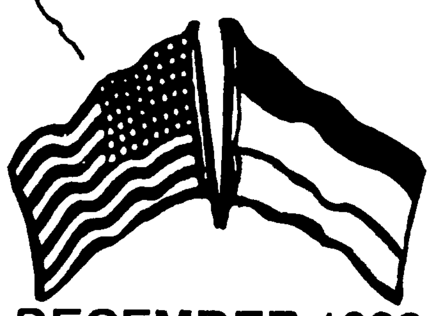
COESAM/PDM-91/002

EVALUATION OF WATER RESOURCES IN BOLIVIA, SOUTH AMERICA



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This is a reprint of a limited advance edition of a December 1990 report on the same subject. This edition differs from the original report primarily because of typographical and grammatical corrections. The only substantive change is the addition of a "Rainfall Gage Network" discussion on pages I-10 through I-12 in Appendix I. This discussion was added to clarify the adequacy of rainfall monitoring networks.

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ACKNOWLEDGMENT

This report was prepared for the United States Agency for International Development in Bolivia, South America (USAID/B). The report was authored by the "Water Resources Advisory Team" - the four undersigned water resources specialists from the U. S. Corps of Engineers Office in Mobile, Alabama, USA. The objective of this evaluation was to assist USAID/B in developing a framework plan for future water resource investments in Bolivia.

The Water Resource Advisory Team conducted water resources investigations in Bolivia for one month in October and November 1990. During this period, the team consulted with numerous individuals in the public and private sector. In all, literally hundreds of individuals throughout Bolivia helped form the recommendations outlined in this report. The cooperation and support of USAID/B officials, the American Embassy, Department leaders, national officials and private professionals were simply exceptional. The undersigned members of the Water Resources Advisory Team wish to thank all of those individuals for their contributions to this report.

DONALD J. CHATELAIN, P.E.
Team Leader, Water Resources
Planning Specialist

HOWARD M. WHITTINGTON, P.E.
Engineer, Hydrology and
Hydraulics Design Specialist

JOHN H. BAEHR, P.G.
Geologist, Ground
Water Specialist

CLAUDIA M. ROGERS, Ph.D.
Social Anthropologist,
Social and Economic Specialist

EXECUTIVE SUMMARY

In early 1990, several regions in Bolivia suffered from a severe drought. The United States Agency for International Development in Bolivia (USAID/B) retained the U.S. Corps of Engineers to conduct a professional appraisal of the drought situation. The purpose of this appraisal is to establish a framework which will assist USAID/B, and possibly others, in making water resource investments in Bolivia. This report is the product of a two-month effort on the part of four water resources professionals - the "Water Resources Advisory Team" from the Mobile, Alabama District of the Corps.

Bolivia is rich in hydrologic resources, although the spatial distribution and the temporal variations in hydrologic activities complicate the efficient use and management of the resources. The recent drought has highlighted the need for better conservation and management of water resources. The major needs are: water quality and pollution control; erosion control; changes in land use practices and soil conservation; a stronger national water resource management and policy structure; a rehabilitation of existing water resource projects and equipment; environmentally sustainable development of water supply resources; the improvement of the natural environment; and the involvement of the Bolivian people in water resources development.

Obviously, satisfying these needs will have to be a long-term undertaking of the Bolivian government. The intent of this report is to provide a framework for the first step in this long and arduous process. Thus, the recommendations documented in this report are directed towards a practicable approach of blending water resource development projects with reasonably attainable changes in water management, environmental improvements and populace involvement.

There is an enormous need for various water resource projects and programs in southwestern Bolivia. There are serious shortages of water supply throughout the southwestern part of the country. The rural areas of the department of Cochabamba need both potable and irrigation water. The city of Cochabamba is in dire need of a water supply. Likewise, the department and city of Potosi are in dire need. Water is provided only for 2 hours or less each day in both these cities. The cattlemen and farmers of the Grand Chaco areas of the departments of Tarija, Chuquisaca and Santa Cruz are in desperate need of both potable water and water for livestock and crops. Cattle populations have dropped drastically because of drought. There is a tremendous erosion problem which needs to be addressed in the area - especially in the department of Tarija. The people of the Altiplano in the departments of Potosi, Oruro and La Paz are in serious need of potable water. Many are having to walk hours to obtain water for household use. Water pollution is a serious problem throughout southwest Bolivia - especially in La Paz.

To begin to address these problems, 23 projects and programs are recommended in this report. These are: the San Juan diversion project in Potosi; a National Well Drilling Program; a National Water Resources Management and Policy Strategy; a National Program for the Rehabilitation of Existing Water Projects; a Cistern Design and Construction Program in the Grand Chaco; an erosion control project at Tarija airport; a flood warning system for the city of Santa Cruz; a National Stream Gaging Network System; geophysical surveys in Vallegrande; erosion control projects in the Tarija Valley; a multipurpose dam in Cochabamba; a diversion project to help 40 communities between Baisilio and Rio Seco in the department of Santa Cruz; a groundwater analysis in the departments of Cochabamba and Potosi and in the Chaco areas; construction of undrground dams in rural areas of the departments of Cochabamba, Chuquisaca and Potosi; a water supply dam and distribution system in the Yacuiba area; small water supply dams in the Aiquile area; providing engine-driven pumps for wells in rural areas without electricity; the evaluation of dam sites in the Chaco area; a water budget for Cochabamba; construction of water distribution systems in rural areas of the department of La Paz; modern rock drilling tests; water treatment for La Paz; and technical assistance in developing water resource plans.

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IN BOLIVIA, SOUTH AMERICA
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INTRODUCTION

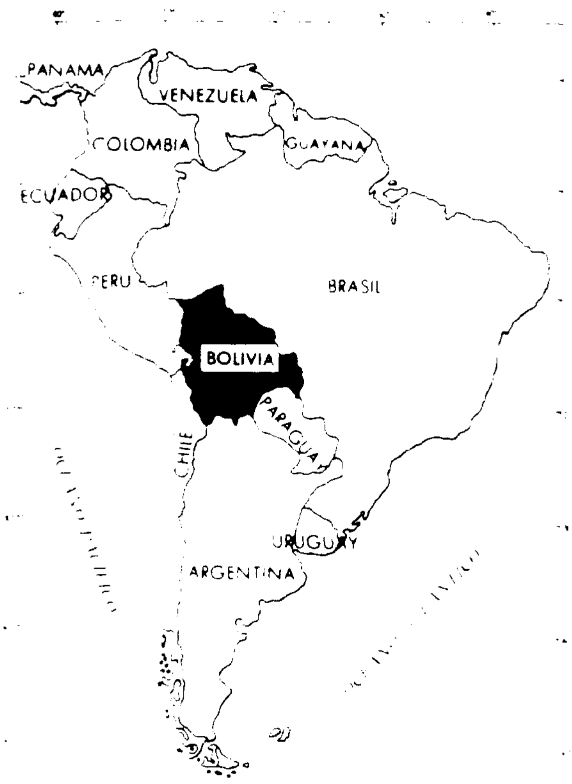


Figure 1. Location Map of Bolivia

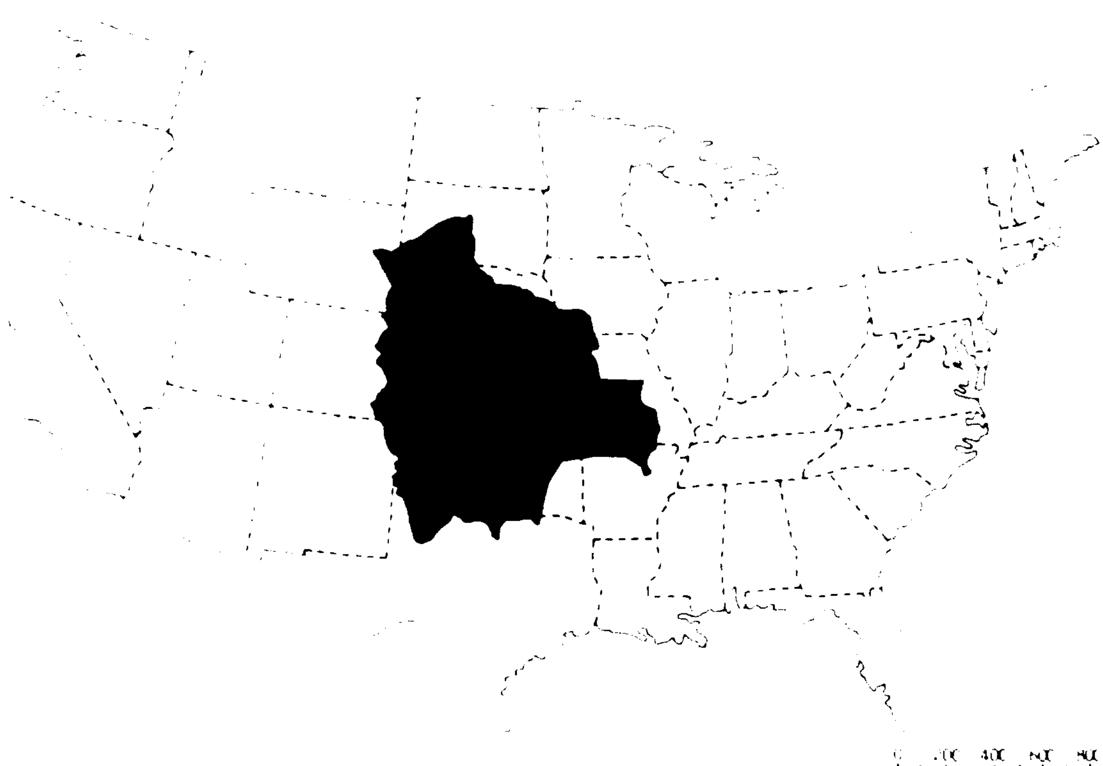


Figure 2. Relative Size of Bolivia vs. United States

INTRODUCTION

General Background. In early 1990, several regions in Bolivia suffered from a severe drought. In many areas it was an extension of a drought which had plagued the country since the early 1980's. On April 26, 1990, Acting President Luis Ossio declared several areas of Bolivia to be disaster and emergency areas because of severe drought. That declaration identified approximately 60 provinces in the departments of La Paz, Potosi, Cochabamba, Tarija, Oruro and Chuquisaca with drought problems. Initial estimates of the number of people impacted by the drought ranged as high as one million.

Along with the government of Bolivia's declaration of drought emergency came a request for international assistance. In response to this request, the U.S. Mission in Bolivia initiated action through several forms of American assistance. Concurrent with emergency assistance, the United States Agency For International Development in Bolivia (USAID/B) conducted an assessment of the scope of the drought problems. That assessment identified about 57,000 families who were impacted by the drought. Of these, about 15,000 families were classified as suffering very severe hardship.

The immediate response to assist drought victims was providing potable water, food aid and water for animal consumption. Beyond this immediate need, several of the regional development corporations in Bolivia prepared reports identifying near- to long-term proposals that would help alleviate drought. The comprehensiveness of these reports varied between departments; however, the net results of all the proposed actions and projects recommended totalled billions of dollars. A summary of these reports as well as a large number of other reports is documented in the 24-page Annotated Bibliography contained in Appendix O. A brief review of all this diverse information will illustrate the impracticability of determining the "best" utilization of available resources without follow-up evaluations. This was one of the primary reasons USAID/B retained the U.S. Corps of Engineers to conduct a professional appraisal.

Purpose. The purpose of this report is to establish a framework plan which will assist USAID/B, and possibly others, in making water resource investments in Bolivia. To accomplish this goal, the Mobile District selected an interdisciplinary "Water Resources Advisory Team" consisting of four water resources professionals to assess the situation. This team's appraisal was accomplished by reviewing existing documents and reports, visiting Bolivia for one month to consult with various engineers, officials and others, and making reconnaissance-level site visits in order to assess the water resource needs of the country.

Scope of Evaluation. This report is the product of a two-month effort on the part of the four water resource professionals. Its scope was necessarily confined to a "professional opinion" given the large geographical area involved and the host of technical reports available on drought in Bolivia. The research of existing technical documents can best be defined as selective and cursory. The field data gathered was strongly influenced by the expertise of in-country engineers and officials and the degree of their involvement in water resources development. Nevertheless, we feel that the broad perspective of this assessment will assist USAID/B in making wise investments decisions in the water resource development of Bolivia.

Level of Detail and Costs. This report presents a number of cost estimates for various water resources activities and projects. All of these costs are in US dollars. Many of the project cost estimates are a restatement of the cost quoted by in-country technical specialists. The scope of our evaluation limited us to accepting those estimates without verification. The many estimates we did develop should be recognized as order-of-magnitude numbers based on professional opinion. For exampie, we provided an estimate for repairing all of the malfunctioning pumps in Bolivia without an inventory and prepared estimates for overhauling drill rigs we had never seen. The Water Resources Advisory Team felt that it was appropriate to generate these unrefined estimates since our primary purpose was to assist USAID/B in deciding on water resource investments. Without these estimates, it would be extremely difficult to make decisions and to budget funding for the future.

We trust these educated guesses are used in the spirit of the context for which they were given.

Limits of Study Area. Because of the drought emphasis of this report, the study area is limited to the southwestern portion of Bolivia. A generalized map of the country is included as Figure 3 page 34. This area is commonly referred to as the Altiplano (high plain), the eastern ridge of the Andes and the Chaco area. The tropical lowlands in the departments of Pando, Beni, northern and eastern Santa Cruz and northern La Paz have an abundance of rainfall and in general have not been impacted by drought. The areas most impacted in Bolivia are the departments of Cochabamba, Potosi, Tarija, Chuquisaca, Oruro, western Santa Cruz and southern La Paz.

Socio-Economic Profile of Bolivia. Bolivia is one of two land-locked countries on the South American continent. See Figures 1 and 2 on the first page. The size of the nation is approximately 1.1 million square kilometers. Fifty percent of the land area is in the tropical and sub-tropical Beni/Chaco plain extending from the northwest to the southeast. The remaining land mass is divided almost equally between the mountainous and high plateau zones (Brockmann 1986:8). Recent estimates put the number of people in Bolivia at nearly 7 million with a majority living in the mountainous half of the country (Americas Review 1990:30). The plains and tropical lowlands are rapidly becoming key population centers however. For example, in the department of Santa Cruz, sugar, cotton, and oil and gas refineries attract thousands of Bolivians from other areas. In Cochabamba, the Chapare region has become well-known for its lucrative cocaine production. Indeed, a World Resources Institute report claims that while Peru produces almost 60 percent of the world coca crop, Bolivia is the second largest producer with up to 30 percent. Colombia, Brazil and Ecuador make up the remaining 10 percent. Between 1980 and 1986, land devoted to coca in Bolivia was expanded from 23,000 hectares to 71,000 hectares, an increase of over 300 percent (World Resources Institute 1990:44). By 1988, the Bolivian government estimated that coca production had gone up by 20 percent.

Despite this increase in coca-plantings and continued clearing of rural lands for coca production, the population in urban areas has increased. Today, almost 60 percent of Bolivians live in urban centers compared to 40 percent in 1980. This shift puts pressure on municipalities that local officials cannot meet. One estimate claims that 80 percent of the nation's populace live at or below poverty levels (Americas Review 1990:32). Such serious human problems also affect the economic health of the nation. The agriculture sector accounts for about 22 percent of Gross Domestic Product (GDP) and includes nearly 50 percent of the workforce. Yet food production has not kept pace with the nearly 3 percent annual increase in population. As a consequence, precious foreign trade dollars must be paid to import food.

Another 20 percent of GDP comes from industry which primarily supports the limited domestic market. The industrial base of Bolivia is centered on the processing of minerals such as tin, lead and zinc; on foodstuffs; and on exploiting oil and natural gas reserves. Mining has declined in importance in the past twenty years so that its current contribution to the nation's economy is only 7 percent. Bolivia continues as a major world tin producer but this status is undermined by the relatively low quality of the ore and the high cost of extraction. The country also has gold, silver, copper, limestone and significant reserves of lithium and potassium.

Bolivia appears to have a reasonably diverse economy and substantial and impressive resources, both natural and social. Unfortunately, there are several factors which seriously constrain development in Bolivia and, therefore, hinder its progress toward wealth and quality living. Those factors include: location of major subsistence farming in areas besieged by either drought or flood; shortages of raw materials for manufacturing; limited investments in local enterprises; weak domestic demand for industrial goods combined with a poor infrastructure; cumbersome institutional bureaucracies and a viable and growing black market production and retail sector (de Soto 1989); and the human and financial costs of the drug trade.

<u>Water Resources in Bolivia</u>. Bolivia is rich in hydrologic resources, although the spatial distribution and the temporal variation in hydrologic activity complicate the efficient use and management of these resources. Figure 4, on

page 35 shows the distribution of average annual rainfall in millimeters (mm) throughout Bolivia from 1951 through 1982. The country's resources of rivers range in size from those that are navigable year round to those that are strictly seasonal and short-lived. Despite the apparent abundance of water resources in Bolivia, the recent drought has served to identify the need for better conservation and management of resources.

The country is located within three hydrographic basins (See Figure 3 on page 34):

The Amazon Basin	724,000 square kilometers
The De La Plata Basin	229,500 square kilometers
The Altiplano Basin	145,081 square kilometers

The Amazon basin is located in the middle, north and northwestern part of the country and drains approximately 66 percent of Bolivia. Its influence is particularly evident in the Pando, Beni, and Cochabamba departments as well as part of La Paz, Santa Cruz, and Chuquisaca. It has four sub-basins:

Madre de Dios	31,000 square kilometers
Beni	183,000 square kilometers
Mamore	216,000 square kilometers
Itenez/Guapore	294,000 square kilometers

The De La Plata basin drains about 20 percent of the nation and lies in most of the central and southeastern parts of the country. This basin influences the departments of Tarija and parts of Oruro, Chuquisaca, Potosi, and Santa Cruz. The three sub-basins are:

Bermejo	16,200 square kilometers
Pilcomayo	98,100 square kilometers
Paraguay	115,200 square kilometers

The Altiplano basin is located in the western part of the country and drains about 14 percent of the nation. Its influence is mostly found in the La Paz, Oruro, and Potosi departments. It has four sub-basins which are:

Lake Titicaca	12,580 square kilometers
Lake Poopo	43,100 square kilometers
Salar de Coipasa	28,951 square kilometers
Salar de Uyuni	60,450 square kilometers

Water Supply and Treatment. Public water supplies in Bolivia vary greatly in quantity and quality. Available supply to some of the major cities has been estimated to be:

City	Amount in Liters Per Person Per Day
Sucre	100
La Paz	150
Oruro	100
Cochabamba	40-80
Santa Cruz	150
Tarija	40-180
Cobija	30

The lack of treatment of public water supplies in many areas poses health risks. Contamination of water supplies occurs primarily due to inadequate sanitary waste disposal practices. Data indicate high levels of water-related illnesses and deaths in both rural and urban areas. These problems are complicated by lack of money to develop better facilities and an absence of abundant water sources in many of the more heavily populated areas. On a national basis, household effluents are treated and disposed of as follows:

Public Sewerage	12.4%
Septic Tanks	2.0%
Latrines	7.5%
No Treatment	78.1%

Clearly there is much to be gained in the area of public health by merely constructing public sanitary facilities and teaching basic sanitation.

Irrigation. Although over two million hectares are under cultivation, less than 10 percent of the area is irrigated. Additional irrigation projects are badly needed in Bolivia to support the livelihood of the people. These projects are especially needed during periods of prolonged drought.

Hydropower. The hydropower potential of Bolivia has been estimated at about 241,500 MWH according to the Organization of American States (OAS) in 1985. About 35 percent of the population receives its electricity from hydropower sources.

Summary of Report Contents. The balance of this report contains the following:

(a) EVALUATION OF WATER RESOURCE NEEDS AND OPPORTUNITIES. This section of the main text contains a water resources profile of Bolivia and summarizes the national water resource needs of the country. This is followed by a similar summary for each of the seven departments in the study area - Cochabamba, Potosi, Chuquisaca, Tarija, Santa Cruz, Oruro and La Paz. These department discussions are essentially a summary of the detailed information on each department contained in Appendices A through G.

(b) RECOMMENDED APPROACH TO WATER RESOURCES DEVELOPMENT. This section outlines the suggestions and recommendations of the Water Resources Advisory Team. Cost estimates for these projects and activities and potential phasing of work are also discussed.

(c) Appendices A through G contain a complete discussion of water resources in each of the seven departments. These appendices include a discussion on: climate, rainfall and topography; socio-economic profile; surface water resources; groundwater resources; specific problem areas; and a suggested strategy.

(d) Appendices H through M contain a detailed description of needed national programs and suggested engineering design of selected water resource structures.

(e) Appendix N contains a biographical sketch of the four members of the Water Resources Advisory Team.

(f) Appendix O is a annotated bibliography of the water resource materials which was used in preparation of this report. This reference information was included to assist others who may undertake the study of this subject in the future.

(g) Appendix P contains photographs which are referenced throughout the report.

EVALUATION OF WATER RESOURCE NEEDS AND OPPORTUNITIES

EVALUATION OF WATER RESOURCE NEEDS AND OPPORTUNITIES

General. Bolivia is a land of contrast. This landlocked country covers an area of nearly 111,000 square kilometers - an area about the size of Texas and Oklahoma in the United States. See Figure Number 2 on the first page. The topography of the country greatly influences the climate and thus the environment. The northern and eastern portions of the country in the departments of Pando, Beni and Santa Cruz are tropical lowlands. Rainfall in these lowlands generally ranges from 1,000 to 2,000 mm per year. This rainfall and runoff from the mountains of the Yungas and eastern Cordillera flows into several major streams such as the Beni and Mamore Rivers. Ultimately these waters become a part of the massive Amazon River system. This is in great contrast with the Altiplano where average annual rainfall ranges from less than 100 mm to 600 mm, with an average of about 200 mm. This area is also on a high plain, almost 4,000 meters above sea level, where evaporation rates are especially high. The rivers of the Altiplano are few and small because of the arid climate. Further, salt flats in the area make a great deal of the water unuseable. As one might expect, this area supports little vegetation and is sparsely populated. To the east are the Valley, Yunga and Chaco areas of Chochabamba, Chuquisaca, Tarija and some parts of La Paz, Oruro, Potosi and Santa Cruz. Rainfall is these areas ranges from 300 to 1200 mm. These rains, however, are very seasonal - with about two thirds of the precipitation occurring in the spring months of December through February. The intensity of these rains coupled with the steep topography and soil conditions leads to a rapid runoff. Thus, many of the streams are dry most of the year. This "normal" situation together with fact that 75% of the people and most of the agricultural production in Bolivia are in this region, makes the area very susceptible to drought. This report focuses on that problem.

In any developing country, infrastructure needs are enormous - water resources, roads, hospitals, schools, electrification, regional development, etc. Even from a narrower viewpoint of water resources development, the needs and opportunities are very complex. Minimizing the effects of drought can be over-simply stated as harnessing additional supplies of water for a specific area whether it be from the construction of dams, tapping of groundwater, saltwater conversion, weather modification or by transferring water from one area to another by various means. That may be true to a certain extent but other variables must be considered in the formula to visualize the broader picture. The long-term solution to water resource needs in Bolivia must incorporate a combination of proper management, conservation and changing societal habits in the use of water and land resources. Without these ingredients, the beneficial effects of water resource projects (dams, lakes, ponds, groundwater, diversions, etc.) will be short-lived. For the purpose of this report, we limit our recommendations to a "practicable" approach of blending water resource development projects with "doable" management, environmental and societal changes. However, we feel that this is just the first step in a long and arduous process.

There are several water resource needs in Bolivia which transcend geographical boundaries or political subdivisions. Although some of these national needs could be reduced to a project in a specific location, the need is common throughout the drought impacted areas of southwestern Bolivia. These water resources needs can be broadly classified into the following categories:

(a) Water Quality and Pollution. This is a major problem in every major city and community as well as throughout the rural areas of Bolivia. It has serious implications on the health of the entire nation. Even as serious as these problems are, we feel that the realistic opportunities at this time are limited to education of the populous and relatively small-scale, problem-by-problem programs. This is simply because of the enormity of needed environmental and societal change and the billions of dollars it would take to correct these problems. For the purposes of this report, these problems are not considered to have realistic solutions for immediate implementation and must be considered as a part of a long-term comprehensive water resources development program of Bolivia. Further, most of these problems would exist even without drought, although acute shortages of water can greatly compound them. Perhaps the development of comprehensive water resource management plans and projects will neutralize the impact of drought on water quality and pollution. Nevertheless, the basic problem will remain.

(b) Past and Present Land Use Practices. Throughout Bolivia we observed signs of inefficient past and present uses of soil and water resources. Poor farming methods, lack of knowledge in soil conservation techniques, slash and burn agriculture, overgrazing, and deforestation of land have led to high run-off of rainfall, soil erosion, degradation of vegetative cover, loss of soil productivity, sedimentation in streams and lakes, loss of groundwater recharge, and pollution of surface and groundwater resources. In Appendices A through G we discuss the need for a long-term improvement process in these areas as a part of any water resources development project.

(c) National Well-Drilling Program. In many of the departments we visited, the most cost effective means to combat drought in the near term is through well drilling. Thus, we suggest that a national well-drilling program be considered for Bolivia. This program would consist of overhauling the well drilling rigs in-country, purchasing four additional small drilling rigs, and procuring an initial inventory of materials, pumps, parts and a spare parts package. The central theme of this program however, is overall national development and strict monitoring of the program. This program is estimated to benefit about 200,000 people over the three-year period at a cost of about $2.5 million. This program is discussed in detail in Appendix H.

(d) National Stream Gaging Network. A tremendous amount of technical data and information is needed to effectively develop and manage the water resources of Bolivia - topographic mapping, climatic data, river flow data, groundwater data, etc. Appendix I contains a detailed discussion of a program to develop a national network to monitor river flows on critical streams in the country. This vital information will better equip engineers for the design of public works such as dams and bridges. The initial cost of this effort is in the order of $1 to $2 million depending on the amount of coverage that is selected.

(e) National Water Resource Management and Policy. There are numerous national water management and policy issues which should be pursued. Among these are: establishment of a strong national water resources agency; enactment of national water laws; promotion of land and water conservation through education and experimentation; enhancement of coordination between various local, national and international agencies; a strengthening of the interchange and coordination of technical data and information; and the establishment of a national data base. The opportunities for improving Bolivia's ability to manage its water resources by improvements in these areas are great; however, a realistic appraisal of the chances for success is limited due to societal attitude and the parochial nature exhibited by local bureaucracies throughout the world. Despite this, we do recommend being proactive in these areas. Perhaps the most practicable and tangible approach lies in two suggestions - the establishment of a President's Commission on Water Resources and sponsoring periodic national/international symposia on Bolivian water resources. The Commission would evaluate the nation's overall and regional water policy needs and make recommendations to the President. The symposia would be co-sponsored annual, or bi-annual, meetings designed to promote interchange of information and technology. The more difficult proposals deal with the possibilities of establishing a national clearinghouse; establishing a water resources council comprised of agency heads, international entities and political leaders; and independent staffing for a complete inventory and evaluation of all water resources activities in Bolivia. All of these propositions are discussed in more detail in Appendix J.

(f) Rehabilitation of Existing Water Resources Projects. Throughout the drought stricken areas of Bolivia, there are wells without pumps, wells with broken pumps or parts, artesian wells without valves and water holding and distribution systems with serious leakage. Many of these problems can be corrected with a very small investment per person benefited. Our brief visit to Bolivia did not allow us time to completely inventory all of these problems; however, we received reports on hundreds of such situations and suspect that there are a thousand or so. The possibility of developing a program to inventory and correct most of these deficiencies nationwide is discussed in Appendix K. The cost of this program is estimated to range from \$200,000 to \$600,000. It is felt that these improvements will benefit from 30,000 to 90,000 people.

Cochabamba. The department of Cochabamba lies in the heart of Bolivia along and in the eastern range (Cordillera Oriental) of the Andes mountains. The department covers some 55,600 square kilometers and has a population of nearly one million. The economy of the area relies heavily on agriculture - producing about one-third of the grain and foodstuffs for Bolivia. Because of the orographic effects of the eastern Andes mountains, rainfall varies drastically, from less than 300 mm in the western part of the department to over 4000 mm in the Chapare region north of the capital city of Cochabamba. Average rainfall in the most populated area of the department, near and east of the city of Cochabamba, is about 600 mm. The topography of the department is characterized by a series of northwest-southeast trending valleys and ridges with considerable faulting.

Water supply in the department is obtained primarily from groundwater with supplemental reserves from reservoirs near the city of Chochabamba. Irrigation water in rural areas is normally obtained from small scale stream diversion projects and holding ponds. The central valley in the populated areas contains two aquifers approximately 60 and 120 meters deep. The yield for wells in these heavily used aquifers averages 10 to 50 liters per second. In fact, there are signs that the aquifers are being over stressed by over 1000 wells in the valley.

Major impoundments in the area include a large shallow reservoir, Laguna Angostura, southeast of Cochabamba and the German Punata-Tiraque project east of Cochabamba. The Laguna Angostura reservoir was used for the city water supply; however, the water is no longer of sufficient quantity or quality for use as public water supply. The newly constructed Punata-Tiraque project consists of a series of inter-connecting lakes and an elaborate distribution system of canals to carry water to various farming communities.

There are rather serious water shortages throughout the department. There is a need to develop both surface and groundwater resources in many of the outlying areas of the department. A national well drilling program will satisfy many of these needs; however, surface impoundments are needed in areas such as Aiquile. The construction of underground dams (Wadi dams) is also needed to maintain water levels in many rural wells or infiltration galleries. Wadi dam construction is discussed in Appendix L.

The city of Cochabamba and its environs have been severely affected by the drought. The city's water authority is limiting water use to two hours per day. Further, the problems are expected to worsen in the future if corrective actions are not taken. The solution to the city's water problems lies in the balanced development of both groundwater and surface water. The tremendous number of wells in the area are stressing the aquifers. The city needs to develop a water budget and monitor groundwater withdrawals to protect this vital source of water. The wise use and expansion of the wells in the area can sustain the area water needs in the near-term. However, the increasing demand for water in Cochabamba is expected to exceed available supplies by a 2 to 1 margin by the year 2010. Groundwater supplies are not adequate to sustain this increasing trend, especially in periods of drought. The future water resource needs of Cochabamba can only be accommodated through the construction of a major surface water impoundment(s). There are numerous sites available; however, the costs of these projects would be in the hundreds of millions of dollars. These projects would also take years to formulate, design and construct. The price tag for this type of development makes funding a paramount problem. However, the simple fact is that there will be critical water problems in the city of Cochabamba without their construction. Further, if drought conditions persist or recur in the future the impacts will be especially severe.

It should be mentioned that the department of Cochabamba provides about one-third of the grain and foodstuffs for the people of Bolivia. During the drought there has been a steady decline in hectares under cultivation and in crop production. Thus, in all likelihood, there will be a simultaneous increased demand for water and decreased agricultural production. This alarming trend could result in crucial economic and sociological impacts for all of Bolivia.

<u>Potosi</u>. The department of Potosi lies in the southwestern part of Bolivia in the heart of the Andes mountains. The department covers an area of 118,218 square kilometers and has a population of about 700,000. The economy is based mostly on subsistence agriculture since silver and other mining has been declining in recent years. The topography of the area is varied, but is generally at higher elevations ranging from 1,800 to 5,000 meters above sea level. The city of Potosi is one of the highest cities in South America

situated at an elevation of about 4,000 meters. Average rainfall within the department varies from less than 100 mm in the arid southern and western parts of the department to about 500 mm in the northeastern region. The rainfall in the most populated central region of the department, near the city of Potosi, averages 380 mm per year.

Sources of water vary in different areas of the department. In the Altipiano there are reserves of groundwater available; however, the small population densities make the well development cost-per-person high. The United Nations has dug a number of small shallow wells equipped with hand pumps. In the central region near the city of Potosi there is a very limited supply of groundwater. Thus, their water supply is supplied by a series of 24 small reservoirs in the mountains above the capital city. There are two major drainage basins which lie partially within the department - Rio Pilcomayo and Rio San Juan. However, the utilization of these resources is presently limited to floodplain farming and small-scale irrigation diversion structures.

The department of Potosi has been severely impacted by the drought. The needs in the rural areas such as the Altiplano can be met to some extent through a national well-drilling program. However, the critical need for water supply in the central part of the department, in the area of the city of Potosi, can only be satisfied through major water resource development projects.

The city of Potosi is in dire need of water supply. Currently, water use is restricted to two hours a day, if available at all. Fourteen of the 24 reservoirs which supply water to the city are dry. Even if the lakes were full, demand for water would exceed supply by a 3 to 1 margin. There has been a high out-migration of people from Potosi because of this problem. That trend will almost certainly continue unless some corrective action is taken.

Unfortunately, there is no substantial source of water in the Potosi area. Groundwater is very limited. Most of the good sites for surface impoundments have been developed. The most realistic option appears to be to transport water from a fairly distant source. Engineers from the regional development corporation for Potosi (CORDEPO) have identified a water source about 45 kilometers southeast of Potosi - the San Juan River. This river has a high year-round flow of good quality water. Transporting water from the San Juan

River to Potosi could be accomplished through gravity flow via pipeline or channel. Preliminary cost estimates range from $9 to $16 million. This seems to be a prudent investment to solve the most serious urban water supply/drought problems in all of Bolivia.

Chuquisaca. The department of Chuquisaca lies in the south central part of Bolivia and along the eastern range (Cordillera Oriental) of the Andes Mountains. The department covers an area of 51,524 square kilometers and has a population of around 475,000. Sucre, the capital city of Chuquisaca, is also the legal capital of Bolivia although today Sucre houses only the Supreme Court. The economy of the department is primarily centered around agriculture and animal husbandry. Rainfall in the department varies from less than 500 mm to more than 1200 mm per year, with Sucre having an average of about 600 mm. Elevations within the department range from around 500 meters in the Chaco region to over 4,000 meters above sea level in the Cordillera de Tacsara mountains. The elevation of Sucre is about 2,750 meters above sea level.

The city of Sucre has an adequate supply of water from both ground and surface sources. The water supply in the Chaco region of Chuquisaca is obtained primarily from earth cisterns (farm ponds supplied by rainfall) and from wells. Wells in the semi-arid Chaco area are used as a source of potable water only. In the cattle-raising areas, ranchers depend on earth cisterns for both domestic use and watering cattle. Irrigation is limited in this semi-arid climate; therefore, most agricultural areas are dependent on rainfall.

The most serious drought problems in Chuquisaca are in the southern mountains and the Chaco area. The cattlemen in the Chaco region have been especially hard-hit. Well drilling possibilities in the Chaco area are very limited due to costs. These costs are high for four major reasons: wells must be 200 to 300 meters deep; wells are generally low-yielding (3 to 5 liters per second); well diameters must be 8 inches (20 cm) due to pumping requirements; and large engine-driven pumps costing from $35,000 to $40,000 each must be used because there is no electricity available to operate less expensive pumps. Surface impoundments are also limited because of the lack of major streams in the Chaco. The most viable solution would be to build scores of earthen cisterns (farm ponds) to capture and store rainwater for domestic consumption and watering of cattle. The regional development corporation of Chuquisaca (CORDECH) is building as many of these cisterns as resources allow. They need assistance in the form of either help in the actual construction or the donation or loan of equipment.

Tarija. The department of Tarija lies in the south of Bolivia on the border with Argentina and Paraguay. The department covers some 37,623 square kilometers and has a population of around 200,000. The economy of the area is very diversified. There is a heavy dependence on agriculture - potatoes, corn, citrus, tobacco, corn, grape vineyards, manioc, sugarcane, wood, and animal husbandry-cattle, sheep, goats and hogs. Manufacturing includes the production of bottled drinks, construction materials, furniture, soap, candles, sugar, vegetable oil and wine. Mining production includes salt, gypsum, lime and construction stones.

The climate and topography of the department are varied. The western end of the department is in the eastern Andes with elevations ranging up to 5,000 meters above sea level. The eastern half of the department lies in the lowlands in the semi-arid Chaco region at elevations of a few hundred meters. The capital city of Tarija, in the fertile central valley, is at elevation 1,900 meters above sea level. Annual rainfall in the department ranges from 400 mm in the west and east to 1,200 mm in the extreme south central part of the department. Average annual rainfall in the central valley near the city of Tarija is 600 mm.

There is an abundance of surface water and groundwater resources in the department. The two major river basins are the Rio Pilcomayo and the Rio Grande de Tarija. Major water resource projects include the massive San Jacinto multipurpose dam project in the Rio Tolomosa valley and Phase I of the Esquema Irrigation project near Villa Montes. Other water resource projects planned are the Santa Ana Dam project east of the city of Tarija and the Aguayrenda water supply dam project in the Chaco area north of Yacuiba. The city of Tarija obtains an adequate supply of water from the relatively shallow aquifers in the area. The area of the department in the sub-Andean zone uses water from the numerous streams in the area. The semi-arid Chaco area depends on earth cisterns for much of its water supply with some use of low-yielding wells (2 to 5 liters per second) for potable water.

The most serious problem in the department is the immense soil erosion problem in the central Tarija valley. This erosion has affected about one-third of the central valley - an area of some 1,000 square kilometers. The primary cause of this erosion is the nature of the highly dispersive clay which covers much of the valley, i.e., this soil literally falls apart in the presence of water. Other factors compounding the problem are basin slopes of 3 to 5 percent, rainfall patterns, poor farming practices, and deforestation from natural and man-made forces. The regional development corporation of Tarija (CODETAR) has constructed about 50 small, 1 to 2 hectare, watershed projects in the headwaters of the streams feeding the central valley to help restore these eroded areas. These projects consist of a small dam, terracing, reforestation, fencing of the restored area to prevent overgrazing, and educating the campesinos in soil conservation practices. We believe that this is the best approach to correcting this erosion problem. However, assistance in accelerating this program is needed since it would take thousands of these mini-projects to solve the problem. We would suggest that such a program should at least keep pace with the continuing erosion which claims another 200 to 400 hectares per year.

There are two erosion related problems which warrant special attention. First, there appears to be erosion developing under the runway at the Tarija airport. The total extent of the erosion is not known; however, further investigations and corrective actions should be done immediately. The second problem is related to the San Jacinto project. This project was designed for a useful life of 100 years. The siltation in the reservoir, however, is greater than expected. It is estimated that the reservoir will be completely filled with sediment in 30 years if no corrective action is taken. This valuable resource needs to be protected. It is suggested that erosion control measures be concentrated in this basin and that some gabion grade-control structures be constructed on some of the major streams flowing into the reservoir. This should help trap and slow the movement of sediment into the reservoir.

The needs for other water resource development consist of four elements. First, the cattlemen in the Chaco region need assistance in constructing more earth cisterns. Second, a well-drilling effort in the Chaco region needs to be accelerated under a national well-drilling program. Third, the Aguayrenda project near Yacuiba needs to be constructed to solve the critical water supply problem in that area. Fourth, the Mendez province in the Villa Montes area needs to consider diversification of crops to minimize dependence on water-sensitive crops with the associated depletion of soils.

Santa Cruz. The department of Santa Cruz lies in the eastern part of Bolivia on the border with Brazil and Paraguay. The department encompasses some 370,621 square kilometers and has a population of about 331,000. The western half of the department is mountainous with elevations ranging up to 2,500 meters above sea level, while the eastern half lies in the lowlands with elevations of only 300 meters. The economy of the area is booming - Santa Cruz is the fastest growing city in Bolivia. Agriculture has long been an important staple economic component of the department. Today its economy is further diversified with the production of oil, gas, sugar and the most lucrative crop, cotton. Average annual rainfall in the department ranges from 600 mm in the southern part of the department to over 2,000 mm in the sub-Andean mountains in the west. Rainfall in the capital city of Santa Cruz averages 1,200 mm per year.

Most of the department of Santa Cruz is blessed with plentiful surface water resources. The areas mostly impacted by drought are in four of Santa Cruz's western provinces - Florida, Caballero, Vallegrande and Cordillera. About 40,000 people and 80,000 hectares of land are estimated to be affected by drought in this area. Surface water resources in Vallegrande are meager to nonexistent. There is also no data on groundwater resources in the area. The city of Vallegrande is dependent on water from a natural spring. Wells are being drilled in the other three provinces; however, these wells are very expensive because of well depths and the requirement for engine-driven pumps in the area where there is no electricity. There should be a geophysical survey of the Vallegrande area to evaluate the groundwater potential. The other three provinces need assistance in constructing more earthen cisterns and in well-drilling.

Another problem area is in a region south of the city of Santa Cruz near Basilio and Rio Seco. Presently their water supply is brought in by railcar and sold at extremely high prices. Consideration should be given to completing the Parabanon project to bring spring water to about 40 communities along the railroad track between Basilio and Rio Seco.

Other needs in the department of Santa Cruz are a flood warning system for the capital city and a comprehensive water resource study of the entire department.

Oruro. The department of Oruro lies in the western part of Bolivia south of the department of La Paz. Most of the department lies on the high Andean plateau known as the Altiplano. The department covers some 53,588 kilometers and has a population of about 300,000. The economy of the area is primarily mining and subsistence farming. The department's annual rainfall averages less than 400 mm, thus exhibiting arid to semi-arid characteristics. Elevations in the department range from 2500 to over 6500 meters above sea level. Most of the population resides in the eastern half of the department near the capital city of Oruro.

Almost the entire department lies in the Altiplano drainage basin. Water in this area flows into vast salt flats from which the water evaporates. Most of the surface water supplies in the department are so saline that they are not suitable for any use. The entire area can be classified as one with small to meager supplies of brackish to saline water. In most of the departments, groundwater is available in very shallow depths in alluvial aquifers. This water is fresh near the top of the water table and brackish to very salty below. Freshwater can be found at depths of only 6 to 30 meters. The underlying brackish water is about 180 meters deep.

There are two basic needs in the department of Oruro. First, they need a small drill rig to install shallow, inexpensive wells throughout the Altiplano area. Second, there is a need to evaluate the overall water resources of the department. It seems that Oruro is the least studied department in Bolivia. Such technical assistance would help officials of the regional development corporation of Oruro (CORDEOR) plan their water resources for the future.

La Paz. The department of La Paz lies in the western part of Bolivia north of the department of Oruro. It covers an area of some 134,000 square kilometers and has a population approaching two million. The economy of La Paz is diverse, accounting for 50 percent of all manufactured products in the nation as well as all federal government functions except the Supreme Court. The city is the country's service and retail center. The department also has the most varied terrain of all the departments in Bolivia. A portion of the department lies in the Altiplano. The center of the department is cut by the high eastern ridge of the Andes mountains and the northern part lies in the lowlands of the Amazon river basin. Elevations in the department range from 250 to about 6,500 meters above sea level. The capital city of La Paz is the highest capital city in the world at elevation 3600 meters. Average annual rainfall also varies drastically from less than 200 mm in the Altiplano to over 2,000 mm in the northern section of the department. In the city of La Paz the average rainfall is about 480 mm.

The department of La Paz has areas of both abundant and scarce water resources. The northern part of the department is a tropical jungle. In the west is one of the world's most famous lakes - Lake Titicaca. This massive inland sea covers over 9,000 square kilometers and is over 200 meters deep in some places.

Water supply in the capital city of La Paz is obtained from the rivers and lakes fed by rain and by snow and glacial melt in the mountains north and east of the city. In contrast, the arid to semi-arid Altiplano in the department has only one significant watercourse - the Rio Desaguadero which drains water from Lake Titicaca. As the water moves south it become increasingly saline and less useable. For this reason, much of the Altiplano area in the department must rely on groundwater which is plentiful.

The most serious water resource problem in La Paz is water pollution in the capital city. The water pollution is so severe that the fertile valleys south of the city reportedly cannot use the water for irrigation. The regional development corporation of La Paz (CORDEPAZ) is proposing to store the snow and glacial melt from the mountains to the east in a reservoir and then release the water as needed to the southern valley. Financial resources which are available for this type of work should be dedicated to water pollution control.

The basic need in the drought-stricken area in the western part of the department is the expanded development of groundwater. This can be accomplished by two means. First, more wells can be drilled through a national well-drilling program similar to the one discussed in Appendix H. Secondly, there are hundreds of wells in this area that are not functional, primarily because of broken pumps. The repair and replacement of these pumps will also help alleviate the drought problem in the area.

RECOMMENDED APPROACH TO WATER RESOURCES DEVELOPMENT

RECOMMENDED APPROACH TO WATER RESOURCES DEVELOPMENT

General. Our USAID customer very specifically asked that we prioritize the water resources needs of Bolivia. The criteria for prioritizing was left to the judgement of the Water Resources Advisory Team. Our collected experience and education indicate that priority selection has been the subject of debate in many societies throughout history. As a way of example, we will discuss the evolvement of that policy in the United States. After the great depression in the U.S. in 1929, the creation of jobs was the driving criterion for project selection. As a result, the U.S. is still benefiting from the great public works projects built with that primary goal. The 400-mile-long Blue Ridge Parkway is an example of that work. As good as these projects may be, the primary goal was employment. Toward the end of the great depression in the late 1930's the criteria for selecting public works began to change. The Flood Control Act of 1936 stated that the benefits to whomever they may accrue should exceed the cost. Our predecessors in the Corps of Engineers used this general guidance to invent a thing called the benefit-to-cost ratio (B/C ratio). This standard holds as one of the criteria used throughout the world today.

After World War II, legislative language began to change. Phrases such as "in the interest of national security" and "stabilization of employment" were used in the authorization of many of the major water resources projects in the U.S. Even so, economic efficiency under the B/C ratio remained as the guiding criterion.

During President Johnson's administration in the 1960's, the "War on Poverty" gained national prominence. The philosophy was that the poverty in the Appalachian area of the U.S. transcended economic efficiency criteria. That criteria of "regional development" has been a subject of debate until this day. In most cases however, the B/C ratio still governed.

In the modern era of water resource development in the U.S., there have been many criteria used in our evolving society. The most significant was environmental quality which had its birth with the passage of the National Environmental Policy Act of 1969. For the first time in U.S. history there were co-objectives on water resource projects: national economic development

(B/C ratio) and environmental quality. During the debate and evolution of this policy four accounts, or sub-criteria, surfaced. These accounts were National Economic Development, Environmental Quality, Regional Development and Social Well-being. Also added were four "tests" that had to be met by all water projects. These were Completeness, Effectiveness and Efficiency, Acceptability, and Certainty. This era left the water resources planners and engineers with a real challenge in formulating water projects. This evolved to the criteria used today in the United States - national economic development consistent with protecting the nations' environment.

Criteria. The above discussion was added to illustrate that criteria for prioritizing public works projects evolve with the needs of a society. It would not be appropriate to use United States criteria to decide on water resource investments in a country like Bolivia. Obviously, when a society's needs are subsistence and employment, criteria of only economic efficiency and environmental quality are poor tests. The Water Resources Advisory Team discussed this issue at some length. Ultimately, we decided on eight criteria - benefit-to-cost ratio, regional development, environmental quality, social well-being, visibility, implementability, immediacy of relief, and long-term (lasting) benefits. These criteria are discussed in detail in the following paragraphs.

(a) Benefit-to-Cost Ratio. As previously discussed, the B/C ratio is the most universal criterion used in making water resource investment decisions. Its strength as a criterion is that it forces water resource planners to thoroughly analyze all costs and benefits. With this information, decision-makers can determine the financial rate of return. The weakness of this criterion is that the analysis primarily relies on tangible and quantifiable benefits and costs. Some aspects given detailed consideration are construction cost, operation and maintenance cost, interest during construction, flood damages prevented, savings in transportation cost and the market value of water supply and hydropower. Items not normally considered include human suffering, creation of jobs, losses to the natural environment, etc. Obviously, these intangibles are the reason for the evolution of other criteria in the United States. Further, these intangibles are the reason that we decided to make the benefit-to-cost ratio only one of eight criteria.

(b) Regional Development. Another urgent need in Bolivia is jobs. We felt that projects which were labor-intensive should be favored over those that are not. Included in this criterion are projects which help stimulate the overall economy of a region. A completed dam project, for example, can provide water supply and hydropower which help generate employment in the farm community and industry over the long-term. There is also a secondary or indirect effect in that new workers have money to buy things which, in turn, stimulates the retail economy.

(c) Environmental Quality. This criterion relates to man's natural environment - the trees, vegetation, land, water, atmosphere, fish, wildlife and their interrelationships. As mentioned throughout this report, the environment is a serious national problem in Bolivia. There are some alarming trends which must be redirected - water pollution, deforestation, soil erosion, etc. These problems are impacting the basic subsistence needs of the people, the overall economy, and the quality of life. Thus, we feel that environmental quality is an important criterion in any water resource investment.

(d) Social Well-Being. In addressing the "environment" the need of the people as part of the environment is often overlooked. We believe that social well-being is a critical need in Bolivia. The environmental problems of Bolivia and the drought have had serious implications on health and the quality of life of the people. Intangibles in this criterion include considerations such as sickness, life span, pride and belief in self-worth.

(e) Visibility. This criterion appears to be at a lower level than social well-being or environmental quality. In reality this is a very important criterion because of the Bolivian people's requirement for national and international help. The simple fact is that major investors in the Bolivian economy seek high-visibility projects or programs.

(f) Implementability (Doability). Another important criterion is whether or not a project or program can be realistically accomplished. There are countless projects in Bolivia which would have enormous benefits to regional development or social well-being. However, many of these projects simply cannot be done because of physical constraints, political considerations or acceptability to the local people. Examples of projects/programs which were eliminated from consideration because of this criterion are: complete elimination of water pollution, complete restoration of the natural environment, massive change in the water resource management and policy in Bolivia, and large-scale change in the personal habits of the people. All of these things would help but are simply not doable from a realistic point of view. Initiatives in these areas are limited to small-scale, gradual transition projects and programs.

(g) Immediacy of Relief. Given the current situation in Bolivia, it is important that actions taken give immediate relief to the population. For example, a large, multipurpose dam project may have enormous benefits but may take ten years to design and construct. A project that provides immediate relief should be favored over a dam, assuming the same scale of benefits. Thus, we included this criterion favoring evaluation of actions which provide immediate relief.

(h) Long-term (Lasting) Benefits. Immediate assistance is important, but any investment should consider the accumulated benefits over time. The example in the previous paragraph also illustrates the importance of this criterion. An immediate action such as providing a temporary supply of water is essential, but so is a dam that will provide benefits for 50 years or so. By adding this criterion we favor projects with long-term benefits as well as actions with immediate benefits.

Using the eight criteria, we developed a matrix to evaluate all of the projects and programs that follow in this section of the report. We ranked each project/program as high, medium or low in each of the criteria. From that weighting, each of the four team members determined a priority for each project/program. Then, through consensus, the consolidated priority list shown below was developed. Interestingly, the various projects and programs fell into three general groups. The first group consisted of actions which were either critical or need immediate attention. The second group of projects and programs are much needed work with a slightly reduced sense of urgency. The last group of projects and programs is a mix of needed actions on a long-term basis and small-scale water development. The following is our professional opinion on the most viable of the water resources needs for development in Bolivia.

CRITICAL OR IMMEDIATE NEEDS

1. San Juan Project. There is a critical need for potable water in the central part of the department and the city of Potosi. This project would consist of transporting water via pipeline from the San Juan River to the city - a distance of some 45 kilometers. Construction costs are estimated to range from $9 to $16 million. See Appendix B for details. We recommend that USAID consult with the European Economic Community (EEC) about the design and construction of this project. The EEC consultation is necessary because they have performed the survey investigations and are considering constructing the project.

2. National Well-drilling Program. The most cost effective means to combat drought in the near-term is through an extensive well-drilling program throughout Bolivia. We recommend that this program be both sponsored and strictly monitored at the national level. The 3-year program will cost about $2.5 million and will benefit about 200,000 people. Details of the National Well-drilling Program are included in Appendix H.

3. National Water Resources Management and Policy. The benefits of improving the water resources management and policy of Bolivia are enormous. This is a highly sensitive and complex institutional and political area; nevertheless, we feel that the opportunities are so great that this matter should be actively pursued. We recommend a gradual, two-pronged approach. First, we suggest that the U.S. Ambassador encourage the Bolivian President to establish a President's Commission on Water Resources. The other element of our proposal is for USAID to sponsor periodic international symposia to encourage the exchange of information. These proposals, along with alternative strategies, are discussed in detail in Appendix J. The cost of these efforts can vary considerably according to how the programs unfold. The President's Commission will require a few staff people if the program is successful. We recommend that $250,000 be budgeted for the international symposia. Naturally, co-sponsors and certain other arrangements can reduce this cost.

4. Rehabilitation of Existing Water Resource Projects. Throughout the drought-stricken areas of Bolivia, there are wells without pumps, wells with broken pumps or parts, artesian wells without valves, and serious leakage from

water holding and distributing systems. We recommend that these minor problems be inventoried and corrected immediately. The cost of this program is expected to range from $200,000 to $600,000 and will benefit from 30,000 to 90,000 people. Details on this program are contained in Appendix K.

5. Rainwater Cistern Design and Construction Program. Throughout the Chaco area in the departments of Tarija, Chuquisaca and Santa Cruz, there is an urgent need for more cisterns to capture rainwater for human and animal consumption. There is also a serious health problem because of the sharing of water between people and animals. We recommend this program to solve both of these problems. The program would involve the USAID purchase of three D/7 bulldozers for construction of cisterns in the Chaco. The local interest would be required to adopt the rainwater cistern design discussed in Appendix M. USAID should negotiate with local interests on possible cost sharing and operation and maintenance costs. The key to success is a rigid monitoring of the program at the national level. The purchase price of three D/7 bulldozers is about $750,000. Detailed discussions of these needs are contained in Appendices C, D and E.

6. Erosion Project at Tarija Airport. There is a serious erosion problem developing under the runway at the Tarija airport. That project should be thoroughly investigated and corrected as soon as possible. The investigations to determine the exact extent of the problem will cost about $50,000 and correction of the problem could range from $500,000 to $1,000,000. This project is discussed in Appendix D.

7. Flood Warning System. In 1983, the Rio Piray flooded the city of Santa Cruz with peak discharges that were four to six times larger than the 100-year flood. This was caused by landslides and damming effects in the upper watershed. The flood killed over 800 people. This could have been avoided with a flood-warning system. To prevent this type of disaster in the future, we recommend that a state-of-the-art flood-warning system be installed in Santa Cruz. Details on the flood warning system are contained in Appendix I. The cost of such a system is about $300,000.

8. National Stream Gaging Network. There is a tremendous amount of technical data and information needed to effectively develop the water resources of Bolivia. Especially needed is a national network of gages to

monitor river flows on critical streams in the country. This vital information will help engineers design public works such as dams and bridges, thereby eliminating the waste of overdesign and the tragedy of project failure. The initial cost of this effort will range from $1 to $2 million depending on the amount of coverage that is adopted. Details on the stream gaging network are contained in Appendix I.

MUCH NEEDED WATER RESOURCE PROJECTS

9. Vallegrande Geophysical Survey. The Province of Vallegrande in the department of Santa Cruz has been especially hard-hit by drought. In fact, in parts of the province it hasn't rained in over a year. This dry condition obviously limits any potential surface water development. The best alternative for much needed additional supplies is the development of groundwater resources. Unfortunately, there is no data available on groundwater. Thus, we recommend that a geophysical survey be made of the area. Once a determination is made on the availability of groundwater, a decision can be made on the development of that resource. The cost of the survey is about $115,000. Details on the problems in Vallegrande are contained in Appendix E.

10. Tarija Valley Erosion Control Project. The most serious problem in the Department of Tarija is the immense erosion problem in the central Tarija Valley. This erosion has affected about one-third of the central valley - an area of some 1,000 square kilometers. The correction of these problems will have to be a long-term proposition; however, we feel that work needs to be initiated now. Thus, we are recommending construction of two types of projects. First, some erosion control structures, gabion checkdams, should be constructed on the major streams flowing into the San Jacinto Dam project. If these structures are maintained, they will help reduce the sediment load being deposited in San Jacinto Lake, thereby increasing its useful life. The second type of construction consists of a series of mini-erosion projects. These small projects of 1 to 2 hectares each would be constructed in the headwater steams of the central valley. Each project consists of a small dam, terracing, reforestation, fencing of the restored area to prevent overgrazing,

and educating the camposinos in soil conservation practices. Both of these project types are discussed in detail in Appendix D. The cost of these projects will vary according to the number of sites constructed. We would recommend that a minimum of $1.5 to $2 million be invested in this area annually. This level of construction is necessary to match the increased erosion each year.

11. Cochabamba Multi-Purpose Dam. There is a critical need for potable and irrigation water in the general area of the city of Cochabamba. In fact, the demand for water is expected to exceed the supply by a two-to-one margin by the year 2010. We had a difficult time placing a priority on this project due to the tremendous expenses involved. The cost of solving the total water supply problem in the City area will likely approach a billion dollars. Yet, the fate of Cochabamba will have an impact on all of Bolivia. Thus, we recommend that a two-phase survey investigation be conducted in Cochabamba. The purpose of this investigation would be to formulate the best plan for a multi-purpose impoundment(s) in the Cochabamba area. With the best plan and an accurate cost estimate in hand, it will be easier to attract international investors. The various alternatives are discussed in detail in Appendix A. The cost of the first phase of the survey investigation is in the range of one million dollars. The second phase of the investigation would be accomplished by the constructors of the project.

12. Parabanon Spring Diversion Project. There is a serious potable water problem in about 40 small communities along the railroad track between Baisilio and Rio Seco in the department of Santa Cruz. Currently, water is being brought in by rail and sold at extremely high prices. The Parabanon project would tap water from a spring about 35 kilometers away and transmit the water, via pipeline, to the communities along the railroad track. Details of the project are contained in Appendix E. The cost is estimated to be about $10 million.

13. German Groundwater Study. Officials from GEOBOL indicated that the German government had agreed to undertake a major groundwater study in the Cochabamba, Potosi and Chaco areas. This $5 million study would be of enormous benefit. The German government agreed to pay all salaries but required that the Bolivian government pay for administrative and logistic support. Unfortunately, GEOBOL does not have the financial resources to pay

their share of the study. For just a few thousand dollars, engineers and scientists can develop the much needed groundwater information in the area. We recommend that GEOBOL be given a grant to pay for their share of the study. The costs are in the neighborhood of $50,000. This effort needs to be coordinated with two groups - the Canadian government which is studying groundwater resources in Cochabamba and the Cattlemen's Association in Tarija who are doing geophysical testing in the Chaco area.

14. Construction of Wadi Dams. In the departments of Cochabamba, Chuquisaca and Potosi, there is a substantial amount of seasonal runoff that infiltrates into the ground and flows down the valley gradient as groundwater. The construction of a subsurface dam, called a Wadi dam, will store the water for use during the dry season. A design for Wadi dams is shown in Appendix L. These dams can be built mostly with hand labor. If a source of clay, bentonite, has to be trucked in, there would be an additional cost of $2,000 to $6,000. We recommend that the camposinos be given technical assistance in the siting and construction of Wadi dams. The cost of this program will vary according to the number of sites evaluated and the amount of materials needed, but should be less than $100,000.

15. Construction of Aquayrenda Project. The town Yacuiba and its environs is in need of water supply. A potential surface water impoundment site has been identified north of the city, the Aquayrenda Project. We estimate that the project cost will range from $5 to $6 million. This project would include a pipeline distribution system to the five communities from Aquayrenda to Pacitas. We recommend construction of this project. Details of the project are contained in Appendix D.

OTHER WATER RESOURCE NEEDS

16. Aiquile and San Pedro Dams. In the vicinity of the city of Aiquile, in the department of Cochabamba, there is a need for dependable supplies of potable and irrigation water. The best alternative to meet these needs appears to be the construction of small dams. We recommend the construction of a dam named San Pedro located about 3 kilometers northwest of Aiquile.

This $1.5 million project will irrigate between 300 and 500 hectares. A second site about three kilometers upstream of the failed El Salto site should be further investigated for development. The feasibility of dams at these sites could be developed for a cost of about $75,000. Details on these dam sites are contained in Appendix A.

17. Purchase of Engine-Driven Pumps. In our travels throughout Bolivia, we discovered several deep wells which have been drilled but for which pumps have never been purchased. These wells require an engine-driven pump since there is no electricity in the remote areas. The pumps are expensive, $35,000 to $40,000; however, they could service a large population in serious need of potable water. We recommend that pumps be installed at these sites. The inventory of these wells should be included in the overall inventory prepared for recommendation number 4.- "Rehabilitation of Existing Water Resource Projects" on page 26. The number of these sites is believed to be limited, therefore the cost should be in the range of $100,000 to $200,000.

18. Evaluation of Dam Sites in Chaco. There is a high potential for the development of surface water resources in the relatively wet sub-Andean area overlooking the Chaco. Thus, we recommend that a reconnaissance of potential dam sites in the area be conducted. The estimated cost of this reconnaissance is $400,000.

19. Cochabamba Water Budget. There is a critical need for a water budget in the Cochabamba valley. The many wells in the area are stressing the aquifer and the city needs to develop a water budget and monitor groundwater withdrawals to protect this vital source of water. There are two potential sources of data which might help the City develop such a budget: the Canadian government's study which will be finished in 1991, and the German/CEOBOL groundwater study previously recommended in this section. We recommend that USAID coordinate these two efforts to avoid duplication and assure the German/CEOBOL study produces results that will assist in developing a water budget.

20. Construction of Water Systems. The western sections of the department of La Paz have been hard-hit by the drought. CORDEPAZ officials indicated that they plan to install about 60 gravitational pipeline systems per year to small settlements of about 500 people. There are about 2,500 villages in need;

therefore, we recommend that this program be accelerated. We suggest that the CORDEPAZ program be doubled by outside help. At 60 projects per year, this would represent an investment of about $900,000.

21. Modern Rock Drilling Test. Groundwater could be available in useable quantities in the hard rock formations in the area. This water is either trapped within the rock's inherent porosity or in fractures that occur in the rock. If the opportunity presents itself these tests should be supported. U.S. military well drillers have the capability to perform this type of drilling.

22. Water Treatment for La Paz. There is a serious water pollution problem in the capital city of La Paz. The water leaving the city is so polluted that it cannot be used for irrigation downstream. Correction of these problems will cost in the hundreds of millions of dollars. However, the positive gains in regional development, environmental quality, social well-being, visibility and long-term benefits would be enormous. For this reason, water treatment in La Paz surfaced in our matrix rating. We don't have enough information to make tangible recommendations, but we wanted to emphasize the importance of this problem.

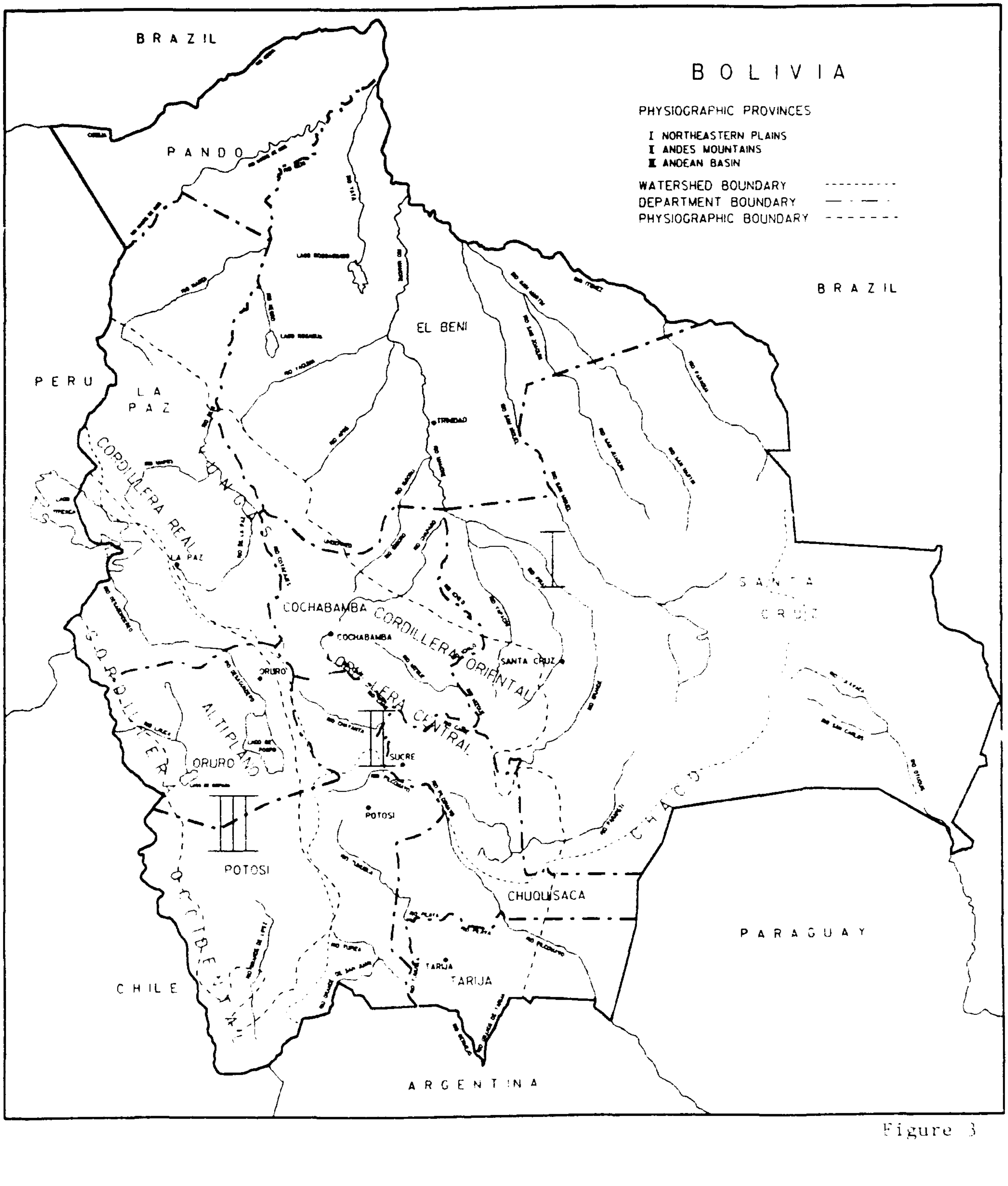
23. Comprehensive Water Resource Plans. Several department spokesmen mentioned the need for technical assistance in developing comprehensive water resource plans for the department. This could be a wise investment in the future. Our observation of the situation in most departments indicated that advance planning was limited due to the nature of funding in Bolivia. Sporadic funding has most water managers in a reactive mode rather than developing plans and goals for the future. Well-thought-out plans could lead to efficiencies in operation. Further, having a defined need and a project plan may help attract international investors. Oruro, Santa Cruz and La Paz were the departments requesting assistance. We recommend that USAID consult with these departments, and perhaps others, to determine their interest. If they are interested in such a study they should be asked to make a detailed proposal of what they intend to study and why. Then a professional appraisal of the value of the proposal should be made before proceeding.

OVERRIDING CONSIDERATIONS

The implementation of the above projects and programs is a good starting point for the development of Bolivia's water resources. We want to emphasize, however, that these efforts should consider the long-term needs of Bolivia. The long-term solution to water resource needs in Bolivia has to incorporate a combination of proper management, conservation, and changing societal habits in the use of water and land resources. To accomplish this, we feel that there are two vital ingredients which should be incorporated into any water resource project or program: the involvement of the Bolivian people, and environmentally sustainable development.

It is our belief that the Bolivian people have to be involved in their water resource development. First, they must use their own scientists and engineers to tackle water problems. Currently, there may be a need for foreign assistance; however, Bolivia needs to train additional experts through time. The selection of projects should favor labor-intensive construction to provide jobs and to stimulate the economy. There must be community involvement in the formulation of projects so that the local citizenry have a sense of ownership and will help make things better. Finally, the leadership of the country needs to begin the process to better the water management and policy of Bolivia in the water resources area.

The other cornerstone to a successful water resources program is environmentally sustainable development. This is why we recommended that an environmental improvement or societal change package be included with any water project. As mentioned throughout the report, this package should include work such as reforestation, adopting soil conservation practices, limiting effluents into streams and lakes, including public health facilities or programs, and experimenting with new drought-resistant crops. Without these provisions, we are fearful that the beneficial gain of the water projects recommended will be lost in short order.



BOLIVIA
PHYSIOGRAPHIC PROVINCES
I NORTHEASTERN PLAINS
II ANDES MOUNTAINS
III ANDEAN BASIN
WATERSHED BOUNDARY
DEPARTMENT BOUNDARY
PHYSIOGRAPHIC BOUNDARY
BRAZIL
BRAZIL
PERU
CHILE
ARGENTINA
PARAGUAY
PANDO
EL BENI
LA PAZ
COCHABAMBA
ORURO
POTOSI
CHUQUISACA
TARIJA
SANTA CRUZ
CORDILLERA REAL
CORDILLERA ORIENTAL
CORDILLERA CENTRAL
ALTIPLANO
CHACO
TRINIDAD
LA PAZ
COCHABAMBA
ORURO
SANTA CRUZ
SUCRE
POTOSI
TARIJA

Figure 3

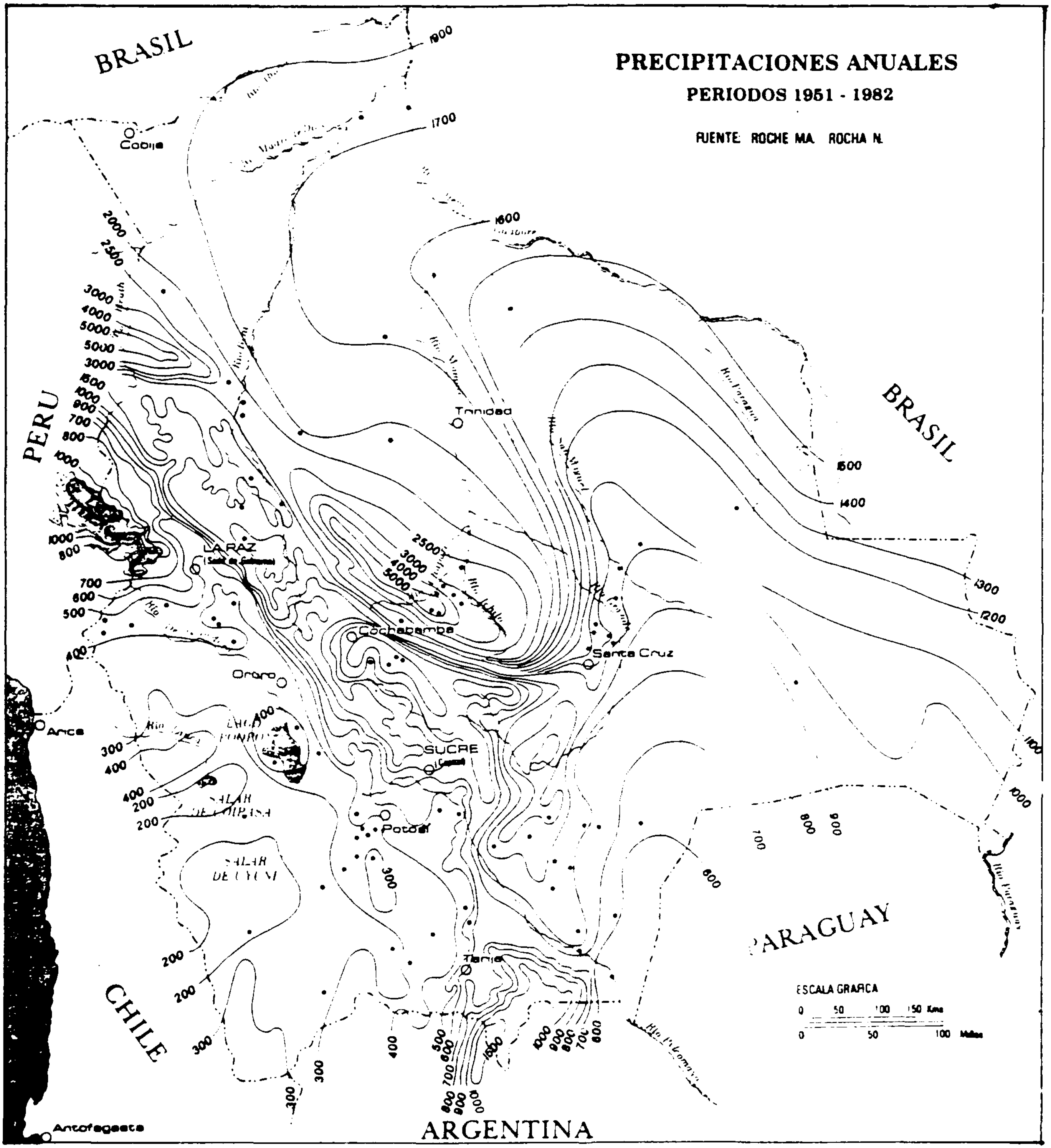
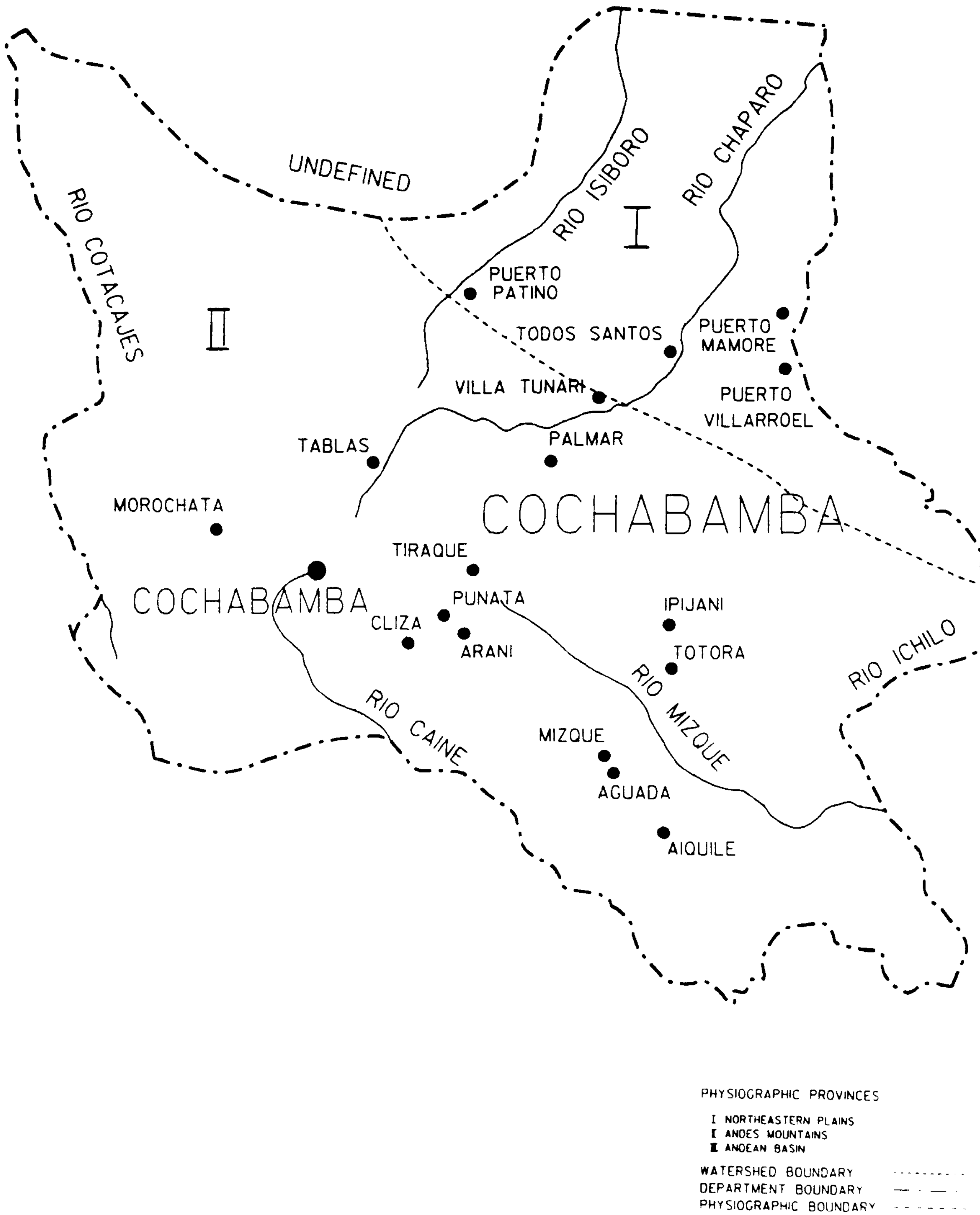

PRECIPITACIONES ANUALES
PERIODOS 1951 - 1982
FUENTE: ROCHE MA. ROCHA N.
BRASIL
PERU
CHILE
ARGENTINA
PARAGUAY
Cobija
Trinidad
LA PAZ
Cochabamba
Santa Cruz
Oruro
SUCRE
Potosi
Tarija
Arica
Antofagasta
ESCALA GRAFICA

Figure 4

APPENDIX A

COCHABAMBA



UNDEFINED
RIO COTACAJES
RIO ISIBORO
RIO CHAPARO
I
II
PUERTO PATINO
TODOS SANTOS
PUERTO MAMORE
VILLA TUNARI
PUERTO VILLARROEL
TABLAS
PALMAR
MOROCHATA
COCHABAMBA
TIRAQUE
COCHABAMBA
PUNATA
IPIJANI
CLIZA
ARANI
TOTORA
RIO ICHILO
RIO MIZQUE
RIO CAINE
MIZQUE
AGUADA
AIQUILE
PHYSIOGRAPHIC PROVINCES
I NORTHEASTERN PLAINS
I ANDES MOUNTAINS
II ANDEAN BASIN
WATERSHED BOUNDARY
DEPARTMENT BOUNDARY
PHYSIOGRAPHIC BOUNDARY

APPENDIX A - COCHABAMBA

CLIMATE, RAINFALL AND TOPOGRAPHY

The department of Cochabamba lies in the heart of Bolivia and along the eastern range (Cordillera Oriental) of the Andes mountains. The capital of the department is the city of Cochabamba which is known as the "City of Eternal Spring" because of the mild climate which exists nearly year around. Average annual temperature in the city is about 18 degrees Celsius, while average annual temperatures within the department range from 5 to 19 degrees Celsius. Because of the orographic effects of the eastern Andes mountains, average annual rainfall within the department varies drastically, from less than 300 mm in the western parts of the department to some of the wettest areas in the country. These wet areas yield precipitation of more than 4000 mm in the Chapare region on the high eastern slopes of the mountains north and east of the capital city. Precipitation in the most heavily populated areas of the department near Cochabamba average around 500 mm per year. Elevations within the department range from around 200 to over 5000 meters above sea level. The most populated area of the department, and the most populated rural areas in the country, are in four valleys - Valle Alto, Valle de Sacaba, Valle Central, and Valle de Santivanez near and east of the city of Cochabamba. In these populated areas the annual rainfall normally varies from 500 mm to 700 mm. During the present drought however, which began in the early 1980's, the rainfall near Cochabamba has averaged only about 30 percent of normal. This lack of rainfall has severely reduced the already scarce supply of surface water in the area and placed growing pressure on the limited and over-stressed groundwater resources. Average evaporation rates in the semi-arid valleys range from 1200 to about 1800 mm per year.

The topography within the department of Cochabamba is a result of regional geologic processes which have formed a series of northwest-southeast-trending valleys and ridges. Faulting is common along the axes with some minor faults crossing the general structure. The ridges and mountains are primarily composed of sedimentary rock with some areas underlain by igneous rock. The valleys within the mountains have many smaller communities which have only minor amounts of alluvial material from which to obtain water supplies. Most of the population centers are located in the valley areas near the capital city of Cochabamba. This region has limited rainfall and runoff is rapid due to the amount of topographic relief.

SOCIO-ECONOMIC PROFILE

Characterized in one source as the vital link between Bolivia's western and eastern sectors (Guide 1984:32), the department covers some 55,600 square kilometers, or slightly more than 5% of the country. The current population of nearly a million persons constitutes 14.5% of the country's populace (CORDECO. Emergency Plan 1990. Vol. I:7). Distribution of the population is 44% urban with the remaining 56% located in small, peasant villages principally in the once-arable valleys of Cochabamba. See Photo No. 4, Appendix P. Two-fifths of the total number of people are under the age of 15, a significant clustering when one considers that crises such as drought tend to be hardest on the young and dependent and the old and helpless.

According to the National Statistical Institute, Cochabamba generated nearly 18% of Gross National Product (GNP) in 1989, or $84.4 million (Emergency Plan, ibid.:30). The most important economic activities center on farming - both cultivation of crops and animal husbandry. Indeed, farm production in the department makes up nearly one third of all such productivity in the nation. Using information collected by the national Ministry of Farming and Rural Affairs (MACA), potatoes, alfalfa, grain corn and onions are the most lucrative crops, saving coca production, grown in Cochabamba. As shown below, these and other grain and vegetable crops have been severely affected by the drought during the past five years.

Table A-1
Production Values 1985 and 1990
of Cultivated Crops
($US)

Crop	1985 Values	1990 Harvest Values	Disparity 1985 - 1990
Potatoes	22,392,903	9,937,518	12,455,385
Grain Corn	7,478,481	2,017,723	5,460,757
Wheat	3,569,869	681,666	2,888,203
Barley	1,941,070	1,213,779	727,291
Eating Corn	1,600,494	1,137,943	462,551
Carrots	2,429,120	1,956,320	472,800
Tomatoes	3,021,656	1,888,669	1,132,987
Onions	7,100,844	4,970,503	2,130,341
Lima Beans	3,082,832	1,908,996	1,173,836
Peas	2,461,428	629,370	1,832,058
Alfalfa	19,780,320	11,499,684	8,280,636
TOTALS	74,859,017	37,842,173	37,016,844

Source: CORDECO. Emergency Plan 1990, Vol. II:140.

The same ministry also estimates that throughout the department of Cochabamba there are some 1.32 million hectares with the potential for agriculture. Only 443,000 hectares, 32% of the potential, have been cultivated. Since 1985, the area under cultivation has dropped to 252,700 hectares. Of that number, approximately 156,300 hectares were affected by drought (Plan to Confront Drought Effects, May 1990:33)

The manufacturing sector in Cochabamba is estimated to represent about 12% of the more than 1,100 incorporated companies registered in the nation. These companies make a range of products from foodstuffs, including beer and soft drinks, to leather goods and textiles (Guide 1984:66).

SURFACE WATER RESOURCES

The development of surface water supplies within the department is very limited; however, there is considerable potential for further development of this resource. Several reservoirs in the mountains above the city provide some of Cochabamba's water for domestic supply while groundwater is pumped to supplement these limited surface supplies. Because of a lack of resources to develop supplies, the city of Cochabamba has a deficient water supply system which presently is able to fulfill about 50 percent of the existing demand. Ongoing project construction is expected to allow supply to catch up with demand in the mid-1990's, assuming normal precipitation patterns. The 2010 demand, however, is expected to again outpace supply by nearly a 2 to 1 margin. No additional reservoir sites are nearby in the mountains north of the city. Additional sites can be developed but are farther away and will require extensive and very costly systems to transport the water around or through the mountains to the population centers.

A large shallow reservoir, Laguna Angostura, exists upstream from Cochabamba near the town of Tarata. This reservoir had been used in the past for water supply for Cochabamba but due to low levels caused by the drought and pollution from agricultural irrigation and domestic wastes, the water is no longer of sufficient quantity or quality for use in a public water supply.

Plans have been developed for a number of years for a major project which would capture some of the abundant water on the other side of the mountains north of the city and transport it to the Cochabamba area for use in irrigation and domestic water supply. This project, Misicuni, has been in the preliminary planning stages since the mid-1970's. The Misicuni project would be a high dam on the Rio Misicuni which would impound the abundant rainfall in that area. It would provide a dependable flow of about 8 cubic meters per second to produce hydropower, provide potable water for the city of Cochabamba and irrigate about 18,000 hectares of land. The project would provide water to the valley regions by tunneling through some 20 km of mountains. The preliminary cost estimate of this project is $300 to $400 million.

Another major project under consideration for several years is the Kewina Khocha project. This project would provide a series of 2 to 5 interconnected dams and reservoirs located in the mountains north of the city of Cochabamba. Water from these dams would be collected in canals and routed some 200 km around the mountains to the valleys to provide water for irrigation and domestic use. It is estimated that this project would provide dependable flows of about 6 cubic meters per second. Irrigation from this project would benefit an area of about 25,000 hectares. Cost estimates for this project range from $100 to $200 million.

Both projects appear to have good potential for relieving the severe water shortage in the Cochabamba area. Unfortunately, their high price tag has discouraged potential investors in the projects. Moreover, by some local estimates, the construction of both the Misicuni and the Kewina Khocha projects would not totally solve the water supply problem of the greater Cochabamba area.

There is one existing irrigation project under construction and nearing completion in the high valley area near the cities of Punata and Tiraque which will bring some relief to this area's need for irrigation water. It was designed and funded by the German government and should provide about 26,000,000 cubic meters of water per year to irrigate about 7000 hectares of land with benefits for about 5500 families. This project consists of a series of interconnected reservoirs east of the city of Tiraque and an elaborate distribution system to carry water to the different farming communities in the area. See Photos No. 5 and 6, Appendix P. The project is essentially complete and awaiting the return of normal rainfall amounts to fill the reservoirs.

Other areas in the department which were identified for investigation of water resources were the valley areas around the cities of Aiquile and Mizque. These areas have been severely impacted by the drought and are in need of projects which can provide dependable supplies for potable and irrigation water. The team did not have time to investigate the Mizque area for surface water resources, but was told that the area sets over an alluvial aquifer which can yield suitable supplies of groundwater.

The Aiquile area was investigated in some detail for surface water resources and it was found that several small stream diversion projects for irrigation and water supply have either been completed or are under construction. The campesinos have built low-head stream diversion structures that divert flow into ditches which carry the water onto fields for irrigation or divert the flow into excavated holding ponds. See Photo No. 7, Appendix P. These holding ponds are later used for water supply, irrigation, or watering of livestock. Near the town of Aiquile three potential dam sites were investigated for future development. At one of these sites. a dam had been built in the mid-1970's but the structure failed during reservoir filling and has never been rebuilt. The other two sites appear to offer potential for future development. For purposes of dependable water supply and for reservoir filling, it has been estimated that rainfall in this area averages between 500 and 600 mm per year.

GROUNDWATER RESOURCES

The interior of many of the valleys is filled with alluvial sediments that have sufficient porosity and permeability to allow rainwater and runoff to infiltrate into subsurface aquifers. Some of the larger valleys, such as the Cochabamba Basin, act as recharge basins allowing a high percentage of the runoff to enter the aquifers. On the other hand, the narrow valleys throughout the mountainous areas only act as a conduit for the underground migration of the water. Especially evident in the larger valley areas are alluvial fans where surface drainage enters the basins. These fans are typically composed of course-grained sediments near the apex with the grain size of the sediments lessening as it extends out into the basin.

The primary areas of recharge for the Cochabamba Valley are in these alluvial fans adjacent to the mountains around the valley walls. To help prevent local flooding, much of the seasonal runoff flow has been diverted through flood control channels. The flow in these channels is at such high velocity that little water can infiltrate into the subsurface aquifers preventing effective recharge as it enters the basin. Future planning should consider slowing the runoff in these areas to allow more surface water to recharge the aquifers. The main areas of recharge for the valley were mapped as part of a study made by the United Nations in 1978 (Reference UNDP and GEOBOL. 1978. Groundwater Investigations in the Cochabamba Basins).

Two aquifers have been identified in the Central Valley. One is approximately 60 meters deep and the other is approximately 120 meters deep. Both are heavily used in the area. The yields range from 10 to 50 liters per second from most wells although present heavy usage is lowering the water table in many areas. Again, the best source document for this information is the 1978 United Nations report.

The other basins around the Central Valley also have alluvial aquifers that are heavily developed. The Punata-Cliza Basin has a good aquifer comprised of an alluvial fan in the flood plain of the Pucara Mayu River. The depths of this aquifer range from 40 meters to 60 meters.

Officials from GEOBOL indicated that the German government had agreed to undertake a major groundwater study in the Cochabamba, Potosi and Chaco areas. This study reportedly would cost about $5 million over a six-year period. The German government agreed to pay all salaries but required that the Bolivian government pay for administrative and logistic support. Unfortunately, GEOBOL officials indicated that they did not have the financial resources to pay their share of this much-needed study.

Groundwater is sometimes available in useable quantities from the hard rock formations. This water is either trapped within the rock's inherent porosity or in fractures that occur in the rock. Little, if any, information is available on attempts to construct wells in rock in the department of Cochabamba. Considering the high number of faults in the area, there could be a large amount of untapped groundwater associated with fracturing from these faults. A program being conducted by CORDECO is presently underway to test this by excavating a lateral tunnel into a mountainside near Cochabamba. Hopes are that this tunnel will penetrate into enough water-bearing strata to supply a useful amount of water that will flow from the excavation by gravity.

SPECIFIC PROBLEM AREAS

Initial USAID assessments of the drought of 1990 indicated that there were about 106,000 people seriously affected by drought in Cochabamba. Most of these impacts were centered in the provinces of Campero, Mizque, Tapacari, Jordan and Tarata. Other visible effects of the drought range from migration, diminished agricultural and manufacturing production, to decreases in income levels for those whose livelihood is centered in the department's valley regions. Migration has been a problem for several years, per 1976 data from the National Statistical Institute (INE). As of 1976, there were 756,000 persons born in Cochabamba, 748,000 residing in the department, some 78,000 moving to Cochabamba but 86,000 leaving it. This produced a deficit or loss of 8,000 persons (Brockmann 1986:9). Within the past 14 years, however, drought has been a factor for at least half of that time, causing increasing numbers of people from throughout Bolivia to move to the Chapare area. This is a low-lying, sub-tropical region within the department. It has no water supply problems and is famous or infamous for coca-related activities. Exact numbers are not available but there is speculation that the deficit of 8,000 reported for 1976 has been translated into a net gain of thousands of campesinos seeking work and income in the Chapare.

Another effect of drought, lowered agricultural productivity, is especially significant in Cochabamba, per the table on page A-3. Given that this department furnishes almost one third of the grain and foodstuffs for the people of Bolivia, then the country is being deprived of needed food and will suffer increasingly as the drought worsens.

One report states that the department lost 3% of its arable land in the one year from 1989 to the end of the 1990 agricultural year (Evaluation of Drought on Crops, 1990:14). The same document, prepared by the Ministry of Farming and Rural Affairs, estimates a 14% decrease in crop production. Hence, the ratio of land loss to decreased production is 1:4.7, that is, for every 1% of land lost to the effects of drought, nearly 5% of the crops are similarly forfeited. Extrapolating this period of record into the future is not statistically correct. Nevertheless the trend is alarming. If this trend continues there will be a substantial loss of arable lands in the future.

If the estimate of 106,000 persons heavily affected by drought grows larger by anywhere from 2% to 5% per year, then within 20 years, nearly one quarter of the department's population could be classified as "severely affected" and therefore in urgent need of not only food, drinking water and income but also a stable livelihood.

The city of Cochabamba is in dire need of additional water supply resources. Presently the city provides water supply to a 30-square-kilometer area while the area of demand for this public water comes from some 110 square kilometers. In terms of volume, it has been estimated that only about 50 percent of the demand for public water in the city is being met (400 liters/second supplied and 790 liters/second demanded). Because of the effects of the drought, SEMAPA (Servicio Municipal de Agua Potables y Alcantarillado, the area water supply authority) is presently only able to supply water for about two hours per day. Since the existing reservoirs in the mountains and from Laguna Angostura are not sufficient to provide the required water volumes, SEMAPA is shifting emphasis for the near future to operating and digging wells in the area to supplement the meager surface water resources. SEMAPA is adding additional high capacity wells near the recharge areas of the aquifers to provide water for their distribution systems. While this may provide temporary relief for their system, the population served by wells further into the valley is being deprived of historically available well water. In addition, since most of the area residents are not served by SEMAPA, they are also digging wells to supply their needs. There are no existing laws to regulate groundwater development and this practice leads to the potential groundwater depletion problems discussed in the preceding section on groundwater and in the next paragraph. The continued growth of the city will depend on additional sources of water, both for potable and other uses. Due to the limited amount of groundwater, the only long term solution is the development of new surface water resources.

Large, but finite amounts of groundwater are available in the alluvial sediments in many of the larger valley areas around Cochabamba and are utilized as a source of potable water and for irrigation water on a smaller scale. Due to the limited amount of rainfall and groundwater recharge characteristics in this region, it is possible to withdraw more groundwater than is being recharged into the aquifer. This results in a local lowering of the water table. If this stressing of the aquifer extends over a period of time, or if a period of drought occurs, existing wells which tap the aquifer may essentially dry up and become unuseable. Cochabamba is in this condition at the present time. Another possible side effect of the stressing of an aquifer is when the groundwater is removed, loss of the effects of buoyancy from the water allows the sediments to consolidate. There is then a decrease of available storage within the pore space of the aquifer. This consolidation also decreases the permeability and may result in settlement of the ground surface over the aquifer.

Many of the existing wells around the city of Cochabamba are artesian and have enough head so they flow at the ground surface. There are no flow control devices on most if not all of these wells. This constant waste of water causes an unnecessary depressurization of the aquifer which lowers the water levels in other wells in the valley. Installing flow-control devices is a quick, easy way to replenish water to other wells.

Some of the smaller villages that are located in the narrow valley areas use surface water during the rainy season, but this source is not available during the rest of the year. Infiltration galleries constructed into the alluvial valley sediments are used for the dry seasons. This alluvial material allows the water to flow underground following the channel bottom gradient and much of the water may migrate away down the valley during the dry season. When this happens, the village may be left without a dependable source of water. See Photo No. 2, Appendix P.

The German irrigation project in the Punata-Tiraque area has pointed out a significant problem that should be avoided for future development projects in the country. When the irrigation channels were originally located, they naturally followed an alignment that coincided with the hydraulic and topographic reality of the area. It was found, however, that this did not coincide with the geographic and political alignment of the campesino communities. For this reason, the people would not use the system or would make their own unauthorized modifications to the distribution system to coincide with their own desires. There would have been a considerable savings in time and modification expenses if the local citizens were included in the planning and design process. Whenever a project is to be used by the locals, they must be included in the planning, design, and construction to the fullest practical extent to ensure that they not only take a sense of ownership in the project, but also that their special needs for the project are included in the design.

When investigating the German Punata-Tiraque project, the last dam site investigated was the Kehuina Khocha Dam. It is the only structure that presently has an outlet pipe through the dam with the control valve at the downstream end of the pipe. Generally, this is not good practice because it places a pressure-flow pipe within the earth fill structure and any leakage can quickly lead to erosion and potential failure of the earth fill. It was noted at this structure that some seepage is apparently occurring along the pipe within the dam since flow is emerging along the pipe as it exits the dam, but upstream from the control valve. This situation warrants immediate investigation to determine the source of the leak. Furthermore, it is recommended that steps be taken to relocate the control valve to the upstream end of the pipe as has been done at several of the project's other dams already.

The towns of Aiquile and Mizque were reported to have adequate groundwater sources for potable water but lacked a dependable source of electricity to operate the pumps and the water distribution system. Aiquile is in serious need of additional surface water sources to supply water for irrigation. The relatively few flow-diversion and irrigation projects in the area have captured almost all of the available flow during low-flow periods, and surface impoundments are needed to store the available water during the rainy season for later use during dry periods. One such dam was completed near Aiquile in 1975, but because of improper design and construction techniques, the El Salto Dam failed during the initial pool-filling operation when the reservoir was only about 70 percent full. This dam site was doomed to fail for several reasons. First, the dam was built on weathered material which was not properly prepared for foundation and abutment construction. It appeared that earth fill material was merely placed upon the highly irregular surface of the rock. When initial settlement of the fill occurred, voids naturally opened under outcrops of rock where they projected into the fill. See Photo No. 8, Appendix P. This immediately opened seepage paths for the water to flow through the dam. In addition, the earth fill dam was constructed with available fill material which appears to be a dispersive clay that is unsuitable for almost any construction project, especially dams. As the reservoir was initially being filled, seepage paths along the dam's foundation developed and quickly led to the failure of the dam.

Land use practices in this area and throughout Bolivia are not making efficient use of the available soil and water resources. Poor farming methods, lack of knowledge in soil conservation techniques, slash-and-burn agriculture, overgrazing, and deforestation of land have led to high run-off of rainfall, soil erosion, degradation of vegetative cover, loss of soil productivity, sedimentation in streams and lakes, loss of groundwater recharge, and pollution of surface and groundwater resources.

SUGGESTED STRATEGY

The overall strategy for the water resource development in Cochabamba has to be a three-pronged approach - development and management of groundwater resources in the short- and long-term, a long-term restoration of the environment and the long-term development of surface water resource. It should be emphasized that the long-term water resource needs of Cochabamba cannot be met without a significant development of surface water resources. Further, without environmental improvements and societal change through time, the effectiveness of water resource development will be undermined through changing hydrologic conditions, pollution, erosion, sedimentation, etc. Such improvements extend far beyond reforestation to areas such as conservation, changes in water and land use, modification in farming practices and basic sanitation.

SUGGESTED STRATEGY (SURFACE WATER)

A major surface water impoundment(s) such as development of the Misicuni and Kewina Khocha projects is highly recommended. Discussions with GEOBOL, (Bolivian geological survey agency), indicate that much detailed design remains to be done to select the best array of alternatives for these projects. The item of most concern for these projects of course is a sponsor and funding for detailed design and construction. In addition, we recommend a review of the decision to use unlined channels to transport water for the Kewina Khocha project. It is our judgment that the added expense of concrete lining of the channels will pay for itself by saving significant quantities of water that would be lost to infiltration into the channel bottom and by preventing erosion of the channel. According to reports from other departments, unlined channels lose as much as 60 percent of the water due to infiltration. Furthermore, as demonstrated in many areas throughout Bolivia, hand-placed stone and grout channel linings are economical and labor-intensive.

Another potential dam site identified is in a narrow gorge on the Rio Pucara Mayu just a few kilometers upstream from the city of Punata. Initial geologic inspections of the site indicate the presence of sound impermeable rock for an excellent dam foundation. An impoundment 100 meters high would store an average of about 30 million cubic meters of water which could be used for irrigation in the Valle Alto and also for water supply for the city of Cochabamba and surrounding communities. Even with this large volume of water, the surface area would only be about 1 square kilometer. In comparison, the existing Angostura reservoir near Cochabamba is relatively shallow and thus has a larger surface area for any given volume of water. The large surface area increases evaporation losses which is compounded by the high evaporation rates (1200-1300 mm per year) at this altitude. This accounts for a large percentage of annual water loss from the reservoir. The dam site near Punata has a drainage basin of about 440 square kilometers. If one assumes that 10 percent of the rainfall actually runs off and appears as stream flow, annual flow volumes for this reservoir would average about 22 million cubic meters per year. This is enough water to more than satisfy the existing water demands for the city of Cochabamba. The drawback to the construction of this project is that it may require a number of years (possibly 5 or more) for the reservoir to fill. This project with a mass concrete dam would probably cost between 120 and 150 million dollars to design and construct. A reinforced concrete dam would be less expensive if foundations permit this type construction. We recommend preliminary investigations of this potential dam site.

The area around the town of Aiquile is in need of additional surface water resources. We investigated two potential dam sites and learned of a suitable third site. One site investigated was the location of the failed El Salto dam. It is located about 4 kilometers southwest of Aiquile. This site can only become useable with a great amount of effort. As previously stated, the foundation conditions are very poor with weak and highly fractured rock which will require extensive grouting before it can be used. In addition, suitable fill material will have to be imported. For these reasons, the cost of this structure would be high. Since there are other suitable sites nearby, it is suggested that this site be eliminated from consideration.

A second site was reported to be about 3 kilometers upstream from the failed El Salto location, but time constraints prevented actual inspection of the site. It appears from map reconnaissance that this site has only about one-half the drainage area of the El Salto site. This site only has about 6.5 square kilometers of drainage area and will yield average flows of only 10 liters per second. Reportedly, foundation conditions were better at this upstream site and, thus, may warrant further investigation.

The third site appears to be the best dam location in the Aiquile area. It is located about 3 kilometers northwest of Aiquile and is called the San Pedro site. The dam can be built across a fairly narrow gorge of the Rio Mizque on what appears to be a very sound rock outcrop. The rock underlying the site is a durable quartzite and this material could probably be quarried and used to construct a masonry dam. This type dam would reduce construction costs over a concrete dam. There appeared to be insufficient amounts of suitable soil for an earth fill structure. The site would require stripping to sound rock across the valley and up the abutments and probably some pressure grouting to prevent underseepage. Ideally, several core drill holes should be located along the axis of the dam and samples taken of the rock during early design stages if this project is undertaken. A twenty-five- to thirty-meter-high dam at this location will have a drainage basin of about 11 square kilometers and can impound about 3 million cubic meters of water. This will yield average annual flows of about 17 liters per second. The estimated cost of the dam is around $1.5 million and will irrigate between 300 and 500 hectares. This appears to be an excellent project for consideration.

SUGGESTED STRATEGY (GROUNDWATER)

Since the start of the present cycle of drought around the city of Cochabamba, supplies of surface water have been depleted. Potable water is coming almost entirely from the vast number of wells within the valley. There are no reliable records that can identify the number of wells that are withdrawing water from the underlying aquifers, but wells in many areas are experiencing a steady decline in the static water level. No law governing the regulation of well drilling or withdrawal of water is in place to prevent this from occurring. Further, due to the small area of the valley with its high population density, this will continue to be a problem in the future. Local authorities must develop a water budget for the valley area. On the basis of this budget, regulations need to be enacted to assure that the available groundwater is used in such a manner that the aquifer is not damaged or the water levels do not drop drastically. A reliable means of developing a water budget is not currently available. However, the Canadian Government and CORDECO are developing a numerical model which will help quantify the availability of groundwater supplies and impacts on various withdrawals. The model is scheduled for completion in 1991. CORDECO has assembled a data base of 3000 nodes for the model which may be the only data base of its type ever done in the country. The results of the model can be used to establish a water budget utilizing groundwater supplies and the amount of surface water which will be required to supplement the wells. The model may also indicate that certain wells should discontinue or limit pumping to prevent stressing of the aquifer. Another product of this study may be the need for regulation of well drilling through some type of permit system with one agency having this responsibility.

The German/GEOBOL comprehensive groundwater study could also be of considerable help in establishing information for Cochabamba's water budget. It is suggested that funds be sought to help GEOBOL fund its relatively minor share of the $5 million study. Before proceeding, the study should be coordinated with the Canadian government to avoid potential duplications of efforts.

As a short-term solution to the lack of potable water in many areas, additional low-yield wells could be installed with hand pumps in areas where there are no water systems available. The amount of water that can be removed with a hand pump is minimal and should not be a major detriment to the aquifers. These types of wells are inexpensive to drill. Further, the pumps are inexpensive and the maintenance cost is low. These costs coupled with the high density of population in many areas in the department will yield a low cost per family served.

Wells which were inventoried by CORDECO and are noted as naturally flowing artesian wells should be capped immediately with a flow control device. This can be as simple as a regular gate valve. The local population should be instructed in water conservation and advised to shut off the water supply when not needed. Consideration should also be given to putting valves on wells that have flowed in the past as they may start again when the aquifer is allowed to recharge.

In the short-term, additional wells need to be developed through either well-drilling contractors, government agencies that have drilling capability, or through further U.S. military troop exercises. Conversations with the national geologic agency, GEOBOL, revealed that they have a good well-drilling program and they keep most of their seven drill rigs working. They need additional supplies such as drill rods, bits, and a spare parts package which would increase their productivity. An extension of a program of cost reimbursable well drilling for wells in outlying villages is worthwhile and should be continued. Their forces could also be used in drilling small wells in the city of Cochabamba similar to what the U.S. Army was asked to do during 1990. Another national agency that has drilling capability is the Ministry of Health. We had no direct contact with this agency, but they reportedly had two drilling rigs that are in extreme need of repair and additional supplies. A program for well drilling throughout the country is described in Appendix H.

Conversations with the various agencies that had drilling capability revealed that no one had modern hard-rock equipment for drilling wells into sound rock. While the initial cost for obtaining this type of system is high, its productivity is also very high. A trial program of drilling into fractured linaments could provide a new source of groundwater for the Cochabamba area. These drilling systems consist of down-hole pneumatic hammers that operate with a conventional drill rig coupled with a high pressure, high volume air compressor. These are commonly used in exploration for minerals and may be available in areas like Potosi. The drilling detachments of the U.S. military also have this capability. While a program such as this would require some study for actual site selections, this should be attempted in the future if the opportunity presents itself.

A procedure that could be adapted for use in many of the narrow valleys for retaining the groundwater in the alluvium within a localized area is to construct a subsurface wadi dam. These are used in many arid regions of the world where geologic conditions allow. The construction of these projects simply consists of placing an impervious barrier through the stream channel alluvium. This barrier is installed by excavating an open ditch across the stream which extends to the valley bottom. Once excavated, the ditch is backfilled with a core of impervious slurry of mixed soils. The procedure is labor-intensive and the material costs are minimal. The only material required is a source of clay. If none is available, a clay called bentonite that is mined in Bolivia can be transported to the site and mixed with available soils to form the required impervious material. The procedures for constructing these types of structures are described in Appendix L. There appear to be many sites that are well-suited for this type of construction. The water stored behind these subsurface dams is available for infiltration galleries or other types of wells. Since these structures are installed below the surface, there are no stability or erosion problems with long-term maintenance.

The costs of aiding the Cochabamba area in the long-term will be very high since continued development will require that water resources be transported into the populated large valleys through pipelines or channels. Any number of major projects could be implemented with proper funding, but all will take a period of years to complete. In the short-term, smaller projects can help relieve the lack of water in most areas. The city of Cochabamba must accept a water budget based on the available resources and move ahead with a major, new source of water, both for potable water and irrigation uses. Well drilling is both fast and effective if a program is implemented which utilizes the available equipment and the aquifers are not overstressed. The drilling program that is described in Appendix H and summarized in the main body of the report can provide high quality water in most areas of the department at a reasonable cost. The use of subsurface dams will also provide a project that can involve the local population at a very small cost.

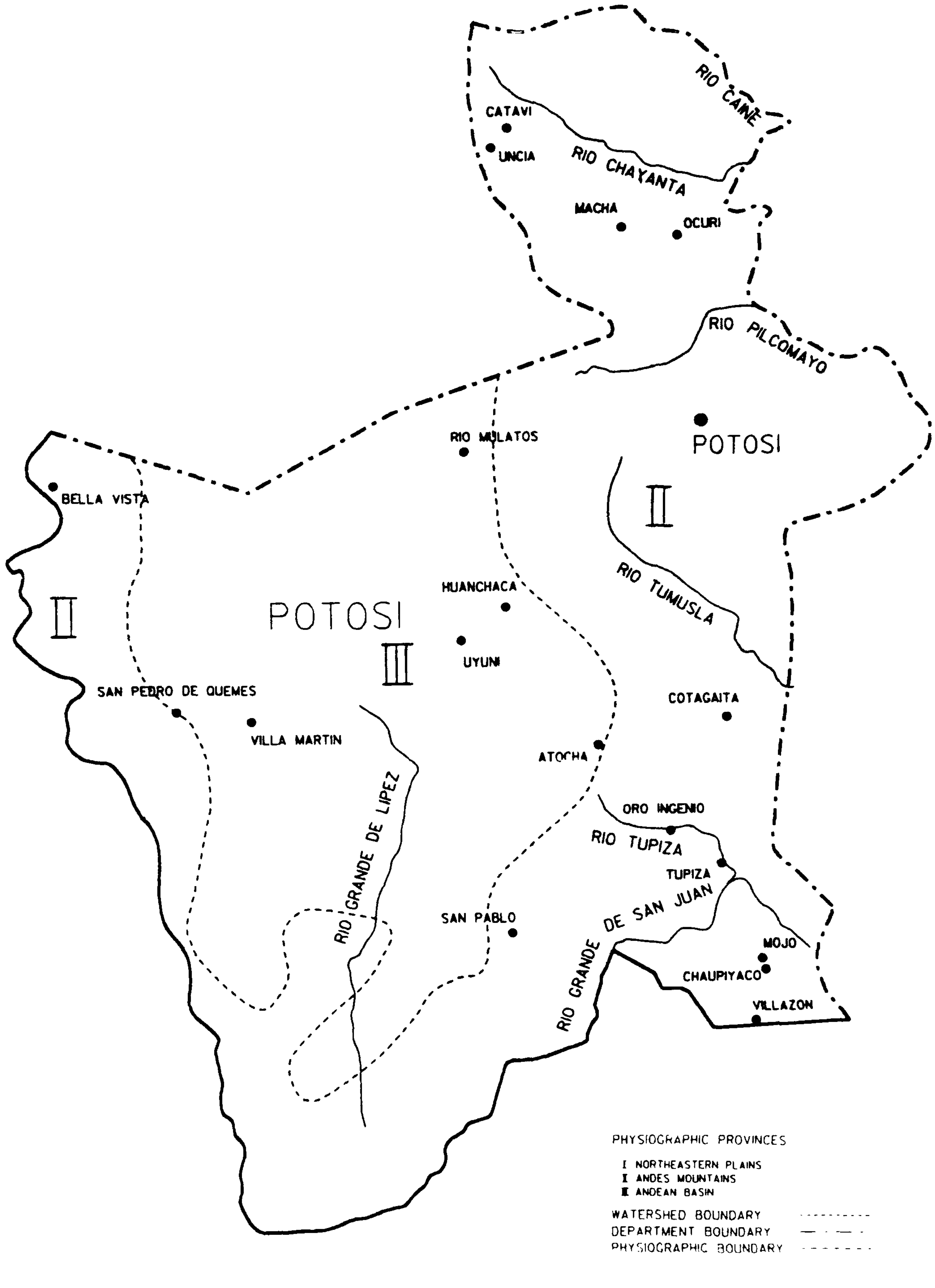
SUGGESTED STRATEGY (OTHERS)

Throughout Cochabamba, there are severe signs of overgrazing, deforestation and poor land use practices. The grazing of farm animals, especially goats, has severely damaged much of the native pasture in the department. The campesinos' daily need for firewood is rapidly depleting the remaining trees and vegetation cover. Other poor land use practices have led to erosion, sedimentation, pollution, etc. These trends must be reversed. At a minimum, we recommend that any water resource development projects include substantial environmental improvements and community involvement as a condition of the development. We further propose a positive program be undertaken in reforestation, education, and experimentation in better farm practices. For example, demonstration projects to prevent overgrazing can illustrate the benefits of change to the campesinos.

Given the systemic and complex nature of water use in any area, the development of water resources must involve a concerted effort to change human behavior. Changing behavior denotes involvement of the people in any plan or program affecting them. This involvement must be from the outset when problems are being discussed and defined because solutions depend largely on how a problem is stated. If the population of a given area views a situation one way and so-called experts foreign to the area define the situation differently, then the solution often is ignored, misused or destroyed. A case in point is the large scale irrigation project of Punata-Tiraque which the German government financed with Bolivian technical assistance. According to engineers who worked on this project, initial plans and specifications and even some newly constructed irrigation orks had to be scrapped or substantially modified. The campesinos who were to be the beneficiaries of this well-engineered system either refused to use the water or diverted the channels to suit their needs. It speaks well for the project manager and others involved when they shifted gears and included campesino groups in planning sessions. The results of this involvement are visible today: a system of lakes and channels which irrigates over 7,000 hectares and benefits some 5,500 families in the High Valley of Cochabamba. Further, the operation and maintenance of the inter-connected lakes and channels will be transferred completely to Campesinos' Irrigation Associations by 1992.

APPENDIX B

POTOSI



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POTOSI
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SAN PEDRO DE QUEMES
VILLA MARTIN
COTAGAITA
ATOCHA
RIO GRANDE DE LIPEZ
ORO INGENIO
RIO TUPIZA
TUPIZA
RIO GRANDE DE SAN JUAN
SAN PABLO
MOJO
CHAUPIYACO
VILLAZON
PHYSIOGRAPHIC PROVINCES
I NORTHEASTERN PLAINS
II ANDES MOUNTAINS
III ANDEAN BASIN
WATERSHED BOUNDARY
DEPARTMENT BOUNDARY
PHYSIOGRAPHIC BOUNDARY

APPENDIX B - POTOSI

CLIMATE, RAINFALL AND TOPOGRAPHY

The department of Potosi lies in the southwestern part of Bolivia in the heart of the Andes mountains. The topography of the department is varied, but is generally at higher elevations ranging from 1800 to 5000 meters above sea level. The western portion of Potosi is on the Altiplano (the high plateau) between the western Andes ridge on the Chilean border and the eastern ridge which runs down through Bolivia. The eastern half of the department of Potosi is in the Los Frailes, Chichas, and Lipez mountain ranges. These mountains contain large mineral deposits which have long made Bolivia an important mining region. Minerals in abundance include magnesium, lithium, sulphur, silver, potassium, antimony, and manganese.

The capital of the department is the city of Potosi. This city is situated at 4000 meters above sea level and the average temperature is only about 9 degrees Celsius. Average annual rainfall within the department varies from less than 100 mm in the arid southern and western parts of the department to about 500 mm in the northeastern region. Precipitation in a very small area in the northern part of the department averages around 900 mm per year, the wettest part of the department of Potosi. Because of this limited rainfall, the department exhibits arid or semi-arid characteristics. The most populated area of the department is the central region of Potosi which averages about 380 mm of rainfall per year. The present drought period began in early 1983 and has caused from 40- to 100-percent reductions in livestock production in different parts of the department. Many of the department's farming regions have also been severely impacted by drought. Furthermore, this lack of rainfall has severely reduced the already scarce supply of surface water in the department. Thus, there is a serious shortage of potable water throughout the department.

SOCIO-ECONOMIC PROFILE

Historically, the mines near the city of Potosi made this one of the wealthiest and most heavily populated departments in the nation. Indeed, historical sources state that the city of Potosi had 150,000 residents in

1611. By 1650 it had 160,000 inhabitants and was one of the largest cities in the world because of mining (Montes de Oca 1982: 45). As of the 1976 census, however, it showed the highest out-migration of the nine departments, losing almost 73,000 people (Brockmann 1986: 9). This loss is indicative of several changes in the status and well-being of Potosi's residents: the decline of mining as an economic mainstay; deforestation which is part of the larger soil depletion problem; endemic droughts throughout the decade of the 1980's; and population pressures on a shrinking amount of arable land, that is, too many people planting too many crops on too little land.

In 1976, the department had a population of 689,183, making it the third most populated after La Paz and Cochabamba. Of that total, about 248,000 or 36 percent, are Quechua or Aymara (Montes de Oca 1982: 49). The 1984 demographic estimates indicated that Santa Cruz ranked third with Potosi claiming the fourth largest populace (Brockmann ibid). According to a recent report, there are 118,022 residents of the city (AAPOS: 3). Local development officials claim that the economy of the department is now dependent on subsistence agriculture. Sixty percent of the people are farmers with only 7 percent working in mines. Indeed, mineral extraction now accounts for less than 25 percent of the revenue generated in Potosi (CORDEPO November 1990).

SURFACE WATER RESOURCES

There are three major drainage basins which partially lie within the department of Potosi. These are the basins for the Rio Pilcomayo, the Rio San Juan and the Altiplano. Much of the department relies upon surface supplies for a water source. Although these supplies are very limited due to the arid/semi-arid climate, the mountainous terrain yields further potential for the development of surface water impoundments.

The city of Potosi relies upon surface water for most of its supplies. Approximately 24 small reservoirs in the mountains above the capital city supply water for domestic use although most of them are now empty because of the drought. Many of these reservoirs date to the Spanish Colonial period when the water resources were developed to process the silver and other minerals being mined in the area. Quality of the water is not particularly good and residents are cautioned to boil all supplies before consumption.

Activities are under way to add two new chlorine treatment tanks to the water treatment facility. These are scheduled to go into operation during January 1991. This project is being sponsored by the European Economic Community (EEC).

GROUNDWATER RESOURCES

Due to the population density of the city of Potosi, many studies have been conducted for the availability of any type of water source. The limited amount of alluvial material in the greater Potosi area does not support a large groundwater supply. Numerous hydrogeological studies have reportedly been performed by agencies such as the European Economic Community and no significant aquifers have been discovered. The mining practices of deep shafts and tunnels have reportedly intercepted only minor amounts of groundwater. The water that is removed from the mines is used in the mining processes and becomes heavily polluted.

The portions of the department that are in the Altiplano have available reserves of groundwater, but the population density is so small that wells can serve only a small number of persons. Programs funded by the United Nations have led to the installation of a number of shallow, small-diameter (4") wells with hand pumps. These types of wells are reportedly in demand in many parts of the Altiplano.

Other than data gained conducting explorations for mineral deposits in certain areas, no information is available on possible water-bearing zones in the hard sedimentary rock formations in the northern section of the department. Numerous faults and fracture zones in these mountains could contain significant amounts of water. The presence of these zones could be explored with modern rock-drilling systems.

SPECIFIC PROBLEM AREAS

The 1989-1990 drought has affected communities scattered throughout eleven of the sixteen provinces of Potosi. Two reports from the department's development corporation list those provinces as follows: Frias and Scavedra in the central part of the department, Chayanta, Bustillos, Ibanez, Billbao and Charcas in the north (CORDEPO, Farming/Forest Development, 1990: 1, 11) and Baldivieso, Nor Lopez, Campos and Quijarro in the west (CORDEPO, Project Profile, 1990: 6). Not surprisingly, the seven regions in the north and center (Frias to Charcas) are all on the United Nations' listing of impoverished provinces in Bolivia (UNDP 1986: 50).

Estimates of the exact number of people suffering the effects of the drought range from 10,000 in dire need to a total of 18,425 affected (USAID May 1990: 5-6). Actual losses in crop production were fairly minimal, despite a 33-percent drop in the amount of rainfall during the growing season (MACA, April 1990 Evaluation of the Drought: 20). The cumulative effects may be more striking than the immediate effects: larger portions of land with no productive capacity, increased dependence on irrigation with decreasing source water and heavier losses of cattle and crops due to the spread of incipient disease (MACA ibid: 21).

The focus and number one priority for Potosi's development corporation (CORDEPO) is developing a dependable water supply for the city residents of Potosi. It will be very difficult for the city to even maintain its present level of development unless the municipal water supply can be significantly increased. Since there are no undeveloped sources of surface or groundwater in the vicinity of Potosi, it appears that the development of alternatives to bring water from outside the Potosi area is the only option available for providing Potosi with a dependable source of water.

Because of the extended drought, only about 10 of the 24 water supply reservoirs above Potosi have any water at all. See Photo No. 9, Appendix P. From these, the city residents can only get water for a few hours per day and sometimes even this is not available. Further, there are difficulties with losses in the city's water distribution system. Although there is no accurate data, losses through the pipe carrying water to the city from one of the lower lakes were reported at 60 percent. Demand from the population of Potosi is about 18,000 cubic meters per day. With all 24 reservoirs full and an efficient distribution system, the maximum support potential is about 6,200 cubic meters per day. Because of the drought, present supply capacity of the system is only about 2,400 cubic meters per day. The city has been rationing water since 1983, and since April 1990 has been on a very austere rationing schedule. Obviously, the city is in extreme need of further water supply.

Neither groundwater in the greater Potosi area nor additional reservoir sites are available in the mountains above the city, so other sources must be found for Potosi. Two plans have been proposed to bring water from distant rivers to the city to supplement the existing reservoirs. These will be discussed in the following section on "Suggested Strategy."

Drought is a severe problem throughout much of the department. Although critical in the city of Potosi, other areas have also been hard-hit. It was reported that 12 percent of the population has left the department in search of better opportunities. Of the remaining people twenty percent are apparently unemployed. The population in the department is dispersed making it difficult to develop any large-scale water resource projects since there will not be a significant concentration of benefits to make the project worthwhile. CORDEPO reported that on several occasions they had gone to an area to assist residents with water resource problems only to find out that whole communities had essentially departed in search of better conditions.

There are few towns of sizable population within the mountains of the northern portion of the department of Potosi. Population centers are typically clustered in the valleys perched on the high plateaus. These towns have sufficient surface supplies during the rainy season, but have to rely on the groundwater moving through the alluvium while it is available. Any period of drought can quickly deplete this source. The residents of the high plateaus have to rely on wells or small surface impoundments for their water supplies. These wells generally only produce enough water for potable use. Small surface impoundments are dependent on rainfall; therefore, future development in these areas is limited.

Land use practices in this area and throughout Bolivia are not making efficient use of the available soil and water resources. Poor farming methods, lack of knowledge in soil conservation techniques, slash-and-burn agriculture, overgrazing, and deforestation of land have led to high run-off of rainfall, soil erosion, degradation of vegetative cover, loss of soil productivity, sedimentation in streams and lakes, loss of groundwater recharge, and pollution of surface and groundwater resources. These conditions destroy the basis for human settlement.

From a positive viewpoint, the department of Potosi has initiated an impressive reforestation program. Over a million trees have been planted around the city of Potosi. Each of these trees is protected from animals by a stone and mortar encasement. See Photo No. 10, Appendix P. This work was completed by the campesinos for the cost of food. While this was a noble effort, the success of the program is questionable because of the marginal survival rate of trees at this altitude (4000+ meters).

SUGGESTED STRATEGY

The city of Potosi is obviously in dire need of additional water supply resources. Two significant plans have been investigated to bring water to the city. One plan envisions bringing water from the Rio Cira Palca by means of pumping. This would require pumps and a pipeline to transport the water some 40 kilometers to the City of Potosi. It has been estimated by CORDEPO that this option would be more expensive than a similar alternative which would get the water from the Rio San Juan.

The San Juan project would channel water some 45 kilometers to the city of Potosi. There are two main advantages of implementing the San Juan project. First, the water would flow by gravity and thereby require no pumping. Secondly, the river has a dependable year-round flow of good quality water. It was reported that the Rio San Juan can yield a dependable source of water that will average about 400 liters per second. A couple of different proposals have been put forth to bring this water to the city. One is to dig an open channel to carry the water to Potosi. This would be relatively inexpensive and perhaps more importantly, create needed jobs in the area. This type of system, however, would be subject to significant losses from evaporation and seepage, encourage development and water use along the route, and subject the water to man-induced and natural pollution. The open channel would be between 65 and 150 km in length, depending on the route chosen. If the water were carried in a pipeline, it would conserve much water and discourage use and pollution of the water as it is moved along. The 24-inch pipeline will have to be about 55 to 60 km in length. The pipe could be constructed above ground or buried, which would further protect this resource. However, it has been estimated that the use of a pipeline would increase the cost by about $6 million, from $9 to $15 million.

Because of the reduced cost, it is believed that the alternative of bringing water from the Rio San Juan is the better choice for the Potosi water supply. The use of a pipeline to transport the water to Potosi is recommended to conserve water and protect the water quality during movement. However, if an option to transport the water in a channel is chosen in order to save money and create jobs for the campesinos, we recommend that the channel be lined and covered to reduce infiltration losses, evaporation losses and pollution hazards. We observed several examples of excellent stone and concrete channel construction projects which would accomplish both the objectives of creating jobs and providing an efficient distribution system.

The continued construction of wells in the Altiplano area should be funded. These need be only four-inch wells with hand pumps which are not expensive to construct nor maintain. Procurement of a drilling rig capable of depths to 100 meters would be of great benefit to the department. Utilization of this rig in the Altiplano area could add hundreds of wells at reasonable cost. We suggest that a small truck-mounted drill rig be included under the National Well Drilling Program discussed in Appendix H.

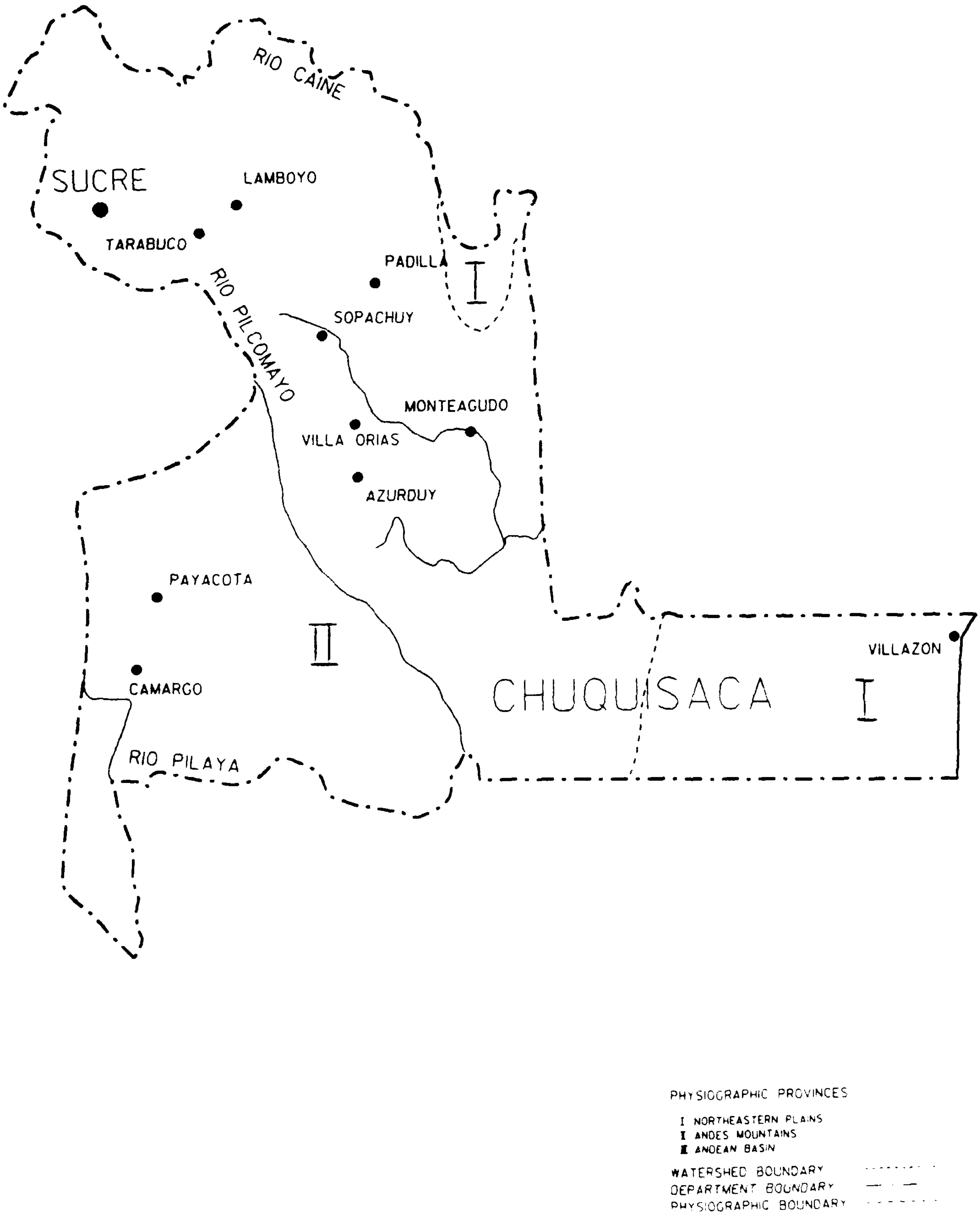
The potential for large amounts of groundwater existing in hard rock formations should be explored if possible. This may be possible if U.S. military well-drilling detachments continue their activities in Bolivia.

The existing pipelines that bring water from city reservoirs above Potosi should be monitored to determine the amount of water loss that is actually occurring. If there is a significant amount of loss, the pipe should be repaired or replaced. Unlined channels should be lined to reduce infiltration losses. These would be positive short-term projects that would not have a high cost.

In each of the departments we visited there were severe signs of overgrazing, deforestation and poor land use. The campesino's daily need of firewood is rapidly depleting the remaining trees and vegetation cover. Other poor land use practices have led to erosion, sedimentation, pollution, etc. These trends must be reversed. At a minimum, we recommend that any water resources development projects include substantial environmental improvements and community involvement as a condition of the development. It is also important that the department of Potosi be encouraged to continue the reforestation program only if it is proven that some type of tree will survive at this elevation. It is highly desirable that a positive program in areas such as education and experimentation in better farm practices be undertaken. Campaigns to teach and encourage water conservation measures in both urban and rural areas are important endeavors.

APPENDIX C

CHUQUISACA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WATERSHED BOUNDARY
DEPARTMENT BOUNDARY
PHYSIOGRAPHIC BOUNDARY

APPENDIX C - CHUQUISACA

CLIMATE, RAINFALL AND TOPOGRAPHY

The department of Chuquisaca lies in the south central part of Bolivia and along the eastern range (Cordillera Oriental) of the Andes mountains. The population of the department is around 475,000. The capital of the department is the city of Sucre, which is also the official capital city of the country, although La Paz is Bolivia's de facto capital. Sucre now houses only the Supreme Court and thus is the seat of the judicial branch of the government. The city is known for its outstanding Spanish colonial architecture and clean whitewashed buildings. The city is located at about 2,750 meters above sea level and the average annual temperature in the city is about 16 degrees Celsius. Average annual rainfall in Sucre is about 600 mm.

Average annual rainfall within the department varies from less than 500 mm to more than 1200 mm per year with most of the department averaging around 500 to 600 mm. Rainfall of over 900 mm occurs only over an area along the eastern edge of the mountains near the Chaco area. This is caused by the orographic effects of the eastern Andean mountains interacting with the moist air coming off the Atlantic Ocean and across the Amazon and Paraguay River basins. Elevations within the department range from around 500 meters in the Chaco region to over 4000 meters above sea level in the Cordillera de Tacsara mountains.

SOCIO-ECONOMIC PROFILE

Unfortunately, there was a dearth of social data available for this area. One 1986 publication lists Chuquisaca as the fifth most populous of Bolivia's nine departments, with 347,890 persons residing as of 1976. During that same year, the department had a net loss from out migration of 32,846 individuals (Brockmann 1986: 9). Ethnically, over half the population regards itself as Quechau (113,217 persons), Aymara or both (505) or Guarani (3,000 people) (Montes de Oca 1982: 49). With a land area of 51,524 square kilometers, Chuquisaca has an average population density of 6.75. It is heavily rural, with (281,000) 80% living outside urban communities (ibid.:70).

Despite a predominately rural settlement pattern, there are indications that Chuquisaca has a reasonably diversified economy. The department boastsssss the third largest of 5 crude oil refineries in the country (ibid.:116), a significant number of cattle ranchers, a growing service sector, all in addition to the traditional subsistence agriculture.

SURFACE WATER RESOURCES

The department's development corporation, CORDECH, has taken a proactive approach to water resource problems within the department. It has developed a drought response plan and has begun planning for development of the area's water resources. In addition, the department has a Civil Defense Force which will assist during natural disasters such as floods, earthquakes, droughts, etc. The surface water supplies within the department are limited, but there exists potential for further development of this resource, particularly on the wet eastern mountains which overlook the Chaco. This sub-tropical area of the eastern mountains contains numerous small impoundments from which the residents derive most of their water supply. Farming communities have developed around these water sources and as these areas continue to develop, the limited water sources will quickly become overstressed. For this reason, more of these type structures must be built. Presently CORDECH has a dam under construction at Macharati which will impound 2 to 3 million cubic meters of water.

In the dry Chaco area, water needs are the most critical in the whole department Residents in this semi-arid area have traditionally used earth cisterns to catch water for domestic use and for watering livestock. See Photos No. 26 and 27, Appendix P. Because of the drought, many more of these cisterns are needed to save the livestock and preserve the health of the campesinos. CORDECH is in the process of acquiring additional construction equipment to be used to excavate more small impoundments which will retain rainwater. These cisterns are normally made by scooping out earth and constructing encircling dams which are about 1.5 to 2 meters high. These projects will impound from 4,000 to 6,000 cubic meters of water. Initially these cisterns are required to provide clean water for human consumption and second for livestock watering after the human need is met. Efforts have been made to increase the water holding capabilities of the cisterns by lining them with synthetic materials made from layers of asphalt, foil, and polyethylene. This has proved beneficial with a life of about 20 years, but costs about $6 per square meter. Evaporation rates in the Chaco area average around 1,400 mm per year.

GROUNDWATER RESOURCES

Groundwater is used extensively within the department of Chuquisaca, especially in the arid regions of the Chaco. The aquifers underlying the Chaco are relatively deep and do not generally produce high-yielding wells. The depth of wells in the Chaco area range from 200 to 400 meters. Most of the wells reportedly only produce 3 to 5 liters per second. These depths coupled with low yield makes groundwater utilization a very expensive proposition. Thus, most wells are used primarily as a source of potable water.

SPECIFIC PROBLEM AREAS

Emergency drought plans written by the regional development corporation include four provinces designated as severely affected: Tomina, B. Boeto, Azurduy and L. Calves. The first three names are on the UNDP list of the thirty most impoverished provinces in Bolivia (1986, op. cit.: 50-51). USAID estimates focus on L. Calvo, Tomina and H. Siles, with the latter also on the impoverished provinces list. Individuals affected number some 11,375, or 2,275 families. About 9,000 of those people lost over 50 percent of their crops during the 1989-90 agricultural year (US AID op. cit.: 5-6). Those 9,000 persons constitute 79 percent of the total affected, the highest percentage of all the departments suffering from drought.

The two principal areas that were identified as problems due to drought were the areas in the southern mountains and the Chaco area. The mountain areas rely mostly on surface water supplies for livestock and crops that are seasonal while the crop production in the valleys rely on raintall without extensive irrigation. This makes these areas especially susceptible to drought. The worst problem area by far, and the top priority of CORDECH, is the Chaco region. The drought has caused many cattle to die for lack of water and adequate pasture for grazing. In addition, the dry packed soil has caused rapid runoff of any available rain with very little infiltration which would increase soil moisture. Furthermore, a dwindling supply of surface water in the earthen cisterns has contributed to the loss of much livestock and severe health problems for the inhabitants. The health problems have increased because the campesinos often share the same water supply with the livestock and consume water which becomes increasingly polluted as the holding ponds become smaller and smaller. One of the main problems is one of education where the campesinos do not see the relationship between sharing water with livestock and declining health. Currently, the existing water supplies are continuing to dry up. This is causing ranchers to move their cattle to the next available source which stresses or depletes that source and increases its pollution potential. When the ranchers do not have another source of water, they must then slaughter or sell their available herds which floods the market with beef and decreases their earnings.

Efforts which are underway to construct small surface impoundments at the edge of the Chaco near the mountains to trap runoff are hampered by poor soil conditions. The soils are permeable and erodible, making construction difficult. Much of the water trapped behind the impoundments is lost to infiltration. They are presently experimenting with various soil additives to overcome this problem. An asphalt-based product is now being tried.

Further development of additional surface water impoundments in the sub-Andean mountains along the western edge of the Chaco is possible but not effective in the short term for relieving drought conditions. Planning, design, and construction of these dams will probably take a minimum of two years even if the funding resources are available. For this reason, CORDECH is mainly looking to additional well-drilling for short-term solutions to the drought.

The construction of water wells is the immediate concern of CORDECH, however, the depth of well installation and the limited amounts of available groundwater make this a very expensive proposition. The costs of drilling in this region are high because of the depths required, the extra large casing size due to the pumps needed to lift the water from the deeper depths and the costs of the pumps. Many, if not most, areas require a pump which is powered by a diesel engine or a dedicated generator since there is no electricity available. The average costs reported for these items were $260 per meter for drilling with a pump cost of $40,000, based on a 8-inch diameter well. If this well produced five liters/second, it could serve approximately 2,500 persons for potable use only. The initial cost is about $150,000, based on 400-meter depth with pump and power source. This total figure seems high as compared to wells in other areas, but the cost per person is only about $60. If the well was drilled in an area where only a limited number of people could be served, the unit cost per individual would rise sharply.

A drilling rig, owned by CORDECH, is reportedly almost worn out from 15 years of use. They are limited to a drilling depth of 200 meters by the amount of drill rods that they presently have in inventory. Due to numerous breakdowns with their equipment, they report that the use of well-drilling contractors is presently less expensive than their in-house operations.

Rainfall patterns have also been a problem for the farmers in this department. With the crops they are presently growing, it is critical that the rainy season begin in the normal October to November time frame. If the rainfall comes later in the year, as it has been doing lately, they lose an entire growing season. Similarly, if the rain comes too early, the farmers are not prepared for planting. Alternative crops or growing cycles need to be developed which can better cope with the variability of the rainfall patterns.

Land use practices in this area and throughout Bolivia are not making efficient use of the available soil and water resources. Poor farming methods, lack of knowledge in soil conservation techniques, slash-and-burn agriculture, overgrazing, and deforestation of land have led to high run-off of rainfall, soil erosion, degradation of vegetative cover, loss of soil productivity, sedimentation in streams and lakes, loss of groundwater recharge, and pollution of surface and ground water resources.

SUGGESTED STRATEGY

One of the major problems in the department is the lack of water in the cattle-raising area of the Chaco. The most pressing need in the Chaco is for the construction of more cisterns ($3,000 to $4,000 each). CORDECH estimates tha water demand in the department to be about 200 liters per day for human consumption and 50 liters per day for each head of livestock. CORDECH is already in the process of acquiring additional equipment to construct more of these water holding ponds but could still use assistance in the short term. Use of Bolivian or U.S. military engineers could be of assistance in this construction. If U.S. assets are requested, it may be necessary to rent the heavy equipment from within country because of a present deficiency in available heavy-lift aircraft to transport engineer equipment from the United States. Any equipment available to CORDECH should be used for construction of these holding ponds.

As an alternate or supplement to this action, we would suggest that USAID consider either leasing or purchasing a bulldozer for CORDETAR to dedicate toward building earthen cisterns. USAID would have to negotiate with CORDETAR and the cattlemen on a cost-sharing agreement. Because of potential profits for such work, we suspect that the local costs will be a high percentage of the total cost. Thus, it appears that significant progress could be made toward alleviating the drought problems in the Chaco area with a limited investment. The total cost of an appropriate bulldozer for this type work is $250,000. If this idea is adopted, we would suggest close monitoring by the sponsoring agency.

We also suggested that CORDECH obtain plans of the holding ponds used in Argentina which separate the holding pond water in such a way as to allow sharing among humans and animals, but prevent contamination of the water of human consumption by livestock. A suggested design of such a cistern is discussed in Appendix M. This would allow people to withdraw rainwater which was collected in a main holding tank, while excluding livestock. This would prevent the animal contamination of the water. At the same time, water would be available in a watering trough for animal consumption. A control valve in the pipe connecting the main holding tank and the trough would prevent water from passing back from the livestock through the pipe into the pond for human consumption. While this would cost slightly more to construct, it would provide considerable intangible benefit in the form of improved health of the campesinos. If the idea of furnishing a bulldozer is adopted, it is recommended that the program be contingent on adopting this type of design.

Another short-term solution for parts of the Chaco affected by the drought is the construction of additional water wells. The drilling equipment owned by CORDECH may be in such condition that a thorough reconditioning may return it to efficient operation. Additional drilling supplies for the rig would allow drilling to deeper depths as required in some areas. The costs of supplying well-construction materials for the use with the department's own rig should only be considered if the drilling rig is refurbished to good operating condition. For construction of an 8-inch well, the well-casing costs will be $30 per meter and the costs of well-screen will be about $315 per meter. The cost of rehabilitating the drilling rig cannot be estimated until it is checked out by a factory representative from the George Failing Company or other experienced drill rig repair specialists. The most that should be spent on the rig is about $40,000 before giving consideration to replacement at a cost of about $250,000. The costs of well contracts will vary according to the required depth, but will be in the range of $100,000 to $150,000 each, including the cost of the pump.

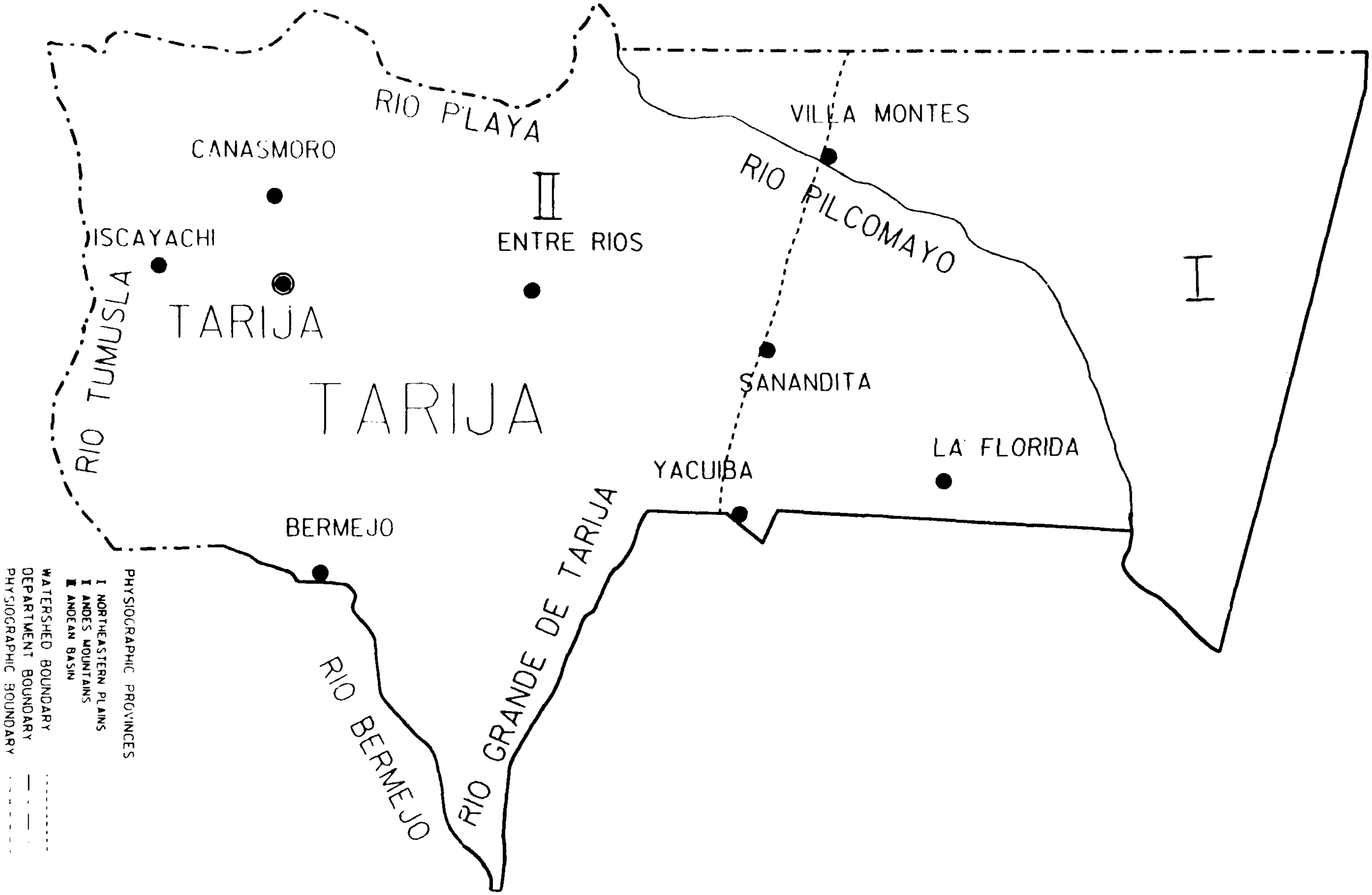
CORDECH is encouraged to continue development of the water resources of the relatively wet sub-Andean area. Time did not allow a visit to look at the area, but studies of potential dam sites should yield many worthwhile projects which could benefit many families.

Studies of farming practices in the department will probably find that changing the type of crops grown or modifying the traditional planting schedules can greatly reduce the susceptibility of the crops to the timing of the rainy season. It is recommended that such a study be completed.

The problem with excess infiltration of water from the earthen cisterns can probably be corrected in a cost-effective manner. Simply lining the ponds with an impervious soil, such as bentonite, would probably solve this problem. If desired, we recommend that CORDECH seek technical assistance in this area.

APPDENDIX D

TARIJA


RIO PLAYA
CANASMORO
II
ENTRE RIOS
ISCAYACHI
TARIJA
RIO TUMUSLA
TARIJA
VILLA MONTES
RIO PILCOMAYO
I
SANANDITA
LA FLORIDA
YACUIBA
BERMEJO
RIO GRANDE DE TARIJA
RIO BERMEJO
PHYSIOGRAPHIC PROVINCES
I NORTHEASTERN PLAINS
II ANDES MOUNTAINS
III ANDEAN BASIN
WATERSHED BOUNDARY
DEPARTMENT BOUNDARY
PHYSIOGRAPHIC BOUNDARY

APPENDIX D - TARIJA

CLIMATE, RAINFALL AND TOPOGRAPHY

The department of Tarija lies in the south of Bolivia on the border with Argentina and Paraguay. Tarija has a population of about 200,000 and covers some 37,623 square kilometers. The department of Tarija has a varied terrain with a corresponding difference in climate. The western end of the department is included in the eastern ridge of the Andes, part of the high mountain chain which dissects Bolivia. The eastern half of Tarija lies on the lowlands of the semi-arid Chaco having elevations of only a few hundred meters. The capital of the department is the city of Tarija which is located in a large valley known as the Central Valley. Tarija is situated at elevation 1900 meters above sea level and has an average annual temperature of about 18 degrees Celsius. The city sits in the heart of an extremely fertile valley which, unfortunately, is undergoing very severe problems with erosion. Average annual rainfall in this valley is about 600 mm. Rainfall within the department varies from less than 400 mm in the western parts to around 1200 mm in the extreme south central part of the department. Elevations range from around 300 to over 4000 meters above sea level while average annual temperatures range from around 10 to about 23 degrees Celsius. Evapotranspiration potential in the department averages about 1400 mm per year.

East of the high Andes mountains are a series of lower mountains (sub-Andean) that were formed by regional tectonic activity. In this region, folding and faulting of the rock layers with subsequent erosion has produced four major parallel valleys separated by high ridges averaging about 2,500 meters high. Each valley has a permanent stream as a result of the 1,200 mm of annual rainfall within this area. At the eastern edge of these mountains begins the Chaco region. The Chaco is a peneplain with an average elevation of only 400 meters and other than a narrow strip adjacent to the sub-Andean mountain zone, is arid with only an average of 400 mm of rainfall per year. The narrow zone against the mountains is known as the "Wet Chaco" and has increased rainfall as well as runoff from the mountains. Most of the streams that enter the Chaco from these mountains flow east, then lose their water to infiltration and evaporation and the streams disappear.

SOCIO-ECONOMIC PROFILE

Created by presidential decree in 1831, the department of Tarija is one of the two southernmost in Bolivia and borders on both Argentina and Paraguay. The 1976 census showed a population of 187,204 persons, or 3.4 percent of the nation's total 4.5 million. Occupying only 4.1 percent of the country's land mass, Tarija boasts a significant variety of Native American groups, topography, climate and economic activities. One measure of economic health is reportedly the diversity within income-generating sectors. Tarija produces and exports soy flour, refined and crude oil, wood, foodstuffs such as fish, chili peppers and fruit, and leather goods. Near Yacuiba, there is a cotton factory (CODETAR. Detailed Project Report: Multifunctional Project Gran Chaco. June 1989: 11)

The capital city of Tarija with approximately 60,000 people is situated in what was once a highly fertile agricultural valley (Shichar 1985: 93). Endemic erosion has destroyed much of that fertility. The city serves as the transportation hub of southern Bolivia with connections to all metropolitan centers in the country and to Argentina. According to one of Tarija's national deputies, the capital city receives hundreds of migrants from Potosi (Arturo Liebers, November 1990). These are individuals who can work no longer in the mines and, therefore, must seek employment elsewhere. As Tarija has the reputation of being a farming and commercial center, they go to this city. Reportedly, at least fifty percent of these people ultimately migrate to Argentina, Santa Cruz or to the Chapare area in Cochabamba.

The entire department has undergone startling changes since the 1940's. After losing a large number of men and territory in the Gran Chaco War, Tarija gained a belated sense of unity with its easternmost provinces when communication and transportation lines were installed. The opening of several private banks in the capital city provided needed commercial impetus and the installation of two sugar factories in Bermejo, near Argentina, spurred foreign trade (Diagnosis of the Department of Tarija, 1981: 5).

The economy of the department varies so much that the primary report referenced in this section divides Tarija into five distinct subregions, each centering around a major city (Diagnosis, 1981: 8+). The major economic center is the capital city, with 57,475 people (1976 tatistics). The Tarija subregion is characterized by heavy dependence on farming, which includes foodstuffs, sheep and goat herding and of increasing importance, vineyards for wine production. The manufacturing sector produces bottled drinks, construction materials, wood and metal furniture, soap and candles. Subregion II is centered around Entre Rios in the central part of the department. See Photos No. 19 and 20, Appendix P. With a 1976 population of 15,052, it is a predominantly agricultural area with the primary crops consisting of potatoes, corn, citrus fruits, tobacco, and manioc. Hogs and cows are the mainstays of animal husbandry. Mineral production includes salt, gypsum, lime and construction stones. Villa Montes is the largest city in Subregion III, boasting a vegetable oil factory which has spurred significantly the cultivation of oleaginous crops. Of greater importance is the discovery and exploitation of oil and natural gas. Depending on the amount available and the ease of marketing, these energy sources could make the region the most influential in the department. The fourth subregion has its "headquarters" in Yacuiba and depends on farming and incipient trade with nearby Argentina. Subregion V, with its principal urban center of Bermejo, is reputedly second only to the capital, Tarija, in commercial importance and level of development. The opening of two sugar refineries is the reason given for a good part of that development. Farming is also a notable contributor to the economy with sugarcane, citrus, corn, potatoes, wood and cattle the primary products.

SURFACE WATER RESOURCES

There are two major river basins in the department, the Rio Pilcomayo (see Photo No. 1, Appendix P) and the Rio Grande de Tarija. The number of water projects that have been developed in the department is limited and there is potential for further development of surface waters. However, water supplies and uses that have been developed within the department are quite varied. A major reservoir was constructed in the Tarija Valley on the Rio Tolomosa and completed in 1988. This project is the San Jacinto Dam which stores water for irrigation, erosion control, hydropower, fisheries development and recreation. The 40-meter-high reinforced concrete dam impounds some 41 million cubic meters of water, creates a lake covering about 700 hectares, and was constructed to provide a useful life of about 100 years. The spillway capacity is about 3,000 cubic-meters-per-second which is reportly enough to pass the magnitude of floods which occur on an average of once every 10,000 years. See Photo No. 18,

Appendix P. The hydropower plant is located 1 km downstream and is connected to the reservoir by a penstock. The installed capacity of the plant is 7,000 KWH and has a normal operating head of 57 meters.

Feasibility studies are complete and final design is underway for a new irrigation project for the Santa Ana river basin southeast of Tarija. It will be a 30-meter-high dam to provide water for irrigation and erosion control in the fertile valley. This valley is famous for its vineyards which produce some of Bolivia's best wines. Presently, the farmers in the area use infiltration galleries and rainwater catchment ponds to collect and store water for irrigation. The distribution system for irrigation water in some vineyards could serve as an example of water conservation. They are using a highly efficient drip irrigation system - a series of rubber hoses with holes laid down the rows of grapevines. See Photo No. 22, Appendix P. This system uses a small fraction of the water required for a typical flood irrigation system.

The entire Tarija valley was once flooded, but now lies in a prehistoric lake bed. The natural dam which impounded the lake was located about 25 km downstream of Tarija on the Rio Tarija. Several million years ago, this dam broke and released the water from the lake. See Photo No. 21, Appendix P. The ancient sediments provide a very rich and productive soil for farming, but also a soil which is highly erodible and not suited for use as construction material. When the dam broke, the erosion and headcutting processes began and persist until this day.

At the town of Villa Montes in the eastern part of the department, Phase I of the Esquema Irrigation Project is nearing completion. This phase of the project diverts part of the flow of the Rio Pilcomayo for use in the irrigation of some 3,500 hectares of farmland. The project is financed ($13 million) by the Italians but is being built and operated by the Bolivians. The project is being built to provide water for a number of newly constructed farms, each of 20 hectares in size. Campesinos will be selected before the next growing season to settle and cultivate each of these farms. This is an effort to encourage locals to stay in the area instead of migrating to the cities or coca growing regions in search of better living conditions. Eventually, the project will provide irrigation water for about 40,000 hectares and will cost about $400 million. This includes a dam on the Rio Pilcomayo which is one of the few rivers in the department which carries water throughout the year. CODETAR is also looking into a proposal for adding a hydropower plant to this project, but the cost is not yet included in the $400 million price tag.

In the Chaco area of Tarija, ranchers use the same primary methods used by the ranchers in other departments of the Chaco for water collection and storage. They rely on earthen cisterns to collect and hold rainwater which is used for cattle and human consumption. See Photo No. 27, Appendix P.

Another water supply source is proposed for the people in and around the Yacuiba area. The Aguayrenda project will be a water supply dam constructed in the foothills overlooking the Chaco and located about 20 km north of Yacuiba. A dam 30 meters high will provide water for the communities of Aguayrenda, Palmar Chico, Campo Pajoso, Yacuiba, and Pocitos. Water will be used for potable water supply, flood control, erosion control, and recreation. See Photo No. 23, Appendix P.

GROUNDWATER RESOURCES

Groundwater plays an important role in the valley area where the city of Tarija is located and in the entire Chaco area. It is not as critical to the areas within the sub-Andean zone due to the presence of numerous streams. In the Central Valley where the city of Tarija is located, much of the potable water is obtained from wells. Hydrogeological studies have shown that two main aquifers are located in the valley. These aquifers are recharged on the upper western slopes of the valley and provide artesian water to the wells. The city currently has about 15 wells on their system. The "shallow aquifer" is only about 30 to 60 meters deep and underlying this is the "deep aquifer" at a depth of 80 to 100 meters. Many of the wells have a relatively high yield of 10 to 30 liters per second.

Within the Chaco area, the use of wells is widespread due to the arid climate and lack of permanent surface water. Drilling of wells in the Chaco region has never been based on any type of hydrogeological study, only on a need for a well in a certain location. This drilling has indicated that no major aquifer exists since wells vary in depth and yield. The wet Chaco region reportedly has higher well yields (4 to 15 liters per second), than areas further to the east. This would be expected since alluvial outwash from the mountains is normally much coarser-grained nearer the source area and would correspondingly have a higher permeability. Further east in the dry Chaco region, most wells produce only 2 to 5 liters per second. The quality of groundwater is good throughout the Chaco area and is well-suited for potable water.

The sub-Andean region depends mostly on the permanent streams that occupy the valley areas. While groundwater is readily available within the alluvium of the valleys, it is not widely used for water supplies other than potable water. The wells in this area are relatively shallow and produce high yields, thus are relatively inexpensive.

SPECIFIC PROBLEM AREAS

The drought in Tarija has principally affected the people and land in four provinces: Gran Chaco, O'Connor, the Valle Central around Tarija, and Mendez, per USAID estimates in May 1990. This same document puts some 3,500 families (18,750 persons) in the significantly affected category, 1,500 families (7,500 persons) of whom are suffering severe hardships. In this case, severe means a loss of over 50 percent of their crops during the 1989-90 agricultural year.

For those people living in the province of Mendez, the hardships of the ongoing drought are compounded by the extreme poverty which already existed. According to a United Nations report in 1986 on critical levels of poverty in Bolivia, Mendez Province in Tarija ranked nineteenth among the thirty poorest provinces throughout the nation. Hence, Mendecenos suffered just as much as others in Tarija, even though losses to crops were lower than in the Chaco provinces (Evaluation of the Effects of Drought 1990:23+).

Indeed, the rains came on time and even slightly heavier in volume in Mendez and in the high zone of the department than in previous years. The Chaco area had enough rainfall to enable farmers to plant their crops. This rainy season, however, failed to meet expectations from the previous year, although Tarija is not as devastated as other departments such as Oruro and Cochabamba.

Table D-1 below shows that families fared differently depending on both location and the kind of crop or crops they planted. By far the highest number of people affected live in the Yacuiba part of the "Wet Chaco". But the portion of people who felt the effects of lack of rain was highest in and around Villa Montes. There, 80 percent of all hectares planted produced lowered yields because of drought and 710 families suffered accordingly.

Table D-1
Status of Crops Affected by the Drought
Provinces of O'Connor and Gran Chaco
1989-1990 Agricultural Year

CROP	PLANTED HECTARES	PERCENTAGE AFFECTED	FAMILIES AFFECTED
	Entre Rios		
Corn	2,661	30	346
	Villa Montes		
Corn	500	80	500
Soybeans	1,200	80	160
Peanuts	10	80	50
	Yacuiba		
Corn	5,286	30	877
Soybeans	5,049	30	1,000
Peanuts	177	10	500
Total	14,883		3,433

Source: Evaluation... 1990:24.

The department seems to be wisely using its available resources and building new surface impoundments when the funding and justification are available. It appears that the department has two very significant problems with which it is trying to cope. One is the serious drought which has devastated much of Bolivia. The other is the incredible erosion problem which is wreaking havoc in the fertile Tarija valley. See Photo No. 13, Appendix P. While there are severe effects throughout the department of Tarija, the area most severely affected by the drought seems to be the Chaco area where most of the people rely on cattle-raising for a living. These ranchers usually depend solely on rainfall and they water their stock from the earth collection and storage ponds which are so common in the Chaco. The ranchers also share this water source with the cattle and it often becomes very polluted, particularly as the supply concentrates in smaller and smaller pools as the drought continues. See Photo No. 21, Appendix P. The ranchers do not seem to associate sickness with the shared use of their water supply. They are badly in need not only of education in basic sanitation, but also of more collection ponds to store the limited rainfall when it does occur. In some areas of the Chaco, the drought has been so bad that no rain at all has fallen during some of the recent years. Because of the drought and the limited ability of the pasture to revegetate after grazing, each head of cattle requires about 7 hectares of grassland. In addition, each head needs about 40 liters of water per day and each rancher requires about 140 to 150 liters per day to live. Alternate water sources, in lieu of waiting for rainfall, will have to come from groundwater as no other alternative is presently available.

The erosion problems in the central Tarija valley are immense. There are a number of factors which contribute to this erosion, but one of the main factors is the presence of highly dispersive clay soils which cover much of the valley. In the geologic past, uplifting of the land surface in parts of the basin created a Paleo-lake from water that was trapped behind this natural dam. The lake began to fill with sediments which had the necessary physical and chemical characteristics to have dispersive properties when exposed to water. Later in the area's geologic history, natural erosion opened a water gap through the uplifted rock layer and an outlet for the lake was created. The water cut this gap down and allowed the entire lake basin to drain leaving the accumulated sediments behind. As the free water left the sediments, the material dried out and what was left was a thick deposit of dispersive clay. This material literally falls apart in the presence of water, so as rainfall wets the soils, it chemically disperses on the slopes and erodes into the streams to be carried away as sediment load. As natural streams drain, the valley is cut deeper and more and more tributary stream channels or gullies are eroded into the other areas. This process has been taking place for hundreds of thousands, if not millions of years. Estimates are that approximately one third of the Central Valley or 1,000 square kilometers have been affected by this process.

Today the erosion has other factors which make the process difficult to control. In addition to the nature of the soil, these factors include: basin slopes of 3 to 5 percent, rainfall patterns, poor farming practices, and deforestation from natural and man-made forces. Erosion in the watershed is so severe that much of the basin looks like the "Bad Lands" found in the United States. See Photos No. 13, Appendix P. The sediment flows that are generated threaten to shorten the useful life of the new San Jacinto hydropower and irrigation reservoir. Although designed to last for at least 100 years, it is estimated now that the reservoir will fill from sediment in only 30 years. Furthermore, it is estimated that each year, erosion claims another 200 to 400 hectares of land and produces sedimentation which clogs channels and threatens their ability to carry flood flows.

The erosional processes of the dispersive clays are very difficult to control. The only positive way to control the erosion is to establish a base level for the stream that carries the eroded soil. The natural water gap that provided an outlet for the Paleo-lake sets a base level for the main river by acting as a dam. Erosion does not take place below the base level, (in this case the invert of the water gap), so this is a means of controlling the erosional process. The thousands of gullies that extend out across the valley from the river are actively downcutting during every rainfall. This erosion is especially bad at the head of the gullies where the gradient is the highest.

Erosion control efforts to date have cost about $8,000,000 and have had almost no measurable effect in reducing the rate of erosion. The German government spent some $3 million in a futile reforestation program that apparently had no positive results at all. In the past few years CODETAR has embarked on a program of reducing erosion in the upper ends of the valley's watershed by means of terracing, construction of small impoundments, reforestation, fencing of the restored area to prevent overgrazing by sheep and goats, and educating of the campesinos in soil conservation practices. Each watershed treatment covers only 1 to 2 hectares and about 50 of these projects has been completed. See Photos No. 14 and 15, Appendix P. These 50 projects are effective in their micro-environment, but have made only the smallest step toward the final solution to the Tarija erosion problem. The cost of these mini-projects is about $6,000 each.

At the Tarija airport, another serious erosion problem was investigated. It is apparent that water is seeping under the runway and removing the material which provides the support to the aircraft operating surface. This is apparent because erosion caverns are now appearing on the downstream (south) side of the east-west runway. See Photos No. 16 and 17, Appendix P. This is particularly critical because the soil appears to be a dispersive clay which readily loses cohesion and erodes when exposed to moving water. The caverns appear some 30 to 40 meters from the runway and thus it is not known if they extend under the runway or not. It is believed that if they do not now extend under the operating surface, they surely will with time if the seepage is not corrected. Because of the dire consequences of a failure of the runway at this busy and important transportation center, it is imperative that this problem be investigated and corrected quickly.

Around the city of Tarija and in the Central Valley area, sufficient groundwater reserves exist to meet their needs for potable water. There is a need for good land management practice in the recharge areas on the western side of the valley to ensure that the groundwater remains pure and that recharge can take place.

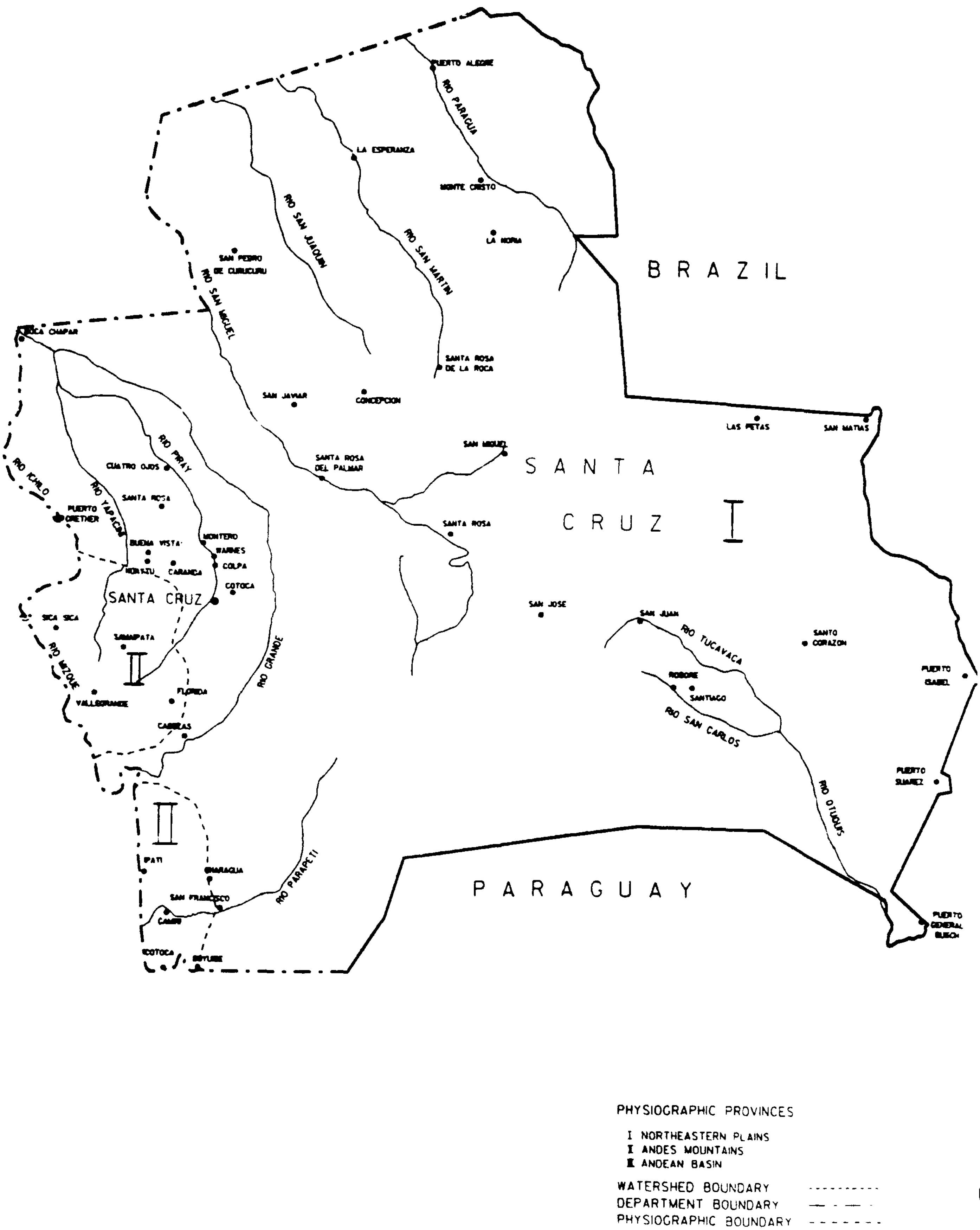
The Chaco region of the Department of Tarija has less well-defined aquifers for the extraction of groundwater. Many of the wells that are drilled have low yields, so either additional wells are required or simply less water will be available per capita. The cost of well-drilling is high, up to $200 per meter without the pump. This cost coupled with low yields makes well-drilling an expensive proposition for a farmer or small town. Some drilling programs are preceded by geophysical investigations that help define the presence of water-bearing strata. This type of investigation is relatively inexpensive and is a good investment in most cases - especially in the Chaco where costs are high and the aquifers undefined.

The wet Chaco region has better aquifers than the other parts of the Chaco, but due to the higher population, this area has a high water demand. Because of this high demand, a surface water supply would be better suited to provide this water. In the southwest corner of the department's Chaco region, the town of Yacuiba and the area north of the town have a severe shortage of potable water. The town is served by a single well that only supplies a small fraction of the requirement. Therefore, the town only has water available to the distribution system for a short period of time daily. The construction of a surface reservoir would provide a reliable water source that would supply both potable water and some water for irrigation. The Aguayrenda project is the site that is being considered that appears to be suitable and is discussed in more detail later in this appendix in the section "Suggested Strategy".

The dry Chaco area is used for the raising of cattle and for some crop farming along the one permanent river, the Rio Pilcomayo. Groundwater is used to provide potable water in many smaller villages and at the more prosperous

APPENDIX E

SANTA CRUZ



BRAZIL
PARAGUAY
SANTA CRUZ
I
II
III
SANTA CRUZ
PUERTO ALEGRE
RIO PARAGUA
LA ESPERANZA
MONTE CRISTO
LA NORIA
RIO SAN JOAQUIN
RIO SAN MARTIN
SAN PEDRO DE CURUCURU
RIO SAN MIGUEL
SANTA ROSA DE LA ROCA
SAN JAVIAR
CONCEPCION
SAN MIGUEL
SANTA ROSA DEL PALMAR
SANTA ROSA
LAS PETAS
SAN MATIAS
BOCA CHAPAR
RIO PIRAY
RIO ICHILO
CUATRO OJOS
RIO YAPACANI
SANTA ROSA
PUERTO GRETHER
BUENA VISTA
MONTERO
WARNES
COLPA
CARANDA
COTOCA
SICA SICA
SAMAIPATA
RIO MIZQUE
VALLEGRANDE
FLORIDA
CABEZAS
RIO GRANDE
SAN JOSE
SAN JUAN
RIO TUCAVACA
SANTO CORAZON
ROBORE
SANTIAGO
RIO SAN CARLOS
PUERTO ISABEL
PUERTO SUAREZ
RIO OTUQUIS
PUERTO GENERAL BUSCH
IPATI
CHARAGUA
SAN FRANCISCO
CAMIRI
RIO PARAPETI
ICOTOCA
BOYUIBE
PHYSIOGRAPHIC PROVINCES
I NORTHEASTERN PLAINS
II ANDES MOUNTAINS
III ANDEAN BASIN
WATERSHED BOUNDARY
DEPARTMENT BOUNDARY
PHYSIOGRAPHIC BOUNDARY

Table E-1

Summary of Area Affected by the Drought and Losses in Santa Cruz, 1989 and 1990

Province	Crops	Planted (Hectares)	Affected (Hectares)	Losses (%)	Losses (US $)
Florida	Corn	11,200	10,700	81	$1,376,400
	Others[1]	7,100	5,480	84	2,075,100
	TOTAL	18,300	16,180	-	3,451,500
Caballero	Corn	630	570	90	74,100
	Wheat	830	790	72	103,400
	Potato	470	400	87	326,400
	Vegetables[2]	1,360	740	54	761,300
	Others[3]	390	170	47	174,000
	TOTAL	3,680	2,670	-	1,439,200
Vallegrande	Corn	5,510	5,070	72	638,700
	Vegetables	530	330	63	430,300
	Wheat	160	80	50	10,900
	Others[4]	80	40	47	37,000
	TOTAL	6,280	5,520	-	1,116,900
Cordillera	Soybeans	2,070	610	27	128,700
	Corn	15,240	12,810	84	1,655,300
	Others	120	120	100	36,000
	TOTAL	17,430	13,540	-	1,820,000
Andres Ibanez (Microregion)	Soybeans	47,550	12,480	26	2,624,200
	Corn	9,130	1,560	17	201,400
	Others[5]	400	100	24	17,400
	TOTAL	57,080	14,140	-	2,843,000
	TOTAL VALUE				$10,670,600

Source: Evaluation of the Effects, April 1990:26-27.

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1 Tobacco, beans, potatoes, manioc, vegetables
2 Potatoes, peppers
3 Citrus & other orchards
4 Apple, citrus & peach orchards
5 Cotton, vegetables, citrus

The same report specifies that much of the lower yield of corn is due to a reduction of 27,000 hectares planted. This abatement was caused by a fall in corn prices from $7.44 to $3.85 a kilo during the 1989-1990 agricultural year (Ibid.). Authors of the document do not discuss whether the difference was made up by increased hectares planted in other crops. Nonetheless, corn is the most important crop of the majority of families affected by the drought in the Province of Cordillera. It constitutes an average of 84% of yearly production (Rural Development Program in Cordillera 1990:27). If prices are low and yields are reduced by drought, prices may rise, spurring an increase in hectares planted. But even if prices can be stabilized at a higher level, Cordillera residents must also cope with decreasing food and water supplies for their herd animals, whether cattle, sheep, goats or burros. If the animals die or must be killed because of drought, then the campesino has no choice but to seek a livelihood elsewhere. That elsewhere reportedly is in the sugar cane fields of Santa Cruz (Ibid.).

Climatic conditions throughout most of Bolivia have not been normal for the past seven years. During the drought of the 1980's rainfall has been particularly meager in four of Santa Cruz's provinces (Florida, Caballero, Vallegrande, and Cordillera). In some areas around Vallegrande there has not been even one drop of rain in over a year. See Photo No. 26, Appendix P. Damages from the drought were reported at about $6.3 million, primarily due to loss of cattle within the department. About 40,000 people and 80,000 hectares of land are estimated to have been affected by the drought. Lack of water also has caused many social problems, such as children missing school due to sickness or having to spend the day carrying water from distant water sources. Health problems have resulted not only from humans sharing dwindling water sources with animals which contaminate the water, but also from the lack of water with which the residents can wash and a lack of sufficient water in the diet.

The department seems to be wisely using its available resources and developing new surface supplies when the funding and justification are available. It appears that the department is correctly concentrating on the four provinces most affected by the drought and of these, surface-water sources are probably most important in Cordillera for watering of livestock and developing potable water sources in the front range of mountains overlooking the Chaco. We suggest however, that the erosion which is evidenced by the sand dunes south of the capital city be addressed immediately before in worsens. Recommended measures include prohibition of slash-and-burn clearing techniques, the planting of trees as windbreaks and to help anchor the soil plus weighting and adding to the current layer of topsoil.

The city of Santa Cruz is adjacent to the Rio Piray. The water is not used for water supply for the city but does pose a significant threat to the city from infrequent flooding. In March of 1983, the city of Santa Cruz was flooded by the Rio Piray with flood discharge peaks that were 4 to 6 times larger than the 100-year flood. This occurred with rainfall amounts that were only in the range of 5- to 20-year frequency events. This was caused by landslides in the mountains which blocked the river flows and dammed up the runoff. When the water built up behind these earth plugs, the plugs ruptured and released the water all at one time. The result was very high peak flows and river stages which had never been experienced until that time. This flood covered 50,000 hectares of agricultural land and 1000 hectares of urban area in Santa Cruz. About 40,000 people lost their property and it is estimated that 800 people were killed. Estimated damages were about $40 million. In an attempt to deal with the flood threat to the city of Santa Cruz, CORDECRUZ separated their flood control organization in 1983 and set it up as a separate authority. It is named SEARPI and, with funding from the European Economic Community and particularly the German government, they are now constructing flood control levees along the river in Santa Cruz. See Photo No. 24, Appendix P.

Additional flood control works are planned in other communities along the river as far as Montero. Although this project appears to be very well constructed, discussions with the design engineers indicated that sufficient data on river flows is not available to adequately analyze the true amount of protection which this project provides. It is estimated that the degree of protection is in the neighborhood of the 100-year event.

Land use practices in this area and throughout Bolivia are not making efficient use of the available soil and water resources. Poor farming methods, lack of knowledge in soil conservation techniques, slash-and-burn agriculture. overgrazing, and deforestation of land have led to high runoff of rainfall, soil erosion, degradation of vegetative cover, loss of soil productivity, sedimentation in streams and lakes, loss of groundwater recharge, and pollution of surface and groundwater resources.

The four drought-stricken provinces of Florida, Cordillera, Vallegrande, and Caballero are in the southwestern portion of the department. Wells are being drilled in these areas to help relieve the problem, but the high cost of drilling along with the frequent requirement for independently powered pumps make these expensive to construct and operate. The lack of electrical power in many areas dictates that the pumps be driven by engines, generators or be of the air-lift type. Using an engine-driven pump also requires that the well casing be increased in size to accommodate the pump which has a larger diameter than other types. The typical cost for one of these wells is about $30,000 for an 8-inch diameter. Smaller wells can be contracted for about $100 per meter. These prices do not include the pump which may be from $30,000+ to $40,000. Hand pumps can be used for many of the smaller wells, as are generally constructed in the northern areas. The possibility of using windmills should also be investigated.

In a region south of Santa Cruz, a number of towns along the railroad are in desperate need of water. Some wells have recently been drilled and others are planned, but none have pumps installed. This is because of the lack of funding for the expensive diesel-driven systems that is required due to lack of electrical power. Presently, water is brought to tanks along the railroad and sold to the people at an extremely high price. The wells that were drilled still will not supply the water necessary to meet the area's requirement. Thus, additional resources are needed. As mentioned above, a suitable supply of surface water is available at the edge of the mountains west of the railroad that can serve some of the communities. The water would be carried through pipelines to the various towns up and down the railway. Further south at the Cordillera-Chaco boundary, wells are used for almost all the potable supplies. Surface water is trapped in small impoundments for cattle, but they are not reliable if seasonal rain is deficient. There are a number of wells in this area that are not used because the pumps originally installed have failed for one reason or another.

The area around the town of Vallegrande needs an immediate evaluation of its water resources for a number of reasons. The existing water supply comes from a spring about 15 kilometers from town and normally yields about 28 liters per second. See Photo No. 25, Appendix P. This is only a fraction of the normal daily requirement for the surrounding area and no other surface water is available. No wells have been drilled in the valley and no information is available on potential aquifers. The valley where Vallegrande is located is a wide alluvial filled area that should have some aquifers from which water could be extracted. The high cost of exploratory drilling could be preceded with a regional geophysical survey to help identify the aquifers. This type of survey would be of great benefit in the future as additional water is needed.

Contamination of some water resources has also created a need for potable water, even when surface water is abundant. In the northern part of the department, the many streams cannot be used for potable water due to this type of problem. Here, shallow wells under 100 meters deep are needed to provide this resource. Even in areas like the city of Santa Cruz, contamination of water resources are of concern.

The entire department has problems with water resources due to lack of data. The continued development of some areas require that a reliable source of water be established and protected. Available surface water will have to be included in long-term planning to provide an inexpensive resource. The drilling of additional wells will be required in some areas along with the procurement of suitable pumps. The investment in a drilling system for the wells less than 100 meters deep would be very beneficial to the department since these wells are quick and relatively inexpensive to construct.

SUGGESTED STRATEGY

As in Tarija, a major concern in the department is the lack of water in the cattle-raising area of the Chaco. Of considerable help would be a means of constructing many more water-collecting cisterns. CORDECRUZ should look into means to acquire additional equipment or assets with which to construct more of these water-holding ponds. Use of Bolivian or U.S. military engineers could be of assistance in this type of construction. If U.S. assets are requested, it may be necessary to rent the heavy equipment from within-country because of a present deficiency in available heavy-lift aircraft to transport engineer equipment from the United States. Any available equipment that CORDECRUZ is not using should be put to work on construction of these holding po...

As an alternate or supplement to this action, we would suggest that USAID consider either leasing or purchasing a bulldozer for CORDECRUZ to dedicate towards building earthen cisterns. USAID would have to negotiate with CORDECRUZ and the cattlemen on the cost-sharing arrangement. CORDECRUZ officials indicated that they would agree to pay for all operation and maintenance for drill rigs. Extrapolating this willingness, they may well pay for the operation and maintenance of a bulldozer. Further, representatives of the cattlemen's association indicated that they were willing to pay for such an operation as long as it was without interest. It appears that significant progress could be made toward alleviating the drought in the Chaco area with a very limited investment. The total cost of a D/7 bulldozer is about $250,000. If this idea is adopted, we would recommend that the program be closely monitored at the national level.

We suggest that CORDECRUZ obtain plans of the holding ponds used in Argentina which separates water for human and animal consumption. A suggested design of such a cistern is discussed in Appendix M. This would allow humans to withdraw rainwater from the main holding tank, while excluding livestock to prevent contamination of the water. At the same time, water would be available in a secondary pond or trough for animal consumption. A valve would prevent water from passing back from the livestock supply into the pond for human consumption. While these ponds would cost only slightly more to construct, they would provide savings in the form of improved health of the campesinos. If the idea of furnishing a bulldozer is adopted, it is recommended that the program be contingent on adopting this new design.

The Parabanon project to bring 1000 liters per second of spring water to the communities from Basilio to Rio Seco appears to be an enormously beneficial project since it will serve over 40 communities in an area which has been hard hit by the drought. The cost of $10 million is relatively minor compared to the expected benefits. This project would also be labor-intensive and help to the local economy.

In general, the country of Bolivia is in dire need of flow data for its major rivers. There appears to be a relatively adequate amount of rain gages with which to measure precipitation, but there is insufficient hard data with which to develop accurate rainfall-runoff models which can be used to predict future events. The city of Santa Cruz is in particular need of hydrologic data on the Rio Piray with which to forecast flood events which may affect the city. We recommend that a flood-warning system be developed for the city to predict damaging floods and provide time for residents to take precautions. A system could be designed and installed which would provide about 8 to 10 hours warning before the arrival of a damaging flood wave. Although we have not done a detailed design for Santa Cruz, preliminary design calculations indicate that this system would cost about $300,000 to install and about $30,000 per year to operate and maintain. For details of the Santa Cruz flood-warning system see Appendix I and Photos No. 32 through 35 in Appendix P. The system would consist of a series of rain and flow gages in the drainage basin upstream of the city, data transmission equipment to send readings of data to an emergency operations center (probably at the CORDECRUZ office in Santa Cruz), and a personal computer station to analyze the data in a real-time mode and issue predictions and warnings as needed. The beauty of the system is its ability to not only continuously gather data which has many advantageous uses, but also to send in data and activate the warning system on its own when conditions warrant. The entire system is composed of off-the-shelf equipment which is easy to install and maintain. The field equipment operates on batteries with solar recharge so no electricity is required in remote areas. Engineers can interrogate the field gages from their offices in Santa Cruz and only occasional visits to the field are necessary to maintain the equipment, calibrate the gage, or to infrequently change batteries. The equipment not only is useful in flood-fighting, but also gathers data for low-flow studies and all ranges in-between. The software used in the computer has prediction capability as well so the engineer can try different amounts of additional rainfall and analyze the consequences. The system also allows for continuous and automatic recalibration of runoff coefficients based on the real-time data which is fed in from the gages. The system is in operation in many communities in the United States and is found to be very effective in reducing damages and saving lives during flood events.

A short-term solution for the water shortage in the department of Santa Cruz is to use the available wells to the maximum. In many cases, simply utilizing existing wells by repairing or installing a pump is all that necessary. In some cases, such as the areas south of Santa Cruz, engine-driven pumps or the addition of electrical power is needed for the newly constructed wells. These can provide immediate relief to the local area. The cost of a diesel-engine-driven pump is about $25,000. Many smaller wells are also available for the installation of hand pumps or windmills.

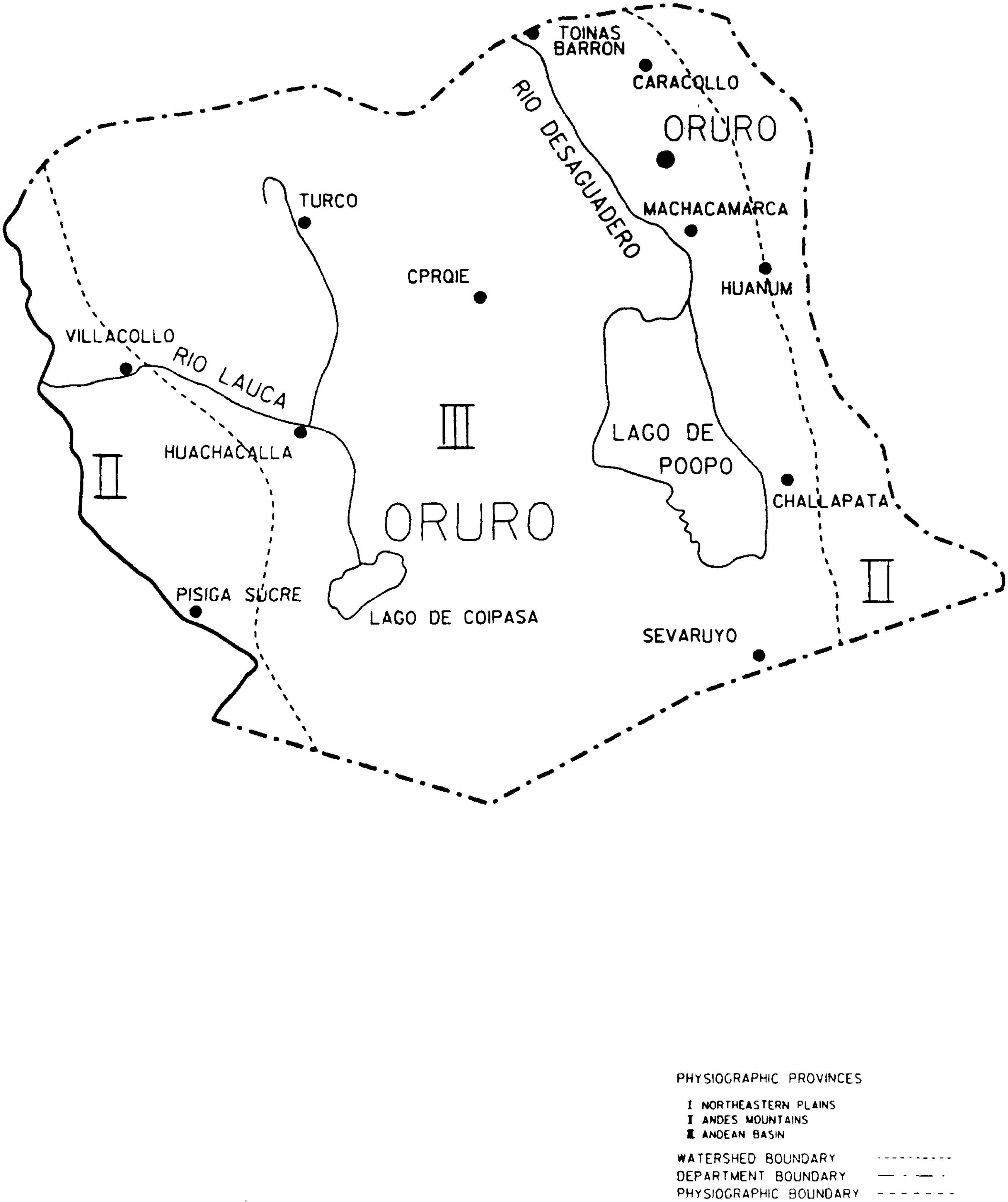
In communities north of Santa Cruz, the contaminated surface water supplies either need to be treated or replaced with clean groundwater. The most economical way to accomplish this is with the construction of numerous 4-inch wells complete with hand pumps. These are low cost items that are also easy to construct. The procurement of a drilling system that can drill to a depth of 100 meters will allow the department to provide this service, as needed. This drilling system should be provided under the National Well Drilling Program described in Appendix H.

The town of Vallegrande and the surrounding valley should have a regional geophysical survey completed to evaluate the potential for groundwater development. Using an experienced agency or contractor, a complete survey of the valley area could be conducted and the results published. This type of survey would cost approximately $115,000 and require about 30 days of field work.

There is a need for a comprehensive water resources study made for the department of Santa Cruz. The usefulness of such a study is greater in Santa Cruz than other departments for two reasons. First, the major rivers and plentiful rainfall in most of the department offer a high potential for beneficial water resource development. Secondly, the department of Santa Cruz is more financially able to develop its water resources. Given these factors, an investment in a water plan would be worthwhile.

APPENDIX F

ORURO


TOINAS
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POOPO
HUACHACALLA
II
CHALLAPATA
ORURO
II
PISIGA SUCRE
LAGO DE COIPASA
SEVARUYO
PHYSIOGRAPHIC PROVINCES
I NORTHEASTERN PLAINS
I ANDES MOUNTAINS
II ANDEAN BASIN
WATERSHED BOUNDARY
DEPARTMENT BOUNDARY
PHYSIOGRAPHIC BOUNDARY

APPENDIX F - ORURO

CLIMATE, RAINFALL AND TOPOGRAPHY

The department of Oruro lies in the western part of Bolivia south of the department of La Paz. Most of the department lies on the high Andean plateau known as the Altiplano. The eastern edge of the department borders the departments of Potosi and Cochabamba and is in the eastern range of the Andes mountains. The western edge of the department borders Chile and is in the western range of the Andes. The department of Oruro contains some of the large mineral deposits which have long made Bolivia an important mining region. Minerals in abundance include magnesium, lithium, sulphur, silver, potassium, antimony, and manganese.

The capital of the department is the city of Oruro with a population of about 150,000. This city is situated at 3,700 meters above sea level and therefore the average temperature is only about 9 degrees Celsius. Average annual rainfall within the department averages less than 400 mm. The department is very dry and exhibits arid to semi-arid characteristics throughout its provinces. Much of the surface water is high in dissolved salts due to geologic formations in the area. The southern part of the department is a vast salt basin and is not suitable for any type of farming. The rainfall provides fresh water that infiltrates down through the soils and literally floats on the brackish water. There is a general absence of permanent surface streams and the one major river that flows southward from Lake Titicaca, Rio Desaguadero, is quite saline by the time it reaches the city of Oruro. The topography is fairly flat in many areas becoming hilly as you approach the mountains going to the west. Elevations within the department range from about 2500 to over 6500 meters above sea level. Most of the population resides in the eastern half of the department.

The drought has affected the department since 1982. This has caused many people to leave the Altiplano area for work in other departments. Staff of the development corporation, CORDEOR, does not know how many people have migrated out of the area, particularly in the sparsely settled western half of the department where there is lack a of electricity and water.

SOCIO-ECONOMIC PROFILE

By Presidential Decree, Oruro became a department in 1826. It contains fifteen provinces and borders on La Paz to the north, Potosi and Cochabamba to the east, Potosi to the south and Chile to the West. Encompassing 53,588 square kilometers, Oruro ranks fifth in size out of the seven departments in Bolivia (US AID/CORDEOR Water Supply in Rural... Oruro 1990:2). The last census in 1976 showed a department population of 306,856 and a net loss due to out-migration of 22,740 persons (Brockman 1986:9). The entire department has an average density of 5.79 persons per square kilometer and a settlement pattern of approximately 55 percent urban and 45 percent rural (Montes de Oca 1982:70).

Nearly the whole of the department is located on the central high plateau, a dry area with an average annual rainfall of 400 mm or less and high salinity in both soils and water, especially at lower altitudes. There is some farming but mining is the principal revenue-producer (Rojo 1989:39). The largest mineral foundry in the country is in Oruro.

SURFACE WATER RESOURCES

Almost the entire department lies in the Altiplano drainage basin which is an internal basin with no outlet to the sea. Water flows into vast salt flats from which the water evaporates. The two largest salt flats are the Salar de Coipasa and the Salar de Uyuni. These ancient basins were once part of a vast inland sea during times of greater precipitation, but are now almost totally dry and barren.

The second largest lake in the country, Lake Poopo, is located in the department of Oruro. However, it is so salty that the water is not suitable for any use. Otherwise there are only a few existing surface water supplies in the department, and only some of these are usable. The entire area can be classified as one with small-to-meager supplies of brackish to saline water. There are a few streams scattered about the department that are fresh enough to support small infiltration gallery systems and are used for potable water supply and irrigation. In addition, there is one dam in the department which impounds about 3 million cubic meters of water. However, it is too salty for consumption and is only used for irrigation on some 4000 hectares of land.

Some rainwater cisterns exist and are used as collections for the watering of livestock and sometimes for irrigation. As in other departments, they cause problems with sickness in humans when they try to share these supplies with the cattle. Generally there is not enough water collected to make it effective for irrigation purposes.

GROUNDWATER RESOURCES

In most parts of the department, abundant groundwater is available at very shallow depths in alluvial aquifers. This water is fresh near the top of the water table but increases in chloride content as the depth increases. This is caused by the natural salt content of the formations which dissolves and goes into solution with the groundwater. Infiltration of fresh rainwater from the surface has leached the salts from the soils above the water table. This fresh water has a lower specific gravity than the underlying groundwater and therefore, the fresh water floats on the brackish water. The depth to fresh water is so shallow in many areas that infiltration galleries are normally dug for the collection of the water. Reported depths to the water table ranged from 6 to 30 meters. The interface between the fresh water and the underlying brackish water was reported to be about 180 meters deep.

Most of the population live in the eastern edge of the country where the infiltration galleries are used extensively. The city of Oruro has a well field just north of town that has a number of wells about 90 meters deep. Currently, just two of the wells are supplying all the water for the city. These wells were sited with the aid of a geophysical survey to help identify the best locations for the wells. Each well yields an average of approximately 55 liters per second.

SPECIFIC PROBLEM AREAS

During the past two agricultural years, 1988 to 1990, the farmers of Oruro have suffered from both lack of rainfall and freezing temperatures. One report describes the effects of these phenomena as a great problem of poverty, begging and a terrible quality of life (USAID/CORDEOR 1990:1). Available estimates of the number of people affected indicate about 6,000 families or 29,800 people who constitute 9.7 percent of the 306,900 population. (USAID May 1990:5). The same document names six provinces as most heavily affected:

two of those provinces, P. Dalence and L. Cabrera, are on the United Nations' 1986 listing of the most impoverished parts of Bolivia (UNDP 1986:50-51). Given the severe climatic changes, differences between the yields of the 1988/89 and 1989/90 harvests average 25 percent, with potatoes hit slightly harder than the quinoa and barley crops (MACA Evaluation of the Effects April 1990:17). Native grasses are not growing well, thus cattle grazing is affected.

Continued drought conditions also take their toll on the mining industry. The separation of marketable ore is made more expensive, thus employment decreases. Since mining and subsistence agriculture are the economic mainstays of Oruro, these trends will likely force local residents to move to La Paz, the Chapare or other large cities in search of new sources of livelihood.

CORDEOR has a number of problems which it is trying to solve. One of the biggest problems is a general lack of water resources information and streamflow data with which to work. It appears that Oruro is one of the least studied departments in Bolivia and consequently has little general information on water resources and almost no usable hydrologic data. It is very difficult to assess the water availability and plan future water resources development without some basic data on water resources. A comprehensive water resources study is needed for the department. Further, a network of stream gages to monitor and report daily stream flows would be of great benefit if rational decisions are to be made on how to best improve the water resources for the citizens of Oruro. In addition, very little is known about the widely dispersed inhabitants of the western Altiplano. Thus, no one is sure of the extent of their problems and needs. It is readily apparent that one of their major needs is water and electricity. This will allow communities to grow and develop and, more importantly, since usable surface water is almost nonexistent in that region, it will provide a power source to drive pumps for the development of groundwater sources.

Education of the campesinos in basic sanitation is also a problem. Many health problems apparently result form lack of understanding about the relationship of sanitation to good health. Some education and installation of about 200 community latrines have taken place, but there is still a great need for more of this.

Near the city of Oruro, the slope of the Rio Desaguadero begins to flatten out as the river nears the basins of the southern Altiplano. The high sediment load that this river carries on its trip down the high plateau begins to fall out as the flow velocities decrease. Much of this channel's sediment deposits in the Oruro area which tends to clog the channel and inhibit its ability to maintain flow within the stream banks. When floods occur, the river quickly jumps its banks and spreads water into inhabited areas. The European Economic Community (EEC) has been designing some channelization and flood control works for the Oruro area to help combat this problem, but so far funding has not been found to begin construction. The estimated cost for these flood control works is around $3 million.

The presence of dissolved salts in much of the surface water dictates the use of groundwater in the Altiplano region of Oruro. The shallow depth to the water table allows the economic extraction of this resource for potable as well as irrigation uses. Normal practice is to dig infiltration galleries to the water table, but the shallow depths make this area ideal for mass-drilling of 4-inch PVC wells. These wells are much more sanitary than any type of dug well and, when sealed after the installation of a hand pump, are better protected from contamination. Because of the shallow water table, the possibility of contaminating the water is very real and care should be used in locating the wells. Wells should not be located near dumps, animal barns or latrines.

The department currently has some well-drilling capability but could use assistance in smaller scale drilling and the repair of pumps. The department presently has an older drilling rig provided by Japan that reportedly needs repairs. This rig is large enough to drill the shallow 4-inch wells, but is probably too large to do it efficiently. It is still being used to drill deeper wells around Oruro. Other areas of the Department are sparsely populated, and the cost of a well would not be possible with only a few families able to participate in the project. Here, a small, efficient drilling rig could provide this at a minimum cost. Another item that would be of immediate benefit here would be to replace the many broken-down hand pumps scattered throughout the department. The installation of windmills and hand pumps along with holding tanks would probably work well in this region, also.

SUGGESTED STRATEGY

Officials of CORDEOR indicated that there was a lack of knowledge on their overall water resources. They cited technical assistance in the area of water resources as one of their priority needs. This need, coupled with the lack of information about the people of the Altiplano and the potential flood threat, may warrant a comprehensive study of water resources in the department. However, before launching an expensive comprehensive study, we would recommend that a reconnaissance evaluation be made to assess need, costs, and potential benefits of such a study. The cost of such a study would vary according to the level of detail desired. A "good" reconnaissance report could be accomplished for $50,000. Another alternative to this would be to ask the department officials to submit a proposal outlining the purpose and scope of the study. Then a determination can be made on the advisability of proceeding with their proposal.

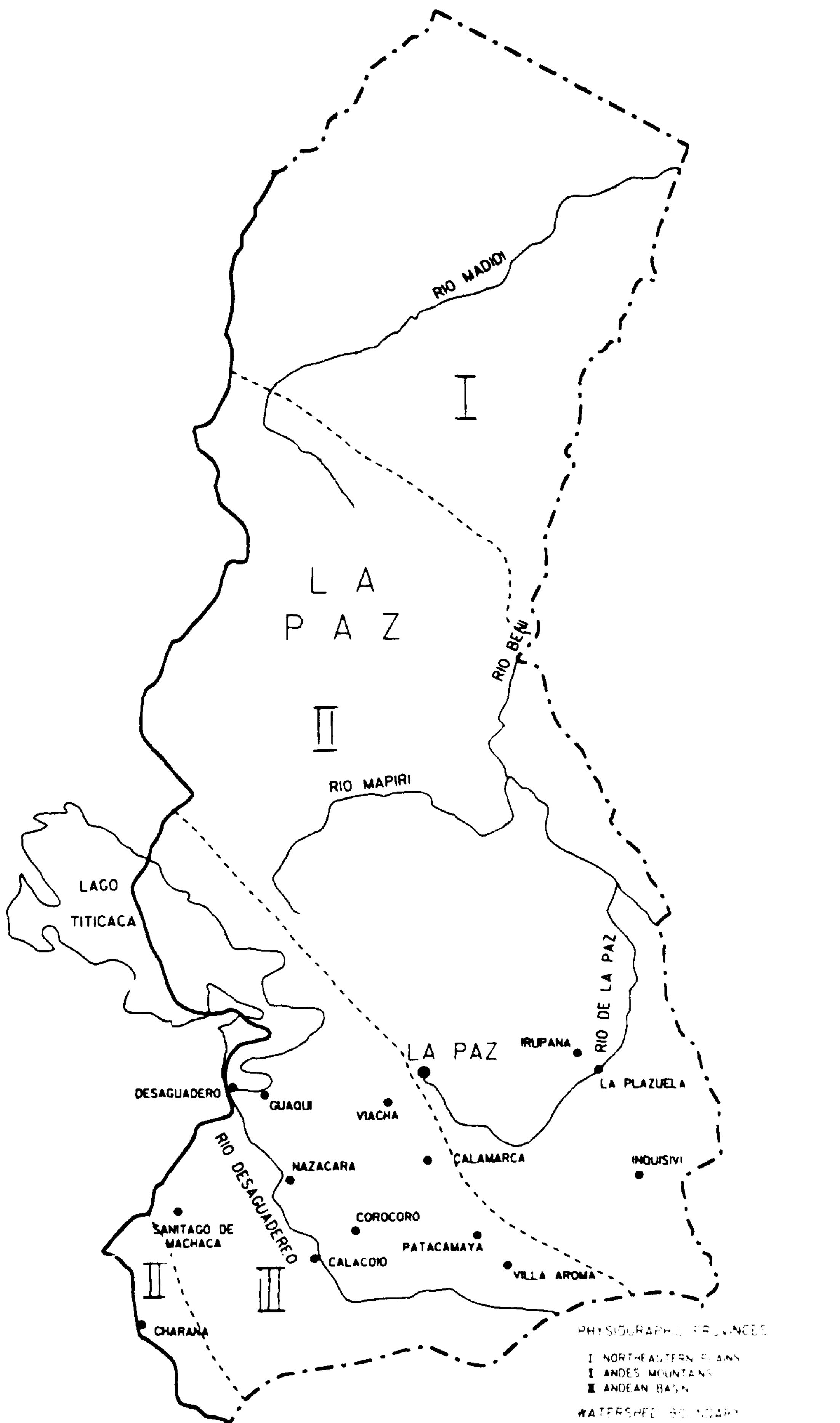
As in all of Bolivia, there is also a pressing need for stream flow data to assess surface water resources. Instead of the conventional gaging equipment, it is suggested that Oruro's needs might be best met with the use of remote flood-warning type gages. This system is suggested for two reasons. First, there is a flood threat in the city of Oruro. Secondly, this system can provide real-time data from which water resources can be managed. In this department particularly, because the terrain is relatively flat, it is likely that only one repeater station will serve a large portion of the department. If this type of equipment is used, it would cost about $290,000 to install and about $20,000 per year to operate and maintain. See Appendix I for a discussion of the typical system and Photos No. 28 through 33 in Appendix P.

Very little information was obtained in Oruro about the European Economic Community's design of channelization and flood control works on the Rio Desaguadero. It certainly seems like the project is worth recommending if the sedimentation is indeed increasing the flood threat to the city. It is recommended, however, that a detailed sedimentation analysis of the river and flood control project be included to ensure that the problem is not just moved downstream to another area, and that it does not cause other erosion and sedimentation problems even if it does solve the flood threat. This analysis could be included as part of the comprehensive water resources study previously mentioned.

Since there is an apparent need for hundreds of shallow wells with hand pumps, this is a department that would benefit from obtaining a small drilling rig. Hand pumps or windmills would be provided with the wells. Also, the repair or replacement of numerous hand pumps that are reportedly out of service should be undertaken. This is fast and inexpensive, providing water from existing wells.

APPENDIX G

LA PAZ


RIO MADIDI
I
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RIO BENI
II
RIO MAPIRI
LAGO
TITICACA
RIO DE LA PAZ
LA PAZ
IRUPANA
LA PLAZUELA
DESAGUADERO
GUAQUI
VIACHA
RIO DESAGUADERO
NAZACARA
CALAMARCA
INQUISIVI
COROCORO
SANITAGO DE
MACHACA
PATACAMAYA
CALACOTO
VILLA AROMA
II
III
CHARAÑA
NORTHEASTERN
ANDES
ANDEAN
WATERSHED
DEPARTMENT

APPENDIX C - LA PAZ

CLIMATE, RAINFALL AND TOPOGRAPHY

The department of La Paz lies in the western part of Bolivia north of the department of Oruro. The department has the most varied terrain of all departments in Bolivia. A portion of the department lies on the high Andean plateau known as the Altiplano. The center of the department is cut by the high eastern range of the Andes mountains and the northern part lies in the flat Amazon river basin. The western edge of the department borders Peru and a small part of Chile. The department also contains some of the large mineral deposits which have long made Bolivia an important mining region.

The capital of the department and the de facto, if not official, capital of Bolivia is the city of La Paz with a population approaching 2,000,000. This makes it also the largest city in Bolivia. The city is situated 3600 meters above sea level making it the highest capital city of any nation in the world. Average annual temperature in the city is only about 11 degrees Celsius.

Average annual rainfall within the department varies as drastically as the terrain, from less than 200 mm in the western part of the Altiplano to over 2000 mm in the regions along the Rio Beni. In the city of La Paz, the average annual rainfall is about 480 mm. The department thus ranges from very dry to very wet. Elevations within the department range from about 250 to about 6500 meters above sea level. Most of the population resides in the central and southeastern regions of the department adjacent to the city of La Paz.

SOCIO-ECONOMIC PROFILE

Founded in the early 1500s, the department boasted a population of several thousand and was comparable to the city of Potosi in its first stirring as a world center. From then until the beginning of this century, La Paz has grown by fits and starts. The 1900s, however, have seen a fairly steady growth rate especially in the urban area around La Paz, the seat of government. As of 1976, the department had 1.47 million people. The city of Nuestra Senora de La Paz (Our Lady of Peace) contained 677,000 residents. The population density in 1976 was 10.9 and 143.9 persons per square kilometer, respectively (CORDEPAZ Population Data 1976:Table 9.1). Estimates for 1980 show a population of 1.78 million, an increase of 21.8 percent.

Encompassing nearly 134,000 square kilometers, La Paz is the third largest department in Bolivia after Santa Cruz and El Beni (Montes de Oca 1982:94-96). It ranks second after Santa Cruz in terms of net gain in people from in-migration. Economically, it is diverse, accounting for 50 percent of all manufactured products in the nation as well as all governmental functions except the Supreme Court. The city is the country's service and retail center. Agricultural production is limited to the use of 214,781 hectares out of a total of 13,398,500 or 1.5 percent (MACA Area Cultivated...1990).

SURFACE WATER RESOURCES

The department of La Paz feeds two of the three major drainage basins of the country. The northern half of the department generates flow which travels to the great Amazon basin to the north. The southern half of the department drains to the Altiplano basin which has no outlet to the sea. Water entering this basin flows into Oruro's vast salt flats from which it evaporates.

One of the most famous lakes in the world, Lake Titicaca, lies across the western border of the department of La Paz. The eastern half of the lake is in Bolivia and the western part is in Peru. This massive inland sea covers some 9,600 square kilometers and is over 200 meters deep in some places. The lake surface is over 3800 meters above sea level making it the highest navigable waterway in the world. The lake is a rich resource which supports agriculture and commercial fishing activities around the lake. Water from the lake flows out through a natural control into the Rio Desaguadero and then to the Altiplano basin to the south.

The northern part of the department has an abundance of water resulting from the heavy rainfall caused by the moist air from the Atlantic Ocean which travels across the Amazon basin to collide with the high Andes mountains.

In contrast, the Altiplano is arid or semi-arid. The population is generally dispersed except for communities along the only significant river in the area, the Rio Desaguadero which carries the water from Lake Titicaca down to Lake Poopo in the department of Oruro. As the water travels south it becomes increasingly saline and less usable for consumption or irrigation.

Water supply for the city of La Paz is obtained from rivers and lakes of the city. These rivers and lakes receive their water from snow and glacial melts in the mountains to the north and east of the city. The water arriving at La Paz is of excellent quality, but it is quickly polluted by industrial and domestic wastes. Water leaving the city is so polluted that it is not even fit for irrigation in the downstream valleys.

GROUNDWATER RESOURCES

Only in the southwest portion of the Department, the Altiplano, is groundwater widely used. Sufficient surface water exists in the northern areas and in the central mountains of the department for most uses. In the Altiplano, groundwater is very important since there is little non-saline surface water in most areas away from Lake Titicaca. Water that flows southward from Lake Titicaca quickly becomes brackish due to inflows of saline water from the geologic formations in the area. Alluvium that covers the surface in this area typically has a layer of fresh water floating on the underlying brackish water. This fresh water is rainwater that infiltrates from the surface, and being less dense than the brackish water, remains on top as a separate layer. The typical depth to the water table is only a few meters, so the utilization of wells is widespread and inexpensive. Many such wells have been drilled during the past years throughout the Altiplano. The alluvial soils have enough coarse grained materials to form a good aquifer and wells may have a high specific capacity.

CORDEPAZ and CARE have a program underway to transport groundwater to the western section of the department. This is being done by constructing a gravitational pipeline system to the small settlements of about 500 people. CORDEPAZ plan to install these systems for about 60 villages per year (120 next year) at a cost of about $15,000 per village. CORDEPAZ officials estimate that there are about 2,500 villages in need.

SPECIFIC PROBLEM AREAS

Nearly 6,000 families or 28,000 individuals are suffering because of the recent drought and one-third are under dire stress, having lost from 50 to 100 percent of their crops (USAID May 1990:5-6). A recent evaluation by the European Economic Community's PAC (Programa de Autodesarollo Campesino) stated that both food and animal production were affected severely this last year by both drought and cold spells. Such was the loss that the EEC plans to spend $ 19.3 million U.S. in La Paz since it began in 1989 (PAC Plan of Action

1990:3-2). This is millions of dollars more than that proposed for Oruro and Potosi together.

The city of La Paz does not feel a lack of water; rather, it has the problem of contamination of the water supply. But in the urban squatter settlements in El Alto, there is a water shortage. The hardships increase in the Altiplano where the small villages of twenty to forty families live off subsistence farming alone. According to a MACA analysis, in those areas of subsistence agriculture, there will be no potato, grain and minimal foliage crops. On farms of a size that support more than one family, the losses only reach 50 percent of anticipated yields. On large farms with more margin for error or loss, mechanized and with a cash flow to afford trucking in water, losses are barely significant (MACA Effects...1990:12).

The most serious water resources problem in La Paz is water pollution in the city. That problem is so extensive that there appears to be no serious attempts to resolve the problem. The department's development corporation, CORDEPAZ, is considering supplying alternate water supply sources to the residents in the heavily populated areas downstream from La Paz. These valleys south of the city of La Paz have some of the most fertile land available in the department, but they are not irrigable because of the poor water quality of the river. Because of this, plans have been developed by CORDEPAZ to capture and use the pure waters coming from the snow melt and glaciers of the mountains to the east of this rich valley. They plan to construct reservoirs to trap and store this water and then transport the water to the valley via pipeline for use as potable and irrigation supplies. It is estimated that this would supply a dependable yield of about 400 liters per second. Cost of this project would be about $30 million. It is estimated that this solution is less expensive than treating the effluent from the city of La Paz (estimated to be $300 million by a German firm). Also, ground water in the area is too saline for use.

The other significant problem for the department with respect to surface water supplies is the serious lack of hydraulic data. As observed throughout the country, there seems to be a sufficient quantity of rainfall data available, but the lack of stream flow data is critical with respect to making intelligent decisions about managing the water resources of the department.

Education of the campesinos and the inhabitants of the cities in basic sanitation is also a problem. Many health problems apparently result from lack of understanding about the relationship of sanitation to good health. Education and installation of public latrines and laundry facilities are needed.

The construction of a well must be followed by the installation of a pump that is properly maintained to be able to provide a source of water. Of the many wells that reportedly have been drilled in the Altiplano region, there are now a reported 60% that have defective pumps, primarily hand pumps. Due to the low population densities, hand pumps are commonly used since there are few distribution systems in the towns and some settlements are but a few families. These hand pumps need to be inventoried and the defective ones replaced. There are expected to be over one hundred pumps in need of repair or replacement. A reported 3000 families are affected by this problem.

Additional wells, and possibly distribution systems, are needed in the Altiplano to both increase overall supply and replace wells which are expected to have water quality problems due to contamination. The normal shallow depths of wells, under 30 meters, requires a small drilling rig for their construction. Since the department does not have a drilling rig in their inventory, the procurement of a small rig would allow the construction of numerous low cost wells. The total cost of materials for such a well will be about $500 which would include the hand pump. Although this rig would be limited in the depth and size of wells which could be drilled, it would serve the immediate needs of areas impacted by the drought and be cost effective.

SUGGESTED STRATEGY

The department's plan to construct a water supply system to tap the water reserves of the eastern mountains certainly seems like a workable and cost effective plan. It is sad to see the Bolivians and their international "friends" continue the often followed custom of abusing the scarce environmental resources with a "use and discard" philosophy. It is recommended that neither USAID nor any other United States agency be involved in any program which supports such a strategy. While the benefit/cost ratio may indicate that it is economically more efficient to abandon the polluted effluent from the city and develop another source, in the long run the country will eventually run out of the scarce resources which it now possesses. Expenditures towards resolving the water quality problems should be dedicated towards water treatment and human behavioral changes. We realize that this is a long and arduous process, but it must start sometime. Even if it costs more in the "long-run", we must do whatever we can to assist in promoting environmental awareness in Bolivia.

An inventory of wells with hand pumps should be undertaken and a program initiated to replace the ones that are defective. There also needs to be a small inventory of spare parts for pumps that could be furnished to the department for use in the future. The initial inventory will probably require personnel to visit the different settlements and actually inspect the pumps. The cost of a good quality hand pump is about $350, so the replacement of say 200 pumps would cost only $70,000, or a few dollars per person. This effort could be included in the rehabilitation of existing water project programs discussed in Appendix K.

The construction of additional wells in the Altiplano should be accomplished through the procurement of a small capacity drilling rig. This rig should be able to drill to a maximum depth of 100 meters and be truck-mounted. Recommended guidelines for procurement, maintenance, use, and stocking of well-construction materials is discussed in Appendix H. The rig should be issued to the department, CORDEPAZ, for their use in the program.

There is also a need to accelerate CORDE[illegible]s program of constructing gravitational pipeline systems to small settlements of about 500 people. CORDEPAZ currently plans to install 60 systems per year (120 in 1991); however, there are 2,500 villages in need.

With respect to the need for stream flow data, the department needs to establish a stream-monitoring program similar to the one described for the department of Oruro. See Appendix I for details and also Photos No. 28 through 35 in Appendix P.

APPENDIX H

NATIONAL WELL-DRILLING PROGRAM

APPENDIX H - NATIONAL WELL-DRILLING PROGRAM

GENERAL

As discussed in Appendices A through G, there is a tremendous need for well-drilling throughout the drought affected areas of Bolivia. In fact, well-drilling is the most significant short term program which can help alleviate drought. This was substantiated through a separate independent study - "Water and Sanitation for Health," WASA Field Report No. 116, May 1984. That report recommended typical drilling systems in Bolivia. Unfortunately, the cost of undertaking well-drilling projects is beyond the fiscal capability of many of the smaller provinces, villages and settlements. Thus, contributions to such a program are very cost effective means to combat drought.

In the past, international agencies have opted to purchase well-drilling equipment or give grants for their purchase to various entities. Normally, this was done because of the economic advantage over hiring well-drilling companies from the private sector. These donations of well-drilling equipment were normally under an agreement that the recipient would be responsible for future operation and maintenance. Our observation of the situation in Bolivia is that this program has been only partially successful. We observed that many drill rigs were not being used at all or were under-utilized for various reasons -- lack of spare parts, materials, manpower, fuel and, in some cases, for no apparent reason. For the most part, the underutilization of drill rigs is due to a lack of control and prudent planning.

We recommend that a national well-drilling program be adopted in Bolivia. This program would provide cost-effective relief from drought and avoid the problems of the past. The suggested elements of the national program would include a full-time resource person to head-up the program at the national level; the utilization of existing government-owned rigs; rehabilitation/overhaul of these national well rigs; procurement of new drilling equipment; providing an initial inventory of materials, spare parts and pumps; a legally binding agreement between the national entity and the operating agency; and an agreement with the local entity who is the recipient of the well.

WELL-DRILLING COORDINATOR

To ensure the success of the national well-drilling program, a full-time program coordinator will be needed for a period of at least three years. This individual should have a solid background in well design, well construction, drilling equipment, pumping equipment, and should be able to make recommendations about well locations based on hydrogeological studies. This person should have several years experience in these areas. While there are many engineers and geologists that would qualify, the possibility of using an experienced well-driller should not be ruled out. Since this person will be responsible for coordination with many different agencies, he must be diplomatic. Furthermore, he must be a technical specialist who is willing to travel much of the time.

A range of responsibilities for the coordinator is as follows:

a. In consultation with department and national officials, identify areas that have the need for well-drilling capability.

b. Assist in preparing scopes of work for hydrogeological investigations prior to well-drilling, if needed.

c. Inventory existing drill rigs for needed parts and repairs.

d. Develop a purchase schedule for new drill rigs.

e. Complete specifications for drilling equipment purchases.

f. Negotiate an agreement with departments or agencies regarding O&M, materials and drilling proposals. This negotiation must insure that a complete turn-key package is developed including items such as pumps, generators, fuel and housing for equipment.

g. Negotiate an agreement with local communities for possible labor contributions and an environmental improvement package.

The responsibilities of the well-drilling coordinator discussed above are very diverse. Further, the initial inventories and evaluations required are quite extensive. For these reasons, the coordinator will likely need some assistance - especially in the start-up stage. Any budgeting for this program should allow for inventory assistance over the first six months and technical assistance throughout the program. The technical assistance will be required to develop appropriate environmental packages and assist in the development of required hydrogeological surveys.

UTILIZATION OF EXISTING GOVERNMENT-OWNED DRILL RIGS

There are many drilling systems among the various government agencies that can be included in a national well-drilling program if that agency elects to take part. Most of these rigs were purchased some years ago, but should be of such condition that an overhaul would put them back in top operating condition. In some cases, the rig itself is in good shape, but due to loss of drill rods or lack of drill bits, the useful capability of the rig is diminished. Some of the rigs which may be included in this category are owned by the Ministry of Health, GEOBOL, CORDECH, CODETAR, CORDECRUZ, and CORDEOR.

While there are other types of equipment being used, the most common drilling rig which we encountered among the different agencies was made by the George Failing Company of Enid, Oklahoma and has a designation as a model 1250. This drill rig has a rated depth capability of 1250 feet (380 meters). Along with the actual drill rig, drill rods and drill bits of various sizes were furnished. These rigs were purchased 10 to 15 years ago. Conversations with many of the different agencies using these drill rigs revealed that they were now limited to drilling shallow depth wells. Three reasons were given for this: the limited number of drill rods that were still available; the drills were inoperable due to lack of spare parts; or the drilling was not accomplished due to lack of well-construction supplies.

REHABILITATION/OVERHAUL OF NATIONAL WELL RIGS

Each of the drill rigs in the national program should be carefully inspected by a factory representative or an experienced drill rig mechanic. This will cost about $350 per day plus expenses. The total cost for inspecting all the drill rigs is about $12,000. The purpose of this inspection is to assess the cost for bringing each piece of equipment back to full capability. Once this cost estimate is completed, a decision can be made as to the actual repair of the rig. Replacement of the drilling rig similar to the Failing 1250 rigs will cost approximately $250,000. If the repairs are not major, the additional drilling supplies needed to operate the drill rig should be procured since these costs will be comparatively low. Once the supplies on hand are inventoried, an order can be placed to fully outfit each drill rig for full capability drilling. The outfitting is not complete without a spare parts package. For example, an item that was frequently lacking was drill rods which are sometimes lost in the course of drilling a well. There is not an experienced driller who has not had this happen. Likewise, the drill bits simply wear out with use and must be replaced. There are also different bits required for different geological conditions which must be available to the crew. Some parts of the drill rig also have parts that wear out rapidly and spares should to be on hand to keep the rig operable.

Any well-drilling program must have the proper equipment and supplies before it can be initiated. Most importantly, the program must have continued support for some period of time until the routines of the program become established. The reconditioning of existing equipment or the procurement of new equipment is a substantial investment that should be monitored like any other investment. While the ultimate goal may be to completely turn the drilling operation over to each respective agency, there should be a plan in place to ensure that the rigs are used properly. This monitoring should include well-drilling schedules, a reliable spare parts availability, a source of fuel for the operation of the rig, and a constant supply of well-construction materials.

Past programs of supplying drill rigs have largely been unsuccessful due to a lack of spare parts and materials to keep the rigs operating. As stated above, parts must be replaced as they are used so that the required items will always be on hand. The same holds true for the materials used to actually construct the well. Each drilling system should begin with an inventory of well casings, well screens, filter material and pumps. Many of the recipients of the wells could pay for materials according to conversations with the various agencies. If this is the case, when a well is drilled, the recipient would reimburse the agency for the materials used. That money would be used to immediately replace stock items. However, there are some items that will still require expenditure by the various agencies: labor cost of the drill crew, per diem for the crew while away from their home towns; support trucks to transport pipe and other supplies; fuel and lubricants; and routine maintenance for the rig. Each of these items should be discussed with the agencies receiving a new rig and to a lesser degree, with each agency having their equipment overhauled.

PROCUREMENT OF NEW DRILLING SYSTEMS

Some areas of Bolivia have no governmental agency with well-drilling capability. This makes the construction of a water well too expensive for many smaller villages and settlements. Many of the needs for wells that were identified were relatively shallow wells that do not require a large or expensive drilling rig. A truck-mounted drilling rig with a depth rating of 100 meters along with associated drilling supplies will cost in the range of $100,000 to $125,000. These rigs are much simpler to operate and cheaper to maintain than their larger counterparts. Departments that would benefit from having a system such as this are CORDEPO, CORDECRUZ, CORDEOR and CORDEPAZ. Each of these departments have areas where hundreds of wells of 100 meters or less can be constructed. A typical well of this depth need only be 4 inches in diameter and can have either a hand pump, windmill, or small submersible electric pump installed. In addition to the relatively low cost of the drilling equipment, the cost of materials for completion of the well are minimal. A typical 4-inch PVC well with a depth of 100 meters, and a hand pump installed in a small concrete slab at the surface will only cost about $700 for materials. A well of this type can also be completed in only a few days. The cost of procuring a totally new drilling rig with a depth capability of 400 meters will cost in the range of $250,000 including the required drilling supplies and a spare parts package. This high initial cost along with the high cost of maintaining a rig like this may make contracting the deeper wells, required in some areas, more attractive.

Many areas of the country have aquifers that require a drilling rig with a deeper depth capacity. These wells can be drilled with drilling rigs already owned by national agencies such as GEOBOL. These wells could be scheduled and completed as needed anywhere in the country without the need to purchase a large and very expensive rig.

INITIAL INVENTORY OF MATERIALS, SPARE PARTS AND PUMPS

Items that will be needed for actual construction of the various wells will depend on the local requirements. Deep wells with vertical turbine pumps will need at least an 8-inch diameter steel casing with a galvanized or stainless steel well screen, while a shallow well with a hand pump can be constructed with a 4-inch PVC casing. The materials provided for the agencies should be compatible up to the capacity of the rig, but must not exceed that capacity.

The existing rigs similar to the Failing 1250 model can drill up to 400 meters and complete an 8-inch well. This is the upper limit of the rig's capacity, as wells of this diameter or depth are not always required. In many cases, 6-inch wells will provide the required pump clearance. There should initially be enough materials for several wells so that the rig can continue working while materials used are restocked. As an example, the following items should be stocked for a 150-meter deep well in an area like the Chaco:

(a).	8-inch-diameter steel pipe, 450 meters @ $30 per meter =	$13,500.
(b).	8-inch well screen, 60 meters @ $315 per meter =	$18,900.
(c).	8-inch screen centralizers, 9 @ $150 each =	$ 1,350.
(d).	6-inch-diameter steel pipe, 450 meters @ $20.00 per meter =	$ 9,000.
(e).	6-inch well screen, 60 meters @ $235 per meter =	$14,000.
(f).	6-inch screen centralizers, 9 @ $125 =	$ 1,125.
(g).	5 liter/second submersible well pumps, 3 @ $3,500 ea =	$10,500.
	TOTAL COST	$68,375.

These items will complete three typical 8-inch wells that require larger pumps (purchased separately) and three typical 6-inch wells that will be completed with pumps as part of the project. Another item that should be stocked is suitable filter material based on experience from the area where wells are being drilled. This material can be stocked in bulk or sacked for transportation to the various well locations.

Obviously, a smaller drilling rig, with a depth capacity of 100 meters, would require a different inventory mix. At these shallow depths, there is no need to use steel casing on most wells when PVC plastic pipe could be used. Well screens could be made from the pipe by simply slotting the required lengths of the pipe. Centralizers could also be fabricated from strips of the pipe. Four-inch pipe will work for hand pump wells and for wells that only require a small submersible pump (< 2 liters/sec). A 6-inch well could be installed in areas where planning may suggest the future installation of a larger submersible pump in good aquifers. A typical inventory follows:

(a).	4-inch-diameter PVC pipe, Sch. 40: 1,000 meters @ $3.50 per meter=	$3,500.
(b).	6-inch-diameter PVC pipe, Sch. 80: 200 meters @ $8.20 per meter =	$1,640.
(c).	PVC cleaner: 12 liters @ $7.00 per liter =	84.
(d).	PVC cement: 24 half liters @ $4.00 per half liter =	96.
(e).	End caps, 4-inch PVC: 12 @ $7.50 each =	90.
(f).	End caps, 6-inch PVC: 6 @ $10.00 each =	60.
(g).	Hand pumps: 12 @ $350.00 each =	$4,200.
	TOTAL COST	$9,670.

The above inventory will be adequate for at least 12 wells. These items would be treated the same with replacement to inventory as they were used. The same would also hold for the stocking of filter material as with the other drilling systems. Most of these wells would be assumed to have a hand pump only.

PROGRAM AGREEMENT BETWEEN USAID AND AGENCIES

To ensure that the new rigs will be used for the benefit of the public and that the investment by USAID has a good return, an agreement should be made with each receiving agency. This agreement should state that the agency, in conjunction with USAID, will develop and follow a program to provide a crew, support the operation with equipment mobilization, maintain the equipment and keep basic spare parts on hand, and keep the equipment operable. This agreement should provide for reassignment of the entire package to another agency if this plan is not followed within reason.

Naturally, agencies that have existing rigs must have a different type of agreement if their rigs are to be reconditioned through USAID, or they are to receive various supplies. Since the basic drilling rig is solely owned by that agency, the agreement should depend on continued support for that agency. This kind of agreement is sensitive and will have to be worked out in detail within USAID.

The basis of these agreements will be to maintain some pressure on the receiving agencies to make the program work. The USAID coordinator must ensure that the wells are being drilled for the benefit of the public and that the well construction supplies are replenished as per prior agreements. Conversations with some of the drilling equipment manufacturers presently in country revealed that they have been unwilling to ship parts to Bolivia without advance payment due to past defaults. This type of problem must be corrected. The purchase of an initial parts package and subsequent replenishment of the parts as they are used should re-establish favorable credit. Thus, parts can be made available or shipped upon request.

AGREEMENT BETWEEN USAID AND LOCAL ENTITIES (RECIPIENTS)

The actual agreements for well construction will be dependent on many different variables. In the way of an example, the following type of agreement may be considered with a town or village for the installation of a shallow well with a hand pump. The well location should be accessible to the public, in a location where contamination is not a concern. The drilling agency would mobilize and construct the well, then the locals would construct a concrete or masonry pad around the well. The hand pump would then be installed in the well. This type of well might consume 80 meters of 4-inch PVC pipe, one end cap, one can of PVC cleaner, one can of PVC cement, one ton of filter material, and one hand pump. The village might be asked to pay the costs of replacing the materials, $650, to the inventory within some period of time (maybe 90 days). If the recipients cannot pay the costs, either the agency or USAID must assume the costs, or the materials for restocking, or choose not to install the well. Although this may seem inhumane, a choice should be made. The important thing is to keep a working inventory available to the drill crew.

Another essential part of any agreement with local entities is in regard to long-term environmental and societal improvements. As constantly stated in Appendices A through G, we feel that it is very important that these types of improvements be included as a condition of the development of any water resources. These improvements could be in the form of planting trees, experimenting with different crops or grasses, rotating crops, contour farming, setting aside native pastures for a season for rejuvenation, improving sanitary conditions through boiling water or use of latrines and sanitary land fills, etc. These conditional improvements obviously must be tailored to the need of the community. It is also important that these need not be mandated by the so-called experts. It must be a coordinated consensus between USAID and the local citizens as to what is needed and a reasonable improvement.

In many areas, there will have to be a tradeoff made between environmental improvement and reimbursement of well-drilling expenses. This tradeoff will be necessary because often times it would be unreasonable to require both. Further, in many of the poorer areas, the campesinos will simply not be able to afford financial contributions. This reason coupled with the importance we place on environmental and societal change led us to favor the latter course. This priority will eliminate the expected difficulty in collecting well-drilling expense and give the campesinos a sense of ownership in their land and water. Ultimately, this will have to be a situational judgement weighing the financial expense, environmental improvements and the long-term needs of the local citizens.

COSTS AND EFFECTIVENESS OF THE WELL-DRILLING PROGRAM

The ultimate cost and effectiveness of this program will obviously depend on the scope of plan implemented. We feel that a comprehensive plan in this area will be the most cost-effective means to combat drought -- especially in the short-term. Further, the incorporation of a multi-year program with environmental and societal improvements will have long-term benefits. To assist USAID in the potential implementation of a plan, we have developed the following "ballpark" estimate of ultimate costs and benefits of a "good" comprehensive three-year well-drilling program. Naturally, the scope of the plan can be tailored to fit USAID needs and resources during the formulation of the program.

COSTS (USAID)

Well-drilling Coordinator 3 yrs @ $50,000 =	$150,000
Inventory Assistance	$ 10,000
Travel Expenses	$ 10,000
Technical Assistance - 1 yr @ $25,000 =	$ 75,000
Hydrogeological Investigations -	$150,000
Overhaul of Existing Rigs 14 @ $10,000 =	$140,000
Purchase of New Drill Rigs:	
- Small (100m.) Rigs 4 @ $150,000 =	$600,000
Purchase of Spare Parts Packages =	$100,000
Purchase of Initial Materials =	$380,000
Purchase of Pumps & Appurtenant Equipment:	
- Hand Pumps 100 @ $350 =	$ 35,000
- Electric Pumps - 10 @ $3,500	$ 35,000
- Generators & Engine driven Turbine Pumps	$100,000
Supervision and Administration	$143,000
Contingencies (20%)	$386,000
TOTAL COST ($2.5 million)	$2,314,000

OTHER COSTS AND BENEFITS

Beyond the capital investment costs, there are considerable operation and maintenance expenses. The typical annual cost to operate and maintain a 100-meter-drill rig ranges from $100,000 to $125,000 - with materials for an active rig being most of that amount ($80,000). The cost to the recipients will vary according to the policy adopted. The benefits for an active drilling program are enormous. After the overhaul of the existing Failing 1250 rigs, it is estimated that two deep wells can be drilled per month. Over a three-year period, this totals 72 wells which will service about 180,000 people. The existing production from these rigs is about 20% of that amount. The four new truck-mounted rigs can drill about 10 shallow wells each per month. Over 3 years, this totals 360 wells each which will service 60,000 people.

SUMMARY

It should be emphasized that the costs contained in this appendix are very speculative. For example, we are speculating on the cost of overhauling rigs we have never seen. Nevertheless, we felt obligated to make an order of magnitude estimate. A comprehensive three-year national well-drilling program will cost USAID in the neighborhood of $2.5 million. The operation and maintenance of each new truck-mounted rig will range from $100,000 to $125,000 per year. The cost of materials alone for these shallow wells is about $80,000 per year. The number of people benefited will approach a quarter of a million. Deducting the number of people already being helped with the existing program, yields a net gain of about 200,000 people benefited. The USAID investment represents an average cost of $12 per person.

APPENDIX I

NATIONAL STREAM-GAGING NETWORK

APPENDIX I - NATIONAL STREAM-GAGING NETWORK

GENERAL

The country of Bolivia apparently has an adequate network of gages to obtain data on precipitation, temperature, evaporation potential and wind speed and direction. What is really lacking is data on the daily stream flows throughout the country. While this is available in very limited areas, and usually for limited time periods, generally it is insufficient for design or calibration of state-of-the-art rainfall/runoff models. The streamflow data which is available has been found to be scattered, scarce, and often unreliable.

This lack of information was verified through our numerous contacts in Bolivia. In La Paz, our visits to the National Institute of Hydrology and Hydraulics, GEOBOL and others, uncovered little real-time river flow data. Numerous Bolivian engineers amplified the need for basic data to utilize state-of-the-art computer models for simulating channel flow. Others requested further information on the Corps of Engineers HEC (Hydraulic Engineering Center, Davis, California) computer model. In short, there is a serious need for basic streamflow data in Bolivia.

There are two primary reasons for gathering hydraulic data on streamflow. The first is for the purpose of amassing a base-line data file from which engineers can assess the availability of water for water supply, hydropower generation, drought or low-flow studies, designing of bridges and culverts, flood protection and control structures, developing water management strategies and contingencies, and for developing and calibrating rainfall-runoff computer models. Without this data, any designs which are done are no more than educated guesses. Projects designed without sufficient data are often over-designed with a resulting waste of valuable and scarce resources, or are under-designed resulting in risk to the safety of local inhabitants. The second important reason for gathering hydraulic data on streamflow is for use in the real-time management of the water resources. This not only includes its use for reservoir regulation and water supply management, but also for the very important task of flood warning and flood fighting.

We recommended that a comprehensive streamflow monitoring program be installed and managed for the country. Bolivia is in desperate need of a network which will gather data from streamflow gages located at strategic points on the country's most important rivers. These locations will be at bridge crossings, downstream from the confluence of large tributaries, downstream from dams, downstream from large industrial effluent points, and at points to monitor water levels near communities subject to flooding.

The initial streamflow network should be operated and data collected and analyzed continuously for 5 years. At the end of this time period, a network analysis should be made and consideration given to expanding the recording station network with the installation of additional gages on other rivers or streams, relocating existing gages to better sites, and upgrading the equipment with state-of-art improvements. The intent of all gage installation should be for continuous operation.

MONITORING EQUIPMENT

If a gaging network is installed and operated, what will it consist of, what will it cost, and who will be in charge of it? To install, operate, and maintain the stream gages and also to make streamflow measurements during floods, low flow periods, or for calibration of gages, it will be necessary to have a small fleet of stream gaging trucks. See Photo No. 28, Appendix P, for an example of this type truck. These trucks will carry all the required tools and equipment to install, operate, and maintain the gages and to perform actual flow measurements. At least one fully-equipped stream-gaging truck should be available in each department. The following is a breakdown of the costs for one stream-gaging truck:

1. 1-Ton Truck equipped as follows:
   a. 8-ft. Utility body with telescoping roof
   b. Dual rear wheels
   c. 30-gallon fuel tank
   d. Steel front bumper with 12,000-pound winch
   e. Retractable boom with winch and electric motor

      Total Cost Approx. $30,000

2. Stream-gaging equipment as follows: See Photo No. 29, Appendix P

   a. Price Type AA current meter

   b. Price Type Pygmy current meter

   c. 50-pound lead weight

   d. Wading rod, top setting

   e. Current meter digitizer with battery charger

      Total Cost Approx. $2,500

GAGE INSTALLATION AND OPERATION

The stream gages and housings for the equipment will initially have to be installed at strategic locations as described above. Generally, they must be in areas where the channel remains in one location rather than meandering across the flood plain as it does in many of the braided channels in Bolivia. To accomplish this, it may even be necessary to use structures to confine the flow to a certain area so that it can be measured. Often gages are located on the downstream side of bridges where they are somewhat protected from floating debris. The bridges also offer a site which is readily accessible and from which actual flow measurements of the current can be made for calibration of the gage. Gages which are placed on the river only measure the elevation of the water surface and thus they must be correlated with actual flow measurements to relate the river stage with some rate of flow. For example, if the physical river conditions remain somewhat constant, there will be a direct relationship between river stage and flow rate. As river stage rises, the river flow rate will also rise. Because erosion and sedimentation cause the river to change the shape of the bank and bed over time, the relationship between stage and flow rate also changes. For this reason it is necessary to periodically recalibrate the gage by making actual flow measurements at different stages of river flow.

There are two basic types of continuous recording gages that should be considered for use in Bolivia. One provides a water-level recorder which runs off power from a spring or weights and records water levels over time on charts or paper tapes. These gages are serviced and checked about every 4 to 6 weeks to retrieve data, rewind the power source, and perform maintenance or recalibrate the gage. See Photos No. 30 and 31, Appendix P, for an example of this type of stream gage. The following is a breakdown of the costs for one stream gaging station of this type:

1. Streamflow gaging station equipment to include:
   a. Leopold and Stevens Type A-71 continuous water level recorder with Chelsea clock, perforated stainless steel float line, float pulley, and 10-inch diameter brass float
   b. Aluminum gage shelter, 36 inches wide x 30 inches deep x 30 inches high with 12-inch diameter PVC pipe stilling well

      Total Cost Approx. $3,500

2. Streamflow station annual operating cost includes:
   a. Vehicle operating cost (150 miles one-way) to and from station, service equipment, perform streamflow measurement, nine trips per year
   b. Two man-days labor and per diem for each for nine trips per year
   c. Publish data in water monitoring report

      Total Cost Approx. $3,500

The other basic type of stream gage is one which provides real-time data on river stage for use in data collection, reservoir regulation, flood warning, and flood fighting. These gages consist of equipment which measures the river stage and reports it back to a central monitoring station computer via radio signal. The computer can continuously monitor the data, store the data for normal daily operation decisions or for future reference, and most importantly issue automatic warnings of potential problems, such as floods or low flow conditions. This type of system does require periodic, though less frequent maintenance than the paper chart recorders, and does also require the periodic recalibration due to changing conditions in the river.

These gages normally consist of a stage measurement device such as a pressure sensor or air bubbler in the river and a metal pipe on the river bank or bridge which houses a radio transmitter and antenna which sends the data to the central data collection point. The pipe may also enclose a rain gauge, thermometer, and anemometer for a complete climatic station. A solar-powered battery provides power for the radio transmitter so no electrical source is needed. If the transmitter does not have direct line of sight to the data-receiving computer, a repeater station may be required on a mountain with which to relay the signal. The repeater also operates off a solar battery and needs no external power source. One repeater can serve a very large number of gages which are placed in various drainage basins being monitored.

All equipment for such a system is readily available from off-the-shelf suppliers to include gages, repeaters, computers, and software to manage the system. Many of these systems are now in operation as flood warning devices, but the relatively low cost and real-time capability for management and use of the data, makes them very attractive for consideration for many applications besides flood warning.

At the end of this appendix is a full description of a flood-warning system and a preliminary design for a system that could be used for the city of Santa Cruz to warn of floods on the Rio Piray. Photographs of the equipment and computer hardware are shown in Appendix P, Photos 32 through 35. The costs that are shown in the design example are typical for such installations.

MANAGEMENT OF STREAM-GAGING NETWORK

Assuming that a program begins that collects this important hydrologic data, it is imperative that a single agency be responsible for the overall management and control of the effort. If there is to be any standard for quality assurance in the acquisition, storage, and analysis of the data, it must be handled at the national level. Actual gathering of data and operation and maintenance of equipment could be handled by the development corporations in the departments, but overall control would have to reside with the Federal government. An institutional framework and organization which would be responsible for this new approach to streamflow data gathering already exists. The National Meteorological and Hydrologic Service (SENAMHI) is a government entity which was created in 1968 to conduct all work related to meteorological and hydrologic sciences. This includes data collection, maintenance of systems and departmental networks, national observatories, data processing, hydrologic studies, climatic studies, agriclimate and agrimeteorology studies, as well as upper atmosphere and ozone layer studies. The charge for SENAMHI gives it authority for administration of hydrometeorologic policy, which includes planning, regulation, monitoring and control of the use and protection of the resources. Furthermore, it is to perform these functions in a decentralized, autonomous manner, as well as providing information services and specialized publications. Already, the organization has developed cooperative agreements with various department development corporations, so it should not be difficult to set up agreements for standard methods of gathering the needed streamflow data. However, this organization must understand the importance and need for this data and it must aggressively oversee the program to ensure that proper methods are used for the gathering, storage, verification, and reporting of this data. If this cannot be ensured, then another organization must be sought or created to perform this function.

FLOOD WARNING SYSTEM DESIGN
RIO PIRAY AT SANTA CRUZ

Many types of flood warning systems are in use today to fulfill the needs of those exposed to the dangers of floods. These systems range from very simple, manually observed gages where a river stage reading at one location causes activation of evacuation plans, to highly sophisticated electronic monitoring networks designed for specific locations. Most river stage, rainfall reporting networks provide some measure of flood warning protection by providing information to maintain a current data base. Actually such information is vital to even the most complex flood warning systems. Current and historical data are necessary ingredients to develop parameters for accurate river forecasting. However, the average data collection networks were originated several decades ago and report too slowly or randomly for optimum reaction by emergency personnel and the general public.

Relatively recent developments in electronics has brought about an evolution of measuring and communications equipment readily adaptable to weather and river monitoring. Private vendors have developed large selections of off-the-shelf items for reporting networks that would have been impracticable or impossible in the past. Many of these new items were designed to modernize existing data gathering networks, but one new concept emerged concerning real-time reporting. Real-time data reporting becomes practical when an existing network needs major modernization, or in locations where early flood warnings are beneficial. The installation and maintenance of real-time reporting networks are competitive with older methods and will likely dominate the market in the future.

For those communities and locations in need of early reporting and/or flood forecasting, small real-time reporting networks can be installed more quickly than revising their entire existing networks. These smaller real-time reporting networks are the basis for the flood warning systems offered by various vendors. In addition to the field equipment, a radio communications system delivers the data to a waiting computer where it is formatted for viewing or for use in forecast models. Observations of field conditions are available to the user as these conditions occur.

A basic plan for flood warning within one river basin is presented here to demonstrate the magnitude and cost associated with these systems. For this demonstration, Rio Piray near Santa Cruz de la Sierra is the subject area. The river basin above Santa Cruz is approximately 100 kilometers long with a maximum width of about 50 kilometers. The area is approximately 3,000 square kilometers. Without access to the historical data base that is necessary for some portions of design, certain assumptions must be made. These assumptions include the following: 1) rainfall occurring in the upper one-third of the basin will take 2 to 3 days to flow to Santa Cruz; 2) rainfall in the lower two-thirds may take from 2 days to a few hours to produce flooding conditions in settled areas, depending on timing and distribution of that rainfall; 3) an adequate gaging network already exists to determine when seasonal changes have occurred and other antecedent conditions.

Rio Piray has two major tributaries in the upper portion of the basin (Rio Piojeras and Rio Bermejo) that must be monitored to forecast flooding from that part of the basin. Below the upstream tributaries flooding conditions may be seen in Rio Piray almost as quickly as in tributaries along the lower part of the basin so there may not be as great a need for tributary gaging as in the upper basin. Along with river monitoring gages there should be a sufficient number of rainfall gages to anticipate water entering the system and thereby predict future flooding. It is relatively easy to incorporate rainfall gages into river stations where they can share the communications equipment but additional rainfall gages will be needed at other locations.

Proper monitoring of Rio Piojeras will require three combination river stage-rainfall gages; one located a short distance above the junction with Rio Bermejo and two further upstream, and four single-purpose rainfall gages at selected sites. On Rio Bermejo, two combination river stage-rainfall gages and three single-purpose rainfall gages will be needed. Further downstream three combination river stage-rainfall gages will be needed on the Rio Piray including one at Santa Cruz and three single-purpose rainfall gages. If a tall radio tower already exists in the basin that can be utilized for the relay station, it may be possible to gather the data with only one relay site. We will assume that no tower is available and that four relay stations will be needed due to rough terrain.

One of the more common methods of packaging river stage, rainfall and relay stations in the field is inside metal stand pipes about eight inches in diameter and standing eight feet above ground level. Sensitive equipment is housed in the bottom of the pipe, below ground level. Solar panels are attached to the side, an antenna extends from the side to a predetermined height and conduit extends from the bottom of the pipe to the stream where a pressure transducer is installed. The rain gage is installed in the top of the stand pipe. Photographs showing installed equipment are in Appendix P. Also see the drawings in Figures I-1 and I-2.

The field equipment described is capable of gathering data, storing that data on internal chips and transmitting the data to a central receiving site, or emergency operating center. Equipment needed at the central site includes receiving antenna, decoder and a computer compatible with late-model IBMs. Also of value is an uninterruptable power supply device to prevent loss of data when normal power is out. See Figure I-3 for a schematic drawing of a complete system layout.

COST ESTIMATE FOR FLOOD WARNING SYSTEM - SANTA CRUZ

(Estimate taken from prices in United States)

Field Equipment	Unit Cost	Number	Total Cost
Automated combination river stage-rainfall gages	$6,000	8	$48,000
Automated single-purpose rainfall gages	$4,500	10	$45,000
Radio repeater stations	$3,500	4	$14,000
CENTRAL STATION			
Computer, antenna, decoder, central display, software, printer, phone modem, and necessary connections	$30,000	1	$30,000
TEST EQUIPMENT & SPARE PARTS			
Items such as remote station tester, battery testers, wattmeters, additional antennas, river stage sensors, raingages, cables and assorted parts	$30,000		$30,000

TOTAL EQUIPMENT COST	$167,000
INSTALLATION	$ 20,000
CONTINGENCIES	$ 40,000
ENGINEERING & DESIGN	$ 40,000
SUPERVISION & ADMINISTRATION	$ 25,000
SOFTWARE CALIBRATION (ASSUMING FORECAST PACKAGE INCLUDED)	$ 10,000
TOTAL	$302,000

RAINFALL GAGE NETWORK

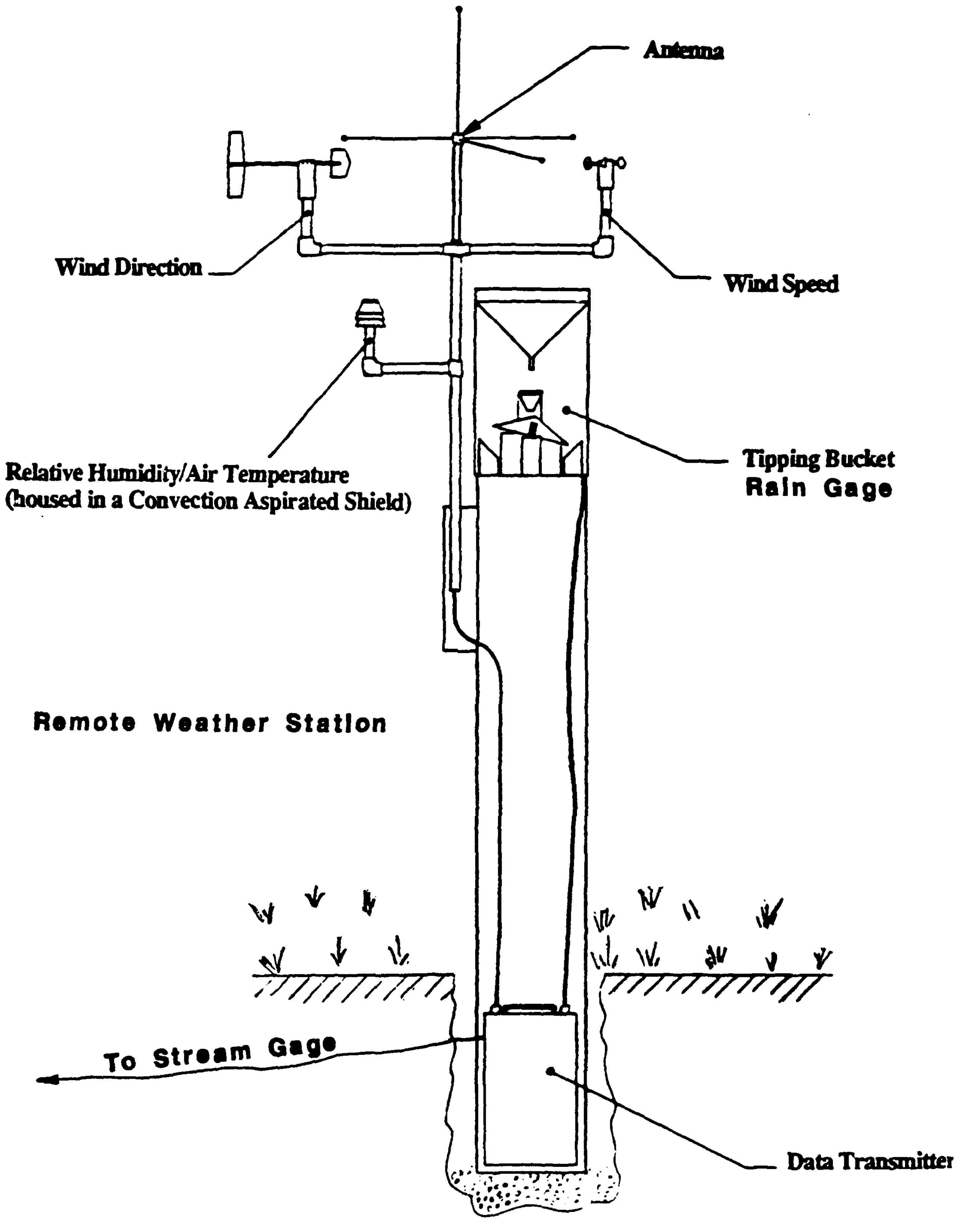
Will the installation of this stream-gaging network fulfill all the necessary requirements in order to have a reliable water resource monitoring program in Bolivia? It will "if" the other necessary elements of the program are in place: a reliable rainfall-monitoring network, a central source where data can be stored and accessed as needed, and an aggressive infrastructure which will operate and maintain the system. In our brief inspection of Bolivia's water resources, we got the impression that an adequate rainfall recording network exists in the country and that a relatively small number of new rainfall gages would be needed to establish an initial resource-monitoring program. Our literature search shows that a considerable amount of rainfall data is available throughout the country over a considerable period of time. We found no reason to doubt that the data is accurate nor that the gages are still in operation. Furthermore, a government agency, SENAMHI, is charged with operation of such a system.

Assuming that the rainfall data in Bolivia is accurate, why is it necessary to add streamflow gages to the network? In order to manage the water resources of the country, it is necessary for Bolivia to gather, archive, analyze, manipulate, and report on all types of climatic and hydrologic data. This includes data on temperature, wind speed and direction, evaporation potential, rainfall, humidity, barometric pressure, and last but by no means least, streamflow discharge. In our study of the water resources of Bolivia, we repeatedly uncovered climatic data on precipitation, temperature, evaporation potential, and winds, but found very little data relative to streamflow discharge. While it is true that mathematic models exist which can use topographic mapping and precipitation to develop rainfall/runoff relationships and thereby predict streamflows, just knowing the amount of rainfall that occurs in a given time period without knowing about the runoff characteristics of the watershed conditions can lead to erroneous results in computing the streamflow discharges that the rainfall event will produce.

When a rainfall event occurs, of the rain which actually hits the ground, some of it evaporates back into the air, some is caught and trapped in depressions in the ground or on vegetation, some is taken up by the vegetation and transpired back into the air, some infiltrates into the ground and is lost to underground storage, some infiltrates into the ground but reemerges from springs or from the bed of streams as additional streamflow (this is usually referred to as the base flow of the stream), and some runs off over the ground and enters the streams. Whether or not the final results from a rainfall/runoff model are any good or not depends on the accuracy of the model's parameters which simulate things like topography of the ground, the soil moisture conditions, soil permeability, soil type, antecedent rainfall conditions, vegetative cover, humidity, time of year, temperature, etc. All of these factors affect the amount of precipitation that will eventually end up as flow in the stream. Because it is impossible, in any practical sense, to know all of these characteristics for each watershed which may be of interest, the math models usually have some generic calibration parameters such as soil permeability, runoff coefficient, and rainfall loss estimates which are used to adjust the model to yield realistic information.

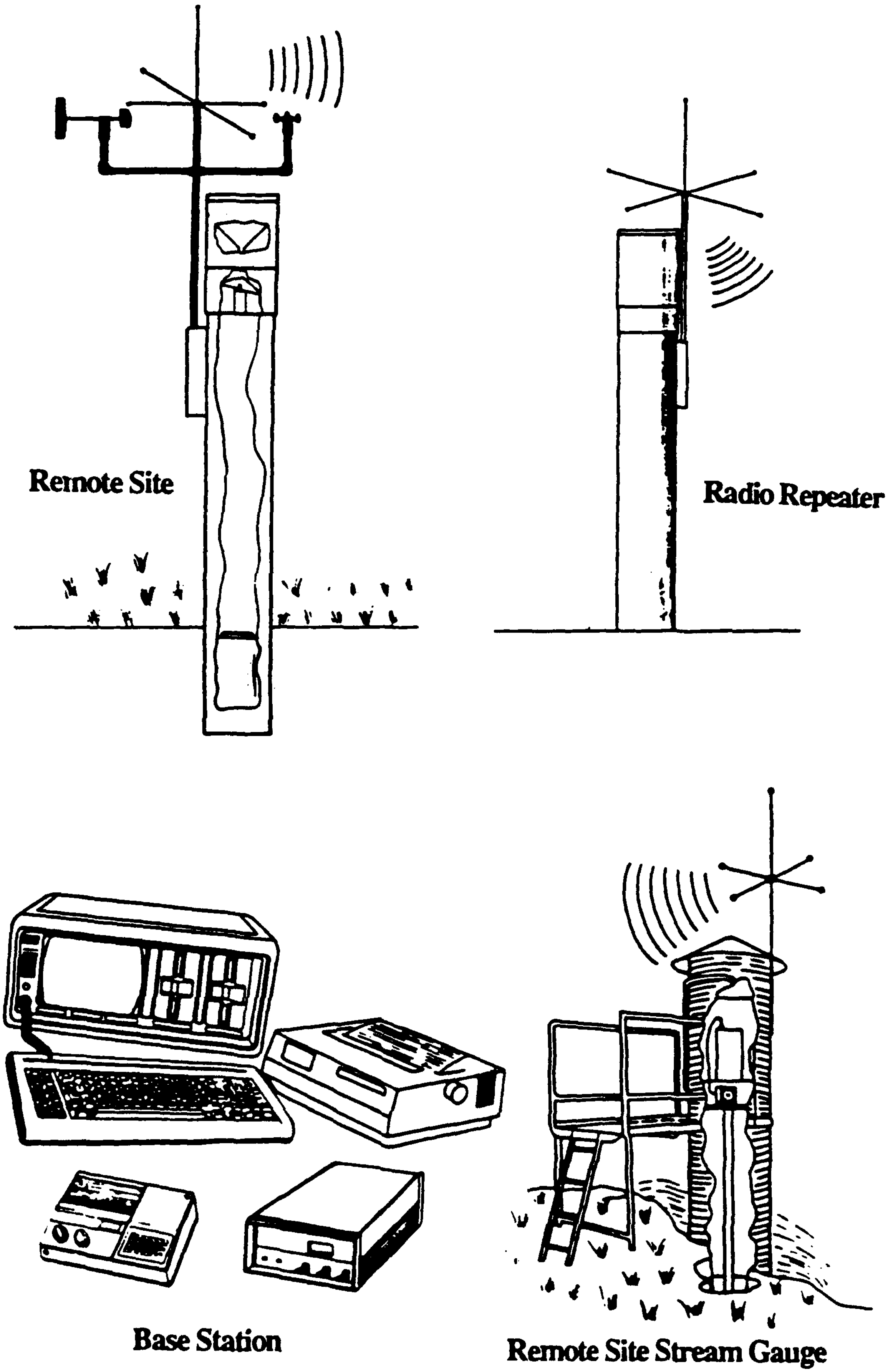
How does the engineer adjust these parameters to produce realistic streamflow estimates? The adjustments are made based on the experience of the engineer; however, this effort is greatly facilitated with data recorded during actual rainfall events and correlating this rainfall with actual measurements of streamflow which resulted from the event. This allows reliable calibration of the model for that specific event and gives an indication on how the watershed reacts to all events. It must be remembered that each event is unique and because of the different watershed parameters that affect runoff, each event will show a slightly different reaction by the watershed. However, by monitoring the data for various events, the watershed can fairly well be characterized by a set of parameters which are used in the computer model. It is best if parameters are determined from observations in the watershed under study, but since it is not practical to instrument every watershed, this calibration can also be done with data measured from similar watersheds in the area. Furthermore, this calibration of rainfall versus runoff must be monitored and adjusted over time because of changing topography, land use, vegetative cover, climate, time of year, antecedent rainfall, etc. Thus, any reliable hydrologic monitoring network must have a very reliable source of both rainfall and streamflow data and the data [illegible]t be continuously gathered and evaluated over an extended period of time.

It has been assumed that an adequate and accurate rainfall monitoring network is in place in Bolivia and the installation of streamflow monitoring gages will complete, for the most part, the elements of the hydrologic network. If this is not found to be true, then resources will have to be obtained to establish or expand the rainfall measuring network as well. In the extreme case, this could roughly double the costs shown above. It is not believed however, that this will be necessary. In the early stages of layout for the data gathering network, the designer will determine the availability of existing gages and types for the watersheds in question and will make use of existing gages when possible. At this time, we do not believe that additional rainfall gages will be a significant item, except for installation of flood warning systems where higher density of gages may be required.



Antenna
Wind Direction
Wind Speed
Relative Humidity/Air Temperature
(housed in a Convection Aspirated Shield)
Tipping Bucket
Rain Gage
Remote Weather Station
To Stream Gage
Data Transmitter

FIGURE I-1



FLOOD WARNING HARDWARE – SANTA CRUZ

FIGURE I-2

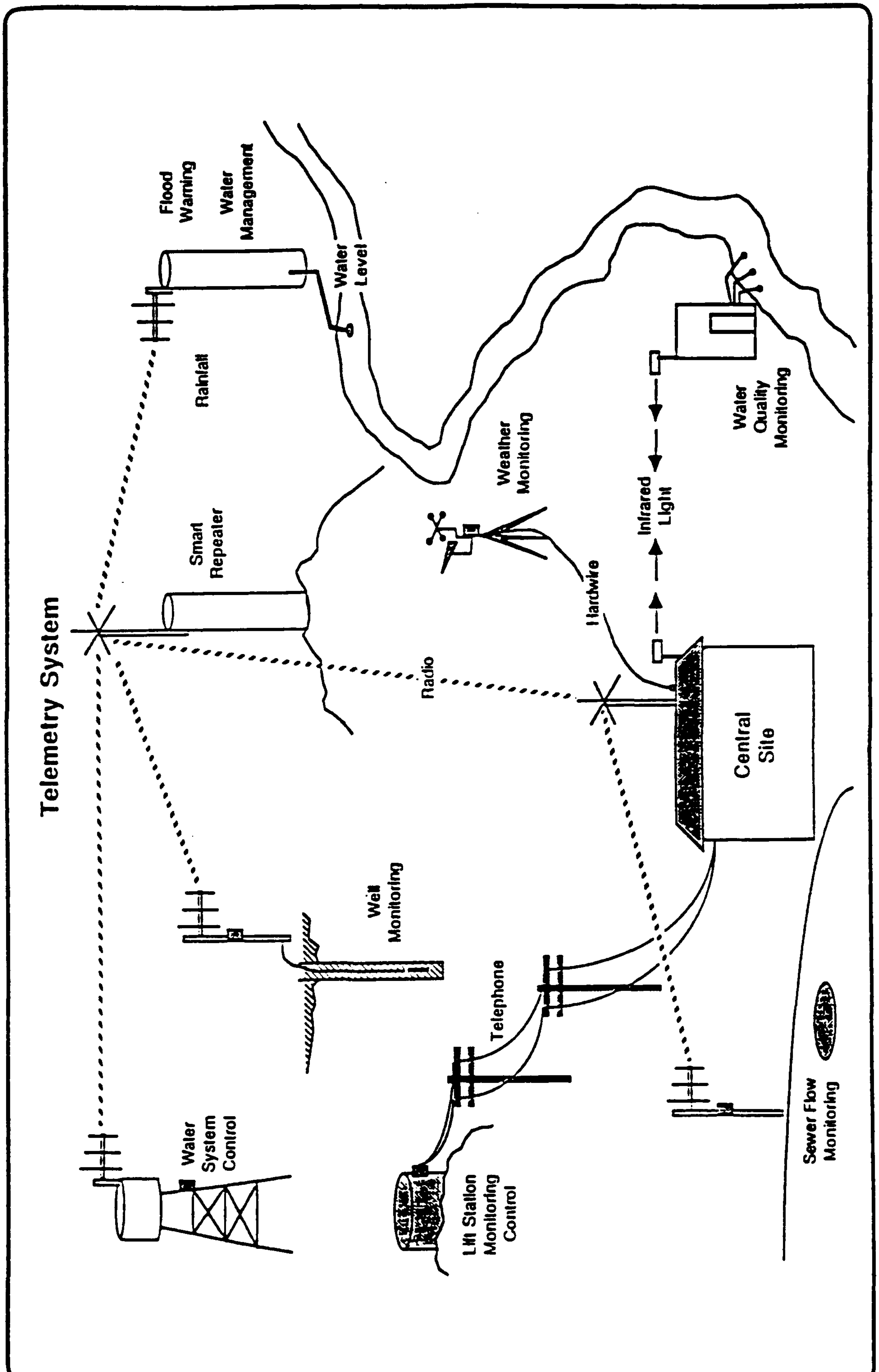

Telemetry System
Flood Warning
Water Management
Water Level
Rainfall
Smart Repeater
Weather Monitoring
Water Quality Monitoring
Infrared Light
Hardwire
Radio
Central Site
Well Monitoring
Telephone
Water System Control
Lift Station Monitoring Control
Sewer Flow Monitoring

FIGURE I-3

APPENDIX J

NATIONAL WATER RESOURCES MANAGEMENT AND POLICY

APPENDIX J - NATIONAL WATER RESOURCES MANAGEMENT AND POLICY

GENERAL

Bolivia's water resource development and management, for the most part, appears decentralized. There are several national ministries or organizations, but, their jurisdiction and authority are somewhat limited. The bulk of water resources activities in Bolivia seems to be directed at the department level - especially in the regional development corporations of each department. Thus, international organizations deal with individual departments as well as national offices. When one considers there are well over 100 international entities assisting in Bolivia's development, the complexity of the overall effort becomes apparent. This situation leads to a lack of coordination between countries and to some extent, between departments. Further, it is expected that there are duplications of effort and a lack of exchange of technical knowledge and data.

The benefits of improving the water resources management and policy of Bolivia are enormous. The broad goals of such an effort would focus on public health, economic development, social well-being, and environmentally sustainable development. Under that framework, certain nation policy issues and management strategies would emerge. This would require an assessment of various water resource project purposes - water supply, water quality irrigation, navigation, hydropower, fish and wildlife, etc. The in-country evaluation of all these needs could well lead to a restructuring of the water resources management of the country and a more-defined national interest or policy.

Because water management and policy are the core of efficient and equitable development, this appendix offers some generalized approaches on how the system might be gradually improved. These alternative approaches fall into the following broad categories: (a) the formation of national and/or international water resource councils; (b) conducting a comprehensive evaluation of all water resources and interrelated activities in Bolivia; (c) the establishment of a national clearinghouse; (d) sponsoring national/international symposiums or meetings to encourage technical interchange; and, (e) forming task forces to evaluate pertinent subject matters such as the need for a national water law, a strong national water resourceeeeee agency, or a national education program.

WATER RESOURCE COUNCIL

Formation of a water resource council at the national or international level would encourage information exchange and possibly shared organizational funding for common needs. The council should be made up of high-level executives from member entities. At the national level, candidate members would be heads of national offices and development corporation presidents. At the international level, candidate members would include the heads of the USAID, CARE, European Economic Community, etc. Each of the members could assign staff to help on special studies and evaluations. The focus of any such council would be to discuss water resource activities in Bolivia and act as a policy advisor to Bolivia's President. It is conceivable that member nations or other entities could contribute to a fund which would finance common water resources development or interrelate needs. Examples of a possible common need are good topographic mapping of the country, development of a national data base for hydrology and hydraulics information, conservation of soil and water resources and environmental enhancement.

COMPREHENSIVE WATER RESOURCE EVALUATIONS

The potential savings that could result from conducting a comprehensive evaluation of all water resources and interrelated activities in Bolivia are enormous. Such an effort would require staffing for several years or through a significant outside contract. The mission would be to analyze all on-going and proposed water resource activities in Bolivia. This would require discussions with the literally hundreds of entities involved. These discussions would be followed with extensive field evaluations. Only then could the long and arduous task of research and analysis begin. This effort would uncover many commonalities and duplications which could be accomplished in a more cost-effective fashion. There is also a significant potential for savings due to economies of scale, i.e., consolidating a dozen similar or identical efforts into one.

NATIONAL CLEARINGHOUSE

Another method of assimilating information among various national and international entities would be through a clearinghouse. The first duty of this office would be to develop a mailing list of all entities which have an interest in a particular subject matter. Next, they would convince all those involved in water resource development in Bolivia to forward their respective water resource proposals. Then they would simply mail pertinent data to appropriate parties upon request. There are two primary difficulties with this alternative. First, the expenses would be high due to the amount of staffing required. Secondly, there could well be difficulty in obtaining uniform cooperation from all those involved. The only known examples of success with clearinghouses is in environments where the use of the process is mandated by force of law.

NATIONAL AND INTERNATIONAL MEETINGS

National and international symposium or meetings are a common means of encouraging the exchange of information. This is an excellent forum for scientists, engineers and water managers to exchange ideas, concepts and proven water resources management experiences. One word of caution - the meeting should not be too theoretical. There must be immediately implementable suggestions, as well as long-range proposals. We suggest that a national gathering with selected international participation would be a good starting point for the initial meeting. That first meeting would also be a good forum to discuss other national water policy alternatives, i.e., water resources council, comprehensive water resource evaluations and national clearinghouses, etc. The meeting should last from 3 days to a week and be held in an easily accessible city. La Paz would be an ideal candidate. Suggested topics and workshops to be covered include: national water policy issues, water conservation, drought management, major water resource projects either planned or under construction, experiments in changing crops, reforestation, soil erosion, irrigation techniques, well drilling, water quality, water treatment, hydropower, etc.

FORMULATION OF TASK FORCES

This idea is somewhat similar to others previously discussed. The difference is that one major national or international organization would have to take the initiative to lead the program over time. An organization like USAID would be a good candidate for the lead role. The first step would be to identify a national need that would be of widespread interest to entities operating in Bolivia. Discussions might include subjects such as: a national water law, a national education program, a national data base for technical data, national surveys and mapping, a national program for soil and water conservation, etc. The lead agency would then need to correspond with the various national and international entities to co-sponsor the project by assigning members of their organization to the task force.

Another variation of the task force concept and the water resource council idea should be mentioned. On the basis of the recommendations in this report, USAID or the American Ambassador could approach the President of Bolivia to discuss the possibility of establishing a President's Water Resources Commission. The task of this commission would be to evaluate the same national water policy issues discussed in the previous paragraph with a view toward making recommendations on water policy and the appropriate level of federal involvement. These recommendations should be documented in a report by the commission. The commission would consist of from three to six high-level officials in Bolivia. These members would be appointed by the President for one to three years with staggering terms for consistency and fresh approaches. They should have a blend of various backgrounds - engineers, scientists, agricultural scientists, university professors, politicians, economists, geologists, socialists and campesino representation are all good candidates. This commission would need a few staffers to manage the details of the commission operation and to prepare and dissiminate reports. The commission members would hold a series of public meetings and/or use a format of requesting testimony from a wide spectrum of professionals, agencies and the general public. They would also solicit input from various national and international agencies. This, in effect, could result in a cost-free (to Bolivia) task force representing a variety of entities. From this pool of manpower, several committees and subcommittees could be formed to thoroughly evaluate various subjects related to national water policy, water agencies' involvement and other national water resource needs.

SUGGESTED STRATEGY

It is difficult to suggest a strategy because of our lack of knowledge of the reality of the bureaucracy and the political arena in Bolivia. A well-designed program in any of the areas discussed in this appendix could conceivably be worthwhile. From an outsider's perspective, it appears that a two-pronged approach would produce the greatest results. First, we would recommend that the President be approached about the possibility of establishing a water resource commission. This approach would involve the Bolivian people and represent their views in lieu of the views of an "outside expert". The other suggested program is to conduct national and international symposiums or meetings. We suggest that USAID seek co-sponsors for the first annual symposium on water resources in Bolivia. The cost of the first effort will include an indirect need for staff to support the commission in the future. If special staffing is needed, there may be an expense of $150,000 to $250,000 according to the support given. The budget for the first international water resource symposia will be high. We would suggest budgeting $250,000. Naturally, the cost to USAID could be reduced through co-sponsorships and certain other arrangements.

APPENDIX K

REHABILITATION OF EXISTING WATER RESOURCE PROJECTS

APPENDIX K - REHABILITATION OF EXISTING WATER RESOURCE PROJECTS

GENERAL

The development of public works in any society is often oriented toward short-term benefits. Even projects which have long planning horizons of fifty or one hundred years are usually not adequately funded for the out-years. Therefore, it is common that operation, maintenance and major replacements are not adequately performed on many public works projects. The reasons for this vary from the need for immediate visibility of benefits for government investments to poor judgment on the part of the designers.

In a developing country these same pressures exist. Further, these problems are intensified by the very nature of funding for many projects in a country like Bolivia. For example, international investors in such countries often construct massive projects but make little provision for future operation, maintenance, and major replacements. In many cases, the local citizens agree to assume that responsibility, but simply do not have any reasonable ability to meet that commitment. The same process occurs internally within Bolivia - an impoverished community agrees to maintain a well when they have no means to do so, simply because it is the only way they will get the much-needed well.

THE PROBLEM

There are signs of this short-term philosophy throughout Bolivia. The need for a "National Well-Drilling Program" discussed in Appendix H has been brought about, in large part, for this same reason. There are also water resource facilities, both large and small, which are in serious need of rehabilitation, maintenance or repairs. The purpose of this appendix is to suggest that a limited program for the rehabilitation of minor water resource facilities be considered.

During our limited tour of Bolivia, we observed many facilities which were not functional because of the lack of minor parts, repairs or replacements, i.e., wells which never had pumps, wells with broken pumps, wells with pumps but without a power source, artisan wells without valves, serious leaks in water distribution systems, etc. The nature of our visit did not allow us to compile a comprehensive inventory of these problems.

However, we received reports of over 300 such minor problems. Based on our firsthand observations, we suspect that the problem is widespread the country. We also feel that there would be a high return on any investment in rehabilitating many of these small water facilities. For example, in the drought-stricken area of La Paz, an investment of $25,000 to $50,000 would bring desperately needed water to several thousand families.

SUGGESTED STRATEGY

We suggest that USAID sponsor a program to rehabilitate many of the small water resource facilities in southwestern Bolivia. The first step would be to conduct a department-by-department inventory of the extent of the problem. This inventory would include the location, cost, families benefited and description of the parts or repairs needed. With this information, the program coordinator could develop a purchase and repair schedule tailored to USAID resources. The coordinator could be a special hire, the assistant to the national well-drilling coordinator, a temporary hire or a contract hire. To avoid the reoccurrence of this problem a few years down the road, this program should include a spare parts package and a small inventory of extra pumps. These items could well be included with the spare parts and inventory which would have to be purchased if the national well-drilling program, discussed in Appendix H, is adopted.

The cost of this program will obviously vary according to the scope of the program developed. To help USAID decide on the merit of this proposal, we speculate the cost of this program will range from $200,000 to $600,000. Naturally, the program could be tailored to fit USAID's desires during the formulation of the program. It is speculated that the program has the potential of benefiting from 30 to 90 thousand people.

APPENDIX L

CONSTRUCTION OF WADI DAMS

APPENDIX L - CONSTRUCTION OF WADI DAMS

INTRODUCTION

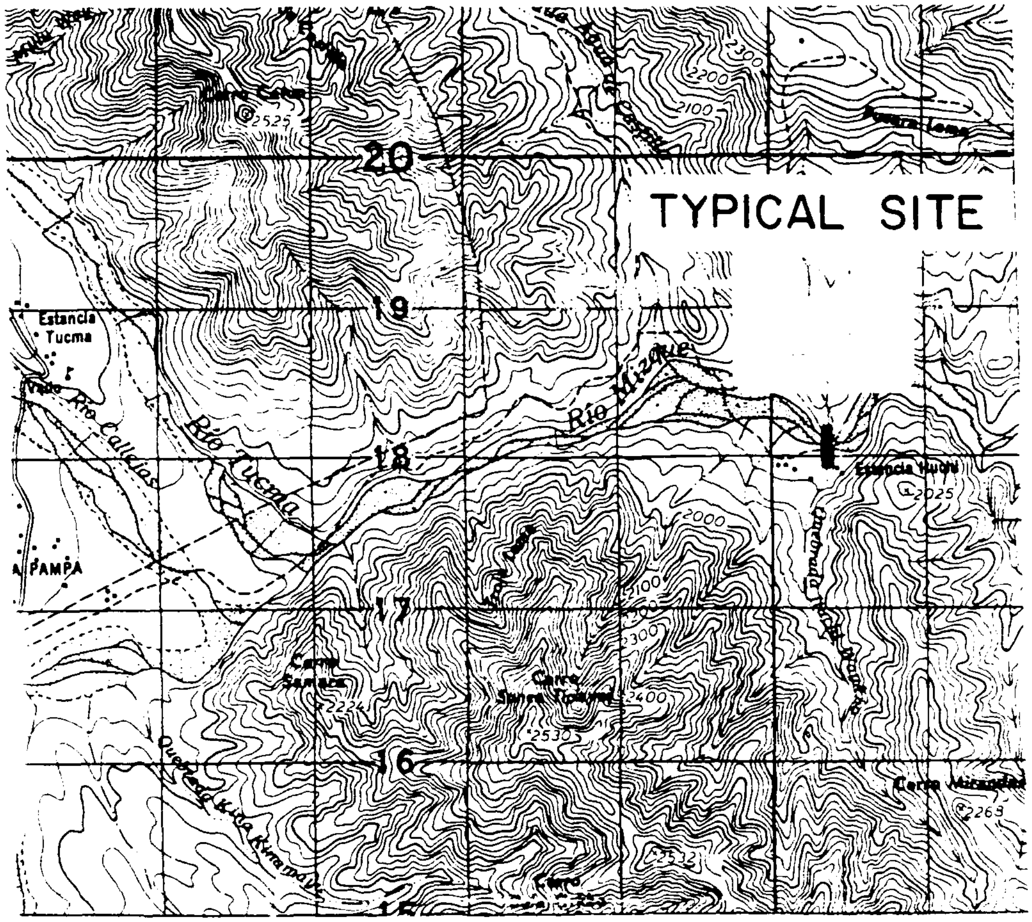
In many arid regions, substantial amounts of seasonal runoff from rainfall infiltrates into the alluvial fill in narrow, rocky valleys (called wadies in many arid countries) and moves down the valley's gradient as groundwater. This subsurface flow may migrate completely away from an infiltration gallery or other point of extraction during prolonged periods without rainfall, leaving the well or infiltration gallery dry. Installing an impermeable barrier across the valley immediately downstream will retard the migration of the water and create a subsurface reservoir that will allow water to be available for withdrawal. Construction of these barriers is like building a dam below the ground and has somewhat the same inverted symmetrical shape.

LOCATION

Many potential wadi dam sites were observed in the valleys within the mountains of the department of Cochabamba and Potosi. See Photo No. 2, Appendix P. This process requires that an excavation be completed all the way through the alluvium to the actual base of the valley. To help control the excavation quantity, a narrow portion of the valley should be chosen near the spot where water is needed. In most cases, the depth of the alluvium should be determined before construction. This is to ensure that there is enough alluvial material to store the water or to find out whether the material is so thick that excavation is too great within the construction period. As an estimate, one could assume that the porosity (space available to store water in the soil), of the generally course-grained alluvium in these valleys is about 30%. A typical site for construction is indicated in Figure L-1.

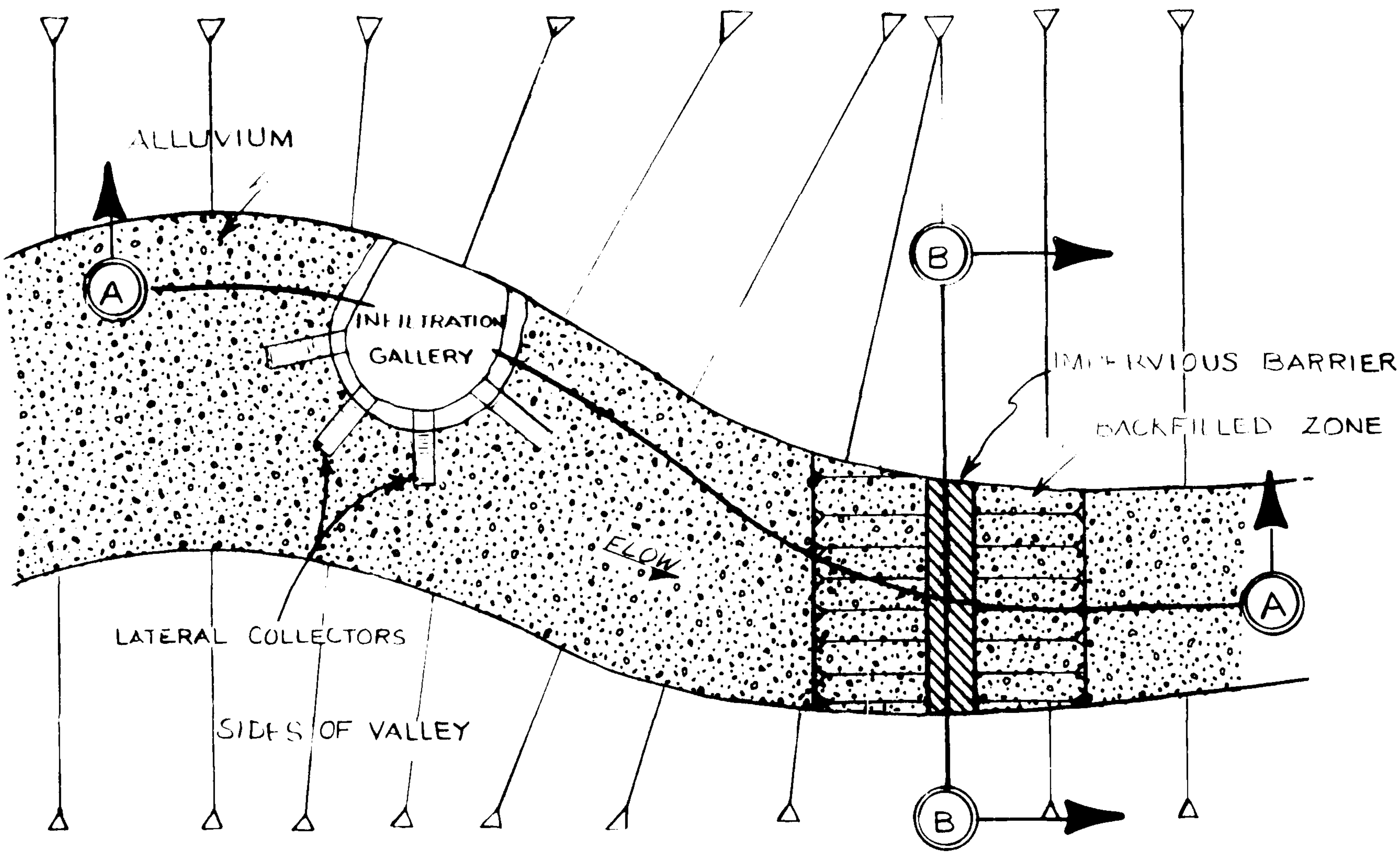
CONSTRUCTION

The project actually has two structures, the barrier and some type of well to extract the water. The extraction of the water will be upstream of the barrier, as close as possible. See Figure L-2. This can be either a well or an infiltration gallery, with the gallery probably best. The excavations should be made during the dry season when the least amount of groundwater is present. Any necessary dewatering can be done with the gallery once it is dug. The excavation for the barrier needs to be cleaned down to rock, then backfilled placing a core of soil and bentonite clay about 120 centimeters thick as indicated in Figure L-3. The blended soil should consists of at least 15% bentonite well-mixed. Only sand-sized or smaller material should be included in the mix, and a sand filter should be placed for a meter or so on both sides of the core. If a natural, local clay is used, it should be all clay. The excavation's backfill, including the core, should be brought up in lifts similar to any fill, although compaction of the fill need only be minimal. The core should extend almost to the original ground surface, then a layer of riprap-sized stone placed on top to help prevent scour from surface water. The important thing is that the barrier must have contact with the sides and bottom of the valley (see Figure L-4) or the water stored behind the dam will leak. The next rainy season after the valley carries away the floods and normal runoff, and the water drops below the alluvial surface, the wadi dam will store the water behind the barrier and make it available to the well. Care should be used in locating the well so floods do not destroy the structure. The construction of the infiltration gallery can be similar to what is normally done throughout Bolivia.



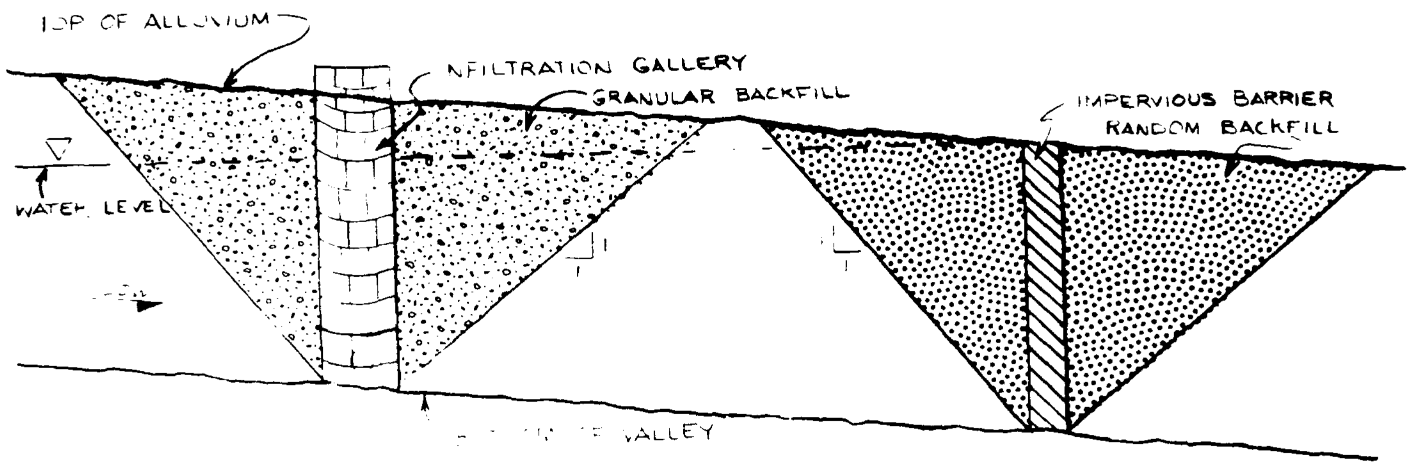
Typical location of Wadi Dam construction through alluvial deposit.

FIGURE L-1



PLAN VIEW
(NOT 10 SCALE)

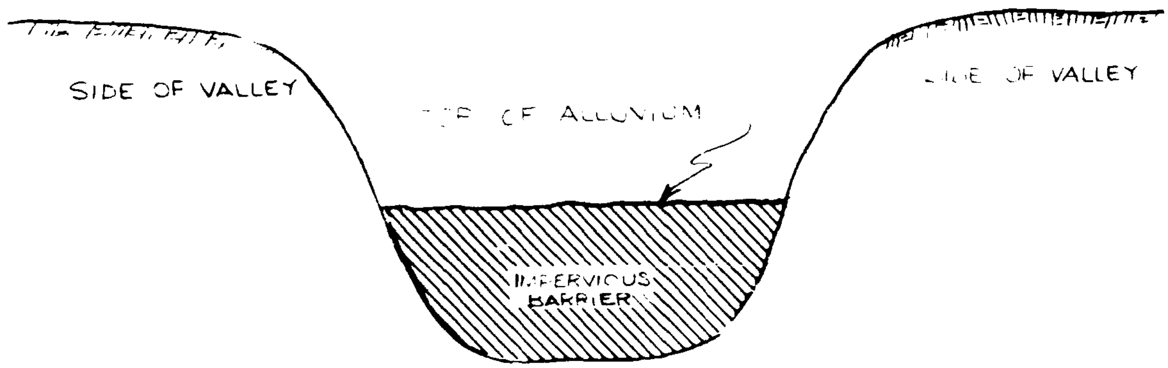
FIGURE L-2



SECTION A-A

(NOT TO SCALE)

FIGURE L-3



SECTION B-B

(NOT TO SCALE)

FIGURE L 4

APPENDIX M

RAINWATER CISTERN DESIGN

APPENDIX M - RAINWATER CISTERN DESIGN

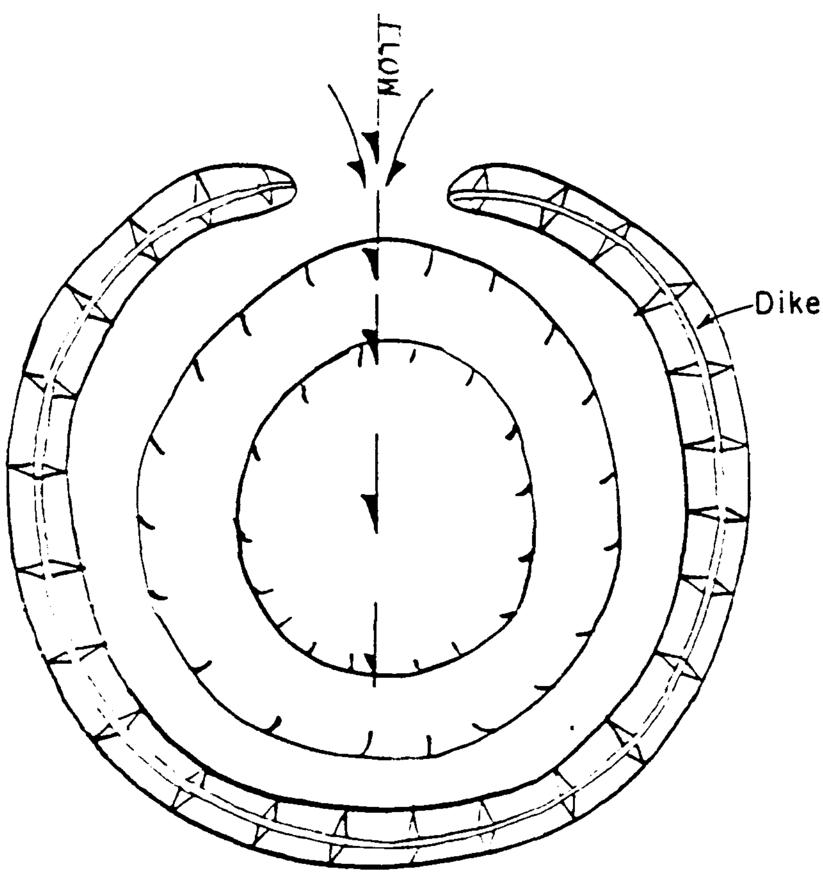
In order to prevent the shared use of rainwater cisterns by humans and livestock, a suggested modification to the cistern construction is provided in this appendix. Presently, the cisterns consist mainly of scooped-out earth basins which catch runoff from rainfall. Berms around the pond are built from the excavated material and serve to contain the maximum amount of water (See Figure M-1 and Photo No. 26 in Appendix P). The problem is that humans and animals share this same water source and thereby cause disease and sickness in humans.

A simple solution is in use in other parts of South America which fences off the pond to prevent livestock from entering and polluting the water supply. A pipe with a control valve (see Figure M-2) supplies water to a trough or a pond for the animal consumption. This supply is even more healthful for the animals since they cannot actually enter the water nor defecate in it, thereby, creating a source without so many harmful bacteria (see Figure M-3).

When constructing the ponds, bentonite or another type drilling mud should be spread on the bottom of the pond and disked or plowed into the soil. This will make the pond bottom relatively impermeable and prevent water loss due to infiltration. Additional suggested designs can be found in the Soil Conservation Service's Engineering Field Manual, published by the U. S. Department of the Interior.

RAINWATER CISTERN

PRESENT DESIGN

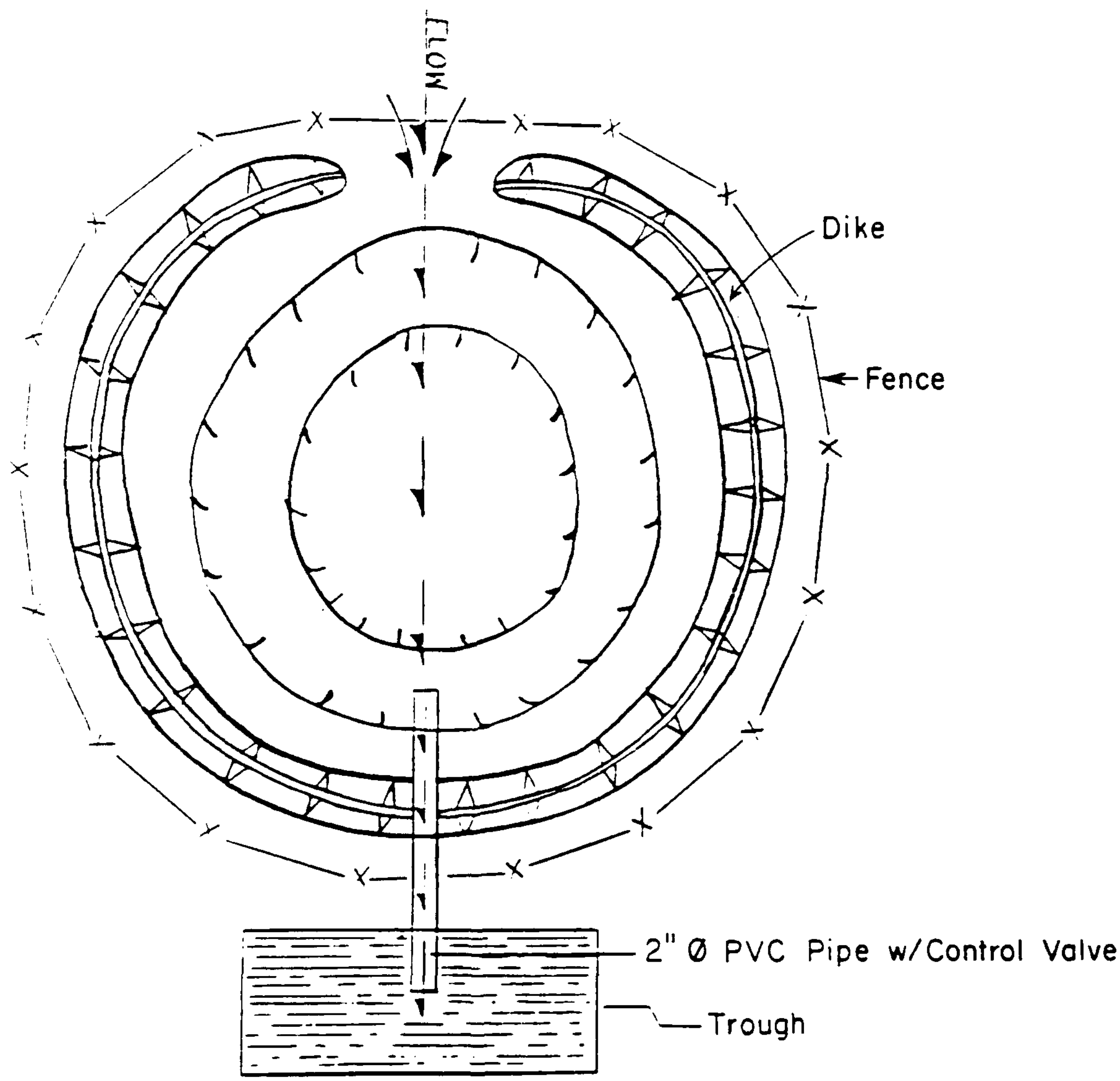


PLAN VIEW

NOT TO SCALE

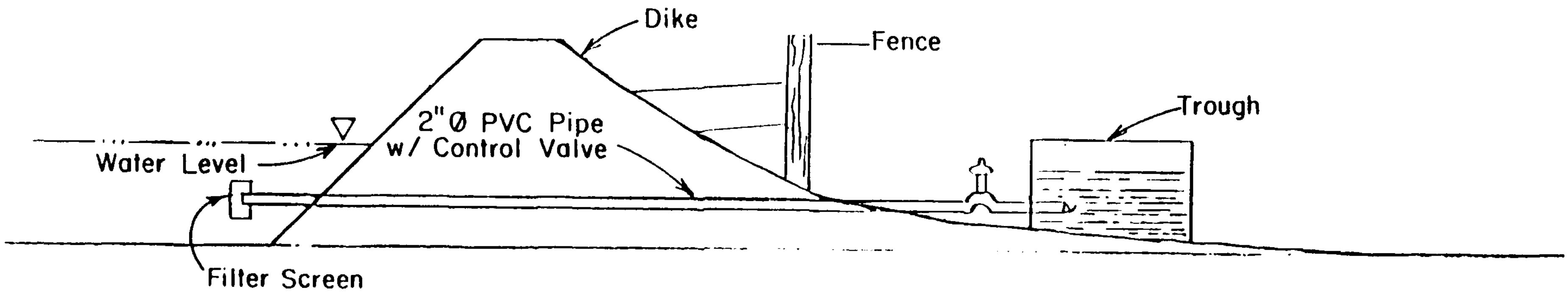
FIGURE M–1

RAINWATER CISTERN
SUGGESTED DESIGN



PLAN VIEW
NOT TO SCALE

FIGURE M—2



SECTION THROUGH CISTERN

NOT TO SCALE

FIGURE M—3

APPENDIX N

BIOGRAPHICAL SKETCH OF WATER RESOURCES ADVISORY TEAM

APPENDIX N - BIOGRAPHICAL SKETCH

OF

WATER RESOURCES ADVISORY TEAM

DONALD J. CHATELAIN, P.E. - Mr. Chatelain graduated from Lamar University, Texas, with a Bachelor of Science degree in Civil Engineering in 1962. He has been a registered professional engineer since 1967. Mr. Chatelain has varied experience in the technical aspects of practically every level and involvement of civil works from planning, design, construction and political considerations. Early in his career he was a project evaluation specialist, project design engineer, construction management specialist and a facility engineer. Since 1973 he has specialized in general water resources planning. In 1976 he obtained a water resources planning certificate as a Planning Associate with the Board of Engineers for Rivers and Harbors. In 1976/77 he was a member of committee staff of the U.S. Senate Committee on Environment and Public Works as a water resources advisor. He has served as a supervisor in the following Mobile District Offices: Project Management Section, Navigation and Coastal Branch, Flood Control Branch, Eastern Basins (multi-purpose projects) Section, Planning Support Section, Assistant Chief of Planning Division and a management consultant to the Chief Executive Office. In the past 17 years he has also served on numerous special missions--including limited work in Panama, Korea, Peru and the head of a regional task force on drought in the southeastern United States.

HOWARD M. WHITTINGTON, P.E. - Mr. Whittington is the Chief of the Hydrologic Investigations Section, Mobile District, U.S. Corps of Engineers. He has been a Registered Professional Engineer since 1974. He graduated from college at The Citadel in 1968 with a Bachelor of Science Degree in Civil Engineering. In 1976 he earned a Master of Science degree in Water Resource Planning from Colorado State University. He has over 20 years of experience in hydraulic design of water resource projects. He has been selected as a member of the Corps' National Committee on Channel Stabilization. He was also selected in 1985 to travel to the Peoples Republic of China and serve as the Corps' expert to consult with the Chinese engineers for hydraulic design of the world's highest-lift navigation lock. He has also consulted on hydraulic and hydrologic design of flood control structures in the Republic of Panama.

JOHN N. BAEHR, P.G. - Mr. Baehr has been a professional geologist for the Corps' Mobile District for over 17 years, specializing in groundwater resource development. He has a Bachelor of Science degree in Geology from University of South Alabama in 1975. He also has a strong geotechnical engineering background. Mr. Baehr has been an instructor on water well design and drilling in the United States as well as in El Salvador. He has designed and supervised construction of numerous wells in many parts of the world including Africa, the Middle East, the Far East, both Central and South America and the United States. Mr. Baehr also works with a team of groundwater specialists which provide water resources data and well design recommendations to the U.S. Government for all areas of the world.

DR. CLAUDIA M. ROGERS - Dr. Rogers is the social scientist for the Corps' Mobile District where she has worked for the past 10 years. For 2-1/2 of those years she served as special assistant to the Chief Executive Officer. She holds several degrees, ranging from a Bachelor of Arts in Political Science and Language from Colorado State University, 3 masters' degrees, including one in Latin American Studies, to a Doctor of Philosophy in Social Anthropology from Columbia University. In her 22 years of experience in the research and analysis of social and economic problems, she has worked and traveled in South America, the English-speaking West Indies and major metropolitan areas in the United States.

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APPENDIX O - ANNOTATED BIBLIOGRAPHY

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Grillo, Eduardo and G. Rengifo. 1990. Agriculture and Culture in the Andes. (Agricultura y Cultura en los Andes.) La Paz.
The authors contend that the restoration of native cultural and agricultural practices are basic to an alternative national development plan. To date, too much reliance has been placed on foreign technologies and practices.

de Zutter, Pierre. 1989. Myths of Rural Andean Development. (Mitos del Desarrollo Rural Andino.) La Paz.
The author advocates a conceptual reevaluation for those involved in field and extension work. He encourages increased involvement and new means of communication between field personnel and farmers. Fifty tips are provided.

Valencia Vega, Alipio. 1990. Bolivian and Latin American Integration. (Integracion Boliviana y Latinoamericana). La Paz.
This book deals with the topics of integration at the Bolivian and multi-country levels. It discusses the concept of economic integration and the issues related to it. It also details the Latin American organizations that deal with integration: ALALC (Latin American Free Trade Association); the Cartagena Agreement; the Plata Basin Pact and regional and subregional agreements.
At the Bolivian level, the organizations are described, as is the importance of national integration and development planning.

DEPARTMENT OF COCHABAMBA

CORDECO. Sept. 1988. Project: Small- Scale Irrigation (in the community of) Copa Pujllo Kankani. (Proyecto: "Micro Riegos Seccion de Copa Pujllo Kankanri.) Cochabamba, Bolivia: Planning and Projects, Regional Corporation for the Development of Cochabamba (CORDECO).
Contains some data similar to an EIS re: the community, e.g., population, crops cultivated; by project; references aerophotographs of project area. Major emphasis on soil series, 24 pp. of geomorphology. Gives water requirements for principal crops (pg 33) in cubic meters per year and per month. Computations of excavations required for hydrodraulic works. Cost estimates by project for machinery, labor, time. Benefit/cost ratio of project, incl. net and gross crop values. Financial schedule i.e., annual outlays. Appendix A gives detailed irrigation needs of several crops; B-1, water quality. Appendix C, design calculations plus canal distribution.

CORDECO. September 1988. Project: Potable Water System (in) Pocona. (Proyecto: Sistema de Aqua Potable.) Cochabamba, Bolivia: Planning and Projects of CORDECO.
Chapter I details current conditions, including demographics, population, economic activities, water usage, infrastructure, water quality and growth projections from 1988-2013, or 25-year project life.
Chapter III outlines costs and benefits of a water system for the community. Chapters II and IV are proposed project specifications, incl. distribution network.

CORDECO. April 1990. Emergency Plan to confront the Effects of the Drought in Cochabamba. (Plan de Emergencia Para Afrontar Los Danos de la Sequia en El Depto. Cochabamba.) Cochabamba, Bolivia: CORDECO, Planning and Coordination and Farming Development. Volumes I (El plan) y II (Appendices).
Vol. I precipitation data, watershed divides, climate cycles, economic base with maps of provinces affected by drought, meaning all. Specifics of agricultural areas affected by drought plus costs of project estimated at $35 million. Total plan outlined on pg 90. Schedule of installation, pg 94.
Vol. II contains 7 appendices which cover everything from description of projects and locations to meteorological data from gauges to farming production. Specifically, Appendix 1 describes rural area of the deptartment. Appendix 2 is a map. Appendix 3 is detailed description, locations, costs of proposed projects. Appendix 4 lists the public and private agencies supporting rural development. Appendix 5 gives agriculture damages by community and their province (20 pp). Appendix 6 shows precipitation data by province & village for last 15 years. Appendix 7 gives farming production.

GEOBOL. Water Well Locations in Chocabamba.

CORDECO. May 1990. Program of Well Drilling & Rehabilitation (Programa de Perforacion y Rehabilitacion de Pozos.) Cochabamba, Bolivia: CORDECO, Gerencia de Recursos Naturales y Medio Ambiente.
3 Components: I) high volume well-drilling for irrigation; II) well-drilling of low volume for human consumption; and III) cleaning & rehab. of existing wells. Each component's description includes type, # and cost of wells.

CORDECO. March 1989. Information on Exploiting Ground Water in Quillacollo-EL Paso.
General description of area. Listing of aquifers. Estimates of water volume in aquifers, available for irrigation and for reserves. Appendices give names and map of human settlements plus inventory of drilled wells, those in use, those with pumps, and those without.

Amurrio, Ing. M.C., Fidel. August 1989. Irrigation Project for Valle Alto. Brief discussion of the problems in the Valle Alto; contains a detailed cost estimate for a water resources study ($627,000 U.S.) concentrating on management, socio-economics, soils, land and cattle industry, water demand, identification of projects, available hydric resources, pre-selection of alternatives, study of subprojects and a evaluation, schedule watershed map and location map.

Author and Title Unknown. Detailed map of Cochambamba with provinces and watersheds.

MACA (Ministry of Farming and Rural Affairs). 1978. Technical Information about Irrigation Projects Constructed by the National Service of Community Development: El Salto. (Informes Tecnicos Sobre Proyectos de Riego Construidos par El S.N.D.C.)
Assessment 'y Ing. Magnus Bennedsen re: the reasons for the failure of the El Salto dam near Aiquile, Dept. of Cochabamba.

PDAR (Alternative Regional Development Program). October 1990. DRAFT Document on Erosion and Scouring in the Aiquile Area: Magnitude and Role Played in the Land Degradation. (Erosion y Escurrimiento en el Area de Aiquile: Su Magnitud y Rol en La Degradacion de las Tierras.) Cochabamba, Bolivia: PDAR
Initial results of a year-long study by Ing. Macias, Soils Engineer, & Ing. McDowell, Conservation Evaluator. They discuss land use, track rainfall, its intensity, average annual precipitation over 5 yrs & 20 yrs., degrees of soil erosion throughout agricultural sectors of the Dept. They installed 2 rain gauges & stream guage.

Clark, Howard Ph.D. Listing of Bolivian and International Agencies working in Rulal Development in Cochabamba.
Source: Unknown
Good list, incl. cross-referencing by technical specialty & geography.

DIA, PDAR, etc. 3 Aug. 1990. Preliminary Information about Agricultural Productivity in the Aiquile-Mizque Area During the Drought of the 1989-90 Agricultural Year. (Informacion Preliminar Sobre la Productividad de Campos Agricolas de Aiquile-Mizque durante La Sequia del Ano Agricola 1989-1990.)
Preliminary evaluation by project engineers, Segundo Alandio and William McDowell. Incl. 1 chart on rain-fall (pg 3).

MACA. Sept. 1987. Seminar on National Regulation of Irrigation. Held at the Hotel Prefectural in Coroico. (Seminario "Reglamento Nacional de Aguas Para Riego": Documento Final.)
3-day meeting of water experts from throughout Bolivia. Conclusions/

recommendations include strong support for the General Water Law later passed by Senate in Feb. 1988, the prioritizing of water use & urging that water & environmental laws be complementary.

Comite de Emergencia de Sequia. May 1990. Plan to meet the Effects of Drought in the Dept. of Cochabamba. Cochabamba: MACA/CORDECO/Prefectura. (Plan Para Afrontar Los Efectos de la Sequia en el Depto. de Cochabamba.)

Guide to Cochabamba (Guia Para Conocer Cochabamba). 1984. Cochabamba, Bolivia: Los Amigos del Libro.
Includes history, folklore, tourism, partial listing of major mfg. companies. Small map of the departmental capital.

GEOBOL. 1989 (?) Summary of Pre-Feasibility and Feasibility of the Kewina Khocha Project in the Tunari Mountains. (Resumen del Estudo de Prefactibididad y Factibilidad Proyecto Kewina Khocha.) Cochabamba, Bolivia: GEOBOL, Ing. Ricardo Ramirez.
History, justification, socio-economic background, design summary, estimated costs, phasing of the project. Lists kinds of data and analyses needed.

GEOBOL. January 1990. Kewina Khocha Project: Surface Water of the Tunari Mountain Range. (Proyecto Kewina Khocha. Aguas Superficiales de la Cordillera del Tunari.) Cochabamba, GEOBOL and engineers Oscar Siles and Ricardo Ramiriz.
Status report on a grandiose scheme, including project characteristics and justification + proposed funding of GEOBOL's data collection efforts at $Bs 97,850.

Romero Cruz, Roberto. Sept. 1986. "Cochabamba: A Garden City Without Water." (Cochabamba: Una Cuidad Jardin Sin Agua.") Revista de Ingenieria (vol. 6): 32-33.

Pereira Melgar, Mario. Nov. 1987. "Misicuni: Multiple-Purpose Project." ("Proyecto Multiple Misicuni".) Revista de Ingenieria (Vol. 7): 10-17.
Description of project + some hydrological data from rain gauges and flow meters.

United Nations and Servicio Geologico de Bolivia (GEBOL). 1978. Groundwater Investgations in the Cochabamba Basins. (Investigaciones de Aguas Subterraneas en las Cuencas de Cochabamba.) Technical Report 1.
The study area included the Cochabamba, Sacaba, Punta-Cliza and Santivanez basins that encompass 3,750 kms2. The project established the amount of available groundwater resources; the implementation of several well and irrigation projects. Conclusions and recommendations are presented and supported with comprehensive appendices.

SEMAPA. 1987. Final design for the use of the Chusequeri Basin Waters. (Diseno Final del Sistema de Aprovechamiento de las Aguas de Chusequeri.) The Chusequeri Project is an irrigation project for some 500 hectares. The descriptive part of the report discusses the hydrology, geology, geotechnical aspects, topography, the earthen dam and spillway and the conduits. Appendices support this information. Volume 1 of 2.

SEMAPA. 1978. Chusequeri Project Plans. (Proyecto Chusequeri - Anexos y Planos.) Cochabamba.
Volume 2 of 2. This volume contains only the engineering drawings and plans for the Chusequeri irrigation project.

DEPARTMENT OF CHUQUISACA

CORDECH. June 1990. Profile of Projected Drilling of Wells in Louis Calvo Province.
Listing of communities in priority order, costs for drilling of wells in Louis Calvo Province (Subregion V in Chuquisaca Department); map showing location of water wells drilled and to be drilled in Chuquisaca area; hydraulics study of Louis Calvo Province; detailed hydraulic information on the wells with listing; historical weather information on precipitation, temperature, humidity, etc.; detailed boring log on six wells.

CORDECH. 1990 (est.) Profile of Projected Drilling of Wells in Chaco-Chuquisaca Area.
Listing of communities, in priority order, where wells are to be drilled with estimated cost; listing of existing water wells with detailed data on well characteristics in Chaco Chuquisaqueiro; hydraulics study (detailed) of Chaco de Chuquisaca; climate conditions for area - precipitation, temperature, humidity, etc.; drilling log on four holes; map of province with the location of drilled wells and those to be drilled.

Subregional Development Plan - Central Chuquisaca. August 1989. Program Profiles: A. Irrigation and Small Irrigation (Riego y Microriego). B. Recouping Lands and/or Defensive Construction (Recuperacion de Tierras y/o Construccion de Defensivos). Provincias: Tomina; B. Boeto; Azurduy. Sucre: CORDECH - Emergency Drought Plan.
15-year rehabilitation plan to benefit 3,320 families in a 4,000 hectare area scattered among 53 zones. Includes 6 large-scale maps identifying feasible zones for small irrigation & recouping lands.

CORDECH. 1990. Project Profiles for Subregion V: Luis Calvo Province (Chaco). Sucre: Corporacion Regional de Desarollo de Chuquisaca.
Lists 5 proposed projects in the Chaco province of Luis Calvo: a) Water supply for human & animal use; b) Gravity-fed Potable Water for Nancorainza, El Parvenir and El Salvador; c) Well-drilling; d) Construction of Atajados (Excavated Water Storage Ponds); and e) Social Infrastructure.
Under each proposal are estimates of amount of surface & ground water, costs, water produced + short- & medium-term recommendations.

CORDECH. 1990. Project Profile - Drilling of wells in the Chaco Chuquisaqueno. (Perfil de Proyecto - Perforacion de Pozos en el Chaco Chuquisaqueno.) Chuquisaca.
Water supply in the Chaco zone is a problem. This project, in Luis Calvo Province, consists of drilling 10 wells/year at a depth of 500 meters in the mountainous zone and 250 meters in the prairie regions. This project should be completed in five years.

Golani, Uri. 1990. Water Resources in the Chaco Chuquisaqueno and Their Development. (La Situacion de los Recursos Hidricos del Chaco Chuquisaqueno y su Desarrollo.) New York, New York: United Nations, Department of Technical Assistance.
After spending 10 days working with CORDECH, he concluded that five of CORDECH's water projects required profile changes and that the Chaco Chuquisaqueno's problems be resolved in conjunction with those of the Santa Cruz and Tarija Chacos.

DEPARTMENT OF TARIJA

Villena G., Ing. Hernan. Date? Investigation of Aquifers in the Tarija and Chuquisaca Chaco. (Investigation de Aquas Subterraneas en el Chaco Tarijeno y Chuquisaca.) La Paz: Comando General de Ejercito.
Identifies areas with potential to tap aquifers, by states of Tarija and Chuquisaca. Each area is detailed. Map showing areas selected for drilling in Tarija. General hydrology of Chuquisaca including infiltration, existing wells and sites of potential wells. Monthly rainfall data at 4 stations and hydrologic charts at same 4 stations. Geologic maps of each station, scale 1:50,000. Geography unknown. Soils logs. Hydrologic maps (2), 1:50,000 of Chuquisaca part of Chaco, with locations of gauge stations and existing wells.

Iturricha, Ing Edgar, Zubiaure, Oscar, Quiroza, Juan Julio and 8 additional committees. April 1990. Evaluation of the Drought Damages, Chaco Province of Tarija.
In each community evaluated, from 30 to 40 percent of manioc and corn crops suffered significant damages during 1989-90 agricultural year.

GEOBOL. November 1983. Vertical Electrical Soundings in the Villa Montes and Chaco Seco Zone. La Paz: GEOBOL.
2 page description of the 45 electrical soundings taken: descriptions, locations, graphic illustrations of results of soundings. Geoelectrical logs.

Tesoro Bolivia Petroleum Company. April 1985. Water Wells Dug by Tesoro in the Gran Chaco Province of Tarija. (Pozos de agua perforados por Tesoro en la provincia Gran Chaco del depto Tarija.)
22 wells dug. Description of each. Production ranges from 1800 to 10,000 ltrs/hr. Complete logs for 4 wells. Maps showing locations of wells. Drilling and lithology profiles of 6 wells.

GEOBOL. November 1983. Vertical Electrical Soundings, Yacuiba Region. (Sonidos Electricos Verticales.) La Paz: GEOBOL.
Soundings in 2 towns, with maps, descriptions and graphic presentations of each.

CODETAR. March 1990. Using Ground Water in the Chaco Tarijeno. (Aprovechar La Agua Subterranea en El Chaco Tarijeno.) Tarija: Gerencia de Desarrollo Agropecuario.
General description of area + listing and maps of 60 exploration wells and materials and costs.

CODETAR. 1990. Erosion Control: Work to be conducted in Tarija in Cooperation with the MilGroup of the United States. (Control de la Erosion: Trabajos a Ejecutarse en el Valle de Tarija con la Cooperacion del Grupo Militar de los EE. UU. de Norte America.) Ing. Forestal Jaime Mendoza Nogales and Ing. Agvonamo Samuel Quiroga. Tarija: Gerencia Agropecuaria.
Two sub-basins were selected for work: El Monte-San Pedro and El Molina. Erosion in the Tarija valley is increasing at a rate of 827 hectares/year. A $2.2 million budget was prepared to rehabilitate the two sub-basins. Activities include small dams, erosion control, wells, terracing.

CODETAR. 1986. Prefeasibility Study for Tomayapo Irrigation Project (Proyecto de Riego Tomayapo - Prefactibilidad-Resumen.)
This project entails the construction of a reservior on the Tomayapo River and distribution canals along both sides, thus benefiting some 400 hectares of high agricultural productivity. Cost is estimated at $1.8 million. The feasibility study should also consider hydroelectric and water supply purposes for the reservoir.

Japan International Cooperation Agency (JICA). 1990. The Feasibility Study on Agricultural and Rural Development Project in Santa Ana, Tarija - ANNEX
A comprehensive appendix (annex) accompanies the Santa Ana irrigation project feasibility study and comprehensive plan. Data include socio-economics, metereology and hydrology, geology and groundwater, soil and land use, agriculture, irrigation and drainage; infrastructure, cost estimate, topographic surveys, proposed facilities and drawings.

CODETAR. 1981. Resource Inventory of Tarija: Areas to be Incorporated by SENARB (Diagnostico de Departmento de Tarija: Areas a Ser Incorporadas por el SENARB.)
This comprehensive resource inventory covers the following elements: general background, historical growth, socio-economic features, human resources, education, health, housing, roads and highways, air transport, rail transport, communications, manufacturing, agriculture, and animal diseases.

Japan International Cooperation Agency (JICA). 1990. The Feasibility Study on Agricultural and Rural Development Project in Santa Ana - FINAL REPORT.
The Bolivian government obtained JICA's assistance to conduct a feasibility study and development plan for the irrigation of some 1,000 hectares in the Santa Ana area of Tarija. Ten alternative plans (cases) were studied and the most technically and economically viable plan was selected. The project cost for the selected plan, Case 4, was $15.2 million.

CODETAR. 1990. Agricultural Development Project in the Upper Guadalquivir Basin. (Proyecto de Desarrollo Agropecuario en la Cuenca Alta del Guadalquivir.)
The project entails two dams and a canal network that would provide 3,200 hectares with a reliable source of water. It will be located in Mendez y Cercado province and is scheduled for completion in December 1990. Agricultural productivity will increase by approximately 130 percent.

PERTT. 1990. Reforestation and Erosion Control in the Tolomosa River Basin. (Proyecto de Reforestacion y Control de la Erosion en la Cuenca del Rio Tolomosa.)
PERTT, the executive program for land rehabilitation in Tarija. During this first phase of the project only conservation work has been programmed. The measures include planting grass, bushes and multiple-use trees, fencing, crevasse-control and earthen dam construction in critical areas.

CODETAR. 1981 through 1989. Median Temperature Readings. Tarija: Direccion de Cuencas Hidrograficas.
Monthly readings for 1981-1989 are given for the following stations in Tarija: La Vertiente, Pajonal, Palmar Grande, Villa Montes, and Yacuiba.

CODETAR. 1951 to 1990. Miscellaneous Precipitation Data. Tarija: Direccion de Cuencas Hidrograficas.
Monthly rainfall data, some dating back to the 1970s, are provided for various stations in Tarija: Aguayrenda, Palos Blancos, Narraez, Ibibobo, Itau, Capirenda, Timboy, La Vertiente, Palmar Chico, Esmeralda.

CODETAR. 1946 to 1990. Climatic Data Collected at Tarija Airport. Tarija: Gerencia de Cuencas Hidrograficas
Precipitation, median temperature, maximum temperature, minimum temperature, relative humidity, wind direction/speed.
Extensive tables providing monthly information for the above climatic features.

CODETAR. (no date). Hydrometereologic Stations in Tarija (existing, projected and summary). (Hidrometereologicas en Operacion, Proyectadas e Hidrometricas.)

CODETAR. 1981-1990. Gage Summaries for Aguayrenda and Entre Rios. (Resumen de Aforos.) Tarija: Direccion de Cuencas Hidrograficas.
The Aguayrenda gage readings date back to 1981. Flow, velocity and elevation data are included in the table, by date of reading. Similar information for 1989 is given for Entre Rios.

CODETAR. 1986. Pajonal Project. Tarija: Direccion de Cuencas Hidrograficas.
The Pajonal Project involves constructing a dam and irrigation canals with an estimated budget of $3,076,000. The first phase will affect 1400 acres, but consideration should be given to expanding the project to include hydroelectric and water supply uses for the community of Entre Rios.

CODETAR. 1990. Aguayrenda Project, Socio-Economic Study. (Proyecto Aguayrenda - Estudio Socio Economico.) Two Parts. Tarija: Direccion de Cuencas Hidrograficas & Gerencia Agropecuaria.
There is a shortage of potable water in the community of Aguayrenda, population 30,000. Socio-economic information was prepared in support of demand statistics. Also, the following is included in the report: hydrologic resources, alternatives, regulatory aspects, preliminary design, costs and conclusions and recommendations.

CODETAR. 1986. Final report of the Preliminary Hydroligic and Geologic Study - Valley of Yacuiba - El Palmar. (Informe Final de Estudio Hidrologic e Hidrogeoloic Preliminar, Valle de Yacubia - El Palmar.)
Analysis of drainage and sewage problems in the Yacuiba - El Palmar area. The hydrologist and geologist considered topographic drainage plans, geologic and geomorpholic features, aerial photography, hydrometereology, etc.

Instituto Nacional de Estadistica. 1988. Population and Housing Data for Tarija. (Informacion de Poblacion y Vivienda, Departamento de Tarija.)
Data from the national population and housing survey conducted in 1988 are presented for Tarija and each of its seven zones.

CODETAR and the Japanese International Cooperation Agency (JICA). 1990. Feasibility Study for a Rural and Agricultural Development Project in Santa Ana: Irrigation Infrastructure. (Estudio de Factibilidad Proyecto de Desarrollo Agricola y Rural en Santa Ana - Componente: Infraestructura de Riego.) Tarija.
Report summarizes the findings of a JICA study team asked by the Bolivian government to conduct a demonstration feasibility study in Santa Ana, involving plans to irrigate 1,000 hectares within four years.

CODETAR. 1978-1989. Isohyetal Lines, Central Valley of Tarija. (Isoyetas-Periodo 1978-89-Valle Central de Tarija.)
Two copies of rainfall (isohyetal) lines overlaid on a map of the central Tarija Valley.

CODETAR. 1989. Annual Report, Multipurpose Project - Gran Chaco. (Proyecto Multiproposito Gran Chaco.)
USAID and Bolivia are cooperating in agricultural development to 1) increase seed production; 2) give credit to small farms; and 3) assist 5,000 farmers.

CODETAR. 1990. Feasibility of Aguayrenda Multi-Purpose Project (Proyecto Multiple-Aguayrenda).
CODETAR conducted this study to identify areasures that would provide potable water to Yacuiba, El Palmar y Campo Pajoso. A preliminary design for a reservoir project at Aguayrenda was prepared. The dam's cost is approximately $1.8 million while the means of transporting the water will cost $2.3 million.

CODETAR. 1984. Final Report - geologic and geotechnical study for the Aguayrenda Dam - conclusions (Informe final - estudio geologico - geotechico para presa zona Aguayrenda - conclusiones.) Tarija.
Geologic and geotechnical data and conclusions are presented in anticipation of a dam-reservoir project in the Aguayrenda vicinity. Geomorphological, stratigraphic and structural geology issues are investigated as are soil mechanics, rock mechanics and borrow areas.

CODETAR. 1989. Expansion of the Gran Chaco Multipurpose Project (Ampliacion proyecto multiproposito Gran Chaco.) Tarija.
CODETAR prepared this document to seek financing for an agricultural development project. It entails the purchase of agricultural and heavy machinery that will be used in the production of vegetable oils and cattle growing. Annual costs for the five-year project approximate $2.0 million and range from $700,000 in year 1 to $2.5 million for year 2.

DEPARTMENT OF ORURO

Fernandez Castro, Ing. Alvaro. December 1970. Geologic Study of the Oruro-Paria-Soledad Region (Estudio Geologicio de la Region Oruro-Paria-Soledad.) La Paz, Bolivia:
Geography; Climate; Geomorphology; Geologic Formations; Petrographics; Groundwater; Maps -Geologic of Oruro, Cross-section, Petrographic Patterns.

CORDEOR. April 1990. Emergency Plan and Prevention of Droughts. (Programa de Emergencia y Prevencion Contra La Sequia.)
Covers agricultural Year 1989-90; charts with crop types, hectares planted by province, effects of drought on plantings and cattle, 16 page detailed description. Recommends types of pumps, filtering systems, etc., number, short to immediate needs and projected costs by province. Appendices: App 2, drawings of proposed projects, including filters, holding tanks, channels. App 3, number of wells needed, materials available, cost estimates for construction. App. 4, profiles of projects by province, including inter-institutional cooperation, coordination + 8-page description of drought. App 1, detailed agricultural damages. Map shows drilled wells and watersheds and sub-watersheds.

CORDEOR. 1986. Hydrologic Study. Estimation of Remaining Flows in the Watersheds (Estudio Hidrologico. Estimacion de las Aportaciones en Cuencas.) By watershed, contains tables with amount of rainfall, runoff (escurrimiento), remaining flow (aportacientes), and contributed flow by one rain gauge station per watershed by monthly averages; maps of each of watersheds; similar data for all watersheds (cuencas). Discusses methodology for estimating remaining flows of watersheds. Recommends additional, more detailed technical studies.

CORDEOR. 1980. Boring Log & Location Map of 3 Holes in the city of Oruro.

CORDEOR. April 1990. Emergency Program for Prevention Against the Drought (with 2 maps).
Brief watershed description; hydrology in Cercado Province; location of wells in Cola-Coja; watershed map with well locations in Caracollo-Oruou-Vinto.

USAID/CORDEOR. March 1990. Water Supply in the Rural Area of Oruro. (Abasta-cimiento de Aqua al Area Rural de Oruro.) Oruro, Bolivia.
Eight page discussion of physical characteristics and agricultural practices. Detailed damage information per crop per province for both the 1988/89 and 1989/90 droughts; damages to cattle and other farm animals due to the two droughts; listing of wells required for short and medium term, by province, and by type of pump and well; people benefited, acres irrigated; actions required immediately in each province with cost estimate; pumps, tanks, etc. required to make immediate measures work; detailed costs of immediate actions; detailed schedule (early, immediate, measures June '90-Dec '93); same type of information for intermediate stage--personnel, cost, equipment and schedule by province; cost sharing for $4.5 million U.S. required. Watershed and province maps; drawings of wells, tanks, canals, and pumps; electric transmission lines for Oruro area.

DEPARTMENT OF LA PAZ

CORDEPAZ. 26-31 March 1990. General Evaluation Chart. (Cuadro General de Evaluacion.) La Paz: CORDEPAZ
Charts of communities in each province showing number of families, sowing dates, crops cultivated, livestock by type and number of head, losses and $(U.S.) amounts.

CORDEPAZ. Physical Description. (Resumen del Complejo de Tierras.) La Paz: GEOBOL.
General descriptions of geology, climate, hydrology, vegetation and land use in 3 provinces: Ayo Ayo, Viscachani, Umala.

Dobrovolny, Ernest. Ministry of Mines and Petroleum, 1962. Geology of the Valley of La Paz. (Geologia del Valle de La Paz.) La Paz.
6 Maps in Spanish and English from National Department of Geology: Geological; Groundwater conditions; geologic time zones; and composite map including recommended water projects; downtown La Paz, i.e., Parque Central, Santa Barbara. Book contains general geologic featurs of La Paz.

GEOBOL. 1984. Hydrographic data from 4 stations in La Paz Department. Extract from unknown report. Agricultural cultivation by crop and province, by agricultural year 1989-90.

_________(est.) 1990. Excerpt: Plan of Action on Bolivian Altiplano: Oruro; Potosi; La Paz. European Economic Community sponsored with Bolivian Government.
Describes the PAC (Program of Campesino Self Development) which is a joint effort of the European Economic Community and Bolivian Government. 95% of report deals with La Paz Dept. and covers rain guage stations, socio-economic damages, proposed solutions re: water supply and strengthening agricultural sector.

GEOBOL. 1961. Geological Map of Bolivia

Tables of Population. Author and Title Unknown. Population density information on provinces in Department of La Paz.

CORDEPAZ. September 1990. Integrated Control and Management of the La Paz River Basin. (Control/Manejo Integral de la Cuenca Del Rio de La Paz.) La Paz: CORDEPAZ Dept. of Water Resources.
Special emphasis on middle and lower parts of the basin + their problems of: soil erosion, flooding, contamination of water & agricul'l soils, health, increased urbanization, basic services such as roads, potable water, electricity.
Project consists of 3, labor-intensive phases: 1) data gathering & analysis, 2) formulation of development strategies + specific projects, 3) project implementation.
Costs are for personnel & equipment w/external funding of the major part of total.

CORDEPAZ. 1990. Snow-melt Project for Murillo Province: Drinking and Irrigation Water. (Perfil de Proyecto: Riego y Aqua. Provincia: Murillo.) Authored by Ing. Wilma Montesinos. Project description, incl. the kinds of data on hand -(few) - + the climatic & hydrological info. needed, analysis of supply & demand of potable & irrigation water, feasibility & final design. No construction for an estimated cost of $30 million.
This would alleviate or eliminate all water problems in middle & lower basins of the La Paz Dept. & curb use of contaminated water in food for city of La Paz.

CORDEPAZ. 1990. Profile of Small Irrigation Program for the Dept. of La Paz. (Perfil de Programa de Micro Riego Para El Depto. de La Paz.) La Paz: CORDEPAZ.
Extensive & costly proposal to irrigate all the small villages in 3 provinces of the Dept. encompassing some 2,340 families or about 11,700 people (5 person/family). Proposed project consists of: 40 small irrigation systems containing 80 different works bringing 1,872 hectares under irrigation and using 40 demonstration centers to transfer new ideas/technology re: soil & water conservation + 80 km of new roads constructed + classes in marketing. Initial Cost: $ U.S. 1,641,685.26

DEPARTMENT OF SANTA CRUZ

CORDECRUZ. 1990. Document on the Drought. (Documento Sobre La Sequia.) Santa Cruz: Department of Area Studies and Programs, CORDECRUZ.
Damage to crops, cattle, families in 5 provinces. Recommends a committee to study further. Detailed charts of each province with zones and/or communities and areas planted, lost and kinds of crops grown and lost. Maps of each province.

Kleeberg, Hans B. and Halvor Overland, 1985. Hydrological Problems of the Rio Piray/Bolivia. Federal Republic of Germany.
Flood Report of 3/83 of Rio Piray in and near city of Santa Cruz.

CORDECRUZ. April 1990. Emergency Plan for the Province of Cordillera. Santa Cruz, Bolivia. (Index).
Unknown Author & Title. Appendix (Annex) to Santa Cruz Report.
Map of Provinces in Santa Cruz and map showing location of drilled wells; graphs of normal rainfall for selected provinces and isopithal line map for all of Santa Cruz.

SEARPI. May 1990. Educational and Motivational Series of Booklets & Posters re: Conservation and Flood Control of Pirai River. Santa Cruz: Servico Encauzamiento-de Aguas y Regularizacion del Rio Pirai & Mision Tecnica Alemana. 2 sets of : 3 booklets, 3 large & 7 medium posters.

CORDECRUZ. September 1990. Rural Development Program (in the province of) Cordillera. (Programa de Desarollo Rural Cordillera.) Santa Cruz: CORDECRUZ and CCPL-Consorzio Cooperativo di Produzione e Lavoro (Italy).
Good overview of social, economic & physical characteristics of Santa Cruz Dept. Description of multi-purpose project which includes plans for roads, small irrigation, increased productivity, manufacturing of jojoba oil + bldg of small water holding ponds. Also includes teaching, organizing campesinos re: production, marketing.
Costs = $18,708,000 ECU
13,085,000 ECU = loan
5,623,000 ECU = investment

CORDECRUZ. July 1990. Highway Project: Santa Cruz-Abapo. Santa Cruz de la Sierra: CORDECRUZ.
A quarterly status report on a section of the highway which eventually will run from Santa Cruz to Yacuiba. CORDECRUZ is handling the administration of this joint Israel/Bolivia funded work. Project is divided into 2 phases with 2 sets of contractors. Total cost estimated at $ U.S. 44.8 million over a 4-year period, beginning July 1989, to complete 128 kms.

CORDECRUZ. 1990. The Image of CORDECRUZ. (Imagen de CORDECRUZ.) Santa Cruz: Dept. of Social Communication.
Glossy publication with useful pieces of information, in particular the history & current priorities of the Dept., sources of funding of CORDECRUZ. Lists each division of the corporation, explaining its accomplishments (includes SEARPI). Good charts of rural & water projects throughout the 15 provinces.
Multi-page explanation of history, economy and population shifts in Santa Cruz.

CORDECRUZ. 1990. Division of Rural and Farming Programs. (Unidad de Programas Rurales y Agropecuarios.) UPRA. Santa Cruz. (2 copies)
Lists each different department w/in this division of CORDECRUZ & all the projects w/costs, # of people benefitting, often the # of population in a given province, funding sources, crops & animals raised. Also mentions briefly the 3-department cooperative effort to help cattle ranches in Chaco, i. e., Santa Cruz, Tarija and Chuquisaca.

CORDECRUZ. May 1990. Feasibility Study: Irrigation Project for Comarapa Saipina/San Rafael. (Estudio de Factibilidad: Proyecto de Riego Comarapa - Saipina-San Rafael.) Santa Cruz: Consorcio Comarapa. Executive Volume. Joint multi-phased project w/Germans. Report has useful information, including flow and runoff (pg 5) for Comarapa River, water demands for agriculture, the proposed irrigation system & its efficiency (pg 17), relationship of this project to regional development.
10-page description of the project + costs + # of potential users of the system.

CORDECRUZ. 1990. Executive summary, Design of a Potable Water System - Mora/Zanja Honda. (Resumen Ejecutiva-Deseno del sistema de Agua Potable.) Santa Cruz, Bolivia: Empresa Consultora E.T.I.A.
The consultants prepared a four-volume report for CORDECRUZ in which they design a potable water system for Mora-Zanja Honda. The project is to be ultimately financed by the IADB. Volume 1 is an executive summary of this multi-volume report.

CORDECRUZ. 1990. Document about the drought. (Documento sobre la Sequia.) Santa Cruz, Bolivia.
The 20+ page report attempts to identify the nature, magnitude and extent of damages associated with the 1989 drought. This information will serve then to prepare short, medium and long-term action plans.

PRODEVA-IP/GT2. 1990. Report on Drought Effects in the Valle del Trigal. (Informe Sobre Diagnosticidad la Sequia en la Zona Valle del Trigal.) Vallegrande, Bolivia.
One of the most limiting factors for agricultural and cattle production in the Vallegrande micro-region is drought. This report notes that the 1989-90 summer crop was severly compromised and total losses will be high.

PRODEVA-IP/GT2. 1990. Emergency Project for the Distribution of Seeds to Small Farmers Affected by the 1989/90 Drought. (Proyecto de Emergencia por Sequia de Apoyo con Semillas Para Pequenas Productores Damnificados en la Gestion 1989/90.) Vallegrande, Bolivia.
After PRODEVA ascertained the gravity of the drought problem in the region, an emergency project to distribute seeds to small farmers was approved.
This report details the objectives, beneficiaries, project administration, distribution mechanisms, supervision and control and financing.

CORDECRUZ. 1989. Internal Communication, from Ing. Ramon Roca Roca to Ing. Jorge Robledo A. (Communicacion Interna.) Santa Cruz, Bolivia.
This internal memorandum transmits three reports prepared by Roca, Chief of the [illegible] Project, to Robledo, Chief of Engineering. The reports deal with emergency plans to confront the drought problems in Cordillera province.

CORDECRUZ. 1989. Irrigation Project-Mairana. (Proyecto de Riego-Maira..a.) Santa Cruz de la Sierra, Bolivia.
This profile discusses the institutional, social, demographic and agricultural aspects of an irrigation project in Mairana, province of Florida. Project's objective is to provide irrigation for 1500-1800 hectares in the Valle del Rio Mairana, which now depends entirely on rain water.

CORGEPAI. 1990. Research Studies for Production and Development. (Estudios de Investigacion Produccion y Desarrollo.) Estacion Experimental "Cml. Armando Gomez Z" Corporacion Gestora del Projecto ABAPO-IZOZOG "CORGEPAI". ABAPO-IZOZOG is a project associated with the Ministry of National Defense and takes place in the Chaco Norte. The objectives are to determine the agricultural potential of the region; conduct socio-economic studies with an eye to relocations in this zone; prepare a development model with concrete proposals.

CORDECRUZ. 1990. Executive Summary. Project Parabano, Agua Mora-Zaja Honda System (Resumen Ejecutiva Proyecto Parabano. Sistema de Agua Mora-Zanja Honda). Dr. Angel Equez Castedo, Santa Cruz, Bolivia.
This executive summary discusses Dr. Equez' proposal to bring water to 40 farming communities located along the Santa Cruz-Yacuiba railroad line.

CORDECRUZ. 1990. Cattle Development Project in the Bolivian Chaco. (Proyecto de Desarrollo Ganadero del Chaco Boliviano.) Santa Cruz: Chuquisaca, Santa Cruz & Tarija Development Corporations.
This is the first of four volumes of a proposal submitted to the OAS to promote cattle development in the Bolivian Chaco region. The project has as its goal to involve 3,000 producers by the time of its completion in 5 years.

CORDECRUZ. 1990. Interinstitutional Cooperation Agreement. (Convenio de Cooperacion Interinstitucional.) Santa Cruz.
This is a draft agreement between the National Metereological and Hydrological Service (SENAMHI) and the Regional Development Corporation of Santa Cruz (CORDECRUZ). Short, medium and long-term objectives are presented along with the obligations of both parties to carry out the agreement.
The agreement is for work with hydro-metereologic stations in Santa Cruz.

DEPARTMENT OF POTOSI

CORDEPO, 1990 (?). Drought Relief Plan. Potosi, Bolivia.
Gives location of drought affected areas, number of people and population density. 2 pages on geomorphology and other general characteristics; description of measures needed within provinces to prevent drought, percent damages, detailed cost estimates and map of problem areas.
Map - Regional map of Cadetac-Yaouba area.

AAPOS - Potosi July 1990. Technical Report. Semester Primer. (Informe Tecnico. Primer Semestre). Potosi: Administracion Autonoma Para Obras Sanitarias.

CORDEPO. 1990 Project Profile. Areas Affected by Drought (in the) Provinces of: Nor Lipez, E. Baldivieso and Daniel Campos. (Perfil de Proyecto. Areas Afectadas por la Sequia, Provincias: Nor Lipez, E. Baldivieso y Daniel Campos.) Potosi: CORDEPO.

CORDEPO 1990. Farming/Forest Development in Areas Affected by the Drought in order to Increase Production. (Perfil de Proyecto. Desarrollo Agropecu-Ario Forestal en Areas Afectadas por la Sequia.) Potosi: Project Profile.

OTHER REFERENCES CONSULTED:

Agricultural Outlook. October 1989. "Triticale: Has Its Time Finally Come?" Volume AO-157.

Wright, James D. and Peter H. Rossi (eds.) 1981. Social Science and Natural Hazards. Cambridge, Massachusetts: Abt Books.
Proceedings of a conference held in May 1979 in Washington, D. C. which 40 scholars & government officials attended. Sponsored by the University of Mass. at Amherst. Social and Demographic Research Institute (SADRI).

World Bank. March 1976. Village Water Supply. A World Bank Paper. New York: New York.
Focus on water supply for domestic use, not irrigation, in rural areas, especially communities of 300 to 10,000 residents. Lists common problems to supplying water to rural dwellers, discusses technical aspects and costs sans need of B/C ratio 1 or greater. Paper is based on a 1970 World Health Organization survey + additional research by World Bank, Interamerican Development Bank and Ad Hoc Group on Rural Potable Water.

World Resources Institute. 1990. World Resources 1990-91. Latin America: Resource and Environment Overview (pages 33-48). New York, New York: Oxford University Press.

de Soto, Hernando. 1989. The Other Path: The Invisible Revolution in the Third World. New York.
The author describes the informal economy in developing countries such as his native Peru, as being the public's response to the state's inability to satisfy the public's basic needs. The formal system is not available to the general public and thus have had to resort to "their will, their imigination and their desire to work." The Institute for Liberty and Democracy studied the business, manufacture, housing and transportation areas.

Tourbier, J. Toby and R. Westmacott. 1981. A Handbood of Measures to Protect Water Resources in Land Development. Washington, D. C.: Urban Institute.
This report consists of a description of measures that can be integrated into urban development to prevent, reduce or ameliorate potential problems which could otherwise affect water resources. The problems consist of runoff, erosion and sedimentation, flooding, runoff pollution and sewage effluent.

APPENDIX P

PHOTOGRAPHS

Photo 1. 19th Century Suspension Bridge Over the Rio Pilcomayo

Photo 2. Typical Wadi Dam Site in Alluvial Valley

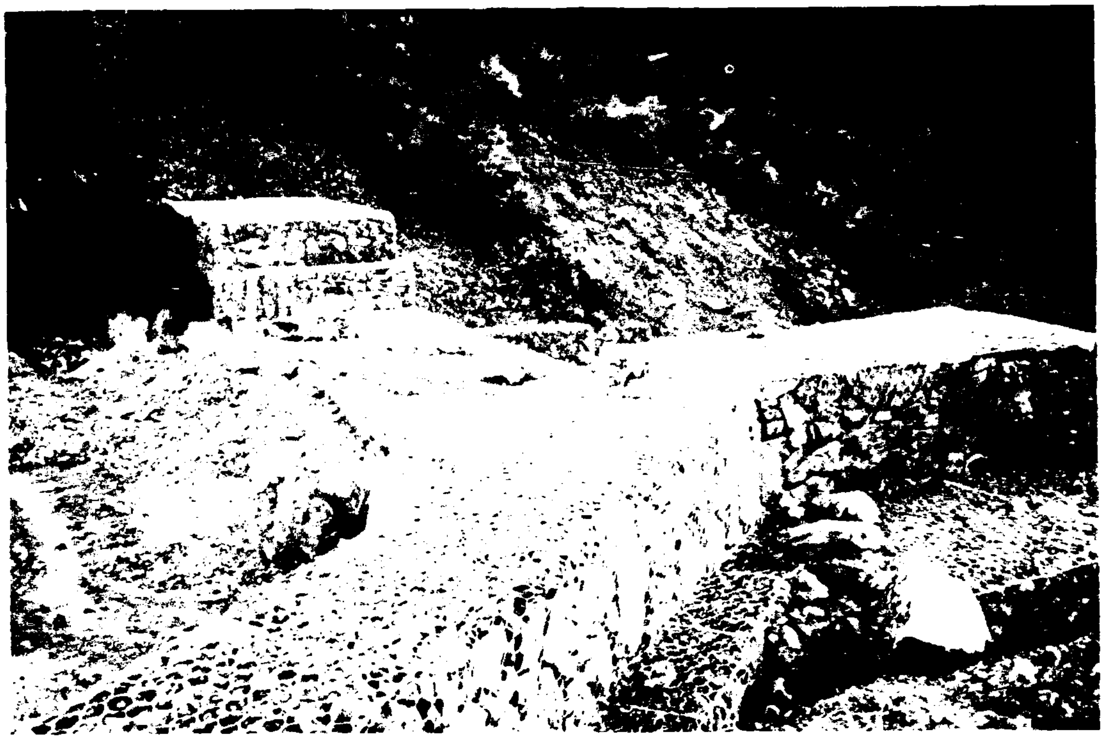

Photo 3. Typical Gabion Grade Control Sediment Retention Structure

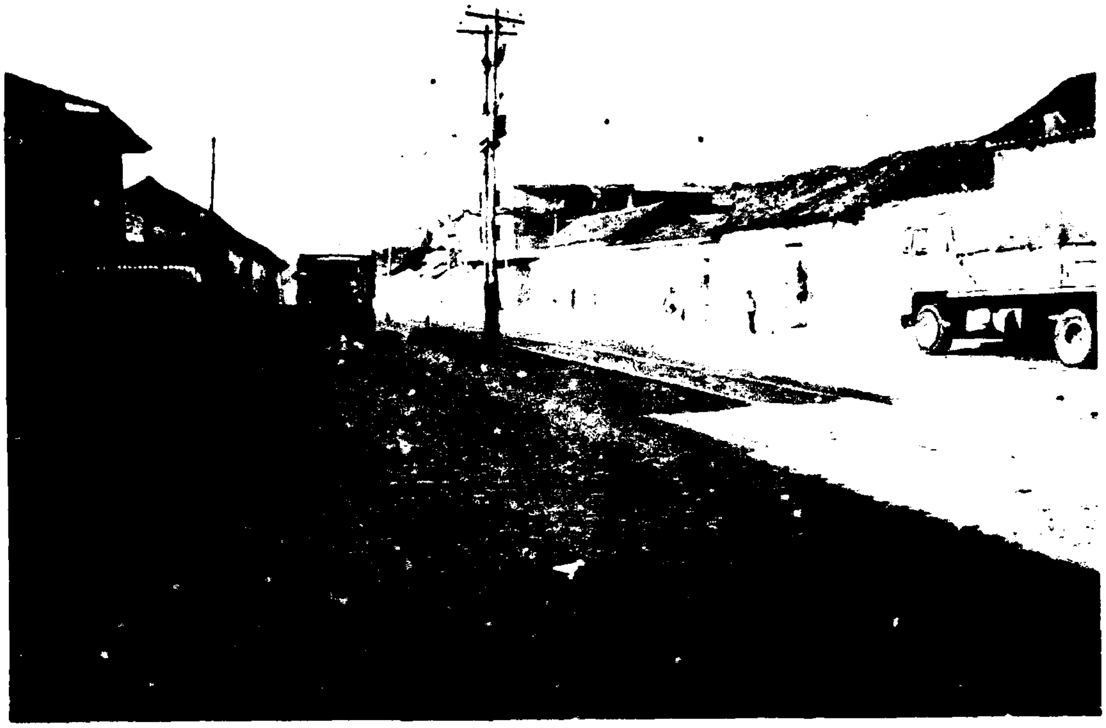

Photo 4. Early Morning on Main Street in the Rural Town of Aiquile - Pop. 5,000

Photo 5. Punata Tiraque Irrigation Project Showing a Lake and Distribution Channel

Photo 6. Punata Tiraque Irrigation Project Showing Irrigation System Channels

Photo 7. Flow Diversion Structure for Irrigation of Farms Near Aiquile

Photo 8. El Salto Dam Failure - Note Rock Outcrops in Earth Fill

Photo 9. Nearly Empty Water Supply Dam Above City of Potosi - Elev. 4,500 meters

Photo 10. Reforestation Project Above the City of Potosi - Elev. 4,200 meters

Photo 11. Tarija Valley - Note Failure of Natural Dam at Scar on Hillside

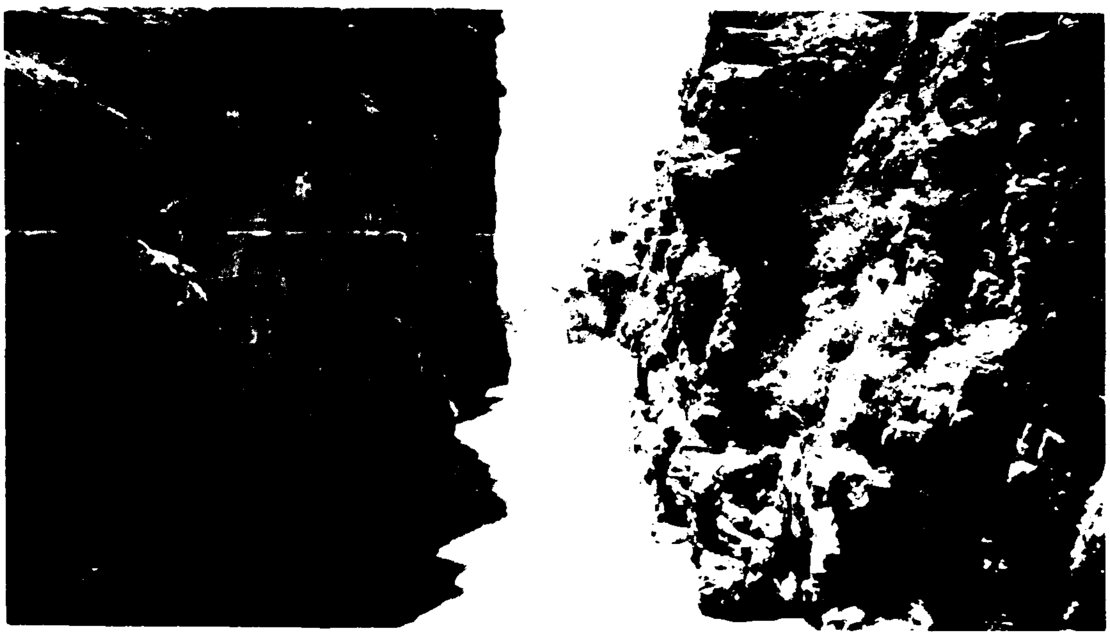

Photo 12. Location of Failure Which Drained Tarija Valley Lake - Prehistoric Event

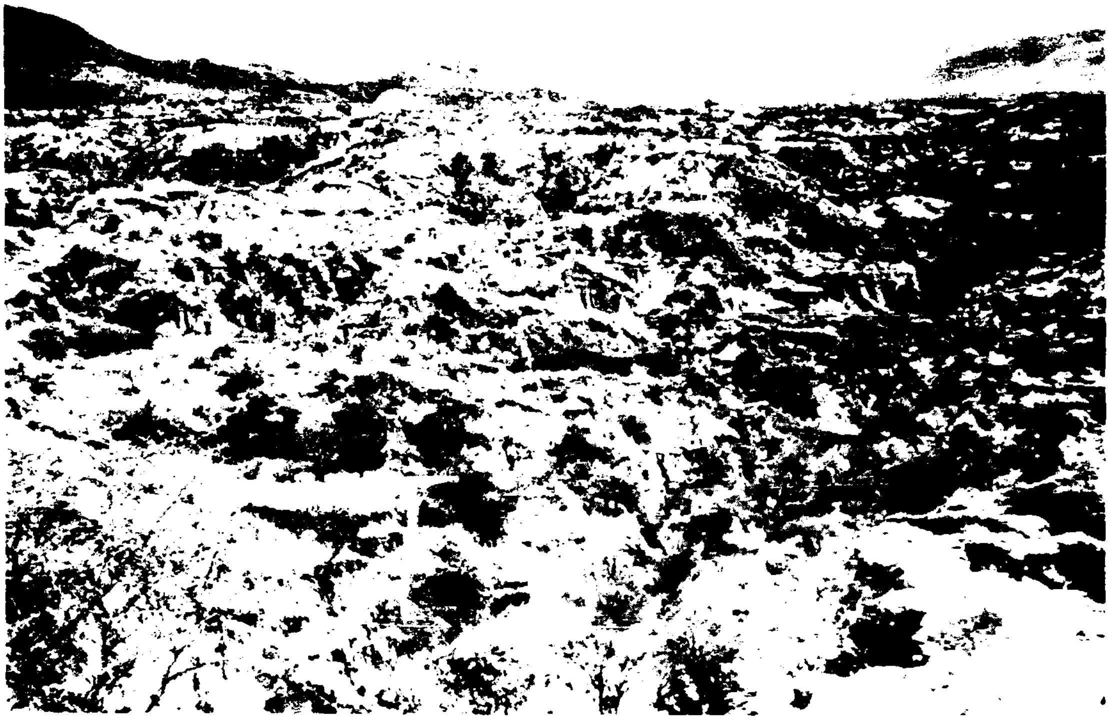
Photo 13. Erosion Damage Near the City of Tarija


Photo 14. Watershed Erosion Control Dam Under Construction Near City of Tarija

Photo 15. Erosion Control Dam Being Filled - Note Flow Entering from Right Tarija

Photo 16. Tarija Airport Erosion - Flow is Toward Runway in Background

Photo 17. Tarija Airport - Erosion Caverns Downstream from the Runway in Background

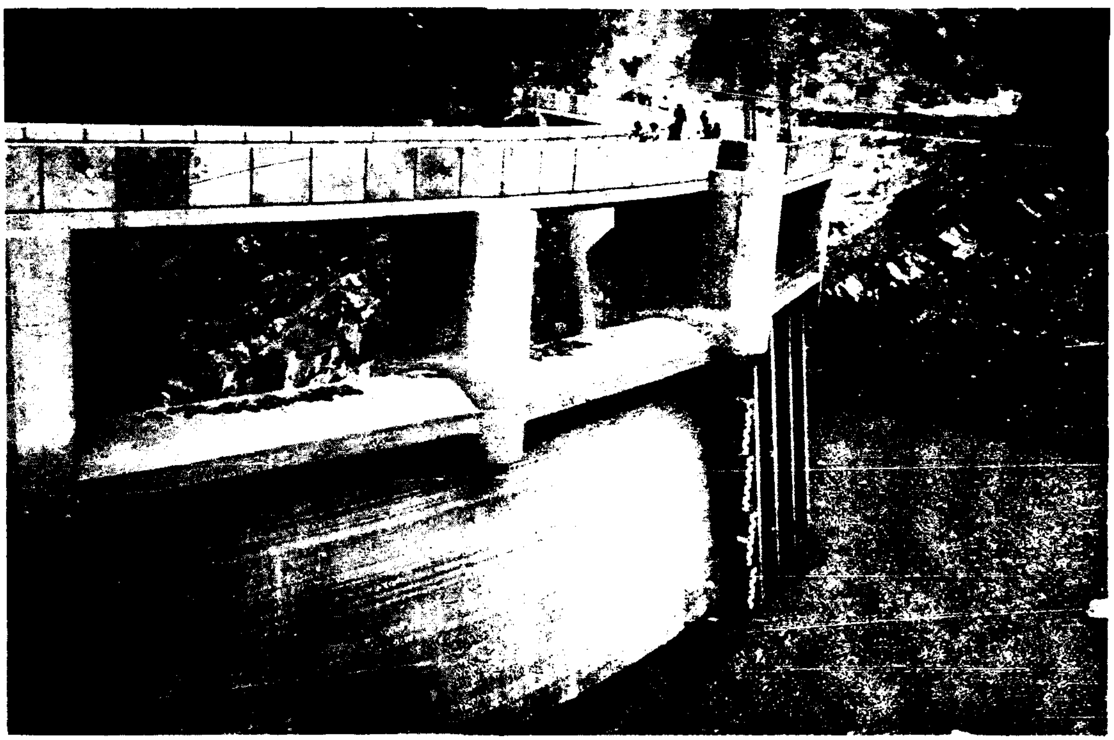

Photo 18. San Jacinto Dam - Note Very Low Water Level Below Normal Crest Elevation

Photo 19. Typical Campesino Farm Near Town of Entre Rios, Department of Tarija

Photo 20. Experimental Soil Conservation Farm Project Near Town of Entre Rios

Photo 21. Water Intake Esquema Irrigation Project - Rio Pilcomayo Near Villa Montes

Photo 22. Drip Irrigation of Vineyards in San Juan Valley Near City of Tarija

Photo 23. Stream Gage Near Location of Aguayrenda Dam - Department of Tarija

Photo 24. Flood Control Levee Under Construction on Rio Piray - City of Santa Cruz

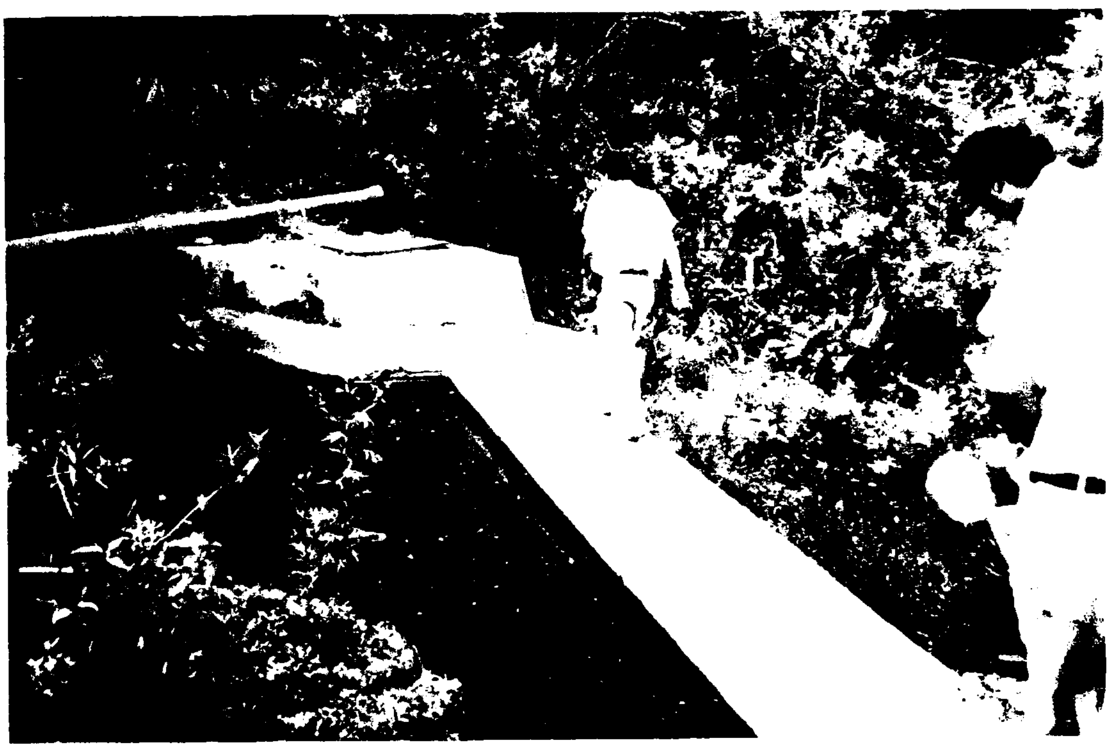

Photo 25. Water Collection Dam for Spring Feeding Town of Vallegrande - 28 Lt/Sec

Photo 26. Water Holding Ponds Near Vallegrande - Department of Santa Cruz

Photo 27. Typical Watering Cistern in Chaco - Water Shared by Humans and Livestock

Photo 28. Typical Stream Gaging Truck - Rigged for Flow Measurement from Bridge

Photo 29. Flow Meters for Measurement by Wading with Rod or From Bridge with Winch

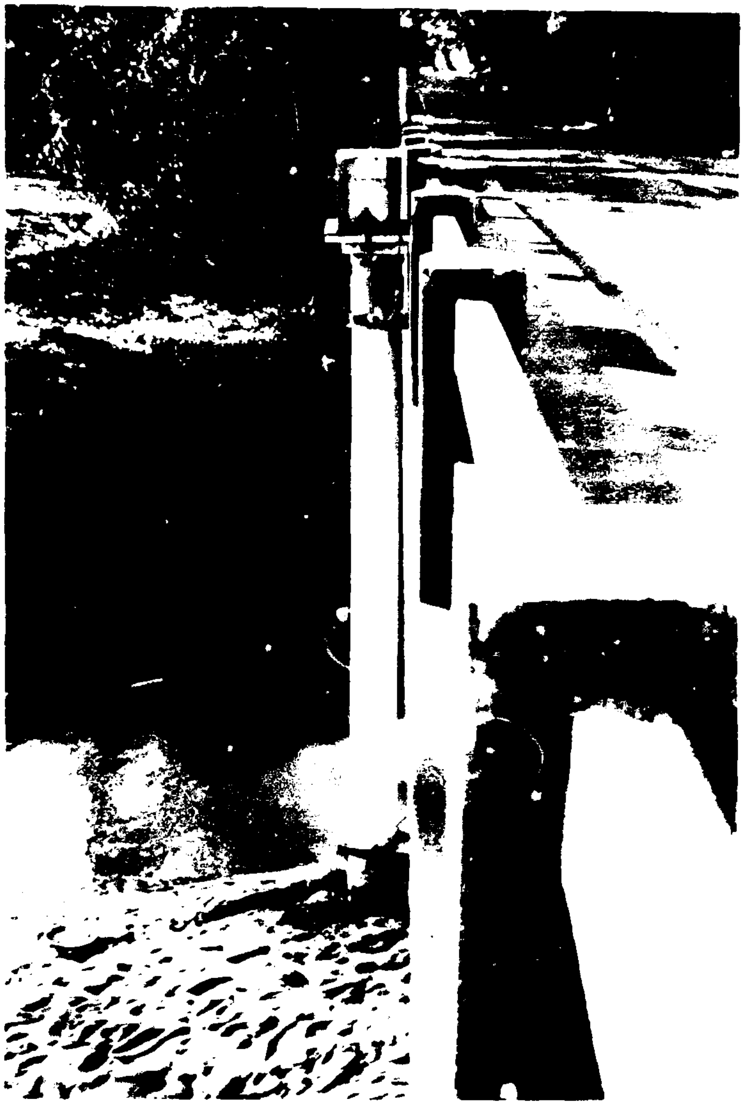

Photo 30. Housing and Standpipe for Stream Gage Recorder Mounted on Bridge

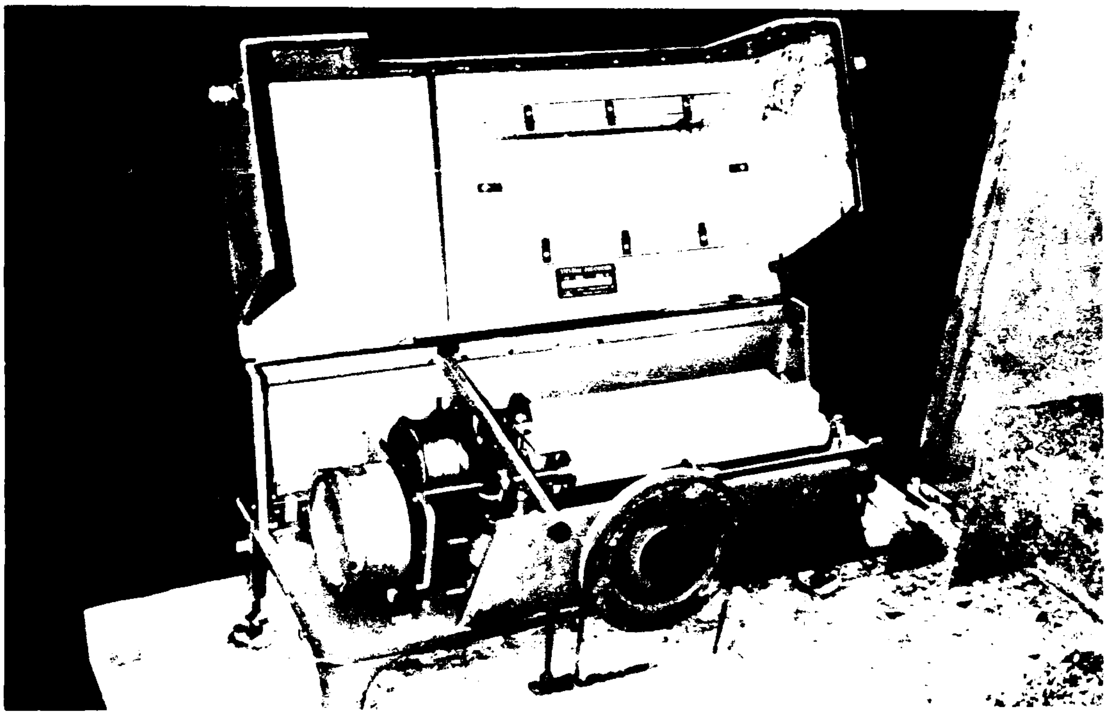

Photo 31. Leopold/Stevens Strip Chart Recorder - Continuous Record of Water Level

Photo 32. Automatic Radio Reporting Station - Rain and Stream Flow Data

Photo 33. Pressure Transducer to Measure Water Level - Radio Reporter in Background

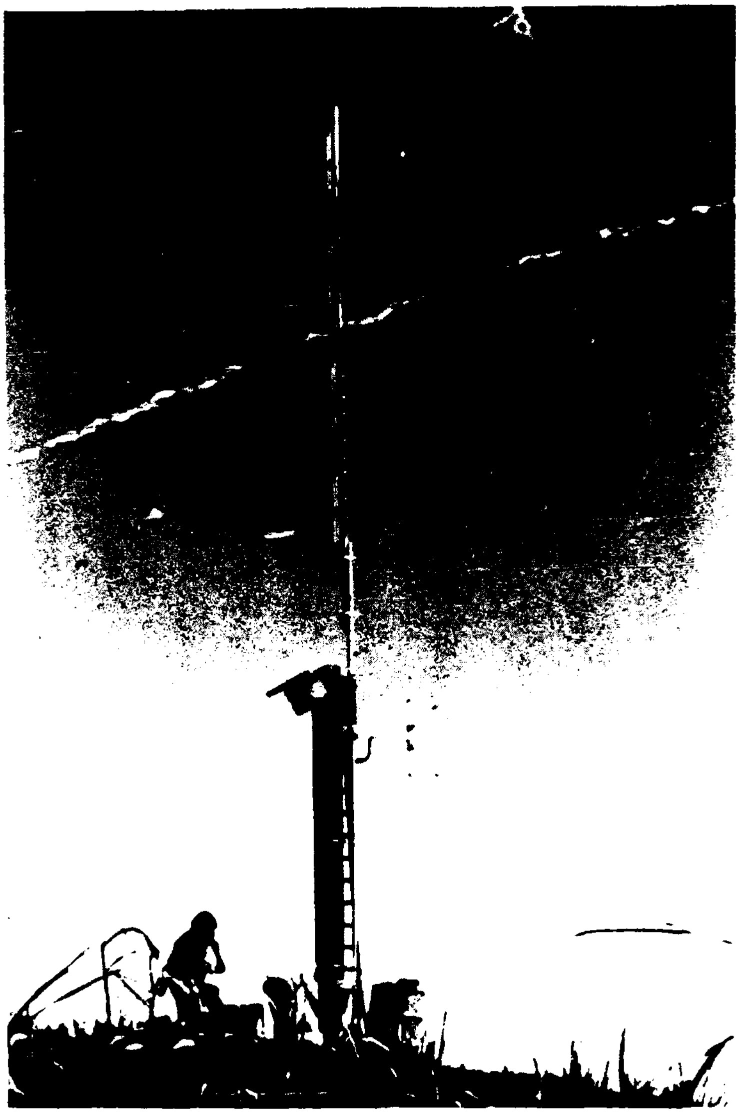

Photo 34. Repeater Station with Rain Gage - Note Solar Panels for Battery Power

Photo 35. Base Station Control Center for Data Collection and Flood Warning

TABLE OF UNIT CONVERSIONS

METRIC TO INCH-POUND UNITS

TO CONVERT FROM	TO	MULTIPLY BY
VELOCITY:		
Centimeters/second	Feet/day	2830.0
Meters/day	Feet/day	3.28
FLOW RATES:		
Cubic Meters/second	Cubic Feet/second	35.3
Cubic Meters/second	Gallons/minute	15,800
Liters/second	Cubic Feet/second	0.0353
Liters/second	Gallons/minute	15.8
LENGTH:		
Millimeters	Inches	0.03937
Centimeters	Inches	0.3937
Centimeters	Feet	0.0328
Meters	Inches	39.37
Meters	Yards	1.094
Meters	Feet	3.28
Kilometers	Feet	3,280.8
Kilometers	Miles	0.62
AREA:		
Sq. Centimeters	Sq. Inches	0.155
Sq. Meters	Sq. Feet	10.758
Sq. Meters	Sq. Yards	1.196
Hectares	Acres	2.47
Hectares	Sq. Feet	107,580
Sq. Kilometer	Acres	247
Sq. Kilometer	Sq. Miles	0.386
Sq. Kilometers	Hectares	100
VOLUME:		
Cubic Meter	Liters	1000
Cubic Meter	Gallons	264
Cubic Meters	Cubic Feet	35.314
Cubic Meter	Cubic Yards	1.30795
Cubic Meters	Acre-feet	0.000811
Liters	Gallons	0.264
Liters	Cubic Feet	0.03531
MASS:		
Kilogram	Grams	1000
Kilogram	Pounds	2.205