APPENDIX VI

CONDITIONS OF PAST DISASTER AND DAMAGE

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Contents

Lift of Table (Appendix VI)

Lift of Figure (Appendix VI)

APPENDIX VI
CONDITIONS OF PAST DISASTER AND DAMAGE

1. GENERAL DESCRIPTION OF PAST DISASTER

(1) General Features of the Rimac Basin

The feature of the Rimac river having its source on the Andes Mountains is explained in such that the river has a fast-flowing stream debouching into the Pacific Ocean with only its length of 140 Km. The river basin belongs to arid or semi-arid climatic zone as shown in Fig. VI-1-1. Under such a circumstances, vegetation coverage is so scarce that sediments, yielded due to mechanical weathering, tends to be deposited in small valley or mountainous slope by the gravity momentum.

Those sediments cause sediment transportation owing to intense rainfall during short time span. According to hydrological data, the higher elevation is, the more it has annual mean precipitation. Since most of rainfall is concentrated on months from January to March, the degree of occurrence of sediment or flood disaster is so high.

In the upper or middle reach of the Rimac river, settlement area and traffic route has been developed in valley plain or an alluvial fan whose surrounding area is steep hilly or mountainous slope. In the downstream area lots of illegal inhabitants called Pueblo Joven are identified along the river.

Bank protection structures are seen at some parts of the river, however, the river itself is still a natural river with no systematic protection structures.

(2) Disaster in Peru

The definition of natural disaster by CNDC indicates an extensive disaster categories such as sediment and flood, earthquake, meteorological one, and an infectious disease. Out of them, categories of collapse, landslide, debris flow and inundation caused by sediment or flood disaster has been outstanding year by year, which is shown in Table VI-1-1.

As shown in Table VI-1-2, Departamentos de Lima including the Rimac basin has the large number of disaster occurrences in 1983 particularly. It was presumed that a massive volume of rainfall caused by large scale of El Niño brought about big disasters in the basin.

According to CNDC's data covering January through June of 1983, total toll was recorded 285 consisting of the dead 52 and the injured 233 which is shown in Table VI-1-3.

In 1987, serious disaster happened in some areas in Peru. The official statistical records are not yet compiled. However, investigation on March 1987 disaster happened in the Rimac river basin was carried out.

(3) Description of Disaster in 1983 in the Rimac River Basin

The precipitation from February to March increased remarkably due to intense rainfall caused by El Niño event. Monthly rainfall records indicate 62.8 mm of Feb. and 189.2 mm of March in Matucana. As a result, an intensive damages were inflicted on settlement area in the middle reach between Chosica and San Mateo, and central highway of Route 20 and railway connecting Metropolitan Lima and mountainous area. The traffic system had been interrupted for a long time, and rehabilitation works were required. The list of disaster in the Rimac river basin in 1983 is shown in Table VI-1-4.

The following characteristics of disaster can be summarized;

(a) Flooding in Matucana (Feb. 23-4), a wash-away of San Juan bridge (Feb. 23), and flooding in San Bartolomé (Mar. 14-16) was caused by the fact that debris flow flowing from nearby small valleys and damming up the main stream of the Rimac river.

(b) Most debris flows from valley were made between Chosica and Matucana. (See Table IX-1-5)

(c) A large quantity of boulders and mud in the debris flow had effect on the river bed variation.

(d) Debris flow occurred successively at some places.

(e) The debris flow happened in the downstream area of Sta. Eulalia river where any disasters were recorded in these years.

(f) A intermittent rainfall continued in a long span of period. Disasters did not occur in specific areas.

(g) Occurrence time of disaster mostly concentrated in the afternoon owing to time feature of intense rainfall.

(h) Consecutive time of heavy rainfall was mostly short.

(i) Interview survey made it clear that rainfall pattern was characterized by localities.

(4) Description of Disaster in March 1987

In March 1987, the heavy rainfall, possibly caused by El Niño, occurred in the areas located on the right bank of Chosica district and induced the serious disasters of debris flow and flood flow in some areas as shown in Table VI-1-6.

The particular features are to be summarized as follows:

(a) All the disasters happened in the comparatively densely populated areas with much properties.

(b) The disaster areas by debris flow was located in the adjacent areas each other.

(c) The disaster happened almost at the same time in each disaster area.

(d) The disaster becomes bigger by man-made structures such as houses in channel, culvert with insufficient capacity, etc.

(e) Most disaster areas didn't suffer the serious disaster for many years.

(f) The heavy rainfall zone was limited in a local area in the basin.

(g) Some disaster areas got slight rainfall several times before March 9.

(h) The rainfall came within some hours in the afternoon.

(5) Description of Disaster in Other Years

As shown in Table VI-1-7 and 8, sediment and flood disaster occurred in the area between Lima and Matucana in Feb. 1984 because of large precipitation (196.2 mm). Sediment disaster caused by debris flow usually occurred during three months from January to March.

"Quebrada" spreading on both banks of the Rimac river between Corcona and Matucana is considered to be habitual area causing debris flow. Most of disaster records are originated in those area.

2. MARCH 1987 DISASTER

2.1 General

2.1.1 General

During the period from January to March 1987, the natural disaster came out one after another in various districts in Peru due to a influence of El Niño phenomena in comparatively large scale.

In the Rimac river basin, the serious disaster happened in Chosica district due to debris flow caused by heavy rainfall and in Campoy/Zarate area due to inundation, respectively on March 9.

The Study Team made investigation of March 9 disaster separately for the debris flow disaster in Chosica district and for the inundation disaster in Campoy/Zarate area.

In regard to the disasters happened before March 9 such as the debris flow disaster in Qda Cantuta on March 2 and the slope failure disaster in Sta Rosa de Pallebajo village on March 8, the descriptions are to be made separately from March 9 disaster.

The general locations of these disaster areas are shown in Fig. VI-2-1 and the general descriptions of a series of disaster in the early part of March 1987 are summarized in Table VI-2-1.

2.1.2 General Description of Debris Flow Disaster

A large scale disaster due to debris flow happened on March 9, 1987 in and around the Chosica district. The following 5 areas of Quebrada suffered serious damages at that time.

(a) Qda Quirio (R6)
(b) Qda Pedregal (R7)
(c) Qda Corosio (R8)
(d) Qda Corrales (R9)
(e) Qda Cashahuacra (S1)

The above disaster areas are located in the same district on the right bank of the Rimac river or the Sta. Eulalia river. The locations of disaster areas are shown in Fig. VI-2-1.

Every disaster area has common damages which are destruction of houses and traffic block, though the scale of disaster is different. The death and missing of inhabitants were recorded in three quebrada areas.

The direct cause of disaster was heavy rainfall. However, the effective and reliable rainfall records were not obtained as the rainfall distribution was very local and the insufficient system of rain gage observatory. As far as the information obtained from the hearing of inhabitants, the rainfall distribution as well as the rainfall intensity was not uniform even in a quebrada district. For example, it was informed in Qda Pedregal district that no rainfall was seen when the debris flow reaches to the downstream stretch for the first time though the dark clouds covered the upstream area.

Though the beginning time, duration and intensity of rainfall are different in each quebrada, the conditions of rainfall and disaster time were similar in general. That is, the debris flow came between 3 o'clock and 4 o'clock in the afternoon, the rainfall continued 1 to 5 hours in the afternoon, and the duration of heavy rainfall was only 10 minutes in the shortest and almost 2 hours in the longest. However, these conditions were applicable only for the village area located downstream of each quebrada. No information was available for the conditions in the upstream area.

At the time of Debris flow, the inhabitants became aware of a roaring sound like airplane/helicopter and vibration like earthquake and most of them could escape to the safety area located on the mountain slope. The inhabitants who couldn't escape or stay in the house suffered the damage.

Though it is called "the Debris flow", the flow contained much sand & earth and the size of debris became bigger as the flow discharge was increased. In addition, the debris flow came not only once but also 2 or 3 times.

Though some parts of sedimented debris and sand were transported from the upstream mountain slope and gully area, considerable large part of the sediments would be transported from the scoured materials in the valley on the way of transportation. The sediment conditions are different in each quebrada district. However, in general, the bigger boulders are deposited first and the sand & earth deposits were seen in the downstream area. The boulders are generally as large as 0.5 - 2 m and some huge boulder of approximately 5 m in diameter are also seen. In the mid of disaster area of Qda Pedregal, the sediment thickness is generally more than 2 - 3 m.

In the downstream area including the central district of Chosica, the sediments of mud flow extended along the roads are seen.

As a result of survey, it is estimated that the total disaster area is about 50 ha and the total sediments' volume is about 500,000 m^3 in 5 quebrada districts.

All the quebradas usually have almost no stream flow except at the time of rainfall. The debris flow seldom happens in these quebradas. Therefore, the houses have been built in the channel portion and the width of channel became artificially narrow.

Among 5 disaster areas, it was informed that Qda Carosio and Qda Corrales suffered the disaster for the first time in the past. However, Qda Cashahuacra suffered the big disaster in 1983 and Qda Quirio and Qda Pedregal suffered the disaster 2 or 3 time for these 20 years. In addition, it was informed that the big debris flow happened in these areas about 60 years ago though no serious damage was recorded as no inhabitants were living there.

2.1.3 Investigation Items of Debris Flow Disaster

The fundamental data for studying the debris flow disaster prevention measures, the records of past disasters, are not sufficient in the Rimac river basin. Therefore, the new records on March 1987 disaster presented very precious and significant data for the preparation of master plan. Though the reliable and detailed rainfall data are not obtained, the definite data of big disaster will be important references on the following points of study.

(a) Estimate of probable disaster damage
(b) Establishment of basic concept and criteria for disaster prevention planning
(c) Classification of disaster area
(d) Classification and selection of objective study areas
(e) Establishment of disaster prevention plan
(f) Evaluation of disaster prevention plan

The field investigation on March 1987 disaster was carried out for about one month from June 12 until July 7. The data collection and field survey were carried out on the following items.

(a) Investigation of the basin

- Name and division of stream and sub-basin
- Catchment area
- Geological conditions
- Land form conditions (Slope, elevation, particular features, etc.)
- Stream conditions (length, gradient, shape, alignment, cross sections, etc.)

(b) Investigation of the Existing Structures

- Location, design, scale etc. of existing structures

(c) Investigation of Disaster Conditions

- Disaster condition (judgement of debris flow and mud flow)
- Beginning time of disaster occurrence
- Rainfall conditions
- Discharge

(d) Investigation of Outbreak Conditions

- Cause of debris/mud flow
- Remaining unstable debris after the disaster
- Scouring condition of valley or gully
- Gradation of unstable materials

(e) Investigation of Flowing Conditions

- Flowing conditions
- Gradient of flowing channel
- Width and section of flow
- Routes of flow
- Change of valley/river channel (Scouring, sedimentation, vegetation, etc.)
- Bending degree

(f) Investigation of Sediment Conditions

- Classification of landform
- Gradient of sediment area and the downstream area
- Relation between damage level and sediment slope
- Stream channel condition before disaster (channel width etc.)
- Sediment distribution (width, length, depth, angle, area, etc.)
- Sediment volume
- Sediment size accumulation

(g) Investigation of disaster and damage (with classification of distribution, quantity, amount)

- Human
- Houses and buildings
- Farm land
- Structures
- Animal
- Traffic block/disturbance
- Other indirect damage

(h) Investigation of structural effect for disaster prevention

- Effect on reducing disaster by existing structures

(i) Investigation of disaster rehabilitation and re-lief activity

- Activity by central government
- Activity by local government
- Activity by inhabitants
- Activity by others

(j) Data collection work

- Report and data of investigation executed and prepared by the Peruvian government
- Topographical maps and plans of disaster areas
- Aerial photographs (taken after disaster)
- Photographs of disaster
- Scraps of news on newspapers and magazines

(k) Investigation of past disaster

- Disaster conditions
- Damage conditions

(l) Investigation of disaster in the surrounding area

- Disaster conditions
- Past disaster

The investigation was to be carried out in every division of disaster area though the data for some items were not obtained sufficiently.

2.1.4 General Description of Inundation Disaster

On March 9, 1987, the stream of Qda Jicamarca, flowing into the Rimac river from the right bank, overflowed at the confluence with the Rimac river. The inundated water flowed down about 10 km along the right bank of the Rimac river and the disaster area was extended to a part of central district in Lima. The location of inundation area is shown in Fig. VI-2-1. Qda Jicamarca is the biggest tributary in the basin, excluding the Sta. Eulalia, though the flow discharge seems to be comparatively small considering the catchment area of 440 km^2.

The inundation of this time was caused by the increase of discharge due to heavy rainfall in the upstream area and by the blockage of culvert channel due to drift woods at the confluence with the Rimac river. It can be said that the inundation is a man-made disaster as no structure was existed in this confluence and culvert structure was constructed as a new highway was planned to cross this tributary.

The inundation zone was extended about 10 km long and 50 m to 1 km wide.

The damage rate is higher in the upstream inundation area as the water was deeper and contained much earth. Many houses are washed away and buried with sediments. In addition, the traffic block in the densely populated district caused the serious damage on economy and society.

2.1.5 Investigation Items of Inundation Disaster

The following investigation was carried out in respect of the inundation disaster.

(a) Investigation of outbreak stream

- Features of the basin (location, area, landform, geology, vegetation, etc.)
- Features of stream (shape, length, slope, cross section, width, etc.)
- Structures (location, type, dimension, function, etc.)

(b) Investigation of inundation conditions

- Inundation area
- Depth and velocity of inundated flow
- Time and duration of inundation
- Cause of inundation
- Flowing condition of inundated water
- Conditions after subsidence of water (condition of sedimentation, etc.)

(c) Hydrological investigation

- Rainfall
- Water level and discharge

(d) Investigation of damage conditions

- Distribution and classification of damage (human, building, traffic block, etc.)
- Quantity and amount of damage

(e) Investigation of rehabilitation and relief activity

(f) Data collection

(g) Investigation of past disaster

(h) Investigation of disaster in the surrounding areas

2.2 Meteo-Hydrological Conditions

2.2.1 Rainfall Conditions

The rainfall observed on and around March 9 was limited only at 6 gaging stations in the Rimac river basin of which locations are shown in Fig. VI-2-1. The daily rainfall records from March 7 to March 9 at these stations are summarized as follows:

	Daily Rainfall (mm)			
Location	March 7	March 8	March 9	Remarks
Callao	0	0	0	Lower reach
Lima	0	0	0	"
Autish	4.1	3.4	11.6	Sta Eulalia river
Carampoma	0	9.1	8.9	"
Mina Colque	9.4	1.8	1.7	"
Matucana	3	0	0	Upper reach

As seen in the above table, the rainfall distribution which caused the disaster is considered to be very local. Though comparatively much rainfall is recorded in the basin of Sta. Eulalia river, almost no rainfall is recorded not only in the lower reach but also in the upper reach of the Rimac river.

Though the official rainfall records are scarce, the following informations are obtained.

(a) In the afternoon on March 9, heavy rainfall came to the Chosica disaster areas.

(b) The debris flow occurred from all the tributaries located on the right bank of main stream from Qda Cashahuacra to Qda Quirio.

(c) There was no rainfall in the lower reach area of Qda Jicamarca on March 9 when the inundation disaster happened.

(d) Qda Jicamarca has two big tributaries. The flood marks are seen in a tributary of which upstream area is adjacent to the Chosica disaster district.

The area of heavy rainfall on March 9 seems to be narrow along the right bank of Chosica district.

The rainfall duration is judged from the hearing investigation to be generally from PM 3:00 to PM 7:00. In Chosica district, light rainfall came at around PM 3:00 and heavy rainfall of 15 - 30 minutes came at around PM 4:00 and then misty rain continued from PM 5:00 until PM 7:00.

It is considered that the rainfall in areas with higher elevation came first in prior to the rainfall in areas with lower elevation. In Qdas with bigger catchment area, the debris flow arrived in the lower stretch when the heavy rainfall didn't yet come there. However, in Qdas with smaller catchment area, Qda Carosio and Qda Corrales, the debris flow came almost at the same time of heavy rainfall.

Though there is no definite record of heavy rainfall, the following informations were obtained from the inhabitants in the disaster area.

(a) Working clothes (thick) are wet through within a few minutes

(b) Like shower in the bath

(c) Hard to walk without hanging down his head

(d) Hard to walk with glasses

(e) A lunch box of 3-5 cm in depth becomes full with water

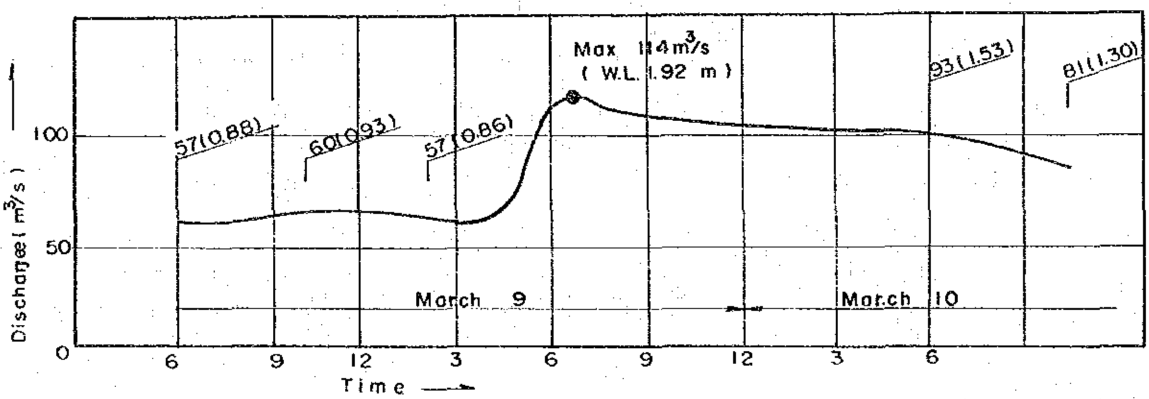
The total rainfall on March 9 is considered to be 20 - 50 mm judging from the hearing information, the record at Autisha gaging station, and etc. This value seems to be reasonable as the past maximum daily rainfall of 8 years records in Chosica (La Cantuta station) is 32.2 mm and the estimated total rainfall from the distribution obtained from the hearing. The past maximum daily rainfall records at some observatories in the basin are shown for the reference as follows:

Location	Period	Max. daily rainfall
Campo Marte	1932-83	17.0 mm
Ñaña	1966-76	8.0
La Cantuta	1974-81	32.2
Autisha	1980-86	14.0
Matucana	1970-?	31.7

It is informed that, in some quebradas where no water runs usually, the slight rainfall and stream were observed for a few days before March 9. In addition, the heavy rainfall usually happens in the afternoon in accordance with the information from the inhabitants.

2.2.2 Run-off Conditions

The run-off record on March 9 was obtained at only Chosica gaging station which is located at the downstream stretch of the confluence of Rimac river and Sta. Eulalia river. The water level as well as discharge in the main stream did not vary until the early afternoon on March 9 but suddenly increased in the late afternoon as seen in the figure below.



The sudden increase would be more remarkable in the downstream stretch of Chosica town as some disaster Quebradas are located in the downstream stretch of the Chosica gaging station.

However, any run-off records could not be obtained for quebradas/tributaries as no gaging station exists there. Therefore the flood discharge in tributaries (quebradas) was estimated from the assumed water level obtained by the flood marks as well as the information of inhabitants. The cross sections and profile of each tributary channel were measured by simple survey.

As the scouring action was remarkable, the cross section of channel seemed to be changed during the debris flow. As some flood marks are seen in channel, the marks in a section where the variation of channel section was small were taken for the estimation of discharge.

In regard to the velocity, it is hard to calculate as the channel section is remarkably changed on the way of flowing and the gradient is also variable. In addition, the velocity of debris flow will be different from that of ordinary flood flow. The velocity is to be assumed at 5 m/s from the velocity records of debris flow observed in Japan and also the information of the inhabitants who said that the velocity was almost as same as man's running speed in Qda Pedregal. The examples velocity of actual debris flow in Japan and the other countries are shown in Table VI-2-2 for the reference.

The maximum discharge at the time of debris flow on March 9, 1987 is estimated from the assumed velocity and the flood marks or the maximum water level obtained by hearing in each quebrad.

Location	Catchment area	Max. discharge
Qda Quirio	10.4 km^2	50 m^3/s
Qda Pedregal	10.6 km^2	160 m^3/s
Qda Cashahuacra	15.1 km^2	140 m^3/s

The maximum discharge is the total run-off including debris and mud and at the peak possibly caused by damming up in the upstream channel. The difference of specific discharge at each tributary is considered to be due to the difference of rainfall volume and intensity.

The discharge at small quebradas, Qda Carosio and Qda Corrales, was not estimated as the information and data are not enough.

2.3. Debris and Mud Flow Disaster

2.3.1 General Description of Disaster Areas

Five quebradas which caused the serious disaster for this time are located on the right bank of main river in the Chosica district as seen in Fig. VI-2-2. All the valleys of quebradas are formed by erosion action and they are classified into a valley type or slope type mainly based on the difference of catchment area, geology, channel profile, cross section of channel etc. as summarized in Table VI-2-3. The channel profile in debris flow disaster quebradas are shown in Fig. VI-2-3.

The valley type quebradas are Qda Quirio, Qda Pedregal and Qda Cashahuacra which have the catchment area of larger than 10 km^2 and the border, facing to the sub-basin of Qda Jicamarca, higher than EL. 2,000 m. The shape of basin is like a tree which is wider in the upstream area. The average slope is approximately 15°, however, steep in the upstream channel and less than 10° in the middle and downstream channel. The fan is developed in the outlet of valley. The fan is developed by compound topography as the top of fan seems to be movable. The flat base valley of 300 - 350 m in the max. width is extended from the top of fan to the upstream side. In the bottom of valley, the old sediments are piled for more than 30 m in depth and the deep erosion channel possibly caused by the past debris flows is formed there. This erosion channel has the height of 10 - 30 m and the width of 10 - 30 m. The width is generally wider in the downstream stretch, however, there is a wide portion also in the just downstream stretch of the confluence of upstream tributaries.

The erosion channel in Qda Cashahuacra is comparatively small. This channel was formed along the small irrigation channel at the time of 1983 debris flow disaster and extended from the top to the end of fan. The fan of Qda Cashahuacra is formed to bury the river-terraces developing in the vicinity area of the confluence of the Sta. Eulalia river and the Rimac river. However, the new small scale fan is formed from the outlet of new erosion channel. The debris flow on March 9 made this fan wider and thicker.

On the other hand, the slope type quebradas are Qda Carosio and Qda Corrales of which catchment area is less than 2 km^2. The valley has slope of 35° on an average and forms short and small V-shape valley and the small cone shape fan is developed at the outlet of valley. The slope of fan is much steeper than that of valley type. In Qda Carosio, the sediments spoiled from the tunnel construction for waterway of power station in the 1970s are seen on the right side slope and the piles of garbages are seen on the upstream side of fan.

In these disaster areas, there is usually no stream water in the channels as the rainfall is scarce. The ground surface seems to be remarkably weathered.In the slope higher than EL. 1,400 - 1,600 m, the vegetation of mainly cactus species is seen and the vegetation of grasses and low shrubs is seen along the water channel. The most areas are almost desert.

All disaster areas are located in the downstream area of each quebrada and are developed in these 20 - 30 years by the extension of resident area from the flat areas along the main river. The disaster areas are originally formed by the deposits of past debris/mud flows. No remarkable disaster prevention structures are constructed yet except parapet walls in Qda Quirio and Qda Pedregal. On the contrary, the channel is cut on the way and the width become narrow at some portions due to invading of houses.

Small villages are scattered in the farm land area located at the outlet of Qda Cashahuacra valley. Though there is a recreation club in the downstream area of Qda Cashahuacra when much deposits remained by March 9 disaster, it has been left alone without use after 1983 disaster.

2.3.2 Debris and Mud Flow Conditions

(1) General

The heavy rainfall came in the Chosica district in the afternoon on March 9 and the debris flow occurred at some quebradas from PM 3:00 or PM 4:00 until around PM 6:00. The occurrence of debris flow depends on the intensity and volume of rainfall as the disaster areas are adjacent each other and include the quebradas with small catchment area.

The disaster conditions are more or less different in each quebrada. The main points obtained by hearing from the inhabitants in Qda Pedregal are to be described below.

(a) Debris flow with step-wave occurred several times.
(b) Discharge of debris flow increased gradually.
(c) Big sound and ground rumbling were accompanied.
(d) The size and volume of debris were increased in accordance with the increase of flow level.
(e) Big boulders flowed down by rolling.
(f) In the sediment area, big boulders repeated the action of deposit and movement.
(g) The direction of main flow was changed due to the deposits of boulders.
(h) The damage became serious by the impact of boulders.
(i) The content of debris became small when the water level became low.

Though it is usually said that the debris flow is caused by the gravity action and flowing water action, the debris flow on March 9 disaster seems to be influenced more by the flowing water action.

Each quebrada can be divided by the movement conditions of debris and mud into the following three zones.

(a) Upstream (Mountain slope) zone
(b) Transportation (Flowing) zone
(c) Deposit zone

(2) Upstream Zone

The upstream zone has mountain slopes with 35 - 45° on an average. On the slopes, the bed rocks of granite are seen and the reddish brown-colour boulders suffering weathering action are scattered there. The marks of movement action is almost not seen on this surface. However, in the concave portion on the slope, the colour of rocks is changed to whitish brown. It is clear that movement action occurred there. The concave portion become deeper in the lower slope and these gullies are connected to a erosion channel.

(3) Flowing Zone

In the flowing zone of valley type quebrada, the flat base valley occupies the longest section. Therefore the alignment of erosion channel is generally not stable as several shallow channels are seen in the valley.

However, the erosion channel in Qda Quirio as well as Qda Pedregal has sufficient capacity and the channel alignment is almost fixed as no overflowed portion is seen on the way of this zone.

In Qda Cashahuacra, the erosion channel formed at the time of 1983 disaster become deeper and wider by the disaster in March 9, 1987. Judging from the inspection after the disaster, the remarkably vigorous action of lateral and longitudinal erosion was made as seen in the scouring marks at not only the channel bed but also at the bottom of side slopes. The heavy scouring happened at the very steep portion and bending portion and generally formed step-like profile. The most boulders depositing in the downstream area are considered to be produced in this flowing zone.

In this flowing zone, the scouring action as well as deposit action was carried out. The deposit phenomena at the time of succeeding flow seem to be occurred at some places in the channel. In addition, the piles of debris caused by collapse from the unstable side slopes are also seen in some places. These deposits and piles will be transported as a part of the debris flow in the future.

In the flowing zone of slope type quebradas, the steep slope V-shape valley occupies the most part and the base rocks are appeared in many places by the flow on March 9.

(4) Deposit Zone

The main features of deposit zone of each quebrada are to be described in Table VI-2-4 and VI-2-5 and are seen in Fig. VI-2-4 to VI-2-7.

The total area and volume of sediment run-off are estimated respectively at 49.5 ha and 491,000 m3. The difference of specific volume (volume per unit area of each basin) is considered to be caused by the difference of rainfall distribution and volume of unstable debris/mud. The maximum boulders in the deposit zone was 6 m in longest diameter and 3 m in shortest diameter and possibly about 20 ton in weight.

The deposit zone is started from the point where the slope become gentle (4 - 6° in case of valley type quebrada) and the point where the control by erosion channel becomes weak, generally at the outlet of valley. However, as far as seen in each individual quebrada, the deposit zone is started at the bending portion of channel and suddenly reduced section of channel. That is, the deposits are remarkable at the narrow portion by the invading of houses and at the closing portion under bridges. In case of valley type quebrada, the deposits are seen in the residential area.

In the deposit zone, larger boulders are seen in the central area and mud deposits are seen in the surrounding area of boulder depositing zone. The mud area is extended through the roads and the deposits become shallow at the ending zone.

It seems that the shape of deposit zone become cone type like in Qda Cashahuacra if no restriction exists on the way. However, the shape become line-type like in Qda Carosio where the expansion of flow was restricted by houses along the road/channel. In case of Qda Cashahuara, the mud flow was extended downstream along the old channel of Sta. Eulalia river.

Further, the opposite side of Rimac river was inundated for about 2 hours by the damming-up action caused by the debris flow from Qda Pedregal.

2.3.3 Damage Conditions

The official reports in regard to March disaster were issued by SE/CNDC. The report for the disaster in the Rimac river side and the report for disaster in the Sta. Eulalia river side are prepared separately. The results are summarized in Table VI-2-6 and VI-2-7. The total damage in the disaster in the Rimac river side was reported to be I./222,000,000.

The human damage was counted as 38 person were dead and 12,414 persons are wounded in the report. Though the details of human damage are not shown, the police (PIP) reported the location of 19 dead bodies of which identity were confirmed as follows:

(a) Qda Corrales 4 people
(b) Qda Pedregal 15 people

In Qda Pedregal, the removal of deposit is not completed yet as of June. Therefore it is probable that the number of dead can be increased. The most of dead people were old men, children and women in bad condition. That is, the people who could not move quickly suffered the disaster. However, there is another reason that most men were out of village for working at the time of disaster.

The damage on houses was counted at 700 - 1000 in number which include complete destruction and semi-destruction. About 60% of them were located in Qda Pedregal as seen in Table VI-2-8. As shown in Fig. VI-2-8 and Fig. VI-2-9 and Table VI-2-9, most houses were destroyed in the area where the debris flow made deposits. Especially in the main route of debris flow, the level of destruction was heavy and almost completely destroyed. However in the surrounding area of main route, the level of destruction was different by the type and location of house.

Besides the above, the damages were reported in power-generating facilities/structures, transportation structures, water supply facilities and etc.

Further, the indirect damage was also remarkable. Though the reports of SE/CNDC don't describe the matter, it seems that the indirect damage made serious damage on the Peruvian economy. The most serious damage was the traffic block of Carretera Central (National road No. 20). The stop of electric generation at Huampani power station due to the sediments in the waterway and the stop of water-supply due to the destruction of pipes and facilities are also considered to be serious.

2.3.4 Evacuation and Relief Activities

(1) Evacuation Conditions

In valley type quebradas such as Qda Pedregal and Qda Cashahuacra, the inhabitants knew the occurrence of debris flow by the following.

(a) Big sound and echo like sound of airplane or helicopter caused by bumping of rocks or crushing of structures.

(b) Flow preceding to the debris flow (as usually dry).

(c) Rumbling of the ground.

(d) Voice of people who inform the coming of debris flow.

The most inhabitants evacuated to mountain slope or hill nearby their houses. However, some inhabitants didn't evacuate immediately after they knew the occurrence of debris flow. Some of them went to the channel to see the debris flow and some of them returned to their house to bring their clothes.

Though the inhabitants living nearby the channel knew the debris flow earlier, the inhabitants living away from the channel knew later and some people could not evacuate before the arrival of debris flow which overflowed from the channel.

It seems that most inhabitants don't have experience of big debris flow as they started to live in these 20 years. No system for evacuation was established in every village which suffered the disaster.

Most dead people stayed in the resident areas located in the main route of debris flow and they are old men, children and pregnant women who could hardly evacuate.

(2) Relief Conditions

On the day of disaster, the Chosica district office took some actions for accommodation of sufferers. However they couldn't supply sufficiently the facilities and materials. The other government offices including the central offices started the action from the next day. The material supply could start at around noon on the next day, March 10. Possibly the communication between the disaster areas and Lima was not well.

On March 11, the Presidential decree "DECRETO SUPREMO No. 025-87-PCM" was announced by the President of Peru who inspected the disaster areas. Based on the decree "Comando de Emergencia", the Chosica district became the urgent rehabilitation area and the special organization headed by the Mayor of Lima for taking relief actions was established. The various orders were made to the offices concerned for the relief activities. The organization has the role to coordinate the government offices which joined the relief activities. Such organization was established for the first time in Peru. For the activity of the organization, the special budget of I./5,000,000 was prepared and the special right for using the budget was given.

The contents of relief activities taken by the organization were as follows:

(a) Food supply
(b) Drinking water supply
(c) Supply of labours and construction machines
(d) Clothes and bedding supply
(e) Tents and simple houses supply
(f) Despatch of medical care team
(g) Removal of deposit
(h) Others

The following offices engaged in the relief activities.

(a) COOPOP
(b) ONAA
(c) Electro Lima
(d) Minist. Salud
(e) Minist. TRANSPO. Y COMMU.
(f) Minist. AGRICUR.
(g) Minist. VIVIENDA
(h) Lima City
(i) ENCI, ECASA
(j) CONAMAD
(k) SE/CNDC
(l) Contractors
(m) Army
(n) Others

2.3.5 Rehabilitation Activities

The organization established by "Comando de Emergencia" started the rehabilitation activities from the rehabilitation of roads. The rehabilitation of main road, Caretera Central, was completed within two weeks. However, the removal of deposits in the resident area was much delayed. For example, the much deposits in San Miger de Pedregal which suffered the most serious damage still remained as of June when the Study team inspected the site again. In Qda Corrales, the new channel by only excavation and simple embankment was constructed, however, the works seems to be not yet sufficient for the safety against the debris flow.

The government office has an idea to remove the houses from the dangerous zone. However, the actual action seems to be difficult due to the shortage of budget, the opposition of inhabitants and etc.

Electro Lima, as a sole enterprise, completed the rehabilitation of waterway by spending about 20 days and the expense of over I./1,490,000. Huampani power station started the generation then.

2.3.6 Existing Disaster Prevention Structures

The recurrence period of disaster in the March 9 disaster areas seems to be pretty long. Therefor, the disaster prevention structures are not sufficient.

The following structures existed at the time of March 9 disaster.

(A) Qda Quirio and Qda Pedregal

Concrete parapet walls on both sides of channel are constructed at some places in the residential area on the fan. The construction was executed by a self-government body or by a private person.

(B) Qda Cashahuacra

Concrete retaining wall of V-shape was constructed by Electro Lima for protecting the tower for transmission line at the top of fan.

The structures mentioned above are a kind of protection and the scale is small. The effect against the debris flow of large scale seems to be very limited. During the March 9 disaster, the channels in Qda Quirio and Qda Pedregal were buried and blocked with boulders. In case of Qda Pedregal, it seems that the blockage of channel caused the overflow of debris flow to the residential areas and made the damage bigger. It seems that the concrete parapet walls were constructed without the standard or the comprehensive study. In addition, the houses built inside the channel made the channel width extremely narrow.

In Qda Carosio and Qda Corrales, the flow is scarcely seen for many years as the catchment area is small and the rainfall is very slight. Therefore, no structure was constructed there.

2.3.7 Past Disaster in these Areas

In most parts of disaster areas, no village existed about 20 or 30 years ago. Therefore, the hearing from the inhabitants about the past disaster was hardly obtained.

In accordance with the information from the inhabitants and the reports prepared by the government, the comparatively big debris flow occurred in the past as follows:

Year	Name of Qda
1925	Qda Quirio, Qda Pedregal, etc.
1970	Qda Quirio, Qda Pedregal
1976	Qda Quirio, Qda Pedregal
1983	Qda Cashahuacra

In the above years, El Niño phenomena was relatively active. In the above list, the debris flow happened in 1925 was informed to be as big as that on March 9, 1987 though the damage was not serious. And in Qda Cashahuacra, the scale of debris flow in 1983 was almost same as that in this year.

No debris flow was reported in Qda Carosio and Qda Corrales.

2.4. Flood Inundation Disaster

2.4.1 General Description of Disaster Areas

Qda Jicamarca which induced the inundation disaster has the catchment area of 489.3 km^2 and the average slope of about 8%. This basin is the biggest one in the Rimac river basin except the basin of Sta. Eulalia river and has two major upstream tributaries, Qda Huayco and Qda Riocteco of which areas are located in the arid zone and have wide flat base valley of almost 1 km in width. In the wide valley, there is a shallow erosion channel with a little stream flow in usual days. The land of valley is used only in the limited areas where mines are located. However, in the downstream area from Cajamarquilla district located in the outlet of valley to the Rimac river, some villages and farm lands are seen.

The confluence of Qda Jicamarca and the Rimac river is located in the border area of Campoy district and Huachipa district. The new highway connecting Lima and Ricardo Palma under construction crosses Qda Jicamarca just before the confluence portion. A culvert structure with two semi-circular corrugated pipes of about 5 m in width and 2 m in height is constructed there. However, the capacity of these two pipes seems to be short at the time of flood in Qda Jicamarca. No consideration seems to be made for the blockage by driftwood. This highway has a function of dike as it runs along the right bank of Rimac river up to the Atarjea intake. The land on the right bank of Rimac river also inclines to downstream direction as same as the river. The residential areas including Campoy and Zarate continues to the central area of Lima city. No remarkable drainage channels to the main river is seen on the way as the rainfall is seldom in the lower reach of the Rimac river.

2.4.2 Inundation Conditions

Though Qda Jicamarca has usually very little flow, the flood flow caused by heavy rainfall in the upstream areas induced the inundation from two places at around PM 5:00 on March 9, 1987.

The inundation occurred by the blockage of culvert channels at crossing points of road by driftwood. The locations of inundation areas are shown in Fig. VI-2-10.

(A) At about 5 km upstream from the confluence

A part of Cajamarquilla district along the Qda Jicamarca was inundated.

(B) At confluence of Qda Jicamarca and the Rimac river

The right bank areas from the confluence to the central area of Lima city including Campoy, Zarate and Rimac district are inundated.

At the crossing point of road and Qda Jicamarca located 5 km upstream from the confluence, the driftwood blocked the culvert for about an hour from PM 5:00 until PM 6:00 as the section of culvert channel was small and the channel was sharply bent at this portion. Then the inundation occurred on the upstream left bank zone along Qda Jicamarca. The farm lands, some houses and a part of road suffered the damage. The traffic block was only temporary. The driftwood could naturally flow through the culvert later and then the water level lowered.

On the other hand, at the confluence, the corrugate pipes under the new highway were blocked by driftwood at around PM 5:00 and the water level was suddenly raised. The water overflowed from the right bank of Qda Jicamarca flowed into the Campoy district along the right bank of the Rimac river.

The water depth in the area nearby the overflowed portion reached to 1.0 - 1.5 m at the maximum which continued for about 3 hours. Then the water level lowered gradually and almost no inundation area remained at around PM 10:00 or PM 11:00. The flow went down along the right bank of Rimac river mainly through the roads. The water depth became shallow as the distance from the overflowed portion became far. The inundation area reached to a part of central zone in old Lima which is about 10 km from the confluence point.

The width of inundation area was changed by the topographical conditions. It was about 1 km at the wide area but only 30 m at the narrow area. The inundation flow include plenty of mud but does not include boulders as well as stones. The sediment depth was much different by the place. The depth on the road was shallow and only 10 - 20 cm at the place nearby the overflowed portion as the velocity was comparatively high. However, the sediment depth in the housing zone was deep and the sediments of over 1 m deep were seen in some places

It was informed that a flood of small scale happened in Qda Jicamarca on March 6.

2.4.3 Damage Conditions

In accordance with the report prepared by SE/CNDC, the damage of inundation disaster was as follows:

(A) Houses

Totally destroyed	149 houses
Semi-destroyed	50 houses
Washed away	46 houses

(B) Well

Among 1,300 wells located in Huachipa, Campoy and Zarate districts, 316 wells (about 25%) lost its function any many other well suffered the muddiness.

(C) School

2 colleges suffered the inundation.

(D) Traffic

In Zarate district the roads of about 20 km in total were buried with sediments of 7,000 m^3.
In Campoy district, about 2 km section of main road was buried with mud.

(E) Power

A substation suffered the damage.

(F) Agriculture

Farm land of 80 ha was inundated in Cajamarquilla.
About 5,000 chickens were dead.
Secondary irrigation canal of 1,500 m long was buried.
Others.

(G) Public Park

60% of public green zone was buried with water and mud. A park in Zarate was buried with mud of 50 cm deep.
Planting farm of 14 ha was buried.
Others.

The destruction of houses mainly occurred in the area located within about 500 m from the confluence point as the flow velocity is comparatively high and the water depth is comparatively deep. Especially in the border area of Campoy and Zarate where a part of inundation flow returned to the main river, the rate of destruction was remarkable. The mud piled about 0.3 - 1.0 m in these houses and the most household goods were flowed away. The number of houses affected by inundation was large as the total inundation area was wide.

Though the sediments on the roads were shallow, the damage due to traffic block was serious as the area was located in a densely populated zone.

2.4.4 Evacuation and Relief Activities

As far as the information from the inhabitants, the flood overflowed and inundated into the right bank zone without giving notice as it did not rain in the inundation area. However the serious human damage was not recorded as the water depth was not so deep. Many people evacuated to the higher places when the water depth was shallow.

Though the disaster area was wide, the relief activities were carried out comparatively smoothly as the heavily damaged areas were limited and the location was close to the central government office.

As already explained in Section 3.5, the relief activities were taken by the presidential decree "Comando de Emergencia". The activities for this inundation area are mainly under the control of the district office of San Juse de Lurigancho. Various activities such as food supply, water supply, clothes supply and provision of house building materials were carried out.

2.4.5 Rehabilitation Activities

The rehabilitation of houses and structures which suffered the damage and the construction of temporary facilities for houses were mainly executed by the inhabitants themselves though some materials were supplied from the government.

The driftwoods which blocked the culverts were removed by the government on the next day.

The removal of sediments on the roads was carried out by the government office and the rehabilitation was completed within a few days as the volume of sediments was not so large.

2.4.6 Past disaster in These Areas

It was informed that the disaster happened in Cajamarquilla district in 1983 but the details are not known.

Qda Jicamarca has a big tributary and the possibility of big flood is high if it rains heavily though the recurrence period will be long.

The main cause of inundation for this time was the shortage of capacity in culvert channel at the confluence portion. The culverts were constructed a few years ago. If the flood occurred before the construction of culverts, the scale of disaster would be much smaller even if it overflowed.

2.5. Other Disaster

2.5.1 Disaster in Qda La Cantuta

The debris flow happened in Qda La Cantuta on March 2, 7 days before March 9 disaster. The deposit zone in Qda La Cantuta is shown in Fig. VI-2-11.

Qda La Cantuta is located on the left bank of the Rimac river and has the catchment area of 15 km^2 and the average slope of 23%. In the middle stream stretch up to the point of 4 km upstream from the confluence with the Rimac river, a flat base valley of about 350 m at the widest section is formed. In the downstream stretch from the outlet of valley, the fan develops to the Rimac river. The erosion channel on the fan is comparatively shallow, 10 - 50 m in width and 8 - 12% in gradient. It seems that the channel route is not yet fixed as some marks of old routes are seen on the fan.

There are a big recreation club of which members are about 11,000 persons and some private villas on the fan. The railway crosses the downstream edge of fan.

The debris flow occurred from PM 3:00 to PM 4:00 on March 2. Though no serious damage was reported, the piles of sediments were left at some places on the way of channel.

The debris flow contained only small cobbles and mud. That is, it's better to call it as the mud flow. No inundation occurred from the channel ($A = 6 - 8\ m^2$) in the club. However, at the downstream stretch, the flow destroyed a part of wall used for the border of the club and formed the deposit area of 0.5 m in thick, 50 m in width and 6 - 8% in gradient. The area and volume of deposit are estimated at 0.5 ha and 2,000 m^3 respectively. In addition, some damage was reported at two villas. No damage was reported for the railway.

In Qda La Cantuta, the disaster by debris flow happened about 10 or 20 years ago and the channel was constructed in the club.

At the outlet of valley, the concrete wall was constructed for guiding the flow from the erosion channel to the channel in the club. However the route of erosion channel seems to be not yet fixed. The structure will be available as a temporary measure.

2.5.2 Slope Failure in Santa Rosa de Palle Bajo

On March 8, the slope failure happened on the mountain slope located on the right bank of Sta. Eulalia river. A part of Santa Rosa de Palle Bajo village suffered the disaster.

The slope is talus slope of 200 - 300 m long.

At around PM 3:00 on March 8, the heavy rainfall came and continued about 30 minutes. The boulders located on the slope moved down with flow. It is considered that the deposits on talus slope lost the stability due to the surface flow which eroded the talus deposits of repose slope by liquefaction. The type of flow will be the intermediate type of slope failure and debris flow.

The report prepared by SE/CNDC informed the damage as follows:

(A) House
- Totally destroyed : 5 houses
- Semi-destroyed : 9 houses

(B) Family affected
- 14 families

(C) Road
- Traffic block for 4 - 5 days

The human damage was not reported as the inhabitants evacuated as they went out of house when the heavy rain came and ran away when they saw the slight movement of rocks on the slope.

Though no slope failure has occurred for these 50 years in this village, they informed that it was their custom to see the condition of slope when it rains heavily.

2.5.3 Inundation in the Rimac River

The discharge in the Rimac river was recorded at the Chosica gaging station. The flood was a scale of the annual biggest flood.

Though no remarkable inundation was made from the main stream of the Rimac river, the damage was reported as follows:

(a) Two houses located nearby the river at Santa Rosa of Huachipa district suffered the inundation.

(b) The function of Atarjea intake was stop due to the high content of mud. The supply of city water to Lima was suspended for one or two days.

3. CLASSIFICATION OF PAST DISASTER

3.1 Terms

It is necessary to define the following terms.

(a) Quebrada
(b) Huayco/Huaico
(c) Debris flow
(d) Slope failure
(e) Land slide
(f) Inundation

"Quebrada" is a valley which has no or negligibly few flow except at the time of rainfall or in the rainy season. Then the mud and debris flow happened in Quebrada is generally called "Huayco" though the term of "Huayco" used in Peru sometimes includes the flood with debris or mud occurred in the rapid stream like the Rimac river. "Huayco" in the later case is to be classified in the Inundation type in this report.

The term of "Huayco" seems to be remarkably sensational word as "Huayco" is frequently seen on the top column of newspapers during the rainy season. "Huayco" is generally used as the general term of disaster caused by mud and debris flow, rapid flood flow, sometimes land slide or slope failure. A Peruvian engineer defines the term of "Huaico" as "fast flows and turbulent of dirty-water with rocks, tree logs and branches produced because of intense rain in arid and semiarid climates".

"Debris Flow" is the movement phenomena of debris and mud due to the actions of gravity and fluvial process. The mix proportion of debris and mud is higher than the flood flow and the debris and mud are transported farther than those in case of slope failure or land slide. "Debris flow" is sometimes classified into two types; Debris flow and Mud flow, by the diameter of debris, movement condition and etc. However, in this study, the term of "Debris flow" shall include the mud flow, otherwise the division of them is to be described.

"Slope Failure" as well as "Land Slide" is the mass-movement of rocks and earths due to the gravity action. In this report, the division of slope failure and land slide is to be defined as follows:

Description	Slope failure	Land slide
Movement speed	High	Low
Scale	Small	Comparatively big
Slope	Steep	Generally gentle
Movement of mass	Disordered	Original mass generally on sliding circle line
Notice	Suddenly happen	Some notices appear
Geology	No-relation with geology	Happen in particular geological conditions

"Inundation" is the phenomena of inundation caused by overflow of flood in a river. Inundation in the Rimac river sometimes contains much sediments though the boulders are scarce and the content ratio is smaller than Debris flow.

3.2 Disaster Type

(1) Classification

The rainfall and earthquake will be the most typical cause to induce the disaster due to rockfall, slope failure, landslide, debris flow, mud flow and flood. It seems to be not always easy to classify the disaster types. However, in order to make clear the features of disaster happened in the Rimac river basin, the disaster is to be classified into the following four (4) types.

(a) Landslide Type: landslide, slope failure
(b) Debris flow Type: debris flow, mud flow
(c) Inundation Type: Inundation (flooding)
(d) Earthquake Type: earthquake

More specific classification of these four (4) types of disaster is shown in Table VI-3-1.

The Earthquake type is the classification by the cause and includes the landslide and debris flow caused by the earthquake. Therefore, the above (a) - (c) types are used for the case caused by the rainfall.

(2) Land slide type disaster

Though no definite record of this type was found in the data collected from the offices concerned, the locations of rockfall, slope failure, and landslide were seen in almost every areas of the Rimac river basin at the time of field reconnaissance. Specially in the areas along the main road and railway, the potential and frequency of disaster, even if the scale is not so big, seem to be high as no protection works were seen for the steep cut of talus deposits slope.

(3) Debris flow type disaster

The disaster of this type has been frequently happened in the middle reach of the Rimac river basin. Specially, Quebradas located in the stretch between Corcona and Matucana have disasters to houses, road and railways almost every rainy season (January to March).

(4) Inundation type disaster

The disaster of this type is caused by the overflow of flood out of the river channel. The following are major reasons for this type of disaster;

(a) The river channel is artificially narrowed, resulting in the shortage of the river flow capacity.

(b) The necessary flow capacity is not given to such structures as bridges and culverts, etc., causing the blockade by floating materials and flooding there.

(c) There are many defects in the dike and bank, easily broken by the flood.

(d) The debris flow from a quebrada dams up the river flow, resulting in the overtopping of flood over the dike.

(5) Earthquake type disaster

The Republic of Peru is located in the zone of earthquake belt where the frequency is comparatively high. In accordance with the past records, the big disaster happened in the following cases.

(a) Oct. 28, 1746 in Lima Dead-5,000 persons (including by Tsunami)

(b) May 24, 1940 in Lima (River mouth areas La
May 31, 1970 Molina, Chorrillos, etc.)

The big disaster due to earthquake seems to be limited in the coastal areas in accordance with the past disaster records. However, a few traces of collapse on large scale are seen in upper reaches and the possibility of collapse due to earthquake can not be neglected even in middle and upper reaches.

4. DISASTER AND DAMAGE IN EACH AREA

4.1 Division of Disaster Area

Among four (4) types of disaster mentioned in the previous sub-section, the attention is to be paid on the disaster by debris flow type and inundation type for the division of disaster area based on the distribution of disaster, topographical location and social conditions as shown in Fig. VI-4-1.

(A) Area I : The Rimac river (River mouth-Chaclacayo)

(B) Area II : The Rimac river (Chaclacayo-Corcona) Sta. Eulalia river (Confluence-Callahuanca)

(C) Area III: The Rimac river (Corcona-Tambo de Viso)

(D) Other areas

The division is made for the specific description of disaster.

4.2 Disaster and Damage in Area I

This area has dry climate whole year long and the natural vegetation is seen only in the areas along the river. The metropolitan area of Lima and Callao is developing in this Area I where the significant properties are gathered. In this area, the disaster of inundation type will be probable as the river mouth areas on the left bank was widely inundated in 1984. The scouring at the foundation of structures in and along the river will also induce the problems for the maintenance of them.

The disaster area due to inundation are located in the stretch from Lima to Chaclacayo.

The following areas suffered the inundation type disaster in these years.

(a) River mouth - Bridge Faucctt in Lima City

Left bank near the river mouth
(Navy base)
Right bank near the airport

(b) Atarjea intake - Chaclacayo

Huachipa, right bank
(Downstream area of Huachipa bridge)
Santa Clara (Left bank)
ÑaÑa
Moron - Chaclacayo

As far as the disaster in these years, the inundation disaster occurred in various places in 1983, 1984 and 1986. In 1984, the Naval base located on the left bank in river mouth stretch suffered remarkable damage caused by flood flow with much mud. The cause of the inundation seemed to be not only much flow discharge but also the rise of river bed.

After the disaster in 1983 and 1984, some rehabilitation works such as dike embankment, gabion placement and river bed excavation have been carried out, such countermeasures seem to be still a temporary measure. That is, the potential of disaster will be still high.

In the stretch of Lima city, the bridges suffer long-term scouring. The maintenance works by consolidation works have been already carried out for Ejercito Bridge and Piedra Bridge by INVERMET. One of the cause of scouring will be the increase of flow velocity due to the decrease of river cross section which have been made by the earths and rubbishes thrown into the river by the inhabitants.

At Atarjea intake administrated by SEDAPAL, the scouring problem have been serious since 1968, next year of the completion. At present, five low dams (Consolidation work) have been constructed in the downstream stretch of the weir.

The areas of Rimac, Zarate and Campoy located on the right bank of Rimac river were inundated on March 9, 1987 caused by the overflow from Qda Jicamarca.

4.3 Disaster and Damage in Area II

This area also has dry climate. This area hardly has rainfall which causes the movement of earths and rocks. Talus deposits with almost critical slope of 36 - 37° are seen on slopes of every mountains and quebradas have sohlental valley developed by the deposits of earths and rocks. In this Area II, the disasters of inundation type and debris flow type are seen. In 1983 and 1987, the disaster of debris flow type was prominent, however, the frequency of disaster seems to be low in the ordinary years. That is, the interval of disaster in this area is generally long.

The disaster of debris flow type in this area frequently occurred caused by heavy rainfall in February - April of 1983 and in March of 1987 by the effect of El Niño. The disaster in 1983 happened in the downstream quebradas of the Santa Eulalia river and the other areas. The disaster in March 1987 happened mainly in Chosica district located on the right bank of Rimac river and Santa Eulalia river. However, no big disaster has happened in these 20 - 30 years except those of 1983 and 1987 according to the information from some inhabitants in the disaster areas, On April 1, 1983, Huayco including big stones with over 5 m in diameter has occurred in the afternoon. Twelve (12) houses have been completely destroyed and washed away, much amount of mud entered into some houses and a church and the main road was blocked by mud and rocks for longer than a week. The rough sketch of this area is shown in Fig. VI-4-2.

In Quebrada Cashahuanca, Huayco occurred several times in Feb. and March in 1983. The serious damage among them happened on Feb. 24 and March 23 in accordance with a newspaper. The facilities of vacation club and some houses were destroyed and the lost of human life was also informed. The mud flow reached to the main highway near Chosica through the routes of old river course and had serious effect in this area. At that time, the deep channel was newly formed by the erosion along a small stream. The erosion action in March 1987 occurred but not so strong as that in 1983.

The debris flow occurred on March 9, 1987 in Qda Quirio, Qda Pedregal, Qda Carosio and Qda Corrales which are located in Chosica district. The serious disasters including the human death and destruction of many houses occurred in the areas located in the outlet of these quebradas.

The inundation occurred in Chosica in 1983 where the town areas develops to the edges of river channel. In Chosica, the flood flow entered from the vicinity place of Moyopampa intake and some areas including the Chosica railway station were inundated.

The inundation area has the range of 200 - 300 m wide confined by river terraces on the both sides of the Rimac river.

4.4 Disaster and Damage in Area III

The Rimac river in this area forms V-shaped valley. The valley has steep slope with the difference of more than 2,000 m in elevation and consequently quebradas running in the valley of these slope have very rapid flow. The fan is generally formulated at the confluence. This area has semi-dry climate and the much part of annual rainfall is recorded in the period from January to March.

This area is known as most habitual disaster area in the Rimac river basin as the main highway and railway run along the river and some villages are developed on the fan as well as on the terrace. In 1983, the disaster happened in whole areas.

As the river bed seems to be raised remarkably in these years, the potential of inundation type disaster will be increased.

This area is the most habitual disaster area of debris flow. Almost every year, the disaster occurs and the national highway and railway suffer damages. It is informed that the most serious disaster happened in Feb. and March 1983 and the traffic of both highway and railway was completely blocked for long period in and around San Bartolomé, San Juan and Matucana. Some human life and much properties are lost. In Matucana, Huayco occurred in Qda. Paihua checked the mainstream. Then the streets of Matucana suffered inundation on Feb. 23 and 24. Matucana suffered serious disaster on March 6, too, by Huayco from Qda. Paihua. Qda. Paihua has the fan in front of the mainstream of Rimac river and rapid flow with series of falls are seen in the upstream stretch of the fan. It is considerable that the flood flow with high velocity rolled earths and rocks in the fan at that time. The disaster in Matucana in 1983 is summarized in Table VI-4-1 and the rough sketch of this area is shown in Fig. VI-4-3.

It was informed that similar disaster by Huayco happened to Matucana in Feb. 1959 (Qda. Paihua) and in 1970 (Qda. Paihua, Qda. Chucumayo).

In San Juan, Huayco occurred at the upstream quebrada on Feb. 23, 1983 washed away a part of national highway and railway. The downstream stretches from San Juan to Surco also suffered inundation damages to highway and houses. The river bed rose in these stretches. Further, the disaster of human death occurred in the next year when the road on river bed still used. Then it was decided to change the routes of not only the highway but also the railway so as not to cross the San Juan village. The disaster in San Juan in 1983 is summarized in Table VI-4-2 and the sketch of this area is shown in Fig. VI-4-4.

In San Bartolomé, Huayco occurred from Qda. Rio Seco on March 14, 1983 and checked the mainstream of Rimac river. Tornamesa village located upstream suffered a large scale inundation. Qda. Rio Seco is one of the most habitual stream of Huayco. Almost every year, Huayco happens in Qda. Rio Seco. The maintenance of highway and railway in this area is serious problem. The disaster in San Bartolomé in 1983 is summarized in Table VI-4-3 and the sketch of this area is shown in Fig. VI-4-5.

In Corcona, Tornamesa, the levee was constructed after 1983 inundation which provided damages to highway, houses and farm land. In accordance with the hearing from the inhabitants, the cause of inundation was the river bed rise by the earth born by road construction in the upstream stretch and the sediments of debris flow in upstream quebradas.

4.5 Disaster and Damage in Other Areas

Other area is the areas other than the Areas I, II and III. The other area is considered to be not so important from the viewpoints of disaster.

In the middle and upstream reaches of Sta. Eulalia river, the villages and roads are located generally in the higher places from the river bed of mainstream. No record of disaster, except some small scale disaster happened in 1983, was found.

In the upstream reach of Rimac river, the disaster occurred at Ocatara, Tamboraque (Qda. Challumay) and San Mateo to highway, railway and houses in 1983. In San Mateo, the debris flow occurred from the small quebrada located on the right bank in the upstream stretch of the town and the town area was inundated caused by the damming in the Rimac river. It was informed that the disaster of comparatively large scale occurred at San Mateo in 1959 and 1970.

Large dumps of excavation materials from mines are seen in Qda. Santa Rosa, Qda. Tacpin and Qda. Rarac located in the upstream stretches of Rimac river. The scouring damage occurred at Yauliyacu (Qda. Santa Rosa) in 1983.

The most parts of these area are located in the upper reach area of the Rimac river or the Santa Eulalia river. The glacier topography is seen in the areas higher than EL. 4,000 m. The quebradas in the upper reach have gentle slope U-shape valleys covered with talus deposits of high permeability and the occurrence possibility of debris flow or flood flow seems to be low. However, some valleys have lagoons (lakes) in the upstream end and it would be necessary to consider the stability of structures located at the outlet of each lake.

5. TYPICAL MECHANISM OF MASS MOVEMENT IN SLOPE AND QUEBRADA

5.1 Cause and Mechanism of Landslide and Slope Failure

(1) General

On the slope, the movement of rocks and earths is mainly made by the gravity action. As the mountain slopes in the Rimac river basin are generally large in relief and steep, the movement occurs suddenly and rapidly. That is, the slope failure type occurs more frequently than the landslide.

The cause of movement is generally the rainfall. The earthquake also becomes the cause as seen in the marks of slope failure/landslide in large scale. However, no record of disaster caused by the earthquake is left as the period of disaster records is short. In addition, the man-made cause is also considerable as seen in the steep cut or bottom cut of slope for the road construction.

The descriptions are to be made by dividing the movement on slope into the following types from the conditions and mechanism of movement.

(a) Surface failure type
(b) Talus type
(c) Quebrada erosion type
(d) Circle sliding type
(e) Land creep type
(f) Rock fall type

(2) Surface failure type

The surface failure happens by the rainfall in the loose deposit layer and the weathered rocks on bare slope without vegetation. The volume of failure per unit area is comparatively small.

(3) Talus type

In the area with comparatively little rainfall, the talus slope with the epose of about 34°-37° is formed by the rocks and cobbles failure from the upper part of slope on the lower part of long high slope. The talus surface is high in permeability. Therefore, the slope is stable as the phenomena of surface flow occurrence and increase of pore pressure will be restrained at the time of rainfall except heavy rainfall. In addition, the talus covers the bed rocks layer and consequently the erosion volume of the slope will be restrained by the existence of talus.

However, in case of heavy rainfall, the talus deposits will be saturated with water and the liquefaction will be occurred especially in the gully portion.

(4) Quebrada erosion type

The V-shape valley is formed in the steep slope stretch of many quebradas and the lateral as well as longitudinal erosion in these valleys proceeds violently at the time of heavy rainfall. The mountain slope of valley is sometimes failured caused by the erosion in the channel. The types of failure are various such as the sudden failure, the slow failure like landslide, and the expansion of failure area.

(5) Circle sliding type

The unstable portions which are likely to be failured from the comparatively deep zone are seen on some steep mountain slope. Some of them have slopes with steps of sliding surface or cliff and some of them have gradual failure zone from the lower part. On some failure slope, the farms or the irrigation channel is seen and the seepage water seems to be a cause of failure. However, the circle sliding type failure is also caused by the erosion of valley and the earthquake of which case is generally deep and large in scale of failure.

(6) Landcreep type

In the Rimac river basin, some marks of past failure are seen at the slope with sliding cliff on the upper part and the particular topography of sliding with gentle slope on the lower part. However, no disaster was recorded in the past and no measurement of slope movement was performed in the past.

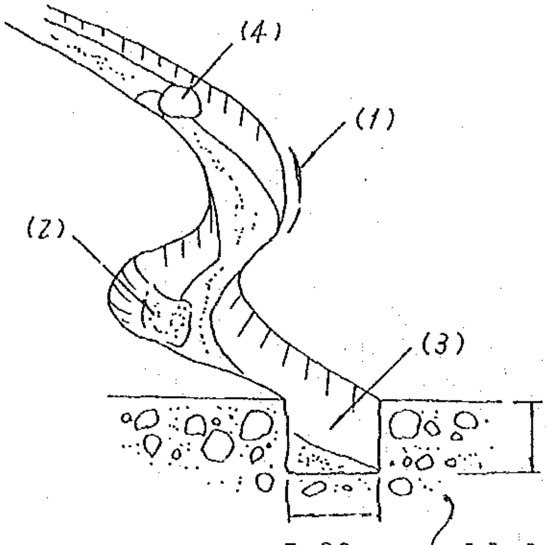
(7) Rockfall type

On the slope without vegetation, many rocks are seen. The rocks are fallen by the slight movement caused by rainfall or difference of temperature. Though no serious disaster of rock fall was not recorded in the past, the rock falls in small scale occasionally happens.

5.2 Mechanism of Debris Flow

A great deal of quebradas in which the debris flow occurred have erosion channel in the upstream stretch of deposit zone. The erosion channel with more or less bending is formed by erosion action of fan or old deposit surface in the valley. The marks of violent downcutting and lateral erosion in the past are seen in such channels. Sometimes, the deep erosion channel is formed by only a debris flow along the small channel.

The debris flow is like ordinary flood flow and erode the old deposit violently on the way.



(1) Cracks (which will be fallen)

(2) Collapsed earths

(3) Concave channel with vertical side walls.

(4) Lateral erosion is suspended by large stones.

Example of Erosion in Quebrada

The stretch with this typical erosion channel has a slope of 5 - 15% and usually be located in the downstream side of flowing (transportation) zone. It is considered that the most parts of deposit in the downstream stretch are transported from the flowing zone where the boulders and earths are eroded by debris flow.

The conditions of flowing zone is different in each quebrada. For example, the deep valley of almost 50 m deep is formed in Qda. Rio Seco. The materials from the following places become the source of deposits.

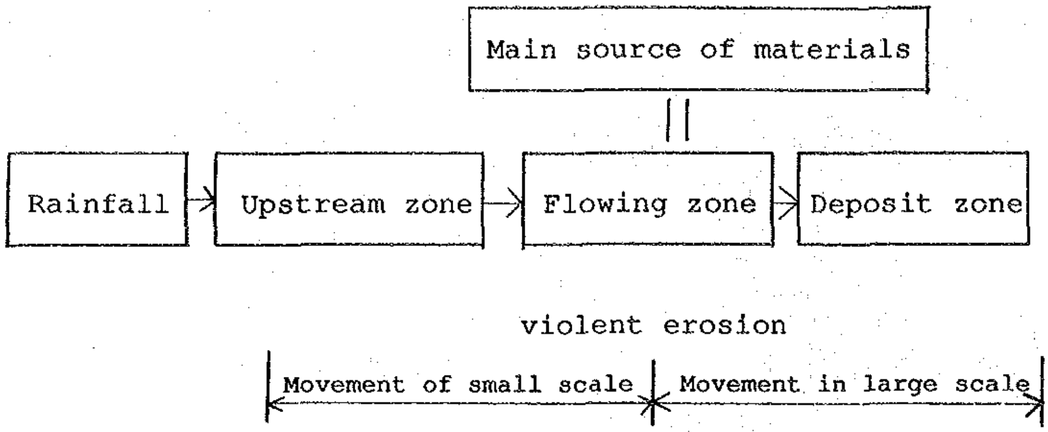
(a) Old deposit surface on valley or fan
(b) Talus slopes
(c) Failured deposit in the bottom of valley

It is considered that the debris flow is the movement by flow action rather than gravity action though the characteristics are different as follows:

(a) Erosion action of flow (velocity, discharge, resistance of materials against erosion, etc.)

(b) Mix proportion of debris and mud

(c) Grading of mixed materials



Flow Chart of Debris Flow Process

It seems that the flow coming from the upstream stretch into the flowing zone more or less contains rocks and earths. The upstream zone has some small tributaries which join each other on the way of flowing. The damming-up seems to be occurred in these small tributaries especially at the confluences, at the time of debris flow. Then the scale of disaster becomes bigger. In some quebradas, it was informed from the inhabitants that the flow was temporarily disappeared or got muddy just before the coming of debris flow. The phenomena possibly were caused by damming in the upstream tributary.

According to the results of investigation, the cause of disaster was the rainfall in any cases. Especially in the years of El Niño, the heavy rainfall frequently attacks locally.

The debris flow disaster areas in the past are located in the range from San Mateo town to Chacracayo town.

6. TYPICAL CAUSE OF INUNDATION

(1) General

The Rimac river is the steep-gradient river and the sediment volume is large. The inundation sometimes accompanies much sediments. Though the direct cause of inundation is the rainfall, there are some other causes which are divided into the following two classifications.

(a) Natural cause
(b) Man-made cause

The typical cause of inundation is to be described in each area of three divisions.

(2) Lower reach area of Rimac river

The inundation prone area is located in the upstream stretch of Atarjea intake and in the estuary area according to the past disaster information. In these zones, the sedimentation is active. Though the construction of dikes and the excavation of river bed materials are carried out, the river bed are apt to rise gradually and the probability of inundation in the future seems to be still high. In addition, the reduction of river width is remarkable. The piles of embankment by not only earths but also garbages are seen at many places in this reach, especially in the densely populated areas.

It is reported that the flow direction of flood is changed by the partial deposit zone in the river course of the stretch from Chaclacayo and Atarjea intake and the flow sometimes destroy a part of dike. Further, some parts of dike are cut for the purpose of river gravel pitting. In the stretch from Chosica to Chacracayo, the resident houses invade the channel areas and make the river width narrow by constructing structures such as revetment and parapet walls. The cross sections of river channel seems to be varied remarkably in the lower reach.

(3) Area with strong affect of sediments from quebradas

The inundation areas in the upper reach (Area III) are located at the narrow portion and at the confluence. The damming or the rise of river bed by sedimentation is apt to happen in these portions.

The sediments coming from the upstream stretch are produced from the debris/mud flow in quebradas or the excavation for road construction.

Though dikes are constructed in the past disaster area, the river bed rise still continues.

(4) Area nearby the confluence of quebrada

As seen in the disaster happened from Qda Jicamarca in March 1987, the man-made structures frequently causes the disaster in the Rimac river basin. Especially, the closing of river channel happens many times by driftwood or debris at the crossing points of structure and the channel. The inundation occurs by the overflow from the upstream side of closed portion.

7. INVENTORY OF DAMAGEABLE VALUE

7.1 General

Since actual damage records due to past flood or debris flow disaster are sufficient for neither counting on damage amount of all conceivable properties, nor estimating damage amount of them by different scale of flood or debris flow. In this respect, estimate of probable damage by different magnitude of disaster will be required to count on disaster control benefit which is derived from damage amount to be mitigated by proposed structural plans. This sub-chapter covers inventory of damageable value which is necessary for simulation of probable flood or debris flow damage.

Inventory of damageable value starts with identification of various types of properties in disaster area caused by flooding or debris flow. The list of damageable properties to be directly spoiled are the following items:

(a) Residential House according to qualitative type such as upper, middle, and lower class.

(b) Building and Factory consisting of market facility, school, government office, factory, and others.

(c) Farm crops and cattle.

(d) Public structure such as road, bridge, well, park and others.

Furthermore, rehabilitation cost of removing debris, mud and destroyed structure is added to above items from (a) to (d) in order to formulate direct damage category. Indirect damage due to interruption of economic activities caused by disaster is also estimated in terms of to what extent the stoppage of transportation system in principal road affects economic activities of industrial sectors.

Damageable value of identified properties is presented in the following sub-items such as building cost by type and quality of building, indoor movables by type and quality of building, farm crops per ha, unit rehabilitation cost, and estimate of indirect economic loss caused by a past flood. Damageable value of all properties is assessed at price level of June, 1987.

7.2 Building Cost

Building costs by type and quality of buildings are estimated on the basis of unit cost per m^2, the standard size of buildings, and their salvage value.

(1) Unit Cost per m^2

(A) Residential house

Since housing cost is much different by quality of house with the following construction and equipment items,

(a) Wall and column
(b) Slabs and ceiling
(c) Floors
(d) Doors and windows
(e) Coating
(f) Toilet and bath
(g) Electrical and sanitary facilities

Residential house is tentatively classified into three classes.

(a) Upper class

The houses are generally made of brick, concrete or similar materials for the main structure and coated well on the surface. The facilities of this class are also good in quality.

(b) Middle class

The houses are generally made of bricks or woods for the main structure and coated with similar materials or exposed without coating. The facilities such as toilet, windows, kitchen are sufficient for use but generally not so good in quality.

(c) Lower class

The houses are generally made of exposed adobe (mud-brick) or equivalent materials for walls and columns. Ceiling is similar or does not exist. Floor is made of simple concrete or tile or sometimes just compacted. The facilities are generally not sufficient.

(B) Other buildings

As far as other buildings are concerned, the average unit cost of each type of building per m^2 is used.

(C) Unit cost per m^2

The results of unit cost per m^2 by type and quality of buildings are shown as below.

(a)	Residential house	
	upper class	I./10,000 per m^2
	middle class	I./ 5,000 per m^2
	lower class	I./ 2,000 per m^2
(b)	Market facility	I./ 4,000 per m^2
(c)	School	I./ 5,000 per m^2
(d)	Government office	I./ 7,000 per m^2
(e)	Factory	I./ 5,000 per m^2
(f)	Commercial building	I./ 8,000 per m^2

(2) Standard Size of Buildings

The standard size of buildings by type and quality shows the average size of them. The average size of houses are estimated from informations of inhabitants and site inspection.

(A)	Residential house	
	upper class	200 m^2
	middle class	120 m^2
	lower class	60 m^2
(B)	Market facility	1,000 m^2
(C)	School	500 m^2
(D)	Government office	500 m^2
(E)	Factory	2,000 m^2
(F)	Commercial building	500 m^2

(3) Building Cost

Building costs by type and quality of buildings are estimated as the average cost between purchasing value and salvage one. The ratios of salvage value to purchasing cost based on official data are shown as below.

(A)	Residential house	
	upper class	0.9
	middle class	0.8
	lower class	0.7
(B)	Other buildings	0.8

Building costs are to be estimated with the following equation:

Building cost = (unit cost per m^2 x standard size + salvage value) x 0.5

The results of them is shown in Table VI-7-1.

7.3 Indoor Movables

Indoor movables are estimated as stock value which is typical of inventory belonging to each type of building. As far as indoor movables of a middle class family are concerned, the rough estimate of household effect was conducted by assuming the number of their holdings. Household effects in upper and lower classes are estimated so as to be in proportion to the difference of building cost.

In case of other types of establishment, statistical data are available only for factory of manufacturing industry. Assuming that inventory of manufacturing factory is final products, input material, and capital equipments, its stock value per establishment is estimated by consider-ing stock period of respective inventory. Since there are insufficient data on estimating for stock value of other types of building, stock value of them is estimated by referring to the ratio of respective inventory value to building cost in case of manufacturing establishment. The results of indoor movables are shown in Table VI-7-2.

7.4 Damageable Value of Farm Crops

Farm lands in the disaster area produce various kinds of vegetable, cereals, and fruits, though production of these crops has not been so outstanding. Among them, tomato and maize are represented as typical crops in disaster area. Farm land is roughly classified into good harvest and poor harvest land. Net income of above two crops is taken as damageable value, assuming that crops are spoiled at the time of harvest. The results of damageable value of two crops are shown in Table VI-7-3.

7.5 Public Structures and Rehabilitation Works

Unit construction cost of the major public structures to be damaged by typical disaster is road, bridge and well. The breakdown of unit cost by items is shown in the following way:

(A) Road

- Paved highway with its width ranging from 7 to 20 m — 3,000 Intis/m^2
- Non-paved road having its width around 6 m — 100 Intis/m^2

(B) Bridge

- Concrete bridge in highway with span from 30 to 40 m — 8,000 Intis/m^2*
- Concrete bridge in non-paved road with span of 10 m — 3,000 Intis/m^2*

* Cost per area of top surface

(C) Well excavated in gravel layer with 6.6 cm in diameter and 100 m in depth — 1,200 Intis/m

After disaster, a large quantity of deposits remains in the disaster area. The removal of those deposits become the cost of damage to recover conditions before disaster. The costs of removal works by bulldozer are shown by materials to be removed.

(D)	Rock with cobble stone/ structures destroyed	200 Intis/m^3
(E)	Common/mud	70 Intis/m^3

7.6 Economic Loss due to Interruption of Traffic

When the traffic is interrupted by inundation or deposits of debris/mud flow, the indirect damage affecting social and economic fields is a serious problem. Since there is a national road of No. 20 called Carretera Central and railway connecting Metropolitan Lima with Sierra in the Rimac river basin, the indirect damage caused by traffic block in this transportation was the most concerned matter among various damages. Actually, disasters occurred in quebradas along this principal road led to the traffic block with long duration, resulting in the following fact that economic sectors, in particular, manufacturing one faced with the opportunity loss of selling or producing final products since major intermediate materials or semi-finished products are transported from sierra area through the route 20 and railway.

Although there is no actual or specific damage records concerning to these indirect damage, estimate of economic loss is conducted in the following way:

(A) At first, kinds of consignment transported between Metropolitan Lima and Sierra through the Rimac basin are investigated by referring to data on consignment by railway. Types of consignment in the direction from Lima to Sierra have been agricultural products, mineral, chemical, and metal. On the other hand, typical goods transported in the opposite direction turned out to be floor, petroleum, sugar, and fertilizer.

(B) Secondly, to what type of industrial sectors above materials are supplied as intermediate goods are investigated by referring to national input-output table. Industrial sectors where these intermediate goods are considered to be the significant input factor in terms of value are selected.

(C) Thirdly, area to be affected by disaster is assumed to be Metropolitan Lima if consignment transported from Sierra to Lima is interrupted. In the opposite case, the affected area is assumed to be Departments of Junin and Pasco. GRDP of industrial sectors at 1987 price level in respective area of Metropolitan Lima and Sierra consisting of Junin and Pasco is estimated by using statistical data. The results of them is shown in Table VI-7-4.

(D) Fourthly, indirect damage is estimated as economic loss of value added due to inability of selling final products of selected industrial sectors. Assumptions for counting on indirect damages affecting economy of Metropolitan Lima are as follows:

(a) In case of consignment from Sierra to Lima area, mineral materials conveyed to Lima area are mostly transported through a route of 20 or by railway, whereas other consignment transported to Lima through the above traffic route is assumed to be a quarter based on historical traffic volume in principal roads to Lima. In this respect, ferrous metal industry in Lima area to which minerals are supplied as intermediate material is the sole sector to be affected by disaster in full if the said traffic route is interrupted. As to other industrial sectors to which consignment except for mineral is supplied, a probability to be affected is around 25% if the same traffic route is interrupted.

(b) As far as consignment from Lima to Sierra is concerned, these consignment transported to Junin and Pasco are mostly conveyed through a route of 20 or by railway. So, selected industrial sectors in Junin and Pasco are to be affected in full if the said traffic route is interrupted.

(c) Assuming that duration of interruption is about 1 day, indirect damage in Lima economy is the following equation.

(GRDP of ferrous metal x 1.0 + GRDP of other sectors x 0.25) x 1/365

Indirect damage in Sierra area is
GRDP of selected industries x 1/365

Total indirect damage due to traffic block is estimated to be around 50 million Intis per day.

7.7 Summary of Damageable Value

In accordance with the explanation described in the previous sections, the damageable value of each item is decided as follows:

(A) House (including indoor movables)

Upper class	I./2.45 x 10^6/no.
Middle class	I./0.75 x 10^6/no.
Lower class	I./0.13 x 10^6/no.

(B) Public Building (including indoor movables)

Market	I./3.76 x 10^6/no.
School	I./2.50 x 10^6/no.
Government office and others	I./3.50 x 10^6/no.

(C) Farm Land

Good harvest	I./0.03 x 10^6/ha.
Poor harvest	I./0.01 x 10^6/ha.

(D) Public Structures

Paved road	I./0.003 x 10^6/m^2.
Non-paved road	I./0.0001 x 10^6/m^2.
Main bridge	I./0.008 x 10^6/m^2.
Common bridge	I./0.003 x 10^6/m^2.
Park	I./0.0005 x 10^6/m^2.
Others (Waterway etc.)	L.S.

(E) Rehabilitation Works

Removal of debris	I./0.00020 x 10^6/m^3.
Removal of mud	I./0.000070 x 10^6/m^3.

(F) Traffic Block

National road No.20	I./50/day
Sta Enlalia main road	I./5 /day

Tables

TABLE VI-1-1 NATURAL DISASTER IN PERU (1972 - 1985)

Disaster		1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Collapse	Derrumbe	4	--	1	--	3	9	2	4	6	9	13	18	11	3
Landslide	Deslizam.	6	1	--	2	4	1	--	--	--	1	21	40	19	1
Debris flow	Huayco	2	1	--	--	1	10	6	1	9	33	7	203	38	7
Inundation	Aluvion	2	--	2	--	--	3	1	3	2	10	13	31	1	2
	Inundac.	--	--	6	10	6	24	8	9	2	32	60	157	35	10
Erosion	Erosion	--	--	--	--	--	--	--	--	--	--	--	5	4	1
Heavy rainf.	Illuv. torr.	--	--	1	7	5	1	9	4	22	1	4	109	20	10
Snow	Nevada	--	--	3	--	--	--	--	1	1	--	--	--	--	2
Frost	Helada	--	--	--	--	1	--	--	1	2	--	1	3	--	--
Hail	Granizada	--	--	--	--	--	--	--	1	--	--	--	3	1	--
Thunderstorm	Tempest. ele.	--	--	1	1	2	10	7	2	3	2	2	3	--	--
Storm	Viento hurac.	--	--	2	4	3	--	1	3	1	1	3	3	6	5
Earthquake	Sismo	--	--	2	--	1	--	--	7	12	3	5	2	--	1
Other	-----	3	--	1	13	18	14	8	15	22	10	11	23	12	36
Total	-----	17	2	19	37	44	72	42	51	82	102	140	600	147	78

Note : Data from SE/CNDC

TABLE VI-1-2 NATURAL DISASTER IN EACH DEPARTMENT (1972 - 1985)

DEPARTAMENTOS	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Total Nacional	17	2	19	37	44	72	42	51	82	102	140	600	147	78
Amazonas			1	4	1	8	1				1		3	
Ancash	2		1	3	3		1	7	9	8	12	210	9	3
Apurímac	1		1					2			6	3	3	2
Arequipa			3	2	1	8		4	3	3		7	46	37
Cajamarca	1	1		6		1	1		1	6	1	21	1	1
Cusco			1	3	7	10	25	9	19	6	45	19	27	5
Huancavelice	3			1	3			2	1	2	8	13	3	3
Huanuco				1	2					4	9	11	2	2
Ica			1	1	3		3		1		2	17	6	1
Junín			2	4	5	16	1	7	14	10	11	5	3	2
La Libertad		1			2	2		2	1	1	1	3		
Lambayeque				3				1	1		1	2		
Lima	5		3	1	6	12	2	9	11	42	21	233	20	3
Loreto	1		3	2		1		1	2		1	1	3	6
Madre de Dios							1	2	1	1	5	1		2
Moquegua			1			1						1		
Pasco	2						4	2		5	1	13	4	1
Piura			1	1	5	7	1		3	2		11	4	1
Puno				1	2	3	1		1	5	1			
San Martín			1	2			1		2		6			1
Tacna					2			1		1			6	1
Tumbes									1			9	1	1
Ucayali							1			3	5			1

Note: (1) The Rimac river basin is located in Lima Department.
(2) Data from SE/CNDC

TABLE VI-1-3 DAMAGE IN PROV. HUAROCHIRI AND PROV. LIMA (Jan. - Jun 1983)

DISASTER	TIME	DEAD PERSON	INJURED PERSON	BROKEN HOUSE	NOTE
Landslide	7	4	10	1,099	
Debris flow	65	3	172	507	Damages to Railway and Road are remarkable.
Avalanche	4	40	15	141	Damages to Railway and Road are remarkable. Earth and debris flow disaster on large scale (in river channel)
Inundation	33	--	25	440	Damages to Railway and Road are remarkable.
Snowslide	3	4	7	560	
Heavy rainfall	7	--	--	140	
Other	20	1	4	0	
Total	139	52	233	2,887	

Note: The Rimac river basin is located in both Provinces of HUAROCHIRI and LIMA.

TABLE VI-1-4 LIST OF DISASTER IN THE RIMAC RIVER BASIN (1983)

PLACE	DATE	DISASTER	DAMAGE DEAD PERSON	INJUR. PERSON	BROKEN HOUSES	HIGH WAY	OTHER	NOTE
Qda Reo Seco Qda Yamajune Qda Chacaqyari	Jan. 21-22	Debris flow				x		
Cajamarquilla	Feb. 8	Inundation ?			37			Qda Jicamarca ?
San Mateo	Feb. 19	Slope failure	(1 ?)		(?)	x		
Matucana	Feb. 22-24	Debris flow inundation			Many		Railway station	Qda Paihua
Qda Rio Seco	Feb. 22	Debris flow				x		
San Juan	Feb. 23	Debris flow inundation				x	Railway bridge	Qda Palcacancha
Qda Cachahuacra	Feb. 23	Debris flow					Agricultural facilities	
Qda Chucamayo	Feb. 28	Debris flow			(20 ?)	x	Railway	
Qda Matala	Feb. 28	Debris flow				x		
Qda Rio Seco	Mar. 2	Debris flow				x		
Qda Cachahuacra	Mar. 5	Debris flow			Many	x	College	
Qda Linday	Mar. 6	Debris flow				x		
Chosica	Mar. 6-7	Inundation			?	x		
Matucana	Mar. 6	Debris flow inundation			?	x		Qda Paihua
San Juan	Mar. 7	-	3			x	Railway	From "control de torrentes en la cuenca hidrografica del Rimac" and other
Rio Seco	Mar. 14	Debris flow inundation			?	x	Railway station	
Corcona	Mar. 17	Inundation			?	x		
Qda Cachahuacra Other	Mar. 22	Debris flow			?			
Matucana-San Mateo	Mar. 22	Debris flow	35	15		x		
Chaclacayo	Mar. 30	Inundation			?			

Data Source : SE/CNDC
Note 1. "x" indicates damage.
2. "?" means "not sure".

TABLE VI-1-5 DISASTER BY DEBRIS FLOW 1983
(Central Highway, Ricardo Palma-Tambo de Viso)

Valley (Quebrada)	Position (Central Highway) Km	Jan.	Feb.	Mar.	Apr.	Total	No.
1. Santa Ana	41+900			1	1	2	R11
2. Cupiche	44+400			1	1	2	R13
3. Puruguay	47+000			1	1	2	R15
4. Agua Salada	51+520			1	1	2	R17
5. Ascahuaca	51+600						R18
6. Rio Seco	55+010	1	1	1	1	4	R19
7. Esperanza	57+623			1	1	2	R20
8. Cariñito	59+000			1		1	---
9. Verrugas	60+427			1	2	3	R21
10. Linday	62+000			2	2	4	R22
11. Huacre	66+200						R23
12. Ushupa	66+500	1		1		2	
13. Matala	66+900				2	2	R24
14. Cuchimachay	67+500				2	2	R25
15. Chacamaza	67+880						R26
16. Yanajune	71+130	1			3	4	R27
17. Collana	72+963			1	1	2	R28
18. Chucumayo	76+000			1		1	R31
19. Paihua	77+430	1		1	1	3	R32
20. Pancha	81+000						R34
TOTAL						36	

Note: Data from MINIST. TRANS. and COMUNI.

TABLE VI-1-6 LIST OF DISASTER IN THE RIMAC RIVER BASIN (March 1987)

Place	Date	Disaster	Damage					Note
			dead person	injur. person	broken houses	high way	other	
Qda La Cantuta	March 2	Debris flow			(2)		Club facilities	
Santa Rio de Palle Bajo	March 8	Slope failure			14			Downstream area of Santa Eulalia
Huachipa, Campoy, Zarate	March 9	Inundation			245		Road: 22 Km Farm land: 80 ha	
Rimac							College: 2	
Qda Quirio Qda Pedregal Qda Corosio Qda Corrales Qda Cashahuacra	March 9	Inundation	38	12,414	650	x	School: 4 Farm land: 0.5 ha Waterway for power: 2 Km	Over I./222,000,000
Huachipa (Santa Rosa)	March 9	Inundation			(2)			
Total			38	12,414	913			

Note: Data from SE/CNDC

TABLE VI-1-7 LIST OF DISASTER IN THE RIMAC RIVER BASIN (1980 - 1982)

Year	Place	Date	Disaster	Damage					Note
				dead person	injur. person	broken houses	high way	other	
1980	Qda.Rio Seco	Jan.27	Debris flow	1			X		Central Highway
	Qda. Rio Seco	Mar.16	Debris flow					Road blocked	Blocked two days
	Qda. Esperanza	Mar.27	Debris flow					Road blocked	
	TOTAL			1					
1981	Qda.Rio Seco Qda.Esperanza	Feb.12	Debris flow				X 15Km	Tunnel of Railway	
	San Bartolome	Feb.14	---					500 families affected	
	San Bartolome	Feb.15	---				X		Central Highway Blocked
	Cocachacra-Tornamesa San Bartolome Matucana	Feb.15	---					Road and rail-way affected 350 families affected	
	Qda.Esperanza	Feb.21	Debris flow				X		Central Highway Blocked
	Chosica	Feb.26	---				X		-Ditto- (Km 35)
	Qda. Pate	Mar. 4	Debris flow					25 faimilies affected	
	Rio Seco	Mar. 5	Debris flow	2				35 families affected	
	Chosica	Mar.14	---	1			X		Central Highway Blocked (Km 35)
	Qda.Linday	Mar.21	Debris flow				X		-Ditto-
	Qda.Matala	Mar.26	Debris flow				X		-Ditto-
	Chosica	Dec.18	---				X		-Ditto -
	TOTAL			3					
1982	Central High-way Km.100	Nov. 6	Debris flow				X		Central Highway Blocked
	TOTAL								

Data source: "Control de torrentes en la cuenca hidrográfica del Rio Rimac"

TABLE VI-1-8 LIST OF DISASTER IN THE RIMAC RIVER BASIN (1984 - 1986)

Year	Place	Date	Disaster	Damage					Note
				dead person	injur. person	broken houses	high way	other	
1984	Dist. Matucana	Feb.14	Inundation				X		Central Highway Km.68 71.4
	Provi. Lima	Jan.6,7 Feb.4,29	Inundation debris flow				X		Central Highway Lima-Chosica
	Dist. Matucana	Feb.14, 17,22,24	Inundation debris flow			1	X		
	Surroundings of river mouth	Feb.18	Inundation					Naval Base	
	Prov. Lima (Mo-róm-Chaclacayo)	Feb.15	Inundation				X		Central Highway Km.12 23.5
	Surco-Sanjuan -Matucana	Mar.3,10, 23,29	Debris flow Inundation						No information
	Dist. Matucana	Dec. 5	debris flow		4				
	TOTAL			0	4	1			
1985		Feb.23	debris flow inundation slope failure			16	X		Central Highway Km.27 100,000 Intis
	TOTAL			0	0	16			
1986	Huachipa,Moron Santa Clara	Jan.-Feb.	(3) Inundation		10	30		Agriculture 900,000 intis	
	Matucana	Jan.14	Hail	5	15	10			
	TOTAL			5	25	40			
TOTAL	(1984 - 1986)			5	29	57			

Note: Data from CNDC and Other agencies

TABLE VI-2-1 DISASTER IN MARCH 1987

DATE	DESCRIPTIONS
MARCH 2	Debris flow in Qda La Cantuta. Slight damage in the downstream area.
" 6	Flood in Qda Jicamarca. No damage.
" 6-8	Flow in Qda Cashhuacra and Qda Pedregal. No damage.
" 8	Slope failure on the right bank of Sta. Eulalia river. Damages on houses and road in Santa Rosa de Palle Bajo village.
" 9	Flood overflowed from Qda Jicamarca. Inundation in campoy and Zarate districts. Damage on houses, roads, wells and others.
" 9	Debris flow in Qda Quirio, Qda Pedregal, Qda Carosio, Qda Corrales and Qda Cashahuacra located in Chosica district. Serious damage on human life, houses, roads, farm and etc.
" 9	Inundation from the Rimac river in Huachipa. Slight damage.

TABLE VI-2-2 VELOCITY OF ACTUAL DEBRIS FLOW

VELOCITY (m/s)	MEASUREMENT LOCATION	ANNOUNCED BY	REMARKS
0.6 - 3.8	Wrightwood	Morton and Campbell	Mudflow
4.3 - 7.7	Urakawa (Japan)	Matsumoto Sabo	Head of debris flow Max. velocity
4.5	Wrightwood	Sharp and Nobles	Head of debris flow
5.0	Ashiyagawa (Japan)	Endo	Assumed
5.4 - 8.9	Yakedake (Japan)	Matsumoto Sabo	Head of Debris flow. Max. velocity
7.8 - 13.6	Sakurajima (Japan)	Tahara	Head of Debris flow
About 9	Nigorisawa (Japan)	Yamazaki	Assumed from the Passing time
11 - 16	Enterbach	Anlitzky	1/50 - 1/100 in gradient
13	Tokachidake (Japan)	Murano	Average velocity
13.6 - 14.3	Inoyama (Japan)	Takano	by 8 mm film
15 - 16	Tenmile Range	Curry	Mudflow

TABLE VI-2-3 DESCRIPTIONS OF QDA AREA BY TYPE

DESCRIPTIONS	VALLEY TYPE	SLOPE TYPE
	Qda Quirio Qda Pedregal Qda Cashahuacra	Qda Corosio Qda Corrales
Geology	Granite	Granite
Vegetation	Cactus only	Almost no
Catchment area	Big (10 - 15 km^2)	Small (under 2 km^2)
Qda length	Long (5 - 6 km)	Short (1 - 2 km)
Fan scale	Big	Small
Longitudinal slope	Relatively gentle (about 25%)	Steep (about 75%)
Cross section	V-shape valley in the upstream. Flat base valley in the down stream. Erosion channel.	V-shape valley

TABLE VI-2-4 DEPOSIT VOLUME OF DEBRIS FLOW IN EACH QUEBRADA

NAME OF QDA	TYPE	CATHMENT AREA	AVERAGE SLOPE	SLOPE: TRANSPORTATION SECTION	SLOPE: DEPOSIT SECTION	DEPOSIT AREA	DEPOSIT VOLUME	DEPOSIT VOLUME PER 1 KM^2	AVERAGE DIAMETER OF DEPOSITING BOULDERS
		km^2	%	%	%	ha	m^3	m^3	m
Qda Quirio (R-6)	Valley	10.4	23	9-15	5-7	4.1	14,100	1,400	0.5
Qda Pedregal (R-7)	"	10.6	25	9-14	3-11	30.0	157,200	14,800	1.0-2.0
Qda Corosio (R-8)	Slope	0.4	76	45-60	13-26	2.3	4,400	8,800	0.5
Qda Corrales (R-9)	"	1.4	72	22-45	12-18	5.2	21,700	15,500	0.5
Qda Cashahacra	"	15.1	31	9-16	7-9	21.0	102,000	6,800	1.0
Total		37.9	-	-	-	62.6	299,400	7,900	-

TABLE VI-2-5 FEATURES OF DEBRIS DEPOSITS IN EACH QUEBRADA

NAME OF QDA	MAX. WIDTH	DEPOSIT LENGTH	DEPOSIT DEPTH	MAX. DIAMETER	ANGLE OF DISPER-SION	RATIO OF* DISPERSION WIDTH	STARTING POINT OF DEPOSIT	DEPOSIT AREA
	m	m	m	m	°			
Qda Quirio (R-6)	40	300	1.0	1.5	-	5	Outlet of valley (Bending portion)	Fan (Resident area)
Qda Pedregal (R-7)	200	700	2.5	4.5	-	20	Bending/Blocking portion	Flat base valley fan (Resident area)
Qda Corosio (R-8)	15	250	2.0	2.0	-	2	Outlet of valley (Border of resident area)	Fan (Resident area)
Qda Corrales (R-9)	80	150	2.0	2.0	-	8	Border of resident area	"
Qda Cashahuacra (S-1)	200	200	2.5	3.5	100	20	Outlet of erosion channel	River terrace (No land use)

$$\text{* Ratio of despersion width} = \frac{\text{Max. width of deposit area}}{\text{Average valley width in the upstream strech of deposit starting point}}$$

TABLE VI-2-6 DAMAGE OF CHOSICA AREA (QDA QUIRIO, QDA PEDREGAL, QDA CAROSIO AND QDA CORRALES)

DESCRIPTIONS	OFFICIAL REPORT (SE/CNDC)		OTHER REPORT	
	QUANTITY	AMOUNT	QUANTITY	AMOUNT
(A) Human damage				
Dead	38 - 40		19 persons	
Injred	12,414 persons			
(B) House damage	I./1,261,200,000*	I./50,000,000		
Destruction	241 houses		323 houses	
Semi-destruction	181 houses		167 houses	
Washed away	228 houses		487 houses	
(C) Public structure	I./40,000,000	4 schools	I./50,000,000	Market etc.
(D) Water supply facilities		I./120,000,000	7 days stop (30,000 persons)	I./22,700,000
(E) Power supply facilities			Transmission tower, water-way, Stop of Huampani P.S. for 1 month	I./15,000,000
(F) Traffic block structure	Traffic block I./24,000,000 deposit 14,800 m^3		5 km (3 days stop in Caretera Central)	Traffic
(G) Communication facilities			7 days stop	I./800,000
(H) Agriculture	Farm land 0.5 ha			
(I) Affected people	4,500 families (22,500 persons)			

* Including the other areas

TABLE VI-2-7 DAMAGE OF SANTA EULALIA AREA (QDA CASHAHUACRA)

DESCRIPTIONS	OFFICIAL REPORT (CNDC)		OTHER REPORT	
	QUANTITY	AMOUNT	QUANTITY	AMOUNT
(A) Human damage				
Missing	1 person			
(B) House damage				
Destruction	-		4 houses	
Semi-destruction	1 house		3 houses	
Wash-away	29 houses		86 houses	
(C) Power facilities	Power supply Stop (Temporary)			
(D) Traffic facilities	Traffic block			
(F) Agriculture				
Farm land	4.5 ha			
Channel	2 km			
Intake	1 No.			
(G) Affected family	26 families			

TABLE VI-2-8 DAMAGES ON HOUSES IN EACH QUEBRADA

Name of Qda	Totally Number of Destroyed Family	Semi-Destroyed	Washed Away	Total	Number of Family
Qda Quirio	5	64	21	90	108
Qda Pedregal	284	26	394	704	886
Qda Corosio	12	10	52	74	84
Qda Corrales	14	54	12	80	119
Qda Cashahuacra	4	3	86	93	93
Sta Rosa de Palle*	9	29	-	38	38
Others	8	13	10	31	40
Total	336	199	575	1,110	1,368

(Predes Report)

* Slope failure disaster to be described in Sub-section 2.5.2.

TABLE VI-2-9 DAMAGES ON HOUSES IN MAIN DISASTER VILLAGES

Name of Village	Name of Qda	Totally destroyed	Semi-destroyed	Partially destroyed	Total	Total Houses in village
San Antonio	Qda Pedregal	93	19	103	215	665
San Migrel de Pedregal	Qda Pedregal	50	57	62	169	280
Pedregal Bajo	Qda Pedregal	27	46	132	205	257
Rayos de sol	Qda Corrales	6	38	3	48	62

(Source: Municipalidad de Chosica, refer to Fig. VI-2-8 and VI-2-9.)

TABLE VI-3-1 CLASSIFICATION OF DISASTER TYPE

TYPE OF DISASTER	NATURAL PHENOMENA OF DISASTER ENGLISH	NATURAL PHENOMENA OF DISASTER SPANISH (PERU)	PROCESS	LOCATION	SLOPE	DRAINAGE BASIN	MASS MOVE-MENT	KIND OF DISASTER
Landslide	Landslide	Deslizamiento	gravío	slope	(50 ~35°) steep	small	x	Sediment Disaster
	Land Creep							
	Slope failure	Derrumbe						
	Rockfall and Earthfall							
Debris Flow	Debris Flow	Huayco	gravío-	Quebrada	(25 ~ 3°)		x	
	Mud Flow		fluvial	(Valley)				
Inundation	Inundation	Inuncación	fluvial	river	gentle (3°)	big	(x)	Flood Disaster
Earthquake	Earthquake	Sismo	-	-	-	-	-	-

TABLE VI-4-1 DISASTER IN MATUCANA IN 1983

Date	Description	Damage
Feb.22	Huayco occurred from Qda. Paihua	Houses
Feb.23,24	Heavy rainfall in the afternoon on Feb. 23. Huayco happened from Qda. Paihua for three times and checked the main stream of Rimac river. The flood water raised by checked portion eners into the Central area of Matucana.	Highway Town roads Houses Railways and the station.
Feb.28	Huayco occurred from Qda. Chucumayo and washed away the railway bridge near the confluence.	Highway Roads Railway Bridge Houses
Mar. 6 (or 7?)	Huayco occurred from Qda. Paihua Matucana Town was inundated.	?
Apr. 6	No information.	Highway

TABLE VI-4-2 DISASTER IN SAN JUAN IN 1983

Date	Description	Damage
Feb.23	Huayco occurred from Qda. Palcacancha and much sediments flowed down. San Juan was inundated with water and mud. Railway bridge was washed away about 200 m and approximately 120,000 m^3 of earth was piled in this area.	Highway Railway Roads Bridges Houses
Mar. 7	Sediment disaster gave damage on 2 bridge. Detailed conditions are not known.	Highway Bridge 3 people missing
Apr. 8	No information.	Railway

TABLE VI-4-3 DISASTER IN SAN BARTOLOME IN 1983

Date	Description	Damage
Jan.	Huayco occurred in Qda. Rio Seco.	Highway
Feb.22	- ditto -	Highway Railway Bridge
Mar. 2	- ditto -	Highway
Mar.14	Huayco happened in Qda. Rio Seco and checked the main stream of Rimac river. Torna Mesa village area located upstream side was inundated.	Highway Roads Railway Bridge Tunnels Houses Farm land
Apr. 8	No information.	Railway

Table VI-7-1 BUILDING COST PER ESTABLISHMENT

Item	Building Cost (Million Intis)
Residential house	
upper class	1.90
middle class	0.54
lower class	0.10
Market facility	3.60
School	2.25
Government office	3.15
Factory	9.00
Commercial building	3.60

Source: Official data from several government institutions.

Table VI-7-2 DAMAGEABLE VALUE OF INDOOR MOVABLES

Item	Value of Inventory (Million Intis)
Household effect	
upper class	0.55
middle class	0.15
lower class	0.03
Market facility*	0.16
School*	0.25
Government office*	0.35
Factory	1.80
Commercial building*	0.63

Note: Since data are not enough for estimating inventory value of buildings noted by (*), inventory value of them is calculated in such that building cost of them is multiplied with the ratio of stock value to building cost in manufacturing establishment.

Table VI-7-3 AGRO-ECONOMIC INDICATORS

	Tomato		Maize	
	Good harvest	Poor harvest	Good harvest	Poor harvest
Yield (ton/ha)	17	10	4	3
Price (Intis/ton)	3,000	3,000	4,000	4,000
Gross income (I/ha)	51,000	30,000	16,000	12,000
Production cost (I/ha)	20,000	20,000	4,400	4,400
Net income (I/ha)	31,000	10,000	11,600	7,600

Source: Ministry of Agriculture

Table VI-7-4 GRDP OF INDUSTRIAL SECTOR AT 1987 PRICE LEVEL

Unit: Million Intis

Lima + Callao		Junion + Pasco	
Sector		Sector	
Food	13,493.2	Textile	190.0
Drink	10,298.1	Food	329.4
Ferrous metal	1,457.1	Drink	144.1
Furniture	1,760.0	Paper	-
Chemical	17,018.9	Platic	-
Construction	11,780.0	Chemical	-
Mineral	3,300.0	Petroleum Pro.	24.7
		Hotel/ Restaurant	1,160.0

Source: Basic statistics (Ministry of Industry)
National Census of Perue (Input-Output Table)
GRDP Statistics by Department