pond sites (Ponds--Planning, 1982). Landowner input is essential, they spent their lives farming an area and know their land better than any "outsider" ever will.

Sites need to be chosen where large volume ponds can be made by moving a minimal amount of earth. It is also vital that they be deep enough to maintain water for irrigation until the following rainy season. Ideal "atajado" locations are in small, narrow valley-like areas which tend to widen out above, and catch all the runoff from their upper drainage areas. They should also always be placed in clay or clay-like soils, and on gentle slopes (5% slope maximum) just above the lands they will irrigate by gravity flow (Ponds-Planning, 1982). The low point of a natural depression in the lower reaches of a stretch of land, where past rainwater runoff is evident, usually makes a good location for an excavated pond. Ponds can also be constructed across the upper reaches of the heads of small, eroded gully areas in order to check further erosion, but should not be placed in the lower gully areas due to the possibility of increased silt loads. These areas have an advantage in that less tractor time is needed in construction. A series of ponds that follow the natural drainage pattern of an area, sized and situated to capture all rainwater runoff to one point, is ideal. In other words, in order to minimize evaporation losses, multiple systems of small catchments often yield greater amounts of water overall than one large catchment (Stern, 1988).

When selecting the drainage area (cuenca) of an "atajado," bare, hard rock is best as it will yield large quantities of runoff with little silt (Stern, 1988). If need be, an earth catchment area can be altered to increase runoff by compacting the soil, preferably clay, or even removing some of the vegetation. In some parts of the world where rainfall is extremely minimal, 100 to 200 mm annually, catchment areas have even been purposely paved over so as to catch all available runoff (Pacey-Cullis, 1986). With most drainage area modifications, thought must be given to the possibility of an increased silt load, which could shorten the life of the pond. In general, the longer the slope lengths and steeper the gradient, the greater the chance of erosion.

To avoid sheet and gully erosion in the drainage area, elements like infiltration, vegetation, existing surface water storage characteristics and slope need to be analyzed. The slope of the drainage area is especially important in that it affects both the quantity and quality of water coming into the pond. Within a rock catchment the slope can be quite steep as problems with erosion are minimal. However, within an earth catchment the slope should be steep, 10%, but not so steep that it causes erosion (Ponds-Planning, 1982). Regardless of the material of the catchment area, care needs to be taken to assure that the water will enter the pond in a non-erosive manner.

Alternative Water Sources

Besides rainwater runoff, there are other sources that have the potential to supply water to an "atajado." They can add to the water gathered in the drainage area, or even replace it as the principal water supply (Aquaculture Training Manual, 1990). Other water sources include : the presence of an already existing irrigation system which can help fill an "atajado," storing water for later use and possibly extending the irrigation network, surface water that can be diverted from perennial streams or intermittent streams during stormflow, and springs that can be tapped and channeled into a pond (Figure 8).

The digging of test holes is another method that can be utilized to estimate the depth at which water can be found. If groundwater is to be used as a source, the recommended minimum depth to the water table in semiarid regions should be at least six feet (NRCS). Within the study area this minimum depth could only have been satisfied in the flat topography of the floodplains of seasonally flowing streams. If surface water is to be diverted from a seasonally flowing stream, then measures must be taken to decrease its velocity, as streams in arid and semiarid regions tend to flow very rapidly during storms. If water will be drawn from a nearby existing irrigation system, it should be diverted at night, so that evaporation losses can be minimized.

Soils

In Bolivia, as in many developing countries, there are no soil survey guides, and soil borings and laboratory analyses are usually not done due to cost and lack of proper equipment. The general rule when constructing "atajados" is to avoid sandy, rocky and porous rock areas. Unless there is success experienced with ponds in the immediate vicinity, limestone areas should be avoided completely. Only heavy, well-compacted clay or silty clay soils should be used for pond sites. Sites that don't exhibit the right soil characteristics should be abandoned immediately even if excavation has already begun. It is better to lose the 20 minutes or so of the cost for tractor time than to excavate a large hole in the ground that will never hold water. A pond that leaks should not have been built in the first place, as it can create more soil erosion and potential flooding.

On site methods for determining the soil adequacy of pond sites include not only actual physical inspection but also percolation tests. These tests can be accomplished through the use of 2 sheet metal rings, one of 20 cm in diameter and the other of 50 cm, with the smaller ring placed inside the larger. The topsoil at the prospective site is first removed, the rings placed in the soil at about 5 cm depth and 10 liters or so of water are poured into them. Two rings are used to assure that the water entering the soil of the inside, smaller ring is not in contact with dry soil (see photo 8). If after an hour the water in the smaller ring shows no significant percolation downward, less than 2 cm/hour, the site is deemed adequate for pond construction (Antezana, 1996).

Although there do exist methods for sealing pond leaks such as clay blankets, chemical additives and waterproof linings, they're often too expensive for Bolivian farmers. One practical method used by the project beneficiaries, just after excavation, to compact the floor of a pond was to leave a limited number of sheep and goats corralled within the pond overnight. The season when construction is to take place is another factor to consider. If constructed at the beginning or just prior to the rainy season, the soil in the pond will tend to seal itself (McDowell, 1993).

A type of soil found throughout tropical and subtropical areas is one in which the upper layers drain well, but in which the deeper layers consist of dense, impermeable clay. Although this dense, hardpan-type soil is not ideal for agriculture, it is a good soil for the construction of "atajados." Ideal clay soils for the construction of ponds tend to be fine-textured and reddish-brown. Also some clay soils will often exhibit signs of previous saturation in the form of "soil mottling," spots on the soils created from oxidation. Loess or loess rich soils are often present in arid and semiarid regions and are also ideal for the construction of ponds because they tend to form a crust when exposed to water

Drainage Area Development

Bare hard rock is an ideal material for the drainage area of an "atajado," yielding the most water from a given drainage area. Bare rock will maintain the depth and capacity of a pond by keeping the inflow reasonably free of silt. If bare rock or an undisturbed natural groundcover is not available as a drainage area, then a soil conservation plan needs to be implemented along with the necessary complementary structures, especially where erosion-prone soils exist as they can dramatically shorten the life of a pond through sedimentation (NRCS, 1995). The plan, besides being for soil conservation, could also be thought of as a small-scale, site-by-site watershed management plan for each pond. Simple soil and moisture conservation practices such as berms, terraces, rock check dams and infiltration ditches could be utilized to control sheet flow in the drainage area, thus preventing the formation of rills and gullies. In addition, many of these practices could be integrated with one another and even combined with agronomic practices in the fields to be irrigated below. Gully control structures could also be implemented in appropriate places. Other measures that could be taken along with these soil conservation practices include a vegetation protection or revegetation plan and a fencing plan, to keep out sheep and goats. Live fencing, in the form of prickly pear cactus, has a number of advantages. Pastureland could also be improved in the catchment area through these efforts.

These measures would help to reduce the negative "raindrop impact" that the high intensity storms of the region have on the soil by helping to maintain the soil in place, encourage infiltration, decrease runoff, velocity and increase the time of concentration to the ponds. More water would be retained within the pond catchments, and ponds themselves, for a longer period of time and water during storm events would enter the ponds with less erosive velocity and turbidity, producing clearer, cleaner water for irrigation (Schueler, 1987). In addition, agronomic practices (mulching, contour plowing,) could be expanded upon and improved in the actual fields to be irrigated along with the cultivation of drought resistant crops such as certain varieties of beans that also help to increase nitrogen levels in the soil. Proper training in all these techniques would be essential to the success of watershed management efforts in the region and study area as tied to the use of "atajados."

The layout of the collector canals within a drainage area should be carefully planned before any changes are made to the area. The recommended maximum slope for them is one percent. Rock check dams are especially recommended in the swale areas as they will slow down the rush of water (time of concentration) to the "atajado" and thus decrease the erosive velocity of water flowing into it. Erosion protection, such as a cement silt trap, at the entrance of the pond is also part of drainage area development (Engineering Field Manual, 1991). Soil erosion and the subsequent siltation it causes is a major problem that affects all reservoir systems collecting water from natural catchment areas (Stern, 1988). As part of a routine maintenance schedule, the local removal of silt from within the pond inflow structures and from within the pond itself should be implemented during the dry season. This material can be either placed on the pond banks or in the fields, depending upon its organic content. Additionally, the condition of the catchment area can be checked at this time, as the berms, terraces and check dams need to be adequately maintained due to the potential of washout.

Pond Volume Estimation

The volume of a pond in a semiarid-to-arid region is especially important. If sized correctly, an "atajado" should be capable of maintaining some water for irrigation until the dry season is over, or at the very least be drying up as the rains of the following season are starting. When asked what size ponds they desired a common response from the project beneficiaries was that they wanted a pond that had water in it. Thus a "good pond" is one that has water in it when needed for whatever purpose. The key to sizing an "atajado" for irrigation is to make it large enough to ensure that a farmer will have enough water to mature his crop (Verweij, 1996). Many factors help to determine a pond's size. They include: the water requirements of the crops to be irrigated, the effectiveness of the irrigation method, expected rainfall, evapotranspiration, seepage and the many factors that affect runoff from any given drainage area. Larger ponds that have been sized for both normal and drier years can also be utilized for aquaculture and to water livestock. In arid and semiarid regions evaporation losses are high. Therefore the ratio of a pond's surface area to depth should be low, to avoid rapid evaporation by minimizing the exposed surface area. The recommended minimum depth for a pond in a semiarid climate is 3.5 meters. The size of the "atajados" in the study area averaged 1000 cubic meters, which was considered to be the ideal size for utilization by the farmers at the time. Construction by bulldozer was achieved by excavation of either a rectangular or circular, cone shaped form and the volume estimated with the formulas in Figure 9.

A crude method for determining the required storage capacity for any given pond is to calculate the volume of water that is needed in order to supply the needs for the mean maximum length of the dry season. The determined volume needed is the same as that required for storage. A more sophisticated approach is to use what is known as the graphical mass curve method to determine the storage required for a year-round water supply. By plotting the cumulative month-by-month yearly runoff for a given catchment area against time one can determine the most critical (driest period) in the data record and the storage demand for the year estimated (Figure 10). Average monthly rainfall data in millimeters is available in Table 5. The millimeter values are first converted into meters and then each multiplied by the determined drainage area (in square meters) and runoff coefficient, C value (see hydrology section and Table 4). These values are then added cumulatively, month-by-month for the entire year, and a graph of cumulative runoff versus month can be generated. A line is then drawn representing the steady consumption of water (cumulative water use) throughout the year. It is the area above this line, simply calculated by adding up the squares, that represents an estimate of the required storage capacity for the pond desired, in cubic meters. That value is then multiplied by 0.50 to offset for losses by evaporation and infiltration. This method is best utilized for estimation purposes only but has been used as an aid in pond design in the region and study area with good results. Actual runoff estimates can vary greatly due to cover conditions, drainage area and extent of development (canal collectors, check dams and other complementary structures). However, by using a graphical mass balance curve, an upper limit of the required storage for a pond can be determined (2000 and 4000 cubic meters in the case of Figure 10) and possible over design avoided.

Hydrologic Considerations

The "torrential" rainfall pattern of this region, as in similar climatic zones worldwide, produces storm intensities as high as 50 mm / hour. Within the actual zone of the study area an estimated 65 percent of the total rainfall occurs in storm events of 10 to 40 mm. However, it is estimated that as much as 40 percent of the total rainfall occurs as "short bursts" of 20 to 30 mm / hour (Pacey, 1986). In rainfall events of 10 mm / hour or greater the rainfall intensity is such that water does not get stored in the soil and at least 80 percent of the water is "lost" through runoff (Macias, 1998). Additionally, the rain that does fall is by no means uniform throughout the region or even within the study area, with some zones receiving heavy downpours and others little or no rain at all. Also, due to high evaporation a maximum of only 20 percent of the annual runoff is estimated to reach an ephemeral stream (Stern, 1989). Stream flow is intermittent in all but the region's largest rivers but with brief, often locally devastating, flash floods occurring during the rainy season.

In calculating rainwater runoff, the general rule is that 100 mm of rainfall on a smooth 100 square meter surface with 100 percent runoff produces 10,000 liters of water (Nissen, 1989). Of course 100 percent runoff could only be achieved under ideal circumstances and definitely not within the confines of a natural watershed. Many factors determine rainwater runoff quantities. Besides rainfall, evaporation and plant transpiration (evapotranspiration) the actual physical factors that directly affect water yields from a drainage area include: size, slope, soil porosity/permeability, cover conditions and surface water-storage/transport characteristics within the drainage area. The size of the drainage area above a pond is critical. In more humid regions with a regularly distributed rainfall, determining the ratio of catchment area to water yield is rather straight forward. If the drainage area developed to fill a pond is too small, the pond will often be dry. Conversely if the drainage area developed above a pond is too large, runoff from a heavy rain could easily destroy it (Ponds-Planning, 1982). However, in arid and semiarid regions within or close to the tropics, this rule does not often hold true. In fact, within these regions runoff from a small catchment can account for as much as half the yearly rainfall (Stern, 1979). Therefore, due to high evaporation, a multiple system of small catchments that captures water before it has a chance to evaporate and to a lesser degree infiltrate into the river bed often yields more water than one large catchment. However, while a small watershed may be a more efficient collector of rainfall, in regions where the rainfall is torrential yet very localized at the same time, a large catchment can sometimes produce runoff when a small catchment will not. In general, for arid and semiarid regions the ratio between the drainage area and the actual area to be irrigated can be as high as 50:1 as compared to 5:1 or lower in more humid regions (Pacey, 1986).

These many factors involving catchments as related to rainwater collection exhibit that the proper design of a well functioning catchment system is not something, like the flow of water through pipes that can be analyzed in a purely technical or engineering fashion. Within any given drainage area a slight change in any factor(s) will ultimately affect the runoff in ways that cannot be accounted for by conventional hydrologic formulas. The approach taken by most engineers is to “slightly over design” a pond, building in enough safety factors to assure proper functioning and then do regular maintenance. Each "atajado" is unique when compared to any other and although created with engineering factors in mind the design is as much "art" as it is science.

The problem of estimating runoff to any given pond is further complicated by the lack of good, or in some cases any, hydrologic data for the region and study area. While the collection of hydrologic and weather data, including stream gauging records and rainfall, is much more thorough near Cochabamba City, reliable information on a regional or local level is inadequate as what few weather stations there are lack a uniform distribution throughout the region (Brooks, 1993). Overall the number of stream gauging stations is also limited, only 25 or so in the whole department, and many of these are badly located and of limited use. In addition to this sparse coverage, the majority of the weather stations are placed within the valleys, making a thorough study of regional hydrology impossible as no correlation can be drawn between rainfall in the mountainous areas and runoff. Furthermore, stream flow data for the study area is non-existent, mainly because most streams in the region are intermittent. Good rainfall records do exist for the town of Aiquile, 10 to 20 kilometers from the pond sites, but due to the nature of the rainfall patterns, these records are of somewhat limited use for site-specific hydrology studies. In addition to the lack of stream flow records and accurate estimates of rainfall duration and intensity (as tied to time of concentration), no information exists concerning hydrologic soil groupings or accurate "Bolivian" runoff curve numbers. Until recently, about all that had been established within the region / study area was that a single rainfall event of at least 20 mm was capable of filling any given pond up to a volume of 3000 cubic meters (PDAR, 1998). Because of these limitations it is not surprising that problems often arise when attempting to utilize sophisticated computer models for hydrologic analyses developed in other countries. In one case, the 2, 10 and 100-year storm runoff was estimated in a small 10-kilometer square watershed outside the city of Cochabamba using the SCS TR-20 computer program. Upon analysis of the hydrographs it was noted that the times associated with the hydrograph peaks did not coincide with the time of concentration values utilized. It was hypothesized that this was in all likelihood due to the differences in watershed characteristics and rainfall patterns between the northern and southern hemisphere and that actual time of concentration values are less (quicker) for Bolivian, high valley region conditions (Villarroel, 1987).

Given these limitations for in-depth hydrologic analysis, what formulas or methods could be utilized to estimate quantities of rainwater runoff to the individual ponds? The answer is the Rational Method, adapted for use for the conditions of the study area. This method is an empirical solution to the problem in that it involves the use of data, tables and formulae to estimate the runoff of small watersheds and in this case supplants the need for more complex analysis. It has the advantage in that it can easily be utilized to give an estimate of the maximum runoff of a small watershed regardless of some missing information. Naturally, the greater the precision of the information inputted the more accurate the results. The general formula is as follows: **Q = CIA**, where in metric units,

Q is runoff, usually in cubic meters per second, and

C, dimensionless runoff coefficient (proportion of rain that becomes runoff).
I, rainfall intensity, in mm per hour (but converted to meters / hr. for use here).
A, area in hectares, up to 120 hectares for this formula (converted to square meters).

This formula has been modified somewhat for use within the study area and its use justified due to the limitations in obtaining more accurate hydrologic data. Its utilization here is based upon a 1992 study of a small watershed, located just outside of the town of Aiquile, in which the researcher wished to determine the effect of storm intensity and rainwater impact-runoff on the erosion of different ground covers (Garcia, 1992). As a part of the analysis it was determined that on average 14 percent of the annual rainfall of the watershed was transformed into runoff. This estimate was performed on a 93 hectare watershed in which approximately 20 percent of the land was under cultivation with no available irrigation while the remaining 80 percent was determined to be dry, degraded, native woodland (McDowell, 1991). It was also determined that on any given small (< 1 ha.) cultivated or bare parcel within the watershed that on average 30 percent of the annual rainfall would be transformed into runoff. The percentage of runoff was higher in this case since all of the native vegetation was removed and the overall area being drained was smaller, allowing for less evaporation and more runoff.

Since these runoff proportions (C values) could not be compared with any similar values for small watersheds in Bolivia, a comparison was made with available data for small watersheds (up to 200 hectares) for similar climatic zones in North America. As demonstrated in Table 4, a value of 14 percent of the total rainfall as runoff does fall within the range of values for small, temperate, semiarid watersheds similar to those of the study area. This value translates to 14 percent of 500 mm or, on average, 70 mm a year of the annual rainfall being converted to runoff within the study zone for small watersheds with similar land use (McDowell, 1991). It was these two C values, 14 %

(0.14) for the larger catchment areas and 30 % (0.30) for the smaller catchments, along with known drainage areas and annual precipitation that were utilized in estimating yearly runoff to the ponds by the Rational Method. Drainage areas, due to the lack of funds for expensive field surveys, were usually estimated by the "pace off method" and an area in square meters or hectares calculated. Examples are as follows:

1) Calculate the yearly runoff to a pond with a five hectare drainage area, a runoff coefficient of 0.14 and 500 mm of annual rainfall. From Q = CIA

   (0.14)(0.5 meters rainfall/year)(5 ha)(10000 meters squared/ha) = 3500 cubic meters

2) Calculate the yearly runoff to a pond with a one hectare drainage area, a runoff coefficient of 0.30 and 500 mm of annual rainfall. From Q = CIA

   (0.30)(0.5 meters rainfall/year)(1 ha)(10000 meters squared/ha) = 1500 cubic meters

Note: Actual volumes of water within the ponds would be less than the yearly runoff estimates as water is lost to evaporation and to a lesser extent infiltration. Estimates of water losses can vary greatly according to drainage area size, cover conditions and extent of complementary structures in place, but usually average around 50 percent.

In the absence of more detailed hydrologic studies the Rational Method is an acceptable alternative to determine runoff within small watersheds or for the design of small-scale soil and water conservation measures (McDowell 1991). It can also be utilized to estimate the minimum drainage area necessary to fill a pond for any given volume desired. As information about rainfall and runoff for a region or individual study area improves, the method can be "fine tuned," thus achieving greater accuracy in the estimation of C values, and therefore runoff, for any given land use and drainage area. Of course, the use of actual data, obtained through long-term study, would yield the most accurate results. However, as more information is gathered, such as accurate rainfall data for any given design storm, rainfall intensity as tied to a time of concentration value, hydrologic soils data and site-specific runoff curve numbers, the use of this method could be superseded by more in-depth hydrologic analyses.

Table 4.
Average Annual Runoff, small watersheds in arid to semiarid regions of North America.

Location	Years of Record	Land-use	Ave. Annual Precip. mm	Ave. Annual Runoff, mm	Runoff As Percent
Nebraska	16	Meadow	559	5	1 %
Arizona	14	75-85% bare	206	5	2 %
Arizona	15	80-90% bare	183	10	5 %
New Mexico	16	77% bare	200	10	5 %
Colorado	7	Cultivated	310	36	12 %
Texas	19	Cultivated	510	69	14 %
Nebraska	17	Mixed	550	76	14 %
Oklahoma	14	Cultivated	612	94	15 %

Source : Chow, 1964

Table 5.
Average monthly precipitation (mm), Aiquile-Cochabamba, Bolivia 1969 – 1989.

JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	Total
118.3	113.8	78.70	19.00	1.60	2.20	0.60	8.00	14.90	20.70	39.00	38.80	500.6

Source : CORDECO, 1989

Using Ponds For Irrigation

Irrigation is defined as the process which supplies water to cultivated plants to secure sufficient moisture during the entire cultivation process, in addition to rainfall (Breuer, 1980). This definition also applies to small-scale-irrigation but with the emphasis on an appropriate technology, corresponding to the abilities and needs of the users involved. In general, small-scale-irrigation schemes within developing countries should be designed with some very specific guidelines in mind. The irrigation technology should fit the cultural context of the users, be based at least in part on traditional systems, be useful and understandable, use local skills, labor and materials, and above all be affordable (Netzband, 1980). Once the system is in place and working and no internal conflicts exist between users, the dependence on outside help should be minimal. The performance of any irrigation system can be analyzed in terms of its technical (irrigation) efficiency of providing the correct amount of water to the root zones. Additionally, total agricultural production and project equity should be analyzed as well as water control, which refers to the ability of a system to distribute, apply and/or remove water at the right time, quantity and place. Many farmers simply irrigate their fields for as long as the water supply is available without thought to irrigation efficiency or water control (Sampath, 1986).

Prior to the design and utilization of any irrigation system, the farmer will first have to contemplate if irrigation is worthwhile (Breuer, 1980). Factors such as the climate, soil, topography and water availability need to be considered. In gently sloping areas, where the soils are fertile but there is little or no rainfall, the need for irrigation is obvious, granted that sufficient water is available from a dependable source. In other areas the choice to irrigate may not be as obvious due to any number or degree of the factors just mentioned. A comparison between the benefits of irrigation versus rain-fed farming should first be made. In short, the pluses of irrigation are that it can produce, on average, higher gross yields, allow continuous land use without fallow time, generate greater employment and a higher standard of living as well as increase the value of land that could not have otherwise been utilized. However, these advantages must be weighed against disadvantages such as relatively high start up costs, increased labor costs, the increased used of fertilizers and pesticides and the often slow process of acceptance and assimilation by the users. Furthermore, along with an increase in the agricultural scale, many socioeconomic changes occur which may or may not have been anticipated (Breuer, 1980). Upon analysis of the situation, the farmer may find that moisture conservation techniques are more suited to his or her particular needs. These include many aspects of runoff farming where runoff is not stored but directed to the fields in need or, stored in the actual soil itself through the use of furrows and terracing, or through other in-field soil and water conservation techniques.

At least five main methods of irrigation can be identified, with irrigation water being applied to the land by flooding, furrows, sprinkler, sub-irrigation, and by localized irrigation (Doneen, 1984). Irrigation by flooding, used to cultivate rice, is the most common method used worldwide and consists of the actual "wild flooding" of a section of land between built-up border ridges. It is a cheap and easy method to use that does not require much skill nor expertise; however, this method can greatly contribute to soil erosion problems and over irrigation if not properly managed. Furrow irrigation, the most common method used in Bolivia, is often used for crops such as potatoes, corn and onions. Water is applied to the furrows made between the crop rows which run directly down, or parallel to, the slope. The spacing of the furrows themselves is usually determined by the actual crop planted as well as the soil properties. Unnecessary water losses can occur with this method through deep percolation if the furrows are too long. Water should be applied so that it runs through the furrows rapidly yet not so fast that it causes erosion. Sprinkler irrigation, at least in Bolivia, is often used to water deep-rooted perennials, such as most fruit trees, although due to its gentle spray-like application this method is also ideal for seed germination. It has both advantages and disadvantages. It eliminates the need for ridges and furrows, can be utilized where surface irrigation due to steep topography is not feasible and is also useful where soil problems exist, such as high porosity and/or a high water table. Its disadvantages are its high initial and operating costs, difficulty of transport across large, often muddy fields, agricultural chemical wash off and evaporation losses, especially during windy days. Sub-irrigation involves manipulating the water table so that the plant root zone is continually supplied with water yet at the same time not over saturated. It is not a common method, unheard of in Bolivia, and is often only used on peat or muck soils. Localized irrigation refers to water that is applied directly to the root zone only. It is also known as trickle, drip or daily flow irrigation. Its main advantages are reduced labor costs and water control, while its disadvantages include high initial start up costs as well as a much more complicated delivery system and maintenance compared to simpler systems. It has been most successful where land slope and high water costs have justified its use. It is viewed by many as being too "high tech" for many developing countries.

Regardless of the irrigation method used, in most developing countries expensive water pumping or lifting devices are not employed and gravity flow, even with sprinkler irrigation, should be utilized in the delivery system. Although a common practice worldwide, the use of gravity flow systems are not without their problems which include excessive water losses, low crop yields, water delivery imbalances, water-logging and salinity (Nobe, 1986). The types of gravity flow systems vary from individually owned to community-managed to large-scale governmentally operated ones. Small scale individually owned and community-managed systems, as in the author's project, have an advantage over large-scale operations in that fewer conflicts arise between users.

Since the early 1980s, irrigation in Bolivia was considered to be very inefficient, with poor prospects for immediate improvement (Harvatin, 1980). Although the situation has noticeably improved since that time, a large majority of farmers, especially in the more remote rural areas, still use the primitive production methods of their ancestors. Irrigation and soil conservation along with the use of agrochemicals and fertilizers, although better known near major urban centers such as Cochabamba, are still poorly understood concepts in the countryside. Harvatin, 1980, states, "These poor production techniques, along with the marginal lands upon which they are applied, produce low yields and limited returns. The irrigation of crops on lands having severe capability limitations provide limited short-term benefits and often have disastrous long-term effects on crop yields and soil erosion. As long as marginal lands are being developed for irrigation, the problems of poor crop yields, low returns, soil erosion and poverty will continue." In spite of these problems, the agricultural frontier of the country continues to expand, especially in the more humid eastern region. In terms of current development and utilization of irrigation resources in Bolivia, it is the central high valley region that holds the most promise for future development. However, it is the lowland, more tropical region of Santa Cruz, with its abundant water resources that offers the greatest opportunities for long-term development.

The central high valley region is thought to offer good opportunities for irrigated agriculture since overall the valleys have an excellent climate, adequately fertile soil and the potential for surface and groundwater developments. With the exception of the possibility of slight frosts during the months of June and July, crops can be grown year round if an adequate supply of water is available. In fact, the dry season is viewed by some to be the ideal season for agricultural production due to its cloudless skies, absence of heavy down pours and decrease in pests and diseases (Plaut, 1988). However, past irrigation projects within this region have had varying degrees of success. Projects have been less than successful because of poor preparation, large project scale and inadequate labor, inaccurate measurements of water needs, lack of adequate infrastructure for efficient distribution, high water losses during transmission, insufficient training and farmer attitude toward new irrigation technology (Harvatin, 1980). Many of these large-scale projects took a regional approach to solving irrigation problems in the valleys totally ignoring the benefits of small-scale, site by site, appropriate technology, such as the author's project.

Irrigation from the ponds of the author's project was, and still is, achieved by gravity flow surface application, using furrow irrigation. This is the traditional method of irrigation throughout Bolivia and is adaptable to great variations in land slope and soil texture. Water is simply drained from the pond down-slope to the fields, and then directed accordingly through blocking and/or opening the furrows by moving the soil with a farm implement such as a hoe. To get the water from the ponds to the fields, large plastic hoses of 2-3 inches in diameter are placed inside the pond and then over its banks to siphon water from it. Another method is to install a PVC pipe with an on/off valve within the pond, under the pond bank at the base of the highest point. Both methods are used by the farmers of the study area, but unless livestock were to be watered from the base of the pond, the "hose method" was preferable as PVC pipes and valves can be expensive.

For many of the farmers in the study area, irrigation in this form or any other was new, and technical guidance was needed at least through the first season. One common problem the farmers had was understanding the relationship between available pond volume, particular crop needs and the size of the fields to be irrigated. What a farmer was able to irrigate with his pond depended mostly on the rainfall of that year and the given storage of the pond. Pond capacity must be adequate to meet crop requirements and to overcome unavoidable water losses (Ponds-Planning, 1982). For example, small ponds of 500 cubic meters or less were limited to animal needs or as "emergency use" to help save a crop during drought, supplementing rainfed only agriculture. The water in these ponds would usually be gone by the start of the dry season. With larger ponds of up to 1000 cubic meters, 1000 square meters could be irrigated intensely or up to 1 hectare through supplemental use. Even larger ponds, of up to 3000 cubic meters, could be utilized for the needs just mentioned as well as for agricultural production of traditional crops up to 3 or 4 hectares, and for xerophytic crops up to 6 hectares.

Water Laws Governing Pond Use

Unlike more developed countries, in Bolivia there are no laws that regulate the diversion, allocation and use of public waters (Harvatin, 1980). In theory, the use of water is governed by the Decree Water Law of 1879, but this law lost much of its influence with the Agrarian Reform of 1952. Subsequent legislation does not have general or regional applicability (Painter 1988). Since the 1970's a number of attempts have been made in order to create a workable water use law. At present, it is the de facto legal system of Bolivia which (at least in theory) ties water use rights together with land ownership, requiring that water flow quantities be subdivided accordingly along with any subdivision of the land.

Prior to 1952, the majority of land in the country was owned by a small percentage of wealthy, powerful families who controlled the water needs of their vast properties as they saw fit. The native people living on these lands were essentially "serfs" attached to it, and were allowed to cultivate small portions of the property for subsistence use. Many of these people, upon becoming landowners, had little if any experience with water management (or any other type of resource) outside the limited use of it on their small subsistence parcels. Today, the majority of on-farm water management is controlled by the farmers themselves with little or no government involvement. Disputes over water resources are common throughout Bolivia, with most problems involving water rights and right of way. Problems have arisen between farmers, rural and urban users and between municipal and industrial uses. Closer to urban areas, the use of irrigation water for vegetable production constitutes a significant threat for human consumption as it contains raw sewage (Harvatin, 1980). As the population continues to grow, along with the current demographic transition and population shift from rural to urban, the problems of water regulation will become more and more serious.

Actual on-farm irrigation in Bolivia, being controlled by the farmers, often takes the form of an unwritten contract between all parties involved. These "contracts" between users can often become quite complicated, especially if a large number of users (often families) are competing for a limited resource. Other factors complicating these verbal contracts are social issues, such as the origins of the people that live within the limits of a given irrigation system (Dickinson, 1988). Some families are descendants of the original landowners themselves (the "patron" families), others are the former land indentured servants or their descendants and still others are recent, sometimes unwelcome immigrants. Another factor of more recent interest is the input of deep-well water into an already existing irrigation system, further complicating these unwritten contracts. Groundwater development is often pushed as the sole solution to all irrigation problems, not only in Bolivia but in many developing countries, without adequate thought being given to its different cost structure when compared to surface waters (GOW, 1988). Still another factor involving actual on-farm irrigation is the use and significance of the term "mita." Mita is a pre-Columbian word for collective labor which the patron families adapted to their own use for forced labor on their lands and irrigation systems. The word also has another meaning which is equivalent to the right to water in proportion to the work by each landholding put into the maintenance of a common system (Painter, 1988). In addition, it has a third meaning of a form of water distribution, especially as it relates to available water for irrigation during times of water scarcity. The term and its meaning often play a significant role in the contracts involving water use rights and irrigation.

Within the author's project anywhere from three to eight families shared the water rights of the ponds, with an average of four families per pond. The families all entered into verbal water use and maintenance contracts for each pond and all aspects related to them (drainage area to pond, actual pond and fields below) which included the allocation of all duties and specified water use rights. If one of the users of the ponds was unable to fulfill his portion of the contract, his right to water access would be forfeited, or he would be fined, usually in the amount of the labor cost associated with the unfulfilled task. To date only minor problems have arisen involving water allocation; however, every farmer interviewed stated that the size of the ponds was the most significant problem as water was often lacking during critical periods and that four families per pond was perhaps to many users.

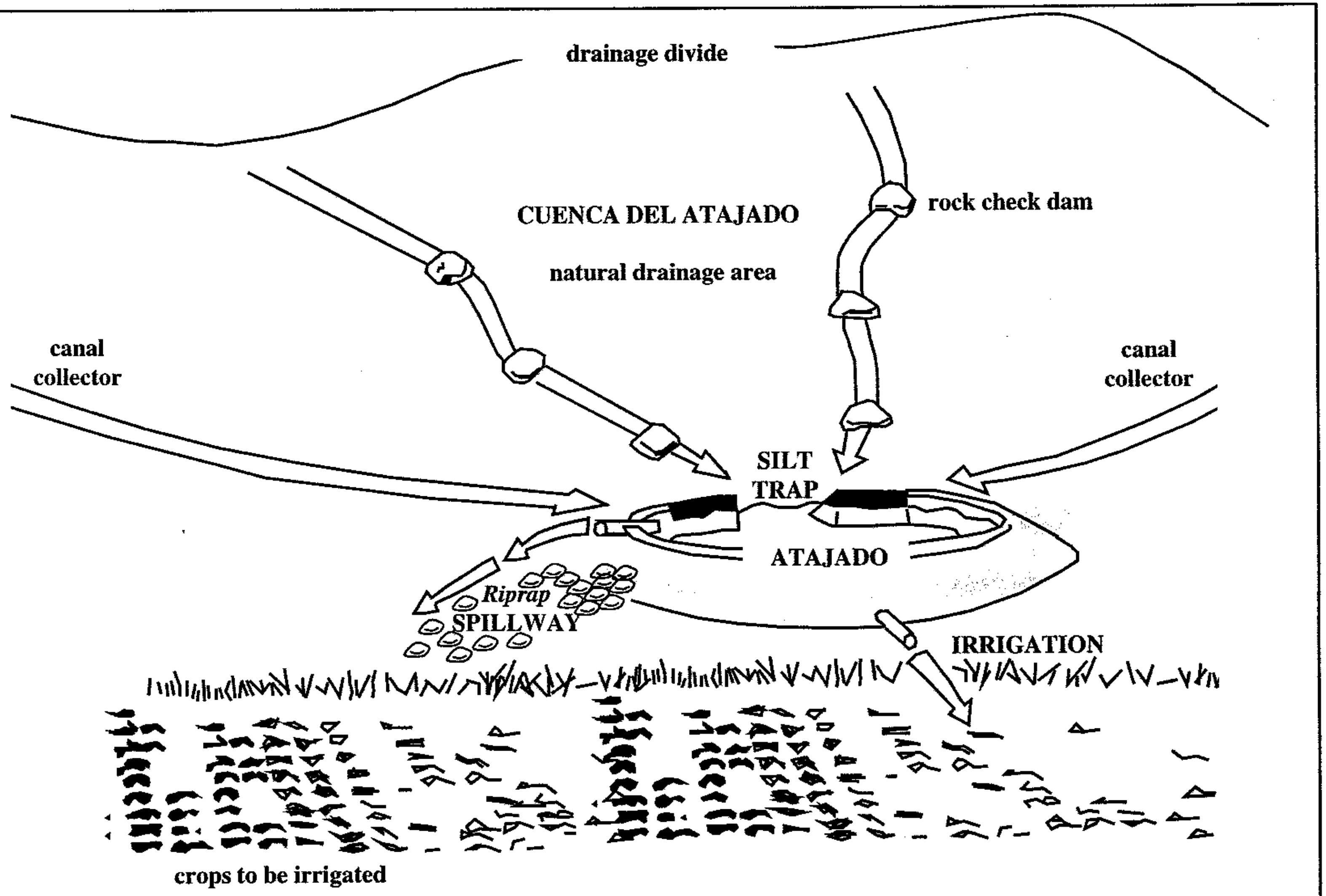


Figure 6

A Typical Atajado (small farm pond)

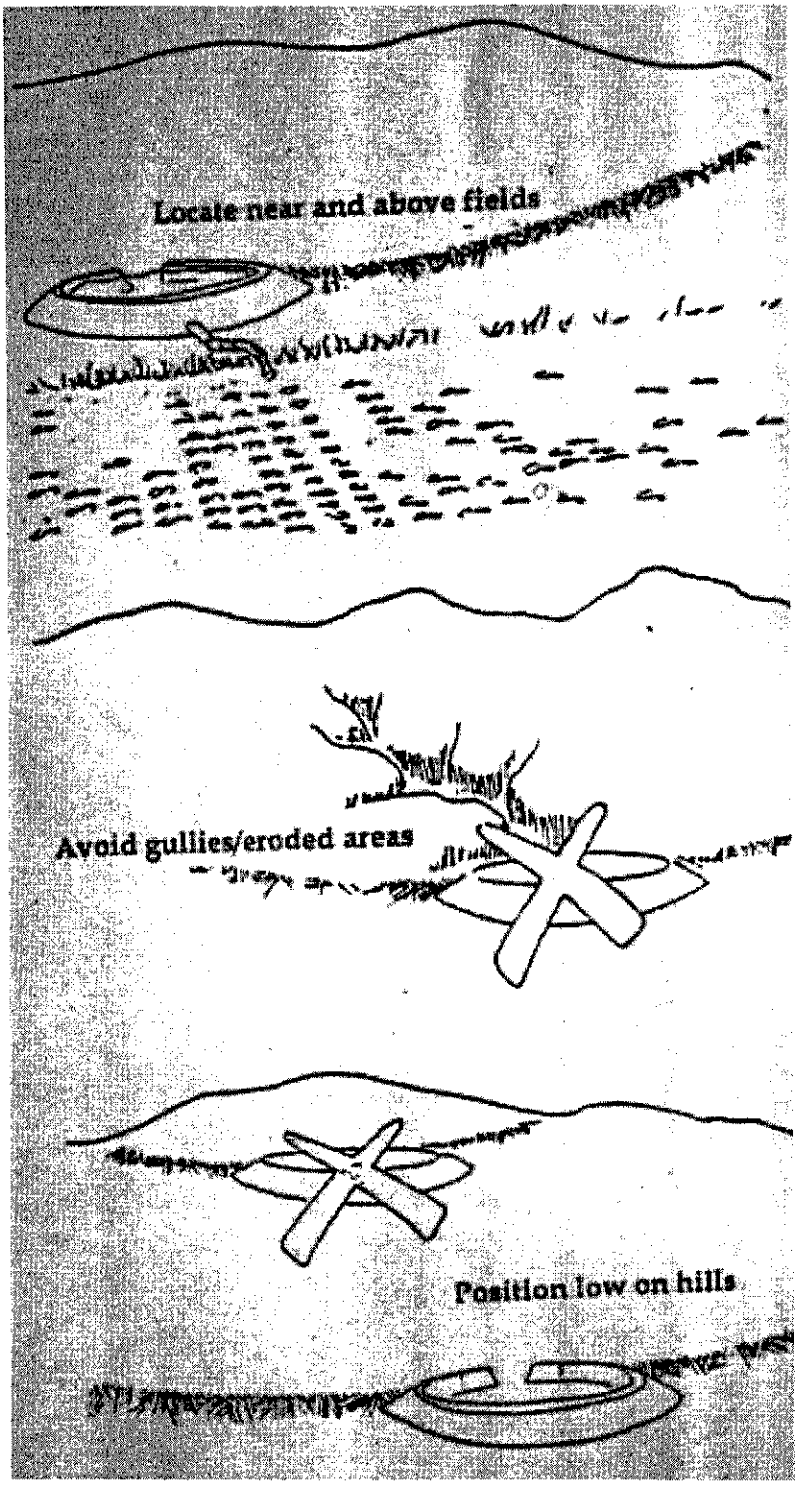


Figure 7

Proper Atajado Locations

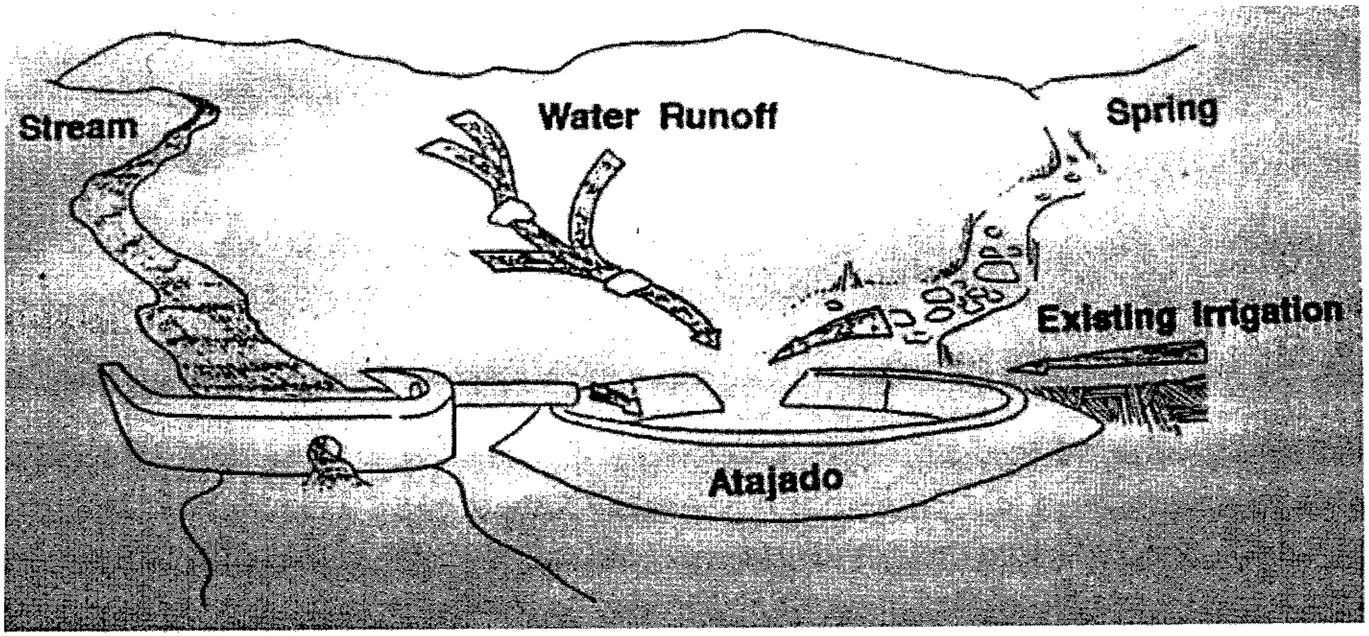


Figure 8

Atajado Water Sources

It is relatively simple to estimate the volume of an atajado, using three measurements and one of the following formulas. Always build ponds so that they can be expanded, if necessary.

For circular ponds, use:

$$V = \pi h / 3 (R^2 + r^2 + Rr)$$

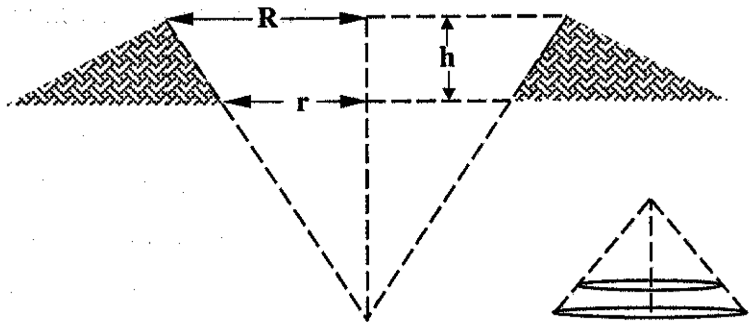
where: V = pond volume, in m^3

$\pi = 3.142857$

h = height (or depth) of pond, in meters

R = radius across the top of the pond, in meters

r = radius across the bottom of the pond, in meters



For rectangular ponds, which are often easier to excavate, use:

$$V = LWH$$

where: V = pond volume, in m^3

L = length of pond, in meters

W = height (or depth of pond, in meters)

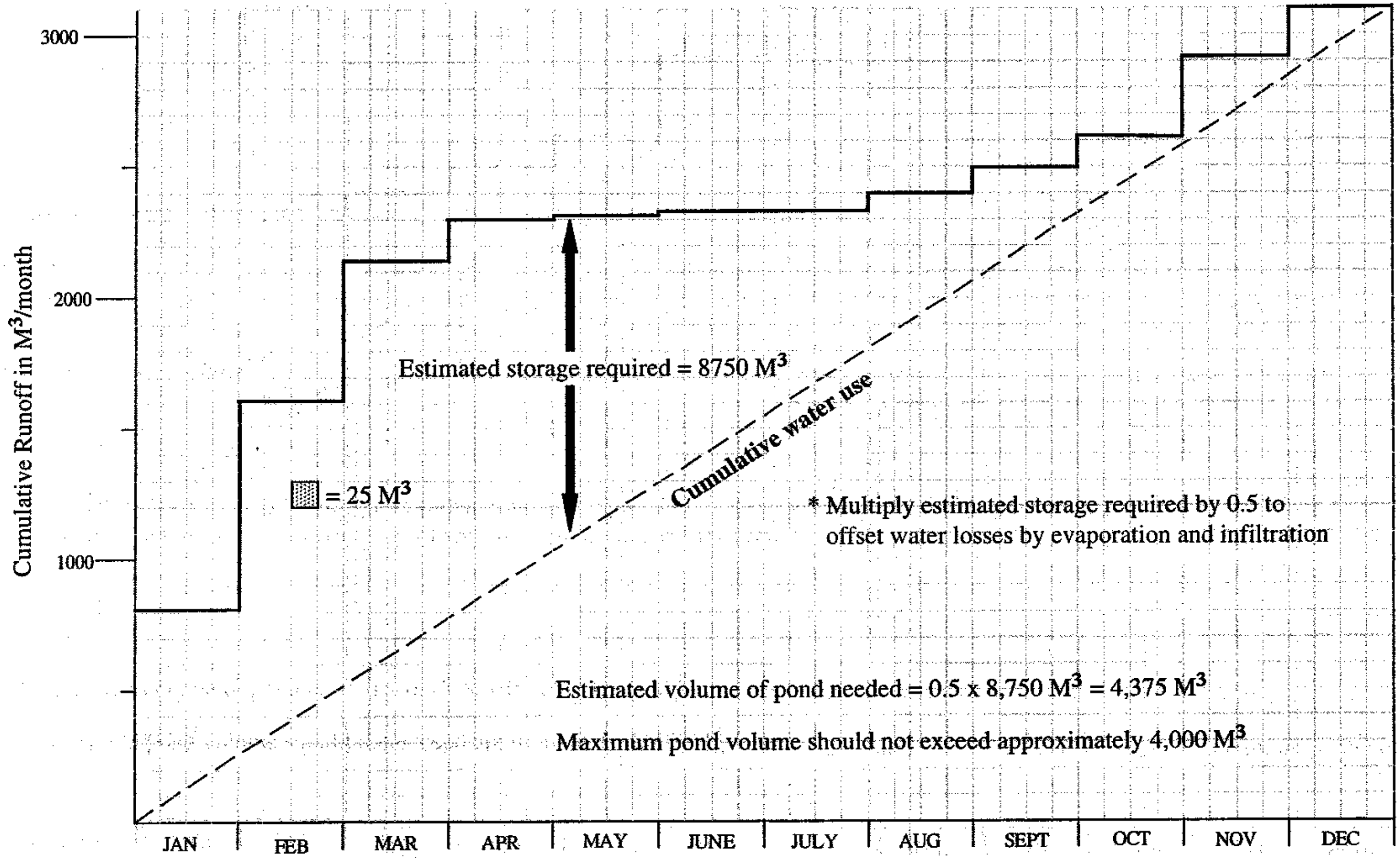
H = width of pond, in meters

Modified from: Antezana, 1995

Figure 9

Determining Pond Volume

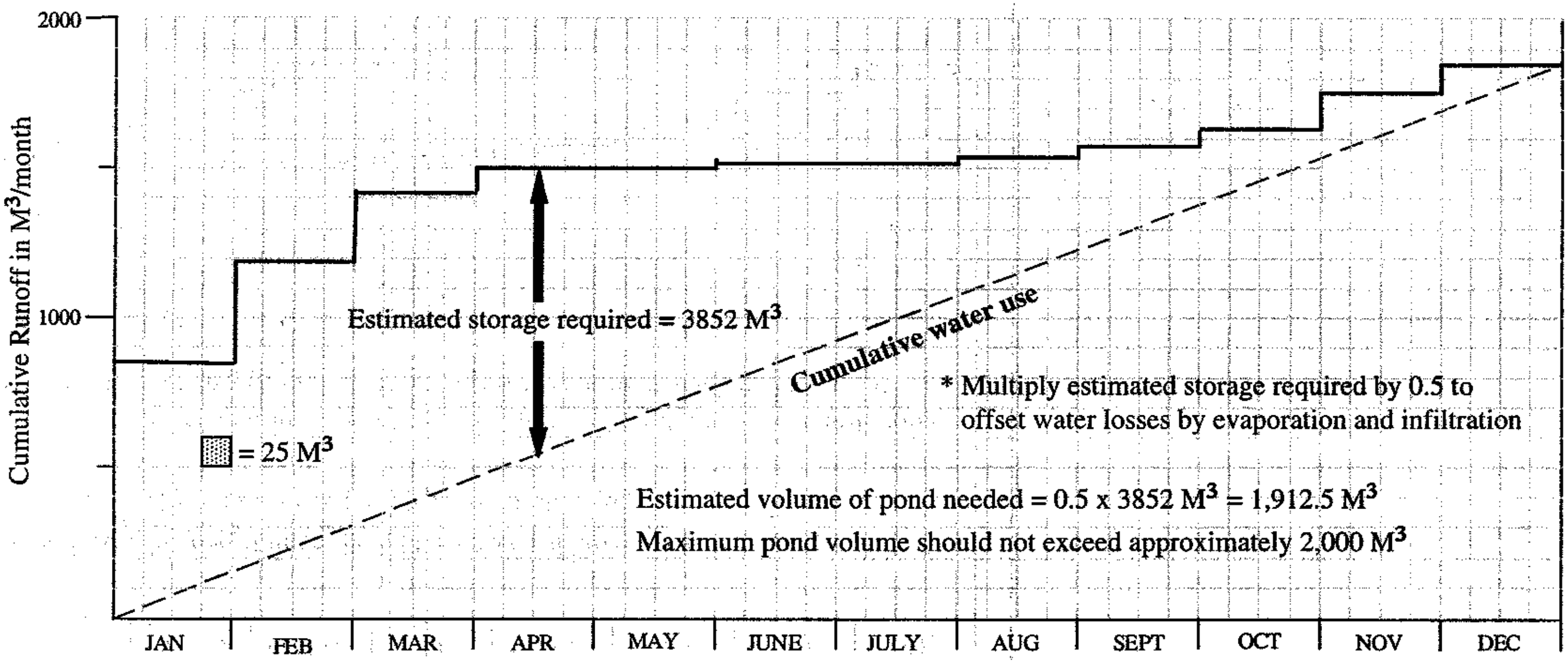
From formula: **Q = CIA** (M^3/month), **C** = 0.14, **I** = rainfall month-by-month (M/month), **A** = 5 hectares, 50,000 M^2



Modified from: McPherson, 1985

Figure 10-A
Estimation of Required Storage Capacity

From formula: **Q** = **CIA** (M^3/month), **C** = 0.30, **I** = rainfall month-by-month (M/month), **A** = 1 hectare, 10,000 M^2



Modified from: McPherson, 1985

Figure 10-B

Estimation of Required Storage Capacity

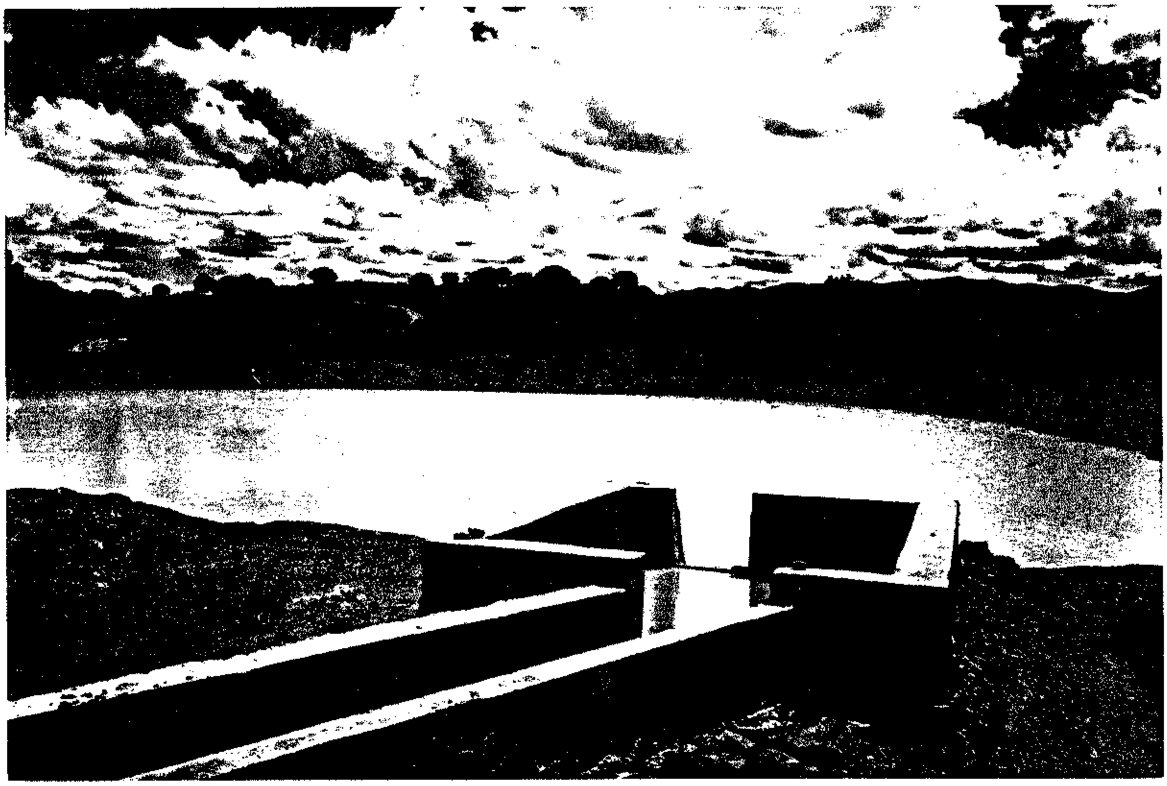


Photo 6. (Above) Ideal Silt Trap, Constructed as Part of Inflow Channel.
Photo 7. (Below) Actual Pond Excavation.

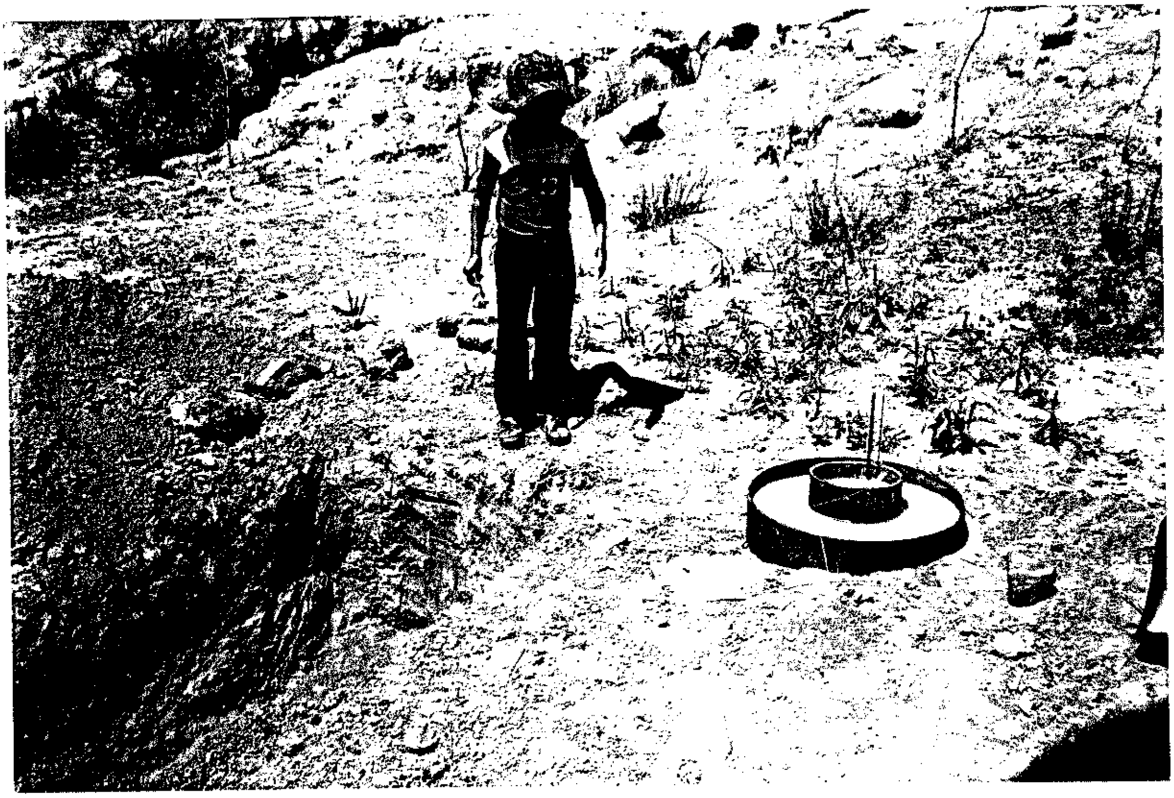


Photo 8. (Above) Determining the Adequacy of the Soil Using the "Ring Method."
Photo 9. (Below) Main street Aiquile, 2 Months After the Earthquake of 1998.

CHAPTER VI

POST-IMPOUNDMENT ANALYSIS

Was pond construction a viable solution to the problem or a short-term costly engineering practice that could have been avoided through other alternatives such as greater emphasis on groundwater development or the implementation of different land use practices? McDowell (1997) stated that "the economic viability of bulldozer-constructed farm ponds is not high according to standard Cost-Benefit analysis" but suggests that the social viability is high if subsidized construction is possible and the ponds will be used and maintained by the farmer. Mitchell (1994) stated that "costly engineering practices such as these need better planning, construction and maintenance if they are to serve a minimum of 25 years."

Methodology

To obtain the needed data to make an adequate assessment as to the success or failure of the project, the author carried out a field survey in the two valleys of the study area, Tipajara and Uchuchajra. The author, using his own professional judgement, along with the help of his former HCA performed an evaluation of the changes that have occurred as the ponds have aged and determined the reasons why some "performed" better than others. The analysis took the form of in-field measurements (sedimentation), actual physical inspection, farmer and HCA interview and the analyses of all-available data and photos. At many of the sites the field survey was the first follow-up study attempted since pond excavation. Local input by the farmers was essential in the analysis but posed no problem as a good working relationship still existed between the author's former HCA and the farm community. The sample field form used is presented in Appendix II.

Between 1990 and 1994, at least a hundred of these ponds were installed by different agricultural extension agencies that worked within the region. The author's project consisted of approximately a quarter of the total ponds installed in the two-valley study area during this time, and baseline conditions (volume) for these ponds were known as they were measured upon completion of construction. With the help of his former host country agency, the author returned to the former project site area in July 1998 to assess the current conditions of the 24 ponds that were installed during the project. The on-site analyses determined to what degree the ponds were functioning, or if they ever functioned, as tied to the meeting of the original design criteria (soils, drainage area, water sources, pond location) at each site. Pond volume was analyzed as related to perceived needs and sedimentation rates were estimated in ponds where such an analysis was deemed valid. Actual topics for analysis within the field form/questionnaire included current pond conditions, the meeting of design criteria, irrigation water and crop production increases and the possible alleviation of land-use problems. Land-use problems were noted (within each general pond area) and if they had been positively or negatively impacted by pond excavation / presence.

The author identified the current state/condition of the ponds as one of four categories: "abandoned," "functioning poorly," "functioning adequately," or "functioning well." Abandoned ponds were generally small ponds that had never been properly developed, lacked all complementary structures and maintenance and were silted in or washed out. Ponds classified as functioning poorly supplied very limited supplementary irrigation and water for livestock, had no complementary structures in place and little if any maintenance. Ponds falling into the functioning adequately category were able to supply water for supplementary irrigation and livestock needs as well as limited permanent water supplies for small-scale irrigation needs during the dry season. These were ponds that had the potential to supply greater amounts of water but were limited by their varied and/or incomplete extent of complementary structures and maintenance. Ponds deemed as functioning well supplied sufficient water for farmer needs, had all or nearly all complementary structures in place, under went routine maintenance, often utilized multiple water sources and provided year round permanent irrigation. The results of the analyses have been summarized in Table 6, the Pond Summary.

Table 6. **POND SUMMARY**

Average Pond Volume		Current Condition			
With Original Project	Expansion With Later Project	Functioning Well	Functioning Adequately	Functioning Poorly	Limited Use or Abandoned
600 M^3	1000 M^3	6/24 = 25%	13/24 = 54%	3/24 = 13%	2/24 = 8% *

* One pond was never properly developed and therefore abandoned, and one has very limited livestock use only. Abandoned pond <u>not</u> included in summary percentage calculations below.

Principal Pond Use				Water Supply	
Livestock Only	Supplemental Irrigation and Livestock	Supplemental Irrigation, Small-Scale Irrigation, and Livestock	Supplemental, * Small-Scale and Permanent Irrigation, and Livestock	Year Round	Seasonal
2/23 = 9%	14/23 = 61%	3/23 = 13%	4/23 = 17%	5/23 = 22%	18/23 = 78%

* Supplemental irrigation refers to irrigation used from a pond in conjunction with rainfall during the rainy season for germination, harvesting or to help increase crop yields or "save" a crop during drought; while small-scale irrigation (in this sense) refers to complete irrigation of small areas (0.5 ha maximum) without the addition of rainfall. Permanent irrigation simple implies large-scale irrigation, during the dry season, without the addition of rainfall.

Water Sources				
Runoff Only	Spring-fed Only	From Existing Irrigation System	Runoff and Gully Flow Combination	Runoff, Gully and Irrigation System
4/23 = 18%	1/23 = 4%	1/23 = 4%	14/23 = 61%	3/23 = 13%

Extent of Complementary Structures			Routine Maintenance*	
All	Partial	None	Proactive	Reactive
8/23 = 35%	3/23 = 13%	12/23 = 52%	7/23 = 30%	16/23 = 70%

* Proactive refers to yearly maintenance of pond and structures while reactive refers to little, or in some cases no maintenance. See page 100 for actual maintenance practices/complementary structures, and summary list Appendix 1.

Land-use Problems Alleviated			Projected Sedimentation-Pond Life Span*	
Improvement	Little or No Improvement	Problem Worse	Without Yearly Maintenance	With Yearly Maintenance
16/24 = 66%	7/24 = 30%	1/24 = 4%	20 Years (on average)	50 Years (on average)

* See pages 101 and 102 for method used in estimating sedimentation rates, and pond summaries for actual estimates.

From Table 6 a number of results are evident. On average there were four families to each of the 24 ponds. A project completed two years after the author's project increased pond volume in the study area by an average of 400 cubic meters. Although existing pond volumes now average 1000 cubic meters, 60 percent of the ponds still have storage volumes of less than 1000 cubic meters. In addition, the later project had no bearing on the most common size (mode) and middle range (median) values which remained the same, 300 and 600 cubic meters respectively. The project, including the expansion, increased the potential of supplemental and permanent irrigation by an average of 41.00 and 11.00 hectares, respectively, when compared to pre-project levels. Close to 10 percent of the ponds provide water for livestock only. Only 17 percent of the ponds can be utilized for multiple purposes such as livestock, supplemental, small-scale and permanent irrigation, 13 percent for more limited use, while greater than 60 percent provide limited supplemental irrigation and livestock use only. Two ponds were never utilized and therefore abandoned, but one of these still supplies marginal amounts of water for livestock. Of the five ponds supplying water year round only two were not supplemented by spring water or an existing irrigation system. By far the largest source of water for the ponds was runoff and channelized gully flow. Greater than half the ponds had no complementary structures in place, and routine maintenance was lacking in 70 percent of all ponds. Some farmers did clean and repair their ponds to a limited extent, but only when the need arose.

Alleviation of land-use problems, the most qualitative of all analyses in the study, focused on whether soil erosion and cover conditions had improved, remained the same or worsened in the five year period since pond construction. This aspect of the study, besides actual visual inspection, consisted of photo and land-use analysis, farmer interviews and discussions with the author's former Host Country Agency (HCA). Improvements were most obvious in areas directly influenced by water from the ponds, around the actual ponds and in fields below, and not in the catchment areas. Improvement was noted in 16 of the 24 ponds (66 percent). Improvements within the catchment areas consisted mostly of the checking of further gully erosion. Sedimentation rates were based upon the amount of sediment the farmers took out of their ponds and silt traps during the dry season. More detailed analyses of current pond conditions and problems can be found in the Pond-By-Pond Summary (APPENDIX I).

Increases In Agricultural Production

What conclusions can be made about increased agricultural production as related to irrigation increases provided by the water storage of "atajados?" Before construction of the ponds the farmers were almost completely dependent upon the marginal, irregular rainfall of the region for the majority of their crop production with crop yields being extremely low during the late 1980s and early 1990s. Corn, wheat, potatoes and dry beans are the principle crops grown during the rainy season (the main season) but without irrigation only in limited quantities. With irrigation, land can now receive either supplemental or full irrigation, depending upon the land extent and season. On any given plot of land crops can be produced during any of three agricultural seasons and on average nine different crops produced. With the new sources of water now available at least one additional rain-fed crop can be produced through supplemental irrigation up to 2 hectares (on average), or the existing crop matured and the harvest assured during times of drought. Planting / seed time can be moved forward if need be and a small (1000 meter squared) vegetable garden planted to supplement dietary needs. In larger volume ponds, 3000 M^3, permanent more intensive irrigation can be undertaken during the dry season.

Onions are one of the most profitable and heavily cultivated crops produced in the region, grown for at least eight months out of the year but most extensively during the dry season. They are therefore cultivated almost exclusively (from planting to harvest) by the use of permanent, intensive irrigation. An "atajado" of 1000 cubic meters or slightly less can easily supply enough water to produce a quarter hectare of onions, irrigating the parcel on average 12 different times. Over 95 percent of the onions produced in the region are destined for the markets of Cochabamba or Sucre as are at least 90 percent of the dry beans, 70 percent of the corn and 50 percent of the potatoes. The remaining percentages as well as the majority of the vegetable crops grown are utilized for on-farm consumption.

Table 7 provides estimates of increases in agricultural production through the use of permanent irrigation as a result of the author's project for a 0.25-hectare parcel, the most common parcel size irrigated. Estimates are thought to be conservative as they are based upon the actual volume of the ponds and not on the potential number of times they could fill with water in a year. The estimates do not take into account the water that many farmers "set aside" for livestock use, perhaps 200 cubic meters. On average the ponds would fill at least once a year, even during drought years, and excavated pond volume is the guaranteed minimum quantity of water available for yearly crop production. The author's former HCA provided the estimates of increases in irrigation potential for both supplemental (41 ha.) and permanent irrigation (11 ha.) based upon their 10 to 15 years of agricultural experience in the region and upon the actual pond volumes. The estimates represent averages for all crops being grown. To clarify these two terms further: Supplemental irrigation refers to irrigation used along with rainfall during the rainy season for germination, harvesting or to help increase crop yields or "save" a crop during drought; while permanent irrigation simple implies larger-scale irrigation, during the dry season, without the addition of rainfall. Supplemental irrigation is also often referred to as occasional, extra or auxiliary irrigation, as it is not considered to be the sole source of irrigation water. In general, within the High Valley region permanent irrigation potential (in hectares) averages a third to a quarter less than that of supplemental irrigation.

The estimates for actual increases in agricultural production are shown for three commonly grown crops (corn, onions and dry beans) for a 0.25-hectare parcel and then each multiplied by 44 to estimate increases for the 11-hectares in permanent irrigation. These numbers were then divided by the total number of families receiving permanent irrigation (71), and the possible extra average income earned in a year was obtained. Increases in agricultural production involving supplemental irrigation are much more difficult to determine due to the very nature of its use, on an as-needed basis in addition to (often sporadic) rainfall. No economic figures are available for the use of supplemental irrigation in the region but on average one or two additional crops can be produced per year depending upon rainfall.

Table 7.
Estimated average yearly increases in agricultural production and profit gained (US dollars) for three irrigated crops of a 0.25-hectare parcel for each crop. (1995 prices)

Crop	**Production** 0.25 Hectare Parcel	**Price Paid For Crop** ($US / Kg)	**Gross Profit**	**Cost of Production**	**Net Profit** (US Dollars)
Corn	727 Kgs.	$0.22 / Kg.	$160.00	$27.00	$133.00
Onions	2000 Kgs.	$0.20 / Kg.	$400.00	$160.00	$240.00
Dry Beans	1000 Kgs.	$0.22 / Kg.	$220.00	$40.00	$180.00

Source : CORACA, 1996

Totals for the 11-hectare parcel are as follows.

Corn, 133.00 x 44 = $ 5,852.00 / 71, equals $82.40 per family.
Onions, 240.00 x 44 = $ 10,560.00 / 71, equals $149.00 per family.
Dry Beans, 180.00 x 44 = $ 7,920.00 / 71, equals $112.00 per family.

Although these values may appear to be low, it should be noted that they represent average potential extra incomes only, for subsistence level farmers whose net rural family incomes average less than $500.00 per capita annually. Also, the average number of families per pond has been reduced from four to two for many of the new projects in the region, thus increasing the income potential. The author's former HCA estimated that in the high valley region a typical "atajado" of at least 1000 cubic meters could be paid off by a group of farmers in approximately one to two years, or four harvests. On average, ponds of at least 1000 cubic meters produced a 35 percent increase in agricultural production while those of less than 1000 cubic meters produced only a 14 percent increase when compared to pre project levels. These levels of agricultural production are expected to gradually diminish as pond volume diminishes but can be maintained for many years as long as all complementary structures are in place and pond maintenance is done on a regular basis.

Farmer Attitude

Soil and water conservation practices are often very difficult to promote with farmers. The benefits of them are often only seen in the long term and seem vague to farmers who can see more immediate effects in their own fields with practices such as moisture conservation. The recuperation of degraded areas, which is often the emphasis of many soil and water conservation programs, is a long term process involving the organization of local labor away from the farmers' own croplands. In implementing the program of soil and water conservation in the study area, including farm ponds, it was essential to first gain the trust of the farmers. Many farmers, although recognizing the problems on their own lands, were wary of the new conservation techniques being introduced as they were neither viewed as being traditional practices nor having any sort of economic return. These first practices included small-scale soil and water conservation techniques that utilized local materials along with in-field agronomic measures; their success was first demonstrated to the farmers over the course of a year in the late 1980s. By the use of "comparison plots" on small sections of the farmers' fields, the effectiveness of these new measures were successfully demonstrated with some parcels increasing their yields by

300 percent in the first year (Macias, 1998). After seeing the actual increases in their own fields, the farmers then became more responsive to the idea of larger scale practices, such as "atajados," for increasing crop yields and alleviating soil and water conservation problems.

New Crop Introductions

Along with soil and water conservation techniques, a number of new crops have also been introduced into the region and study area. Higher value crops, such as dry beans and vegetables were promoted in place of the traditional crop rotations of corn and wheat. Some fruit trees, such as peach and citrus were also introduced with limited results. Vegetable crops included new and/or improved varieties of onions, tomatoes, garlic, green beans, peas and carrots while nitrogen fixing (soil improving) legumes such as alfalfa and varieties of dry beans were also promoted. Dry beans (Phaseolus sps.), while not considered a dietary stable of the region, were widely accepted by many of the farmers due to their drought-resistant qualities, high yields and relatively high market price. In addition, they grow close to the ground providing good ground cover and help to retard runoff and soil erosion better than most any other crop (Garcia, 1992). Dry beans were introduced into the region and study area for many of the reasons just mentioned, but due to their high protein content, were also promoted to improve the diet of the population. Unfortunately, greater than 90 percent of all dry beans grown in the region are exported to other parts of the country, often to the eastern lowlands (CORACA, 1996). It is the view of the author that their usefulness, not only in soil / water conservation and agriculture but also as a part of the regional diet, needs to be promoted further. Their use could be tied into further environmental education programs that are also needed in the region.

Ideal Pond Volume

The volume of an "atajado" is critical since the pond must be capable of storing enough water to bring a given crop to maturity. Since plant water needs vary, serious thought must be given to the water requirements of the crop to be irrigated and water intensive crops should, if at all possible, not be grown. For example dry beans require much less water to mature than cucumbers. Also irrigation works best in semiarid regions when used to irrigate deep-rooted perennials (i.e. most fruit trees) where the water is less susceptible to loss through evaporation. In short, an "atajado" should be constructed so that it can store relatively large volumes of water, at least 2500 cubic meters, and with a relatively small surface area to minimize evaporation.

Although the average size of the ponds in the author's project was approximately 1000 cubic meters, many of the ponds had been increased in volume from their original average of 600 cubic meters with a later project. However, even with this close to doubling in volume, pond size was still lacking for full agricultural use by the beneficiaries. In fact, the ideal size for ponds in the region was determined to be, on average, 3000 cubic meters (Revollo, 1998). With this size pond the farmer could always be assured enough water to harvest his crops regardless of the season, irrigating up to six hectares as often as six different times, but having the absolute assurance to harvest at the very least one hectare. Ponds of this size, while costing approximately twice that of 1000 cubic meter ponds, have the advantage in that they will not fill in as quickly, keep water in them longer yet can still be maintained, (cleaned out and repaired) during the dry season. If these larger volume ponds are designed to maintain water in them year round, they can also be utilized for other purposes such as year-round livestock needs and aquaculture (carp is eaten in Bolivia). However, thought must be given to maintenance, as ponds that do not go dry are more difficult to maintain.

Given the general rule that it takes on average 200 cubic meters of water per hectare to harvest any given crop in the region, small ponds of up to 1000 cubic meters were best utilized for supplementary irrigation during or toward the end of the rainy season, and for livestock. Within the study area, ponds of less than 1000 cubic meters produced, on average, only a 14 percent increase in agricultural production, 2.5 times lower than that of ponds over 1000 cubic meters (see Increases in Agricultural Production). Large ponds, with some as large as 20,000 and one even 70,000 cubic meters have been constructed in the valleys and had a number of problems. These problems included infiltration and hence high maintenance due to pond depth, high banks, water pressure and varying soil characteristics. Additional problems included high transmission losses with as much as 500 l/s of water flowing in earthen canals, social conflicts due to the large number of users, and high construction costs. In short, the scale of ponds greater than 5000 cubic meters made them cost prohibitive. It was found for example to be more cost effective and of greater use to the beneficiaries to construct a series of 10 ponds of 3000 cubic meters storage than it was to construct one giant pond of 30,000 cubic meters. Ponds of this size tend to have much fewer social use problems than those of large ponds, especially when owned by 1 or 2 families only who can easily handle the 20 l/s or so flow from them to the fields below (Revollo, 1998).

Positive Project Aspects

In justifying the project of the study area and its benefit to the people many positive aspects were identified. Some of these, as noted by the author and his HCA, include: more water and thus more land going under irrigation, less wet-season-only farming, documented increases in crop yields, the introduction of new crops and technology, the checking of soil erosion by retarding runoff, land rehabilitation, more water available for other uses such as livestock, improved economic conditions and rural employment leading to more self sustainability, less subsistence level only farming and (of particular interest to USAID/DEA), the curbing of seasonal migration to the coca producing regions. Additional environmental benefits include increased water for wildlife, the promotion of natural vegetation and creation of a microclimate around the ponds. Detaining the water where it falls, through soil and water conservation practices in the catchment areas, also has the advantage of possible groundwater recharge, especially of the heavily utilized shallow unconfined river aquifers. In addition, the semiarid region of the study area can at times receive "too much rain" often in the form of torrential downpours which can either washout or bury crops at critical stages in their development. "Atajados" can alleviate this problem by detaining these waters above the fields for later use.

Overall, the implementation of the project was relatively simple as all that was required was the cost of the tractor for excavation and some technical assistance. Also, because the beneficiaries were required to provide close to half the cost of the project through labor or actual money, it was felt they had more of a stake in the project's successful completion and routine maintenance. Community participation and enthusiasm were high throughout the project and some farmers have adopted many of the new agricultural technologies, including farm ponds, independent of donor programs.

Potential Negative Project Aspects

Although many benefits were achieved by the project, some of the possible negative impacts associated with it merit attention. Without doubt, the most notable adverse impact is the possibility of increased soil erosion / instability, sedimentation and local flooding brought about by poorly designed and / or inadequately maintained rainwater catchment systems leading to pond failure by either silting in or washing out. This potential for pond failure if not adequately checked could actually contribute to the cycle of land degradation as outlined in Figure 3. Mitchell, 1994, in referring to ponds constructed within the overall region states "Poor site selection, improper construction techniques and a lack of maintenance has lead to the failure of many of these and others have a very short life span. Speed and economy appear to have been the overriding factors in planning and construction." Mitchell further states that, "With proper engineering, construction and maintenance, costs may increase 50 to 75 percent but life span and usefulness would likely increase 500 percent." Some of the common problems identified with ponds in the region included steep side slopes and narrow top widths, unstable and poorly designed inlets and outlets, an overall lack of fencing, and removal of critical vegetation during and after construction. Furthermore, many of the ponds in addition to lacking routine maintenance also lacked some or all of the needed complementary structures (canal collectors, check dams, silt trap) for proper system operation. In a 1995 evaluation of 160 "atajados" constructed in the region in the late 1980s an estimated 50 percent were found to have severely diminished storage capacity due to the maintenance and construction problems just mentioned (Antezana, 1997). Many of the ponds analyzed in this 1995 study were those constructed as a part of the first "atajado" projects introduced to the region. Compared to the many projects going on today, these ponds were poorly planned and lacked adequate design, some without any complementary structures or even canal collectors. Today, it is widely recognized by every agricultural extension agency working in the region that the construction of "atajados" without their complementary structures amounts to nothing more than "holes in the ground," lacking little if any agricultural or soil and water conservation benefits.

Within the author's project every pond was, in theory, planned and designed with all complementary structures in place. However, it was the beneficiaries' responsibility for the actual construction of them, and results varied. As exhibited in the Pond Summary (Table 6), greater than half the ponds had no complementary structures in place and routine maintenance was lacking in 70 percent of all ponds. However, all ponds classified as "functioning well" within the author's project contained complementary structures and received at least limited maintenance while all "functioning poorly" ponds contained no complementary structures and received little if any maintenance. In one of the two "abandoned" pond-sites, soil erosion and cover conditions have actually worsened since pond excavation. Efforts must be increased for future projects within the region to assure the thorough construction of all complementary structures, perhaps by delaying actual pond excavation until the majority of the structures are in place. More information concerning pond functionality is presented in the Pond-By-Pond Summary section, (APPENDIX I).

Sedimentation is a natural process affecting the life spans of all natural and manmade water impoundments collecting water from natural catchment areas. However, the shortening of pond life through excessive sedimentation can be significantly reduced if the appropriate measures are taken. These measures include not only the proper design of the rainwater catchment system along with complete construction of all complementary structures, but also include routine maintenance. Maintenance of "atajados" takes the form of not only the periodic cleaning out of accumulated sediment in the actual pond but also the routine maintenance of the catchment area above the pond and all complementary structures. Canal collectors are inspected, cleaned and repaired if need be as well as the check dams / terraces and silt trap at the pond intake area. Fencing is replaced or installed if need be. Within the actual pond the inside and outside banks are inspected as well as the spillway section. Any sediment taken out of the pond can often be used on the actual pond banks for repair purposes. This routine maintenance is obviously best done during the dry season but just prior to the rainy season, right before the ponds will refill themselves often during the months of September and October. Thought must also be given to "ideal pond size" as ponds that are too large in volume may never completely dry up and hence can not be cleaned of all their sediment (see Ideal Pond Volume). This is also an ideal time to inspect the water delivery network from the pond as well as the actual irrigation canals developed to carry water to the fields below.

Sedimentation estimates within the region vary greatly; however, in one pond which was typical of the region a quarter of its initial storage volume (10,000 cubic meters) was being lost on average every four years, giving the pond an estimated life span of 16 years without routine maintenance. In general, larger volume ponds take longer to fill in, not only because they are physically larger but also because they often are better planned without steep slopes and highly eroded drainage areas. In another analysis of pond sedimentation rates, it was estimated that on average, large ponds of 3000 cubic meters or greater would fill in at a rate of approximately 10 percent a year, while small ponds (less than 1000 M^3) would fill in at 20 percent a year (Revollo). These estimates were for some of the first (poorly designed) ponds constructed in the region during the 1980s.

Within the author's project, pond volume averaged only 1000 cubic meters while average life span was estimated to be 50 years with routine maintenance and 20 years without (see Table 6, Pond Summary). Sedimentation rates were based upon the average quantities of sediment in wheel barrel loads (1 load = 1/12 M^3) taken out of the ponds and silt traps in the 7 ponds in which routine yearly maintenance was done during the dry season, hopefully removing all of the sediment accumulated within a year. The original idea for estimating sedimentation rates (noting differences in volume since time of construction) was abandoned upon site visit when it was realized that at least a third of the ponds had been enlarged with an additional project. Furthermore, sediment accumulation and removal within the other 14 or so ponds which lacked routine maintenance was not constant as some farmers did occasionally clean and to a lesser extent maintain their ponds and structures while others did only limited pond cleanings and only when conditions forced them to. Sedimentation estimates for each pond are given in the Pond-By-Pond Summary section in cubic meters per year. These estimates fall in line with other projects going on in the region today with the average life span for small ponds (under 1000 M^3) being about 15 years and that of larger ponds (1000 M^3 and larger) averaging out to 30 years, if not maintained. However, actual pond life and hence utilization would be lower as pond capacity would be severely limited within the last five or so years, especially in small volume ponds. Ponds which received spring or existing irrigation water as their main source were excluded from this estimate as their overall turbidity was low.

Other possible negative impacts associated with the author's project, and other similar projects within the region, include some of the land use and resource management changes which have occurred as a result of the switch from subsistence to more labor intensive irrigated agriculture. With rain-fed only subsistence level agriculture, the farmer relied little if any on the use of agrochemicals, such as pesticides. Pesticide use, along with many other herbicides and fertilizers, is now a common practice as are many of the other in-field agronomic and other soil and water conservation techniques which have been promoted by the various agricultural extension agencies working in the region. New and different crops have been introduced, some of which can be sold for higher prices than the traditional crops, but which often require greater quantities of water. This trend of more intensive irrigated agriculture along with the use of greater amounts of agrochemicals and more water-demanding crops continues in the region and study area. Most agricultural extension agencies as well as the actual farmers feel that the benefits of these new practices outweigh any of the potential future negative impacts which may be brought about by their current use.

Still another possible negative impact associated with the project includes the possibility of increased numbers of livestock, particularly sheep and goats, within the region and study area as a result of greater water availability. It has long been recognized that the farmers will maintain a limited quantity of water in their ponds for livestock use. As more and more water becomes available in the study area, this water allotment could also increase, thus allowing for greater numbers of livestock that in the view of many have already exceeded the carrying capacity of the land. Efforts are currently underway by some of the agricultural extension agencies working in the region to limit the numbers of livestock so there are fewer but healthier, well-fed animals.

The extent of "atajado" projects under taken in the region today is also of concern to some. It has been currently estimated that thousands of "atajados" exist within the overall region, hundreds within the three valleys around Aiquile and (counting the author's project) perhaps a hundred or so within the actual study area. During 1991 alone more than 500 ponds were excavated within the valleys of the study area. This trend continues today with "atajado" projects being planned by many governmental, non-governmental and international agencies who view them as the solution to water supply problems. At current rates of excavation, thousands of them will no doubt exist in the valleys around Aiquile within the next ten years. The large scale and extent of these "atajado" projects taking place throughout the region are viewed by some as having potential negative environmental impacts in downstream watershed areas. Mitchell, 1994, states that "The cumulative impact of water retention structures such as ponds, wells and terraces should be analyzed in regional hydrologic studies."

Most of the agencies involved in "atajado" projects view the concept of constructing too many ponds as being overly preoccupied with aspects outside of the region. They point out a number of reasons (in addition to soil, water and agricultural benefits) why large-scale projects would not only benefit the region but would also have little if any impact on downstream watershed areas. First, it is estimated that all ponds that currently exist within the region capture perhaps a maximum of 10 percent of the total rainfall lost as runoff (Rebollo, PDAR 1998). Also, all rivers of the high valley region eventually flow northeast toward the tropical Amazon Basin where abundant rainfall exists. Moreover, the region is already seriously degraded and due to the rainfall pattern and topography waters pass very quickly in ephemeral streams. Because these waters pass so quickly, they must be detained as they start to runoff not only for farmer use but to prevent further erosion and flooding downstream. Regardless of the number of "atajados" constructed, downstream flooding continues, as does the construction of river defenses in response to it. In addition, this downstream flooding not only continues within the high valley region but also within the tropical Chapare region where all the high valley rivers eventually flow.

An indirectly related environmental problem brought about as a result of the coca eradication / alternative development efforts of the USDEA/USAID in the Chapare region is the expansion of the "cocaleros" into "protected" national park and indigenous land areas. These areas, bordering the Chapare region, have seen sharp increases in coca cultivation and on a smaller scale processing, and include the National Parks of Amboro, Carrasco and Noel Kemph and the indigenous areas bordering the departments of Cochabamba and Beni. Major conflicts involving land-use issues are taking place in these regions between the park administrators, NGO's and local populations. Currently there has been little effort or money allocated toward a solution for this situation as the main emphasis has been placed in the Chapare region.

The Earthquake of 1998

On the night of May 21st 1998 at approximately 11:35 PM an earthquake measuring 6.8 on the Richter scale hit the town of Aiquile, the epicenter of the quake and location of a small geologic fault. The town, having already been damaged by a strong quake some 40 years earlier and constructed mostly of adobe was within a matter of minutes, 80 percent destroyed with as many of a 100 or so of its 8000 inhabitants dead or dying. In addition, much of its recently constructed USAID funded infrastructure (roads, water, electric, etc.) was destroyed in the process. The quake, while not being particularly strong as measured on the Richer scale, was relatively shallow, 60 – 70 kilometers below the surface, as compared to past much deeper quakes in the region which did little if any damage. This quake was felt all over the country but was particularly severe in the province of the study area, Campero. The author, who was scheduled to arrive in country some 2 weeks later, was contemplating to what extent the quake would have on his ability to carry out his project evaluation / field work. Surprisingly, the effects of the quake while relatively far reaching were most severe within the town of Aiquile, with little or no damage having occurred to the ponds of the study area (see photo 9). However, the groundwater resources of the region and study area had been affected. In many places spring flow quantities increased, diminished or stopped altogether, some wells dried up, and stream flow within many of the regions ephemeral streams was also affected as water flows increased in some of the irrigation systems which tapped into the shallow unconfined river aquifers. Some of the ponds in the study area also lost water as their siphoning hoses were inadvertently "activated" by the quake, draining in some cases hundreds of cubic meters of water storage before being noticed by the farmers.

<u>Local Beliefs and Project Implementation</u>

The belief in Pachamama or the earth mother is still strong in Bolivia, especially strong in the more remote rural areas. Pachamama is a deity left over from the days of the Incas whose purpose is to bring forth abundant crops and distribute riches to those who venerate her. Often, especially during celebrations, before any eating or drinking can occur small amounts of drink such as chicha (corn beer) are sacrificed in her honor by being returned to the earth, poured on the ground. If the earth is to be disturbed in any manner through plowing, construction, mining or whatever, an apology must be offered to her. Within the study area, or any other in Bolivia, this apology took the form of a small celebration or "challa" at the pond site(s) upon project completion. Although this tradition does not have the significance it once had, it still is considered a necessity in Andean culture for project success. Many a failed project has been blamed on an inadequate or complete lack of a "challa." Today the celebration often serves as a showcase for the agency or institution responsible as well as a means to bring all the project beneficiaries together in a show of project support and to discuss any last minute details before actual project implementation.

Project Sustainability

One of the main criteria in evaluating the success or failure of any project in which the United States Peace Corps has been involved is self-sustainability. In other words will the project endure and become part of the socioeconomic and cultural aspects in which it was created to solve a given problem; or was the project just another example of short-term thinking to overcome a complex set of circumstances? Many Peace Corps projects involve the utilization of, as in the author's project, small-scale, low cost, site-by-site, simple yet appropriate technology. One of the most current definitions of a sustainable development is : "Development which meets the needs of the current generation without compromising the ability of future generations to meet their needs (Sherrard, 1996)." Sustainable development is often also tied to the sustainability of a particular project, which includes economic, operational and environmental sustainability. Any development which is undertaken for the purpose of increasing food security must be conducted on a sustainable basis (Sherrard, 1996). Could the author's project then be thought of as being sustainable? In the view of the author many of the ponds were well planned and constructed. As long as they continue to be maintained, the project was and continues to be sustainable. It is not the intent of the author to provide answers to every possible outcome related to the project. However, the situation merits at the very least, a more detailed look at some of the possible changes which may occur as a result of the author's and similar projects continuing within the region.

First, how much will the local economy change as a result of this project, and will the new opportunity of farming during the dry season be enough to curb seasonal migration to other regions? Will the economy of these other regions be affected if seasonal migration stops? Currently in Bolivia a geographic transition from rural to urban is occurring with, at last count, approximately 60% of the population living in urban areas. Also, the Bolivian government has a pro-population growth policy and is particularly interested in populating its relatively uninhabited eastern region, especially along its border with Brazil. These trends are expected to continue and raise the question of why are measures being taken to keep people on their land in this part of the country if they may end up leaving anyway? Also, a large amount of money has been pumped into the region to solve a problem that may return from drought, climate change, and pond sedimentation.

What are some of the social and cultural changes that might occur as a result of this project? Unfortunately, this may be the most difficult question to answer as Bolivia has already been touched by the outside world in numerous ways. Bolivia has relied on "handouts" from many foreign governments, financing many different infrastructure projects (plus a myriad of others) for most of this century. In many respects Bolivians are dependent on outside aid as a "way of life" and employment. Currently the country is still very regionalistic with each geographic region having its distinctive dress, customs, food and way of talking, but these distinctions have become blurred in the major urban areas. Only time will tell what the transition to a more capitalistic economy will mean to a relatively small group of people who, for the most part relied upon subsistence-level-agriculture for their existence.

What are the ethical considerations of the project? Was the main objective of the project as stated in a Peace Corps training manual, "to help people find their own solutions to their problems and empower them with the organizational structure and motivation to solve these problems with locally available resources." By requiring the beneficiaries to pay approximately half the cost of each pond, the "locally available resources" in this case meant money. However, if the beneficiaries of the project did not realize that their "atajados" had a limited life and that they would fill in more quickly if they were not properly maintained, then could the project be thought of as being sustainable? Should the ultimate success or failure of the project be measured in the number of ponds dug or crops grown? Knowing that irrigation works best in semiarid regions when used to irrigate deep-rooted perennials such as fruit trees, was it ethical of the agency to encourage the cultivation of more water-intensive crops (i.e., Chilean garlic versus local varieties) now that the people had more water available? The agency preferred these varieties over those of less water-demanding traditional varieties simply because they fetched a higher market price. Also, the agency was available for technical assistance in this matter as well as to sell any needed herbicides and pesticides that (if necessary) did not have to be paid for until after harvest time. Finally, was it ethical of the HCA's source of funding (USAID) to have as one of their main objectives that of keeping these people "down on the farm" so as to curtail migration to the coca producing regions? Perhaps there are no right or wrong answers to these questions, just varying degrees of opinions and political viewpoints.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The following section states the conclusions reached as a result of the author's project and attempts to address the following questions. 1) Did the addition of new sources of irrigation water provided by the project lead to overall greater irrigation of more land more often, particularly during the dry season? 2) Was agricultural production increased and were the beneficiaries able to rise above subsistence level only agriculture? 3) Were soil and water conservation benefits achieved and land-use problems alleviated, and do the project beneficiaries now have more incentive to stay on their land, hopefully improving it? In short, was the author's project a viable solution to the problems of desertification and poverty or just another costly short-term engineering practice? The answer to each of these questions is "yes" with specific conclusions listed below.

1) The project increased permanent irrigation by 11-hectares and supplemental irrigation by 41-hectares, supplying water to the farmers for their immediate to long term needs, approximately 20 years. However, the average pond size (1000 M^3), the median size (600 M^3) and the mode (300 M^3), seriously limit permanent irrigation.
2) The farmers of the study area can increase crop yields, rural employment and income through conservation farming practices such as "atajados." Crops can now be grown, to varying degrees, year round in the study area and with less risk of crop failure. At

least two extra crops can be produced each year.

3) The author's project created large amounts of rural employment and income (relative to Bolivia) but distributed it to too many beneficiaries.

4) The limited water resources of the ponds were divided among too many families, 4 families per pond on average, limiting income potential and in some cases creating pond utilization problems. Family income potential could be doubled by decreasing family use to 2 families per pond.

5) Both diet and family incomes have improved. Diet has improved through new crop introductions and family vegetable gardens and incomes have risen an average of 20 percent per family per year. Some new crops such as dry beans still have a limited appeal for dietary consumption and are sold to market.

6) There is more overall community involvement in farming and greater commerce occurring as the crops being produced are sold in the markets of Sucre and Cochabamba on a more regular basis.

7) Further increases in agricultural production are limited as greater than half the ponds had no complementary structures in place and routine maintenance was lacking in 70 percent of all ponds.

8) Farm ponds are more reliable sources of water when filled with a combination of sources such as water from existing irrigation systems, springs, ephemeral rivers (when flowing), channelized gully flow as well as direct rainwater runoff.

9) Only 25 percent of the ponds are considered to be functioning well, approximately half functioning adequately and close to a 25 percent poorly or not at all. If all

complementary structures were in place along with a regular maintenance plan, pond size would be the only limiting factor in increased agricultural production since greater than 75 percent of the ponds would be functioning well.

10) The ponds have an average life span of close to 50 years if properly designed and maintained and 20 years (or less) if not properly designed and maintained. However, the storage capacity of close to 75 percent of the ponds would be severely limited after approximately 10 years without maintenance and proper design.

11) The alleviation of land-use problems (soil erosion and cover conditions) within the study area was a subjective analysis based upon actual site inspection, comparison with pre project photographs, farmer interviews and discussions with the author's former HCA. "Atajados" in most cases intensify land use in a positive fashion. Improvement was noted in 66 percent of the total pond sites while little or no improvement was noted in 30 percent of pond sites and an actual worsening of soil erosion and cover conditions in 4 percent of the pond sites. Improvements in soil erosion and cover conditions were most obvious in areas directly influenced by water from the ponds, around actual ponds and in fields below, and not in the catchment areas. Improvements within the catchment areas consisted mostly of the checking of further gully erosion. Complementary structures such as rock check dams and terracing were lacking in at least half of all pond catchment areas. Undisturbed natural vegetation best controlled soil erosion and runoff.

12) In addition to land rehabilitation benefits properly designed and maintained "atajados" also increase water for wildlife, promote the growth of natural vegetation,

aid in groundwater recharge and create a microclimate around the ponds. With proper soil and water conservation techniques in-place in the catchment areas forage and cover conditions can be improved. However, improperly designed and badly maintained "atajados" can actually worsen local soil and water conservation problems by increasing soil erosion.

13) Due to the absence of more detailed hydrologic studies for the study area the Rational Method was an acceptable alternative to determine runoff. It was also acceptable in estimating the minimum drainage area necessary to fill a pond for any given volume desired or as a means to estimate the required storage capacity when used in conjunction with the graphical mass curve method.

14) The project returned the initial investment of the beneficiaries (50 percent of total pond cost) in approximately one to two years, or four harvests. On average, ponds of at least 1000 cubic meters produced a 35 percent increase in agricultural production while those of less than 1000 cubic meters produced only a 14 percent increase when compared to pre-project levels. Agricultural production will gradually diminish as pond volume diminishes but can be maintained for many years as long as all complementary structures are in place and pond maintenance is done.

15) The migration to the coca producing regions of the country from the study area / region has virtually stopped, but more as a result of eradication and interdiction measures by the US and Bolivian Governments than from the benefits produced by the author's project.

16) The use of pesticides as well as other agrochemicals is increasing in the study area as a direct consequence of the greater amounts of water available for more intensive irrigation brought about as a result of the author's project.
17) The extent of new projects occurring in the region is thought to have little if any affect on downstream hydrology due to the nature of the rainfall pattern and geographic setting.
18) The farmers of the region and study area are accepting the new soil and water conservation / irrigation technologies being promoted by USAID and others. In particular they are embracing the small-scale, low cost, site-by-site, simple yet appropriate technology of "atajados" as an expansion upon their traditional conservation practices and sources of water. Some have even expanded upon the idea without the assistance of outside funding sources, through manual excavation.

The author's project was just a fraction of the entire USAID plan to improve living conditions in the High Valley Region by creating rural employment and income through expenditures in irrigation infrastructure, agriculture and soil and water conservation practices. USAID viewed the main goal of "atajado" projects as a means to expand the agricultural frontier of the region and to, at the very least, alleviate land use problems exacerbating the process of desertification. The author's project, on a limited site-by-site basis, achieved this goal.

Recommendations

Recommendations include not only particular suggestions for the author's project but also general recommendations for similar projects within the region. These general recommendations may overlap some with the author's project and are as follows.

1) Follow the USDA/NRCS construction guidelines outlined in the Description of Typical "Atajado," when constructing all ponds.
2) Excavate ponds with an average size of 3000 cubic meters storage and a maximum depth of 3 meters for the reasons outlined in Ideal Pond Volume section. Where possible, utilize water from a number of different sources to fill ponds, using springs and irrigation systems as well as rainwater runoff.
3) Avoid costly "high tech" engineering solutions for problem ponds that shouldn't have been built in the first place. In lab soil testing, clay and plastic liners, recompaction and possible reexcavation can double or even triple pond cost. Slightly over design the ponds with engineering safety factors in mind, and do regular maintenance.
4) All ponds must be properly planned, designed, located and constructed with all of their needed complementary structures, or not excavated in the first place, as outlined in Description of Typical "Atajado." If possible, delay actual pond construction until an acceptable number of complementary structures are in place, thus requiring their construction before hand. Small-scale irrigation projects of this type have now been going on for close to 20 years in the region. Incorporate all positive and negative experiences of these projects into proper design practices.
5) Routine maintenance must be attempted at least once a year, see Maintenance Plan.

6) Fence all critical areas, such as pond banks and other areas above and below the pond so they will not be trampled and destroyed by livestock.

7) It is essential that the beneficiaries have the incentive to use and maintain their ponds. They should be involved in all aspects of pond design, especially location, and should be required to pay at least half the cost of pond construction, but this cost could include the actual labor of the complementary structures needed.

8) Stock larger ponds that maintain water in them year round with low oxygen requiring fish species such as carp and talipia, but in limited numbers.

9) Continue environmental education efforts in the region along with the promotion of beneficial and cost productive crops such as dry beans as well as other legumes.

10) To avoid utilization conflicts, construct ponds for members of one or two families only and establish water allocation agreements well before pond construction.

11) Ponds constructed to increase irrigation do not always lead to better soil and water conservation (and vice versa). Ponds constructed for soil and water conservation should be placed in areas where they can be most beneficial (i.e., upper gully areas) and ponds for agriculture located directly above the fields they are to irrigate. In ponds constructed only for soil and water conservation purposes irrigation should be designated for watershed rehabilitation purposes only, such as reforestation.

12) Since accurate hydrologic data for the region and study area are still lacking, do regional hydrologic studies as well as local hydrologic studies before pond construction. Expand efforts to more accurately estimate runoff coefficients and curve numbers for the dry high valley region / conditions of Bolivia. These could take the

form of designated experimental "atajado" watersheds. The use of rain gauges in the catchment areas and the actual timing of the arrival and filling of runoff could be utilized to better estimate a time of concentration value to the ponds associated with any given storm.

13) Implement a plan of watershed management for the study area and possibly the entire region through the use of "atajados" in conjunction with many of the moisture conservation practices, improved soil management and crop diversification practices that have already been implemented through USAID's Soil and Water Conservation Program. In other words, expand the current program so that it would encompass a small-scale, mini-drainage area, pond-by-pond yet integrated approach to watershed management for the study area / region at the farm level. This integrated approach to resource conservation would provide a well-balanced scene into which reservoir construction could be successfully blended. Furthermore, many of the practices involve simple, low cost techniques that utilize the local resources (such as rocks) of the farmers. Practices could be implemented in the catchment area, as well as in the fields to be irrigated that would in essence conserve the precious soil and water resources of the region to the highest degree possible. Each of these three areas (catchment, pond and fields below) could be designated as specific use areas such as limited grazing area, livestock watering area, crop area, etc. As with the promotion of other practices, a sample demonstration site and associated parcel could be set up to demonstrate the success of this integrated approach to the farmers. Many aspects of this plan have already been spelled out in the section on Drainage Area Development.

Specific suggestions for the author's project include the following:

1) Increase the average size of the ponds by a factor of three. Ponds need to be excavated with an average size of 3000 cubic meters storage and a maximum depth of 3 meters for the reasons outlined in Ideal Pond Volume section.
2) The absolute maximum number of families to a pond should be three, and only for ponds of 3000 cubic meters storage on average.
3) Construct new ponds or redesign the existing ones so that they utilize water from a number of different, more reliable sources such as springs and irrigation systems in combination with rainwater runoff.
4) The ponds that maintain water in them year round should be, if not already, made large enough that they can be designated for multiple use, such as aquaculture, livestock needs, domestic use and irrigation.
5) Large ponds which do not go dry should utilize low turbidity spring or existing irrigation system water as their main source as they cannot be maintained as easily as ponds that dry up.
6) If an aquaculture projects are to be undertaken, stock fish in large, low turbidity permanent ponds only, and in sustainable quantities.
7) The threat of sedimentation can be alleviated through an acceptable level of fencing, complementary structures and routine maintenance, all of which are still lacking with the majority of ponds. Efforts must be increased, perhaps along with an environmental education program.

APPENDIX I

POND-BY-POND SUMMARY

POND-BY-POND SUMMARY (Photo follows each summary)

1

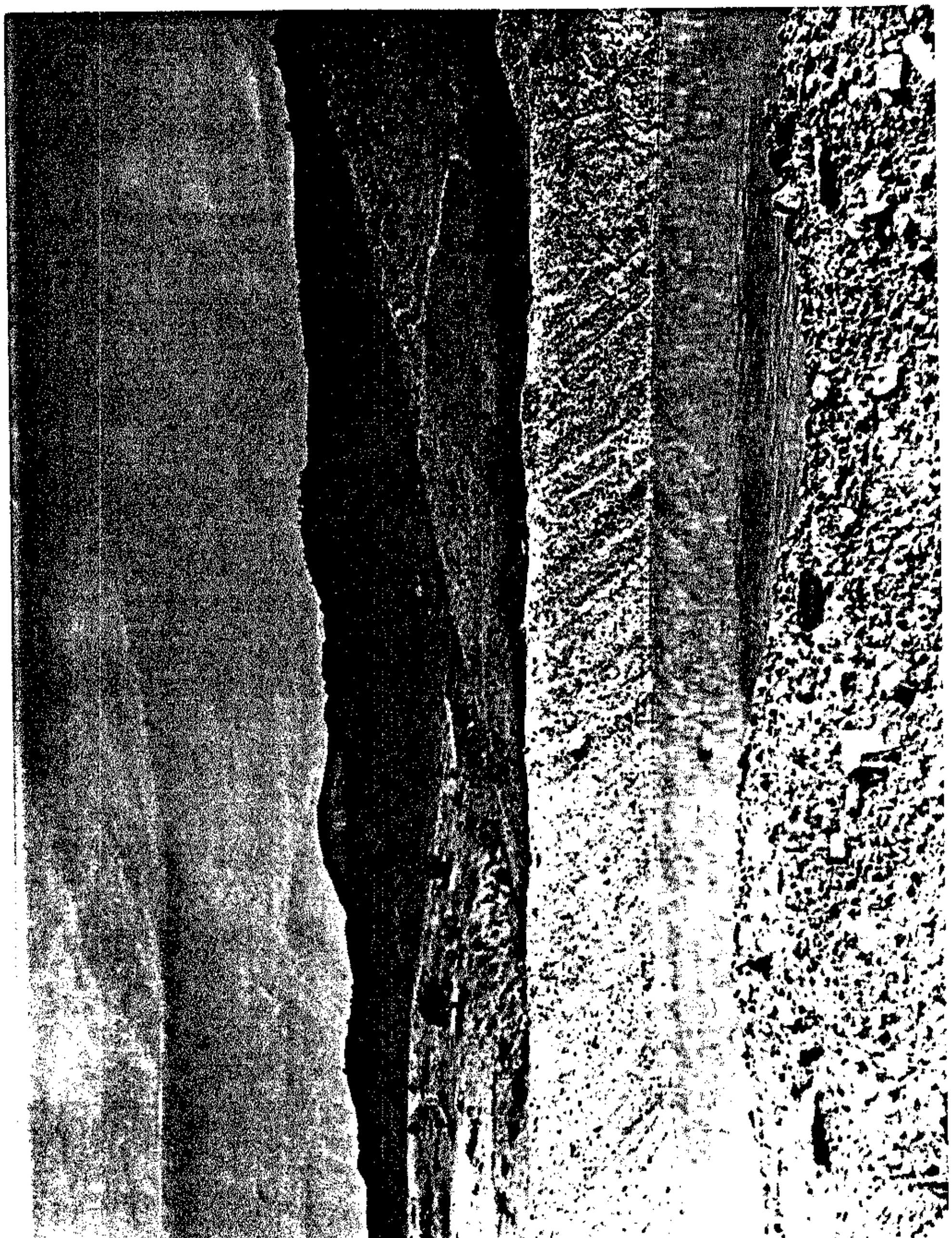
Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Zenon Gonzales, 3 families	800 M^3	Functioning Well	Supplemental Irrigation and Livestock	Runoff, Gully, and Irrigation System

Water Availability	Complementary * Structures, Extent	Extent of Fencing	Maintenance *	Sedimentation Estimate
Dries Up Each Year, By July	All in Place	In Crop Area Only	Do Yearly	40 M^3/ YR. (if not maintained)

* See page 176, end of this section for a breakdown of these practices.

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of soil and cover conditions near sites within pond influence.	Size, despite multiple water sources pond still goes dry. DA* to small?	(In hectares) 2.0 Has.	0.5 Has.	Estimated 25% increase in irrigation and 1 extra crop per year. Size is limiting factor in greater agricultural production.

* Drainage Area



2

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Zenon Butron, 3 families	250 M^3	Functioning Adequately	Supplemental Irrigation and Livestock	Runoff Only

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By June	None	None	Limited, as need arises only	20 M^3/ YR. (Max. life 10 Yrs.)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of soil erosion problems and checking of gully area.	Size is limiting factor for ag. production, soil conservation benefits only.	0.4 Has	NA	Limited supplemental irrigation and livestock, 10% max. estimated increase in agricultural production. Filling-in.

3

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Romulo Delgadillo, 2 families	250 M^3	Functioning Poorly	Supplemental Irrigation and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By June	None	None	Limited, as need arises only	20 M^3/ YR. (Max. life 10 Yrs.)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of soil and cover conditions near sites within pond influence, but limited due to pond size.	Limited size and life span, pond upslope captures bulk of water. Some soil conservation benefits.	0.3 Has.	NA	Limited supplementary irrigation and livestock, 10% max. estimated increase in agricultural production. Pond filling in, size too small.

4

Person In Charge, And Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Epifanio Perez, 3 families	250 M^3	Functioning Well	Supplemental Irrigation and Livestock	Runoff, Gully, and Irrigation System

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Year Round	Partial	In Crop Area Only	Limited, as need arises only	20 M^3/ YR. (Max. life 15 Yrs.)

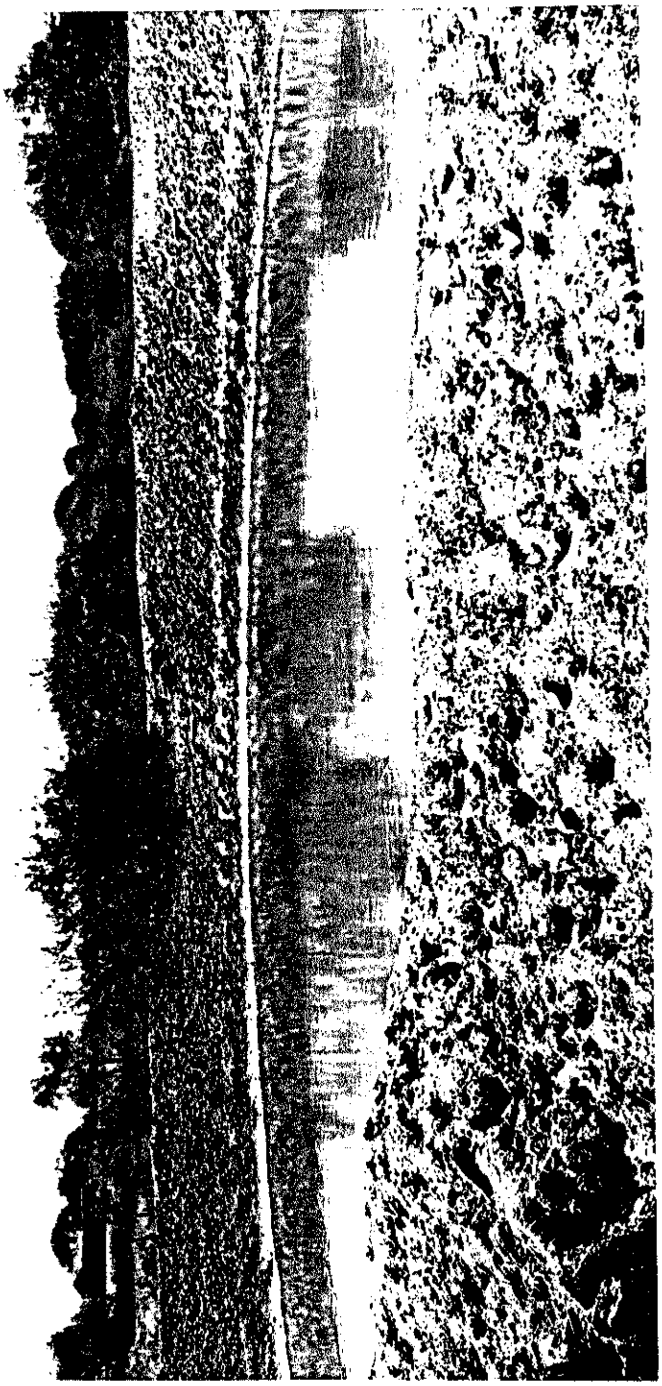
Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of Soil erosion and cover conditions in fields below.	Size, would be dry if not for multiple water sources.	0.3 Has.	NA	Limited supplemental irrigation, 10% max. increase in production, livestock use adequate.

5

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Erazmo Leon, 4 families	1000 M^3	Functioning Adequately	Supplemental Irrigation, Small-Scale Irrigation, and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Year Round	None	In Crop Area Only	Do Yearly	50 M^3/ YR. (if not maintained)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of soil and cover conditions near sites within pond influence, water does not run down road as did in past.	Size somewhat limiting, no complementary structures, but water yr. round. Irrigation could be increased.	2.0 Has.	0.4 Has.	Can produce on average 2 additional crops per yr. of either dry beans or onions. An estimated 25%. increase in agricultural production. Need all complementary structures to increase ag.



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Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Claudio Montano, 6 families	1100 M^3	Functioning Adequately	Supplemental Irrigation, Small-Scale Irrigation, and Livestock	Runoff, Gully, and Irrigation System

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By Aug.	All in Place	In Crop Area Only	Limited, as need arises only	40 M^3/ YR. (if not maintained.)

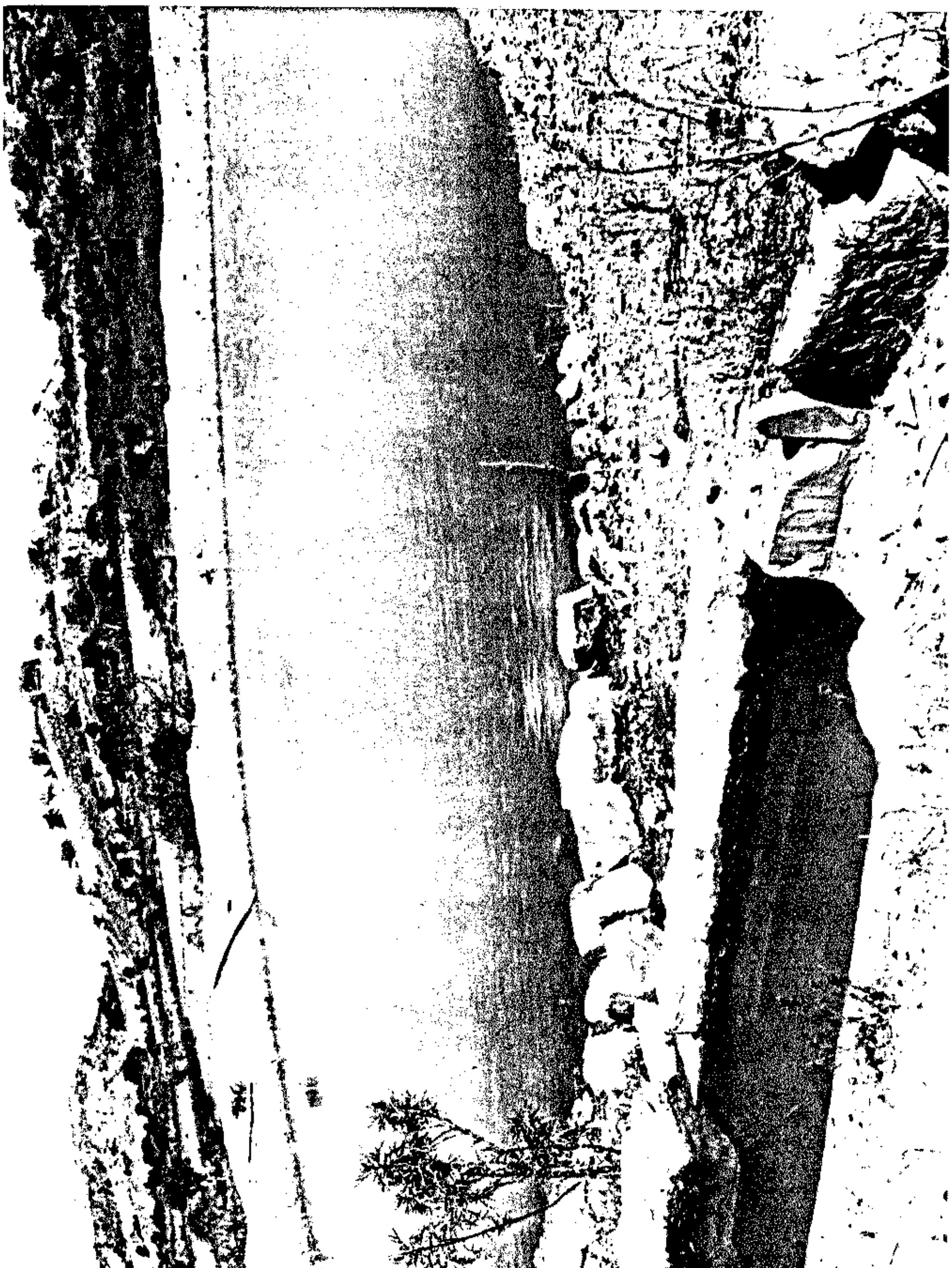
Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of soil and cover conditions near sites within pond influence.	Size somewhat limiting, despite multiple water sources pond still goes dry.	2.0 Has.	0.5 Has.	On average, 1 additional crop of onion, garlic or tomato per year and an estimated 25% increase in ag. production.

7

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Renato Rosales 6 families	1000 M^3	Functioning Well	Supplemental, Small-Scale and Permanent Irrigation, and Livestock	From Existing System of Irrigation

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Year Round	All in Place	In Crop Area Only	Do Yearly	25 M^3/ YR. (Low Turbidity)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of soil and cover conditions near sites within pond influence, water does not run down road as did in past.	Size and number of families using Water source is clear water and pond always full but size is insufficient for full utilization.	2.0 Has.	0.4 Has.	Can produce on average 2 additional crops per yr. but on limited scale. Estimated 50% increase in ag. production. Should increase size to realize full agricultural potential.



8

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Tereza Macias, 4 families	250 M^3 filling in rapidly	Functioning Poorly	Livestock Only	Runoff Only

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By April	None	None	None	NA

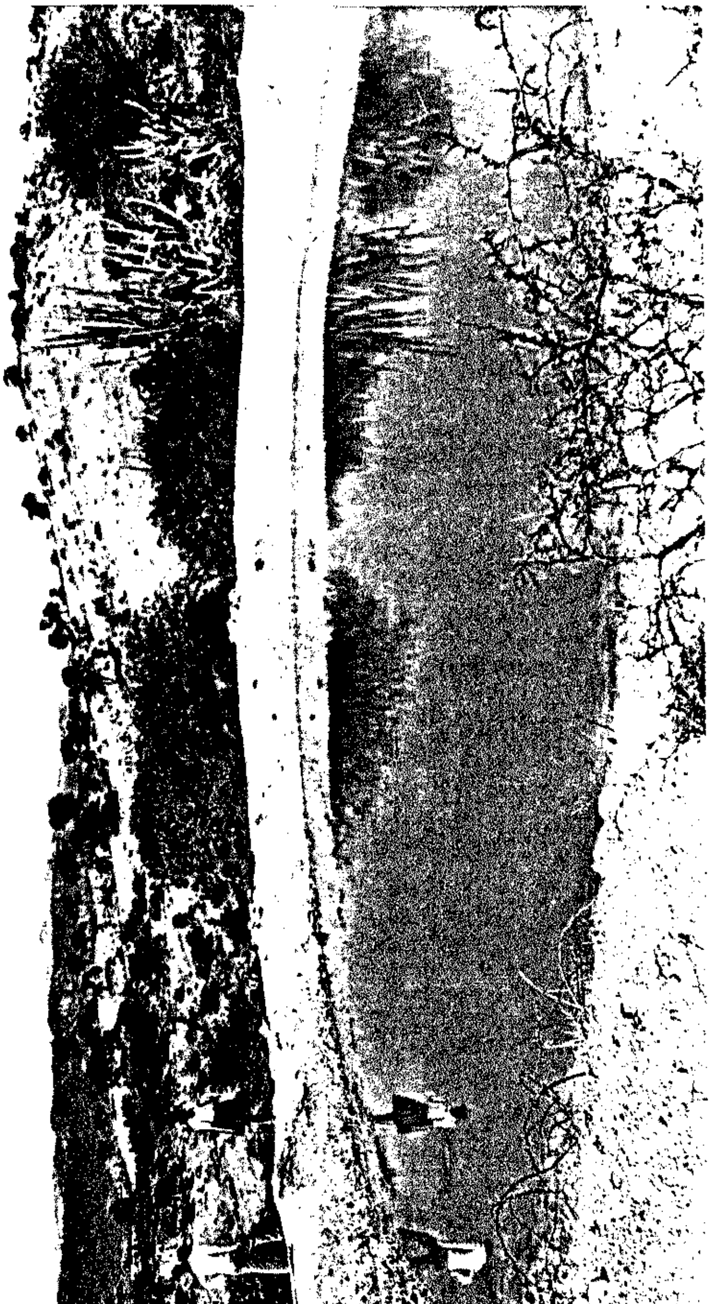
Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Little or no improvement in soil erosion or cover conditions	Size, filling in, no maintenance, complementary structures none	1.0 Has.	0.2 Has.	None, only limited livestock use and seed germination, pond has limited value.

9

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Cirilo Macias, 4 families	500 M^3	Functioning Adequately	Supplemental Irrigation and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By Sept.	None	In Crop Area Only	None	30 M^3/ YR. (Max. life 15 Yrs.)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of cover conditions near pond site and checking of gully erosion.	Size, lack of complementary structures and maintenance limit agriculture	1.0 Has.	0.2 Has.	Limited supplementary irrigation and livestock, Estimated 30% increase in water available at harvest or seed time.



10

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Constancio Villarroel, 1 family	600 M^3	Functioning Adequately	Supplemental Irrigation and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By Sept.	Partial	Adequate	Limited, as need arises only	25 M^3/ YR. (Low Turbidity)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of cover conditions near sites within pond influence.	Size is problem, DA provides clean water, good quantity	2.0 Has.	0.3 Has.	Limited supplementary irrigation and livestock, 20% max. estimated increase in agricultural.

11

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Zenon Crespo, 4 families	2000 M^3	Functioning Well	Supplemental, Small-Scale and Permanent Irrigation, and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By Oct.	All in Place	Adequate	Do Yearly	40 M^3/ YR. (if not maintained)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of soil and cover conditions near sites within pond influence.	No significant problems, some farmers wish to increase volume further.	4.0 Has.	0.8 Has.	On average 2 additional crops can be produced per year. Estimated 50% increase in overall agricultural production.

12

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Roberto Maldonado, 3 families	600 M^3	Functioning Adequately	Supplemental Irrigation and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By May	None	In Crop Area Only	Limited, as need arises only	30 M^3/ YR. (Max. life 15 Yrs.)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential)		Crop Production and Additional Comments
		Supplemental	Permanent	
Improvement of soil, and vast improvement of cover conditions within pond influence.	Size, lack of complementary structures and routine maintenance limit agriculture	1.2 Has.	0.24 Has.	Limited supplementary irrigation and livestock, 20% max. estimated increase in agricultural production.

13

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Expipion Maldonado, 3 families	1000 M^3	Functioning Adequately	Supplemental Irrigation and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By June	None	In Crop Area Only	Limited, as need arises only	50 M^3/ YR. (Max. life 20 Yrs.)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Little or no improvement in soil erosion or cover conditions but did help to check expansion of gully.	Size, lack of complementary structures and routine maintenance limit agriculture.	2.0 Has.	0.4 Has.	Limited supplementary irrigation and livestock, 30% max. estimated increase in agricultural production and an additional crop depending on the year.

14

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Eusebio Jimenez, 4 families	1500 M^3	Functioning Adequately	Supplemental Irrigation and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By Aug.	All in Place	In Crop Area Only	Do Yearly	50 M^3/ YR. (if not maintained)

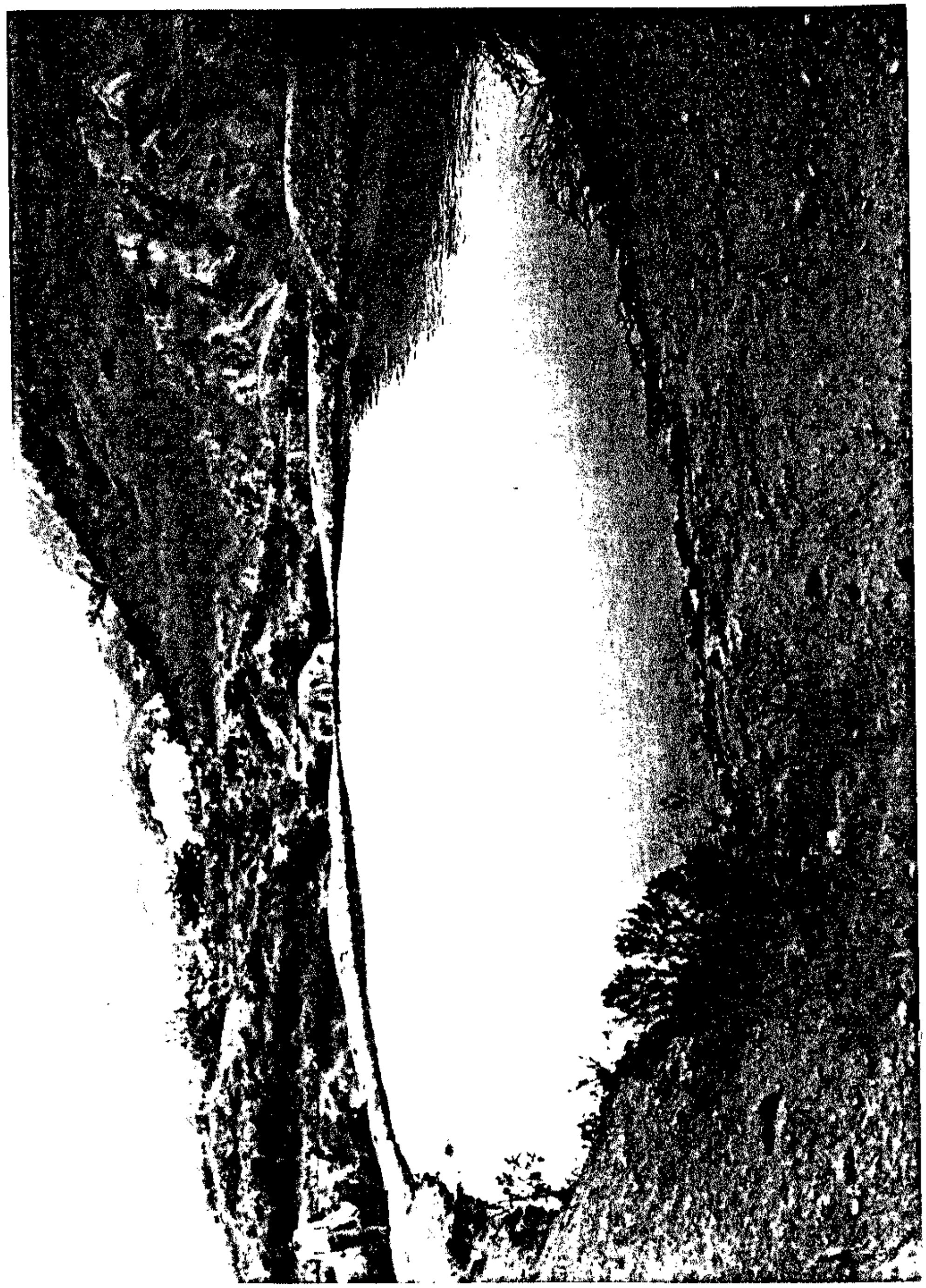
Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of soil and cover conditions near sites within pond influence, soil erosion measures are also in-place below pond.	Due to the steep slopes above, sedimentation is a problem, pond was washed out once but repaired. Silt traps in-place in needed areas.	3.0 Has.	0.5 Has.	Limited supplementary irrigation and livestock, 40% max. estimated increase in agricultural production and an additional 1 or 2 crops depending on the year. Size a factor, but can irrigate small area,wet yr

15

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Gerardo Alvarez, 5 families	500 M^3	Functioning Well	Supplemental, Small-Scale and Permanent Irrigation, and Livestock	Spring-fed Only

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Year Round	None (NA)	In Crop Area Only	None Needed	NA (very low turbidity)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Little or no improvement in soil erosion or cover conditions but no worse, area below pond with permanent irrigation, better cover conditions	No significant problems except size. Water is clean/constant, complementary structures not needed, overall maintenance low.	NA	3.0 Has.	Provides permanent irrigation for up to 3 Has. An average of 2 extra crops per year. Current pond size and # of families limits greater irrigation. Pond is source of small-scale irrigation system.



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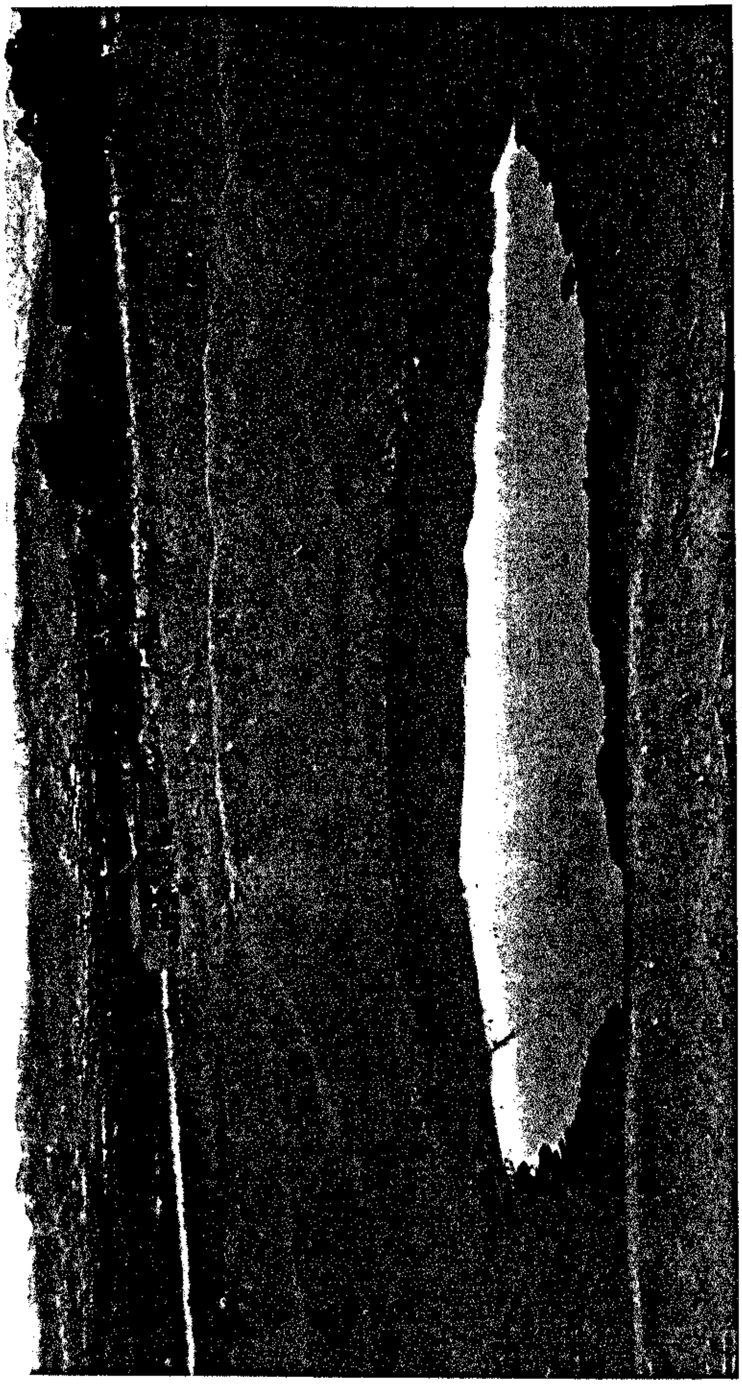
Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Maria Villarroel, 2 families	100 M ³ storage volume very low	Never Used or Abandoned	Livestock Only	Runoff Only

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By April	None	None	None	NA

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental Permanent	Crop Production and Additional Comments
Little or no improvement in soil erosion or cover conditions but no worse, pond to small for any effect.	Original pond volume was only 200 M ³, bad soils, site selection and no maintenance.	No Irrigation, Limited Livestock Use Only	None, only limited livestock use, pond has limited value. Design criteria were not met or properly developed.



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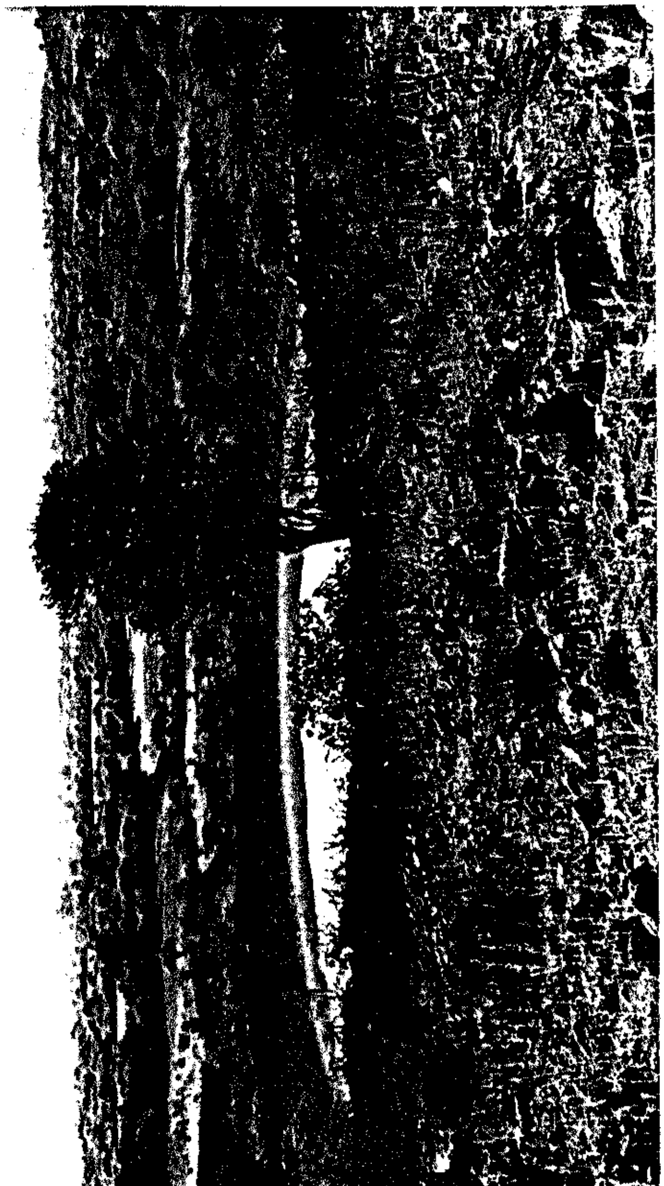
Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Conrado Panozo, 4 families	600 M^3 (actual volume 1200, never fills completely see problems below)	Functioning Adequately	Supplemental Irrigation and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By Sept.	All in Place	Adequate	Limited, as need arises only	40 M^3/ YR.

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Little or no improvement in soil erosion or cover conditions and erosion in actual pond occurring as design criteria were not met.	Size too large for DA, high water losses in canal system, maintenance limited, pond banks eroding as DA steep and few check dams	2.0 Has.	0.3 Has.	Limited supplementary irrigation and livestock, 10% max. estimated increase in agricultural production. Failure to adequately meet design criteria. Plan to divert water from neighboring DA being considered.



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Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Guillermo Rodriguez, 4 families	5000 M^3	Functioning Well	Supplemental, Small-Scale and Permanent Irrigation, and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Year Round	Partial	In Crop Area Only	Do Yearly	60 M^3/ YR. (if not maintained)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of soil and cover conditions near sites within pond influence and cover conditions in fields below.	No significant problems, but all complementary structures should be completed, use water more efficiently, area to irrigate large.	10.0 Has.	2.0 Has.	On average 3 additional crops can be produced per year. Estimated 50% increase in overall agricultural production. If all complementary structures in place could increase ag. production.

19

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Fidel Rodriguez, 4 families	1000 M^3	Functioning Adequately	Supplemental Irrigation, Small-Scale Irrigation, and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By Aug.	None	Good Overall	Limited, as need arises only	50 M^3/ YR. (Max. life 20 Yrs.)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of soil and cover conditions near sites within pond influence, improvement of cover conditions in crop area.	Size, but lack of complementary structures more of a problem, DA feeds at least 5 ponds. Sedimentation and algae high.	2.0 Has.	0.6 Has.	On average 2 additional crops can be produced per year. Estimated 20% increase in overall agricultural production. If all complementary structures in place could increase ag. production.

20

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Indalicio Villarroel, 6 families	No Capacity (originally excavated volume 1000 M^3)	Completely Abandoned	None	None

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Scant Trace	None	None	None	NA

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental Permanent	Crop Production and Additional Comments
Soil erosion and cover conditions within and around pond area worse than before pond.	Farmers never completed any tasks to make pond function, worked initially then abandoned.	Abandoned Pond, No Irrigation	None, pond has no water and value. Pond planned as part of Prickly Pear cactus project in which farmers had no interest. Goats entered project.

21

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Carlos Veizaga 6 families	500 M ³ (in past volume 1000, pond destroyed then rebuilt at current vol)	Functioning Adequately	Supplemental Irrigation and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By Aug.	None (destroyed in storm)	Adequate	Limited, as need arises only	30 M ³/ YR. (Max. life 15 Yrs.)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of soil-erosion problems, rills retarded, but not cover conditions to a great extent.	Size-local, pond was washed out in past. Steep slope of DA and sediment caused destruction.	1.0 Has.	0.2 Has.	Limited supplementary irrigation and livestock, 20% max. estimated increase in agricultural production, 1 additional crop, depends on the yr.

22

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Leonidas Iriarte, 6 families	1000 M^3	Functioning Adequately	Supplemental Irrigation and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By Aug.	All in Place	In Crop Area Only	Do Yearly	30 M^3/ YR. (if not maintained)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Little or no improvement in soil erosion or cover conditions but erosion in actual pond occurring as design criteria was not met.	Size is limiting factor for full agricultural potential. Pond banks eroding, no measures taken to retard process.	2.0 Has.	0.4 Has.	Limited supplementary irrigation and livestock, 25% max. estimated increase in agricultural production, 2 additional crops, depends on the yr. Size of pond and more reliable water sources could increase ag. output

23

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Emilio Montano, 3 families	300 M^3	Functioning Adequately	Supplemental Irrigation and Livestock	Runoff Only

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By April	All in Place	In Crop Area Only	Limited, as need arises only	30 M^3/ YR. 10 yrs., if not maintained

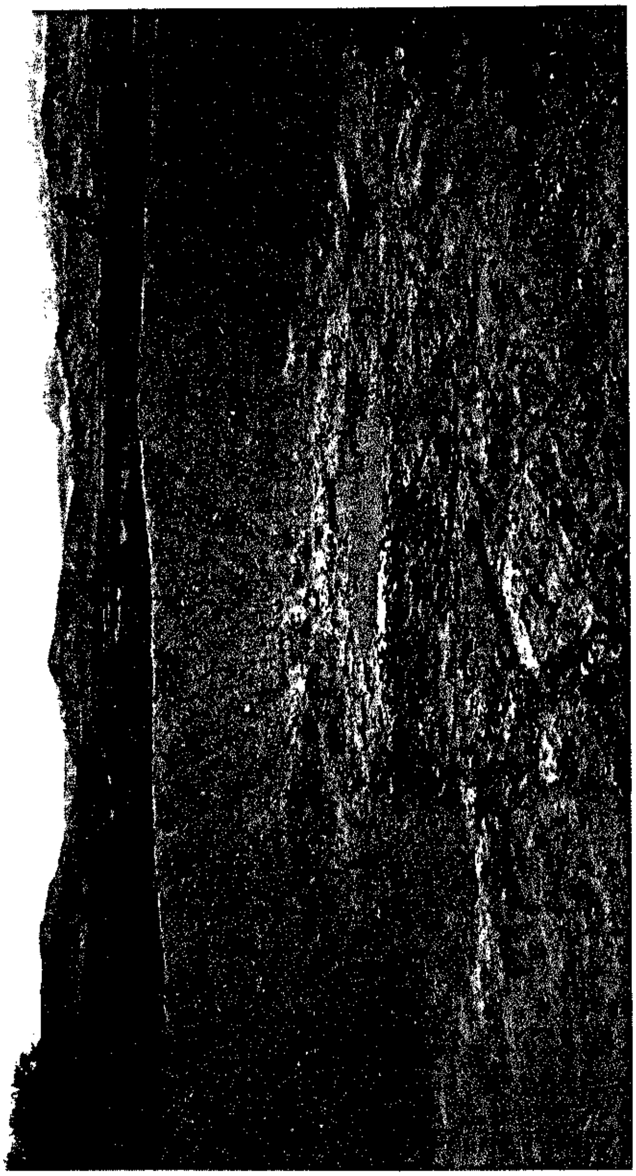
Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Improvement of soil but not cover conditions near sites within pond influence, improvement of cover conditions crop area only.	Size is limiting factor. Design criteria lacking as drainage area far from pond. Pond siltation, maintenance lacking.	0.4 Has	NA	Limited supplementary irrigation and livestock, 10% max. estimated increase in agricultural production. Pond volume insufficient for full agricultural potential.

24

Person In Charge, and Number of Families per Pond	Existing Pond Capacity	Current Condition	Pond Use	Water Sources
Marco Villarroel, 8 families	300 M^3	Functioning Poorly	Supplemental Irrigation and Livestock	Runoff and Gully Flow Combination

Water Availability	Complementary Structures, Extent	Extent of Fencing	Maintenance	Sedimentation Estimate
Dries Up Each Year, By April	None (has canal collectors)	In Crop Area Only	None	30 M^3/ YR. (Max. life 10 Yrs.)

Alleviation of Land-use Problems	Problems Identified Comments	Irrigation Increases (Potential) Supplemental	Permanent	Crop Production and Additional Comments
Little or no improvement in soil erosion or cover conditions at least not on a noticeable scale.	Size, lack of complementary structures and maintenance limit ag. Canal collectors are too long, high water losses.	0.4 Has	NA	Limited supplementary irrigation and livestock, 10% max. estimated increase in agricultural production. Very limited size for agriculture or soil / water conservation benefits.



Summary, Complementary Structures and Maintenance

As outlined in Section 5, Pond Design, Construction, and Use, complementary structures include : canal collectors to channel runoff to the pond, a silt trap at the pond entrance to alleviate pond sedimentation, fencing of sensitive areas such as the around the pond and crop fields below, terracing and rock check dams in the catchment areas to aid in soil and water conservation and to slow down the "time of concentration to the pond," a riprap spillway to prevent pond destruction during overflow and a properly developed water distribution network from the pond to the fields below. Other measures to increase water capture / use efficiency might include additional soil and water conservation practices in the catchment areas in conjunction with in-field agronomic practices.

Routine pond maintenance is done during the dry season and includes not only the periodic cleaning out of accumulated sediment in the actual pond but also the maintenance of the catchment area and all complementary structures. This includes the inspection, cleaning and repairing of canal collectors, check dams, terraces and the silt trap at the pond intake area. Fencing is replaced or installed if need be. Within the actual pond the inside and outside banks are inspected as well as the spillway section. Any sediment taken out of the pond can often be used on the actual pond banks for repair purposes. This is also an ideal time to inspect the water delivery network from the pond as well as the actual irrigation canals developed to carry water to the fields below.

APPENDIX II

SAMPLE FIELD FORMS, ENGLISH and SPANISH

I CHECKLIST FOR ONSITE POND SURVEY TO ASSESS VIABILITY OF 24 PONDS OF AUTHOR'S 1993 PROJECT, (English)

To be accomplished through in-field measurements, physical inspection of pond sites, interviews with all parties involved and the utilization of data/information from HCA NGO and USAID and its contractors. Photographs will be taken at each pond.

A) Current State/Condition of Ponds and if the design criteria were met

1) **Current State:** washed out, silted in, functioning poorly, functioning well, never functioning, never utilized, abandoned, other?

2) **Meeting of design criteria:** soils (clay or other suitable), drainage area (adequately developed and of right material, cover conditions, sized correctly, slope), pond location (collects all runoff, not washing out or filling in, above fields to irrigate), pond design (as per USDA/NRCS guidelines), water sources (runoff or other), volume sufficient for needs, fencing in areas where needed, sedimentation (in all functioning ponds, to be estimated by measuring dimensions and noting differences in volume that have occurred since time of excavation and/or noting actual sedimentation depth in pond through measurement), other?

B) Irrigation water increases: are no "gauging stations" for ponds, how often fill and is volume adequate for needs, water through out year and every year, average volume per year, will meet future needs or volume decreasing, how many more crops/yr. from pond, other?

C) Crop Production: increases (yes or no and in what quantities), agricultural production trends (up or down and what crops, in tons/yr.), comparison with pre-pond conditions, check agricultural records available through NGO and USAID and contractors and farmers.

D) Alleviation of land-use problems: most qualitative of four categories, by Interview with all parties involved, photo analysis, landuse practices in (case by case) immediate area, in short are land conditions better or worse off in pond areas due to project, another thesis?

E) In addition to all field data collected a well functioning "model atajado" will be analyzed to assess its functionality and design features/criteria.

F) In order to update all background information and elaborate upon the topics as outlined in the thesis proposal all in-country resources such as USAID and contractors, Peace Corps library and any other information sources will be utilized to their fullest extent

July 1998 Draft, field form for Master's thesis of John R. Kuiper

Copy, Actual Field Form Used, (Spanish)

ENCUESTA EN EL SITIO DE LOS ATAJADOS PARA VALORAR EL COMPORTAMIENTO POSITIVO O NEGATIVO DE LOS MISMOS DENTRO EL PROYECTO DEL AUTOR.

Parámetros para determinar el cumplimiento de las metas en los atajados en el campo.

A. ESTADO ACTUAL.

1. Condición de los atajados, si los criterios para su diseño fueron realizados o cumplidos.

a) fueron dañados por el exceso de agua.

....

b) Fueron colmados por el sedimento.

....

c) Funcionamiento bueno o inapropiado.

....

d) Nunca funcionaron.

....

e) Nunca fueron utilizados.

....

f) Fueron abandonados.

....

g) Otras situaciones.

....

2. Criterios para su diseño.

a) Los suelos y el material del sitio de ubicación fueron seleccionados.

....

b) - Se efectuó una buena selección de la cuenca.

....

-Se consideró la extensión de la cuenca.

....

-La pendiente de la cuenca.

....

-La cobertura del suelo, tipo de vegetación o hubo una roca en el lugar.

....

UBICACIÓN DEL ATAJADO.

- Fueron ubicados en un sitio adecuado para la captación del agua de escurrimiento.

....

- Se ubicaron en la parte alta de los terrenos que deben ser irrigados.

....

- Se ubicaron en sitios en los que existe una alta sedimentación.

....

FUENTES DE AGUA

- Se alimentan con el agua de escurrimiento de las precipitaciones.

....

- Se alimenta con el agua de un rio o quebrada.

....

- Se alimenta con agua de una vertiente.

....

- Se utilizan como reservorios de agua en un sistema de riego.

....

- El tamaño de su diseño fue suficiente para satisfacer las necesidades de riego.

....

- Fueron necesarios cercos de protección para evitar el acceso de ganado.

....

Se efectuó un plan de mantenimiento del atajado

....

SEDIMENTACION

- Existe alguna forma de calcular la cantidad de sedimento acumulado.

....

B. INCREMENTO DEL AGUA PARA LA IRRIGACION.

- Cuántas veces se llena el atajado durante el año o periodo de lluvias.

....

- Hay agua durante todo el año y cada año.

....

- El volumen del agua es adecuado para satisfacer sus necesidades de riego.

....

- Cuál es el volumen promedio de agua en el atajado.

....

- Va a satisfacer sus necesidades de agua en el futuro.

....

C. PRODUCCION DE CULTIVOS

Cuántos cultivos adicionales se producen con el agua del atajado durante el año.

....

Cuáles son los incrementos de los cultivos en relación a la situación anterior sin atajado.

....

D. SITUACION DE LOS SUELOS EN EL AREA DEL ATAJADO

Hubo una menor erosión o pérdida de suelos en el área del atajado.

....

Hubo un incremento de la erosión de los suelos en el área o cuenca del atajado.

....

Las condiciones generales desde la implementación del atajado han mejorado o empeorado.

....

E. EXISTE UN ATAJADO DE FUNCIONAMIENTO IDEAL Y CUALES SUS CONDICIONES.

- Si se lo encuentra sacar fotografia.

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