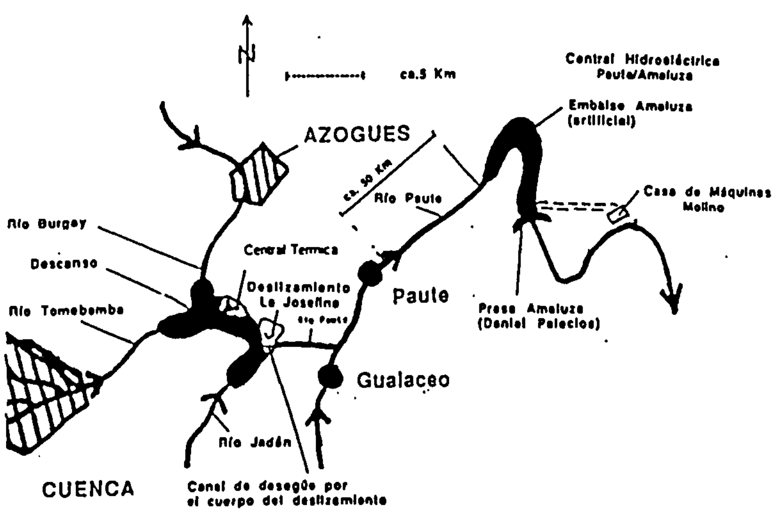
United Nations
Department for Humanitarian Affairs
DHA Geneva

Landslide *La Josefina* on the Paute River, Cuenca, Ecuador

Report on Disaster Management

(English Version of the Consultancy Report)



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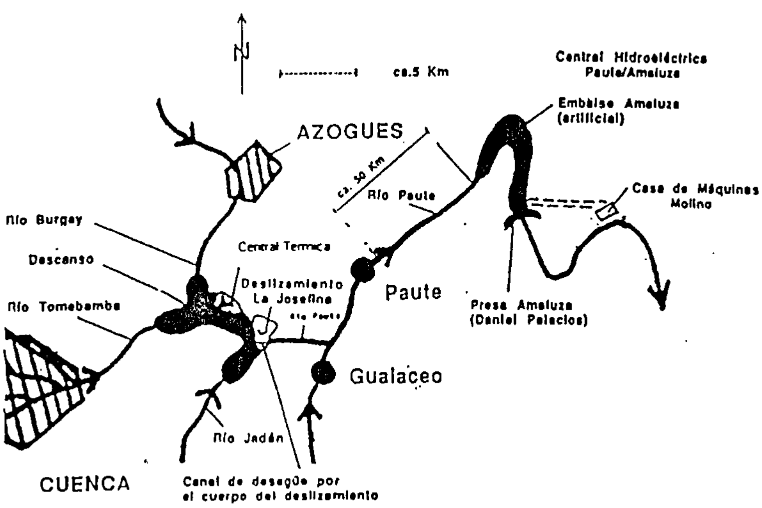

Geneva
1993

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Foreword

DHA is pleased to present the English version of a technical report entitled ***El Deslizamiento la Josefina En El Valle Del Rio Paute, Cuenca, Ecuador***, prepared in Spanish by DHA/SDR (Swiss Disaster Relief) consultants. This report reviews the sequence of events and decisions taken in the aftermath of a huge landslide that occurred near Cuenca, Ecuador, on 29 March 1993.

A landslide of 30 to 40 million cubic metres of soil caused an emergency situation whereby a natural dam of 85 metres high and 1000 metres long was created down river. Behind this dam, the watershed of the Paute River generated within a month a lake of almost 200 million cubic metres, the backwater head in the lake reaching 60 metres. The development of a lake of this size caused technological disasters in the upper river, where the entire infrastructure of lifelines was heavily damaged due to the inundation, to include a Pan-American Highway, rail road, and bridges. The thermal power plant of El Descanso was entirely inundated by 20m of water. Its stock of petroleum products was destroyed and polluted the area down river.

Mitigation work was aimed at discharging the lake and eroding the dam by the discharge water flow. Careful attention was paid to the necessity of keeping the process of dam erosion under control. Scientific details regarding mathematical modelling and scenarios for the landslide dam erosion are provided in the Spanish version of the report, which is available upon request from the DHA Reference Library. An uncontrolled discharge through the dam created by the landslide could have caused even heavier disasters down river, affecting human lives and settlements, and presented a serious danger to a hydraulic power plant on the Paute River of 1,050 Mw of installed capacity. This power plant generates 80% of the country's electrical energy.

The purpose of an English (shortened) version of this report is to make available to a wider range of disaster management authorities the measures which were carried out successfully in this emergency, in order to facilitate mitigation in similar emergency situations which might occur in the future in other parts of the world.

The economic consequences of the landslide are very heavy. One of the consultants' recommendations suggests that, considering the hazards present in the area, the thermal power plant El Descanso should be moved to a safer place. This recommendation concerns the future safety of property valued at hundreds of millions of US Dollars and indicates that pre-investment studies were not based on proper hazard and risk analysis. In our opinion, this case study once again proves the necessity of disaster risk analyses as an essential basis for the preparation of development plans for an area.

Disaster Mitigation Branch
DHA Geneva
November 1993

Summary

On Monday, 29 March 1993, at about 9 p.m., a vast landslide occurred abruptly, affecting the area of the left flank of the Paute valley in the sector known as ***La Josefina*** situated just downstream from the confluence of the Paute and Jadán rivers, causing a total of 72 dead and missing. The volume of material dislodged, some 30-40 million m^3, formed a natural levee (embankment) to a total width of almost 1,000 m that reached a maximum height above the river bed of about 85 metres. The La Josefina sector is some 6 kilometres downstream from the confluence of the Tomebamba and Burgay Rivers, which unite to form the River Paute.

By obstructing the course of the River Paute, the landslide had three effects:

Firstly, two pools of water formed very rapidly upstream from the landslide, one in the bed of the River Jadán and the other in the bed of the River Paute, flooding valuable arable land and destroying many dwellings. The El Descanso Thermal Power Station was initially completely submerged, as were the Pan-American Highway and the railway line from Quito to Cuenca;

The second effect, which occurred subsequently, was that the waters of the La Josefina Reservoir flowed over the embankment produced by the landslide. The outpouring of the dammed-up water, and the subsequent rapid erosion of the material of the embankment, produced an extraordinary rise in level and a wave of considerable size, which caused flooding in the town of Paute and in all the surrounding settlements, as well as at the Paute Hydroelectric Power Station;

The third effect was the damage caused downstream from the Amaluza Dam by the outpouring of some 4,200 m^3/s from the Amaluza Reservoir.

At the request of DHA Geneva and Ecuadorian authorities, the Swiss Disaster Relief Corps (SDR) provided a team of experts consisting of a co-ordinator for operational activities and a technical/scientific adviser. The technical/scientific advisers were Ph. Chamot from

3 April to 4 May and Dr. J. Studer from 4 May to 20 May. The co-ordinator was F. Wirz. The three experts wrote the following chapters:

- Ph. Chamot dealt with technical/scientific aspects: chapters 1, 2.1-2.5, 4.1, 5.1;
- Dr. J. Studer dealt with technical/scientific aspects: chapters 1, 2.6-2.9, 4.1, 5.1, 7.1 and 7.2;
- F. Wirz dealt with operational aspects: chapters 1, 3, 4.2, 5.2, 6, 7.3.

The team had the following objectives:

- Assessment of all the risks that might arise were there to be an abrupt breach of the embankment and an outpouring of water there, and, if necessary, the provision of technical advice to the responsible authorities;
- Definition of the measures needed to reduce the risk of similar incidents in this region in the future;
- Support to the authorities and local institutions in the co-ordination of rescue, evacuation, monitoring and disaster-relief operations;
- Provision of information to the UNDP office in Quito on the actual situation regarding activities and the unsatisfied needs in the humanitarian aid sectors.

The construction of a drainage canal for the main body of the La Josefina Landslide was the only possible decision that could realistically have been taken. For this purpose some 150,000 cubic metres of material were shifted within one month. A concurrent investigation was carried out and calculations and models were used to assess the areas at risk downstream from the landslide. It was possible by this means to delineate areas for evacuation of the population.

On 1 May, the La Josefina Reservoir was emptied through the drainage canal. Retrogressive erosion deepened the canal rapidly, with the consequence that rates of flow also increased very rapidly. The maximum drainage discharge was between 7,000 and 10,000 m^3/s for around three hours. The draining of the La Josefina natural reservoir caused serious damage in the valley of the Paute. Three concrete bridges, some 10 kilometres of metalled roads, about 200 houses, industrial plants and 2 flower-growing plantations were carried away by the water. As the flow rate slackened, large amounts of debris and sand were deposited in the narrow parts of the valley and a large area of cultivable land was lost.

Because the evacuation of the population had been well prepared, the violent drainage did not cause any loss of life or injury. Nevertheless, there are some aspects of disaster relief that can be improved. A set of conclusions and recommendations was made to include the following:

- Topography and geological conditions are such in Ecuador that landslides as large as the La Josefina landslide may recur in the future;
- The building of a drainage canal for the principal body of the La Josefina Landslide was the only possible decision that could realistically have been taken;
- The draining of the reservoir also caused great damage. Because the evacuation of the population had been well prepared there was no loss of life and no injury occasioned by the violent draining down;
- The draining of the La Josefina natural reservoir was far more violent than had been initially estimated, took place in a far shorter time, and with peak discharges far higher than had been estimated. The reason is to be sought basically in the fact that the particle-size composition of the material of the embankment was much finer than had been mistakenly assumed on the basis of geoseismic soundings in the area;
- The Azuay Provincial Civil Defence Council was insufficiently prepared for an adequate response to a disaster on this scale. Nevertheless, the co-ordination of the various bodies involved (i.e. Civil Defence, the armed forces, the church) may be improved. The Azuay Provincial Civil Defence Council should be strengthened and given training with the object of forming a team of suitable individuals for the planned Emergency Operations Centre (COE) for the south of the country.

The following recommendations were made to the appropriate authorities:

- The level of the remaining reservoir should be lowered by a further 7 metres. Any greater reduction would be impossible without an excessive effort;
- The ***El Descanso*** Thermal Power Plant is in great danger of being flooded again. It is recommended that this plant be rebuilt on a safer site;

- Construction of the sewage treatment plants at Cuenca and Azogues should be speeded up with the object of reducing problems of hygiene in the remaining dammed-up water;
- The bed of the River Paute, which has formed meanders in the narrow parts of the valley around Gualaceo and Paute must be stabilized to reduce the threat of flooding when there is heavy rainfall;
- The stability of the valley sides should be monitored in the sector of the ***El Molino*** machine hall and downstream from the Paute hydroelectric station. A landslide in this sector would produce a new natural reservoir on the River Paute and the machine hall would undoubtedly be flooded. Preventive measures are recommended;
- Maps of hazards and risks for the Cuenca Region and the Paute Valley must be produced as a basis for reducing the risk from natural hazards. These maps will serve as a basis for regional and local development planning and for the planning of monitoring and rehabilitation systems;
- The regions of maximum risk must be covered by adequate measures;
- The technical/scientific and organizational experience gained from the La Josefina Disaster should be reviewed in a three-day seminar/workshop in summer/autumn 1994 and embodied in documents that may also serve for the training of future experts in Ecuador and as a guide to similar occurrences;
- The team of experts suggest that the SDR should make an assessment of support for the *Seminar on Hazard and Risk Zoning* (7.1) as a first priority;
- It is proposed that the *Observation System* project (7.2) be carried out (second priority) after the zones of maximum risk have been identified;
- It is proposed that the project *Assistance with the creation of a data bank to assist the Azuay Provincial Civil Defence Council* (7.3) should also be a second priority.

1. Introduction

On Monday, 29 March 1993, at about 9 p.m., a vast landslide occurred abruptly, affecting the area of the left flank of the Paute Valley in the sector known as La Josefina situated just downstream from the confluence of the Paute and Jadán Rivers, causing a total of 72 dead and missing.

The La Josefina sector is some 6 km downstream from the confluence of the Tomebamba and Burgay Rivers, which unite to form the Paute, and roughly 25 km downstream from the city of Cuenca. The location of the landslide is shown on the map in Figure 1.

From El Descanso (located at the confluence of the Tomebamba and the Burgay) to the Chicticay bridge across the River Paute, a point roughly 2 km downstream from the landslide area, the valley is at its narrowest and most sheer-sided. On the left there is a surfaced road linking the cities of Cuenca and Azogues with the small picturesque tourist towns of Gualacéo and Paute.

In the area affected by the landslide, at the foot of the slope along the side of the road, there are various quarries that provide building materials for the Cuenca Region. The idea put forward that these quarries may have been responsible for the landslide must be discounted as highly implausible. It is known that there have long been geological faults high up along the left flank of the valley. Furthermore, the fault band runs below the foot of the quarries and also below the riverbed.

Downstream from the Chicticay Bridge, the valley widens rapidly to the confluence with the River Gualacéo, and the valley floor remains broad until the village of Paute is reached, after which it once again narrows and remains so until it reaches the Paute hydroelectric power station, 50 km further downstream. A paved road runs for 72 km from Paute town to the Amaluza Dam of the Paute Hydroelectric Power Station, after which it continues for 15 km to the machine hall.

By obstructing the course of the River Paute, the landslide was to have a dual effect. Firstly, two pools of water formed very rapidly upstream from the landslide, one in the bed of the River Jadán and the other in the bed of the River Paute, flooding valuable arable land and destroying many dwellings, especially at the lower end of the River Paute Reservoir, where the waters had reached the irrigation channels of Loyola (River Burgay) and Chulluabamba (River Tomebamba).

The El Descanso Thermal Power Station was initially completely submerged, as were the Pan-American Highway and the railway line from Quito to Cuenca. The second effect, which occurred subsequently, was that the waters of the Paute and Jadán Rivers flowed over the embankment formed by the landslide. The outpouring of the dammed-up water, and the subsequent rapid erosion of the material of the embankment, produced an extraordinary rise in level and a wave of considerable size, which caused flooding in the small town of Paute and in all the surrounding settlements along the valley, as well as at the Paute Hydroelectric Power Station.

The objective of this United Nations Mission (DHA, Geneva) was to assess all the risks that might arise were there to be an abrupt breach of the embankment and an outpouring of the water there, and, if necessary, to provide technical advice to the responsible authorities.

The first army division stationed at Tarqui was in command of all operations, with the active participation of a technical subcommittee consisting of representatives of various local and national institutions, and of foreign consultants sent by various Governments and international bodies, listed in alphabetical order below:

Azuay Engineering College
COOPI (Cooperazione Internacionale), Italy

ERSDRA (Empresa Regional Centro Sur S.A.)

ETAPA (Municipal Public Telephone, Drinking Water and Drainage Undertaking)

ESPE (Army Polytechnical School)

INECEL (Ecuadorian Electrification Institute)

INAMHI (Ecuadorian Meteorological and Hydrological Institute)

INERHI (Ecuadorian Water Resources Institute)

IGM (Military Geographic Institute)

Mission of ENDESA (Chile)

United Nations Disaster Relief Organization (DHA, Geneva)

University of Cuenca

USACE (US Army Corps of Engineers).

The list of technical specialists of the Army Corps of Engineers, the University of Cuenca, the foreign missions and other institutions is given as an annex in the original Spanish version of the report. Also annexed in this report is a timetable of all events from the day of the landslide until the dammed-up waters flooded out through the drainage canal and the La Josefina embankment was breached.

2. Landslide, Drainage Canal, Measures Taken

Phase I (from the landslide until draining down)

2.1 The La Josefina Landslide

The giant landslide of the left flank of the valley that occurred in the sector known as La Josefina blocked the River Paute at its confluence with the River Jadán. The volume of material dislodged, some 30-40 million m^3, formed a natural levee (embankment) to a total width of almost 1,000 m and a maximum height of around 85 metres. In volume it may be compared with the mass of rocks that fell on 28 July 1987 in the Valtellina rock fall in the Italian Alps, with the proviso that the height of the latter was greater (1,300 metres).

On 2 January 1990, there had been another landslide of 3.6 million m^3 in northern Ecuador, which blocked the River Pisque.

According to statements obtained from survivors and eyewitnesses in the area, the La Josefina Landslide occurred in three successive phases with very short intervals between them:

- The first landslide, which blocked the River Paute immediately below its confluence with the River Jadán, had a minimum height at the top of approximately 2,352.50 m above sea level;
- The second landslide, which blocked the two rivers at their junction, was 2,352.00 m above sea level at the top;
- The third landslide, the largest of the three, blocked the River Paute immediately downstream from its confluence with the River Jadán. It was 2,375.00 m above sea level at the top.

The stages of the landslide are shown in Figure 2.

The order given above may have been different, since visibility was such that it was impossible for anyone to observe the phenomenon. What is stated is only what emerged from the verbal statements of survivors. The geology of the landslide is shown in Figure 3. The Military Geographic Institute (IGM) quickly overflew the area of the landslide and was thus able to rely on a 1:2,000 aerial photographic survey of the area of the embankment. Water immediately began to collect upstream from the embankment created by the landslide, forming two pools, the levels of which rose rapidly. On 3 April, the water level in the River Paute reached 2,329.00 m above sea level, whereas the original level of the river in the area of the landslide had been no more than 2,300.00 to 2,310.00 m above sea level, as may be verified from maps on a scale of 1:10,000 that were in existence before the landslide.

The level of the dammed-up water on the River Jadán was initially some 13 m lower than that of the dammed-up water on the River Jadán, essentially because of the lesser discharge flow of the Jadán. This difference decreased in the course of time owing to the considerable infiltration through the embankment separating the two.

The levels of both bodies of dammed-up water continued to rise at varying rates depending on the size of the inundated areas, which increased inexorably as the surface level of the water rose, and in response to the volumes of water brought in by the Tomebamba and Burgay Rivers, which varied between 40 m^3/s and 175 m^3/s during April. It is appropriate to mention that April and May are rainy months in the Ecuadorian Andes.

The daily variation in the level of the dammed-up water on the Paute ranged from a maximum of more than 3.00 m to a minimum of 0.50 m. The difference of level between the dammed-up water on the Paute and the Jadán also varied with time in relation to the amounts of water supplied by the River Jadán and infiltration from the dammed-up water on the Paute. The levels of the two water bodies were equalized on 18 April 1993, when the River Paute reached a level of 2,352.50 m above sea level, corresponding to the level of the embankment separating the two bodies of dammed-up water. The rise of water levels in the La Josefina Reservoir is shown in Figure 4.

Water volumes in the La Josefina natural reservoir are graphically plotted against altitude in the form in which it was prepared by representatives of the University of Cuenca. It ought to be stated that this curve is no more than approximate owing to the scale of the existing maps, but is nevertheless extremely useful at this time. Other bodies have arrived at larger volumes, but it may be verified from inflow volumes and the surface levels of the water that the curve prepared by the University of Cuenca is the most realistic. Transversal and longitudinal sections of the landslide are shown in Figures 5 and 6.

As the level of the dammed-up water rose, some landslides occurred in both water bodies, but all were of minor importance. Engineering geologists inspected both slopes of the dammed-up bodies above the La Josefina landslide and came to the conclusion that no other landslides of great size or similar to the one at La Josefina could be foreseen. They were, however, of the opinion that landslides of some size could occur on both banks in the two valleys as the level of the dammed-up water fell.

2.2. The drainage canal through the body of the landslide

In the days immediately following the landslide, the corps of engineers of the Ecuadorian army decided to excavate a canal in the main embankment (third landslide). It should be said that this was the only possible and realistic decision that could have been taken, having regard to the shortness of the time available before the dammed-up water would overflow. Another solution, such as the pumping of water out of the natural reservoir to a point below the embankment was not possible because of the size and the number of teams needed to pump out volumes of between 50 and 150 m^3/s, teams that were quite definitely unobtainable anywhere in the world at such short notice.

The construction of a canal at as deep a level as possible had two purposes:

- To prevent the water level rising to the top of the natural channel formed by the landslide, so as to limit, in as far as possible, the areas flooded downstream;

- To reduce the volume of dammed-up water to the greatest possible extent so as to reduce the scale of the disaster downstream on the draining down of the dammed-up water through the canal.

The maximum level of the natural channel was at around 2,375.00 m above sea level. The idea was to excavate a canal 6 m wide with its bottom at around 2,353.00 m above sea level, corresponding to the level of the embankment between the Paute and Jadán Rivers. The canal was to be supported by the natural right flank of the valley, which consists of volcanic rocks dipping inwards into the rock mass, with minimal plant cover. It was considered that this slope would be quite capable of resisting the erosion arising from the flow rates during draining down. It was planned to have 45° slopes with berms along the left-hand edge. A transversal section of the designed drainage canal is shown in Figure 7.

The teams of heavy equipment belonging to the army and private companies were successfully mobilized in record time. The first bulldozers arrived on site on Thursday, 1 April and work was begun without loss of time with the opening of two access roads. Excavation of the canal was effectively begun with a number of light tractors (type D7 or similar) on Saturday, 3 April. Between that date and 8 April, the number of bulldozers increased daily until there were some 20, most of which were of the heavy type (D8L and D9). Up to 15 tractors worked simultaneously on the excavation of the canal, and the lightest tractors were set to work opening up the access and escape routes. Work continued without interruption from 6 a.m. until 6 p.m. After a lighting system provided by the United States Army had been installed on 6 April, work continued for 18 hours a day in three 6-hour shifts.

What was in progress was nothing less than a race against the clock. To arrive at a level of 2,353.00 m above sea level with the profile adopted, it would have been necessary to excavate 225,000 m^3 of material. Taking an average of 12 tractors working for an average of 16 hours a day it was possible to excavate a maximum of 12,000 m^3 per day, and therefore 18 days would have been needed from 3 April to effect the excavation required.

On the other hand, assuming an average daily inflow to both reservoirs of 70 m^3/s, the reservoir level would reach 2,353.00 m within 15 days of 3 April 1993, on the assumption that the volume of the dammed-up water was 34 million m^3 on 3 April, and that 125 million m^3 would be needed to bring the level to 2,353.00 m above sea level. The curve of volumes of the La Josefina Reservoir is given in Figure 8. This meant that it was possible to achieve the required goal only were there to be higher output from the tractors or a lesser inflow of water. In fact, the time taken for the reservoir to fill to the level 2,353.00 m above sea level was 15 days from 3 April 1993.

Shortly after excavation commenced, the engineers in charge of the work realized that it was impossible to construct the canal to the planned design in the time allotted. On the one hand, the rain had become considerably more intensive from 9 April onward and, on the other hand, the output of the machinery was less than had been assumed. It was then decided to reduce the volumes excavated, increasing the slope angle on the left to 2V:1H, still with the idea of arriving at 2,353.00 m above sea level.

In actuality, the canal could be excavated only to approximately 2,357.00 m above sea level in its highest part, owing to the fact that the width of the bottom was only 5 m in places, which made it impossible to deepen the canal any further (see Figure 9). In effect, it was impossible to excavate the rocky slope on the right any more and unfeasible to have a vertical slope on the left-hand edge.

To be able to deepen the canal, it would have been necessary to re-excavate the left hand slope from a given level, working for several days with the probability of ultimately having a canal at a higher level than it was in reality. Consequently, it was decided on 13 April 1993 to abandon the excavation work. This decision was taken because the contractors wished to withdraw their equipment before it was lost, and because the tractor drivers had some quite justified apprehension over continuing to work when faced with such a risk, and with the impending threat that the continuing heavy rain would cause the water to overflow suddenly.

2.3 Forecasts for the drainage of the La Josefina natural reservoir and the outcome

2.3.1 *Field investigations*

It was apparent that the *La Josefina* embankment would be partly or wholly destroyed by retrogressive erosion. The possibility that the embankment with a total width of around 900 m would give way through simultaneous collapse of its entire mass was excluded from the outset.

The process of retrogressive erosion of the bed of the canal and the equilibrium slope of the new thalweg of the River Paute in the landslide area were dependent on the particle-size of the material of the embankment and on the maximum drainage rates. The process of retrogressive erosion of the bed, accompanied by widening of the canal was due to the landslides of the slopes. In the case of La Josefina, it was expected that only the left-hand slope would collapse, because the right-hand slope consisted of apparently sound rock (the natural slope of the right flank of the valley).

A knowledge of the particle-size composition of the material beneath the canal was a key requirement for anticipation and calculation of the erosion process and the levels of local flooding, but the time available before the dammed-up water had to be drained down was too short for any exhaustive consideration of the matter. When work began, the technicians were convinced that the material of which the embankment was composed was mainly medium-sized and large blocks, because it could be seen that the surface of the landslide was strewn with blocks. Some technicians reached the slightly hasty conclusion that the overflowing of the waters would have practically no effect on the embankment, which would not shift. However, when excavation of the canal began, it could be seen that the material removed by the tractors was much finer in composition than had originally been thought. There were admittedly small to medium blocks, but very few blocks larger than 1 m^3.

There was no possibility of carrying out granulometric studies by excavation, owing to lack of the equipment required and to the fact that operations in the area had to continue without interruption against the clock. Therefore, only particle-size analyses of the surface material were carried out in the bottom of the completed canal; these yielded an average diameter (D_{50}) of 100 mm.

When excavation of the canal was completed, INECEL conducted geoseismic studies on two profiles, one parallel to the canal and the other perpendicular. The results were as follows:

- At around 2,350.00 m above sea-level (seismic velocity 600-900 m/s): loose, little-compacted material; blocks <2 m in diameter, matrix 10 cm in diameter;
- Below 2,350.00 m above sea-level (seismic velocity 1,230-2,300 m/s): compacted material, predominantly large blocks;
- Below 2,310.00 m above sea-level (seismic velocity 4,000 m/s): rock in situ; former thalweg of the river.

It was therefore to be hoped that the particle-size composition no more than a few metres below the bottom of the canal would be fairly coarse, from which it could be concluded that there would be quite rapid erosion in the first few metres of the canal, but thereafter slow erosion within the coarse material, as a result of which an equilibrium slope would be rapidly achieved without any draining down at a catastrophic rate (i.e. $Q<3{,}000$ m^3/s).

It is known that geoseismic studies can yield incorrect data if they are not correlated with test-drilling data. This may be so if, for example, the material is water-saturated. The events of 1 May demonstrated in effect that the results yielded by geoseismic investigation were really not very reliable in this case. On the other hand, it should be pointed out that there was practically no seepage through the embankment during the first 10 days after the landslide. Thereafter, seepage increased gradually until it reached a level slightly below 1 m^3/s, and remained at that level for the week preceding the draining down. This was in itself an indication that the embankment was fairly impermeable and made up of well-graded materials with a relatively high proportion of fine material and clay fractions, without predominance of large blocks.

2.3.2 *Mathematical models*

The University of Cuenca produced two mathematical models with the assistance of engineers from the missions of Italy and the United States of America. The first of these models simulates the erosion that would occur in the canal and the flow-rates that would follow from the erosion. The second model (dam break) simulates peak flow and the variations in the height of the flood wave along the valley downstream as far as the Amaluza dam.

Several models of the erosion of the landslide body and the flow-rates of the outpouring water were worked out. Examples of these are presented in Figures 17, 18 and 19. Cases were simulated, with the results dependent first and foremost on the particle-size composition, but also on the level (and the volume) of the dammed-up water and on the rate of inflow when the water overflowed.

An average diameter of 100 mm in the bed of the canal, with variations of up to 250 mm/700 mm in the equilibrium profile, was considered for the particle-size conditions. Figures 10 and 11 depict the reduction of water levels and of the crest of the spillover from the canal as a function of time. It may be noted that the duration of the flooding produced by the draining down of the water and the peak flooding are essentially dependent on the presumed particle-size conditions.

The most recent version of the *Dambreak* model was supplied by technicians in the United States Mission. Various simulations were made of the water flow and the peak flooding height along the valley for the purpose of arriving at a safety level for the evacuation of residents from both banks of the River Paute whose lives might be at risk. This model made it possible to see, for example, that it was unnecessary to evacuate the inhabitants of the Gualaceo area, even with drain discharge of more than 15,000 m^3/s.

2.3.3 *Physical models*

Both the University of Quito and the Commission Studying the Development of the Guayas River Valley (CEDEGE), in collaboration with the University of Guayaquil, prepared physical models representing the erosion of the La Josefina embankment and the outflow rates. Unfortunately, we still lack any information on the model produced in Quito, although there is a brief information item on the CEDEGE report of 16 April 1993.

The CEDEGE model was on a scale of 1:150. It is difficult to understand how it was possible to produce such a complicated model in so short a time, considering that the map of the landslide was not available until 5 April 1993. Also the results obtained in the two trials are a little odd. In the second trial, with a higher level of dammed-up water, the flooding turns out to be less than in the first trial. This undoubtedly stems from the fact that the reproduction of the scale of particle-size composition could not be exactly the same in the two trials. On the other hand, it should be mentioned that it is extremely difficult (if not impossible) to reproduce particle-size conditions on a scale of 1:150, the more so when the particle-size conditions of the subsoil were not known at the time. Be that as it may, the model produced by CEDEGE was of great use for qualitative assessment of the erosion process.

2.4 The Paute Hydroelectric Power Station

2.4.1 *General description of the hydroelectric project*

The Paute Hydroelectric Power Station, which belongs to the publicly owned INECEL company, is located some 125 km from the city of Cuenca. It exploits the flow of the River Paute, the waters of which descend some 700 m in a distance of 13 km in the sector known as Cola de San Pablo.

The Paute Hydroelectric Power Station comprises the following engineering works:

- The Amaluza Dam, also known as the Daniel Palacios Dam, a concrete dam of the arch-gravity type, is 170 m high and 420 m long at the top. Two bottom outlets built into the body of the dam can evacuate a maximum discharge of 80 m^3/s. Six spillways with sluices 11.60 m wide and 12.00 m high are capable of evacuating flood waters at a rate of 7,724 m^3/s;
- Two parallel tunnels, 80 m apart, which carry the dammed-up water from outlets in the body of the dam to the Molino Power Station. The first tunnel, which is concrete-lined, is 6,070 m long and 5.0 m in diameter. The second tunnel, excavated with a tunnel-boring machine (TBM), which is not concrete-lined, is 6,024 m long and 7.80 m in diameter. The rated discharge is 100 m^3/s for each tunnel;
- Two surge shafts, one at the end of each intake tunnel;
- From the intake tunnels, the water continues through two underground pressure pipes, one of which is 862 m long and 3.75 m in diameter, the other 922 m long and 4.40-4.20 m in diameter;
- The underground machine hall, which houses 10 generator sets (100-115 MW each) of the Pelton type. The cave has an overall length of 184 m, and is 23.4 m wide and 42.5 m high. The turbine runner shaft is located 1,323.00 m above sea level;
- Two outflow tunnels, each 400 m long, 8.00 m high and 6.67 m wide. The tunnels discharge the water to the river down two ski-jumps. The bed level at the outlet from the two tunnels is at 1,313.80 m above sea level and the river bed at the point of return of the water is some 10 m deeper;
- The switchyard, where the control room of the power station is located, is at 1,620.00 m above sea level, close to the machine hall.

The Paute Hydroelectric Power Station, which has 1,075 MW of installed capacity, is capable of an annual output of 5,900 GWh, which represents practically 80 per cent of the power generated in the country.

2.4.2 *Likely effects of the drainage of the La Josefina natural reservoir on the Amaluza artificial reservoir and dam*

The Amaluza arch-gravity dam came into operation in 1983. The total volume of water stored in the reservoir, which is some 20 km long is 120 million m^3, whilst the active volume is only 90 million m^3. The maximum and minimum operating levels are respectively 1,991.00 m and 1,935.00 m above sea level. Since 1983, the spillways have evacuated only discharges less than 1,500 m^3/s. A curve of volumes of the Amaluza Reservoir is shown in Figure 12. Water profiles down the Josefina Landslide are given in Figure 13.

Taking the La Josefina Canal to be 2,360.00 m above sea level and assuming that the embankment might be entirely removed by erosion, the total volume of water that would reach the Amaluza Reservoir three hours later would be of the order of 180 million m^3, with a peak discharge of between 2,000 and 6,000 m^3/s, depending on the most likely particle-size compositions of the material of the embankment. Such discharges would reach the reservoir and pass over the spillways without causing any damage to the dam.

Should the body of the La Josefina embankment contain much finer material than has been supposed, the peak discharge could rise to around 10,000 m^3/s. By virtue of the reservoir-routing effect, the water level would not exceed 1,993.50 m above sea level and the spillway discharge would amount to 8,400 m^3/s.

The following hypotheses were taken for this calculation:

- Rupture of the La Josefina embankment within 12 hours with a peak discharge of 10,000 m^3/s;
- Water level in the Amaluza Reservoir before the arrival of the flood, 1,950.00 m above sea level.

The curve of the volume of the Amaluza Reservoir and the curve of discharges over the spillways plotted against water levels yields the curve of water levels in the reservoir and the drainage discharges. There is then no threat to the dam, even with discharges at

10,000 m^3/s (Figure 14). A dam of the arch-gravity type is readily able to withstand the excess pressures due to a water level 2.50 m higher than the peak operating level and should have been designed for such an eventuality. This dam could therefore tolerate water flowing over its top without being destroyed, obviously with some minor damage in some electro-mechanical parts and in the works located at the foot of the dam.

In order to be able to cope with flooding produced by the rupture of the La Josefina embankment under optimum conditions, INECEL had already made provision to lower the reservoir level as much as possible, without emptying it completely so that sediment should not gravitate towards the intake mouth. A level between 1,945.00 and 1,955.00 m above sea level was adopted as an appropriate level.

2.4.3 *Sedimentation in the Amaluza Reservoir*

Between the time that it came into operation in 1983 and the end of 1992, which represents nine rainy seasons, some 22 million m^3 of sediment were deposited in the Amaluza Reservoir, of which 5 million m^3 occurred during the first year. This represents an average of 2.5 million m^3 of sediment entering the reservoir annually. On the other hand, 1.7 million m^3 have been removed by hydraulic dredge since January 1991. This information comes from regular depth soundings. A half of the 22 million m^3 of sediment lies in the dead volume of the reservoir, while the other half is in the active volume at the end of the reservoir. The active volume, which was initially 90 million m^3, has so far been reduced to 80 million m^3.

The consequences of the breach of the La Josefina embankment for the sedimentation of the Amaluza Reservoir may be roughly calculated in the following way. On the assumption that a canal 30 m wide with slope gradients of 1:1 were to be opened up along the entire length of the embankment, the total volume of material carried away would be some 13 million m^3. The finest grades of material, which would be the only ones that could be carried as far as the Amaluza Reservoir, would not represent more than 30 per cent of the total volume, or roughly 4 million m^3. Adding to this volume the sediments that the flood could carry along with it in its path, the maximum volume of sediment that would be able to reach the reservoir would not exceed 7.5 million m^3, which is three average years of sedimentation. It is obvious that this phenomenon may shorten the service life of the reservoir by three years, but is in no sense catastrophic.

2.4.4 *Countermeasures against the possible effects of draining the La Josefina Reservoir downstream from the Amaluza Reservoir*

Whereas the Amaluza Dam will surely not be destroyed by the emergency discharge from the La Josefina Lake, the same cannot be said of the works located downstream from it. The peak flood so far evacuated over the spillways has been only 1,500 m^3/s and such discharges have not caused any damage. However, with discharges of from 5,000 to possibly 10,000 m^3/s, various kinds of destruction could occur along the path of the flood to the machine hall and severe damage in the machine hall itself, unless the necessary precautions are taken (Figure 15). In the reach between the dam and the machine hall, only the final section of the road and a secondary bridge may be affected, but it is impossible to carry out works to prevent damage in this part.

In the machine hall, a wave of such size could certainly have a considerable effect on the subterranean and external works. Owing to some lack of provision during the construction of the hydroelectric power station, enumerated below, the machine hall in the cavern could be seriously affected:

- Neither the access tunnel to the cavern nor the ventilation tunnel have been provided with a waterproof safety door to prevent water from entering the machine hall should an extraordinary flood occur;
- The turbine outflows have not been provided with compartments in the turbine portals to prevent water from entering the turbine pits. For the 10 turbine generator sets, there are only two sets of bulkheads, which may be installed at the entrance to the turbine pits.

In the light of this situation, INECEL immediately took the necessary precautions, carrying out the following works:

- The entrances to the access and ventilation tunnels were sealed with girders and metal plates. The joints were waterproofed with tar;
- All the openings in the turbine pits were sealed, especially the aeration vents, to avoid water escaping into the machine hall. This work was initially carried out on the shut-down sets, allowing everything to be prepared for the carrying out of the same work just before the arrival of the flood on the other sets that might be crippled;
- Various openings were sealed in the floor of the turbines and the stays and seals of the covers in the bulkhead pits were strengthened.

Now that these works have been carried out, the machine hall may be regarded as safe, it being impossible for it to be partly or completely submerged. However, it is obvious that the power station may be completely stopped before the arrival of the flood, making it necessary to close the compartments in the water inlet to prevent sediment from entering the intake tunnels.

As regards the most important external works such as the access bridge and the installations for discharge of the turbine waters into the river, they may not be seriously affected. The point of access is sufficiently high up above the river bed and the dischargers are cemented on rock. Damage may affect only the access roads, and the old bridge near the discharge installations may be carried away by the flood.

2.5 Overflow from the La Josefina Landslide Canal

On 24 April 1993, the surface level of the water in the La Josefina Reservoir finally reached the level of the highest point of the drainage canal at 2,357.00 m above sea level. However, a small landslide the day before coming from the left slope had blocked the canal downstream from its highest point, thus raising the discharge level to approximately 2,357.50 m above sea level. Consequently, there was only seepage of water through the fallen material and the drainage discharge did not exceed 250 l/s. On the same day, 24 April, another small landslide once again postponed drainage, causing a delay of several hours before the water could seep through.

On 25 April 1993, the water finally began to overflow onto the landslides, reaching a drainage discharge of around 10 m^3/s by the end of the afternoon. The commencement of retrogressive erosion with slumping of the left-hand slope in the final part of the canal (downstream) could clearly be seen on this day.

The third landslide occurred on the morning of 26 April 1993 at the highest point of the canal (one from the left side and the other from the right), drastically reducing the drainage discharge. A tractor succeeded in partly clearing this landslide, which enabled seepage of larger discharges to resume. A fourth landslide did not significantly affect the water seepage. On 27 April 1993, when the surface level of the water rose to around 2,360.00 m above sea level, the water began to flow round the landslides and the discharge increased progressively to around 30 m^3/s.

On 28 April 1993, it could be seen that the drainage discharge had further increased and that the retrogressive erosion had already reached the central part of the canal (the site of the third landslide). It seemed that everything was at last developing as predicted, although a little slower than expected. In effect, owing to the fact that some large blocks from the third landslide had remained in the central part of the canal, erosion was temporarily delayed until the discharge of the water increased. At midday, however, there was an abrupt fifth landslide in the same place as the third; this much larger landslide practically blocked the canal, reducing the outflow to less than 2 m^3/s.

On 29 and 30 April 1993, with the rise in the water level of the La Josefina Reservoir to more than 2,362.00 m above sea level, the discharge once again increased progressively to around 40 m^3/s. However, the retrogressive erosion was unable to progress because the water discharge was insufficient to remove the large blocks remaining from the landslides.

It was not until during the night of 30 April to 1 May 1993 that the retrogressive erosion reached the entrance to the canal, but this could not be seen because of the darkness. An abrupt increase in discharge downstream from the La Josefina embankment, which signified that retrogressive erosion had finally reached the entrance to the drainage canal, was reported at approximately 6 a.m. on 1 May. Assessed discharges can be seen in Figure 14. A longitudinal section of the drainage canal in the process of the erosion is given in Figure 16.

From that moment, draining preceded at an accelerating rate. The canal deepened, the left side collapsed very rapidly, and the waters carried away vast quantities of material. Some slumping could also be seen on the rocky slope to the right of the canal. An extraordinary flood downstream from the La Josefina embankment carried away everything that it encountered in its path - roads, bridges and houses - and in some areas the banks of the valley collapsed, undercut by the water. A large landslide in the reservoir, caused by the lowering of the water level, could also be seen.

When the abrupt rise of water discharge became apparent on the morning of 1 May, INECEL stopped the generator sets of the Paute Power Station. The gates of the bottom outflows were opened and those of the two intakes closed. At mid-day the surface level of the reservoir, which had initially been at 1,950.00 m above sea level, reached the level of the spillways and the radial gates had to be opened.

It was estimated that peak discharge was reached between 10 and 11 a.m., but that was difficult to establish, given that all contact had been lost with the staff gage located downstream from the embankment. According to various measurements and calculations made by INECEL at Amaluza, a flood discharge of around 10,000 m^3/s may have been reached. At 4.30 p.m., the discharge was already estimated to be less than 500 m^3/s and during the day of 2 May it seemed to have stabilized, with the amount of water leaving the reservoir practically the same as the amount entering it, i.e. 180 m^3/s.

A very interesting occurrence could be observed during the great draining down of the La Josefina Reservoir. The embankment separating the Paute and Jadán Rivers (a product of the first landslide), functioned as a retaining body for the draining of the Paute Reservoir. The Paute Reservoir was emptied more slowly than the Jadán reservoir owing to this natural barrier. It was only when a sufficient difference of level had been reached between the two reservoirs that the River Paute began to erode this separating embankment heavily. This phenomenon was very beneficial as regards the main discharge, in that it desynchronized the discharge of large volumes of water. Had the barrier not existed, the flood discharge would have been appreciably greater.

At the end of the afternoon of 2 May, the water level of the La Josefina Reservoir was at approximately 2,321.70 m above sea level, an estimate made from the El Descanso Bridge on the Pan-American Highway, which remained partly uncovered. It is evident that, given the flood discharges of the River Paute, further erosion of the new river bed in the area of the landslide will be impossible. The pool that still remains will have to be drained in some other way or left as it is.

To sum up, the draining down of the La Josefina Reservoir was a much faster and more violent process than had been initially estimated. This arises from the fact that the reservoir level was slightly higher than that assumed in the calculations, but it is due essentially to the fact that the particle-size composition of the material forming the embankment included much finer fractions than had been mistakenly assumed on the basis of the geoseismic tests carried out in the area.

The effective discharge curve calculated by INECEL from the water levels of the Amaluza Reservoir and the discharges over the spillways may be quite realistic, having regard to the fact that the total volume of discharge from the La Josefina Reservoir was less than had been supposed because a certain volume was retained at the end and the phenomenon took less time than had been initially estimated.

Phase II

2.6 Open questions following the draining of the La Josefina natural reservoir

Following the draining of the La Josefina Reservoir on 1 May 1993 through the body of the landslide, parts of the reservoirs of the River Paute and the River Jadán remained. In the course of Sunday and Monday, 2 and 3 May, the outflowing water nevertheless eroded a depth of nearly a metre before stabilizing. This was followed by the stage of the drying up and reduction of the influx. Outflow and influx came back into balance between 4 and 5 May. The reservoir level ceased to exhibit substantial changes for the first time.

These circumstances prompt the following questions:

1. Is it desirable and possible to lower the level of the remainder of the River Paute Reservoir?
2. Are new landslides possible in the rest of the areas adjacent to the reservoir?
3. How is it possible in the long term to detect occurrences such as the La Josefina Landslide in time and to take appropriate steps to reduce their effects?

2.7 The post-drainage situation

We have some idea of the appearance of the region flooded by the landslide on 7 May 1993 from photographs. The intact surface of some of the parts of the mass of fallen earth and stones suggests that larger blocks came down almost intact. The outlet canal constructed in the right-hand part of the landslide adjacent to the right-hand slope of the Paute Valley was eroded. A large part of the volume of the landslide was eroded by retrogressive erosion and the drainage canal was thereby deepened. Retrogressive erosion was also the reason for the widening of the river bed through the body of the landslide and for the relatively steep slope in this sector.

Further downstream from the landslide the valley was strewn with stones and rubble to a height of some 15 metres over a distance of approximately 10 km. However, at the time of writing, no precise calculations were available. The difference of level occasioned by the erosion was particularly apparent. The slopes bordering the landslide area are greatly inclined. Erosion of the rock is also apparent in the heavily inclined slope of the right margin.

2.8 Examples of damage

2.8.1 *Flood damage in the area of the La Josefina Reservoir*

Floods lasting for weeks caused great damage around the La Josefina Reservoir. Because the waters rose relatively slowly, they did not cause damage through erosion. Nevertheless, the saturation that the water caused and the rapid drop in its level after the reservoir overflowed caused various landslides. Fuel oil escaping from the stock of the thermal power station heavily polluted a large area. Damage was caused to the vegetation and infrastructure (roads, railway, etc.) and to dwellings and industrial plants.

Although this damage shows up only as muddying, it is serious. In some places the vegetation is withered and spoilt; some building materials were so damaged as to need replacement. A penetrating smell of waste water arriving at the lake hung in the air. A complete clean-up operation is required.

The valley in which the thermal power station is located here narrows to a steep-sided canyon. Landslides forming new reservoirs in this sector would cause a rapid rise in water level and new flooding of the power station within a day. Moreover, a lake could form, the lower end of which would reach Cuenca.

2.8.2 *Damage downstream from the landslide in the River Paute*

2.8.2.1 Damage suffered immediately below the landslide in the River Paute

In contrast to the damage that occurred in the area of the River Paute Reservoir, the damage to be seen in this sector is, above all, caused by erosion and deposition of mud. The detrimental effects of saturation are scarcely apparent because the flood was of short duration. Photographs show typical damage in the area immediately downstream from La Josefina to the sector downstream from Paute. The most notable feature is the predominant indications of heavy erosion. Extensive sedimentation sets the standard for the difference of current velocity. The thickness of the rubble deposited is a notable feature at various points in the valley. Sand has accumulated on roofs and the water has caused damage to telephone lines.

2.8.2.2 Damage in the sector of the Paute/Amaluza Hydroelectric Power Station

No damage was observed to the Daniel Palacios Dam itself or in its vicinity. During the peak discharge around 4,200 m^3/s flowed over the spillways, which have a capacity of 7,700 m^3/s. Here also there were effects of strong erosion along the river bed. Downstream from the small town of Amaluza the water destroyed some 300 metres of the access road to the machine hall. There was particularly notable damage by erosion during the peak discharge in the sector of the Molino machine hall.

The new service bridge remained intact where the peak water level rose to one metre below the bridge. The access road on the left side was completely carried away in some places. The old bridge, a little lower down, was carried away by the flow. The slopes on both sides of the valley were heavily eroded, which caused undercutting of the outflow structures of the discharge tunnels and instability of the right bank.

2.9 Discussion on measures to be taken following drainage

2.9.1 *Short-term measures*

Conditions have been very stable since 13 May 1993. It is thought that there will not be any drastic fall in the level of the remaining River Paute Reservoir in the medium-term. Maintenance of the existing level may have the following advantages and disadvantages:

Advantages

The reservoir is functioning as a natural sedimentation basin for the Amaluza Power Station. This would make it possible, if necessary, to dispense with the Paute/Mazar settling reservoir, which has been projected for some time. The power station officials seem interested in this solution.

Disadvantages

- Neither the cities of Cuenca and Azogues, nor the other towns upstream from La Josefina have sewage treatment plants. The sewage of some 300,000 people is accumulating in the remaining reservoir and some hygiene problems are to be expected in the short- and medium-term;

- The water level is still so high that the El Descanso Thermal Power Station remains partly submerged;
  The Pan-American Highway, the North-South link, remains interrupted, as does the railway line.

Silt is the main drawback if the present level of the reservoir is maintained. An urgent reduction in the present level is therefore recommended. It would appear to be possible to reduce the reservoir level by five to seven metres without too much effort, because that is the difference of altitude between the point at which water enters the body of the landslide and the point of emergence. That would drastically reduce the volume of the reservoir and keep the power station above the flooding level.

Further reduction would be more costly owing to the great amount of gravel accumulated in the lower parts of La Josefina, which would have to be removed from a narrow valley. It is therefore recommended that a study be made of the possibility of investing the money saved by not reducing the volume of the reservoir on the rapid installation of sewage treatment plants in Cuenca and Azogues. The meandering of the River Paute is still considerable in the extensive areas of Gualaceo and Paute. What needs to be done to reduce the risk of new landslides and flooding is to stabilize the river bed.

2.9.2 *Medium- and long-term measures*

On examining the geological and geotectonic situation in the Paute Valley, it is evident that there are many points, old and new, where landsliding is likely to occur. The available geological maps are very general and do not depict the exact situation. There are no geotectonic maps. A clear view of the existing hazards and threats in the areas concerned is a condition for the carrying out of active and passive measures to reduce the risks of natural hazards.

Given maps of hazards and, above all, of risks, it is possible to adopt measures and to set priorities. These maps are presented as planning tools. The priority for the Paute Valley is to produce maps of natural hazards and risks (landslides, flooding, seismicity). What must secondly be done is to plan and carry out observations and monitoring in the areas of maximum risk. These measures consist of developing an observation network capable of identifying shifts in good time. In areas where there are have already been surface movements, it is worthwhile installing what is known as a slope indicator, the purpose of which is to monitor the behaviour of deep points of unstable zones.

Acute danger of landsliding may also be monitored acoustically. An appropriate monitoring and recognition system can be installed for a relatively modest expenditure. What is important is that the measurements should be carried out regularly and that the results should be available without delay. For instance, Switzerland has experience in surveying the production of hazard and risk-zoning maps, and the planning and operation of observation networks.

Three projects have been identified in the course of the mission for which support from Switzerland seems desirable. The team of experts propose that the Swiss Disaster Relief Corps (SDR) give priority attention to the possibility of supporting a project to produce hazard and risk maps and prepare a training seminar for 1994. The project for an observation network should be tackled after the fundamental risks have been assessed.

3. Organizational Section: Disaster Management

3.1 Training: organization, co-ordination and implementation of disaster management by the Azuay Provincial Civil Defence Council

Apart from the experts, Mr. P. Chamot and Dr. J. Studer, who collaborated on the technical aspects, Mr. F. Wirz covered the humanitarian section of the DHA Geneva/SDR mission in La Josefina. The objectives of the mission were to collect information on the damage that had occurred, and the aid requirements, to provide information to the UNDP (United Nations Development Programme) Office in Quito and to mobilize and co-ordinate the distribution of humanitarian aid from DHA Geneva.

As the Azuay Provincial Civil Defence Council was extremely occupied, Mr. Wirz worked additionally providing logistic support to the army in the construction of evacuation camps for some 3,500 people downstream from the La Josefina embankment (the first phase of the mission until shortly before the draining down of the La Josefina Reservoir).

The second phase consisted mainly of: (a) the (partial) co-ordination of the maintenance and running of the encampments; (b) assistance with the clean-up operation throughout the sector affected by flooding or water discharge; (c) collaboration in planning reconstruction (recommendations) and also (d) the gathering of information on reconstruction plans and investigation of the next steps to be taken both by DHA Geneva and by SDR.

There were therefore three aspects of the mission:

(a) Disaster prevention upstream and downstream from the landslide embankment during the formation of the natural reservoir at La Josefina. Up-stream, the work consisted of minimizing the flood damage and evacuating those affected. Down-stream, an evacuation plan was prepared and evacuation carried out on account of foreseeable flooding during the draining down of the La Josefina Reservoir (or in the case of a sudden breaching of the embankment).

(b) Disaster relief as the reservoir level rose (care for the victims of the landslide and flooding) and after the draining down throughout the sector affected.

(c) Planning of reconstruction/rehabilitation and investigation of disaster prevention measures (with the support of SDR) in the medium-term.

Activities (a) and (b) were co-ordinated by the Crisis Committee headed by the Azuay Provincial Civil Defence Council. As a member of this Committee, the army carried out a large part of the activities required, especially for the evacuation of the population.

This caused some tension in the Committee. There was also tension between the provincial authorities and the church because the church received considerably more money and aid from the population and distributed and administered these resources independently, whereas the Civil Defence is the body intended for that purpose in a disaster situation. There were thus complications over co-ordination of the distribution of aid, since there were several different aid centres.

Because of the scale of the disaster, the Azuay Provincial Civil Defence Council was reinforced by members of the staff of the National Civil Defence Office in Quito. Relief and assistance were carried out through various institutions and by the army (evacuation) .

Food for 6,000-8,000 people had to be provided for some time and it was also necessary to accommodate some 3,500 people. As the Civil Defence was almost entirely engaged in dealing with the problems caused by the flooding upstream from the embankment, Mr. Wirz was also concerned himself with the logistics of assisting the army to build the evacuation camps downstream from the La Josefina embankment. This involved organizing the making and purchase of tents, field kitchens, latrines and showers, and of maintenance equipment, crockery, etc., and of transporting it and installing it in the camps as rapidly as possible. The Youth Brigade, a voluntary organization, provided logistic assistance.

In phase II, following the draining down of the La Josefina Reservoir, the Crisis Committee was replaced by the Emergency Works Scheduling Board. This board co-ordinated the next steps (c). First, an assessment had to be made of the damage and the cleaning up of the sectors affected had to be organized and assisted. DHA Geneva provided the population with the tools required for the clean-up operation (power saws, picks and shovels, barrows).

Following an investigation it was proposed to the Scheduling Board that finances be made available to provide prefabricated wooden dwellings for people who had lost their homes, and to provide them at the same time with the machinery to make building blocks for new permanent housing.

During this period the team also made contact with various institutions to investigate the scope for future collaboration and assistance in disaster prevention for similar cases. The La Josefina Disaster did reveal some weak points of the Azuay Civil Defence Council, which should be improved in the future. The conclusions and recommendations in the next chapter refer to these points.

4. Conclusions

4.1 Technical and scientific section

- Topography and geological conditions are such in Ecuador that landslides as large as the *La Josefina* Landslide may recur in the future;
- It may be concluded from what is currently known that the main cause of the landslide was a combination of the topographic/geological situation and the prolonged heavy rainfall of the winter of 1992/93;
- The building of a drainage canal for the principal body of the La Josefina Landslide was the only possible decision that could realistically have been taken. The purpose of constructing this canal at the lowest possible altitude was to prevent the water level from rising, thereby reducing the magnitude of the disaster.
- The La Josefina natural reservoir was drained as envisaged by the discharge of water through the canal constructed in the landslide. Once the retrogressive erosion had reached the entrance section of the canal, the draining down was able to develop, as had been assumed, at an increased rate;
- It had not been envisaged that a week would elapse between the first outflow of water through the canal and the rupturing of the embankment by erosion. The delay was caused by various landslides that occurred in the upper part of the canal. The water was unable to carry away these landslides instantaneously and their removal was deferred until the rise of the water level in the reservoir provided a greater discharge;
- These landslides were undoubtedly provoked by the high gradient of the left slope. Without wishing to criticize what was done under highly singular circumstances arising from the pressure of time, it might have been more advantageous to have selected a higher bed level for the canal at the outset, for example at 2,360.00 m above sea level, but to keep to slopes no steeper than 1:1, thus avoiding the landslides that occurred;
- The draining of the La Josefina Reservoir was far more violent than had been initially estimated, took place in a far shorter time and with peak discharges far higher than had been estimated. The reason for the differences between what had been predicted and what happened is to be sought basically in the fact that the particle-size composition

of the material of the embankment was not sufficiently analyzed and was much finer than had been mistakenly assumed on the basis of geoseismic soundings in the area, i.e. 100 mm. It might have been better to have relied on visual observations rather than to trust in the results of geoseismic studies. The results must be correlated with test-drilling data, especially when the materials concerned are water-saturated;

- The draining of the reservoir also caused great damage. The evacuation of the population had been well prepared. There was no loss of life and no injury occasioned by the violent draining down.

4.2 Organizational section

- The question of the executive staff in the Azuay Provincial Civil Defence Council had not been solved. There is a need for a director to guide in place the organization and supervise the planning of activities for coping with disasters;
- The Azuay Provincial Civil Defence Council does not have sufficient staff to be able to respond adequately should a disaster occur;
- There are problems in the implementation of the action plan. The duties and responsibilities of the parties concerned (Civil Defence Council and other bodies) have been defined, but have at times not been followed. There is in general a local lack of experienced executive staff;
- There is still room for improvement in co-ordination and communication between all local participants;
- There is an acute need for a data bank containing basic information on the region for far more rapid understanding and analysis of the disaster situation. Experience shows that much time was lost before the exact situation was recognized. In emergencies, time plays a decisive role.

5. Recommendations for Further Work

1. The level of the natural reservoir on the River Cuenca may be lowered by a further 5 to 7 metres. It is recommended that this measure be carried out as quickly as possible.

2. Given the lack of treatment for sewage from various cities, the natural reservoir may cause health problems in the future. The building of water treatment plants is urgently recommended.

3. The possibility should be investigated of retaining the Jadán natural reservoir as a sedimentation basin.

4. The location of the El Descanso Thermal Power Station is at high risk of flooding. Relocation of this power station on a more suitable site is recommended.

5. It is recommended that a potential risks map be produced for Cuenca and the surrounding region, including the Paute Valley.

6. Localities of high geological risk should be monitored by an early warning system.

7. The holding of a seminar/workshop on the La Josefina Disaster is proposed for autumn 1994 with the aims of exchanging and disseminating the scientific results of the research, discussion of long-term measures and experience gained, a demonstration of disaster relief organization and upgrading for future similar events. Participants: institutions and interested individuals and authorities.

8. Improvement of Civil Defence organization and training based on the experience of the La Josefina Disaster.

9. Stabilization of the bed of the River Paute in the relatively shallow parts before next winter.

Recommendations 1, 4, 5 and 6 have high priority. Support is requested for recommendations 5, 6, 7 and 8 from DHA/UNDRO and the Swiss Disaster Relief Corps (SDR) for the imparting of experience gained at the international level. More specific information will be found in the respective reports.

6. Requests from Ecuador

Here we make brief mention only of the points on which assistance was sought from DHA and SDR.

Technical section

6.1 CONUEP, National University and Technical School Council, Quito

- Support for detailed studies by an expert on landslides;
- Installation of a monitoring system in high-risk localities;
- Technical consultancy to CONUEP on the drafting of projects relating to natural disasters, support for the preparation of a post-graduate course on natural disasters for technicians;
- Specialized bibliography on natural disasters.

6.2 Emergency Works Scheduling Board for the Valleys of the River Paute and its Tributaries, Cuenca

- Technical and financial assistance for activities.

6.3 Technical Sciences Research Institute (TSRI), University of Cuenca, Cuenca

- Technical assistance by an expert on geological risk.

Organizational section

6.4 Azuay Provincial Civil Defence Council

- Staff training at the executive, administrative and voluntary worker level;
- Distribution of responsibilities;
- Infrastructure improvement (data bank);
- Updating experience;
- Financial assistance for carrying out the pilot plan.

7. Proposals by the Team of Experts

7.1 Potential risks map and seminar

7.1.1 *Potential risks map*

Objective

The preparation of a planning base for the authorities:

- Assessment of sites (for industrial plants, residential areas, road building, etc.);
- Preventive measures for the mitigation of disasters (planning of capacities, etc.).

Brief description of the project

The potential risks map is not a scientific work for university libraries, but is designed to be comprehensible to and used by the authorities when taking decisions. It is based on the current scientific situation and, therefore, should be completed within a specified time (two to three years). Broader scientific aspects should be dealt with in other projects.

The potential risks map is based on an existing topographic map (e.g. 1:10,000). All natural hazards that may occur in the region are represented on it; they include areas where there may be landslides and rock falls (where there is jointing of the rocks), normal river discharges and maximum levels, areas at risk of flooding without external effects; acceptable water discharges at critical points such as narrow defiles, bridges, etc. Sites of industrial plants using chemicals (with a list of these substances and the minimum and maximum amounts used), and essential infrastructure such as means of transport and services (electricity, water, drainage, etc.).

The project should be limited to a determined high-priority area (e.g. from Tahual to Paute) and the methodology and manner of representation worked out should be that most appropriate to Ecuadorian conditions and conducive to the gathering of information (problems, time requirement, ease of use). Those engaged on the project will have to be able to construct a similar map by themselves in any other place or later circumstance. What is at issue is basically a pilot project that should facilitate the future production of maps.

Use should be made of the investigations already carried out, especially those of a team of Italian geologists. The project has aroused interest in universities, polytechnics and with the authorities. Some preparatory and planning measures have already been undertaken (the Emergency Works Scheduling Board is considering an outline of the project).

Remarks/contact with other projects

The first results of the work on the potential risks map will be presented during the seminar planned for 1994. This will also be the occasion for information on the practical use of the map for decision taking.

7.1.2 *Training Seminar*

Objective

- To use all the experience gained in the management of the La Josefina Disaster;
- To process and upgrade the knowledge gained for application to future projects in Ecuador. This will make it available to persons who were not present during the disaster;
- To strengthen relations between institutions in Ecuador and at the international level.

Brief description of the project

A seminar (three to four days) on work in connection with the La Josefina Landslide will be held in summer/autumn 1994. The participants will present the results of their investigations and experience. The investigation methods and procedures that are of use in dealing with similar incidents must also be presented at this time. The studies will be published along with the documentation of the meeting.

Participants

Scientists, government representatives, and experts on disaster relief and prevention who were involved in the La Josefina Disaster and/or persons who may be interested in such problems.

Suggested programme

Day 1

Opening ceremony, causes and course of the landslide, extent of damage to the reservoir, calculation methods, forecasts, most common hazards in Ecuador, i.e. landslides, earthquakes and volcanoes.

Day 2

Reduction of the reservoir level. Forecast, occurrence, comparison with other similar disasters, extent of the damage caused by draining down, problems in the Paute Power Station, calculation methods.

Day 3

Organizational problems, warning the people, conduct of the authorities and the people, evacuation, rehabilitation and reconstruction.

Day 4

Prevention: scope, projects, summary of what has been learnt, next steps.

Role of the SDR

The SDR will apply its experience in the running of seminars of this kind to the organization of the event (collaboration in the organizing committee) and will meet the costs of printing the documents of the meeting.

Conditions

- Agreement of the universities and polytechnics;
- Agreement of the Emergency Works Scheduling Board;
- Free provision of premises for the seminar;
- The interim organizing committee will be set up by September 1993 and the place and provisional dates will be set by the end of September;
- Partial presence of members of the SDR on the ground.

Other procedures

- A decision by the end of September 1993 on the presence of the SDR at the meeting (including expenditure);
- First meeting of the organizing committee in September 1993.

Remarks

The seminar is complementary to the planned postgraduate course of the universities. The documentation (transactions of the meeting) will be useable for teaching purposes.

7.2 Observation system

Objective

- Early recognition of the threat. Critical areas liable to landslides should be continuously monitored in order to have timely warning of any deterioration in the situation;
- Improvement of the forecasting methods;
- Establishment of scientific analyses of forecasts on movements in unstable areas. Comparison and modification of the results of the observation system to improve their reliability;
- Transfer of instruction and know-how. Training on observation systems (concept, operation and evaluation) for the workers in Ecuador.

Brief description of the project

Periodic topographic measures will be organized in critical areas (where there may be landslides with serious consequences). The project includes the setting up of a measurement network, and evaluation and interpretation of the results. Additional investigations are planned:

- The slope indicator, which measures borehole deformation, is used to assess the area of landsliding;
- Study of the information obtained using the slope indicator.

Role of the SDR

- The SDR will contribute its experience concerning observation systems (design, operation, evaluation, interpretation);
- It will provide financial assistance for the measuring teams (e.g. the slope indicator, etc.).

Conditions for participation by SDR

- To identify areas of critical instability, e.g. through the first results on the potential risks map (could be Tahual);
- Composition of the planning team;
- Contractual agreement on observation tasks and the operation of the system (including the financial aspect for its maintenance).

Other measures: the project will be specified after the critical areas have been identified.

7.3 Assistance with the creation of a data bank to assist the Azuay Provincial Civil Defence Council

Objective

Rapid and efficient analysis of disaster situations with a catalogue of measures for the various regions in the south of the country prepared by the Emergency Operations Centre (COE), clear allocation of responsibilities in this catalogue, and planning of disaster management with a checklist of the work to be carried out or already carried out.

Brief description of the project

The setting up of a computing team with the creation of a data bank on disasters, and personnel training (in collaboration with DHA, Geneva). This knowledge would also be available for transfer to other COEs. In connection with 7.1 there will be opportunity to plan for measures in zones at high risk.

Role of the SDR

Transfer of know-how concerning disaster prevention and disaster-relief planning and concerning the setting up of a data bank, collaboration on the preparation of a simulated disaster and on management of the data bank. The experience gained from La Josefina will be incorporated.

Conditions for the participation of the SDR

- The provincial Civil Defence Council is to carry out the training and the dissemination of knowledge (data bank) and to prepare/participate in the preparation of a simulated disaster;
- Integration of the data bank into the national Civil Defence computer network;
- The National Civil Defence Office is also to pass on the knowledge to similar bodies in neighbouring countries.

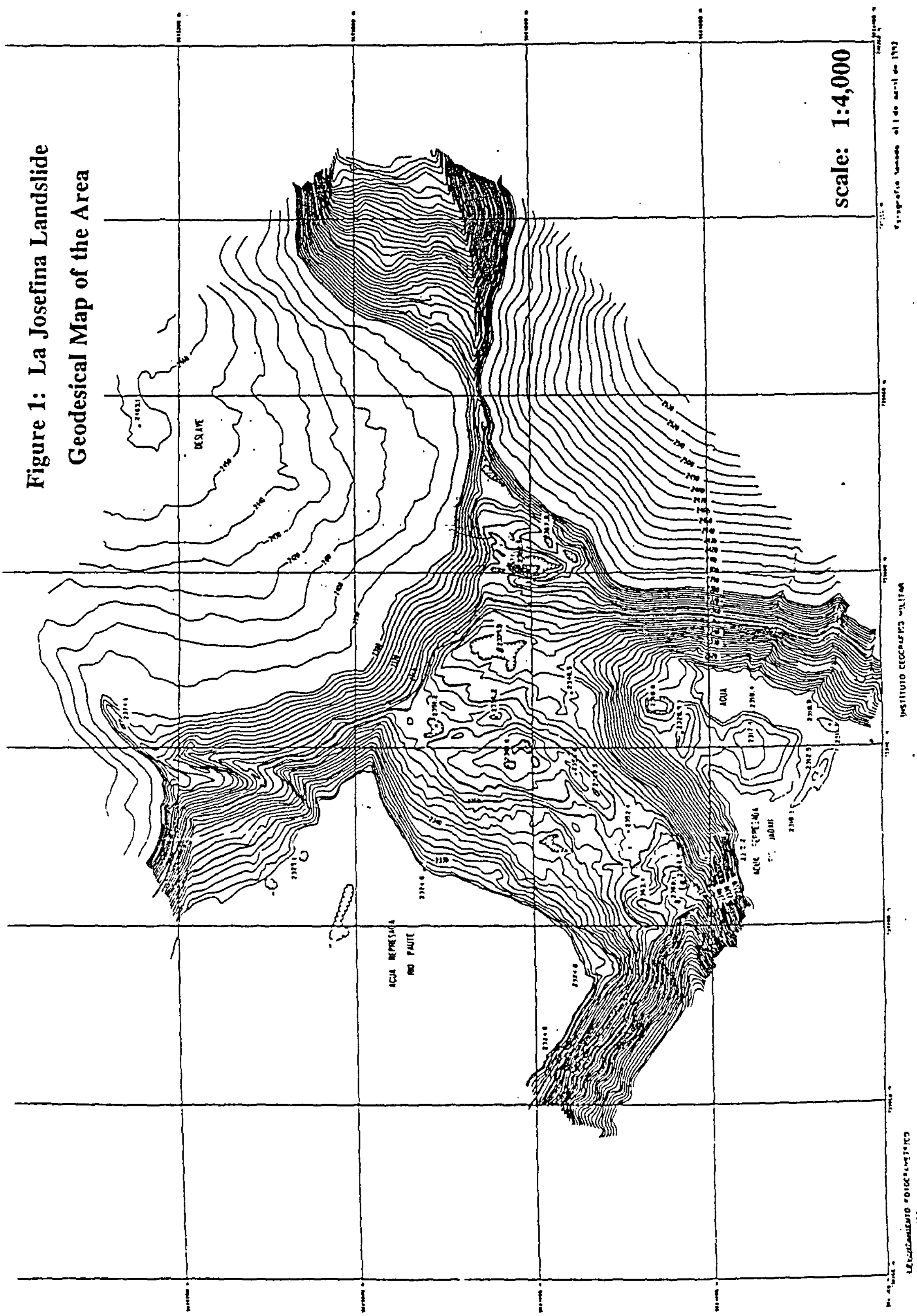


Figure 1: La Josefina Landslide
Geodesical Map of the Area

Figure 2: La Josefina Landslide
Stages of the Landslide

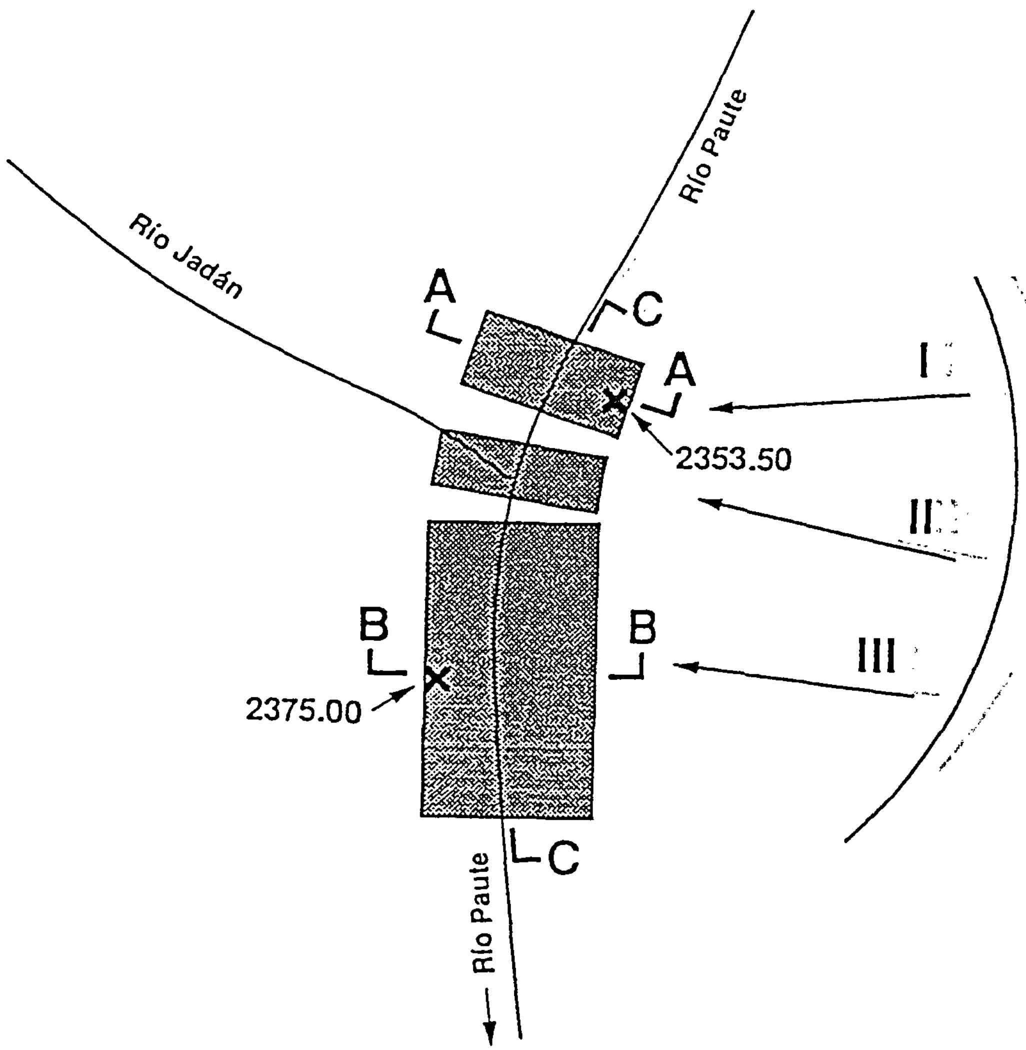


Figure 3: La Josefina Landslide

The Geology of the Landslide

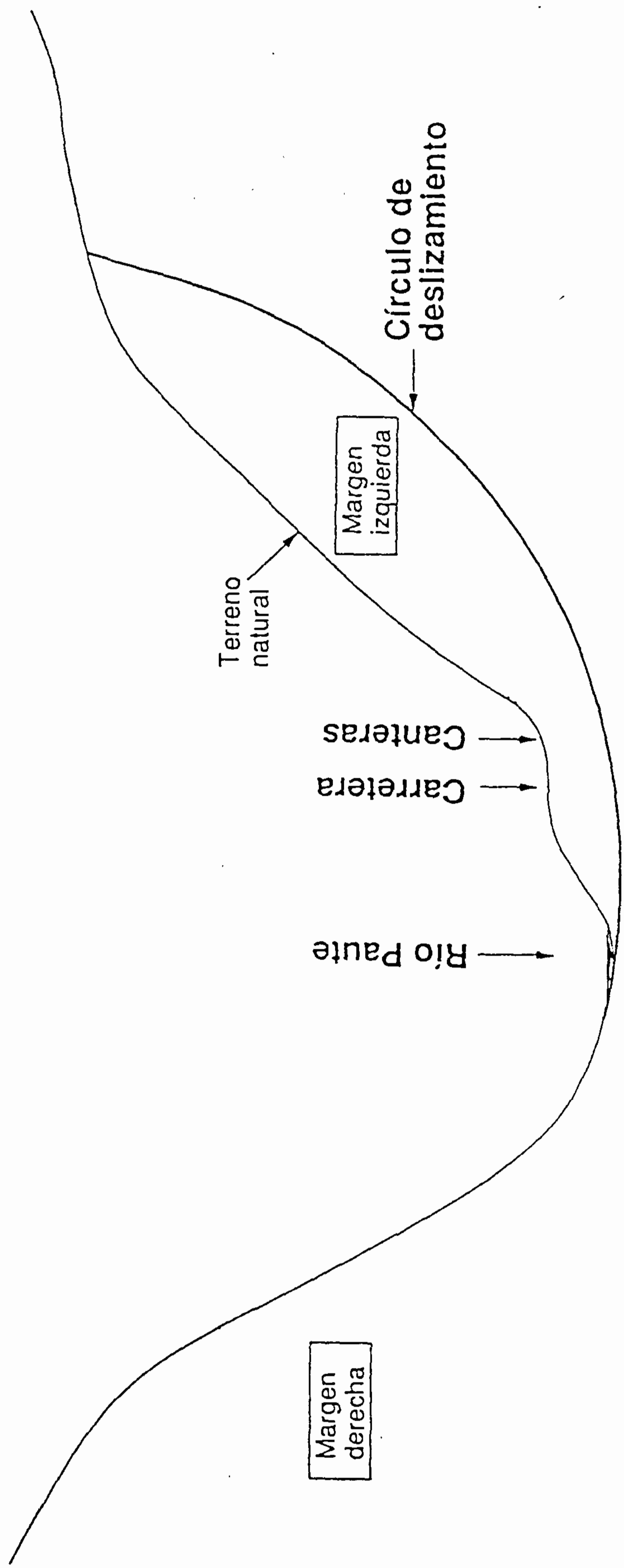


Figure 4: Water Levels in the La Josefina Reservoir

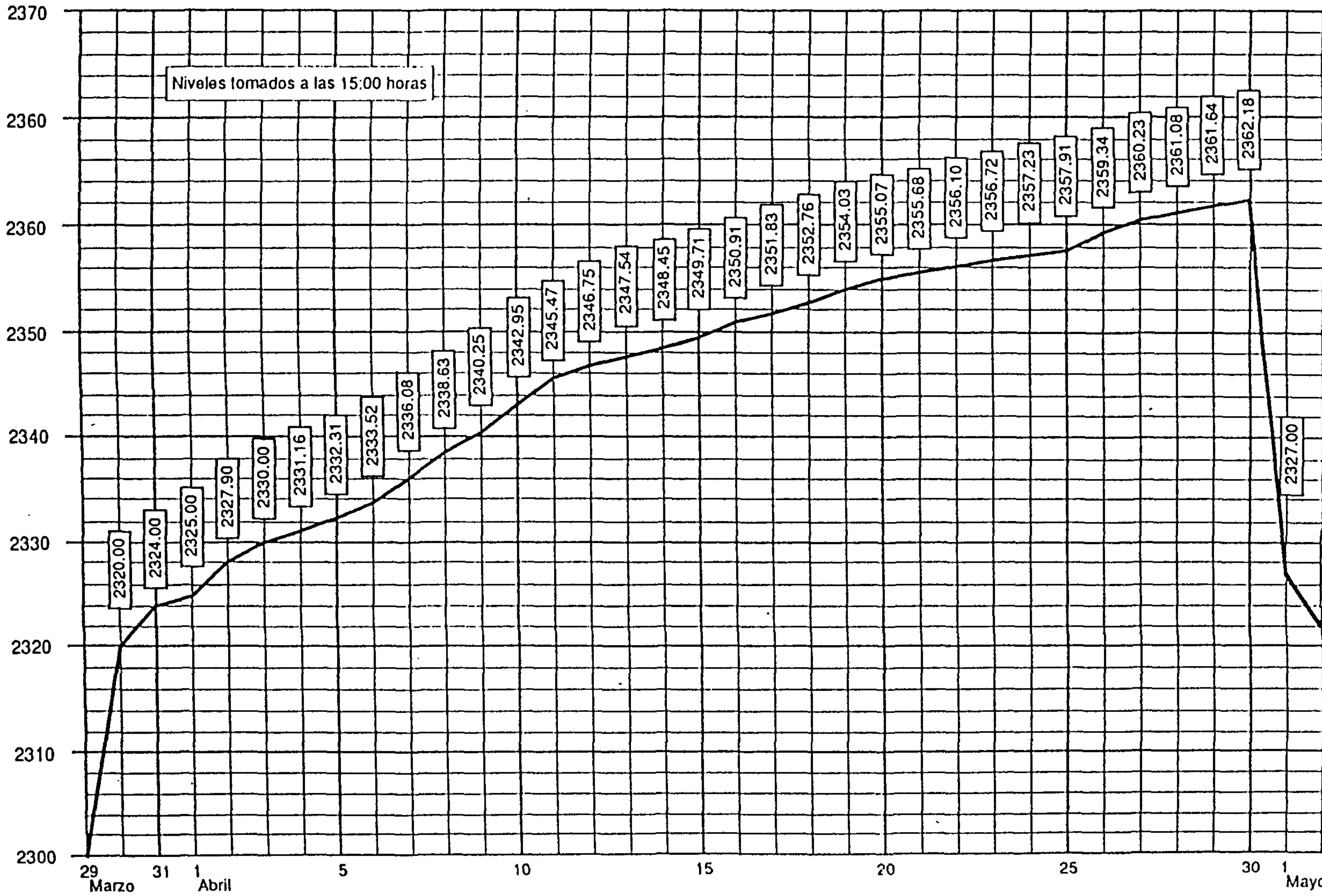


Figure 5: La Josefina Landslide

Transversal and Longitudinal Sections of the Landslide

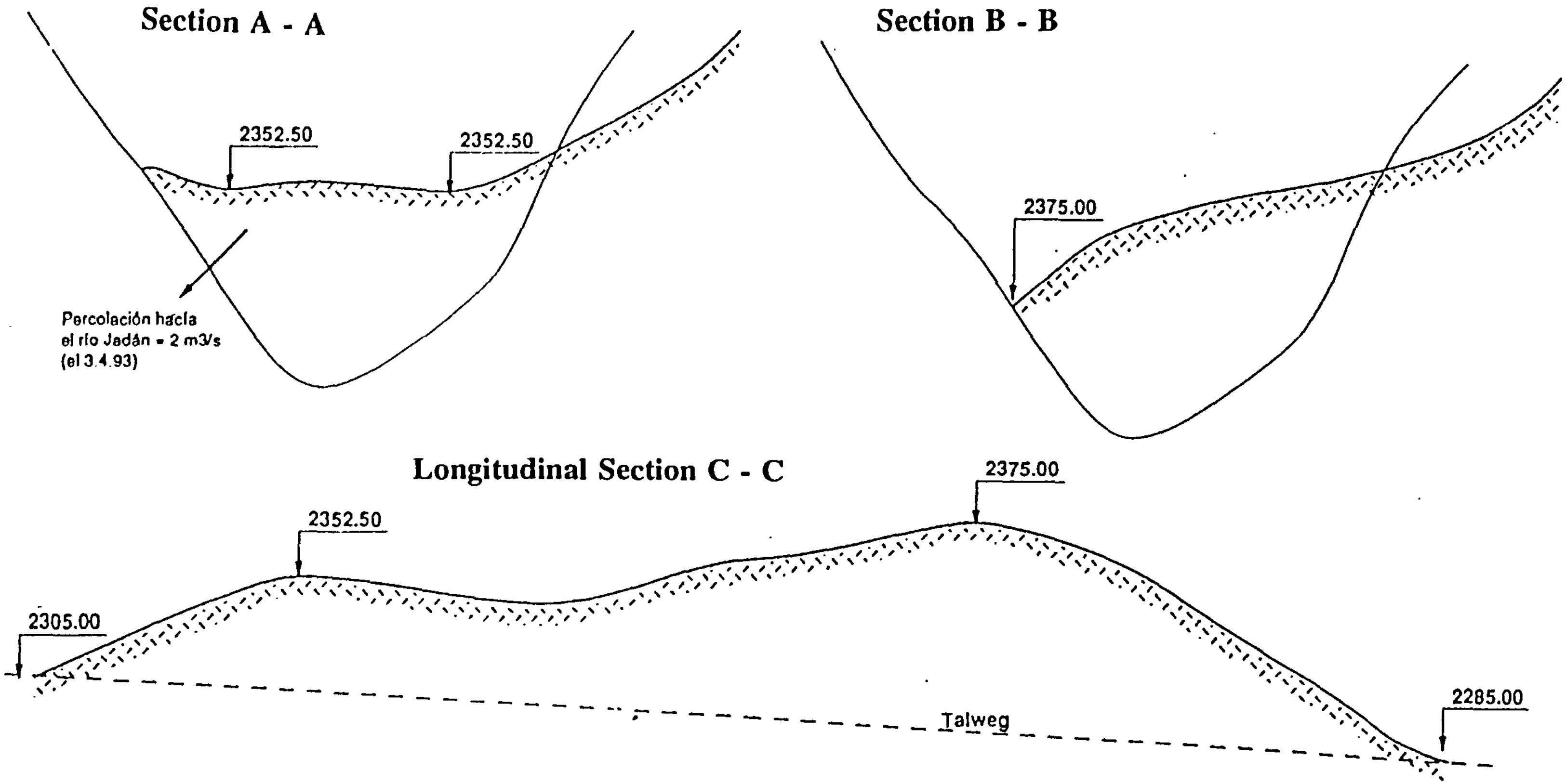
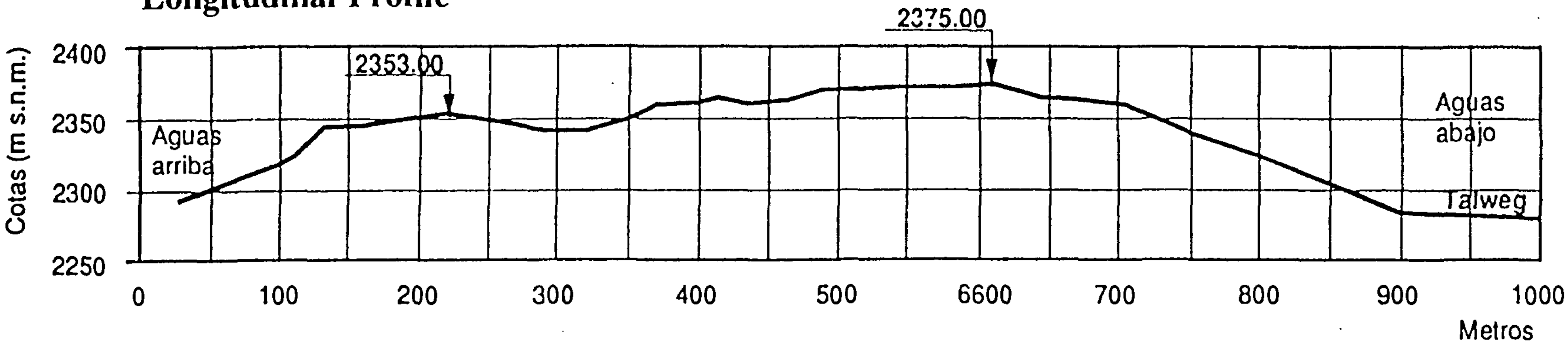


Figure 6: Longitudinal Profile of the Landslide and Transversial Section

Longitudinal Profile



Transversal Section

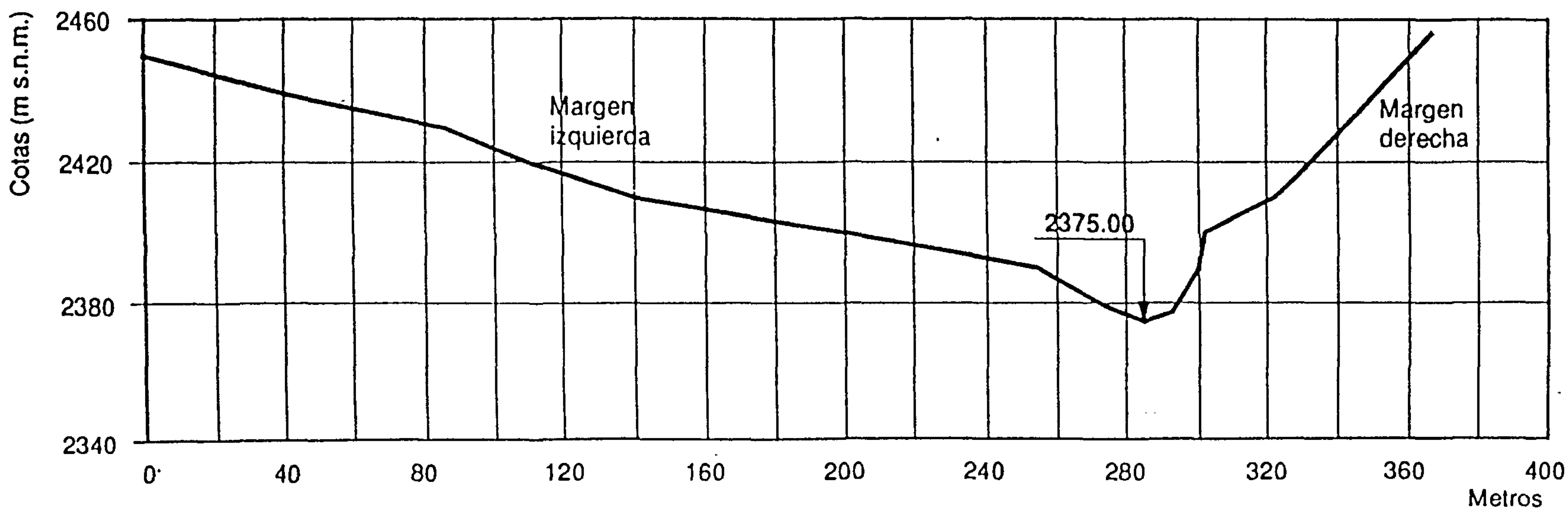


Figure 7: Drainage Canal as Designed

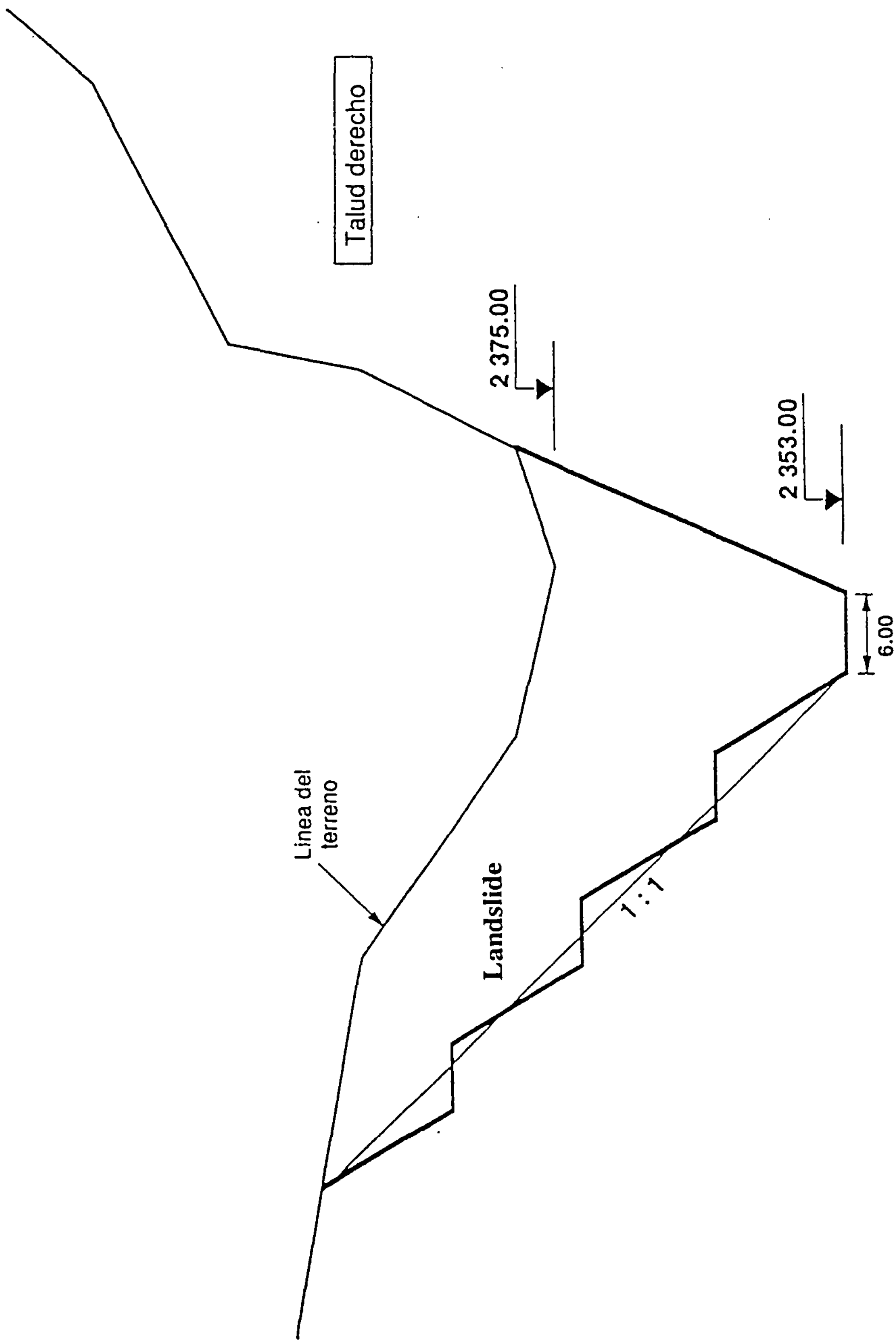


Figure 8: Volumes of the La Josefina Reservoir

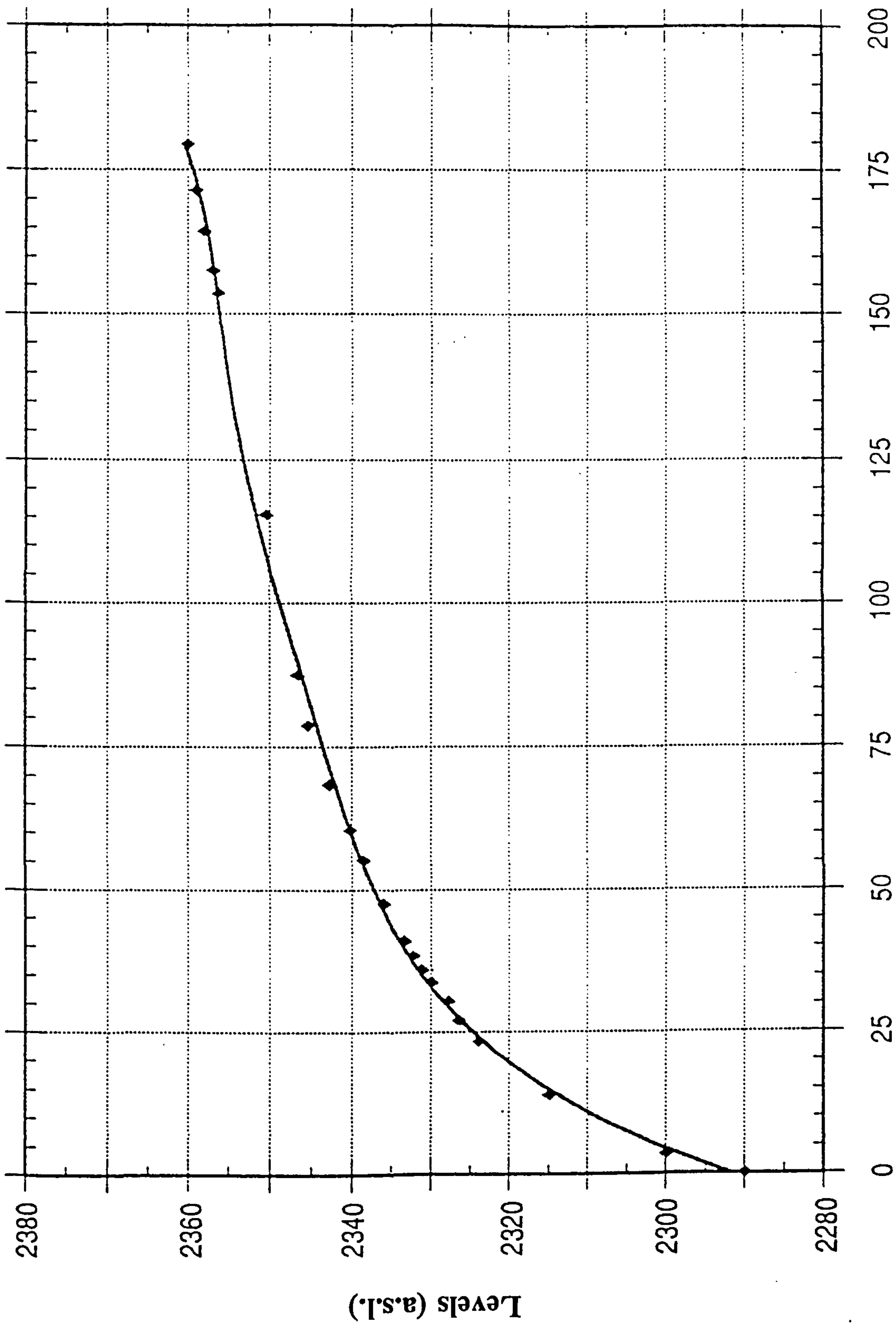


Figure 9: Drainage Canal as was Constructed

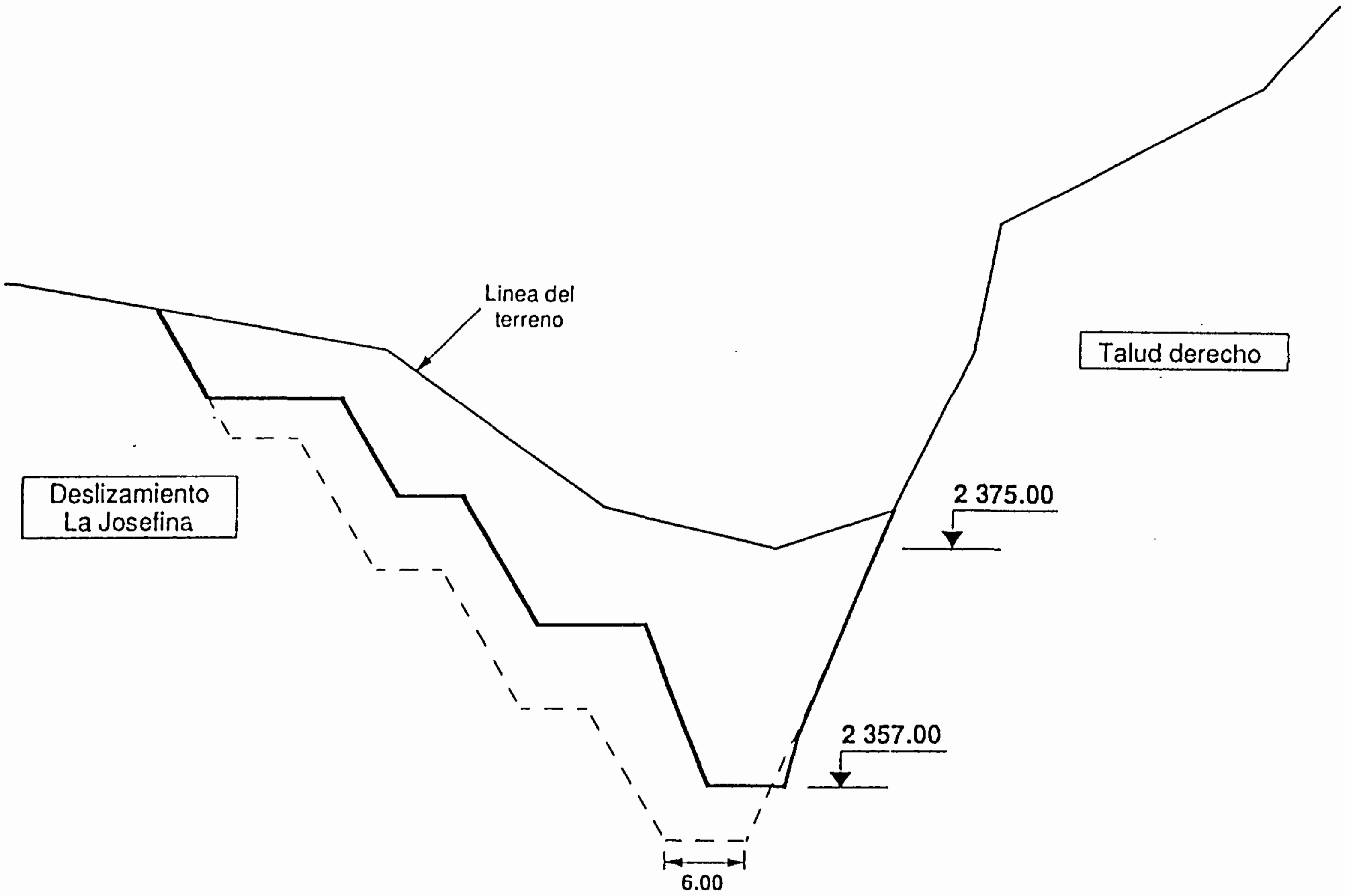
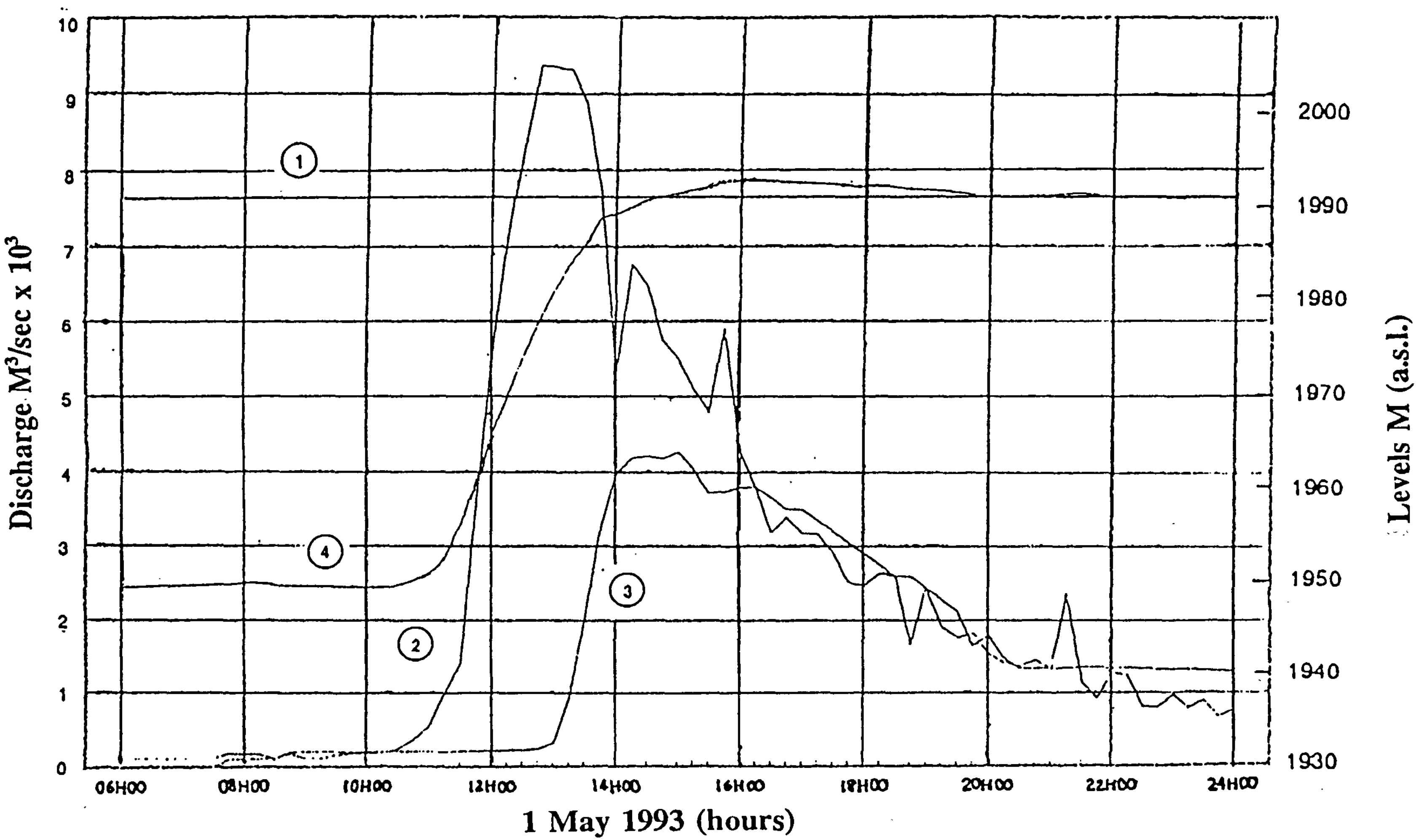


Figure 10: Amaluza Operation at the Drain of the La Josefina Reservoir

(Hydrograms and Levels)



(1) Max. operational level
(2) Inflow discharge in the Amaluza Reservoir
(3) Outflow discharge
(4) Recorded level

Figure 11: Amaluza Dam Discharge

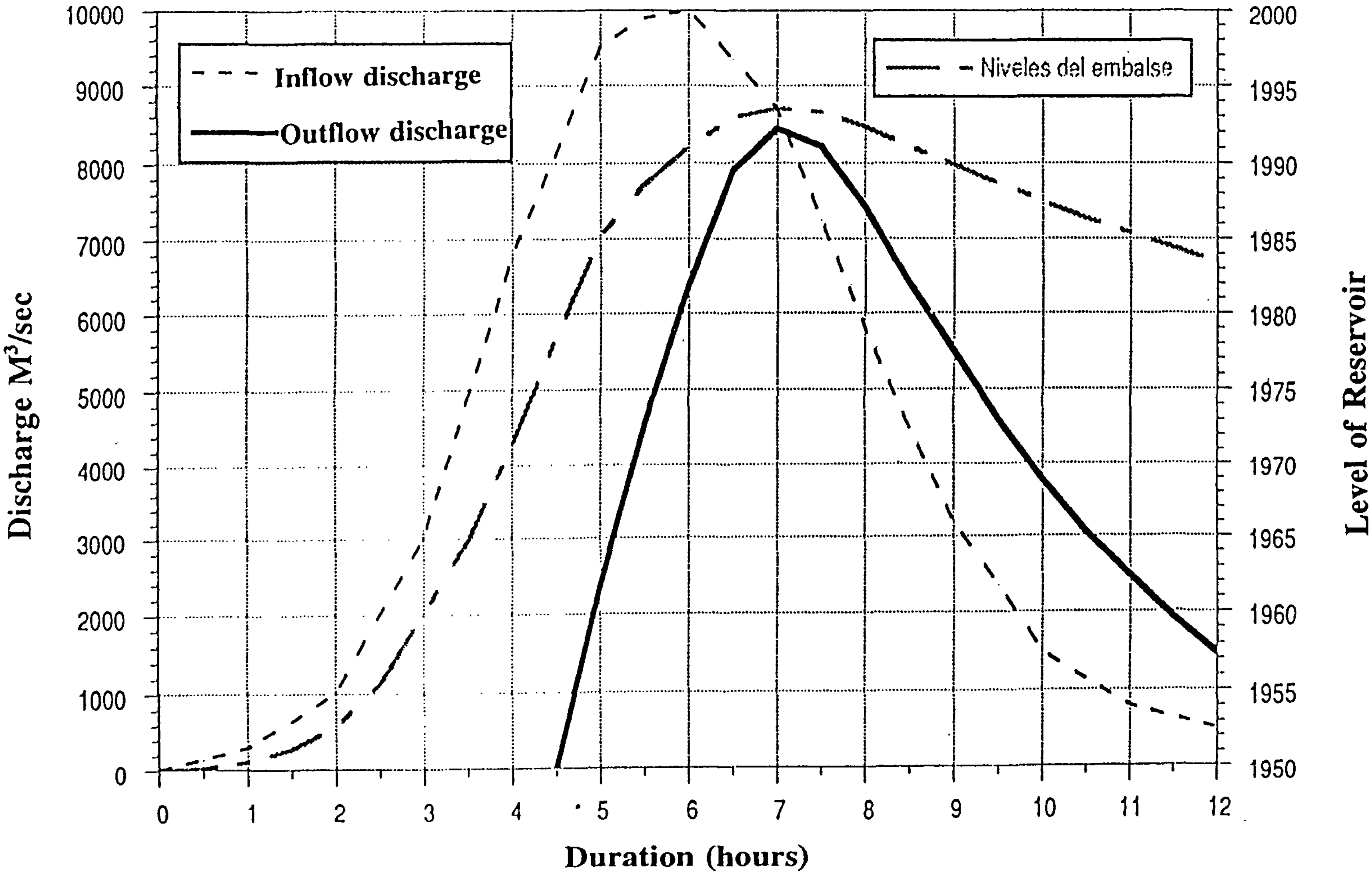


Figure 12: Volumes of the Amaluza Reservoir

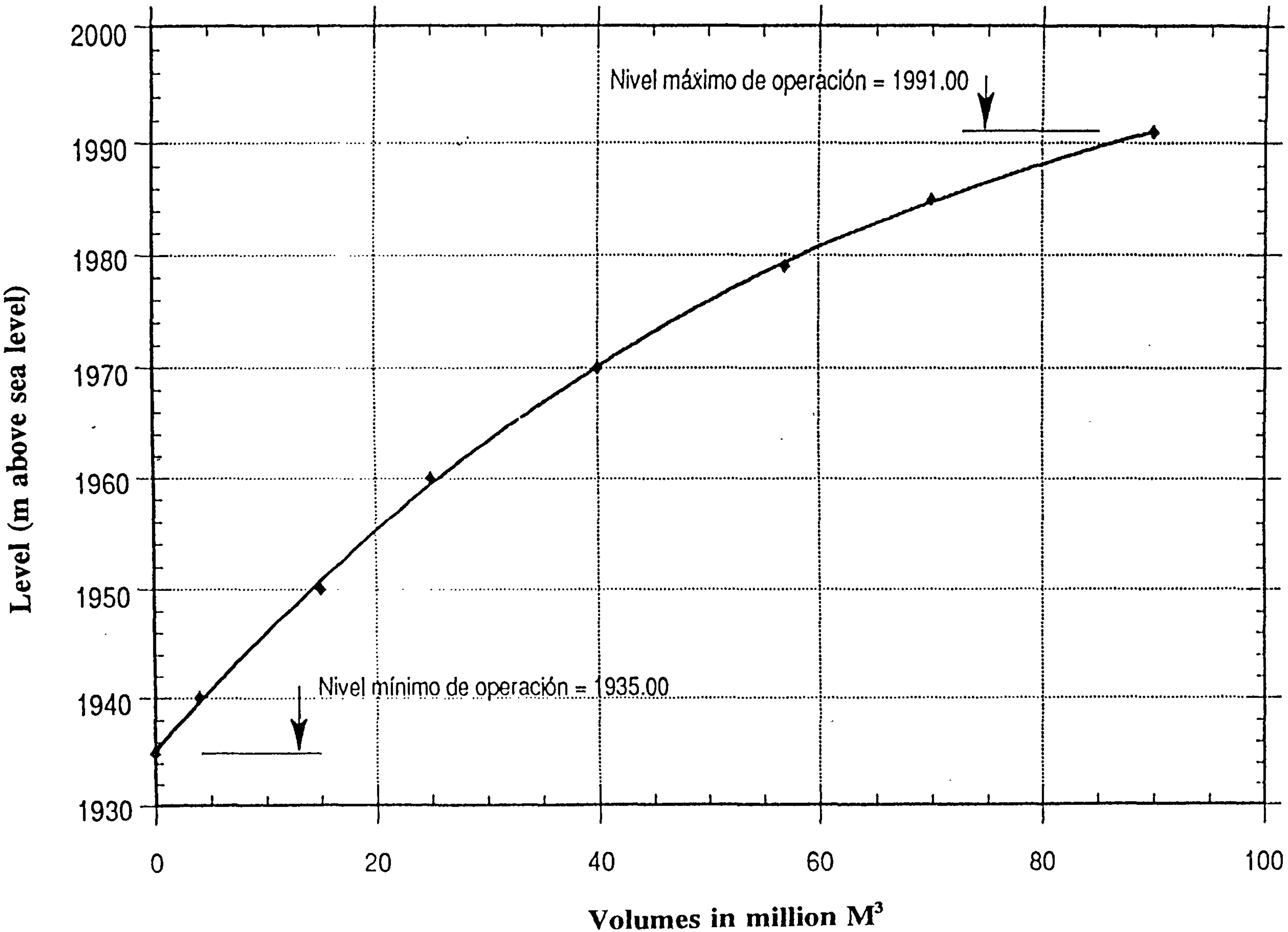


Figure 13: La Josefina Landslide

Water Profiles Down the Landslide

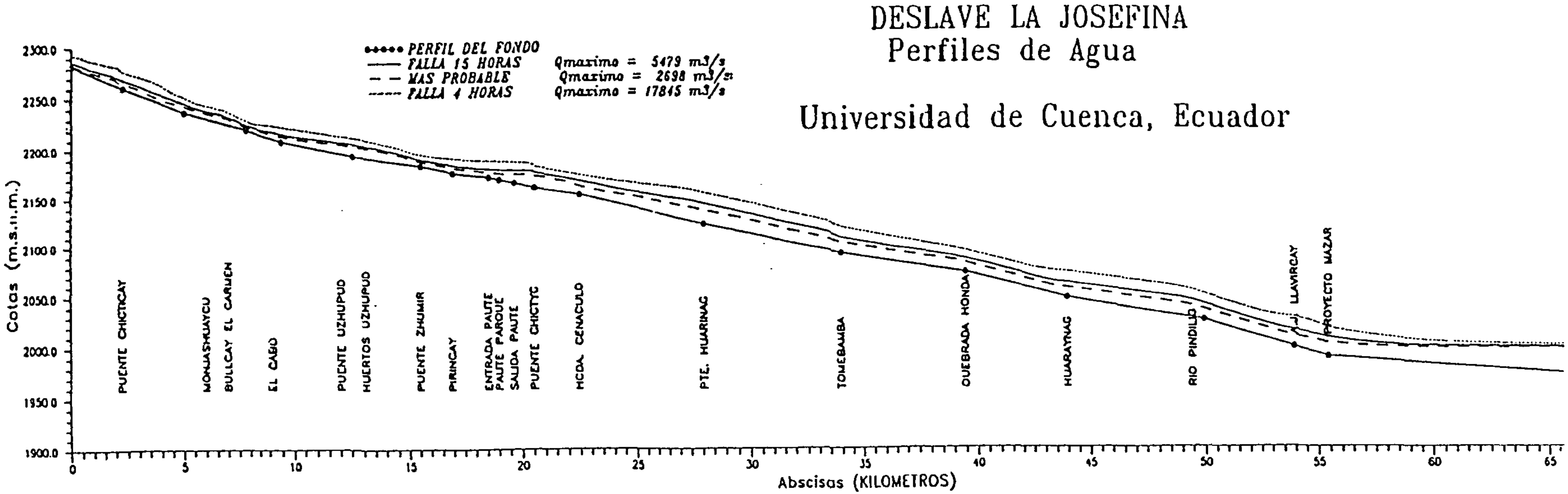


Figure 14: Drainage of the Josefina Reservoir
(Discharges Thousands M³/sec)

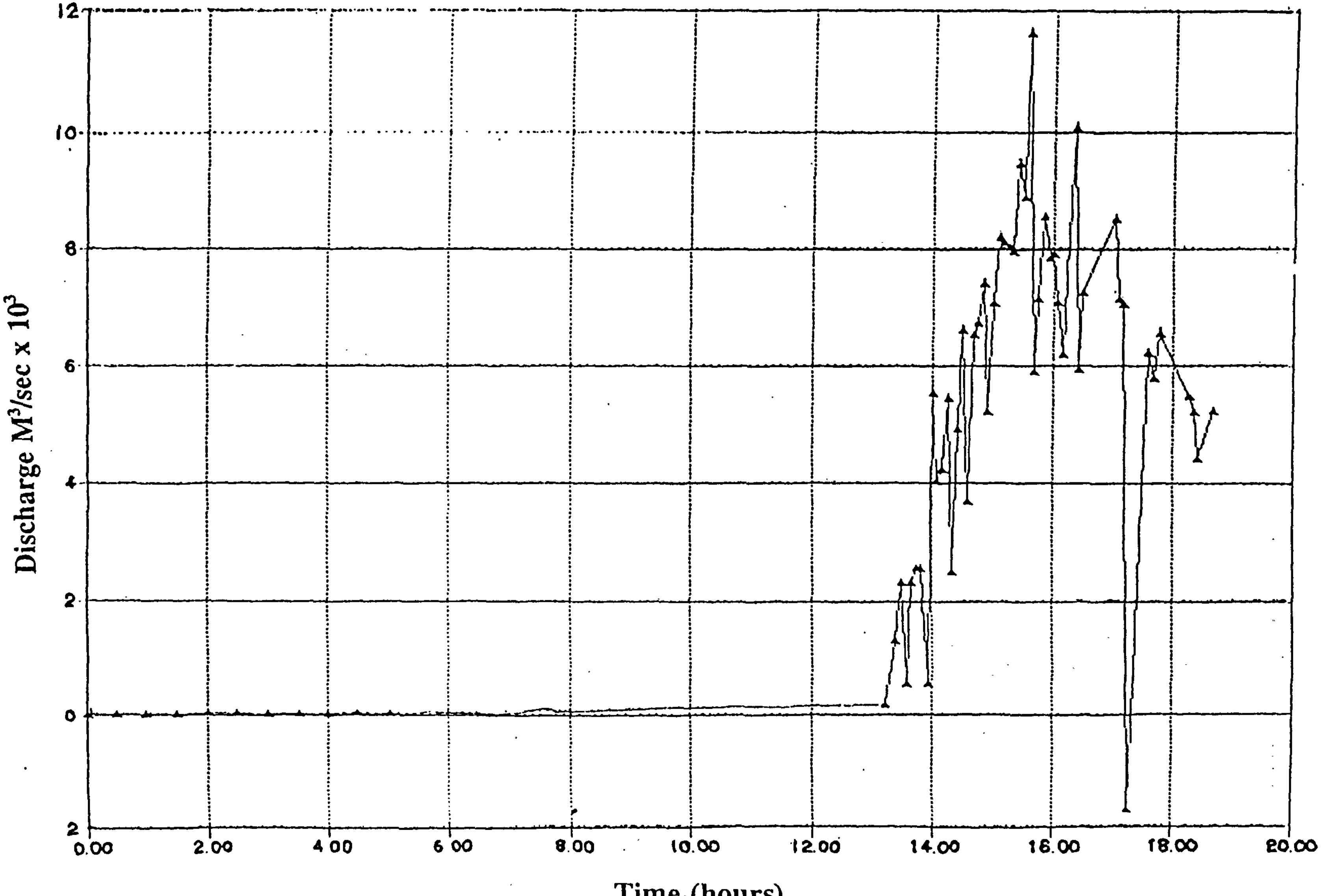


Figure 15: Amaluza Reservoir

Discharges in Time

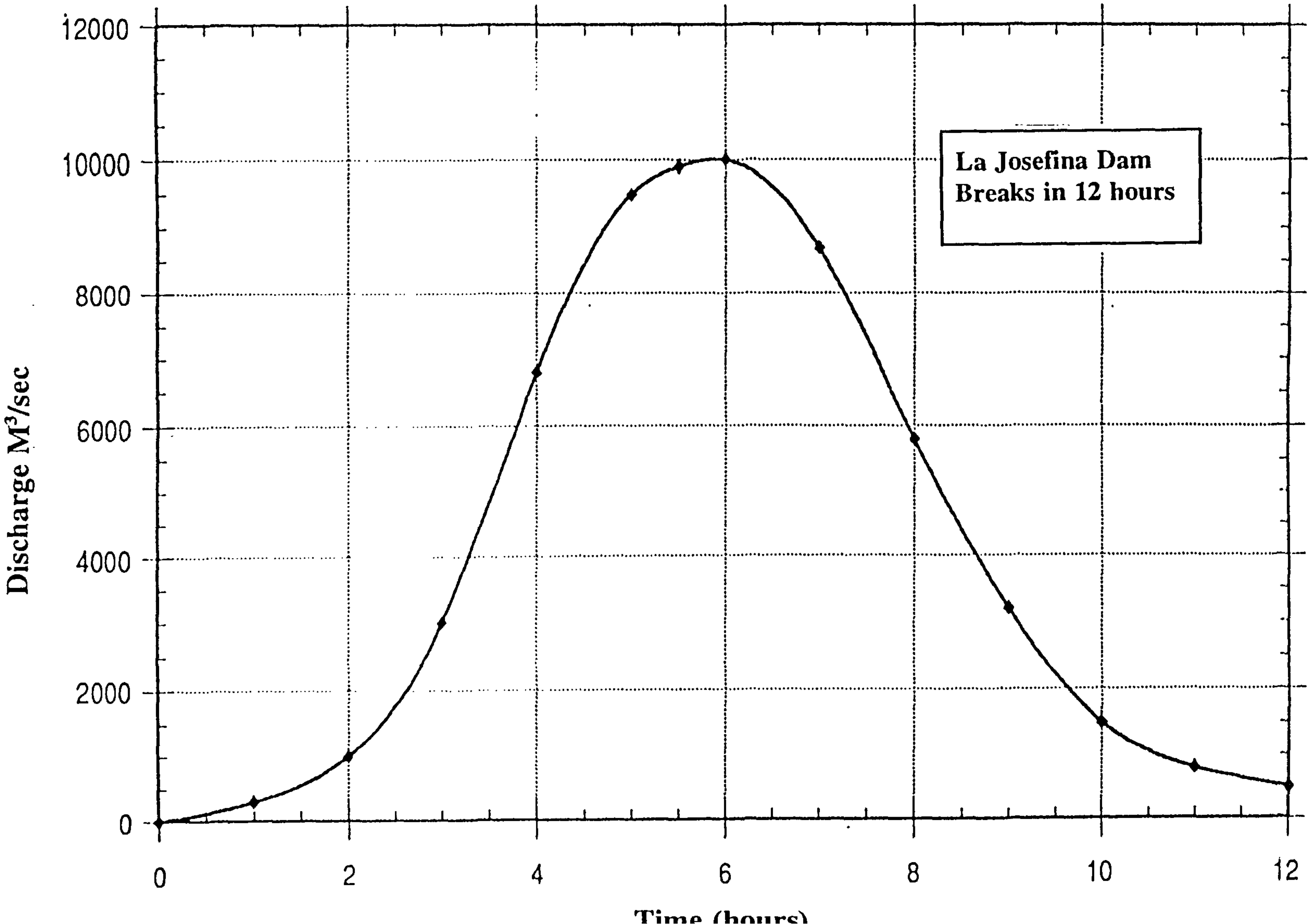


Figure 16: La Josefina Landslide
Erosion Process

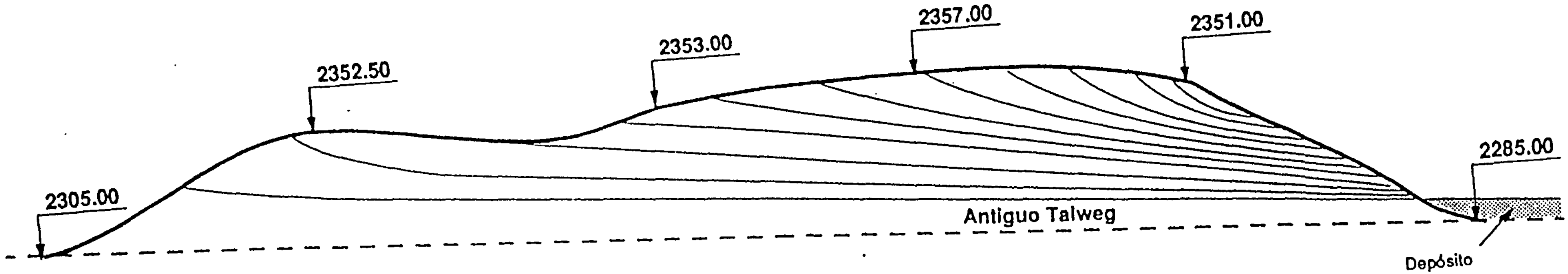
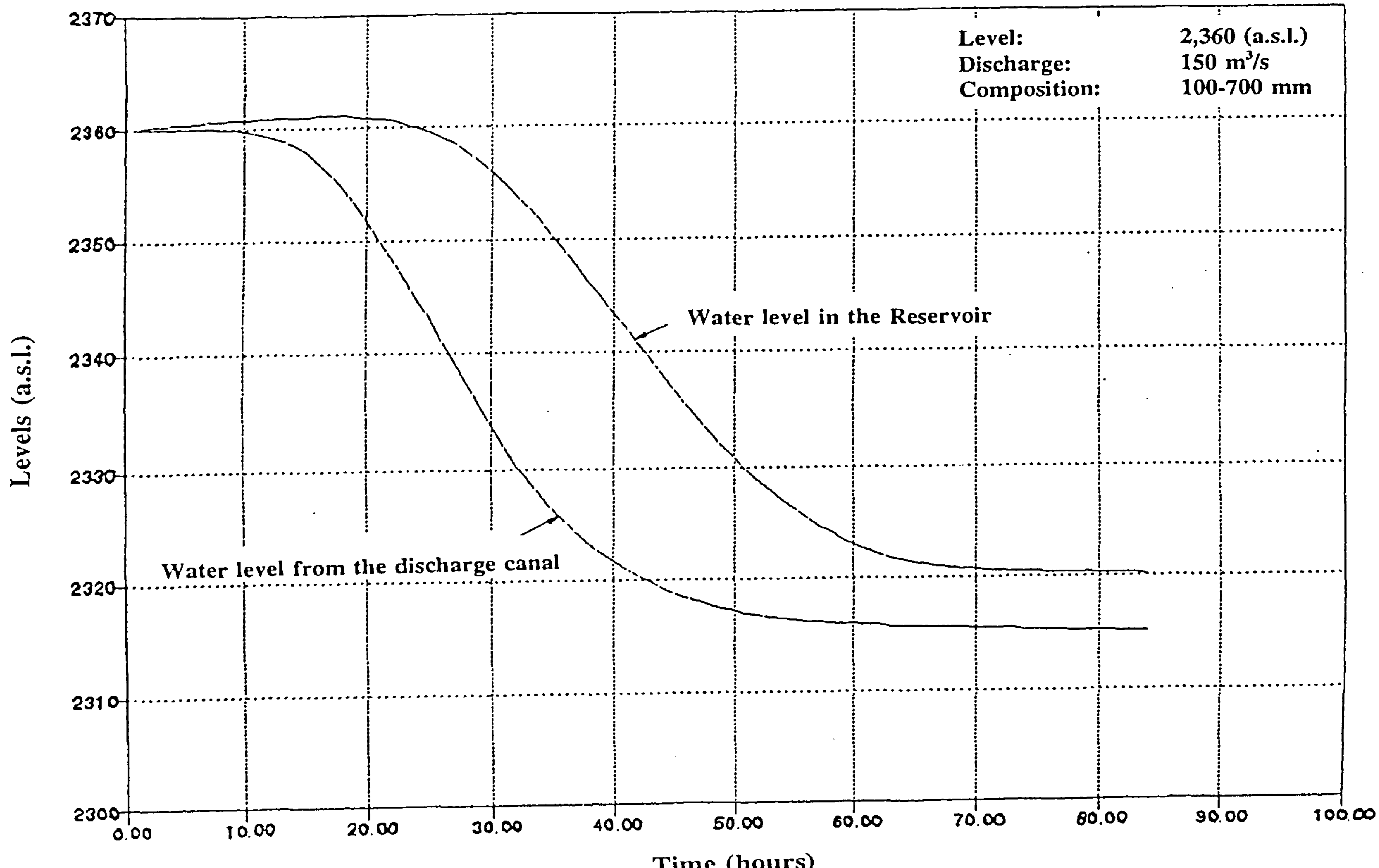


Figure 17: Simulation Exercise
Modelling Canal Erosion
Situation 1



Modelling Canal Erosion
Situation 2

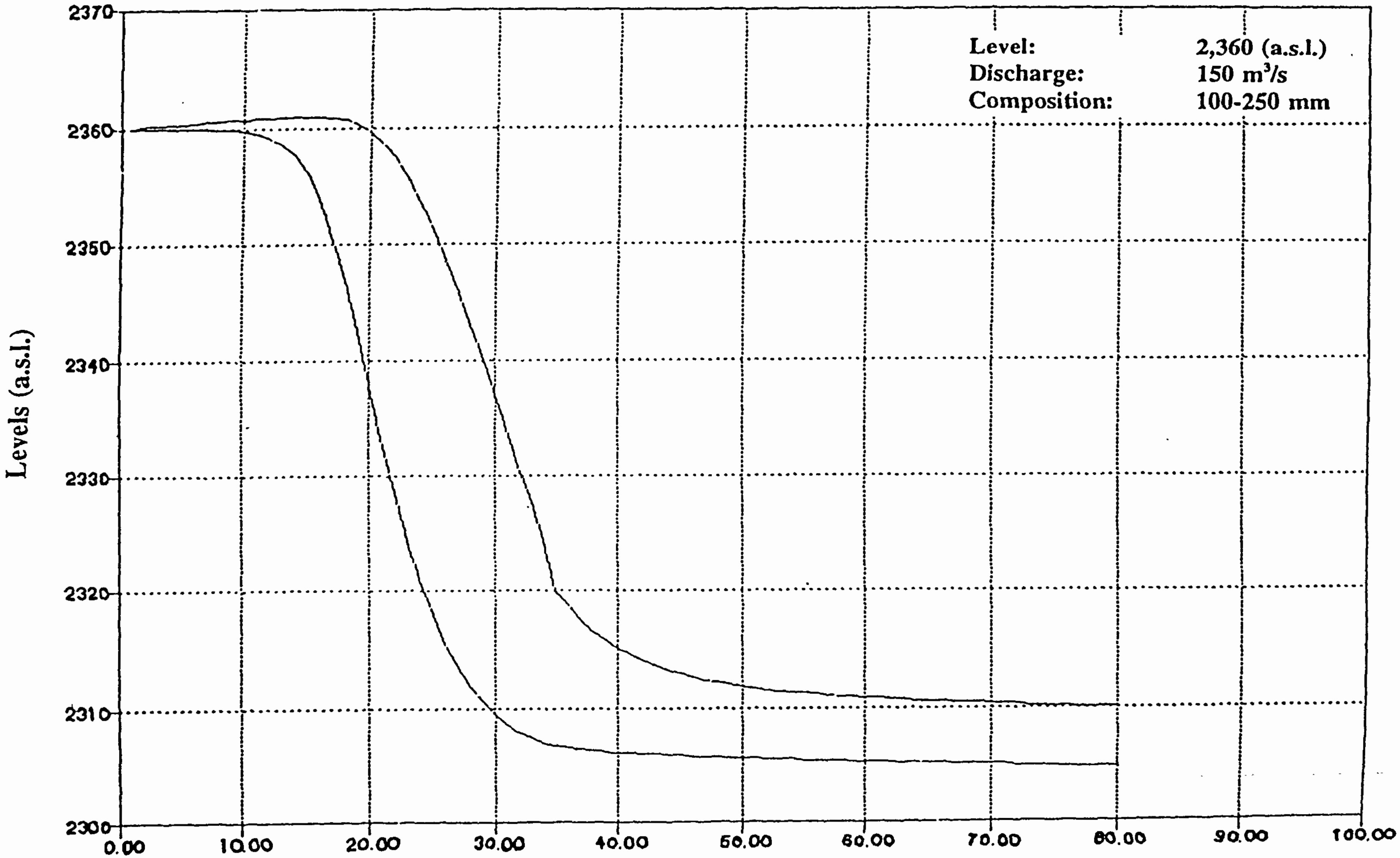
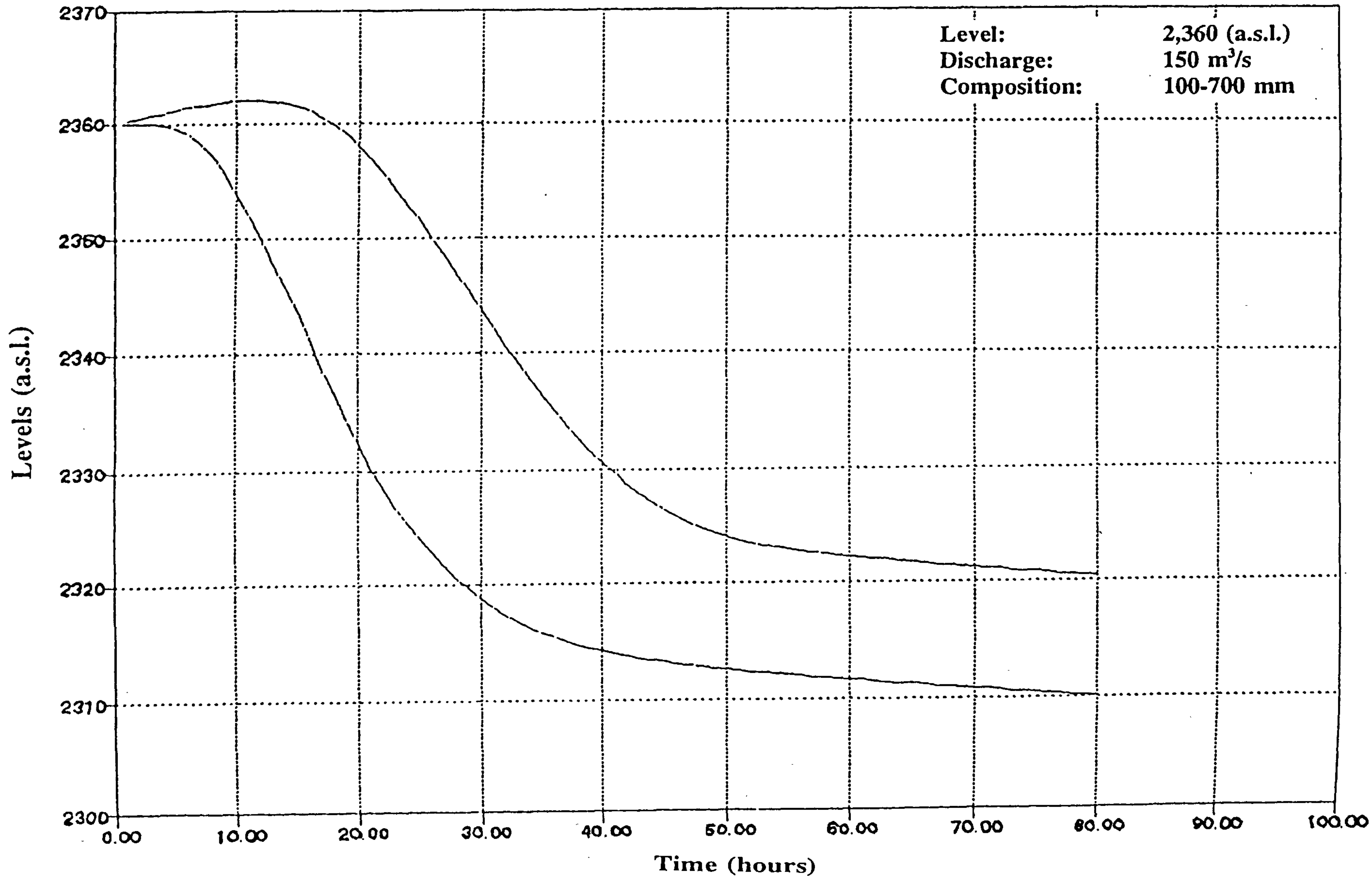


Figure 19: Simulation Exercise
Modelling Canal Erosion
Situation 5



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