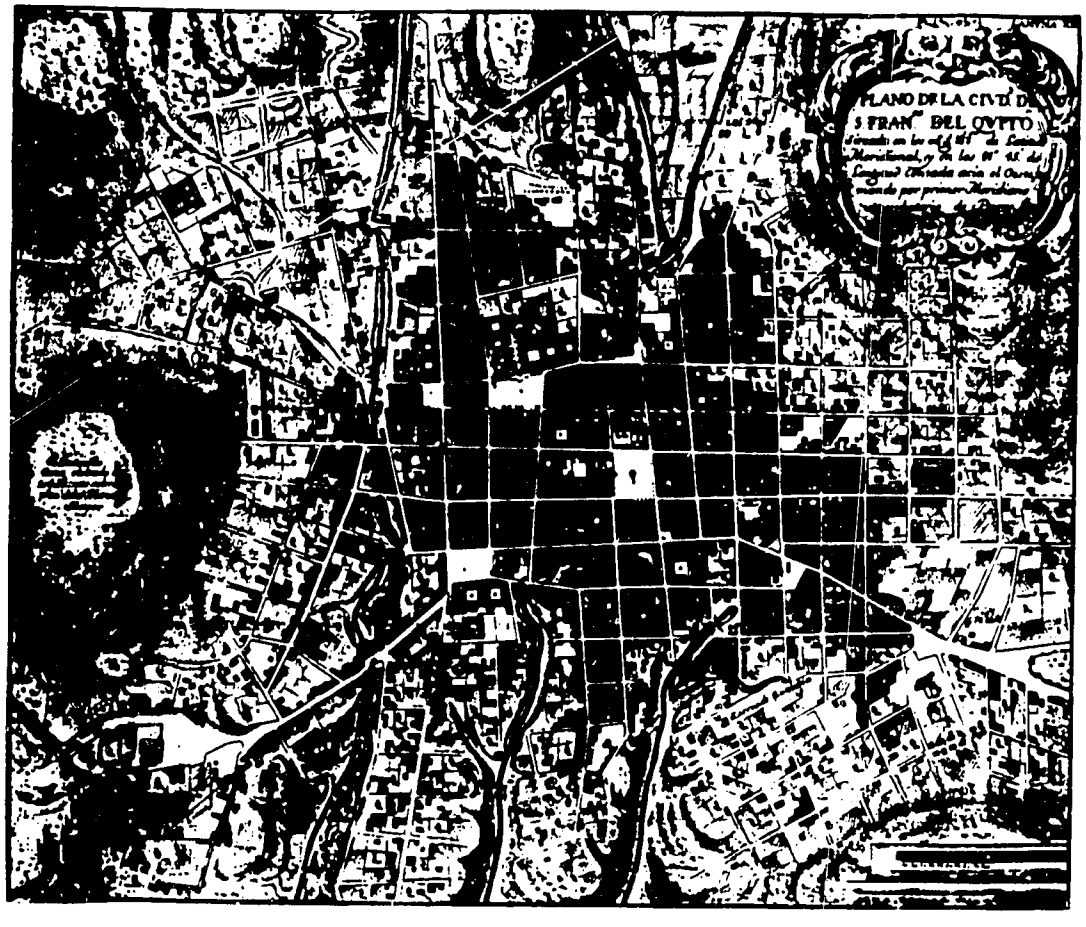
PN-AAS-594 39589

# SUMMARY OF FINAL REPORT

## Control of Erosion and Runoff from the Sides of Pichincha

## QUEBRADA YACUPUGRU



Cohidro Consultores Cia. Ltda.
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**CDM**

*environmental engineers, scientists, planners, & management consultants*

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June 19, 1985

Mr. Gregory J. Goewey
Office of Engineering
Agency for International Development
American Embassy/Quito
APO, Miami 34039

Pichincha Slope Protection
Summary Report in English
Contract No. 518-0046-C

Dear Mr. Goewey:

On March 28, 1985, we submitted to you the Final Report for the Pichincha Slope Protection Study. Subsequently, on April 6, 1985 we submitted a Summary Report as an assist in the review of this study. All this information was prepared in Spanish in order to expedite the report of this project by the local agencies.

Subsequently, we have prepared an English translation of the Summary Report to assist AID in the review of this project and for the consideration of the feasibility and final design phase of Quebrada Yacupugru. We therefore submit to you with this letter three (3) copies of this Summary in English. One additional copy will be forwarded to AID/Washington in accordance with our contract. Please advise if we can be of further assistance.

Sincerely,

CAMP DRESSER & McKEE INTERNATIONAL INC.

Paul C. Dreyer
Associate

PCD/ph

cc: Ms. Dero Helen Davidson, w/encl.

Control of Erosion and Runoff from the Sides of Pichincha

Summary of Final Report for Quebrada Yacupugru

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April 6, 1985

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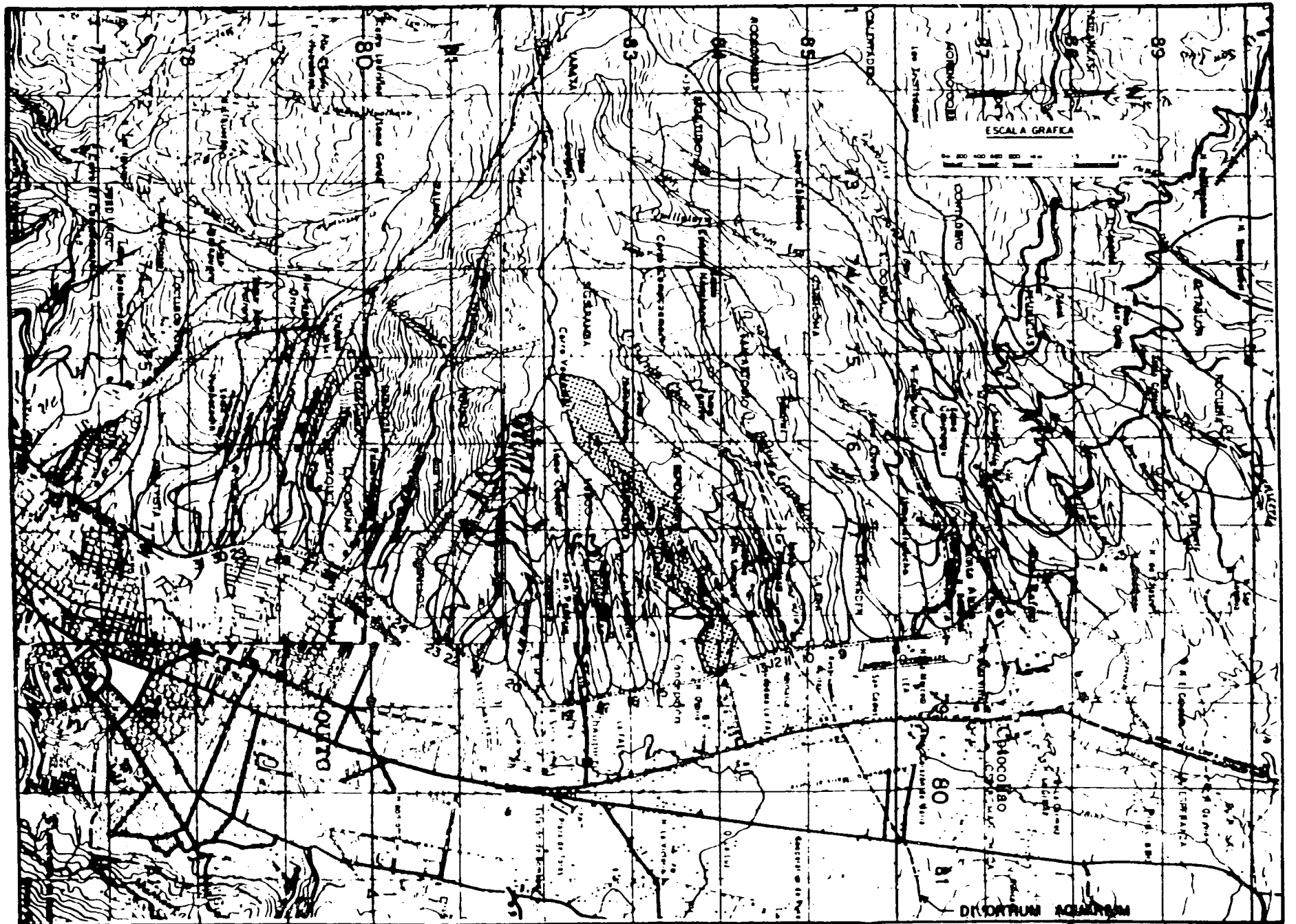
# INTRODUCTION

## Purpose of the Study

In the last two decades, the City of Quito has experienced, with increasing frequency, the results of "aluviones" that have formed on the eastern slopes of Mount Pichincha. This phenomenon is caused by high rainfall intensities in localized areas that usually occur in the winter. Occasional landslides within the quebrada accumulate material in these areas which are transported to the City. The capacities of the collectors that cross the City are generally of insufficient capacity to carry the runoff from the quebradas. The potential danger that threatens the City along the length of the sides of Pichincha is of such magnitude that the National Government declared a state of emergency in 1983.

The scope of work for this project was developed through discussions with the Agency for International Development (AID), the Empresa Municipal de Alcantarillado (EMA) and other representatives of the City together with Camp Dresser & McKee International Inc. (CDM). The intent of the present project is to conduct hydraulic, hydrologic and geologic studies of Quebrada Yacupugru to determine possible erosion and slope failure control solutions in this quebrada. This particular quebrada was selected by the City due to the recent failure (in 1983) and the extensive remedial work actually under construction by EMA in the quebrada. Although all the quebradas on the eastern slope of Mount Pichincha appear to have significantly different characteristics, the present study may serve as the basis for future studies of selected quebradas. The drainage area of the west side of Mount Pichincha and the Quebrada Yacupugru is shown in Figure 1.

Although this study relates only to the Quebrada Yacupugru, it should be noted that to implement remedial solutions, it is necessary to evaluate each of the quebradas, especially those that constitute an immediate hazard.




| | | |
|---|---|---|
| **Camp Dresser & McKee Inc.**<br>**Cohidro Consultores Cia Ltda.** | Drainage Areas of Pichincha | Figure 1<br>**Marzo 1985** |

## STUDY AREA

### Drainage System

The capacity of the system of collectors is generally small when compared to the runoff that occurs from the slopes of Pichincha during heavy rainstorms. The return periods adopted in the design of the collectors in an urban area are generally short, therefore, their dimensions are insufficient to carry runoff with a long recurrence interval (25 years or more). In some areas, especially along the Avenida Occidental, the entrance to the collectors is located as much as 40 meters below the top of the downstream fill, so excess flow can pond at the entrance to the collector until the peak of the storm passes. For other collectors, however, there is little storage space available at the entrance, so when high flows occur, the runoff overflows and causes damage.

Since the collectors are relatively small, they are subject to blockage at the entrance by large rocks, branches, and the large amount of sediment which is carried down the quebrada. In addition, in areas where barriers are located next to the open quebradas, a large amount of solid waste is discarded into the quebrada, which also tends to block the entrance to the collectors. On two occasions in 1983, major blockages at the entrance to the collectors had been cleared with dynamite. Maintaining the flow at the entrance to the collectors is therefore a major maintenance problem for EMA.

EMA has also constructed "azudes" (small dams) in many of the quebradas, in order to stop the downward erosion of the riverbed and to reduce the velocity of flow so that streambank erosion can be reduced. In the Quebrada Yacupugru 43 "azudes" were installed. EMA has planned these "azudes" to maintain a streambed slope of about two percent, as compared to the natural slope of 25 percent or more. Many of the "azudes" have low flow outlets which allow water to drain from behind the "azudes" during periods of low runoff. When these outlets

function properly, the "azudes" serve to reduce peak flows by temporarily storing water, and also help to reduce the effect of debris flows in downstream areas. However, due to the steep slope of the quebradas, these "azudes" have a limited amount of storage space behind them, and their effect on major floods or debris flows would probably be small. Many of the low flow outlets in the older "azudes" have become completely blocked and sediment has accumulated to the top of the spillway. These "azudes", where sediment has accumulated, would have little effect on reducing floods or debris flows, except for the reduction in slope which would cause velocities upstream of the "azudes" to be lower than normal.

In response to the flooding problems which occurred in 1983, EMA has planned and is currently constructing a drainage channel which will carry stormwater from the Quebrada Delicias, Quebrada la Esperanza and Quebrada Yacupugru to the Quebrada Runichanga, which has a collector with a larger capacity and has more storage space at its entrance. Another objective of EMA in combining the flow from several basins in this manner is to stagger the peak flows from each of the Quebradas.

## Surficial Geology

The city of Quito is located in a basin that is a structurally controlled, sediment-filled valley referred to geologically as the Inter-Andean Graben. The valley is oriented on a north to south direction, and is bounded on the west by the Pichincha Volcano. Mount Pichincha is part of a chain of active and nonactive volcanos of the Western Cordillera.

The slope geometry of Mount Pichincha was formed by multiple lava flows. Overlying these lava flows are soil deposits of pyroclastic materials, volcanic ash, debris flows and glacial till. Erosion by glacial ice and rain water has sculptured the various deposits and formed numerous quebradas on the sides of the Mount Pichincha.

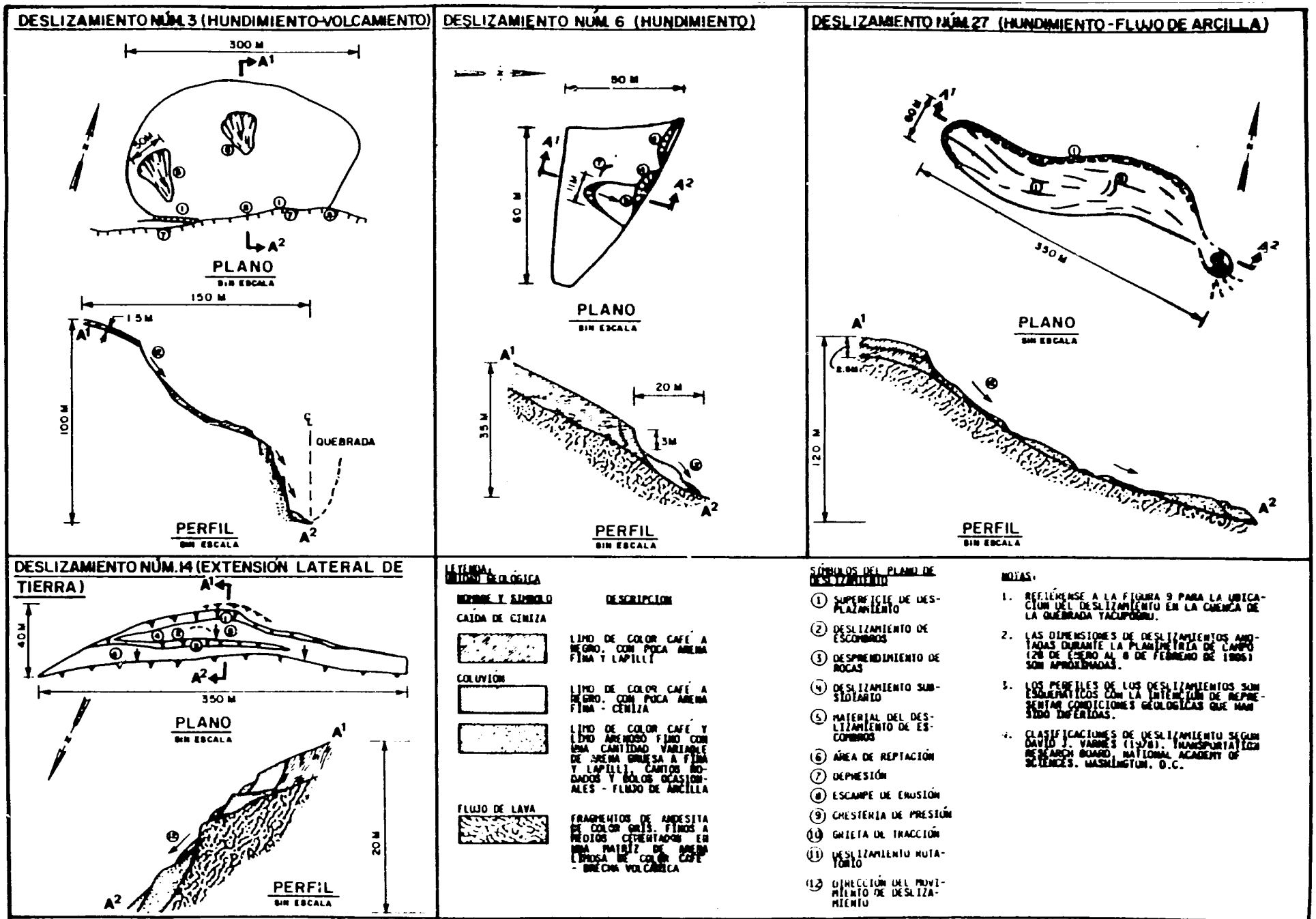
Aerial photogeological interpretation and field geologic mapping were conducted of the drainage basin of the Quebrada Yacupugru. Data relative to the surficial geologic deposits was compiled on infra-red stereo-paired aerial photographs to a scale of 1:10,000. The data was then transferred to topographic base maps prepared at the same scale as the photographs. The overburden soil and bedrock formation identified in the quebrada drainage area consist of three geological units. From the surface, these units are: 1) ashfall, 2) colluvium and 3) lava flows.

## Geologic Hazards

Based on the aerial photogeologic interpretation and field geologic mapping, the geological hazards within the drainage area of Quebrada Yacupugru were evaluated. Landslides were the principal hazards identified, and thus, the emphasis is on their identification and detail. Soil and rock materials from these unstable areas can reach the quebrada channel through a variety of mechanisms which can then be incorporated in the runoff during high intensity rainfall events to produce damaging debris flows.

The identified landslides in the Quebrada Yacupugru are classified into four basic types: 1) topple, 2) slump, 3) lateral spread and 4) earth flow. Figure 2 shows details on the types of landslides in Quebrada Yacupugru.

Based on the geologic conditions, landslide activity and topography, the Quebrada Yacupugru is divided into three hazard zones. These zones are presented in Figure 3. Zone 1 would provide most of the material that might be incorporated in future debris flows. The soil and rock material comprising a debris flow accumulates over a period of time in the stream channel, primarily as a result of landslide activity occurring on the adjacent slopes of the quebrada. Each of the landslides identified in the drainage area of Quebrada Yacupugru

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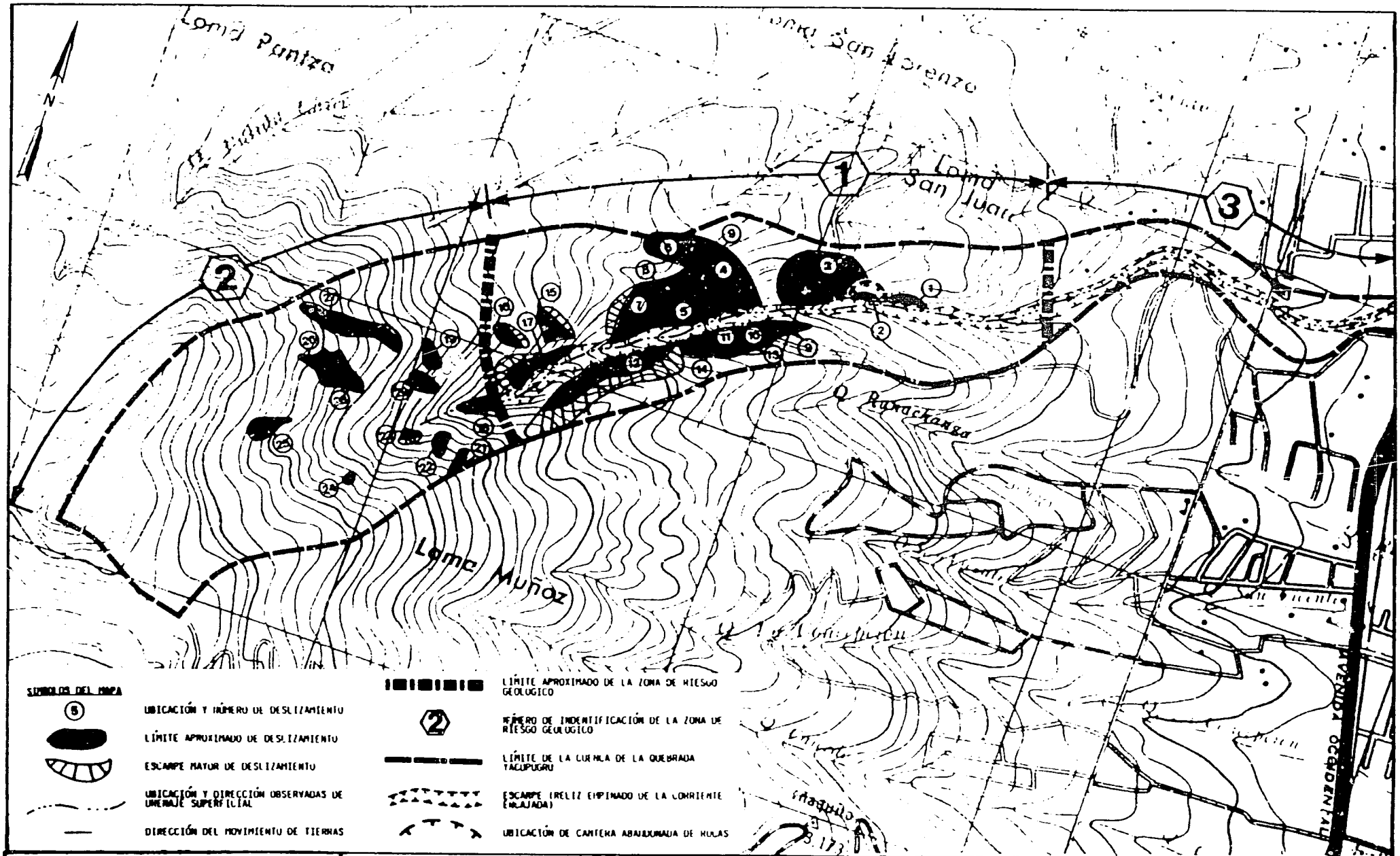
| Camp Dresser & McKee Inc.<br>Cohidro Consultores Cia Ltda. | Details of typical Landslides | Figure 2<br>Marzo 1985 |




| | | |
|---|---|---|
| Camp Dresser & McKee Inc.<br>Cohidro Consultores Cia Ltda. | Map of Geplogical Hazards in Quebrada Yacupugru | Figure 3<br>Marzo 1985 |

can be expected to occur in the future with different frequency. Additionally, the type and location of the future landslides would govern the volume of material reaching the stream channel.

The volume of material that would be incorporated in a future debris flow was estimated, based on frequency of a rainfall event, on the order of 1 in 25 years, or greater. The estimate was made in order to assist in the formulation of a mitigation plan. Such a prediction is difficult to accurately make because of the extreme complexity of the problem. A considerable amount of judgement must be exercised in quantifying the debris-producing potential within the identified hazard zones. The following general assumptions were made:

- Only Zone 1 is capable of producing significant volume of material that will be incorporated in future debris flow.
- "Topple and Spread" type landslides will contribute the greatest quantities of material to a future debris flow.
- "Slump and Flow" type landslides will contribute material to a future debris flow, but of smaller volume than "Topple and Spread" type slides.

Based on these assumptions, the volume of potentially unstable slope material available in Zone 1 for incorporation in a future debris flow is estimated to be 60,000 cubic meters. This volume estimate is approximate and assumes no erosion or landslide mitigation measures exist within the limits of the Quebrada Yacupugru.

Vegetation and Land Use

Based on the interpretation of the false color infrared aerial photography and field observations, the type and varieties of the vegetation in the Quebrada Yacupugru were determined. The physical structure of vegetation is reflected in the definition of mapping units and directly influence hydrologic characteristics of each unit. Figure 4 indicates the pattern of vegetation in Quebrada Yacupugru. The most effective vegetation cover for the purpose of runoff control,

LEYENDA DE TIPOS ECOVEGETATIVOS

1 Paramo 2 Ceja Andina
3 Bosques Subandinos
4 Plantacion de Eucaliptos
5 Tierra de Pasto
6 Pasto o Paramo Acnaparrado
7 Terrenos Semidesarollados
8 Canteras y Canal de Diversion
9 Terrenos Cultivados

| | | |
|---|---|---|
| Camp Dresser & McKee Inc. | Aerial Photograph | Figure 4 |
| Cohidro Consultores Cia Ltda. | Showing Vegetation Use | Marzo 1985 |

occurs within the middle elevation range of Quebrada Yacupugru and on the steep interior slopes of the quebrada. The growth of vegetation along the sides of the Pichincha reflect the interaction of human use and topography. The upper slopes of Quebrada Yacupugru are covered primarily by typical grassland vegetation (Paramo). It is likely that a species of shrubland (Chaparro or Ceja Andina) would replace Paramo grasses in time in the absence of fire. In Quebrada Yacupugru, only the steepest interior slopes of the quebrada are covered by these indigenous vegetation types. Several of these plant species are considered an endangered species by the Museum of Natural History. Because of the presence of these species and numerous other elements of the indigenous flora, the quebradas possess significant scientific, aesthetic and recreational value as natural areas.

Improvement of the hydrological conditions can be obtained with the use of vegetation. The best vegetation types for this purpose which could be produced in the Quebrada Yacupugru are Subandian Shrubland (Ceja Andina) and Subandian Forest (Bosques Subandinos). Natural processes of vegetation change (succession) will favor the development of these shrubland vegetation types over a period of time. Invasion of shrubs in grassland (Paramo) and tame pasture (Tierra de Pasto) would eventually cause the development of shrubland (Chaparro) in the absence of fire. This process would enhance the hydrologic characteristics of Quebrada Yacupugru.

## Hydrology

The rainfall information recorded in the area was used to estimate the runoff from Quebrada Yacupugru. Rainfall records were examined for the major storms of 1983, and other storms, for long term estimates of peak rainfall amounts. The storm of April 30, 1983 produced a great quantity of rainfall localized near Quebrada Yacupugru. Rainfall of close to 70 mm was recorded near the basin, almost all of which fell during a three-hour period. About 40 mm of this total was recorded in the first hour of the storm.

In order to estimate peak flood flows, the intensity curves and rain frequency registered at the Astronomical Observatory of Quito were used. The Observatory maintains daily records since 1891, and shorter duration records since 1929. The intensity of the rainfall registered at the Quito Observatory was increased 20 percent to be applied to the Quebrada Yacupugru based on the detailed analysis of rainfall in other climatological stations. A computer program was used to evaluate the runoff produced in each of the four quebradas that discharge or are channeled to the Quebrada Yacupugru.

The canal system under construction by EMA has the capacity to transport flows from a 100-year rainfall in the basin of Quebradas Delicias and Quebrada La Esperanza. However, in the Quebrada Yacupugru the combined flow from the three basins will surpass the capacity of the canal to the Quebrada Runachanga with runoff from a 10-year storm. For this reason, EMA has proposed a retention tank in this site.

It is important to note the relatively small difference between the peak flows produced from the 10-year, 50-year and 100-year rainfall events. The 50-year peak flow is approximately 25 percent greater than the 10-year peak. The peak flow for 100-year is only about 10 percent greater than the 50-year peak.

## MITIGATION MEASURES

### Control Measures

It is estimated that the maximum flow of Quebrada Yacupugru will exceed the capacity of the existing drainage installations from a 10-year storm. Three basic solutions are presented to prevent flooding in this area of the City of Quito:

- Reduce the amount of runoff through land use control and vegetation cover,
- Improve the flow capacity of the downstream drainage channel, or
- Use a detention pond facility to store peak flows.

Changes in vegetation and land use were considered in order to reduce runoff. Based on the hydrologic analysis of these potential changes, it is apparent that reduction in peak flow amounts can be obtained from changes in land use and vegetation cover, but the net effect is only four to six percent below the peaks that will occur with unfavorable basin conditions. Therefore, additional control measures will be necessary to eliminate the flooding problems. Vegetation and land use changes are still a desirable option to implement because they will be able to reduce the size and cost of other mitigation measures.

In the Quebrada Yacupugru, improvement of the downstream drainage channel will be very difficult and costly. Few of the existing collectors have sufficient capacity to carry additional flows resulting from a 10-year storm, and others are already undersized for storms of this frequency. New collectors would have to be built primarily in existing streets and residential areas.

The use of detention storage appears to be a good way of avoiding the problems and high cost associated with improving the downstream channel capacity. Because the watersheds are small, peak flows

normally occur during a period of several hours or less. Temporary storage of these peak flows would allow the existing drainage facilities to be used. However, due to the steep slope on the sides of Mount Pichincha, finding suitable sites for the placement of the required storage volume will be difficult. EMA has selected a site for a detention tank alongside the new canal that will carry water from the Quebrada Yacupugru to the Quebrada Runichanga. There is a limited amount of level space at this site, with steep cross slopes outside of this area.

An alternate location for a detention pond would be within the Quebrada Yacupugru, upstream of the diversion point for the new canal. The flow entering this site would only be from the Quebrada Yacupugru itself, and a detention tank would eliminate the flooding problems downstream. Because of the steep walls of the quebrada, a relatively narrow dam structure would be required. However, due to the steep slope of the quebrada, a relatively high structure would be required in order to obtain the necessary storage space. An access road to the site would have to be built for construction and cleaning of the basin. A portion of the storage space tends to be filled with water from initial runoff leaving little capacity for peak flows. Therefore, a slightly greater storage volume would be required at this site.

The computer program that was used to estimate the flood hydrographs for the Quebrada Yacupugru basin was also used to study the effect of a detention pond in the Quebrada Yacupugru on the reduction of peak flows. The elevation-storage curve for a detention pond at this site was used in the program, and various outlet and spillway sizes were investigated. It was found that by using two structures, the 10-year peak flow from the Quebrada Yacupugru could be reduced from 17 cubic meters per second to about 9 cubic meters per second; and this peak flow would occur after the maximum flow from Quebrada Delicias and Quebrada La Esperanza had passed, so that the new canal could divert all flow to the Quebrada Runichanga. However, additional structures would be needed to protect against the 50-year and 100-year storms.

## Mitigation Plan

All hydraulic structures are constructed for a specific return period which determines the degree of protection that the structure provides. Flood control structures are susceptible to overflows which produce flooding when storms of higher intensities or return periods than those considered in the design. However, these structures provide protection that mitigates the flooding and overflows.

Since advantages of flood protection can be obtained by locating a detention structure in the Quebrada Yacupugru and because this structure will also help in the retention of debris flows that could occur, the recommended plan includes the construction of two or three detention structures in this area. The recommended structures would be of reinforced concrete with a height of 15 to 20 meters. Because the storage volume behind a dam at this site increases rapidly with increased height, the structure should be made as high as geologic site conditions and economic constraints permit. More than two structures should be considered if the additional protection provided could justify the additional cost. The optimum number of structures, their placement and size, as well as the outlet works were not determined in this phase of the study. These factors should be considered more thoroughly during the design studies.

Even with the recommended improvements, the new drainage channel will not be able to handle all flows from extreme floods (such as the flows from 50-year and 100-year storms), it is recommended that an overflow be constructed from the new drainage canal discharging into the original quebrada channel below the diversion point. This overflow would prevent damage to the canal if an uncontrolled overflow occurred. The analysis shows that design flows used for the concrete channels under construction from Quebrada La Esperanza and Quebrada Delicias to Quebrada Yacupugru are of such magnitude that the channel capacity will be exceeded for a larger than 10-year storm. For this reason, it is considered important that flows from Quebrada Yacupugru be controlled by the construction of detention structures upstream of

the proposed diversion. These structures will reduce excessive channel velocities and will provide a minimum amount of storage for minor reduction in peak flows, and delay of the peak outflow so as not to occur coincidentally with maximum flows being diverted from the other quebradas. This will also contain debris that might be mobilized due to saturation from high intensity or long duration rainfalls.

These proposed structures would be located where they could be keyed into stable rock formations to prevent possible movement. It is proposed that the upstream debris control facility be located at channel elevation 3220 meters with the downstream one at channel elevation 3085 meters. An energy-dissipation structure should be considered at an elevation of 3380 meters to reduce the velocity upstream of the debris-control facilities.

The proposed facilities were detailed on a preliminary basis using the available mapping without benefit of any additional field surveys. The purpose is to provide a conceptual design of these facilities which would enable an approximate cost estimate to be determined and to assess the feasibility of the proposed project. Therefore, the conceptual design provided should be refined when the location, details and dimensions are determined following the detailed investigations which are part of final design. A summary of the important information regarding the conceptual design of each facility is presented in Table No. 1.

## Estimate of Costs

The unit price construction costs prepared for this phase of the study are based on the actual unit cost of material and labor for the magnitude of the civil works recommended in the Quebrada Yacupugru. The unit costs were prepared for prices of material and labor to estimate the preliminary cost of each structure based on the estimated quantities. The preliminary construction costs for each facility are as follows:

Control of Erosion and Runoff from the Sides of Pichincha

TABLE 1

DATA ON CONTROL STRUCTURES UNDER CONSIDERATION

Debris Control at an Elevation of 3085 Meters

| | | | |
|---|---|---|---|
| Top Elevation | 3104 | Spillway Elevation | 3102 |
| Base Elevation | 3084 | Spillway Length | 20 m |
| Structure Length | 44 m | Spillway Height | 18 m |
| Structure Height | 20 m | Storage Volume | 9400 m3 |

Debris Control at an Elevation of 3220 Meters

| | | | |
|---|---|---|---|
| Top Elevation | 3240 | Spillway Elevation | 3238 m |
| Base Elevation | 3281 | Spillway Length | 20 m |
| Structure Length | 80 m | Spillway Height | 22 m |
| Structure Height | 22 m | Storage Volume | 20000 m3 |

Energy Dissipation at an Elevation of 3380 Meters

| | | | |
|---|---|---|---|
| Top Elevation | 3390 | Spillway Elevation | 3388 m |
| Base Elevation | 3378 | Spillway Length | 15 m |
| Structure Length | 41 m | Spillway Height | 10 m |
| Structure Height | 12 m | Storage Volume | 1200 m3 |

| Facility | Elevation (m) | Volume (m3) | Estimated Cost |
|---|---|---|---|
| Debris Control | 3085 | 9400 | S/. 78,000,000 |
| Debris Control | 3220 | 20000 | 138,000,000 |
| Energy-Dissipation | 3380 | 1200 | 55,200,000 |

The estimated preliminary costs for these facilities are based on May 1985 prices (US$ 1.00 = S/.120.00). The facilities recommended have a total estimated cost of S/. 271,200,000 (US$ 2,260,000).

This Summary of the Quebrada Yacupugru is intended to provide an executive summary of the Final Report. Please refer to the Final Report for additional and more detailed information.