SUPPORTING REPORT G

LANDSLIDE DAMAGE MITIGATION PLAN

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1. INTRODUCTION

1.1 GENERAL

This report presents (1) observation of the landslides at Barrio El Berrinche, El Reparto, Colonia Nueva Esperanza, and El Bambu, which are main areas of extensive damage caused by Hurricane Mitch, (2) potential danger of the landslides judged from the observation, and (3) recommendations with respect to the preparation of working plan to prevent further movements of the landslides and to minimize future damage.

1.2 BASIC CONSIDERATION FOR LANDSLIDE PREVENTION PLAN

In principle, types of landslides including slope failure are defined by modes of movements of unstable mass of earth. Preventive measures are proposed depending on the landslide types that are judged by performing geological and other investigations. For the preventive measures to be proposed, understanding of characteristics of the landslides is essential. Furthermore the plan should be in consistent with land conservation plan, land use plan, cost, and environment conservation. Depending on the size of the landslides, combination of several counter measures will be necessary to form an entire landslide preventive plan.

At the present, this report assumes that the plan for countermeasures in the area would be altered and modified depending largely on the investigations to be performed.

2. BARRIO EL BERRINCHE

2.1 TERRAIN CHANGES IN LANDSLIDE AREAS BY HURRICANE MITCH

By observing the topographic data before and after the damage caused by Hurricane Mitch, there is difference in elevation along the boundary between the landslide blocks A and B (refer to *Figure G2.1*). This suggests that there were movements of the land. Eastern half of Block B is higher by some 10m while Blocks A and C are lower. This topographic feature may correspond to a mechanism of the landslide as described later. Block C may still be changing its shape as evidenced by groundwater dissipation, movements together with Block A-1 (servility), and formation of small ravine.

2.2 MODE OF THE LANDSLIDE

2.2.1 AREA OF THE LANDSLIDE

The landslide area is about 180,000 m^2, with a width of 300 m and a length of 800 m, located on hilly areas sloping down from west to east, and is enclosed by a ridge (from Colonia El Porvenir to Barrio El Chile) to the north, a cliff (from Colonia Campo Cielo to El Porvenir) to the west, and a northern part of a ridge (from Colonia Campo Cielo to Colonia Soto) to the south. It exhibits typical topographic features of landslides.

2.2.2 GEOLOGY OF THE LANDSLIDE AREAS

Geological survey revealed that at the east ridge of Barrio El Chile and Colonia El Porvenir, limonite, silt stone, and mudstone of Rio Chiquito Formation of Mesozoic era are exposed below an elevation of 1,015 m, and Tertiary tuff is seen above 1015 m. Boring survey Positions are shown in *Figure G.2.2*. The profile of Berrinche landslide area is described in *Figures G.2.3* and *G.2.4*. On the steep cliff located from Colonia Campo Cielo to Colonia El Porvenir, volcanic rocks of Ignimbrites underlain by tuff are seen. Although it is not very obvious in the landslide area, tuff outcrops to the west of Landslide Blocks C and D, and Rio Chiquito Formation to the east.

The surface condition in the landslide area is expected to be highly pervious because most of Block C is covered by huge volcanic rock blocks that fell from the scarp of the landslide.

Base rocks of the Blocks A and B are most probably of Rio Chiquito Formation that may contain basal shear zones or slide surfaces of the landslide. On the left bank of the Choluteca River, the sheared and weathered Rio Chiquito Formation is observed sheared and weathered for more than 100 m in length.

The landslide type of Barrio El Berrinche landslide is judged to be weathered rockslide. The mechanism of the landslide is considered as follows;

> Water collected from the scarp zones of the landslide and uphill areas flew into tension zones of the landslide (upper most zone, corresponding to Block C) and has been pressurized into artesian conditions within the shear zones of Rio Chiquito Formation.

Judged from the movements of the land together with displacement of the ground surface, the slide surface of Block B is considered to be Closed-end type, while the slide surface of Block A may be Stepped shape type.

2.2.3 SURFACE WATER AND GROUND WATER IN EL BERRINCHE LANDSLIDE AREA

Presence of small ponds and depressions in the western area of the landslide, in the vicinity of the head and the scarp of the landslide, are noted in the aerial photographs taken before Hurricane Mitch. It was also confirmed through the interview survey. (Most of these ponds and depressions, however, disappeared after the terrain changes in the area by Hurricane Mitch.) The ponds and depressions functioned like flood controlling reservoirs during heavy rains as they stored the surface run-off water temporary. The surface run-off water in the plateau and the scarp flew into the ponds and depressions and the ground water in the plateau seeped out in the ponds. It is expected that high porewater pressures built up in the ground had a significant effect on the development of the landslide.

At the time of the Hurricane Mitch, a large amount of surface run-off water, which came from the housing development area on the plateau in the west of the scarp of the landslide, flew into the landslide area. The water flow became muddy and grew into avalanche of rocks and earth, which is one of the main reason for blocking up the Choluteca River.

The most basic countermeasure for the landslide is to establish the drainage system to perfectly prevent the surface run-off water coming from western plateau (Cerro El Berreche) from flowing into the landslide area. However, it is rather difficult to construct the perfect drainage system. The planned drainage facilities to be discussed in the later sections of this report are designed so that they effectively prevent landslides even if the drainage system is not constructed perfectly.

Based on the ground water monitoring data by SERNA and the Engineer Brigade of the USA, the ground water level on the hill side of the landslide area are clearly different between rainy season and dry season. On the other hand, the variation of the ground water level in the low-lying area is small and consistent in both rain and dry seasons. The ground water level used in the analysis of the landslide is determined based on the highest ground water level in the data of SERNA and the Engineer Brigade of the USA and the short-term monitoring results obtained in the soil investigation performed by JICA. The ground water level used in the analysis shall be reviewed and revised, if necessary, based on the future long-term monitoring.

2.2.4 MECHANISM OF THE LANDSLIDE

There are a few views on the phenomena and mechanism of El Berreche landslide. As for the phenomena of the landslide, there is an accepted phenomena and many researchers support the phenomena. On the other hand, many researchers came up with their unique theories on the mechanism of the landslide. At this moment, no generally accepted mechanism of landslide is established yet. This is probably because the quantities of the soil investigation are insufficient in consideration with the large area involved.

The following is a brief description of the phenomena of the landslide (refer to *Figure G.2.5*):

a. Due to a series of heavy rains brought by Hurricane Mitch, a large amount of surface run-off water and the ground water flew or seeped into the landslide area. Block C, which was located under the scarp of the landslide and consisted of boulder blocks fallen from the scarp and porous collapsed soil, contained a large amount of ground water. The water in Block C induced a relatively high water pressure acting on Block A1 located next to Block C.
b. Block A1 started sliding. The major direction of the sliding movement was NW →SE direction as shown in the Soil Profile B-1.
c. Block A1 pushed the lower block B. However, Block B did not slide. Block B was sandwiched and the central portion of Block B was uplifted to form the uplifted terrain.
d. Block A1 kept sliding and pushed Blocks A2, A3.
e. Block A1 led to pushing up of Block B. Push-up phenomenon from Block A1 to Block A2 was also noted. The latter is considered to be a continuous sliding, although there was some time-gap.
f. SERNA and the Engineer Brigade of USA considered that the sliding surface of the landslide was deep in the Rio Chiquite Formation. The deep stiff clay acted as a layer with reverse dip and caused the uplifted terrain of Block B and the sliding at the toe of the landslide.

   Another interpretation of the compressive block of Block B is as follows:

   It was considered that there was a difference in the geological structural field between Block A and Block B. Block A is the area where the landslide movement was actively taken place. On the other hand, the geological composition of Block B was the field where collapsed soils due to the landslides were accumulated, as evidenced in the borehole B-6. The sliding surface developed in Block A was formed in association with the sheared zone in the Rio Chiquite Formation. It was mechanically unclear that Block B created a new sliding surface in the sandy gravel layer or overconsolidated clay layer, or created a sliding surface merging to the existing sliding surface in the deep Rio Chiquite Formation. It may also be considered that the movement did not lead to form any clear sliding surface.
g. The sediments blocked up the Choluteca River were originated from the toe of the Block B. They were slid or collapsed and blocked up the river.
h. Block C was rotated and displaced in association with the sliding of Block A. It shows partly the hanger structure topography today. The inclinometer BS-4 installed by SERNA and the Engineer Brigade of USA showed a deformation of 2mm/month today. However, other inclinometers do not show any significant lateral deformation.

2.2.5 REPEATABILITY OF LANDSLIDE AND LIKELIHOOD OF RISK

Presently, the movements of the landslide are temporarily in suspension except for a part of Block C. It is necessary to investigate geological conditions in detail and to prepare long term monitoring system for the landslide behavior. Continuous monitoring systems are recommended because landslide activities were reported at the time of Hurricane Fifi in 1974.

The most risk prone block within Barrio El Berrinche landslide is Block A-1. Judging from the topography, the direction of the groundwater flow is considered from A-1 to A-2 to A-3. This suggests possible locations and methods of the landslide preventive measures.

There are small-scale slips along the left bank of the Choluteca River. The slips occurred within Rio Chiquito Formation exposed for about 250 m along the bank. Since such slips may repeatedly occur, it is necessary to take some measures on the banks in order to stabilize the riverbed and to prevent erosion of the hilly areas of Barrio El Berrinche.

2.3 PREVENTIVE MEASURES FOR BARRIO EL BERRINCHE LANDSLIDE

As mentioned earlier, it is difficult and impractical to completely deter a huge landslide such as Barrio El Berrinche landslide. However, for better use of land in future in Barrio El Berrinche area, it would be necessary to clearly understand the mechanism of the landslide and to take effective measures against the landslide. Proposed below are possible countermeasures.

2.3.1 CATCHMENT WELLS

The routes of the underground water flow from hilly Barrio El Berrinche area are uncertain. The largest reservoir of the groundwater supplied from surface running water on landslide blocks is judged to be Block C. To block the water supply from the reservoir to the sliding plane of Landslide Block A is the most effective way to stabilize the landslide in Block A. However, the blocking and catching the ground water is difficult in the area, because the slope is steep and consists of rock debris. Under these circumstances, the locations of the catchment wells have been selected with consideration of the following conditions; the areas of abundant groundwater within Block A, the locations likely to become groundwater pocket (reservoir) during heavy rain, and valleys, natural canals, and streams that usually collect groundwater. In other words, the following facts have been taken into consideration; (1) nearby Observation well BS-5 installed by U.S. Army Corps of Engineers, SERNA, (2) there was abundant spring water observed at the south of Block A after Hurricane Mitch hit the area, (3) JICA borehole B-2, exhibiting the geology likely to become underground reservoirs, is a point to affect the movements of the Block A.

The locations of the catchment wells are shown in *Figure G.2.6*. *Figure G.2.7* illustrates structural details of the catchment wells. Major works and quantity for the water collection wells are as follows;

Type of work	Specification	Quantity
Relief well	ϕ 3.5m (30 m c/pieces)	8 (240 m)
Collecting boreholes	50 m ea., 5x2 levels, c/pieces, ϕ 66 mm	4,000 m
Drilling for drainage	ϕ 116 mm, SGP 90,100	About 600 m

2.3.2 DRAINAGE SYSTEM

It is effective and important against landslides to have drainage function as a part of surface water treatment, although the effect may not be quantified. This is to prevent the percolation of rain water or seeping water from spring and canal that may trigger landslides.

(1) Large Scale Conduits

In principle, the large-scale conduits should be planned so that the groundwater levels in the entire landslide areas can be lowered. However, in this area, the conduits are located along the existing river routes in order to effectively treat the surface water. The conduits use gabion wall. Structural details are shown in *Figure G.2.8*.

1) Conduit A

Conduit A is proposed along the route from the west boundary scarp to the meeting point with Conduit B at the south of Boel Chile. It is emphasized to extend the conduit to the west boundary scarp because tremendous amount of surface water runs down the slopes from hilly Cerro El Berrinche and Barrio Campo Cielo during heavy rain. Major works and quantity for the Conduit A are as follows;

Type of work	Specification	Quantity
Open and closed double drainage	About 4.0～5.0 m x 2.0 m Open canal above Gabion drain	610 m

2) Conduit B

Conduit B is proposed from the southwest to north east along the existing river routes at the central part of the landslide area. The Conduit B is an open canal from the meeting point with Conduit A and flows into the Grande or the Choluteca River.

Type of work		Specification	Quantity
Conduit Open and closed double drainage		About 4.0～5.0 m x 2.0 m Open canal above Gabion drain	470 m
Channel	Concrete	2.0 m x 2.0 m	200 m

3) Conduit C

Conduit C is proposed along the unlined canal constructed by the U.S. Corps of Engineers. This is to block the flow of the surface running water to the south of Colonia Soto.

Type of work	Specification	Quantity
Open and closed double drainage	About 4.0～5.0 m x 2.0 m Open canal above Gabion drain	350 m

4) Conduit D

This is an open canal to prevent erosion caused by running of the surface water on the slope of El Berrinche left bank along the Grande or the Choluteca River.

Type of work		Specification	Quantity
Channel	Concrete	1.0 m x 1.0 m	210 m

2.3.3 GABION (CANAL PROTECTION)

This is to install gabions on the hillside of the starting point of Conduit A in order to protect the canal from rock falls and collapses of earth from the landslide scarps and to maintain its function.

Type of work	Specification	Quantity
Gabions (Canal protection)	Gabion: width1.0 m x height 1.0 m (3 layers) x length 2m	50 m (75 Nos. of gabion)

2.3.4 REMOVAL OF SOIL AT HEAD OF SLIDING MASS

In order to increase the stability of the landslide, soil at the head of the sliding mass will be removed as shown in *Figure G.2.9*. The part of the soil to be removed is Block C, which consists of boulders and soil materials fallen from the crown of the landslide. It is necessary to provide drain ditches at the toe of the cut slope.

Type of works	Area, Specification	Quantity
Removal of earth	About 22,000m^2	About 22,000 m^3
Channel	0.8 m x 0.8 m	675 m

2.4 STABILITY OF EL BERRENCHE LANDSLIDE

With an assumption that the factor of safety of the existing slope condition is 1.0, the factors of safety after the completion of counter measures was evaluated in this section. The stability evaluation is carried out based on the existing terrain conditions, monitored ground water level, the estimated location of the sliding surface, the results of the field reconnaissance, borehole results and other information.

(1) Geological section B-4

Conditions: a. A continuous sliding surface through A1, A2 A3 is considered.

b. The highest ground water level monitored is assumed.

c. The back calculation of the stability is based on the parameters below:

$c = 25.0$ kN/m^2 (c : cohesion -- fixed)

phi = 5.8814 degrees (phi : angle of internal friction)

The stability after completion of the countermeasures

a; After lowering the ground water level by 5 m with a catchment well

Fs = 1.051

b; After removal of soil mass (1,600 m2 in section) at the head of the sliding mass

Fs = 1.112

a+b; Combination of ground water lowering and removal of soil mass

Fs = 1.170

Separate countermeasures against the landslide at the toe of Block B and Block A3 on the left side bank of Rio Chouluteca will be analyzed as a river bank protection works.

3. BARRIO EL REPARTO

3.1 OUTLINE OF THE LANDSLIDE

Topography of El Reparto varies from (1) steep slopes from western high land areas of Cerro El Picacho to eastern Picacho road, (2) to gently undulating hills eastward from Picacho road where the topography changes, and (3) to steep cliffs of 10 to 20 m in height further eastward down to the main valley of El Reparto. The hilly areas consist of old landslide blocks and debris deposits derived from the steep cliffs of El Picacho.

The geology of nearby Picacho hilly areas is Tpm Rhyolite and tuff, while whitish tuff dominates this area. Rio Chiquito Formation is distributed at the eastern part of El Reparto and toe portions of the landslide. Rio Chiquito Formation is probably present at the bottom of the landslide and is considered to affect the slide activities.

The landslide is Slump type with about 200 m in length from the landslide scarp to the toe and 150 m in width. The damage extended as a second disaster because debris flows from the landslide blocks were spread over wide areas.

3.2 LANDSLIDE BLOCKS

As shown in *Figure G.3.1*, Barrio El Reparto landslide is divided into (1) Block E that is an old landslide block consisting of debris deposits derived from Cerro El Picacho, (2) Block A saturated with plenty of groundwater when hit by Hurricane Mitch, (3) Block B that is the scarp at the top of the landslide, (4) Block C that is major moving block, and (5) Block D that moved as debris flow. The landslide is judged to be a typical type of Debris landslide based on its shape. The geology at the base of the landslide is expected to be weathered zone of Rio Chiquito Formation judged from the surrounding geology. Most portion of the moving block consists of colluviual deposits from Tmp rhyolite and tuff. The profile of Reparto landslide area is described in *Figure G.3.2*

The scarp at the top of the landslide extends to west side scarp and forms very steep cliff. The east side scarp is distinct near the top of the landslide showing steep cliff, but the scarp is unclear toward the toe of the landslide.

Water springs are observed (1) at the toe of the colluvial deposits in Block E along a stream from El Picacho, (2) at the bottom of the west side scarp near the top of the landslide, and (3) at the slope nearby the pond beside west side scarp in Block C. Attention should be paid to the ponds in Block C because the amount of the inflow of the surface water is significantly large.

3.2.1 CAUSES OF THE LANDSLIDE

The area is of a large-scale landslide. A portion including Block E is an old landslide area. The areas with the landslide caused by Hurricane Mitch have signs of previous landslides; at least several landslides, albeit small, after the road was constructed and the ponds were formed. The causes of the landslide are expected to be combination of the followings in consideration of the above facts;

1. The colluvial deposits from El Picacho hilly areas and the old moving blocks contain large amount of tuff that makes the slope unstable.
2. The ground became saturated by the supply of plenty of surface and groundwater by Hurricane Mitch in addition to already abundant supply of the groundwater from El Picacho.
3. As an artificial cause of the landslide, the stream that was present on the east edge of the

landslide disappeared due to artificial modification to a small drain.

4. Flow of the surface and groundwater was blocked by the construction of the road at the toe of the landslide area resulting in creation of the ponds.
5. The side drains of Picacho road are too poorly constructed to receive the vast amount of the water from the road surface as well as the surface water from the hillside.

Among the above causes, item 3 - creation of the pond - is considered to be the most important factor to enhance softening of the bottom of the landslide block.

3.3 COUNTERMEASURES AGAINST BARRIO EL REPARTO LANDSLIDE

3.3.1 BASICS FOR COUNTERMEASURES AGAINST BARRIO EL REPARTO LANDSLIDE

The following scenarios are expected for the landslides in Barrio El Reparto.

1. At Block B, the scarp will collapse resulting in more stable slope.
2. At Block C, re-activation of the moving landslide block.
3. At Block D, re-outflow of the debris deposits.
4. At Block A, the top of the landslide becomes unstable.

With the consideration of the above scenarios, the following countermeasures are proposed as major works.

1. To stabilize the scarp of the landslide including the side scarp by cutting it to a gentler slope, providing drains and turfing.
2. To rapidly drain the surface water by improving drains and providing catchment wells in order to stabilize the moving landslide block and Block A.
3. To install gabions, drains and turfing as a trap of earth in order to stabilize the debris flow deposits (Block D).

The countermeasures proposed here are basically passive control methods with expected factor of safety of 1.1 to 1.2. Among the above proposed methods, only the groundwater lowering with the use of the catchment wells, and cutting and trimming the slopes directly contribute to improve the factor of safety in terms of numerical values. However, the surface drainage is expected to considerably increase the stability of the slope in this area, although the improvement may not be illustrated by numerical values.

3.3.2 CHANNELS

The best defense measure is to quickly and smoothly drain the surface and groundwater that jeopardize the slope stability to outside the slope. Propose Channel Ds are shown in *Figures G.3.3* and *G.3.4*.

(1) Channel A

This is to provide Channel A along the hillside of Picacho road. The existing road has a ditch to receive only the water from the road surface, but there is no facility to receive surface water running down the long slope of Picacho hills during heavy rain.

Channel A	Type of Works	Specification	Quantity
A	Concrete	1.0 m x 1.0 m	600 m
	Culvert box		3 nos.

The culvert box will be installed across the road to drain the water from Channel A on the hillside to Channel B on the valley side.

(2) Channel B

Channel B works as transition channel for the water coming down from Picacho valleys through the culvert under the Picacho road leading to Channel C and Conduit Cd1.

Channel B	Type of Works	Specification	Quantity
B1, B2	Concrete	0.8 m x 0.8 m	100 m each, 200 m in total

(3) Channel C

This channel almost runs along the existing river routes on the western edge of the landslide area from Picacho road. This channel is important because it passes through the natural canal that disappeared due to the artificial modification of the land and the ponds that were formed by the road construction. Since the slope of the channel is very steep, reservoirs will be provided at two locations to reduce the flow velocity of the water running inside the channel and to behave as flood control reservoir.

Channel C	Type of Works	Specification	Quantity
C	Concrete	1.0 m x 1.0 m	750 m
Reservoirs	Concrete	15 m x 20 m x 2 m	3 locations

(4) Channel D

All the water from the landslide area within the main valley of El Reparto is collected to this channel through other channels. During Hurricane Mitch, the debris flowed along this channel. After Hurricane Mitch, the upstream part of the channel does not function as channel.

Channel D	Type of Works	Specification	Quantity
D1	Concrete	1.2 m x 1.2 m	260 m
D2	Concrete	1.5 m x 1.5 m	150 m
D3	Concrete	0.5 m x 0.5 m	110 m

The Channel D3 is to receive the water from Conduits Cd2, Cd3, and Cd4 that discharge surface and groundwater from debris flow deposits.

3.3.3 CONDUITS

The Conduit Cd1 is a large, open subterranean drainage having two functions; as a canal to receive the water from Picacho road and the surface water from valleys in El Picacho area through B1 and B2; and as Conduit A to discharge shallow groundwater that comes from hill sides of El Picacho through talus deposits. The Conduits Cd2, Cd3 and Cd4 are intended to prevent movements of the earth by discharging the surface water from Block D that was shifted and buried under debris flow. *Figure G.3.5* shows the concept of the structures.

Conduits	Type of Works	Specification	Quantity
Cd1	Gabions, concrete, pipes, water proof membranes	3.0-2.0 m x 2.0 m	350 m
Cd2	Gabions, concrete, pipes, water proof membranes	1.5 m x 1.5 m	220 m
Cd3	Gabions, concrete, pipes, water proof membranes	1.5 m x 1.5 m	200 m
Cd4	Gabions, concrete, pipes, water proof membranes	1.5 m x 1.5 m	110 m

3.3.4 CATCHMENT WELLS

The ponds appear as a result of groundwater gathered to the bottom of the landslide block seeping abundantly from foots and slope of Picacho hills as well as the surface water seeping from zones of previous valleys that disappeared after artificial modification of the land. Springs are also present at other locations. Therefore, the groundwater lowering method is judged to be very effective to stabilize the landslide.

The area around the top of Block C is judged to be most effective for the locations of the catchment wells because the amount of the spring water there is significant.

Type of Works	Specification	Quantity
Relief wells	ϕ 3.5 m x 15 m in depth	1
	ϕ 3.5 m x 10 m in depth	1
Collecting boreholes	50 m ea., ϕ 66 mm	1000 m
Drilling for drainage	ϕ 116 mm, SGP90	230 m

3.3.5 CUTTING, TRIMMING AND SLOPE PROTECTION

The scarp at Block B is the most unstable portion in the landslide with potential danger of collapse due to rain and movements of the collapsed earth.

The measure proposed to improve the stability is to cut and trim the scarp to approximately 1: 1.2. The scarps on the side of the landslide are also cut and trimmed in order to match the shape and elevation of the topography (Some of the houses located along the eastern side scarp have to be relocated). The slope protection methods include berm, transverse drainage, longitudinal drainage and hydro-seeding.

Type of Works	Area	Quantity
Removal of earth	About 150 m x 100 m	About 25,000 m^3
Slope protection	About 100 m x 50 m	About 5,000 m^2

In addition, it is proposed to install the gabion for 100 m section as a part of the slope protection methods in order to protect Channel C located below the east side scarp of Block C from the collapsing earth. Also, 3 layers of the gabion are proposed at the end of Block D in order to prevent loss of earth from erosion.

Slope protection	Type of Works	Specification	Quantity
Protection of Channel C	Gabions	1 m in width, 1 m in height, 2 m in length, 3 layers	100 m (150 Nos.)
Toe protection of Block D slope	Gabions	1 m in width, 1 m in height, 2 m in length, 3 layers	560 m (750 Nos.)

3.3.6 RESTORATION OF ROADS

It is proposed to restore the roads damaged by Hurricane Mitch and to use them for the above construction works.

Road paving		Specification	Quantity
R1 road	170 m	6 m in width	1,020 m^2
R2 road	220 m	6 m in width	1,320 m^2

3.4 STABILITY OF BARRIO EL REPARTO LANDSLIDE

With an assumption that the factor of safety for the existing slope condition is 1.0, the factor of safety after the completion of the countermeasures (preventive measures) was analyzed. The analysis was carried out based on the existing terrain conditions of El Reparto landslide, the geological conditions revealed in the site reconnaissance, condition of the ground water, the results of exploratory borings and other information.

(1) Geological Section O – O’

Conditions: a. The terrain conditions are the same as those in the existing conditions.

b. Ground water level is estimated based on the field observation in the site reconnaissance and the results of exploratory borings.

c. The soil parameters assumed are as follows:

$c = 14.3$ kN/m^2 (c : cohesion --- fixed)

phi = 10.994 degrees (phi : angle of internal friction)

Countermeasures

a. Trimming of soil at the head of the sliding mass

Fs = 1.090

b. Lowering of ground water level with catchment well (with the trimming mentioned above)

Case with a lowering by 5m (at GL-10.0 m) Fs = 1.272

Case with a lowering by 3m (at GL-8.0 m) Fs = 1.205

A factor of safety of 1.2 can be maintained with a combination of (a) the trimming at the head of the sliding mass and (b) the lowering of the ground water level with the catchment well.

4. EL BAMBU

4.1 OUTLINE OF THE LANDSLIDE

This landslide was caused by Hurricane Fifi in 1974, but no significant movements were reportedly observed during Hurricane Mitch. However, as the surface water from upstream areas concentrating to the Bambu River (unlined canal) that runs through the central part of the Study Area, the river has been subjected to severe scour and erosion due to its steep inclination, and has been forming 3 to 7 m high cliffs, many of which have collapsed. People are afraid of the huge amount of the collapsed earth to flow down the river.

The landslide is about 300 m in length from the scarp to the toe. The scarps are a crescent to semicircle in shape and forms two steps (one step is at the slump portion?) with about 200 m in length and 15 to 25 m in height. This landslide is very steep compared to other typical landslides. The shape is like a ladle with a circular shape at lower part.

4.2 GEOLOGY

The geology of the landslide area above the head scarp is whitish tuff of Ignimbritic Formation (Tpm3). Below the scarp is a moving mass of earth consisting mostly of weathered whitish tuff. At the lower part of the landslide, clay of Rio Chiquito Formation is observed. All of them are rapid in slaking when subject to repeated occurrence of shrinkage crack and softening by water absorption.

The shape of the sliding plane is uncertain. However, the landslide, having the closed, circular shape at the toe as explained above and having changed the way the water is supplied to the sliding plane after the slide took place by Hurricane Fifi, seems to be inactive (sleeping?) at present.

The immediate issues at the area at present are scour and erosion likely to be caused by rapid flow of water running down the steep the Bambu River (canal), and resulting collapse of river banks and flowing-out of the collapsed earth. In order to prevent the scour, erosion and outflow of the earth, and to conserve the land of El Bambu area, it is urgently required to prepare and take countermeasures.

4.3 CONSIDERATION OF COUNTERMEASURES AT EL BAMBU AREA

Flow of water is observed at the eastern top of the landslide at good weather condition with small amount of spring water and certain amount of miscellaneous water.

There are side drains constructed with stonewalls along PICACHO road that leads from the north east of the Bambu area to El Picacho. The water may usually seep into the ground from the drains, but considerable amount of water seems to flow into the Bambu River running through the drains at the time of large amount of rainfall. Deep gorges have been formed by erosion of soft soil along the steep river due to the inflow of large amount of water, even though it happens temporarily. Therefore, the measures to halt the erosion should have the first priority.

- Since the landslide is considered inactive at present, any changes in natural and artificial conditions (conservation of the topography, drainage conditions, etc.) should not adversely affect the landslide.
- Influence of the surface water shall be lightened by providing temporary canals to flow the surface water and to prevent erosion at the time of heavy rain.
- In the future, a regional drainage plan including the Bambu area should be established so that the surface water does not concentrate to the Bambu River (canal), even at the time of heavy rain.
- Since the present inclination of the Bambu River (canal) is difficult to change significantly, the present topography of steep, gorge-like slopes should, instead, be changed to more gentle slopes and the land use plan for the gentle slope area should be established. For example, a wooded area combined with earth retaining fence, wicker works and planting trees should be studied. It is advisable for better performance to include the tree planting scheme presently implemented by grass-roots movement (NGO).

4.4 COUNTERMEASURES

4.4.1 CHANNEL AND RECESS (RESERVOIR)

Against the potential collapse on both sides of the gorge-like canal and the outflow of the collapsed earth, installation of gabions is proposed to maintain the function of the canal. Also, recesses (reservoir) are proposed at 3 locations to reduce the velocity of the flow. *Figure G.4.1* shows the location map of the structures and *Figure G.4.2* shows the concept of the structures.

Type of work	Specification	Quantity
Channel	Concrete 1.0 m x 1.0 m	260 m
	Gabions (260 m x 2) x 1/2 x 3 layers	1,580 Nos.
Recess (reservoir)	Concrete 3.0 m x 5.0 m x 2.5 m	3 locations
	Gabions (2+5+5+2) x 3 layers	72 Nos.
	About 24 Nos. x 3	

4.4.2 TREATMENT AT END OF CHANNEL

In order to prevent rapid outflow of the earth in the landslide are Channel A-end- structures are proposed with gabions (3.0 m in height and 10.0 n in length) and Hume pipes placed downside. *Figure G.4.2* shows the planed structure.

Type of work	Specification	Quantity
Gabions at the end of the channel	Gabions 3.0 m in height, 10.0 m in length	20 Nos.
	Hume pipes ϕ 1,350 mm x 2	2 Nos.

5. SUPPLEMENT

5.1 BORING WORKS

Boring works were carried out to investigate the mechanism of the landslide for the planning of the preventive measures for the landslide. At El Berren, 16 boreholes were sunk for the purposes with a total drilling length of 450m. The contents of the boring works were as follows:

- Boreholes for groundwater monitoring
  3 boreholes, B-8, W-1 and W-2
- Boreholes for measurement of displacement in the ground (Inclinometer)
  8 boreholes, B-1, B-2, B-3, B-4, B-5, B-6, B-7 and B-9
- Boreholes for soil investigation
  5 boreholes, C-1, C-2a, C-2b, C-3 and C-4

At El Reparto, 6 boreholes were sunk with a total drilling length of 150m as follows:

- Boreholes for groundwater monitoring
  3 boreholes, R-1, R-3 and R-5
- Boreholes for measurement of displacement in the ground (Inclinometer)
  3 boreholes, R-2, R-4 and R-6

The borehole results were very useful to reveal the stratification and geological structure at the site and to understand the mechanism of the landslide. The monitoring period of the groundwater in this study was 2 months and was rather short. However, we understand that the government of Honduras will continue the monitoring of the groundwater behavior and the results of the monitoring will greatly contribute to the better understanding of the mechanism of the landslide. All the results of the boring works are presented in the Data Book.

5.1.1 GROUNDWATER

The following is noted on the results of the JICA boring works:

1) El Berrinche

Boreholes B-1, W-1, B-2 and W-2 are located at the north edge of the main sliding block of the landslide. The area of these boreholes was once depressed by the landslide and filled later to patch up to the original level. The soils found from the ground level to depths of 15 to 26m are the materials backfilled the depression. The backfilled soils are rather loose with fairly large voids and rhyolite boulders. The groundwater level in this layer was low at the time of the boring. However, the groundwater level will rise rapidly after a heavy rain and the layer will hold a large amount of water, just like a reservoir. In some places such as the locations of boreholes B-3, B-6 and B-8, thick debris is deposited and layers of clay are sandwiched in the debris. Several aquifers are apparently found in such places because of the impervious clay layers sandwiched in the debris. However, drilling through the clay layers usually makes the difference in water heads in the aquifers much less. The long-term monitoring of the groundwater will greatly help understand the behavior of the groundwater and its effects on the landslide behavior.

2) El Reparto

The groundwater levels in all the boreholes except for R-1 and R-6 were encountered relatively shallow. The water levels in the deeper layers were often found at much lower depth because the drilling penetrated the impervious clay layers. However, it may be appropriate to assume a shallow groundwater level for the analysis of the landslide behavior, based on the conditions of the surface water and the topographic feature of the landslide.

At the location of borehole R-1, the subsoil consists of fairly dense debris of the old landslides and Tuff of Teg. There is stream of water in a small valley nearby the borehole. However, the groundwater level in the borehole was rather deep at 17.3m below the ground level.

5.1.2 DISPLACEMENT IN THE GROUND

Based on the results of measurement in all the 13 inclinometer boreholes in El Berrinche and El Reparto, no clear displacement due to the landslide was observed in the monitoring period. The main reasons for this are considered that (1) the monitoring period was short and (2) rainfall in the monitoring period is insignificant. Some apparent displacements were registered in some of the inclinometer boreholes. However, they were the apparent displacement measured in the initial stage of monitoring when the contact between the inclinometer casings and ground became stable. In the inclinometer boreholes in SERNA, the only one inclinometer borehole, BS-4 (INCL-2), registered the noticeable sliding displacement in the ground. The borehole BS-4 is located on the Hanger Structure in the upper part of the sliding mass and the sliding movement caused by Hurricane Mitch has not stopped completely yet.

5.2 SURFACE WATER DRAINAGE WORKS

Discharge of surface water of Berrinche, Reparto and Bambu sites is estimated by use of rational formula as shown in the following table.

Site	A (km2)	f	R (mm/h)	Q (m3/s)
Berrinche	0.7	0.9	20	3.5
Reparto	0.56	0.9	20	2.8
Bambu	0.12	0.9	20	0.6

Drainage channel sections are determined by run-off calculation. Those sections are enough against rainfall intensity of 1/50 years.

Drainage channels have ground sill at 20 - 30 m intervals and foot consolidation is constructed at the ends of each drainage channel and confluence channels.

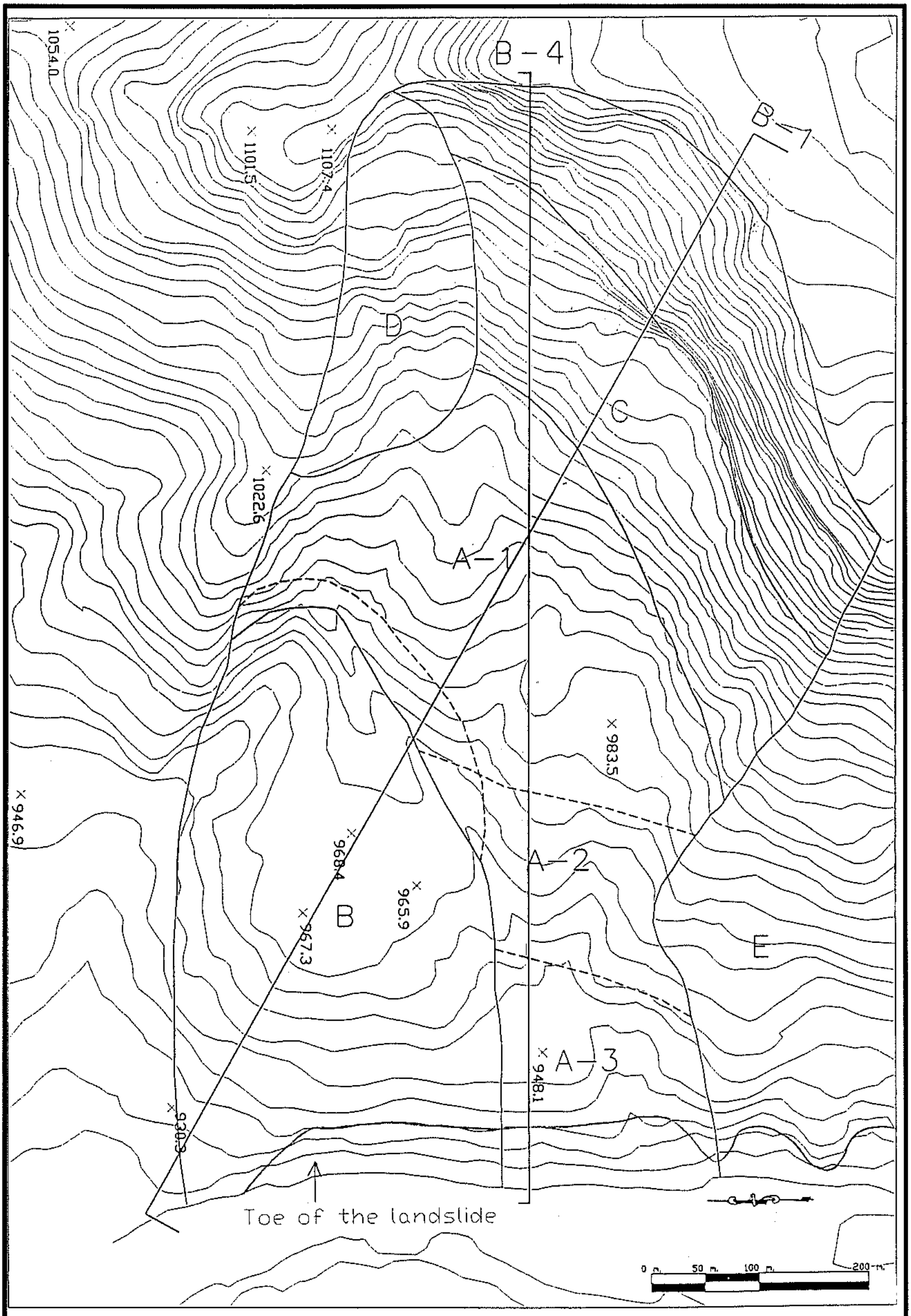


Figure G.2.1	Landslide of Several Blocks (El Berrinche)

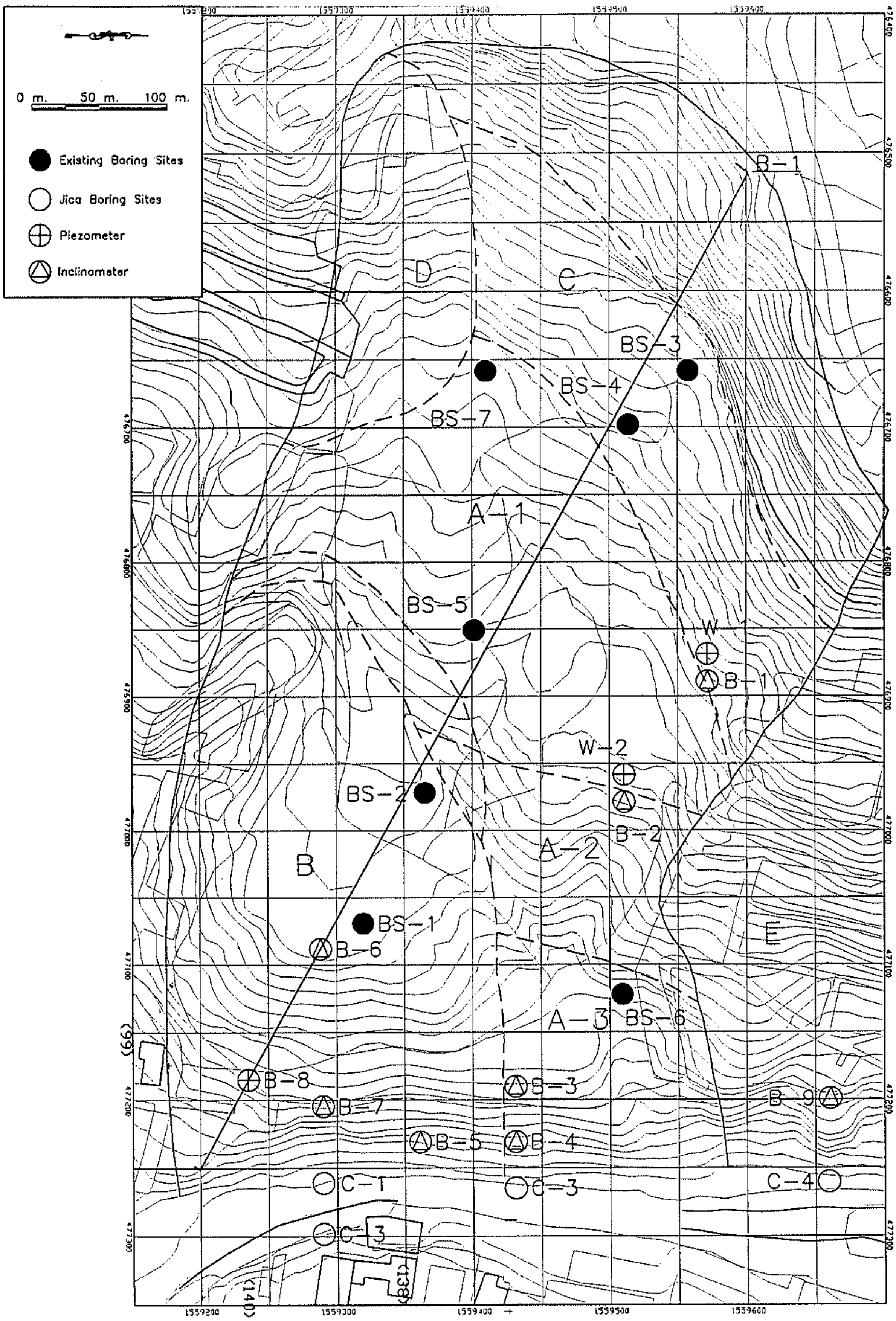


Figure G.2.2	Landslide of Several Blocks and Boring Positions (El Berrinche)

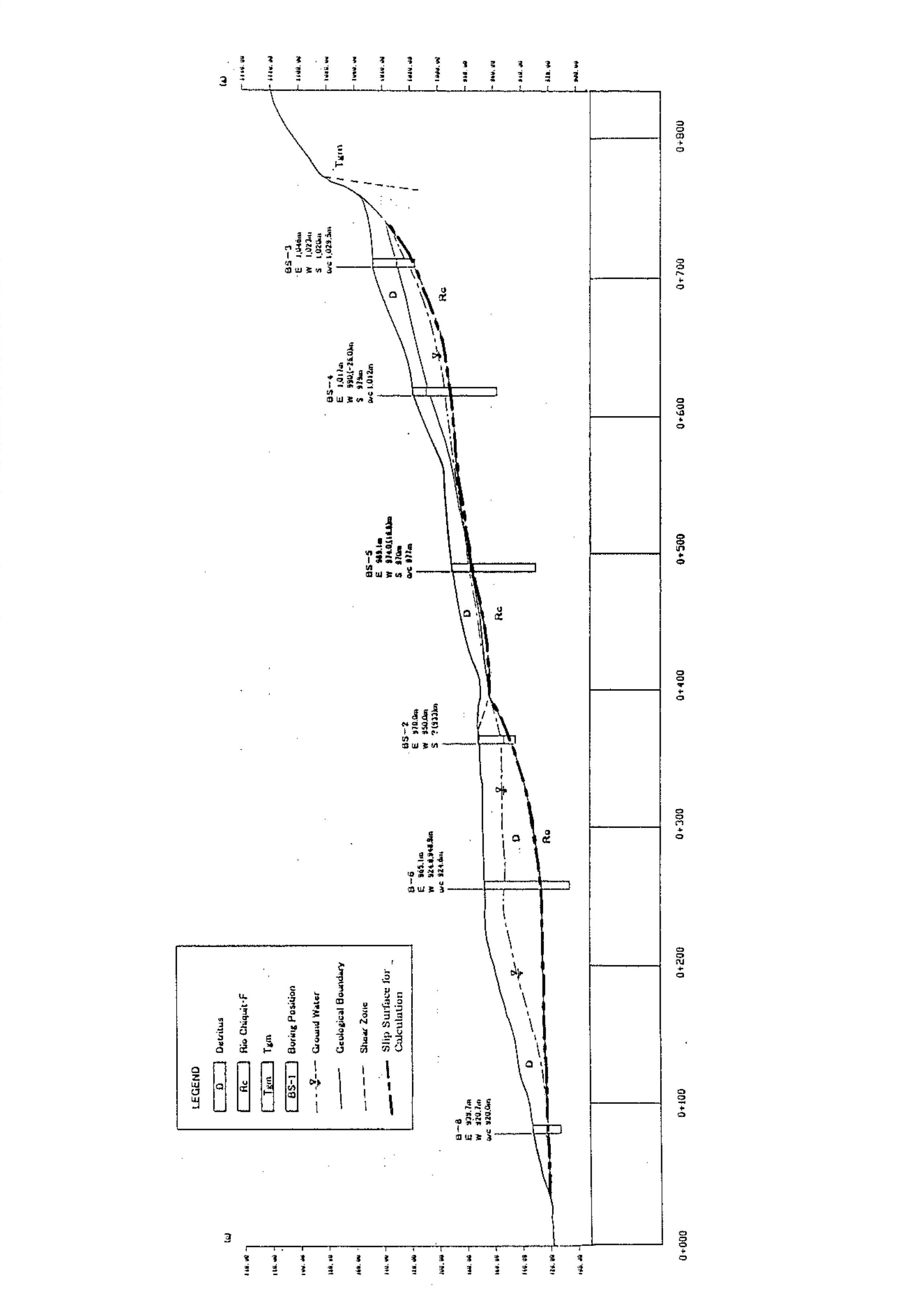


Figure G.2.3	**Profile of El Berrinche (Section B-1)**

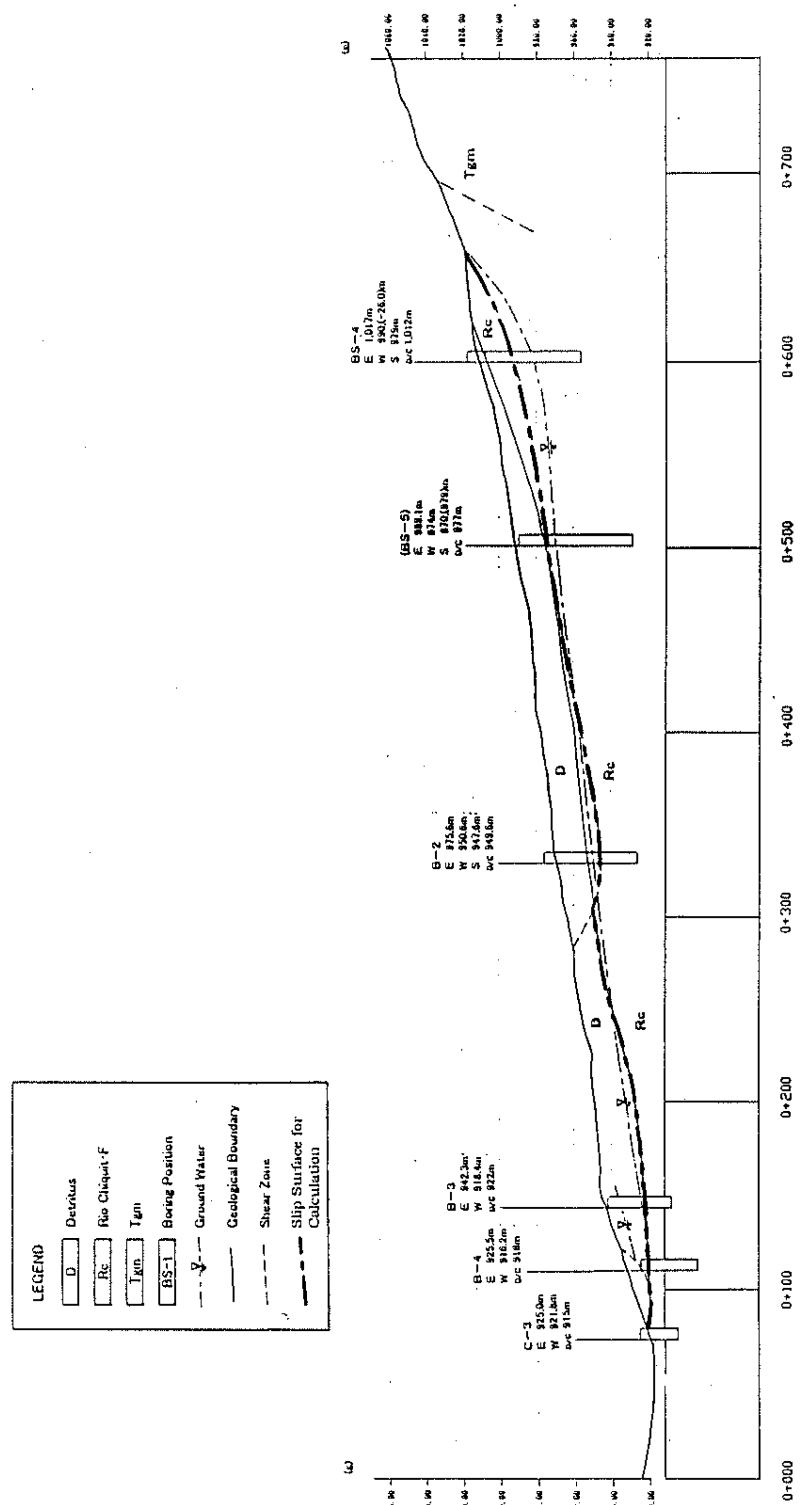
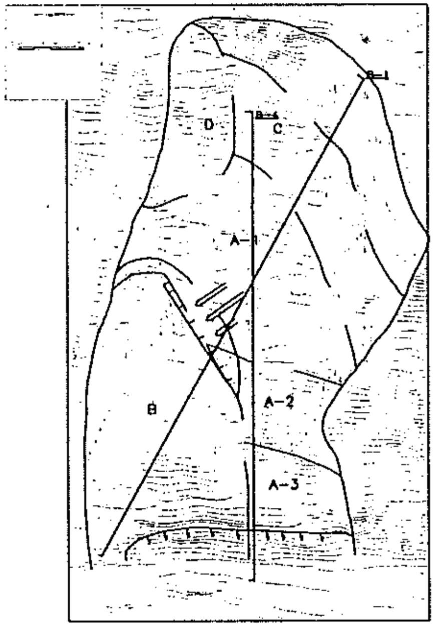
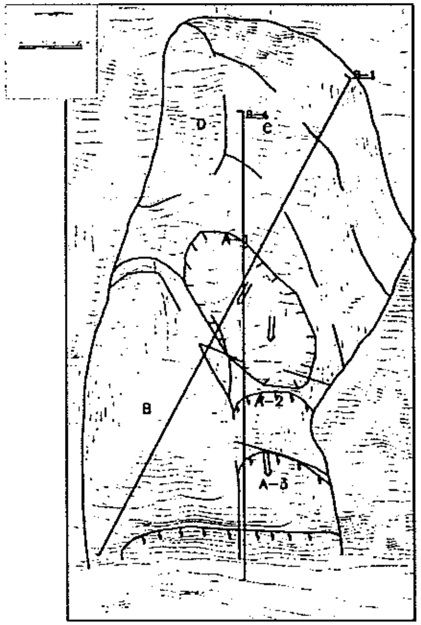


Figure G.2.4	Profile of El Berrinche (Section B-4)



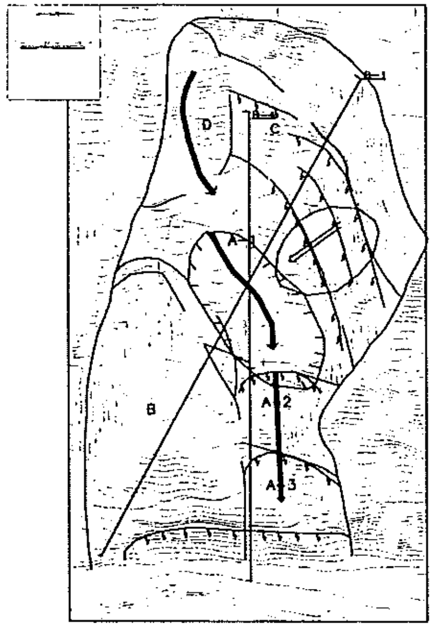
I

When the Hurricane Miche came,
the landslide block A-1 began to
move toward B block.
The landslide block A-1 compressed
the block B, then the toe section of
block B where confront to the Rio Choluteca
began to collapse.
This landslide start to
obstruct the flow of Rio Choluteca.



II

The landslide block A-1 changed
its movement direction toward the block A-2,
the block A-2 pushed the block A-3,
the block A-3 slide toward Rio Choluteca,
Then the block A-3 began to collapse
into Rio Choluteca.
The obstruction of river flow began to increase.



III

The landslide block C began
to move to landslide A-1.
Mud and Debris flow from block D
flows into the Rio Choluteca

Figure G.2.5 | **Progression of Landslide (El Berrinche)**

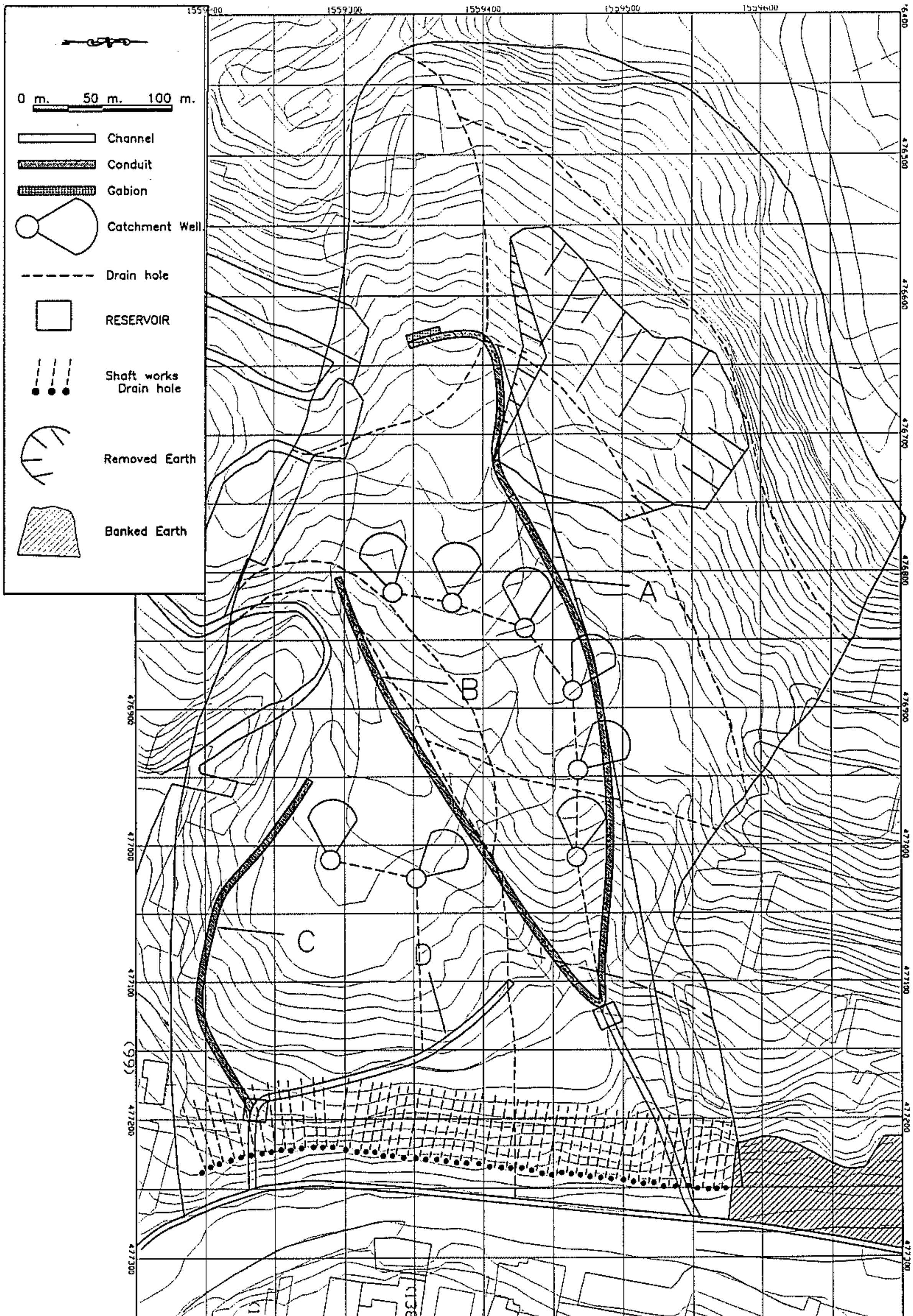


Figure G.2.6	Planned Countermeasures (El Berrinche)

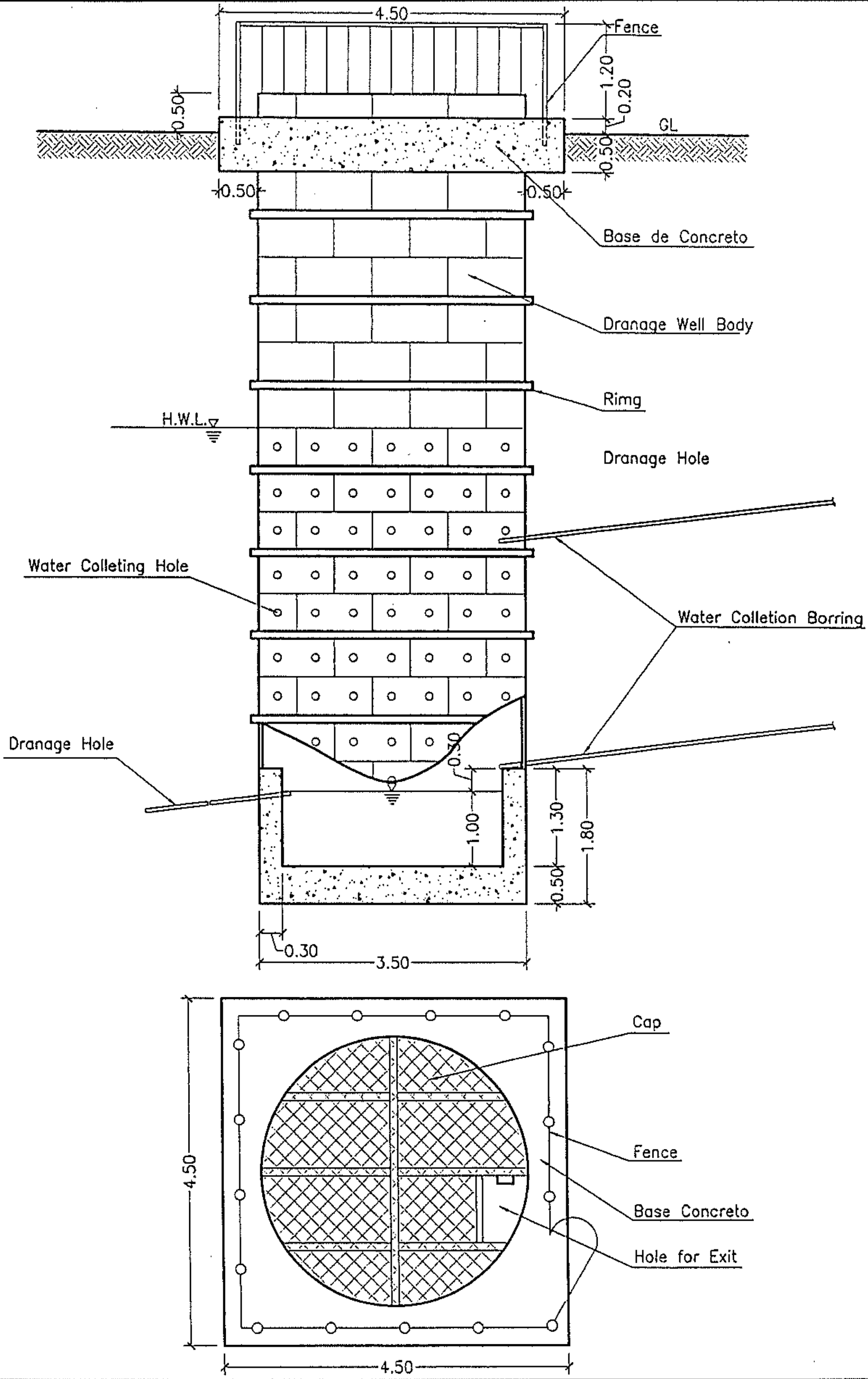


Figure G.2.7	Catchment Well

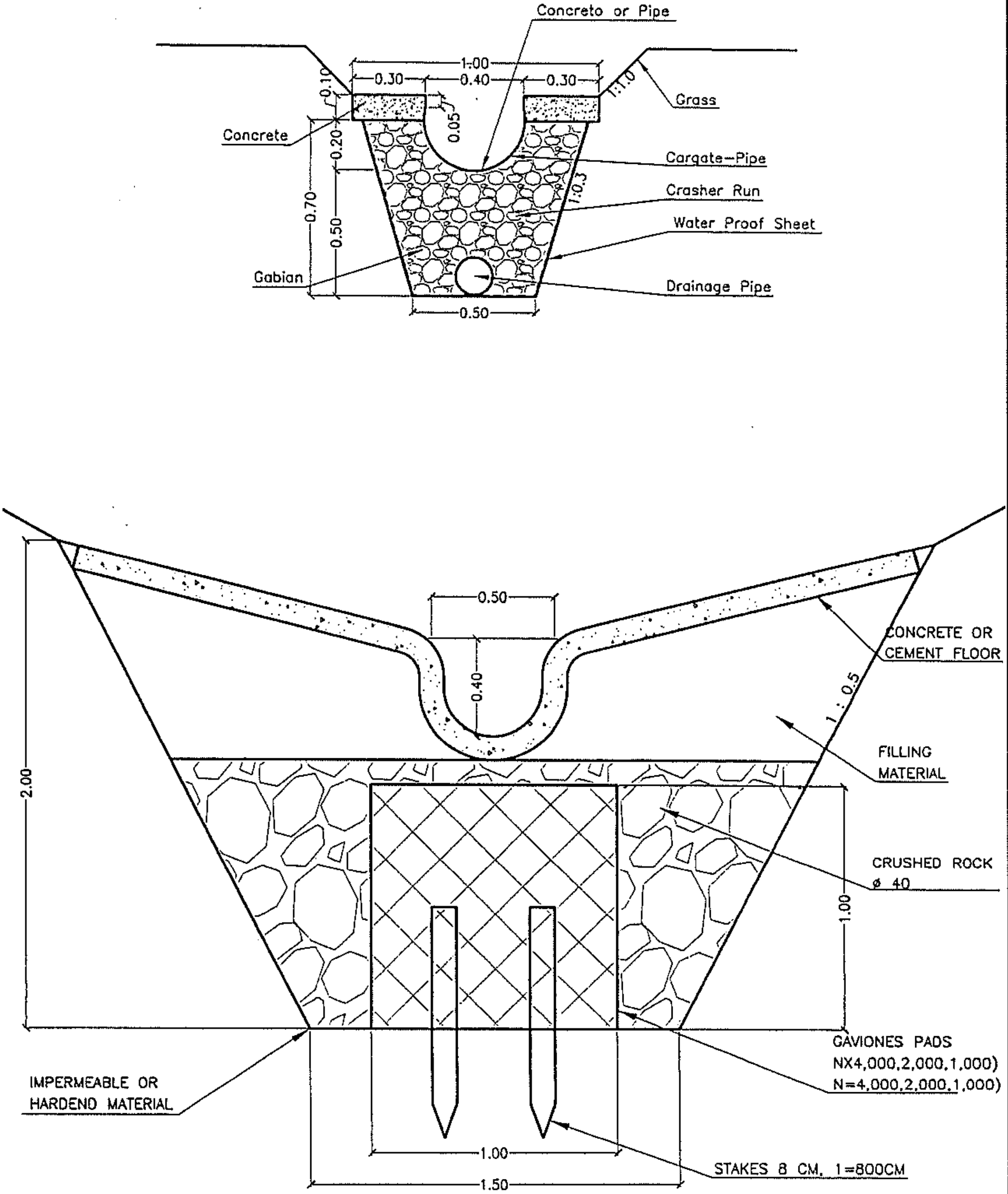
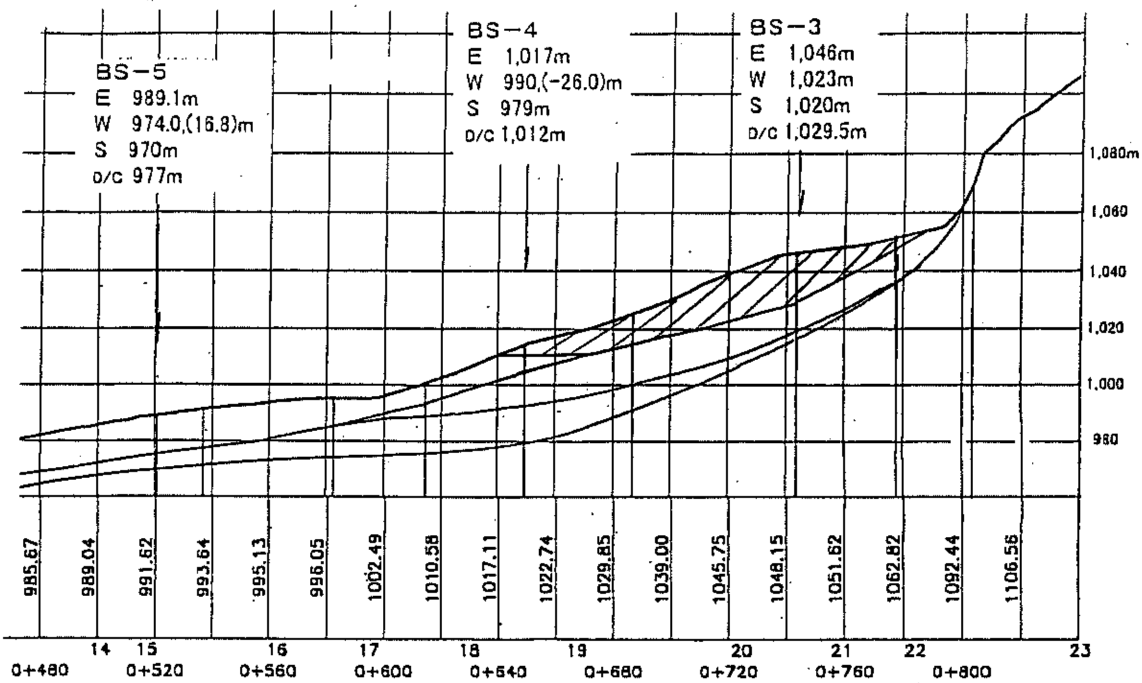


Figure G.2.8	Conduit



Removal Earth Area 1. (Cross Section B − 1)

Figure G.2.9	**Profile of Removal Earth Area (El Berrinche)**

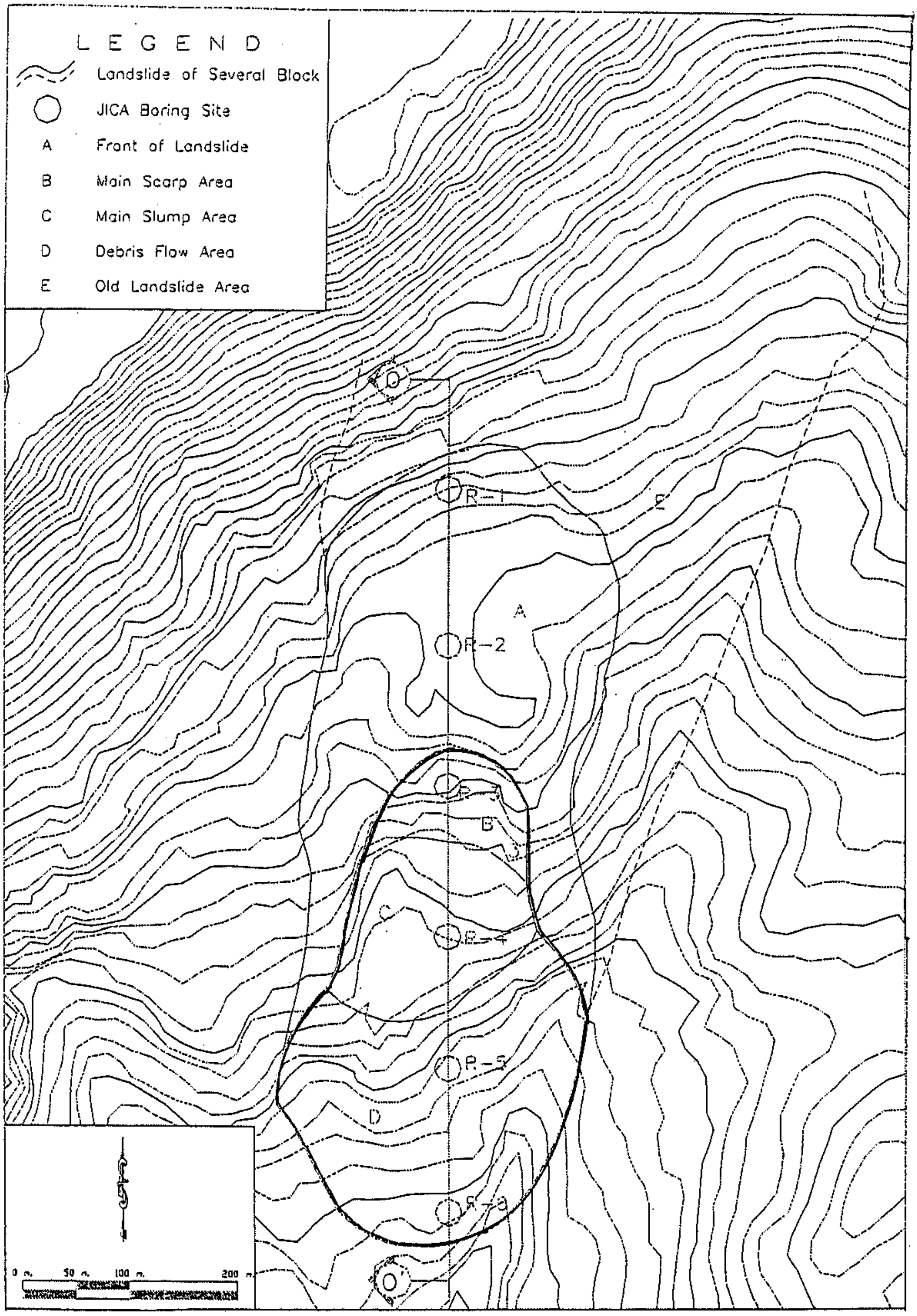


Figure G.3.1	Landslide of Several Blocks (El Reparto)

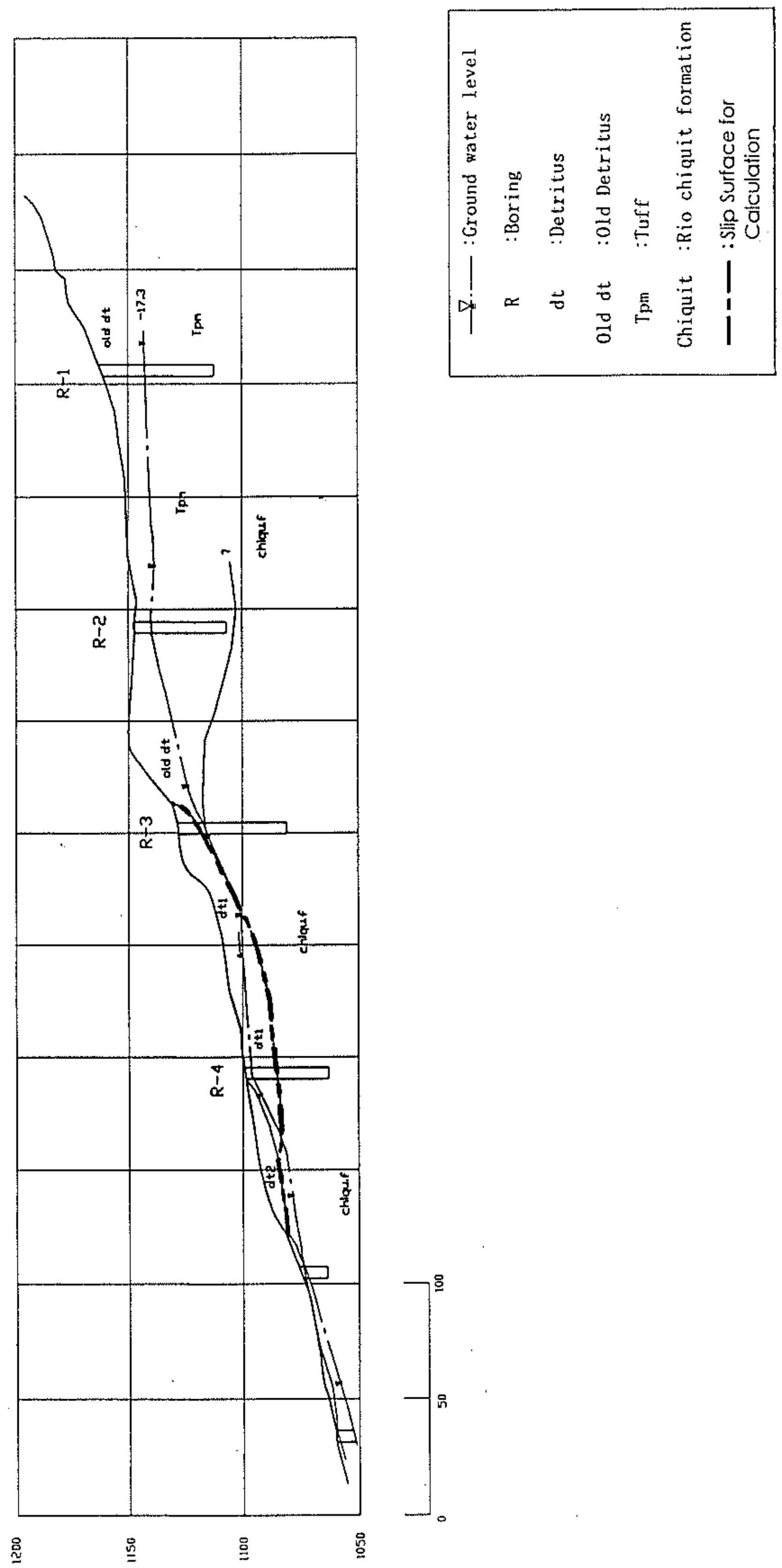


Figure G.3.2	Profile of El Reparto

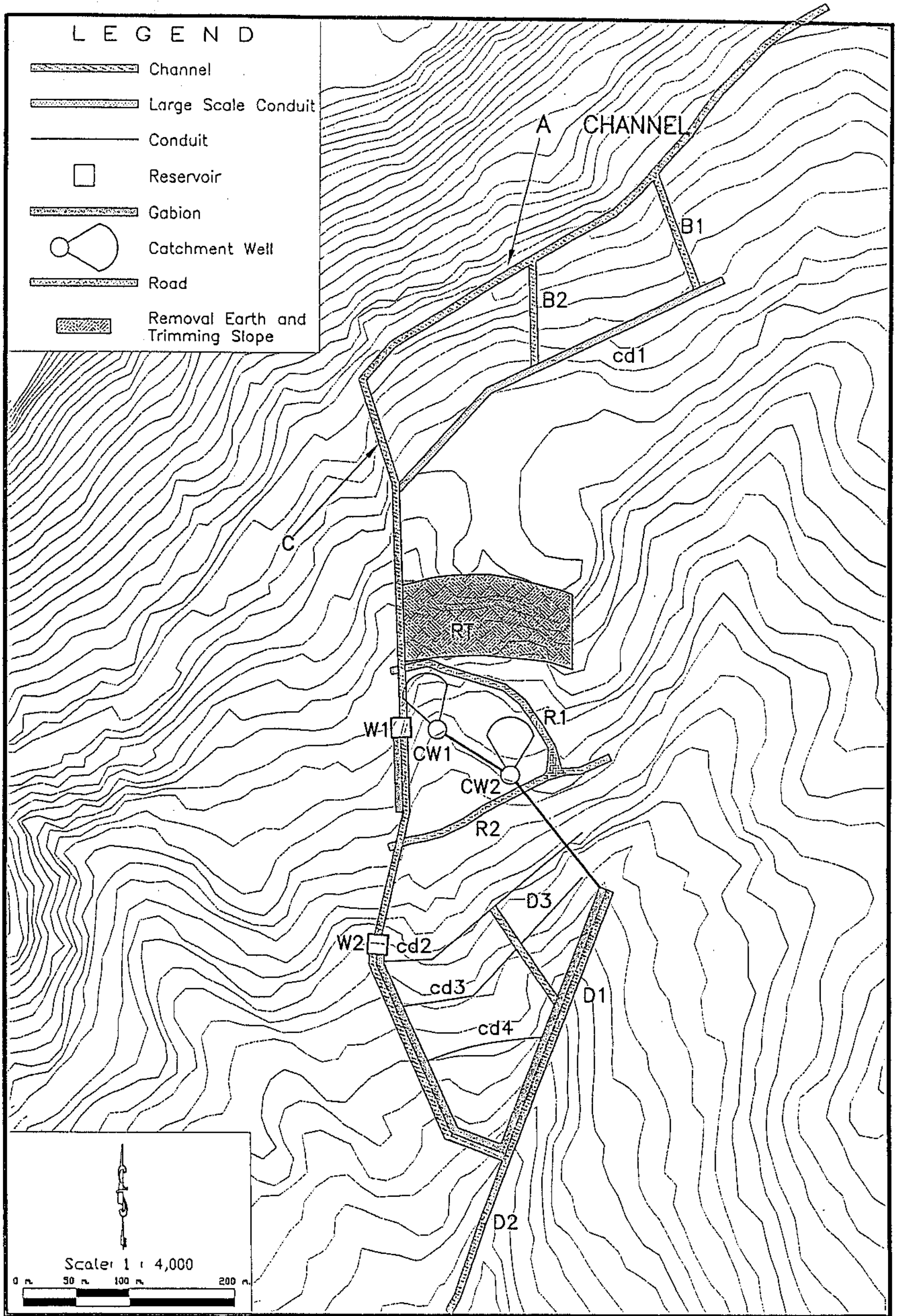


Figure G.3.3	Planned Countermeasures (El Reparto)

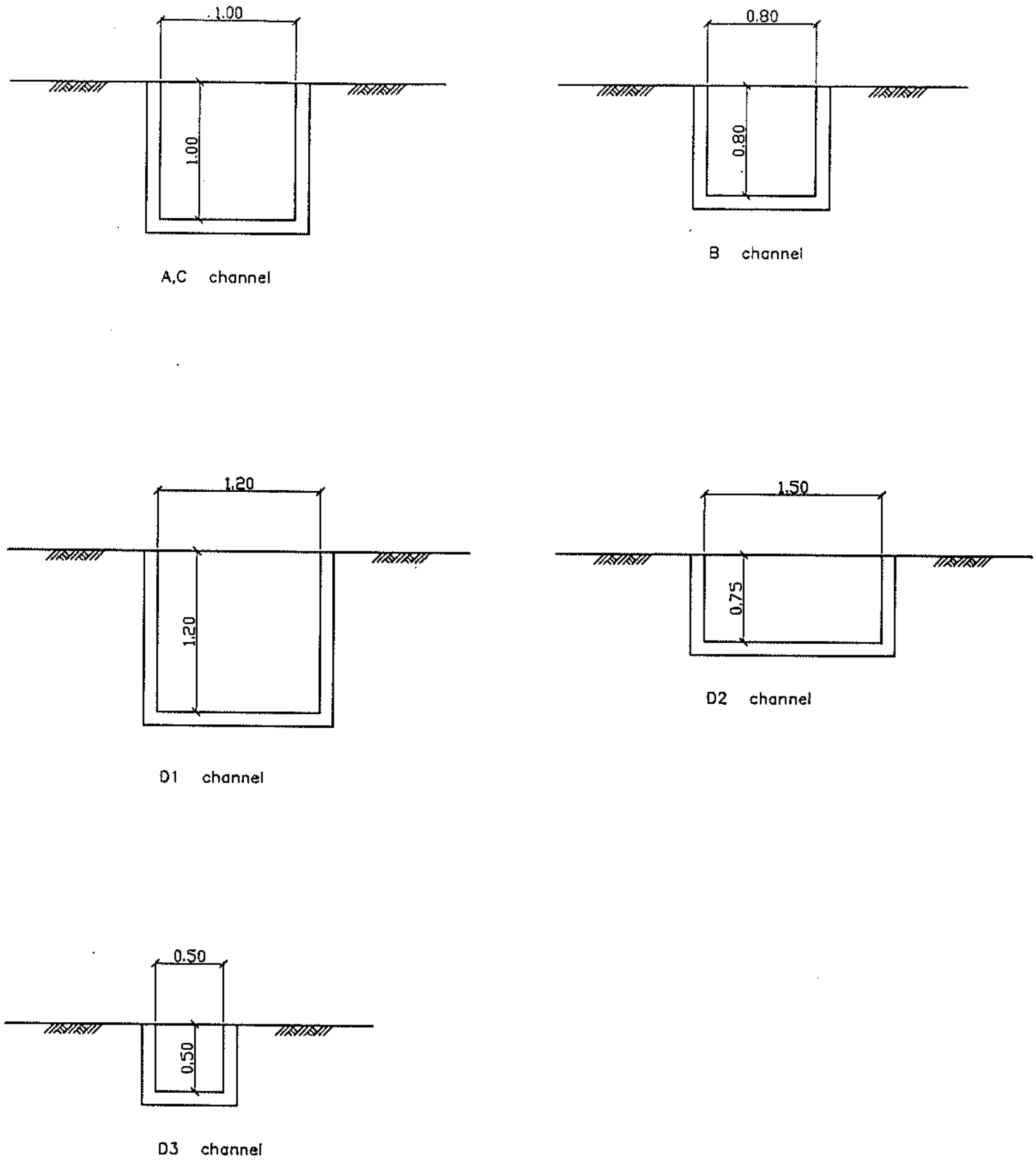


Figure G.3.4	Planned Structure of Drainage System

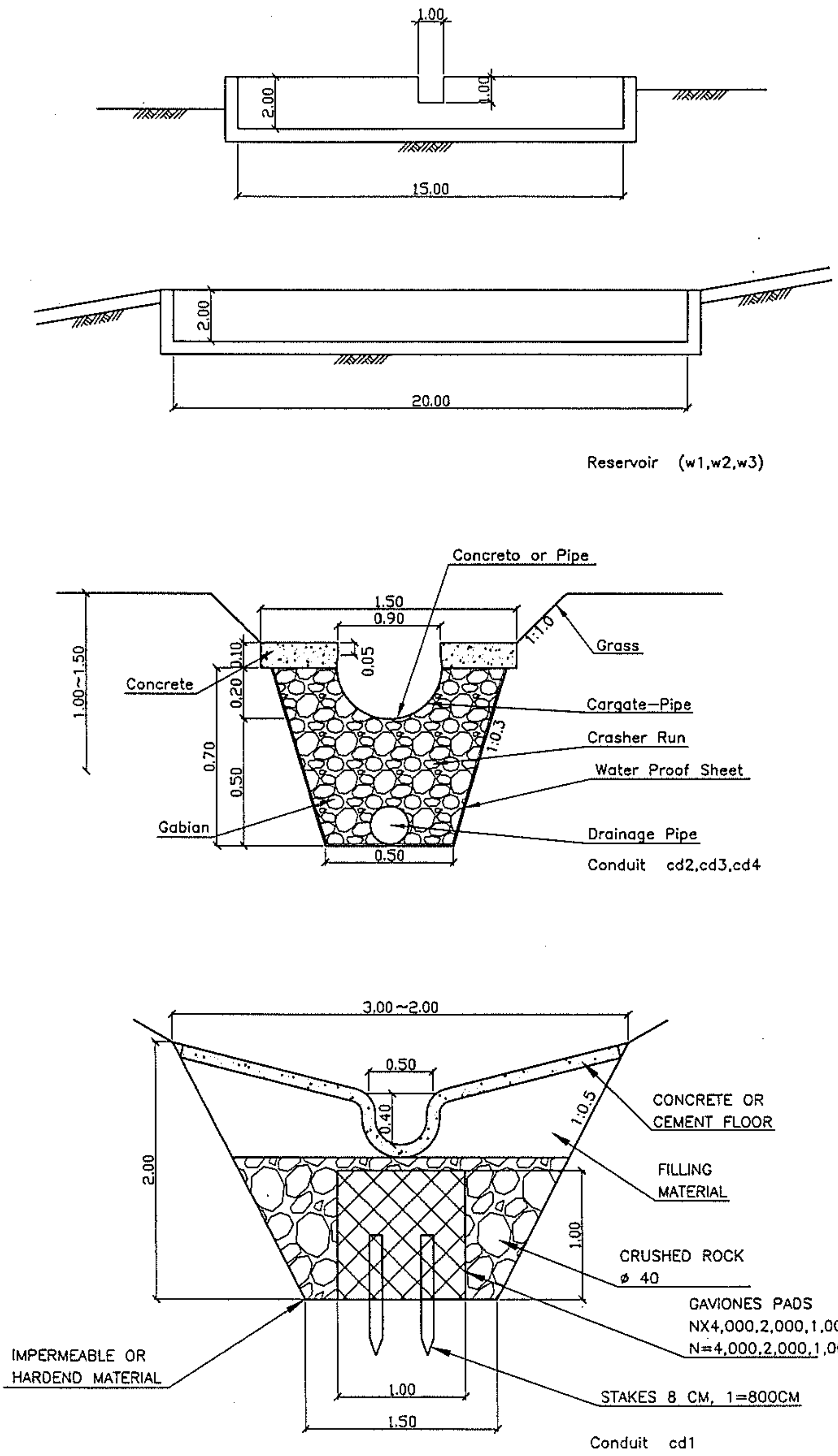


Figure G.3.5 | **Planned Structure of Drainage System**

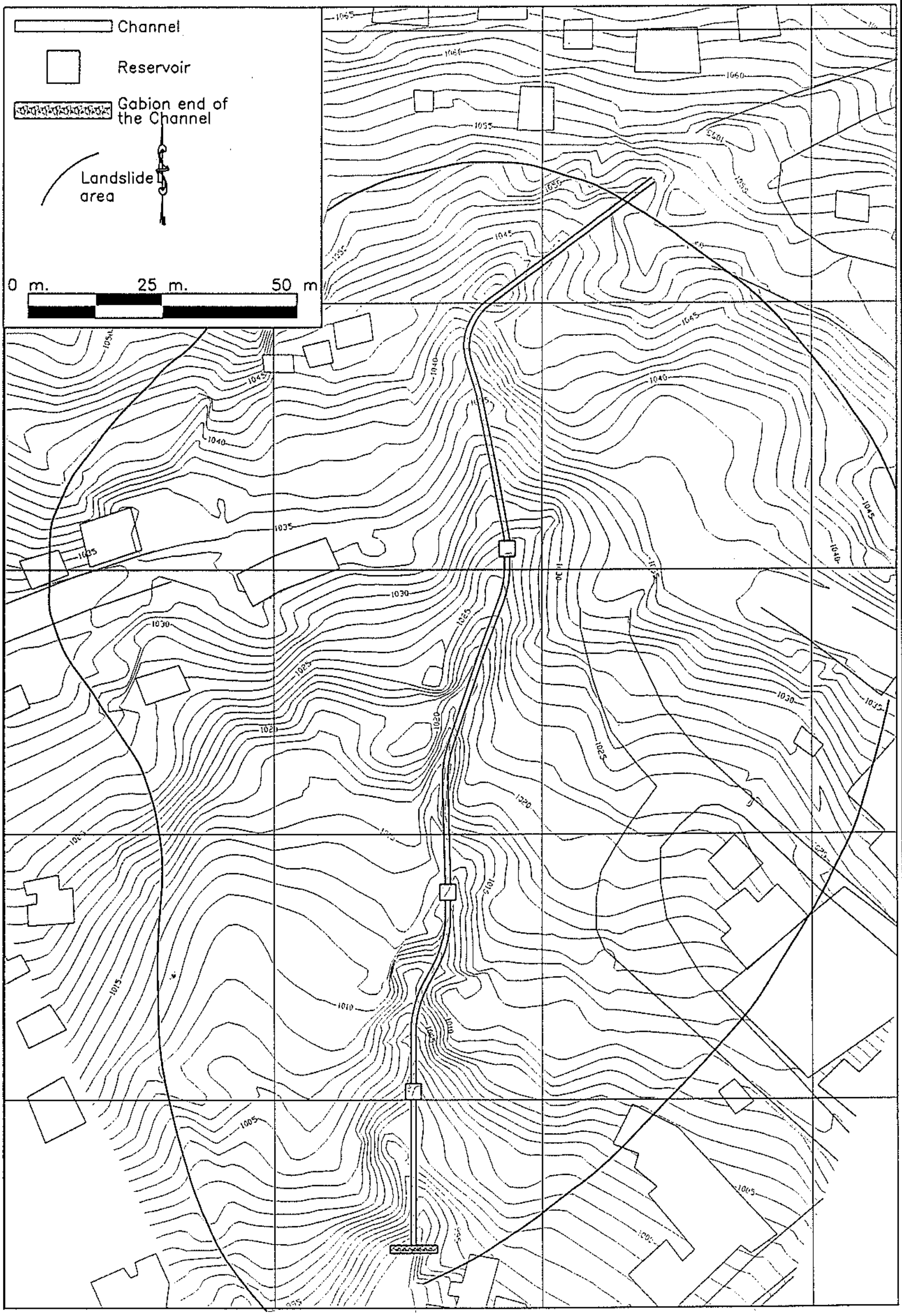


Figure G.4.1	Planned Drainage System (El Bambu)

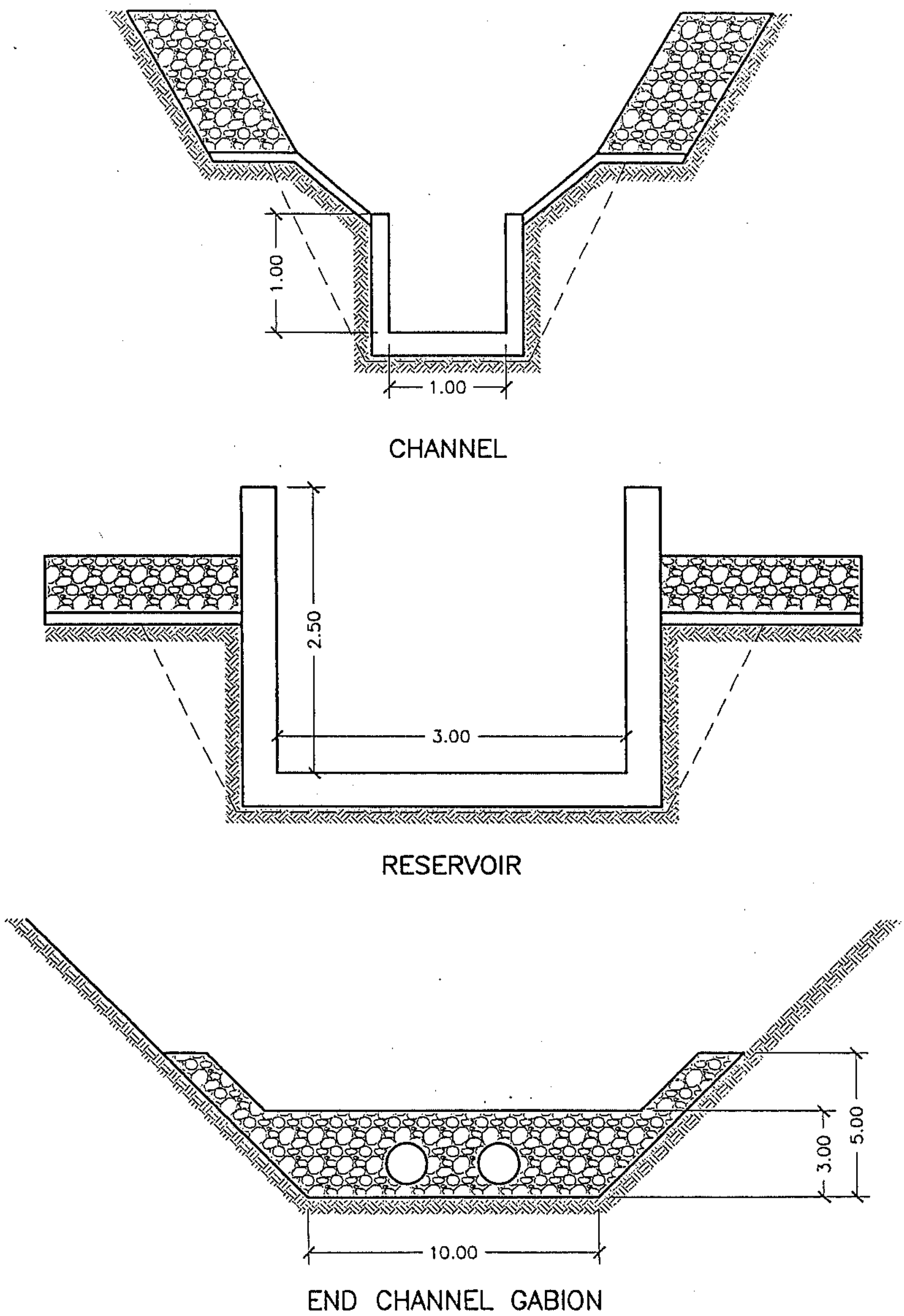


Figure G.4.2	Planned Structure of Drainage System (El Bambu)

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