ANNEX C : GEOLOGY AND HYDROGEOLOGY

ANNEX C GEOLOGY AND HYDROGEOLOGY

TABLE OF CONTENTS

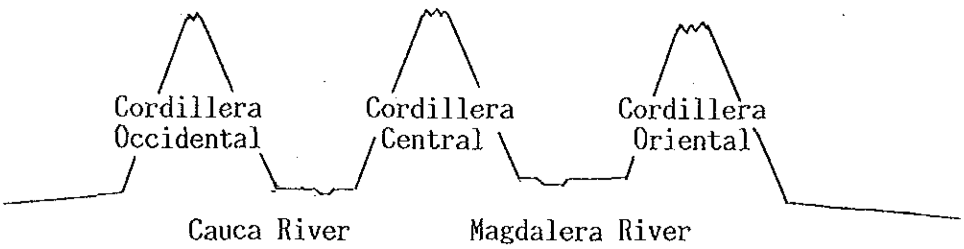
LIST OF TABLES

LIST OF FIGURES

C.1 GENERAL

C.1.1 GEOLOGY OF COLOMBIA

Colombia is located in the northern corner of the South American Continent, extending between Lat.12oN and Lat.4oS. It can be divided into two physiographic blocks: the Llanos area, a lowland (200m above sea level) in the east, and the eastern Andes area, a mountain range extending 1,500km in N-S direction. The Andes Mountains, backbone of the South American continent, are trifurcating in the south of Colombia, so that the eastern Andes area can be subdivided into the following branches:



In the intermontane areas of mountain ranges mentioned above, peneplains lie and are developed particularly in the west and north.

(Note) The three subranges were formed at different times: first the Cordillera Central, in the latest Paleozoic; second the Cordillera Occidental, in the Cretaceous; and third the Cordillera Oriental in the Miocene. Their apparent separation resulted from the interaction among four plates, namely the Cocos, the Caribbean, the Nasca and the South American. Studies on the tectonic development have been advanced recently. The geological structures correspond to the geomophic features classified above, and are outlined in the following:

- Llanos area in the eastern part

Precambrian crystalline schists dominate. Sedimentary rocks in the west are mainly of Paleozoic and Cretaceous age, being thickest in the Sule Andean Trough. The Cretaceous sediments were accumulated with marine transgression. The Tertiary deposits are not marine in origin as shown by the Paleocene coal beds, and their distribution is restricted to the Trough in earlier times.

- Cordillera Oriental area

This area is dominated by crystalline schists of the Giana Shield and metamorphic rocks of the Quetame Series. The host rocks are the same stratea as in the Llanos area. The Devonian to Carboniferous sediments comprise marine beds in the lower portion, and brackish and terrestrial beds in the upper portion. A narrow bay was present over the area from the Caribbean Sea to the south of Bogota during those times. The strata which were deposited in later times are not preserved above the massif but along the margin in general. The terrestrial red sandstone and graywacke are of early Jurassic age. Clastic rocks covering the major portion of the Cordillera Oriental are of Cretaceous age, exceeding 16,000m in thickness in the Cuninamaraca basin.

The Nevado del Cocuy in the eastern half part was generated by the latest upheaval of the Cordillera Oriental. The range is not only dissected with deep tectonic valleys extending in N-S direction, but also suffers active headward erosin of the valleys, which are being buried with talus deposits. Savanna is present in Bogota.

- Cordillera Central area

This area is different in geomorphology and geological structures from the Cordillera Oriental range. Metamorphic and igneous rocks are dominant and the metamorphic grade becomes higher. Phyllite is abundant in the south, while occurrence of mica schist and gneiss becomes frequent toward the north.

The Cajamarca series is composed of the Cambrian-Ordovician sedimentary and igneous rocks and is correlated with the metamorphic rocks of the Quetame series. Metamorphism is assumed to be due to the Caledonian orogeny, but interpretations of Mesozoic metamorphism also exist.

A lot of intrusive and volcanic rocks are seen along the margin of the central range: they were formed under the influence of tectonic movement. A great number of volcanoes, the highest peak of which is the Nevada del Huil (5,750m), are now covered with recent snow.

- Cordillera Occidental area

Paleozoic strata are absent here. The oldest rocks are the Triassic-Jurassic "Group de Dague", which includes a thick layer of phyllite, mica schist, trachyte, siliceous limestone, and basalt. Some of them may be of Cretaceous age. Diabase basalt showing pillow structure exceeds 1,000m in thickness.

- Tertiary basins

There are four sedimentary basins of Tertiary age, as follows:

(1) Sinclinario del Pacifico
(2) Sinclinario del Cauca
(3) Sinclinario del Magdalena
(4) Sinclinario Pre Andio

Marine beds dominated the Tertiary basins, particularly (1) and the northern part of Colombia such as the coastal region of the Caribbean Sea. Terrestrial deposits are thickly developed in the east and south of Colombia. N-S trending subsidence, commencing during the earliest Tertiary, made the grown valleys being buried with gravel and coarse-grained sand in the upper reaches and with fine-grained sand in the lower reaches. Marine beds are sometimes interbedded in the lower reaches.

C.1.2. THE STUDY AREA

Quindio Prefecture is the smallest in Colombia, having an extent of 70km in a N-S direction, and 40km (northern part) or 20km (southern part) in an E-W direction. It is located 180km to the east of the capital Bogota, 180km to the south of Medellin, and 150km to the northnorthwest of Cali.

The prefecture is located at the western foot of the middle of the Cordillera Central range. To the west, Quindio Prefecture borders on the Vieja River, which is one of the tributaries of the Cauca River flowing northward in the middle of the peneplain.

C.2 GEOLOGY AND HYDROGEOLOGY

C.2.1 OUTLINE

Quindio Prefecture can be divided into the eastern and western physiographic blocks. One is a slender montaneous region (western slope of the central range) having extents of approximately 10km in E-W direction and 70km in N-S direction. Along the margin are the Nevado del Quindio (EL 5,150m) and several EL 4,000m-class mountains including the Altoel Espanol, Alto la Guayana, Cuchilla de Campanario, Primo Chili, Cuchilla la Niido, and Paranio la India. These peaks make the borders to Toima Prefecture in the east, and Valle del Cauca Prefecture in the south. Westward the altitude (EL) rapidly decreases to 1,500m (net lowering is 2,500m over a distance of 8 to 15km).

The Cordillera Central, which suffered tectonic upheaval of 4,500m, is characterized by a great number of fault fracture zones. The major structural lines trend parallel to the range axis, and are associated with others in NW-SE direction (intersecting at right angles). Such a conjugate system is frequently seen in the vicinity of Salento, Calarca (Armenia), Cordoba, Pija, Genova, and some sites between Pija and Genova.

The structural lines exerted a great influence on the development of the valleys, which now are V-shaped above 2,500m (EL) and U-shaped below it. Most of the valleys are entrenched to the west or northwest. Some are tentatively directed north and then turned to the west; others are cut to the southsouthwest along the boundary between the mountains and the plain part.

C.2.2 GEOLOGICAL FEATURES

In Qiundio Prefecture the eastern mountains and the western plains are far different in geological features. In the mountains, Paleozoic and Mesozoic basement, penetrated by intrusive and volcanic rocks, are overlain by Miocene sedimentary rocks and Pliocene conglomerates and thick tuff breccia. The overlying Plio-Pleistocene Armenia Formation, 200 to 500m in thickness, partly rests on the basement and is composed mostly of agglomerate, mud-flow deposits and thick lava-flow deposits. The Armenia Formation is partly exposed in the plains because of dislocation by means of the Falla de Romeral (a large reverse fault with a west-side drop). Unconsolidated volcanic ashes of the Formation broadly cover the western plain part (peneplain). Younger igneous rocks are exposed in the north.

The Paleozoic comprises metamorphic rocks such as amphibole schist, chlorite schist, and graphite schist produced through dynamic metamorphism. Basalt, diabase, and pillow lavas are distributed in N-S direction, parallel to the mountain peaks, in the east. The Cretaceous sedimentary rocks consist of chert, slate, shale, and graywacke to the south of Salento. A large block of quartz diorite is seen in those sedimentary rocks to the east of Calarca and near Medellin.

The agglomerate (150 to 200m in thickness) of the Armenia Formation, resting on the basement, lies just below two thirds of the plains and is actually exposed along the Barbas River (the prefecture bounder), the Roble River, and its tributaries flowing from Filandia-Circasia to Montenegro. It is also recorded from wells, the columnar sections of which are described later. Mud-flow deposits and volcanic ash beds, 300 to 100m thick but variable from site to site, cover the irregularly eroded (NE-SW trend) agglomerate. Along the Barbas River, a 30-40m thick volcanic ash layer is exposed above the road at a height of 120m above the river-bed. Here, the agglomerate underlying the ash layer shows the lower boundary below the river-bed, ranging more than 150m in thickness.

The Nevado del Quindio at the northeastern edge is made of Quanternary igneous rocks. Since this volcano is one of the "brothers" of the Nevado del Ruiz, which erupted in 1985 and caused a great disaster, the Nevado del Quindio also might re-erupt in future. The deeper part of this volcanic body mainly consists of quartz graphite schist of the Paleozoic Cajamarca Formation, and makes up the basement in the vicinity of Salento, which is actually observed in the upper reaches of the Quindio River (EL 2,000m) and in the riverside of its tributary Quindio Boquia, where phyllite is exposed.

Above 2,000m altitude, the rivers generally have steep slopes and typical river beds in topography, which have been eroded by flood flow water including mud flow in the flood seasons. In spite of this temporally high transport capacity, the river-bed deposits are poorly preserved at present. This can be attributed to sediment-transportation further downstream. The narrow "violent rivers", with very few terraces and plains within the valleys, give an impetus to the erosion of surrounding mountains.

The Armenia Formation is cut by many faults with little vertical dislocation, except the reverse fault Falla de Romeral, where the basement is in contact with the Tertiary. Between the east and west of the fault, the surface eolian soil is different in material and in formational age (c.12,000 years). The fault probably was active about ten thousand years ago and can be regarded as still active, extending from south of Montenegro through the east of Tabaida, to the eastern part of the junction of the Quindio and the Barrgan River. This must be taken into account when a building is designed or planned in close proximity to the fault.

Structural lines are developed in Pijao and Cordoba to the south, where landslides and slope failures frequently occur due to the weathered basement rocks. Hydrothermal deposits are buried along the Azul River and its vicinity. Serpentinization has promoted the failure of the mountain peaks causing the unstable topography. Some of the large fracture zones are lenticular in shape.

As mentioned above, the fault fracture zones control almost all of the rivers (and valleys). The faults are commonly accompanied by fracture zones of various dimensions, but a width of 10-20m is common in many places. Terraces, made of subrecent river-bed sand and gravels are mainly distributed in the north and south.

A group of ancient large-scale landslides are observed around Genova (father east), and in the southern to eastern areas. The lands of these areas are stable enough to cultivate crops, but may suffer large-scale landslides triggered by earthquakes or heavy rainfalls. The surface landslides cause the occurrence of gullies, which, in turn, results in the former.

No topographic "anomaly" is found in the area investigated except the Roble River and the tributary Q-portachuelo to the north. Rapid reworking of the volcanic ashes led to the peneplain of the area. There may be local dislocations, although the agglomerate exposed in the right and left sides of the river to the north of Montenegro is in the same altitude.

C.2.3 GROUNDWATER

(1) Groundwater Resource

Groundwater was investigated by electric prospecting, in which natural electric potential is measured with two to four electric poles placed on the land surface at arbitrary distances, and in which electric potential and specific resistance are measured in detail with arbitrary electric currents. Based on data obtained, some information on underground geology and groundwater were derived. In the present case, this method was applied, to a depth of 200m, over the broad area of Armenia-Montenegro-Lautebaida-Barcelona, with 13 profiles coded A-B, C-D,..., Y-Z.

The first layer has a specific resistance of 200 to 500 Ohm, consisting of groundwater-free beds such as dried surface soil, volcanic ash, pumice, and scoria.

The second layer, with a specific resistance of 10 to 100 Ohm, comprises groundwater-saturated beds. These are made of either basically the same petrological components as the first layer of thick volcanic ashes rich in clay minerals. Groundwater is unlikely to be drawn up here.

The third layer, having the high value of 200 to 400 Ohm, probably composed mainly of pumice, scoria, lapilli, and volcanic blocks. This layer is an excellent aquifer of groundwater.

The specific resistance of the fourth layer exceeds 500 and sometimes 1,000 Ohm. The main constituents include agglomerate, tuff breccia, and agglutinate, forming something like a basement of low permeability. Some portion comprises loosely-packed pumice and beds mixed with volcanic ashes. There is a possibility of containing groundwater.

The columnar sections obtained from well drilling show a lot of scouring structures in the agglomerate, indicating that the agglomerate (50 to 100m in thickness) consists of superimposed 5-6 layers of about 20m in thickness. As a result of the well-observations, it has been revealed that only 4 or 5 wells are useful to pick a large amount of water.

The data from electric prospecting would be available in research of groundwater resource. Nevertheless, in the present, the data are not always utilized sufficiently to determine the sites of well. This might be due to the locations of wells, namely the well sites are mostly located in and around the private land.

Further investigation is needed in order to promote the development of groundwater. One of the effective methods is to dig a well close to a fault fracture zone as precisely as possible. If electric prospecting is used, the fault fracture zones can be bored efficiently by means of horizontal electric profiling at depth of 5.0m, 10m, 20m, 30m, 50m, and 100m with several profiles over a distance of about 300m.

(2) Recharge of Groundwater and Purification of Filthy Water

The broad, wavelike pasture hills are underlain by several tens of meters thick volcanic ashes, pumice, volcanic sand and lapilli, of the Armenia Formation. The overlying agglomeratic rocks are irregular in morphology and cover the major part of the field, where groundwater is stored in the rocks with a semi-impermeable layer. The field, therefore, has a high infiltration capacity, so that most of the rainfall is stored in the ground. After the groundwater flowed downslope on the top surface of the agglomerate with its geometrical control, it finally discharges into the rivers, by minor springs observed at many places. The groundwater table is usually low and close to the agglomerate, for example 20 to 30m below the land surface, except during the time of continuous rainfall.

The volcanic ash layer has a high effective porosity and a high permeability coefficient, perhaps of a magnitude of 10-3, favorable for groundwater going in and out. It is worth while examining the active utilization of the volcanic ash layer as a storage, with the practical use of the hydraulic mechanism mentioned above. This idea is not uncommon but just a modification of the structure by a kind of "underground dam". Such an equipment is multi-useful to enrich and keep the water for drinking, living, irrigation, and disaster-prevention, especially concerning the management of filthy water from the coffee plantation in Quindio Prefecture. It is, however, still unknown whether the volcanic ash layers of the Armenia Formation are perfectly homogenous and act as a perfect filter or not, how much the permeability coefficient actually is (inferred to be in the order of 10-3cm/sec), and how high the efficiency/cost ratio of such a construction would be. These problems should be further investigated hereafter.

It is recommended to build the equipment tentatively on a small scale as a preliminary investigation, and then to study its effect and concrete problems in C.R.Q. independently. Plans for the construction are as follows:

- Conduit style

  A long and large conduit with a permeable bottom is built in the upper portion of the hills. The water washer of coffee, flowing slowly downward within the conduit, infiltrates into the ground through the bottom surface. Taking a fall of the infiltration capacity into account, sands are preliminarily laid on the bottom and sometimes either stirred or renewed. Another method is to build a pair of conduits and alternately dry and recover their primary coditions. In this case, trenches or large-diameter wells are lowered into both sides of the conduits at a certain distance from the canal works, in order to draw water.

- Small dam style

A dam of 10 - 15m in height is built in a small valley cutting the hills. This dam can be simply made of "rolled soil" which is available inexhaustibly there and used after compressing it, or it may be in a style that excessive water entering through the gateless concrete dam goes out automatically.

As the former type, it will be proposed to construct a fill dam in which the water passes through 0.5 - 2m thick sand filter, at the top of the dam slope. This method must be further examined in various points, having been cancelled once because the proposed dam site was underlain by the Armenia Formation and because of the necessity of a construction to treat the filthy water. No example exists in Japan so far, except an underground dam being built in Okinawa at the time. Such a construction, however, has been investigated for a long time by the Ministry of Agriculture, Forestry and Fisheries, and accordingly can be carried out with the recent technology.

The latter type may be adopted because it is tolerant of overflows during large floods.

C.2.4 MINERAL RESOURCES

Quindio Prefecture is rich in mineral resources of high variety. Except clay minerals and coal, however, the resources are concentrated on the eastern half of the prefecture, where metamorphic rocks and associated intrusive granodiorite dominate. The three major resource provinces are at:

(1) east and southeast of Salento
(2) Cordoba to Pijao
(3) east of Genova.

Oro is abundant in (1), followed by Caliza, Mormol, Plomozine, Plata, and Amtimanio, in the order of decreasing. The provice (2) yields ORO, Sulfurous, Asbestos, Antimonio, Plomo.zine, Plata, and accessory Feedespate, Caliza, and Mormol. Asbestos, Cobre, Arcillas, Hierro-Manganeso, and Calcita are found in (3).

Although a variety of mineral resources are buried in Quindio Prefecture, many mines are not run anymore because mining became uneconomical due to unefficient techniques and therefore too high costs. However, since prospecting, mining, and technology for mineral dressing have been developed rapidly in recent years, the presently dormant mines may be resumed and developed.

C.3 POSSIBILITY OF WATER RESOURCE DEVELOPMENT

C.3.1 GENERAL

Expected dam sites (sites proposed for development of water source) in Quindio Prefecture were surveyed as shown in the difference figures, in order to investigate their suitability for construction independent of dimension and type. It was tentatively supposed that the dam could be in the three classes of H=30, 50, 70 - 80m and be of both types rockfill and gravity.

Most areas in the west part were examined only from the study of the map. This was due to not only the fact that there was no plan to develop water sources in the plain part, but also to the difficulty of buildings a dam exceeding 50m in height where the Armenia Formation underlines (possible for dams ranging from 10 to 20m in height). Building of a H=20 - 30m class dam might be possible without difficulties. In constructing the dam in this area, however, the geological survey has to be carried out in detail.

Because fault fracture zones are abundant in the valleys (river), it must be recognized that the cost for the construction can not be simply calculated by (unit cost) x (supposed capacity of the dam). It is emphasized again that (1) volume of deposit and (2) flood discharge are not changed later. Names and localities of the rivers which were surveyed, and types and possible heights of the dams and/or the headworks are summarized below.

C.3.2 PROPOSED DAM SITES

(1) The Lejos River

In the mountains of the south of Quindio Prefecture multiple structural lines in NE-SE direction and associated oblique faults (conjugate faults) are developed. There also are innumerable fault fracture zones on various scales and intrusive ultra-basic rocks crushing the host rocks. The proposed site for debris barriers along the Lejos River is located at the dissected western foot, of the Cordillera Central, at about 2,000m in altitude. The rivers flow northward, then bend to the west, and finally turn to the southeast to join others, under the structural control. The valleys are wide near Pijao, where the mountains become rounded. Most of the small valley joining the trunk river was caused by ruptural landslides. The Lejos River flows through such a landslide area, having a steep slope and thick deposits of recent age.

Just upstream of the proposed site is a valley originated by a large landslide from the left bank. North of it, the mud flow deposits contain the blocks caused by several times of landsliding and form a small fan by which the trunk stream of the Lejos River is emplaced to the west bank (mountains). The river, in turn, has been eroding the western mountain foot, promoting of the continuous collapse.

The left bank of the dam site, protruding to the right, comprises a steep cliff, along which the river bends. The right bank widens downstream, so that the position to connect the dam is difficult to be determined. The islandlike block, located 120m downstream, was formed by the lateral erosion by the bending or meandering river. The river slope changes around this "island". The hard basement comprises conglomerate of the Kqv-Member with a thin weathered layer.

The right bank is underlain by three meter thick weathered layers. Talus deposits are seen in the right bank, while small and low river terraces are present upstream of the left and right banks of the dam axis.

No fault and no fracture zone have been found during our survey so far. Because water storage is not the main purpose, curtain grouting is not needed in the foundation treatment. Only consolidation or contact groutings are desired.

The river-bed deposits are 5.0m in thickness. The river has a slope of 5 to 10% about the dam axis. A low-H dam would therefore be rapidly buried up with deposits at this site. There is also a drawback of no or poor flood control. Sand and gravel gathering within the storage area is proposed, improving the local conditions in use of this aggregate (sand, gravels, and cobble) for revetment, road repairing, and construction work.

The resources for water supply can be maintained by means of ground water dams in which straner pipes laid underground play a role of collecting-conduit. It is possible to utilize the excessive water for disaster prevention and irrigation.

(2) The Roble River

1) *Northeast of Circacia*

The proposed site for a dam construction is located about 2.0km northeast of Circacia, in the uppermost reaches of the Roble River. The several tens of meters thick volcanic ashes, volcanic sand and lapillo of the Armenia Formaiton cover the agglomerate. The top surface of this agglomerate is undulating and channelized mainly in NE-SW direction. The thick volcanic ashes cover it, forming "wavelike hills".

The agglomerate in a stone pit along the road close to the proposed site contains sandy portions with pebbles, small and large hard breccias, and something like lavas, in irregular mode. The agglomerate, however, is generally homogeneous and hard in the river bed: compositional changes can hardly be detected upstream over a distance of 2.0km. The river has scoured the agglomerate, in dimensions of 10m in width and 3 - 5.0m in depth. A small talus is seen at the margin of that depression. The river-bed deposits consist of few sand and pebbles and much cobbles, boulders, and blocks of 2 - 3.0m in diameter.

In the proposed site the agglomerate is continuously exposed over a distance of 5m, in the river bed and its right and left banks. A joint system in the agglomerate with NE-SW trend shows parallel arrangement of opening joints. The joints caused by the Falla de Armenia when the latent shear planes were profoundly weathered in the river bed.

It is impossible to build a large dam in such a place. Its dimension must be less than 20m, otherwise the bearing capacity and the treatment of the right and left wings would be problematical. (That value of dimension is acceptable in terms of the water required). In such a case, fill dams are adopted generally. In the present case, however, floods in a high-water season are so powerful that silt, sand, and pebbles are hardly seen in the river bed. Besides, the flood discharge is unknown. There is a danger of overflow from the dam which is designed and built in correspondence with the largest flood events during the past one or two decades. It is thus proposed to build a gravity dam, the both wings of which need to be connected deep and long.

The foundation rocks 5 - 10m below the land surface are not so hard and compact. Therefore, it must be taken into account to construct with mat concrete of 2 - 3m in thickness. Temperature is difficult to be managed during the time of concrete placing, because of the hot country. We have to care much about cooling.)

Conclusively, it is possible to build a small dam, if sufficient investigations are made hereafter.

2) West of Circacia

The proposed site for dam construction is located to the west of Circacia, at 4.5km from the Robel River toward Quinibaya. The site is selected on the basis of topography and geology, although it must be examined in more detail. Material and dimension of the dam (volume of water storage) is no determined yet.

A dam of H=50m could be built with the axis normal to the river a little upstream of the road. However, geometry of the left and right banks do not favour such a construction. Overhanding cliff consisting of hard and compact andesitic lavas would have to be modified. It is furthermore possible that the Falla de Romeral (famous actie fault) is running about this river bed. We therefore hesitate to forward this plan actively.

Unless a high-capacity dam is really needed in this area, we will not further any detailed investigations. The dam may easily be built at an alternative site, about 500m upstream, where the valley is narrow (V-shaped) and both river banks are stable, independent of a possible fault running along the river bed.

The construction of a driving channel connected with another drainage system comprising a dam should also be examined.

(3) Upper Reaches of the Quindio River

North of Salento and northeast of the Quindio River, the basement consists of metamorphic rocks and is overlain by a thick layer of volcanic ashes, volcanic mud-flow deposits and lavas erupted from the Quaternary volcano Nevado del Quindio. The Armenia Formation, composed of lavas, agglomerate, volcanic mud-flow deposits and ashes, is irregularly distributed on the eroded basement. The basement in the rihgt bank of the Quindio River, 2,000m above sea level, is made of weathered, greenish grey phyllite, showing fissures and joints so abundantly that the rock can easily be broken by hammer. Except this site, the metamorphic rocks are not exposed below 3,000m altitude.

An outcrop of hard and compact amphibole schists is found in the river bed of the Quebrada Bouquiea (one of the tributary of the Quindio River), northwest of Salento. The Armenia Formation at about 2,500m in altitude is rich in fine-grained volcanic deposits and mud-flows deposits, whereas, at 2,000m altitude, andesitic lavas are present and in some cases make up steep cliffs up to 100m in height. With a decrease in altitude from

1,900 to 1,800m, the lavas change into the agglomerate. Those rocks comprise only one of the right and left banks, not both, where the valley is 300 to 500m wide. Also in the river bed is no agglomerate, while blocks of 2.0 to 4.0m in diameter cover the bed. That is, no convenient dam site is present here.

It is possible, however, to build a low and long dam. Because of the broad river-land compared with other rivers, the dam can have a high storage efficiency relative to the height. As a precaution against disasters related to possible eruptions of Nevado del Quindio, the constructin of three dams in the upper reaches of the Quindio River will ensure safety for cities and equipments downstream, although high costs have to be taken into account.

The first dam in barrier style is built at about 2,200m altitude, working as a guide wall to stop or weaken volcanic mud flows. The flows would be guided to the broad river-land (pasture at present) and promoted to deposit volcanic material such as lapilli. The dam is best placed obliquely to the river flowing westward. The dam height should be 15m, for the sake of convenience in construction.

The second disaster prevention dam in usual style is built at about 2,000m altitude where the left and right banks are made of andesitic lavas and phyllite (upstream), respectively. The river-bed sand and gravels are about 5m in thickness. The foundation excavation has to be lowered to the base of the terrace deposits in the right bank. The type of dam must be gateless and overtopping "gravity", because the volume and energy of mud flow coming over the first dam is unknown.

The third dam is built at either 1,800 or 1,700m altitude, having a height of 50m. In the former case, the dam wing can be connected with hard lavas in the right bank. The left bank also has a sufficient foundation strength, although the position of the dam axis is difficult to be determined because of inconvenient topographic conditions. The dam body is made of concrete and may be able to be combined with a counter dam of rockfill type. The spill way must be gateless and as wide as possible. In the latter case (1,700m in altitude), the dam wing can be connected with fresh agglomeratic foundation in the right bank. Much treatment of the foundation is necessary, because of the unfavorable topography and the minor landslides in the rock mass. It is possible to build a small-scale counter dam here, although minor terrace deposits are present in the right bank. If the thickness of the river-bed deposits is 10m or more, we have to take care of dam type and foundation treatment.

(4) The Navarco River

The dam site is located at the junction of the Navarco and the Boqueron Rivers, 3km upstream of the junction with the Quindio River. Two rock-fill dams with similar geological conditions are being planned. One, 40m high, is built in the Navarco River, while the other has a height of 50m and is just downstream of the junction.

The left bank consists of the hard and compact basement made of alternating beds of conglomerate and basalt (Kqs-Member) with few fissures and joints. Some deep depressions of the left bank in the upstream were not related to faults and/or fracture zones but caused by river action. The right bank is underlain by phyllite of the Kqv-Member which has suffered superficially weathering to a depth of only 3m. Soil bearing power of the both banks is thus enough to construct the dams. The top parts of the right and left banks are covered with a thin layer of volcanic ashes of the Armenia Formation.

Many rivers in Quindio Prefecture are related to large-scale fault fracture zones. In fact, there is a 15 - 20m wide fault fracture zone 1km upstream of the dam site in the Navarco River. The existing data indicate that a few faults cross the river bed. The river-bed deposits, 3 to 5m thick, can be left except in the core sill.

Consequently it is not difficult to build the dam in the proposed site, although the following must be taken into account.

- The Navarco River passes through structural valleys. It must be revealed whether fault fracture zones are present here or not, and if any, what dimensions they have.

- Topography and geology of the right and left banks present some characters of mass movements. Because soft volcanic ashes and others of the Armenia Formation favors the occurrence of landslides, the rate of deposit is estimated to be at least 1,000m3/km2/y. It is therefore needed to take measures to meet active surface erosion. Construction- and surrounding -roads to be connected with the dams are proposed to be built at the level of more than 5m above the maximum water level.

- The boundary between the Kqs- and Kqv-Members has not been detected. Their fault contact would be an important key to foundation treatment.

- There are small terraces and dissecting small valleys outside the dam sill.

- The thickness and distribution of the present river-bed deposits have to be revealed in detail, based on a variety of geological investigations (survey, electric prospecting, boring, etc.). Those data are important for not only the lower portion of the random but also the treatment of temporary shutter part.

- Material for the dam construction has to be sufficiently investigated and tested. Most of the random material can be given from the upstream and downstream of the Navarco River, while insufficient investigation took place for the water stop. The dam slope may be gentler (i.e. the dam may be larger) than planned now, depending on results of the material test. In such a case, the slope end reaches the junction with the Boqueron River, and thus repair work of the river and maintenance (conservation) work of the dam slope should be carried out.

- A bypass is built along the left bank. The road building in early time would give us a good opportunity for geological survey of the ground mass in the left bank.

In the case of the second dam, the left bank is made up of 30 - 40m thick basalt. It is unknown whether the left wind entirely rests on the basalt, although very important for the associated spillway. A few faults and fracture zones, the dimensions of which are unclear, obliquely cross the dam axis. The position to connect with the right bank depends on geological conditions.

Because the slopes of fill dams generally need to be 2.5 times as long as the dam height, the temporary shutter is difficult to be placed in the Navarco and the Boqueron Rivers. As a measure to meet this, it is proposed to set 10m high water-stop walls of concrete in the two rivers and to use them as a temporary shutter and guide wall to lead water into the bypass. If the foundation for the water-stop walls is located within a fault fracture zone, the foundation treatment will be partial "dental work". The dam axis may depend on the water-stop walls. The entrance of the bypass is determined with the positions of the water-stop walls and temporary shutter.

Soil to make the core is given from a profoundly weathered zone in the upper portion of the ground mass in the left bank. It is unwise to lower the dam axis too much, because of the difficulty in placing the dam and enlarging of the apillway and bypass. Excavation of the ground mass would be increased, because the spillway should be placed on the left bank. In this case, however, excavated soil can be used in another construction, leaving no problem of cost. It is rather important to determine the flood discharge in terms of cost.

The present river-bed deposits can be used as fill-material, except boulders.

(5) The Santo Domingo River

The Quebrade-Grande Formation, to the southeast of Calarca, includes the volcanic Kqv-Member (basalt, diorite, and pillow lavas) and the Kgs-Member (chert, shale, and graywacke). The site proposed for dam construction is underlain by the basalt in the Kqv-Member, which shows stratification dipping 20o west and abundant joints and cracks. The several meters thick weathered surface layer rests on the hard and compact basalt. The basalt, however, is disturbed by a fault and associated fracture zone in the north (upstream). The generally narrow valley has a width of 130 - 150m near the mountain trail 45m above the river bed. Further upstream, the topography becomes more convenient for the construction of a dam with H=20m and L=30 - 35m, for example. A minor landslide, however, is seen in the upper part of the right bank, which would enter into the groundwater area in the case of a high-H dam. Processing works in the upper bank (excavation, anchoring, wall retaining) associated with the excavation of additional roads and dam-sill will be needed.

The left bank which is underlain by a thick weathered layer has a very gentle slope compared with the right bank. The dam body has to be significantly longer as it becomes higher. In the river-bed, fresh basement rocks are continuously exposed which show few joints and cracks.

The hard basaltic rocks are also exposed further upstream where a waterfall of 70m height descends in the right bank. The river-bed deposits are about 1.0m thick. In the left bank are minor terraces consisting of 2 - 5.0m thick beds. Upstream of the site, an equipment to draw water (now the drawing part is being modified) has been set in Calarca. This vicinity is underlain by the basaltic basement fresh enough to construct a dam with no geological problem. Because no useful road exists at time, considerbale work has to be taken into account for provisional road building.

Consequently, there are several sites possible to construct a dam to the southeast of Calarca. Both dam types, arch and gravity-arch, can be adopted in terms of valley topography, although the latter is preferable because of the high durability against earthquakes and the simple construction. Dam material is not investigated yet.

(6) The Gris River

1) Proposed Site of High Dam

The proposed site for a dam construction is located 2.0km upstream of the town Genova, where the river has a steep slope. This location is conceptually based on the presumption that the dams are of H=40 - 50m. Other sites may be chosen if the dam is not restricted in height and water reservation, other sites may be chosen.

The left bank is widely dissected to form a gentle slope, with a 10m-tall cliff on the river bed. The right bank consists of a 100m-high steep slope, well continuous upstream and downstream. Because the left is flat 40m above the river bed, the dam height is innevitably restricted to 40 - 50m. In this case the length of the dam body will be 120 - 140m. If a counter dam of 10m in height is built on the left bank, the main dam can be heightened as much. The length of the counter-dam body will be 100m.

Both the left and right parts of the river bed are made up of hard and compact amphibolite, with a thin weathered zone and few joints and cracks. The few small faults observed are not problematical for the foundation of a dam of 50m or so in height.

The upper portion of the left bank is underlain by a 4 - 5m thick weathered layer. Faults obliquely cross the river, above and below the flat portion. They are arranged at an interval of about 200m. The dam still should be within this flat area, if possible. The river-bed deposits comprise large blocks and coarse gravel beds, ranging up to at least 4m in thickness. The rocks exposed in the 20 - 30m wide river-bed was partly scoured out deeply, which must be taken into account in further investigations. In parts of the right bank Recent deposits form a minor terrace of several meters in height. It is not judged yet whether these terrace deposits can be located within a fill dam except its coare sill.

The site is generally underlain by weathered and faulted crystalline schists of high-grade metamorphism with fracture zones. Because of large-scale landslides and slope failures, the rocks, blocks and other land materials are strongly eroded here. It is therefore important to examine the volume of deposits, the value of which is estimated to be 1000m3/y or more. The temporary works for dam construction are easy with respect to construction, because an approach road can soon be built from the road at the left of the river. The road to the river bed better extends from the vicinity of the houses in the upper reaches.

The axis of dam is oblique to the present river at an angle of about 20o, which can be reduced if the height of the dam is decreased. In the case of a fill dam, the left bank is preferable for the spillway. It has to be determined whether 350m3/sec or 500m3/sec should be adopted as a design flood discharge. The value should be considered independent of the type of side-gitter. It must be clarified whether the spillway rests on the inferred faults and fracture zones or not.

2) Proposed Site of Small Dam

Another good site for dam construction is located 1.5km upstream of the town Genova, where the valley is narrow. At this site, close to the one described above, the crystalline schists are partly covered with a weathered layer of 2 - 5m thickness. A dam which has a height of less than 20 is easily constricted there. However, there is a possibility that the flood control funciton does not work in the small dam. Deposition will rapidly progress in the dam because of the steep river slope.

The weathered layer is this in the left bank, while thick in the right bank. Although the left bank offers no topographical problems, the dam wil be restricted in its approach position because of the thin natural ground that juts out in the right bank. A thrust block may have to be set up.

C.3.3 PROPOSED HEADWORKS SITES

The proposed site is located about 3.0km upstream of the bridge (Puente)thrown over the Quindio River south of Armenia City. The site is also about 100m upstream of the small head works where water is drawn at present. From this Puente upstream the valley is narrow and shows agglomerate and lava flow deposits of the Armenia Formation along the left bank. The N-S striking fault plane of the Falla de Armenia is seen in the cliff, nearly along the river.

Based on the existing data, the fault is bifurcated northward from the Puente: one passing through the center of the City and the other extending to the northnortheast, passing east of the city. The very steeply dipping fault has cut the Armenia Formation and the basement Pzr (Complejo Posario-Anfibolitas, en partes granatiferas, y esquistos confibolicos). Thus, it is an active fault.

The right bank of the head works is dominated by volcanic ashes and mud flow deposits, which overly hard agglomerate containing a lot of breccias. The Armenia Formation has been sheared along the boundary between the softer and the harder parts. The agglomeratic rocks were not found at the proposed site for construction because of the absence of outcrops, but are exposed in the right bank downstream (EL ca.1,350m). Just below the river-bed soft volcanic deposits of sand and gravels (Armenia Formation) are found. Because it is unknown at present how thick the river-bed deposits are, two types of design are considered for the structures in headworks : the floating type and the fixed type with water stop. The latter is superior to the former in terms of stability of the dam body.

In the present head works, perhaps in the second stage, piping is used downstream of the dam and has the apron short relative to the water depth. The guide wall in the central part of the river has been overturned due to insufficient mixing of the concrete and subsequent erosion in the river bed. In any case, further detailed survey, electric prospecting, seismic prospecting, and boring are needed, if the construction is seriously considered. If plans were made for building a small dam in the vicinity of this head works downstream of Puente, sufficient investigation in order to select the best site is necessary in a section 3.0km long. It is possible that a 20m-high dam can easily be built. In this case, attention must be paid to water stop and structure and dimensions of the spillway. The types of dam, including gravity, RCD, and fill, should be evaluated, considering their special characters.

C.4 EARTHQUAKES AND ACTIVE FAULTS

C.4.1 EARTHQUAKES

(1) Mechanism

Earthquakes occur together with rapid destruction of rocks in the deep, which are destructed or dislocated along a gigantic fault. The fault may move repeatedly every hundreds or thousand years. An earthquake is propagated in all directions, as a shock wave shaking the ground. The point where the rock destruction occurred at first is the hypocenter, perpendicularly above which the epicenter is located in the land surface. The whole area of the rock destruction is called hypocentral region. Magnitude (M) is the index for the dimension/energy of earthquakes.

The occurrence mechanism of earthquakes is explained by plate tectonics, which has broadly been accepted in the field of earth sciences. This theory was derived from the sea-floor spreading hypothesis. Multiple plates comprise the lithosphere (70 to 80km thick) of the earth surface zone. Oceanic ridges, rift-transform faults, and trenches are situated along the plate boundaries. Plates removed horizontally on the underlying asthenosphere of lower viscosity. They are produced in the oceanic ridges where magma comes up and subducted into the asthenosphere along the trenches. Relative motion of each plate results in a variety of crustal movements such as orogeny. Earthquakes are therefore the phenomenon that a gigantic strain accumulated in plates is rapidly released when faults occur or move. Rocks are destructed with a strain exceeding ca.1/10,000.

Faults of pre-Quaternary age are generally regarded to make no action in future, distinguished from active faults, which moved within Quaternary time (past two million years). Definition of the active faults, however, depends on the fields of science and technology. In engineering technology, for example, the term is limited to those that moved within the last several ten thousand years.

The Cocos, Nasca, Carribean, and South American plates have pushed one another in E-W direction during Quaternary time, causing active fault action and thus earthquakes. Their interaction caused a westside-drop reverse fault, along which the eastern side relatively moved southward. Through repetition of such movement, the fault has evoluted to the recent Falla de Romeral, which extends through Montenegro for a distance of several hundreds meters and moved 12,000 to 15,000 years ago.

The total dislocation during Quaternary time exceeds 100m, as known from existing geological maps. The Tertiary (Ka) borders on the Paleozoic (P2b) with this fault, by which the Armenia Formation is cut.

(2) Damage

Four or five earthquakes of M 7-8 class did directly damage to Quindio Prefecture, where buildings are underlain by the Armenia Formation, except in the eastern mountains. The rivers flow in NE-SW direction over the area where the Formation is distributed. In the upper reaches are shallow valleys and "wavy hills". Because the water table is high in the valley bottom parts, the buildings and small houses constructed there were damaged particularly. According to the existing data, the actual damage was mainly limited to houses made of "bricks laid without reinforcement".

In Niigata Prefecture of Japan the great earthquake occurred in July 16th, 1964, destroying the buildings that rested on lowland marshes, bars, and cray beds. Sandy lands (ancient and recent sand dunes) suffered little damage. Such local differentiation depends on not only the basement composition but also the water-table level.

Recently earthquakes have not done great damage to buildings in the earthquake country Japan, except small fill dams which were constructed on the weak foundation and broken during the Tokachi-oki Earthquake. In Japan, seismic constants and conservational equipments corresponding to M 7-8 class earthquakes have been used.

Four dams, one head works, and other canal works are being investigated and/or planned in Quindio Prefecture. It is needed to provide against M 7-8 class earthquakes, according to the existing data. Potential damage by forth-coming earthquakes can be lessened, if the seismic constants and ideas used commonly in Japan are adopted.

C.4.2 ACTIVE FAULTS

(1) Outline

A <u>fault</u> is the plane boundary along which the both sides of the rock moved relatively, or the shear failure plane caused by crustal stress. When the rocks are dislocated with a fault, an earthquake occurs. Faults that moved or occurred within Quanternary time (past 2 million years) are called "active faults". However, those having a period of several ten thousand years, far longer than the span of human life and buildings, are not so important in practice. Active faults, therefore, are sometimes limited to those that moved within the last fifty or ten thousand years.

In the field of earthquake prediction, active faults are classified into "fault associated with earthquake" and "earthquake faulting". In the case of the former, the following relationship among the magnitude (M) of an earthquake, the length (L km) of the fault, and the dislocation (D m) is usually used:

$$\log L = 0.6M - 2.9$$
$$\log D = 0.6M - 4.0$$

3
Faults always accompany the earthquake when M 7.4, and never occur when M27.0. 60% of earthquakes are accompanied by with faults, if 7ZMZ7.4. The building which were designed and constructed during the past several ten years by means of the seismic coefficient method have not been damaged even when major earthquakes occured. In Japan buildings are constructed in consideration of large earthquake vibration compared to other countries, maintaining their safety.

(2) Investigation

Active faults are commonly investigated, based on the flow chart (to see Figure), showing the guideline to test earthquake proof designs.

Age of fault action is determined with the following methods:

- Overlying strata method
- Displacement topography method
- Direct fission track method
- Analysis of surface structure of quartz grains
- Illite K-Ar method
- ESR dating method

Age of fault action can also be determined from morphology of the faults.

- Decipherment of fault topography
- Geological observation of fault plane
- Analysis of internal texture
- Analysis based on maturity
- Analysis based on measurements of ground pressure

A flow chart for the investigation of fault activity is shown in the next page.

Public structures are designed and constructed after the informations mentioned above are examined sufficiently. In fact, no earthquake and fault has done damage to the structures in Japan. Although the Donto dam (H=758m, gravity type) and the Zao dam (H=67.5m, fill type) were troubled with the problem of active faults, the long-term and high-cost investigation, in which the author engaged himself, led to the solution of it.

Faults and associated fracture zones are developed in Quindio Prefecture, with every river drains structural valleys. Most of the faults are active, including the Romeral and Armenia faults which cut the Armenia Formation. However, dam constructions can be carried out, if fault investigations are based on the methods mentioned above and the sufficient basic data.

C.5 MASS MOVEMENTS AND VOLCANIC MUD FLOW

C.5.1 MASS MOVEMENTS IN MOUNTAINS

(1) Mode of Mass Movements

Mass movements in mountains are various in mode. A single collapse of 30x104 m3 of earth and sand may occur as a slow landslide. In another case, a disintegrated mass flows (falls) downslope rapidly and involves recent sediments (earth nad sand) and weathered rocks on the way, grading into a mud flow. Furthermore, a mass movement of several hundred m3 in volume can occur in a small area. The collapse which recently occurred northeast of Medellin, Colombia, in a typical example of a gigantic mud flow resulting from a long-term rainfall in the mountains made of deeply weathered granodiorite.

The mode of mass movements is in close relation to the factors controlling its occurrence. Landslides or collapses on a gigantic scale and surface erosion are often seen in the southern mountains of Quindio Prefecture. Factors and research methods important for the investigation on maintenance of cultivated areas and for the establishment of countermeasure, as described below.

(2) General Factors of Superficial Mass Movements

The factors can be classified into the primary causes such as topography, geology, soil material, and vegetation, and the inducements such as rainfall and earthquakes.

Where a granite zone receives heavy rainfall, superficial mass movements can occur in the surface soil layer weathered from the basement. In this case geological conditions of the basement rocks do not play an important role, but groundwater capacity may have some impact. Superficial mass movements are related to the four factors: topography, geology, vegetation, and rainfall. When a slip plane in superficial mass movements have a length and a width proportinal to the depth, stability analysis of indefinitely long slope is often applied.

In Qiundio Prefecture the width and height have the highest sensitivity among the variables, followed by the Cs, h, ϕ, and Cr. This means that shear strength (ϕ and Cs) is not so important as thickness and slope of the surface soil layer. When the slope stability is discussed, these factors should be exactly understood, otherwise the statements are poorly reliable. The groundwater derived from the basement rocks is an important factor controlling h.

(3) Research on Slope and Thickness of Superficial Soil Layer

Measurements of the thickness of surface soil lay·rs includes boring, sounding, geophysical prospecting, and well logging. Sounding is the most simple and most certain method, if the layer is 1 - 2m thick.

(4) Actual Cases of Mass Movement Caused by Earthquakes

Gigantic landslides and collapses caused by earthquakes have been recorded also in Japan. Some of them can be detected based on their topographical features. For example, fifteen earthquakes ranging from 5.7 to 7.9 in magnitude (M) occurred from February 1961 (Hyuganada Earthquake, M 7.0) to September 1984 (west Nagano Prefecture Earthquake), associated with washout disasters. The Kanto Daishinsai (=great disaster), triggered by the M 7.9 earthquake, occurred in 1923 and caused innumerable mass-movement events in the Tanzawa-Hakone area. A mud flow of 1-3x106 m3 occurred in the upper reaches of the Nebukawa River and reached the Nebukawa village five minutes after the occurrence of the earthquake. Thereby, 64 houses wer buried and 406 people died. Since the mass movements associated with earthquakes on Izu Peninsula in 1974 and 1978 did so remarkable damage to people and buildings, mass movement has become an object of public concern.

Movements occur abandantly in the vicinity of ridge lines because of the seismic shock being vigorous upslope. In the large slope failure of Mt. Ontakesan, Nagano Prefecture (1984), two stages were recognized in the occurrence process. First, pore pressure was enhanced enough to disintegrate the rocks of the lower slope, due to 150mm of rainfall within five days. In the second stage the upper portion collapsed because of the argillization of a pumice layer, which acted as a slip plane.

(5) Damage in the Constructions to Prevent Mass Movements

The earthquakes in the Izu Peninsula did damage to the constructions to prevent mass movements, as follows:

- High-grade constructions to prevent the failure of slope suffered little damage.

- Concrete placing, mortar placing, nets and fences were not effective enough to prevent rock falls.

- The both sides of the water course were broken by seismic shock, because of insufficient canal works.

- The following constructions were not or insignificantly damaged by the earthquakes:

  (a) retaining walls which were designed to be tolerant of soil pressure,
  (b) those slope-toe framework with concrete placing to stable natural ground, which had some deterrent effect,
  (c) flexible buildings, which could absorb the energy of earthquakes, e.g. retaining walls of the well girders.

(6) Examination of Slope Stability in Earthquakes

The stability of natural slopes is controlled by the inducement (earthquake power) and the primary factors (topography, geology, soil). Seismic reply analysis must take place after sufficient investigation of the primary factors. The items to be examined are as follows:

- Relationship between areas where mass movements frequently occur with rainfall and those where they are induced by earthquakes. Generally the slopes having low resistance to rainfall are likely to be damaged by earthquakes.

- The stability of steep slopes, particularly where they overhang.

- The stability of slopes containing pumice and/or boulders.

- Whether the banked soil above a slope is likely to be disintegrated.

- Whether surface and highly-weathered layers resting on the basement are likely to be disintegrated along the boundary with the basement.

- Whether the head part of a collapse corresponds to the side slope of a mountain where infiltrating water gushes out.

(7) Conclusion

The present situation of mass movements must be further researched everywhere of Quindio Prefecture, and the countermeasures must be taken. The floods may be cut by a dam. Several kilometers upstream of Pijao, a dam should be constructed. Another major landslide area in the mountains is the interior of Genova in the south. Although the countermeasures are not sufficiently, the slopes are stable so far. The preventional effect will be enlarged by means of afforestation, arrangements of plantation concordant with contours and drainage works.

C.5.2 VOLCANIC MUD FLOW

"If Nevado del Quindio is to erupt, such as Nevado del Ruiz did in 1985, and if an enormous amount of mud flow is to attack Quindio Prefecture,..." This is not an imaginary fear but may occur with a certain probability, because Nevado del Qindio is the series of volcanoes including Nevado del Ruiz. In order to prevent the disaster which occurred in the city Armero, various measures should be taken to meet the situation. It is natural that people in Armenia place emphasis on the necessity of investigations for fear of a possible disaster.

Reliable studies on volcanic mud flows in the Nevado del Ruiz were made in the past by Colombian workers. Some administrative problems, however, made the countermeasures delayed and thus led to the disaster. Any plans for the investigation to take measures in a simple and low-cost way are given below:

1. To observe the present conditions of Nevado del Quindio by use of aerial photographs (better with Landsat images). --The photo are taken periodically as often as possible, for example, twice per year, once per year, or once per three years; the photographic series are compared with each other.

2. To draw a map in a scale of 1/5,000 to 1/1,000 on the basis of the aerial photos. This extent covers the portion upper than eighth station in Nevado del Quindio and the whole reaches of the Quindio River, at least the Salento area.

3. To examine the following in detail on the basis of (1) and (2):

   (1) whether there is a sign of eruptive action of the volcano,
   (2) whether erosion and formation of gullies can be observed and how they progress if existing,
   (3) depositional situations, sliding, and dimensional changes of the glaciers,
   (4) geometry and volume of the glacial basement.

4. To make a model to explain the drawn geological map, the rock hardness and the thickness and volume of the volcanic ashes, along the valley from the source area of the Quindio River to

the upper reaches of Salento. The model can be presented as a drawing, a miniature, or computer simulation. (Note: Prof. Takahashi, Disaster Prevention Research Institute of Kyoto University, Japan, made the simulation for Nevado del Ruiz.)

5. To examine the occurrence, dimensions, flow velocity, energy, etc., of the mud flow resulting from melting of the glaciers, by the repeated simulation with an assumption that an eruption on the same scale as in Nevado del Ruiz occurred.

6. To examine how those mud flows can be absorbed in the upper reaches of the Quindio River having a broad area of river bed, based on the above.

   In order to enhance the effect of absorption, it is proposed to build a few barrier dams. Two types for countermeasures are considered as follows:

1) To build one or two barrier dams (concrete) of H=10 - 20m, with no storage of water, or to build a pure barrier (guide) at an angle of 45o to the river to lead the mud flows to the wider portion of the valley.

2) To build a resevor dam (made of concrete) which has H=30 - 50m and stores water to the height of 1/2H to 1/3H. The storage always plays a role of water supply, and its upper half or two thirds parts exhibit an effect of stopping the volcanic mud flows when they occur. Energy of possible mud flows will be dispersed by the dam, the stored water acting as a cushion and brake. The upper two thirds may have holes for some water to escape. Such a water-supply dam will be put into practical use:

   (1) irrigation
   (2) service water
   (3) water-power generation on small scale
   (4) sightseeing.

   It is important to clarify how many years the dams should be effective. That value can be estimated from the occurrence period of the ancient volcanic mud flows which are known from the dating of the plant remains in the Armenia Formation by means of C-14 method.

Note: Nevado Del Ruiz

With respect to the N.D.Ruiz, in the INGEOMINAS predictional map of eruption disasters well coincides with what occurred actually.

The eruptions were generally explosive, associated with pumice fall deposits, volcanic ashes, pyroclastic flows, and rarely, lavas. The C-14 measurements indicate that the major eruptions occurred 18 times in the time interval from the prehistoric age (ten thousand years ago) to about 600 years ago (one eruption/500 years), and also occurred about 500 and 140 years ago (700 - 1,000 people died).

Nevado del Ruiz resumed its action in September 1985, after an interval of 140 years, and explosively erupted, with induced mud flows (lahar). These did great damage to the city of Armero in the eastern foot and many other areas (24,740 dead, 5,485 wounded, and 5,680 houses destroyed: the fourth largest in the history of major eruptive disasters). The appendix figure was partly modified from the predictional, after the disaster. The actual extent of the mud flow disaster are compared with the predictional simulation below, by Profs. Takahashi and Nakagawa, Kyoto University (two figures, left and right).

TABLE C.1 DEPOSITOS MINERALES DEL DPTO DE QUINDIO

por Darío Mosquera T. y Carlos Buitrago R.

1	Mina LA MORENA . Oro , galena , pirita .	X : 995.700	Y : 836.640
2	Mina abandonada TORRA . Oro , calcopirita , pirita .	X : 975.500	Y : 817.580
3	Mina abandonada LA MARIA . Piritas auríferas .	X : 1.000.610	Y : 836.640
4	Mina abandonada LA CONCHA . Piritas auríferas .	X : 975.800	Y : 822.000
5	Mina abandonada SAN PACHO . Piritas auríferas .	X : 1.007.040	Y : 838.000
6	Mina abandonada CAMPOALEGRE . Cuarzo aurífero .	X : 1.000.840	Y : 840.030
7	Mina abandonada CUBA . Piritas auríferas .	X : 995.840	Y : 837.340
8	Mina abandonada EL CONDOR . Oro , galena , pirita .	X : 995.530	Y : 837.830
9	Mina abandonada EL EDEN . Piritas auríferas .	X : 995.610	Y : 838.500
10	Mina abandonada MORAVIA . Piritas auríferas .	X : 998.290	Y : 837.540
11	Mina abandonada SANTA ISABEL . Piritas auríferas .	X : 1.001.840	Y : 844.580
12	Mina abandonada SAN CARLOS . Piritas auríferas .	X : 1.005.820	Y : 847.050
13	Mina abandonada M. vda. de RESTREPO . Piritas auríferas .	X : 977.430	Y : 818.310
14	Mina abandonada EL CHUZCO . Piritas auríferas .	X : 1.001.350	Y : 845.000
15	Mina abandonada LA MARINA . Piritas auríferas .	X : 1.003.390	Y : 846.950
16	Mina abandonada LA CALABACERA . Piritas auríferas .	X : 1.000.070	Y : 844.830
17	Mina abandonada EL CISNE . Oro , galena .	X : 1.001.250	Y : 838.000
18	Mina abandonada COLOMBIA . Oro libre .	X : 990.960	Y : 836.570
19	Mina abandonada ZENO MONTOYA . Oro	X : 1.002.070	Y : 831.970
20	Mina abandonada MINA BONITA . Oro	X : 1.001.170	Y : 833.900
21	Mina abandonada LOS ARANGO . Oro	X : 1.000.950	Y : 834.000
22	Mina abandonada MINA TAPADA . Oro	X : 1.000.700	Y : 834.020
23	Mina LAS NIEBLAS . Galena argentífera .	X : 1.000.880	Y : 843.540
24	Prospecto LA ESPERANZA . Galena argentífera .	X : 998.940	Y : 842.990
25	Mina abandonada LA SIERRA . Estibina , cuarzo .	X : 1.000.470	Y : 838.170
26	Prospecto BARCELONA . Estibina , galena , pirita .	X : 979.700	Y : 817.040
27	Prospecto LAS BRISAS . Calcopirita , galena , pirita .	X : 958.560	Y : 816.170
28	Prospecto EL CAIRO . Calcopirita , pirita .	X : 951.800	Y : 817.000
29	Prospecto LA MORENA Pirita .	X : 974.600	Y : 821.500
30	Prospecto DMT 5238 . Pirita .	X : 971.280	Y : 817.450
31	Prospecto LA PEDREGOSA . Pirita .	X : 971.300	Y : 819.650
32	Prospecto LUIS E. RAMIREZ . Galena , blenda , pirita .	X : 976.190	Y : 822.450
33	Prospecto LA TOPACIA . Hierro , manganeso .	X : 996.900	Y : 811.490
34	RIO GRIS . Arcilla .	X : 953.900	Y : 816.000
35	SAN JUAN . Arcilla .	X : 954.600	Y : 814.450
36	PALOGRANDE . Arcilla .	X : 896.670	Y : 827.600
37	LA DUQUESA . Arcilla .	X : 994.980	Y : 828.400
38	LA QUIEBRA . Arcilla .	X : 974.000	Y : 819.980
39	ROCHELA . Arcilla .	X : 1.000.250	Y : 813.400
40	PTO. ALEJANDRIA . Arcilla .	X : 1.000.450	Y : 804.040
41	GALPON FAYAD . Arcilla .	X : 993.300	Y : 825.600
42	BARCELONA . Arcilla .	X : 975.300	Y : 811.500
43	Prospecto PUENTETABLA . Calizas .	X : 968.000	Y : 819.000
44	Explotación calcárea SELVA . Mármol .	X : 1.000.250	Y : 837.100
45	Explotación calcárea LA CABARA . Travertino	X : 1.000.150	Y : 842.350
46	Explotación calcárea J. BUITRAGO . Esquistos calcáreos	X : 985.530	Y : 830.020
47	Explotación calcárea VILLA BLANCA . Travertino	X : 996.000	Y : 814.000
48	Prospecto EL PINAR . Travertino .	X : 950.500	Y : 819.000
49	Explotación calcárea EL CEDRAL . Mármol .	X : 997.570	Y : 836.750
50	Explotación calcárea MORAVIA . Mármol .	X : 998.000	Y : 837.340
51	Explotación calcárea BETULIA . Mármol .	X : 948.150	Y : 834.950
52	Prospecto CALIFORNIA . Calcita .	X : 955.440	Y : 817.700
53	Prospecto EL CHIVO . Feldespato , cuarzo .	X : 970.510	Y : 817.250
54	Prospecto LA GAVIOTA . Crisotilo , actinolita .	X : 974.360	Y : 819.780
55	Prospecto MAICENA BAJA . Actinolita .	X : 965.300	Y : 818.800
56	Prospecto MAICENA ALTA . Actinolita .	X : 961.090	Y : 818.180
57	Prospecto LA TEBAIDA . Carbón turba .	X : 980.800	Y : 802.300

TABLE C.2 INVESTIGATION OF POSSIBILITY OF WATER RESOURCE DEVELOPMENT

No.	Point		River	Dam type C.	Dam type F.	Dam high H. (m)	Note
1.	FILANDIA	NE	Rio Barbas	O	—	50~70	
2.	ULLOA	E	Quebrada La Plata	—	O	30	
3.	SALENTO	NW	Quebrada La Boquia	O	O	30	
4.	SALENTO	N	Rio Quindio	O	O	50	
5.	SALENTO	E	Rio Quindio	O	O	50	
6.	SALENTO	E	Rio Quindio	O	O	30	
7.	CIRCACIA	NE	Rio El Roble	O	O	30	
8.	CIRCACIA	E	Rio Navarco	O	O	30 50 70	
9.	CIRCACIA	E	Rio Quindio	O	O	30 50 70	
10.	CALARUCA	E	Rio Santadomingo	O	—	50 70	
11.	CALARUCA	E	Rio Santadomingo	O	—	50 70	
12.	ARMENIA	S	Rio Quindio	O	—	50 70	
13.	ARMENIA	S	Rio Santadomingo	O	O	20	
14.	PIJAO	NE	Rio Lejos	O	—	20~30	
15.	PIJAO	NE	Rio Lejos	O	—	50	
16.	PIJAO	S	Rio Azul	O	—	30	
17.	PIJAO	S	Quebrada de La Maizama	O	—	20~30	
18.	GENOVA	N	Quebrada de La Laquna	O	—	30	
19.	GENOVA	S	Rio Grio	O	—	20~30	
20.	GENOVA	S	Rio Grio	O	—	40~50	
21.	GENOVA	S	Rio Grio	O	—	30	
22.	SIRCACIA	W	Rio Roble	O	O	50	
23.	SIRCACIA	W	Rio Roble	O	—	50	
24.	MONTENEGRO	N	Rio Roble	O	—	50	
25.	QUINBAYA	W	Quebrada de Beleu	O	O	30 50	
26.	MONTENEGRO	W	Quebrada Piedras	O	O	30 50	
27.	MONTENEGRO	W	Quebrada La Clars	O	O	30 50	

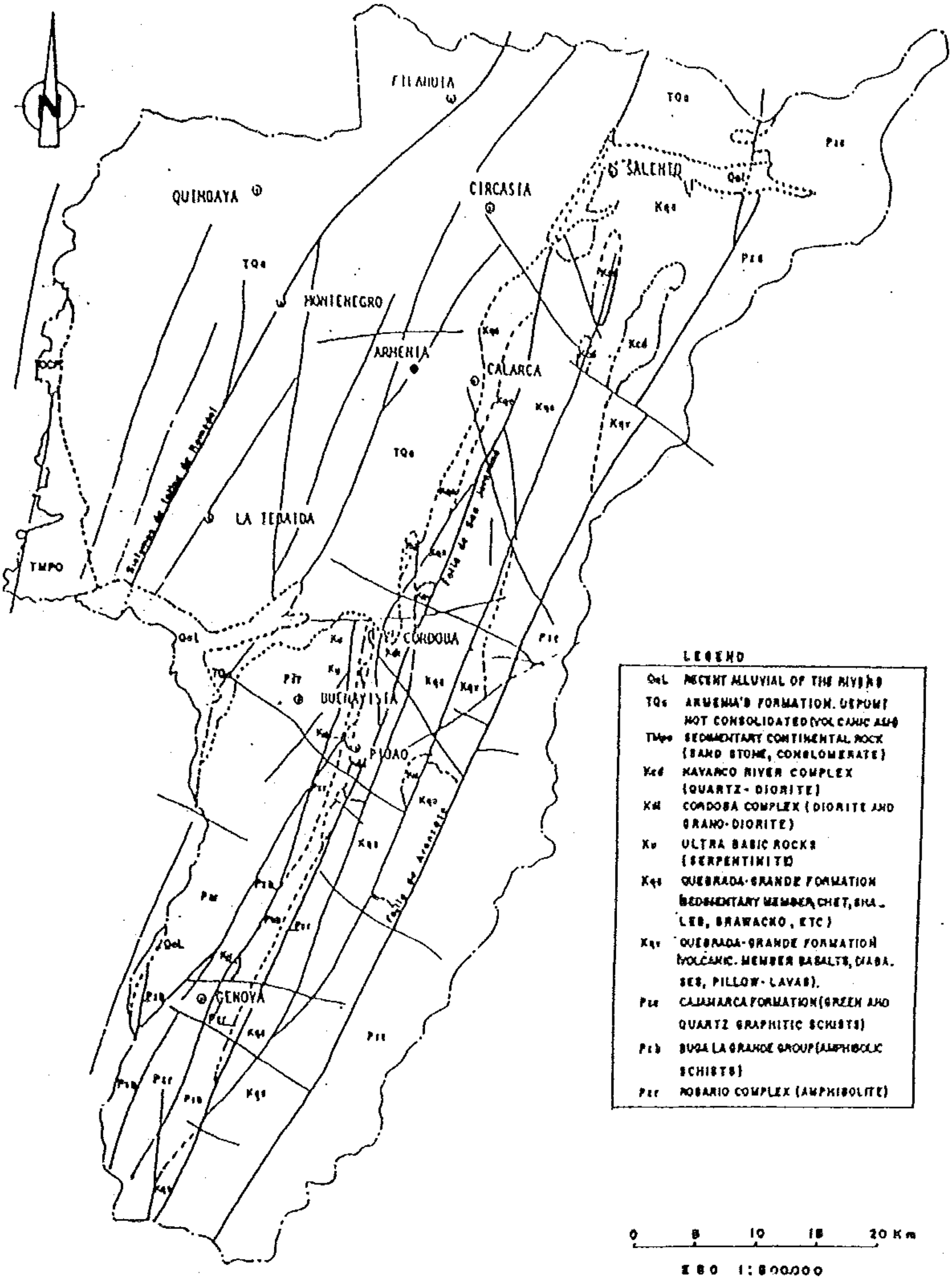


FIG.C. 1 GEOLOGICAL MAP OF QUINDIO

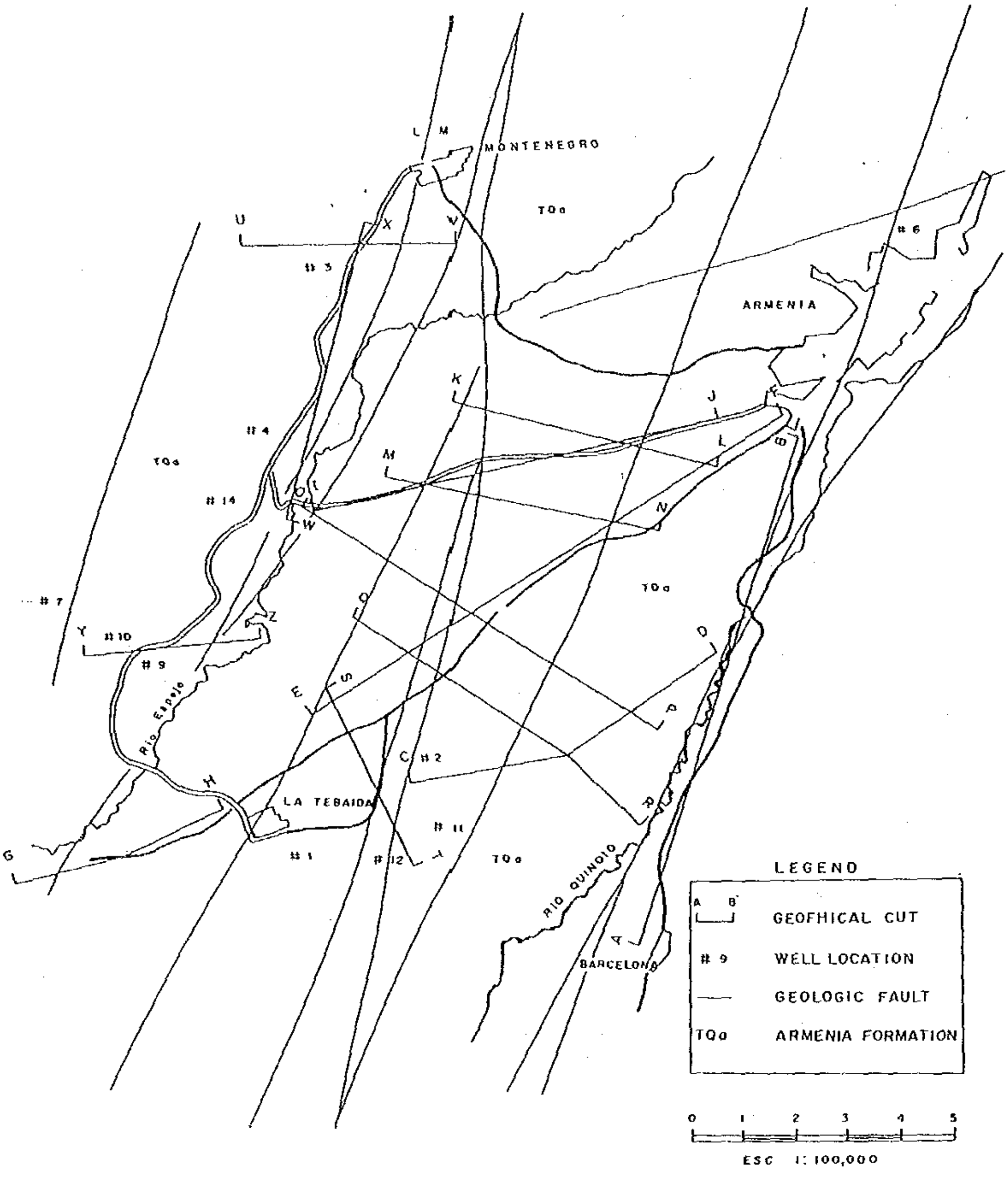


FIG.C. 2 ELECTRICAL EXAMINATION

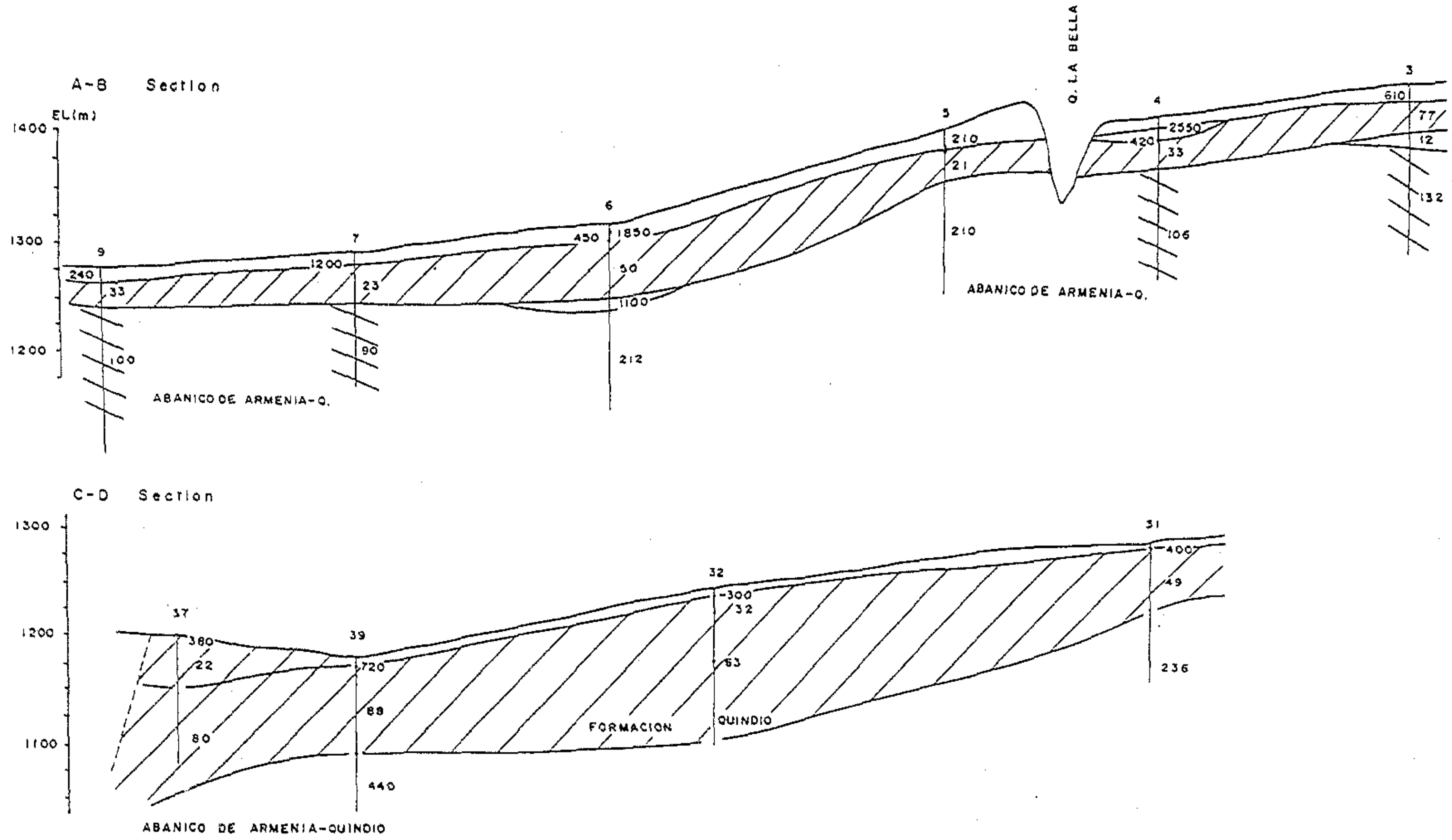


FIG.C. 3 A-B, C-D, SECTION

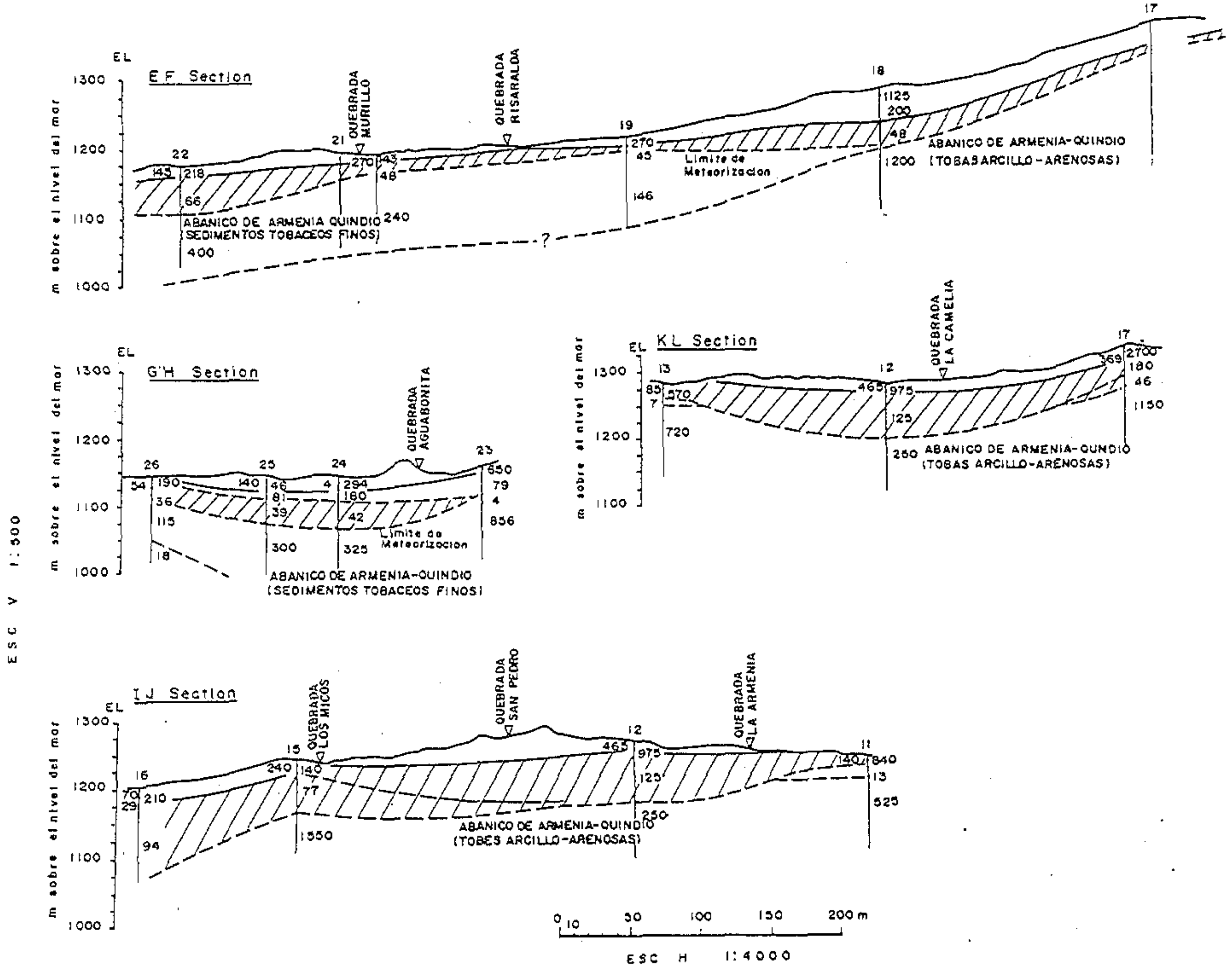


FIG.C. 4 E-F, G-H, I-J, K-L SECTION

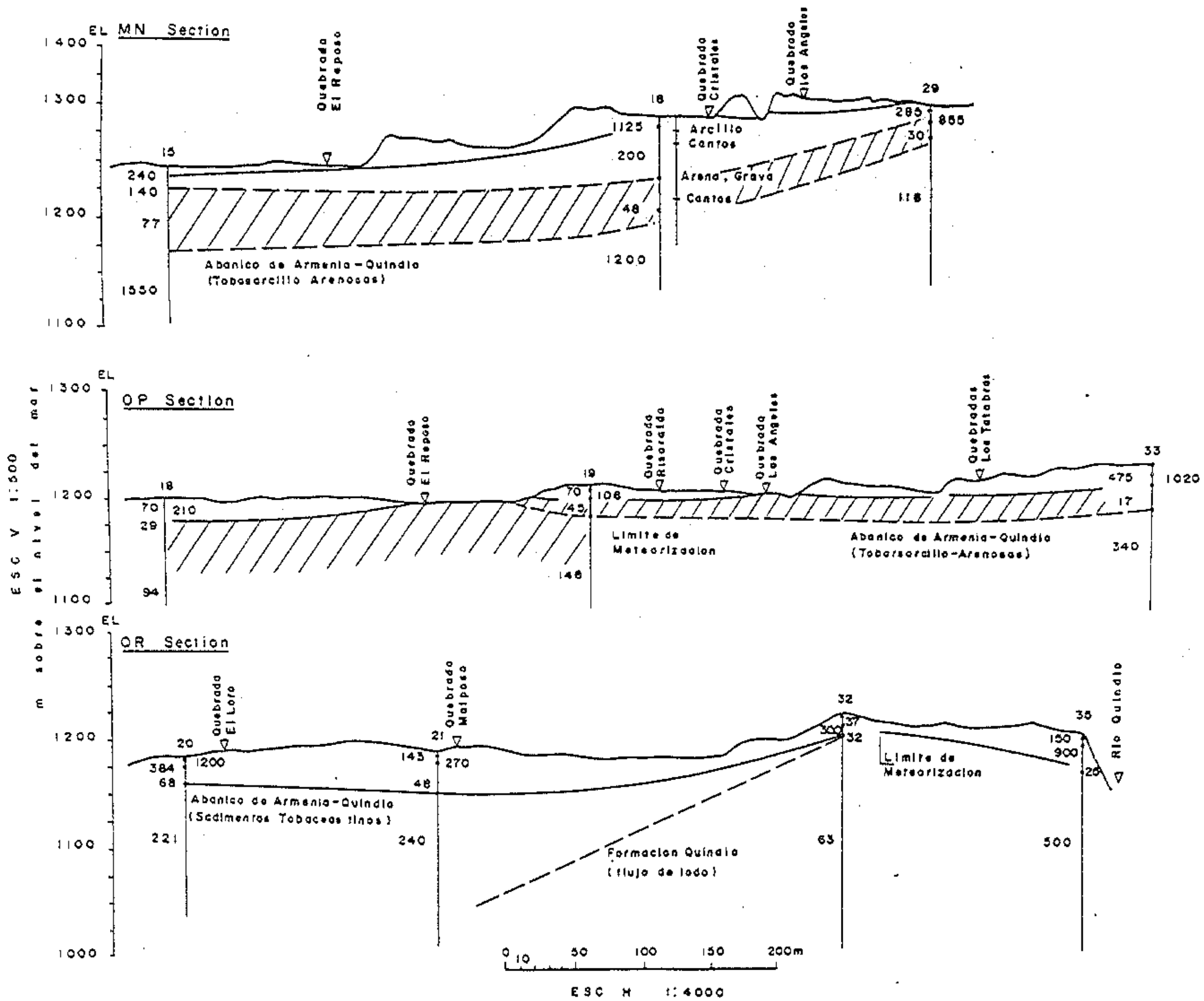


FIG.C. 5 M-N, O-P, Q-R SECTION

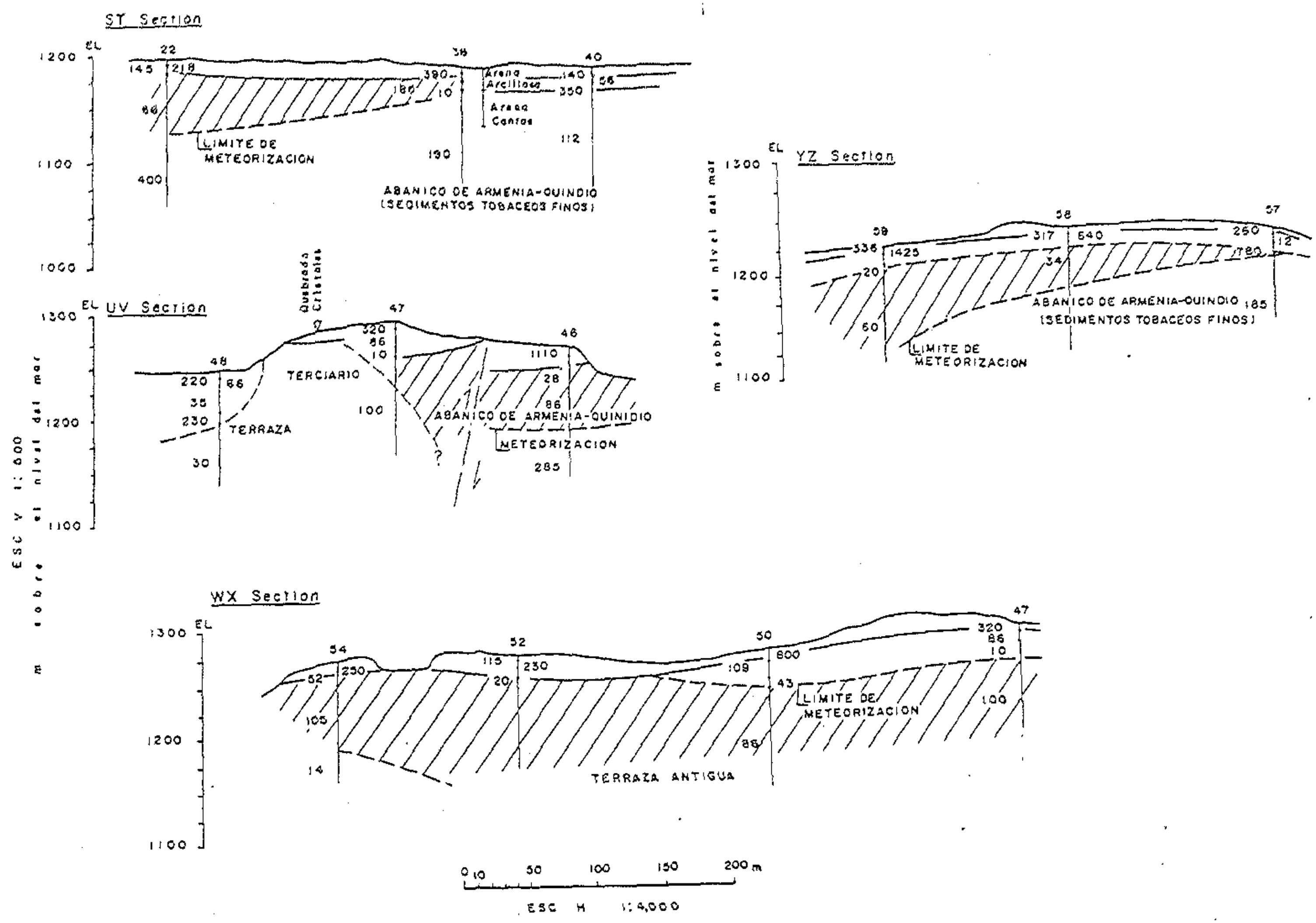


FIG.C. 6 S-T, U-V, W-X, Y-Z SECTION

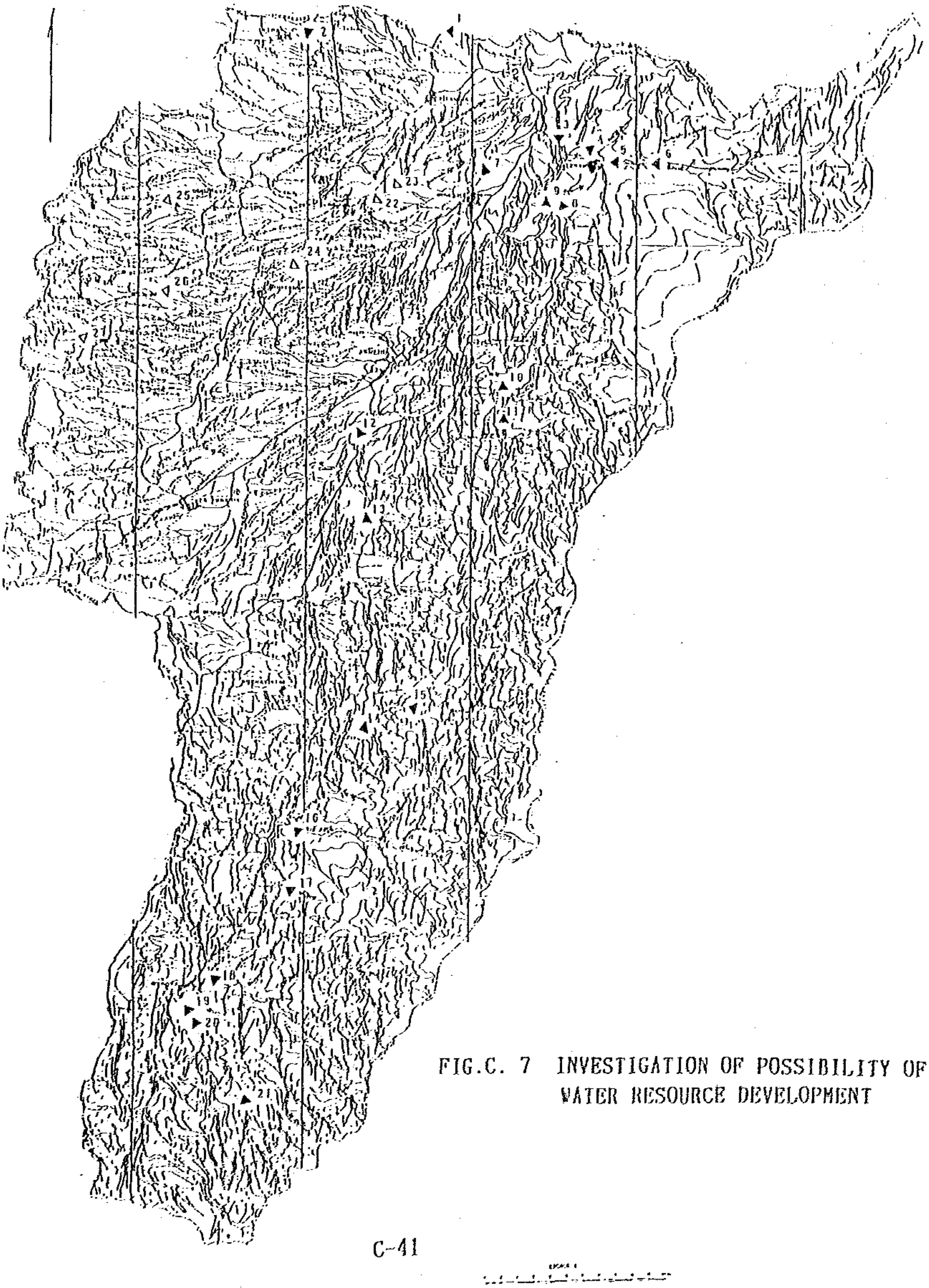


FIG.C. 7 INVESTIGATION OF POSSIBILITY OF WATER RESOURCE DEVELOPMENT

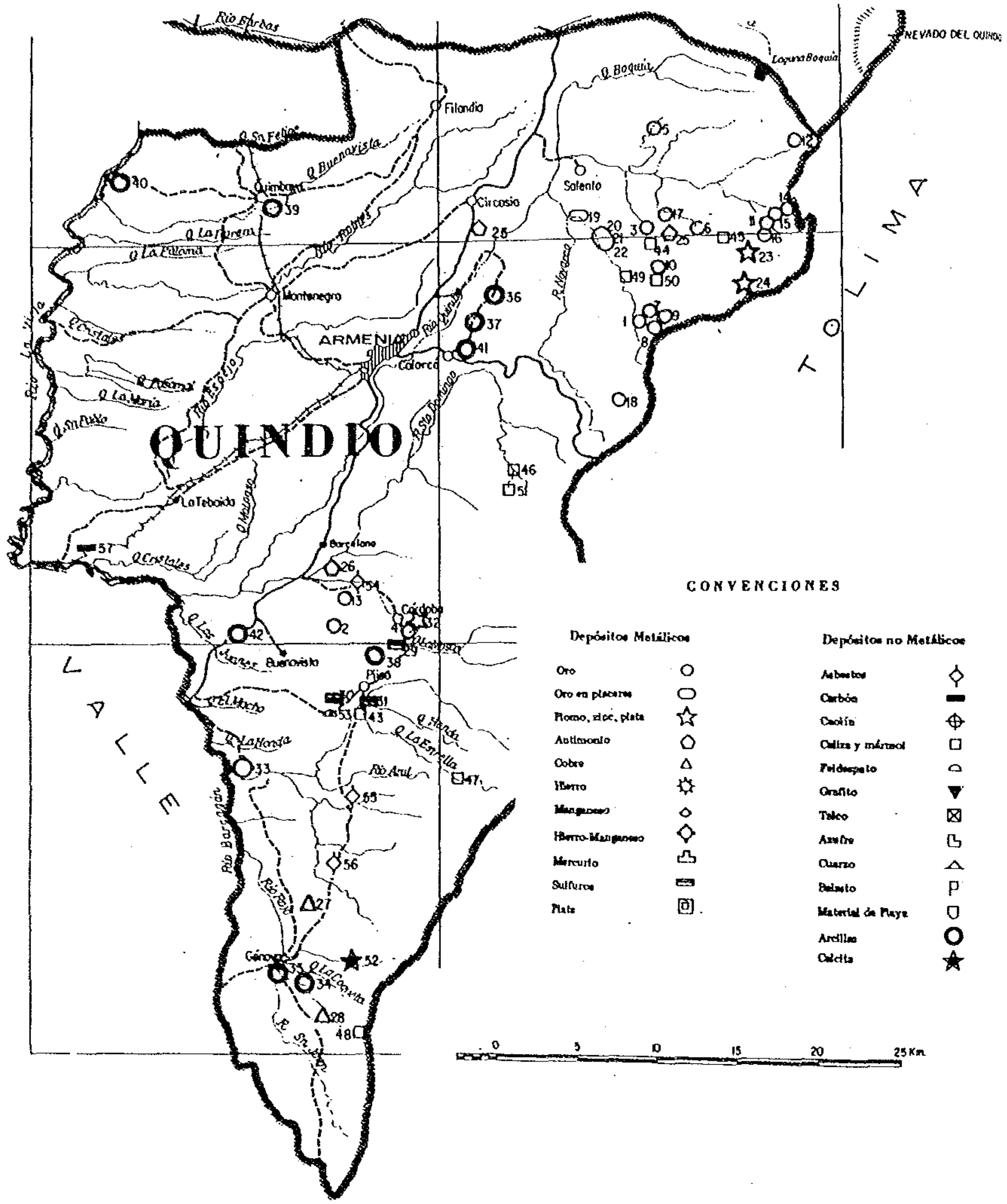


FIG.C. 8 THE MINE OF QUINDIO

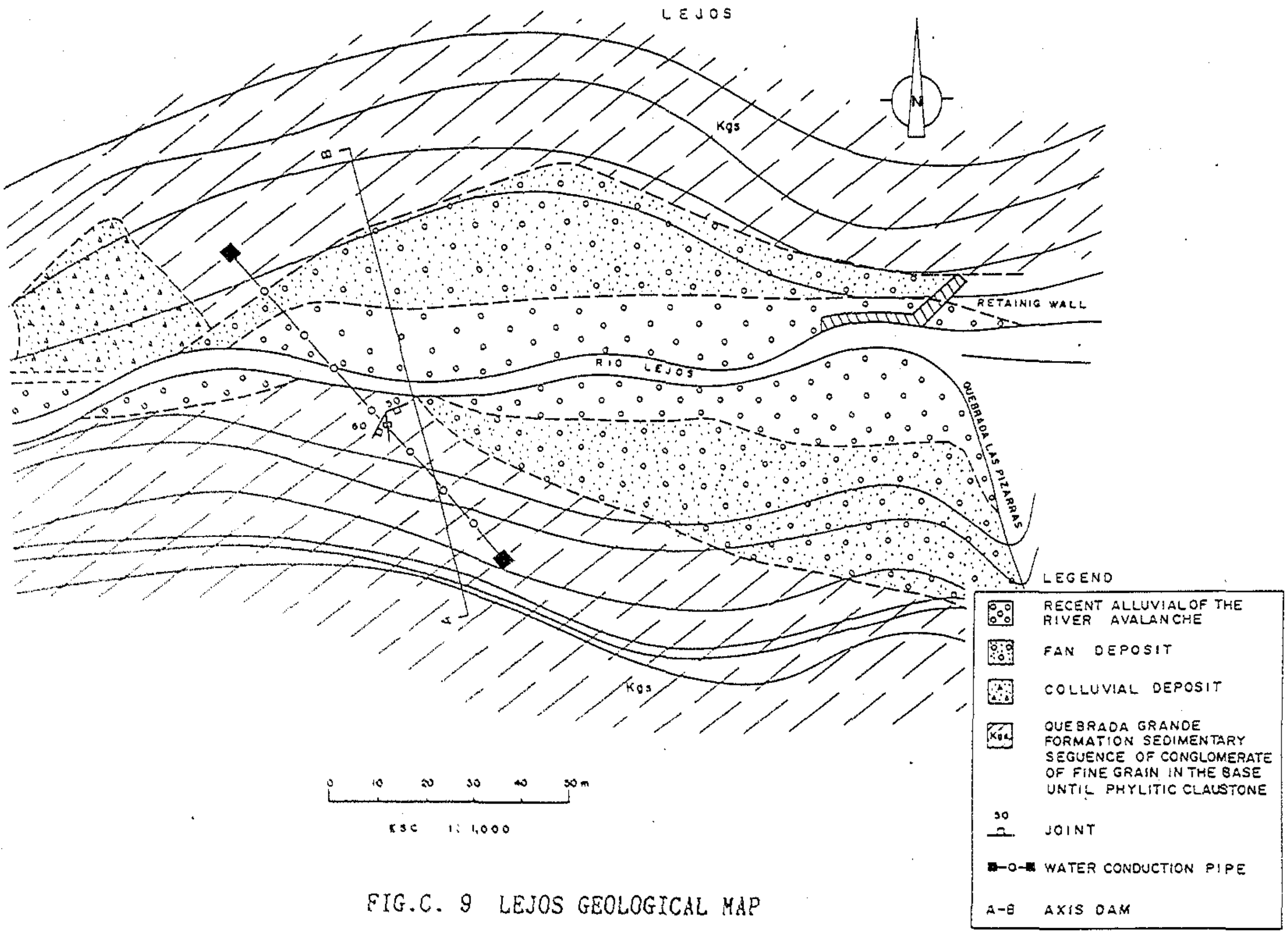


FIG.C. 9 LEJOS GEOLOGICAL MAP

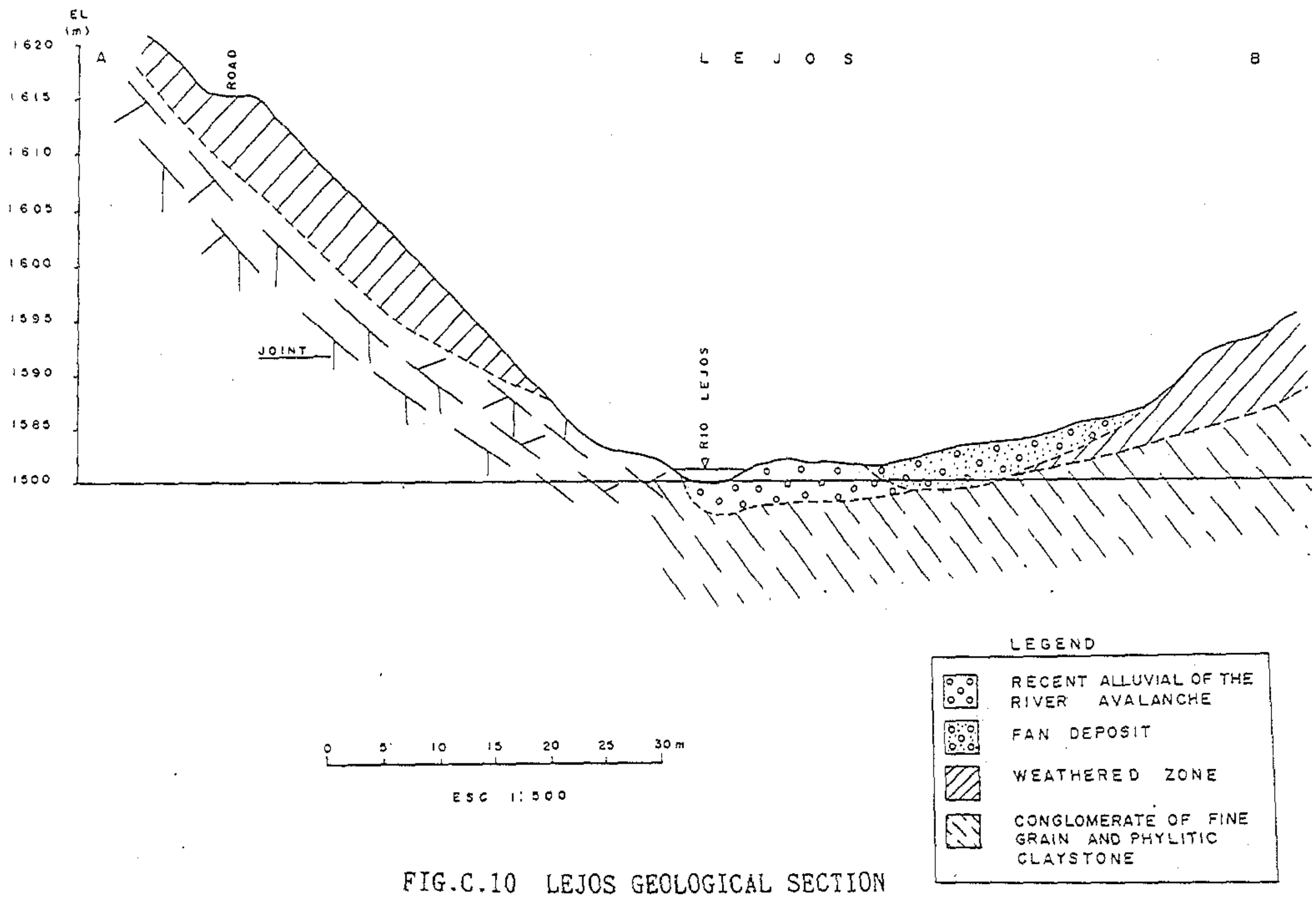


FIG.C.10 LEJOS GEOLOGICAL SECTION

RIO EL ROBLE — N CIRCASIA

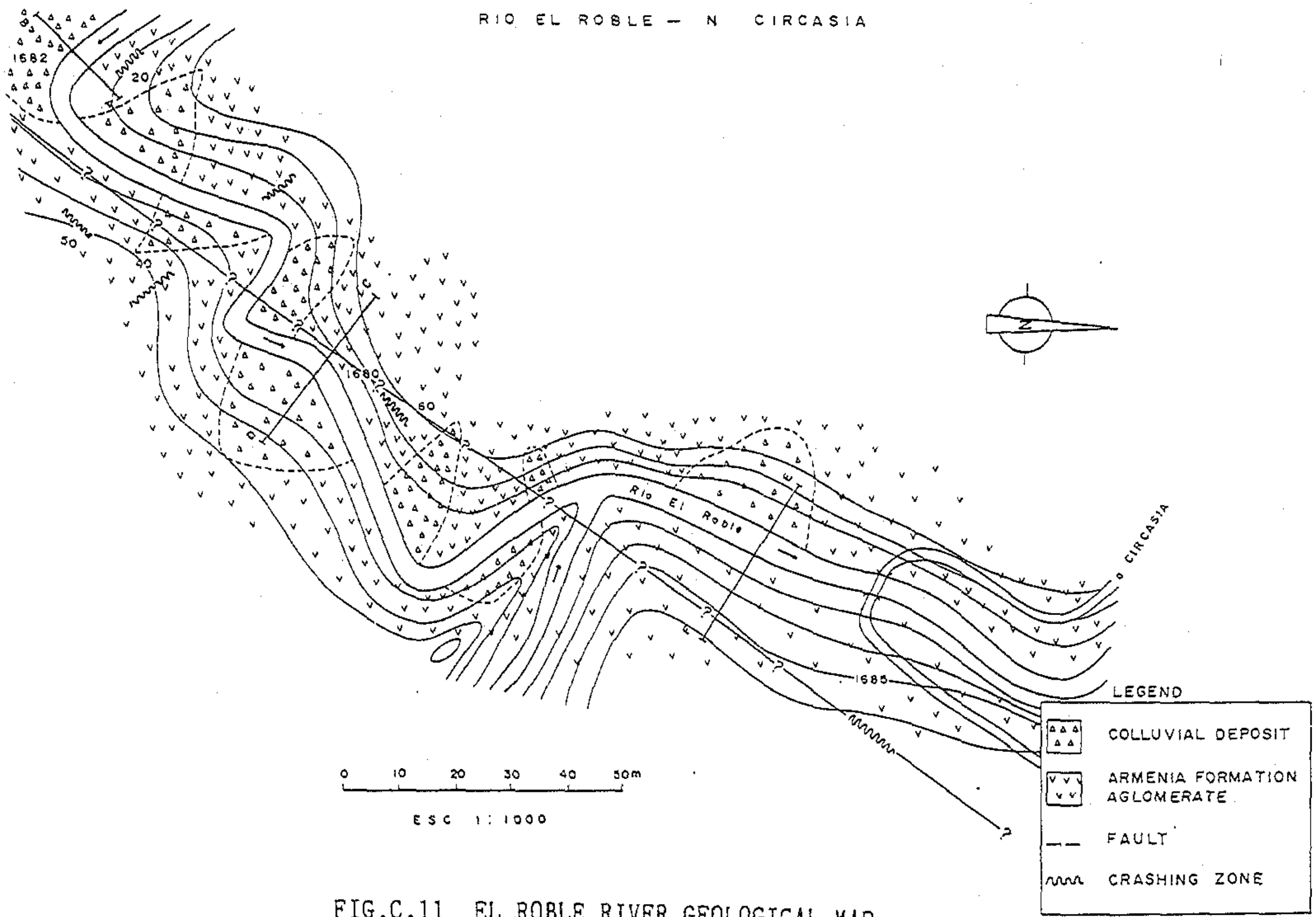


FIG.C.11 EL ROBLE RIVER GEOLOGICAL MAP

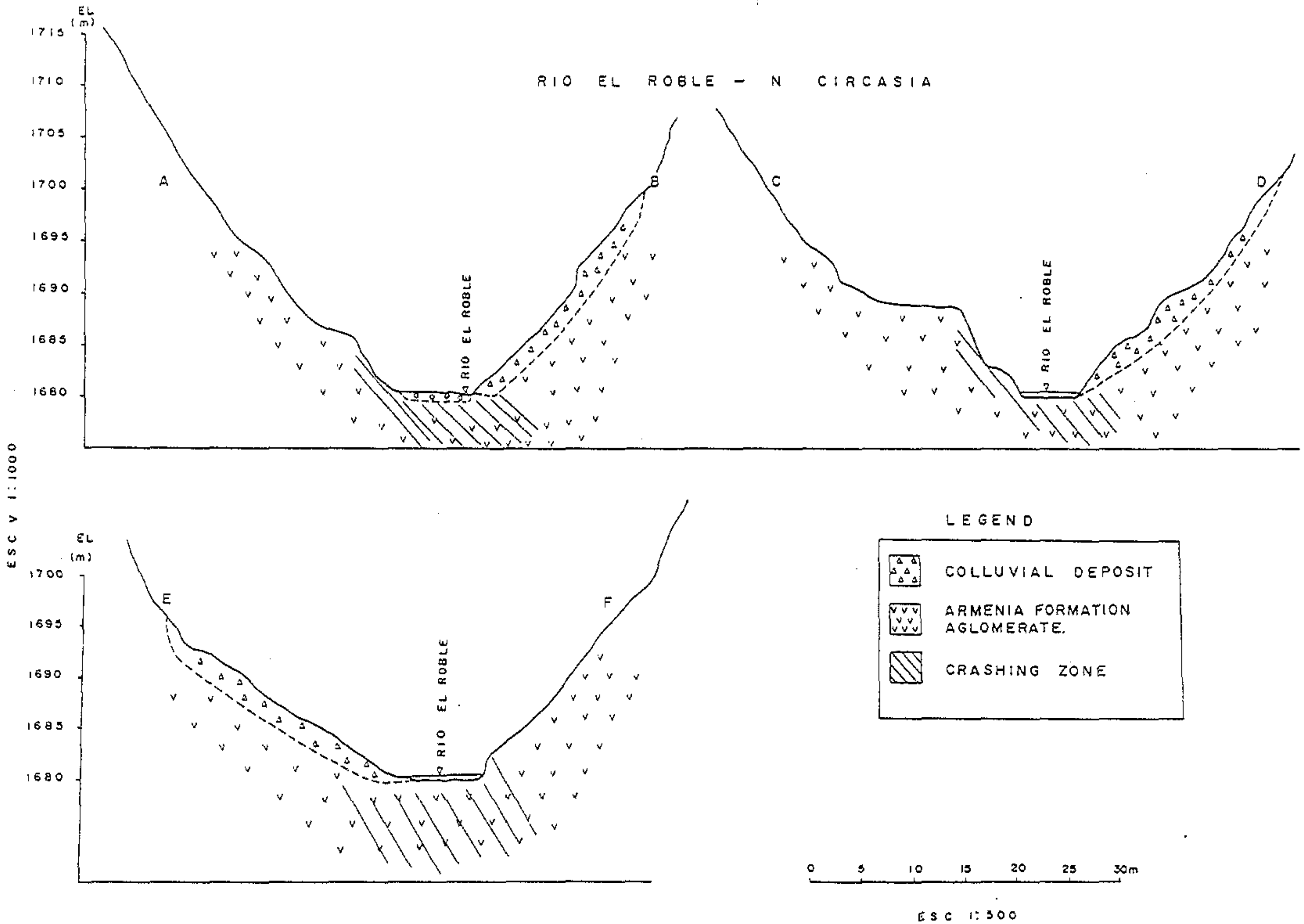


FIG.C.12 EL ROBLE RIVER GEOLOGICAL SECTION-

RIO EL ROBLE — W CIRCASIA

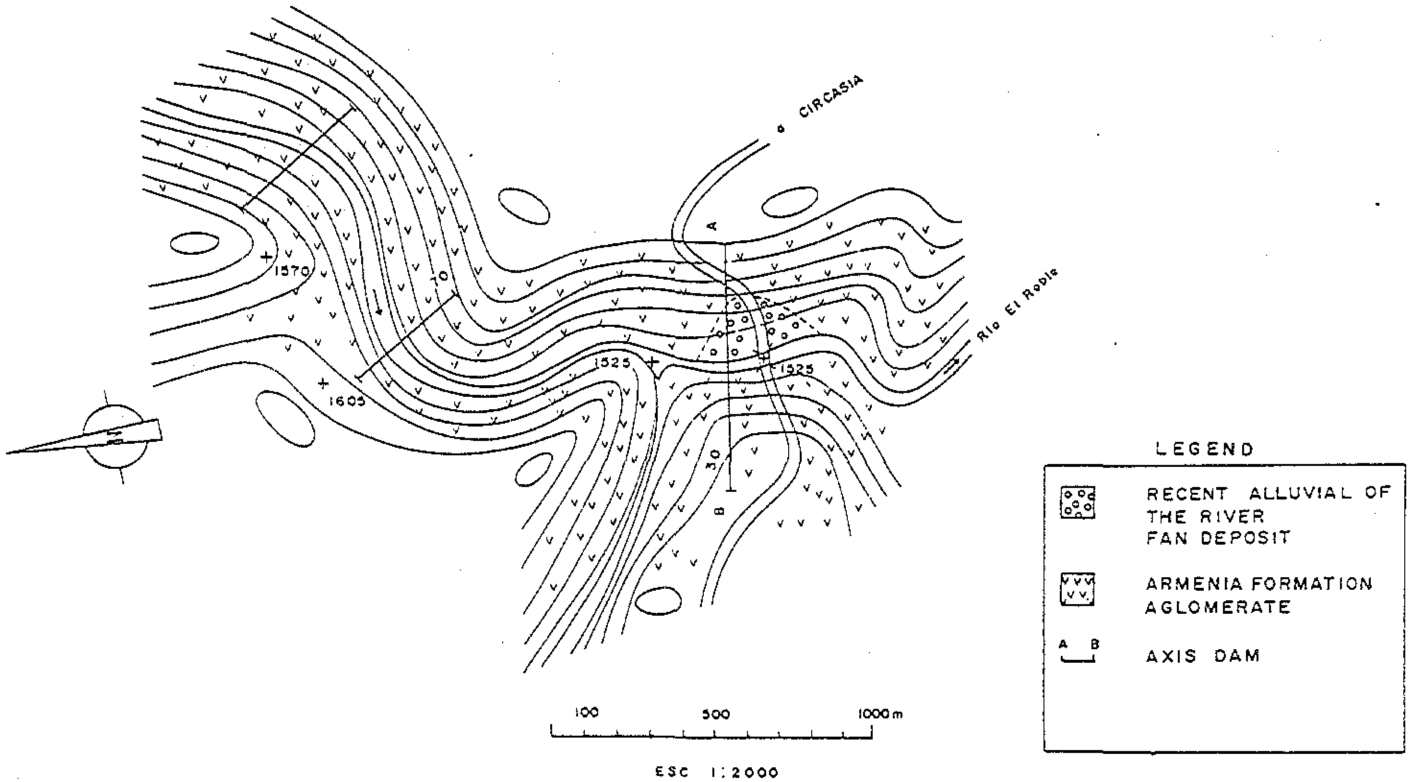


FIG.C.13 ROBLE RIVER GEOLOGICAL MAP

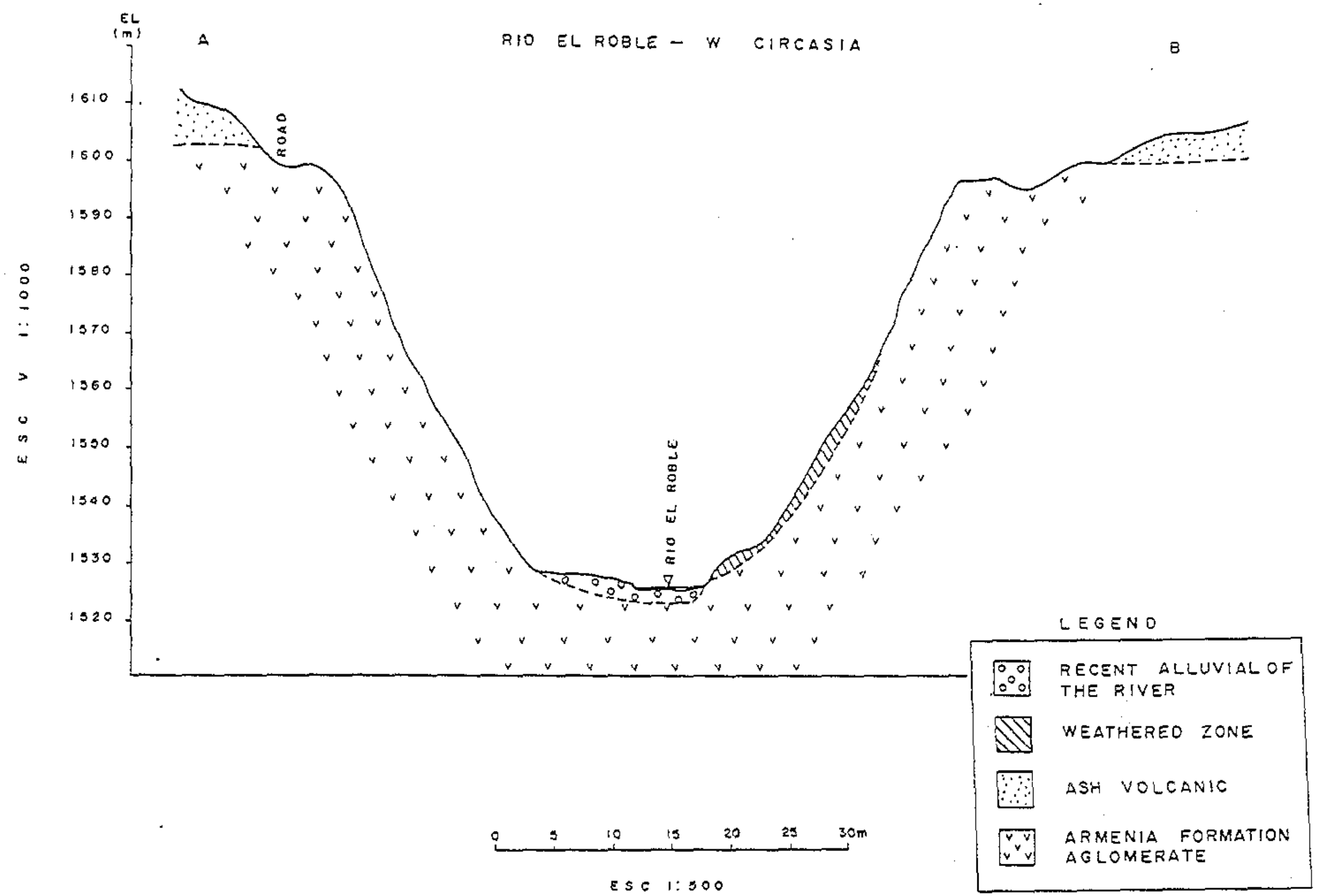


FIG.C.14 ROBLE RIVER GEOLOGICAL SECTION

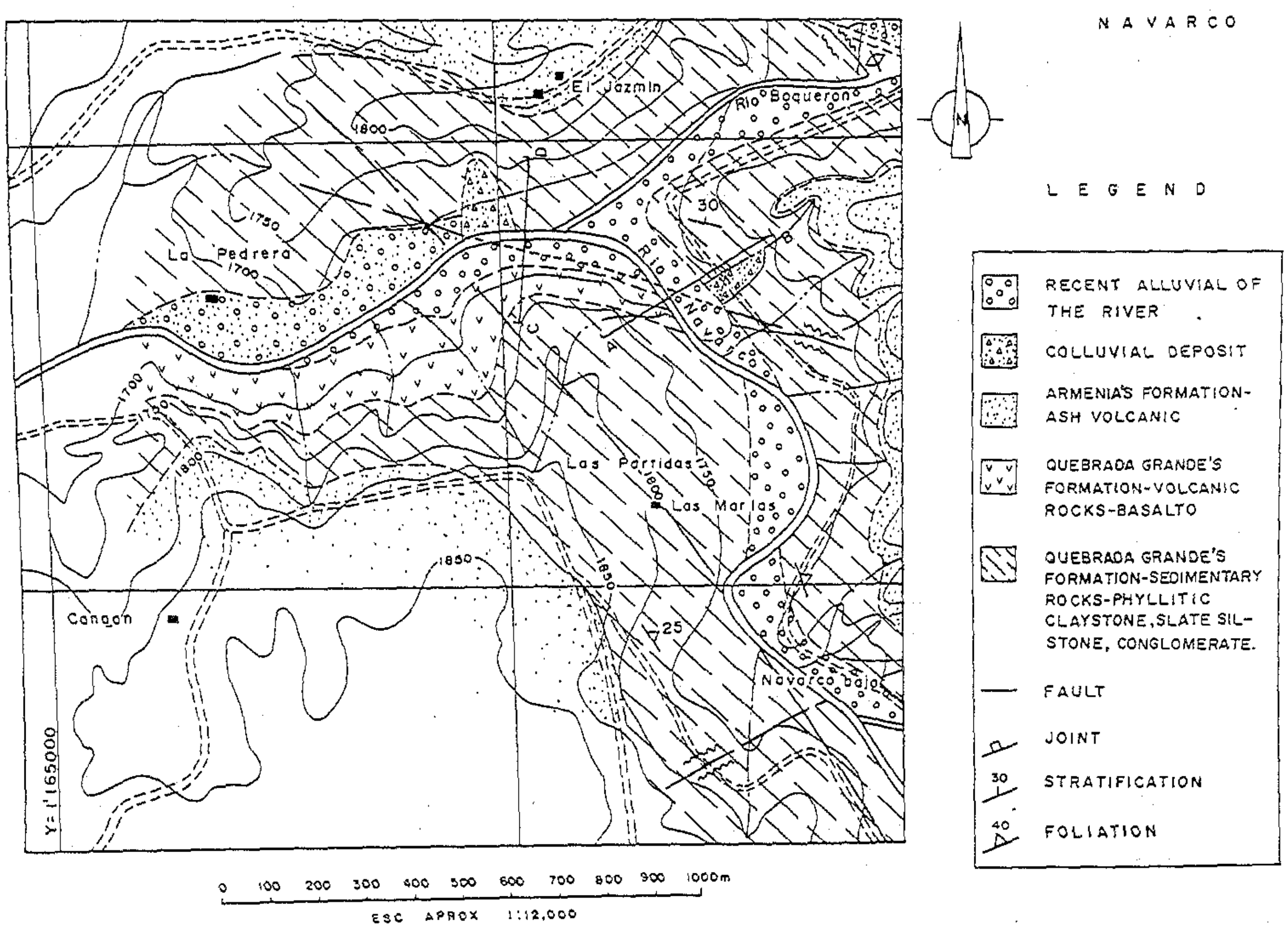


FIG.C.15 NAVARCO GEOLOGICAL MAP

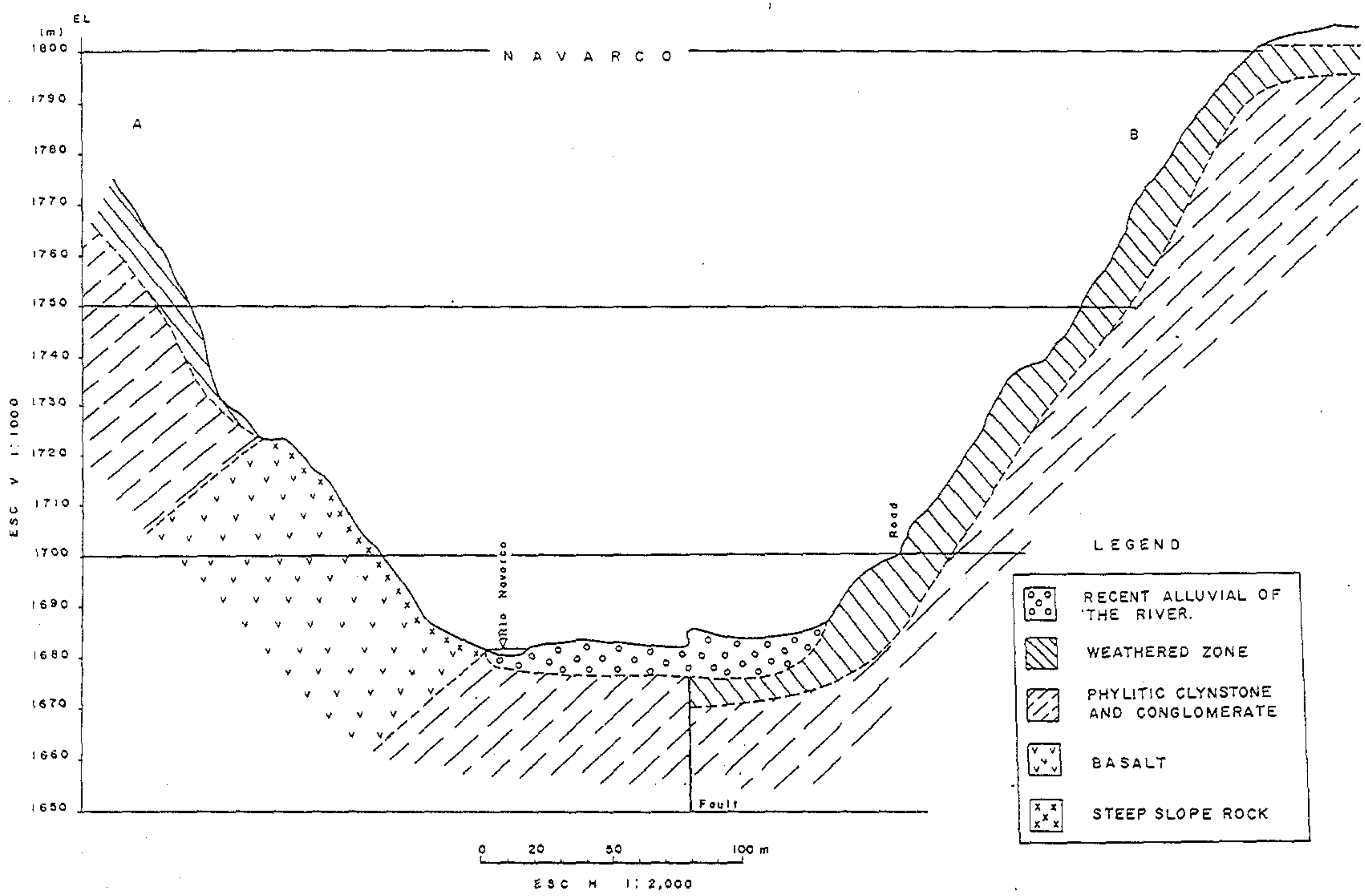


FIG.C.16 NAVARCO GEOLOGICAL SECTION

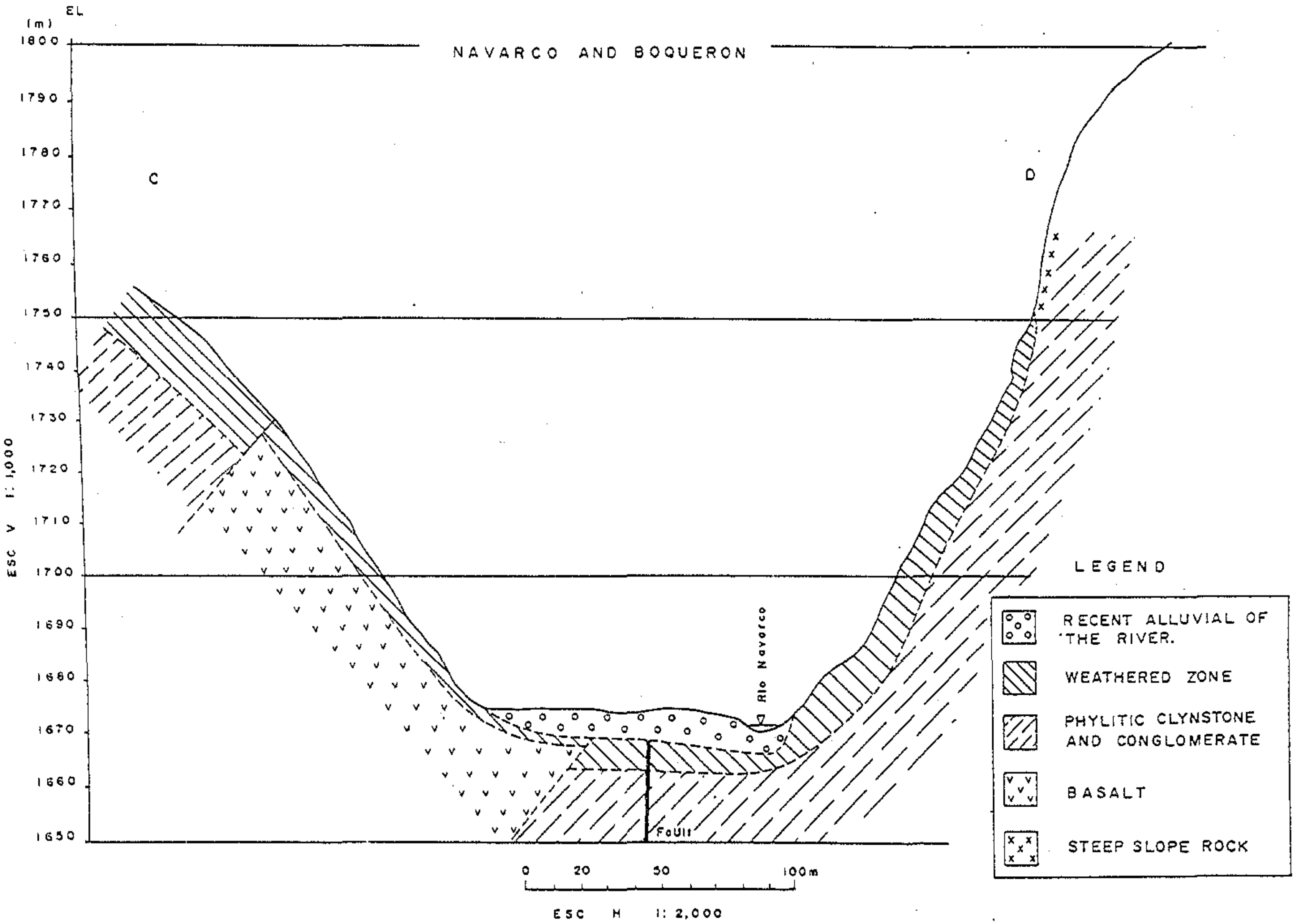


FIG.C.17 NAVARCO-BOQUERON GEOLOGICAL SECTION

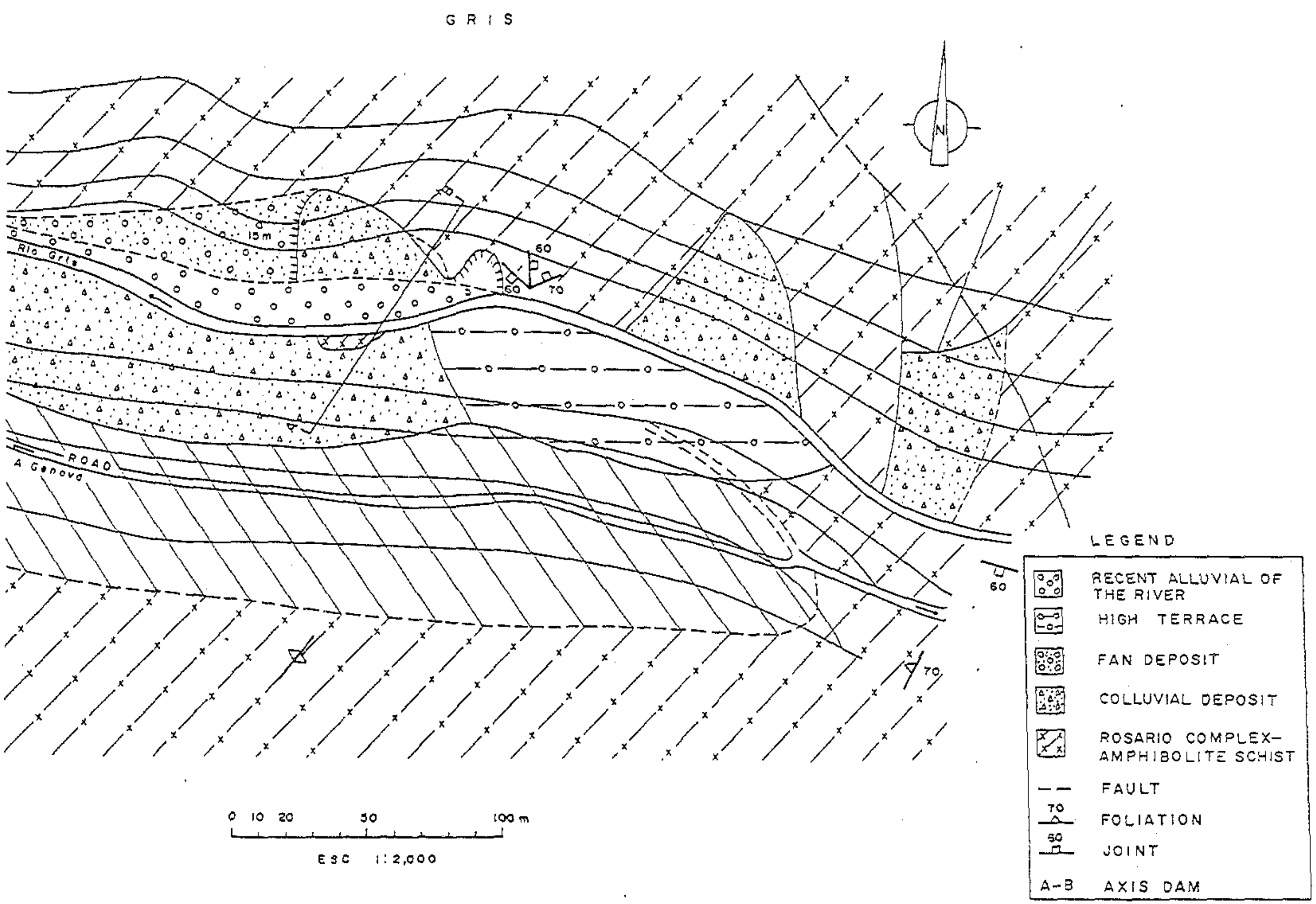


FIG.C.18 GRIS GEOLOGICAL MAP

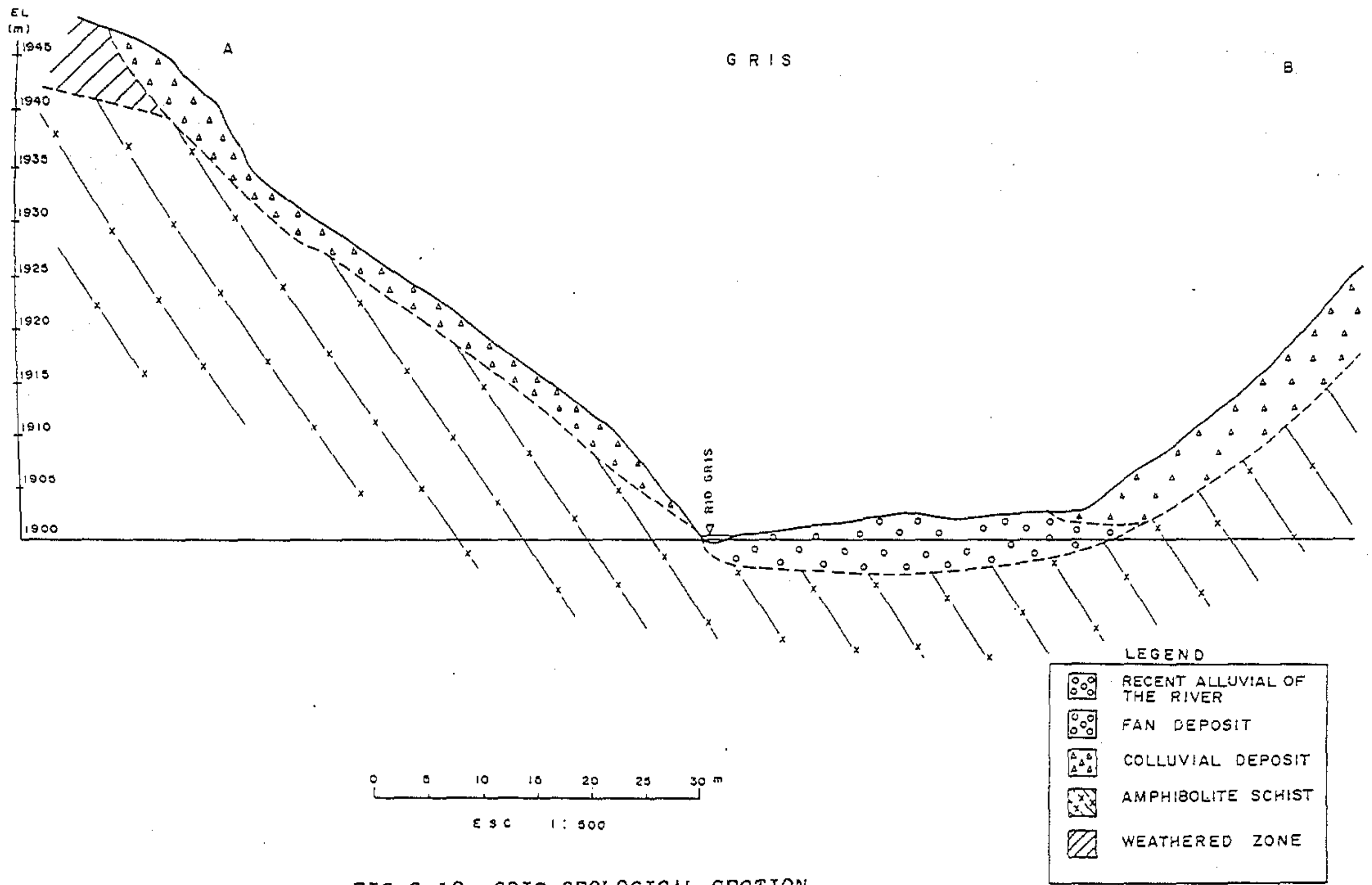


FIG.C.19 GRIS GEOLOGICAL SECTION

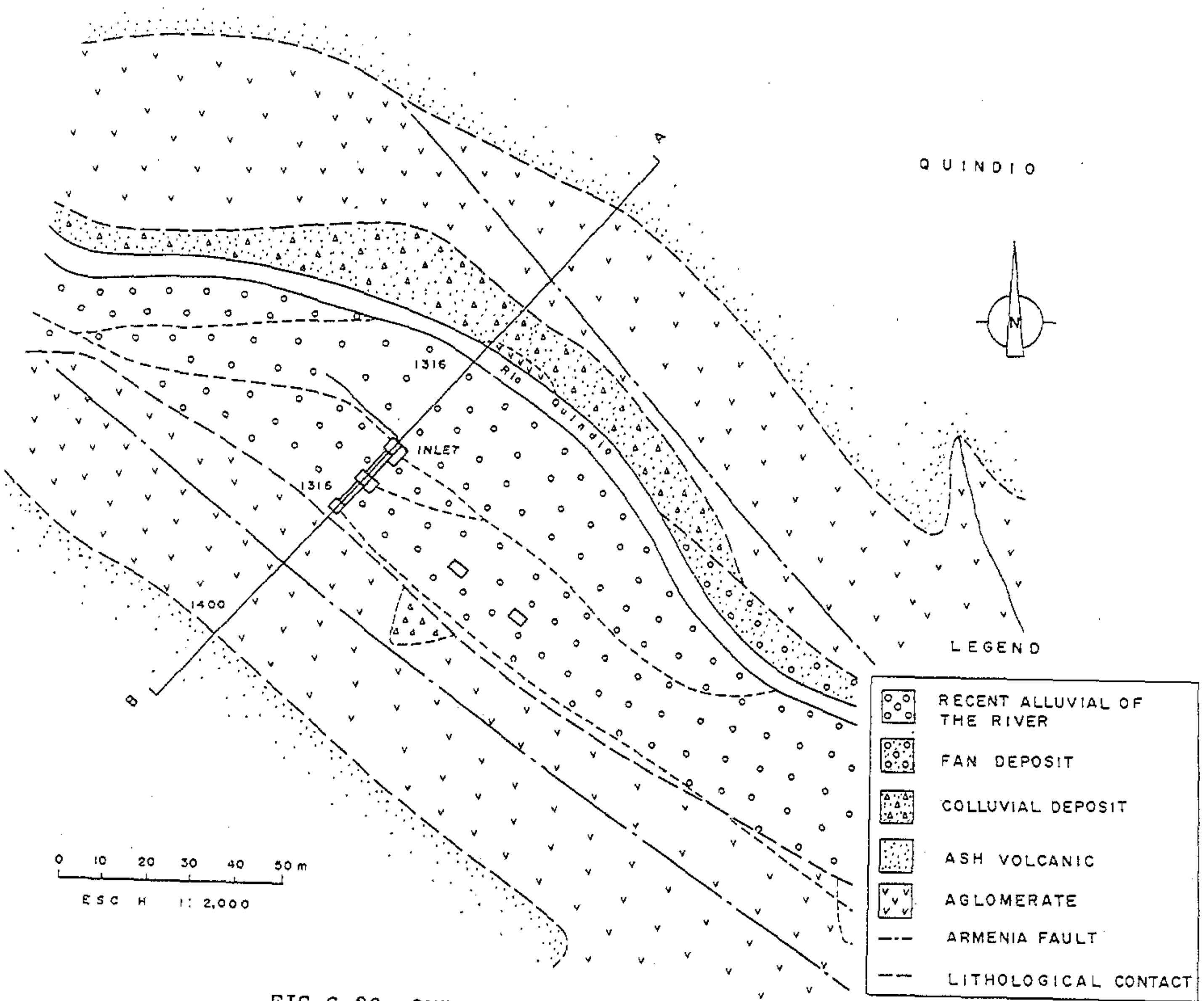


FIG.C.20 QUINDIO GEOLOGICAL MAP

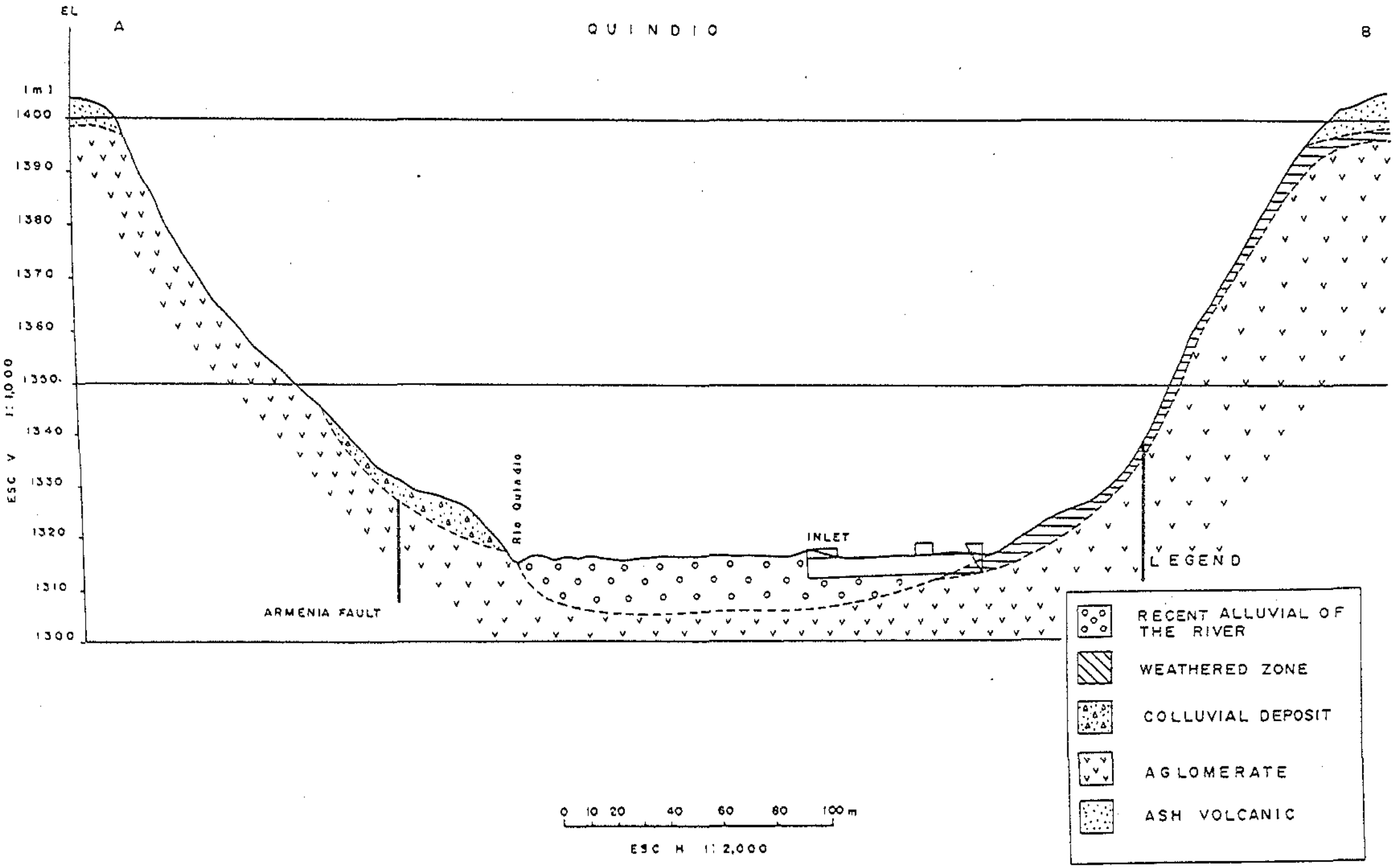


FIG.C.21 QUINDIO GEOLOGICAL SECTION

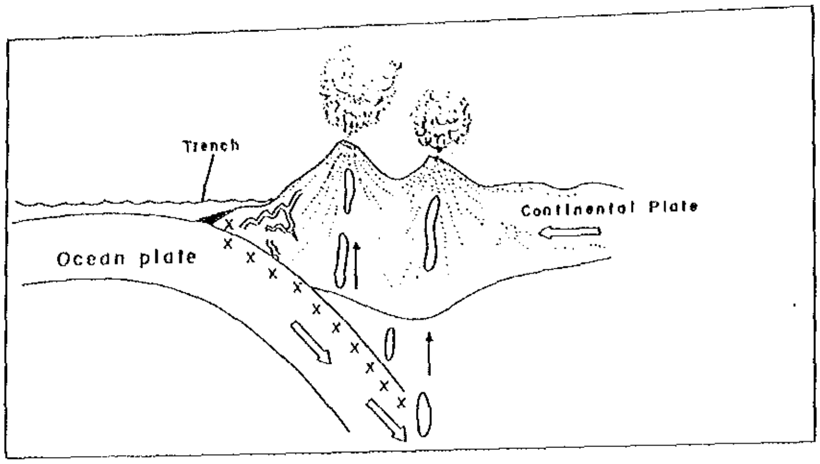


FIG.C.22 MODEL OF SINKING ZONE

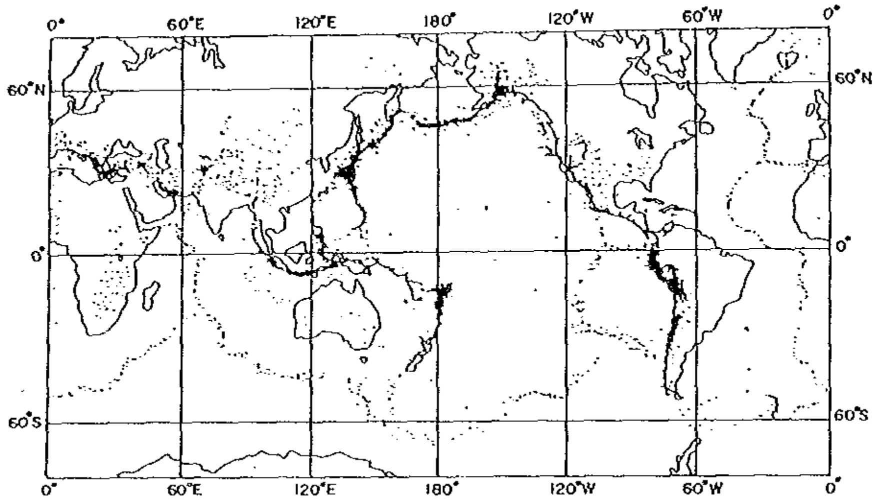


FIG.C.23 EARTHQUAKES ZONE

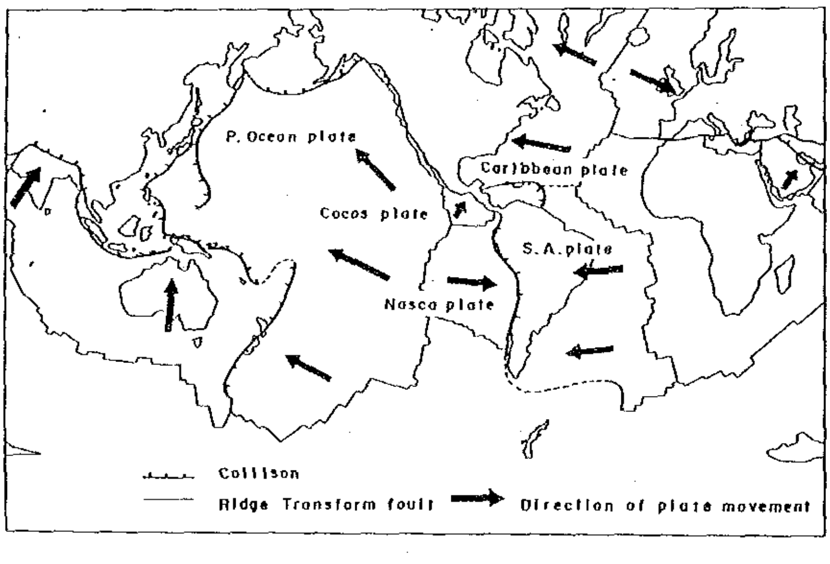


FIG.C.24 PLATE RIDGE TRANSFORM FOULT TRENCH

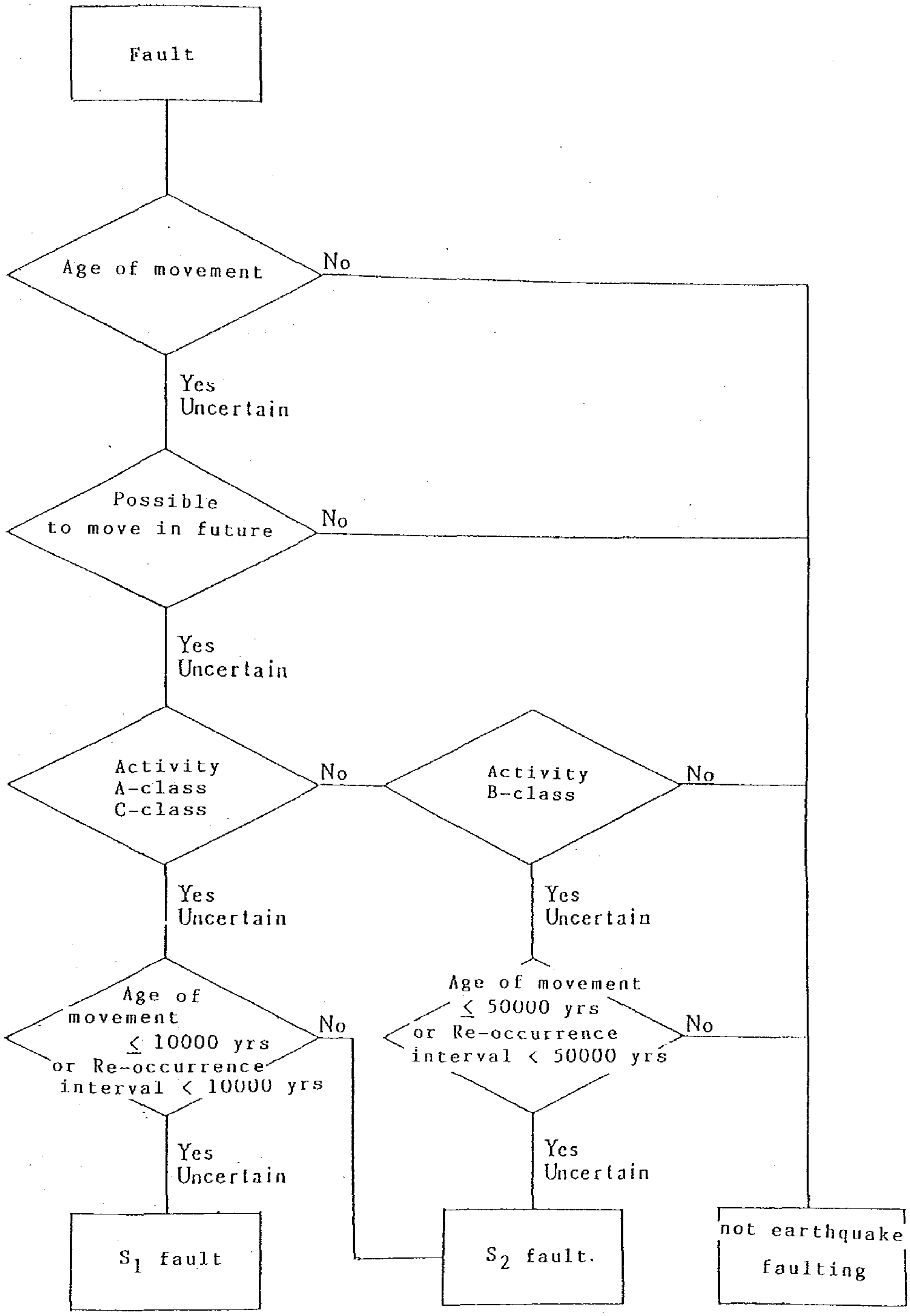


FIG.C.25 FLOW CHART TO JUDGE THE ACTIVITY OF FAULTS

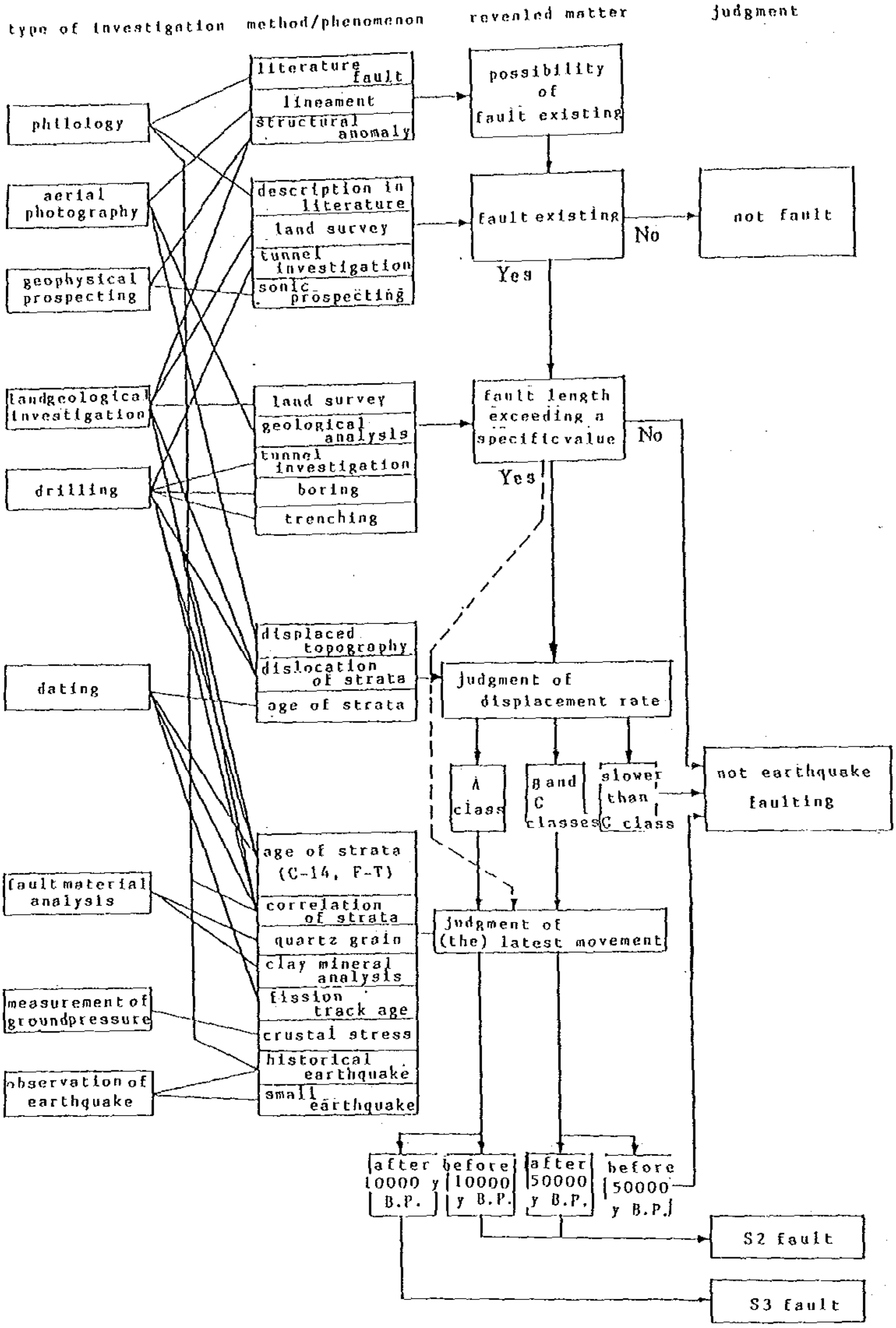


FIG.C.26 FLOW CHART FOR THE INVESTIGATION OF FAULTS ACTIVITY

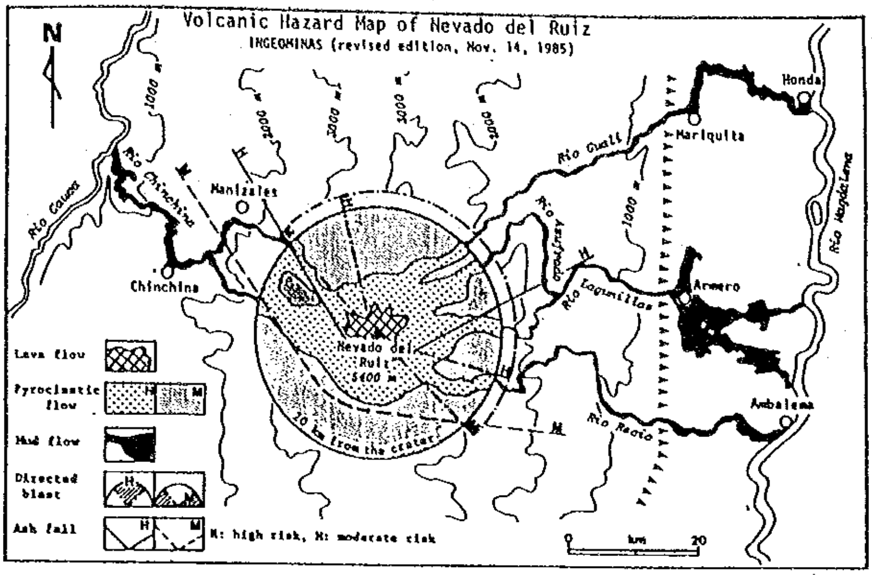


FIG.C.27 VOLCANIC HAZARD MAP OF NEVADO DEL RUIZ

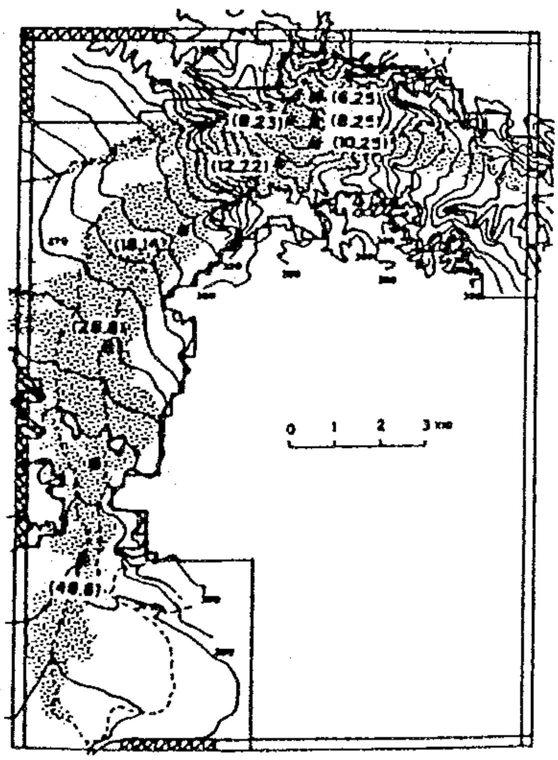


FIG.C.28 ACTUAL DAMAGED AREA BY INUNDATION

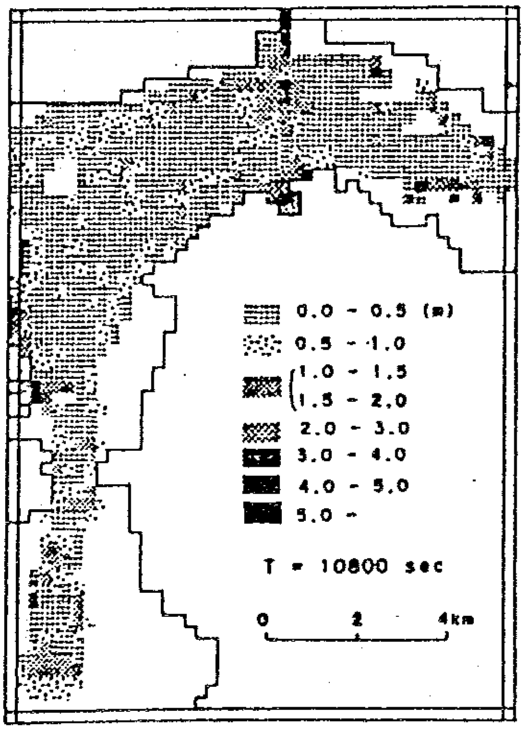


FIG.C.29 ESTIMATED INUNDATION CONDITION BY DEPTH

ANNEX D : METEOROLOGY AND HYDROLOGY

Annex D : Meteorology & Hydrology

Table of Contents

List of Tables

List of Figures

Annex D : Meteorology & Hydrology

D.1 Introduction

D.1.1 The Objective of the Study

The objective of this study is to learn the meteorological and hydrological conditions prevailing in the Department of Quindio for the formulation of the Master Plan, and to carry out analysis to provide basic dimensions for the design of the projects.

D.1.2 Summary of Meteorology

The average annual rainfall of approximately 2,000mm is observed and generally two dry periods (January-February and June-August) and two wet periods (April-May and October-November) are shown in the annual rainfall pattern of the Quindio. Except the mountain areas, warm and humid weathers prevail through out the year.

D.1.3 Summary of Hydrology

(1) Rainfall Analysis

Fourteen (14) stations have been selected for rainfall analysis consideration to the locations, accuracy of data, etc. The results of analysis on the average of total area for the Quindio are below:

Annual Rainfall in The Drought Year (mm/year)

Return Period	1/2	1/4	1/5	1/10
Rainfall	1,987	1,670	1,601	1,433
(Effective Rainfall)	(1,146)	(1,077)	(1,057)	(1,001)

Maximum 24-hour Rainfall (mm/day)

Return Period	1/2	1/5	1/10	1/20
Rainfall	76.7	95.8	107.7	118.6

The rainfall intensity was estimated using the maximum 24-hour rainfall because there is no hourly rainfall data was available.

(2) Runoff Analysis

Low flow analyses were carried out by using the data of the Alambrado bridge (mean discharge 34.5 l/s/km2), and droughty discharge was estimated by using the specific discharge.

Droughty Discharge (Station at Alambrado)

Return Period	1/2	1/5	1/10	1/20
Discharge (m3/s)	12.8	9.1	7.6	6.6
Specific Discharge (l/s/km2)	7.9	5.1	4.7	4.1

The flood analysis was carried out at each point by using the Rational Formula, with consideration to the rainfall and catchment area.

Flood Discharge (Peak Specific Discharge : m3/s/km2)

return period	1/2	1/5	1/10	1/20
Catchment Area				
over 500km2	0.521	0.614	0.668	0.714
200-500km2	1.170	1.444	1.610	1.736
under 200km2	3.967	5.004	5.650	6.249

(3) Sediment Runoff Analysis

From the analysis using the data of the suspended sediment at the Alambrado bridge, approximately 2.6 million tons/year of suspended sediment is observed and 1,500 m3/km2/year can be estimated.

D.2 Available Data

The hydrometeorological stations in the Quindio may be summarized as follows;

Type of Station	No.of Stations	
Meteorological	10	:CRQ(4),HIMAT(3),CENICAFE(3)
Rainfall	40	:CRQ(16),HIMAT(1),CENICAFE(23)
Hydrological	1	:HIMAT(Alambrado)

The usual period of observation of the the above stations is from 3 to 30 years, but, for most of them, it is from 3 to 15 years. Most of these stations are located in the middle and northern part of the Quindio and some are in the southern part. (See Table D.2.1 and Fig.D.2.1)

The river discharge has been observed since 1974 at the Alambrado bridge over the La Vieja River. The catchment area covers approximately 1,624km2 with 1,366km2 in the Department of Quindio, which covers 70% of the total area of the department of Quindio. The discharge measurement of another point has been carried out by CRQ since 1982.

Table D.2.1 Summary of Available Data for Climate and Rainfall Stations (1)

Station	Location				Record			
	LAT.	LONG.	ALT.	Type	1950	1960	1970	1980
1.La Espanola	04° 34'	75° 51'	975	M				
2.Cocora	04° 38'	75° 31'	2500	M				
3.Uni. Quindio	04° 33'	75° 40'	1551	M				
4.Labolatorio	04° 33'	75° 40'	1585	M				
5.La Avenida	04° 33'	75° 40'	1550	M				
6.Tebaida	04° 27'	75° 47'	1200	M				
7.Bremen	04° 39'	75° 37'	2000	M				
8.Gobernacion	04° 32'	75° 41'	1551	P				
9.Filandia	04° 40'	75° 39'	1800	P				
10.San Rafael	04° 31'	75° 38'	1600	P				
11.La Picota	04° 39'	75° 28'	2680	P				
12.El Tunel	04° 27'	75° 35'	2600	P				
13.Buenos Aires	04° 32'	75° 35'	2480	P				
14.Villadora	04° 38'	75° 37'	1900	P				
15.La Albania	04° 28'	75° 42'	1340	P				
16.Planadas	04° 29'	75° 37'	2350	P				
17.Gibraltar	04° 13'	75° 47'	1650	P				
18.Navarco	04° 29'	75° 34'	2800	P				
19.Cordoba	04° 23'	75° 42'	1490	P				
20.Barragan	04° 20'	75° 47'	1180	P				
21.El Sena	04° 32'	75° 40'	1550	M				
22.La Bella	04° 31'	75° 40'	1450	M				
23.Paraguaycito	04° 23'	75° 44'	1250	M				
24.El Bremen	04° 40'	75° 37'	2040	P				
25.La Argentina	04° 26'	75° 46'	1200	P				

Note :The location of the stations is approximate.
P=Rainfall Station M=Meteorological Station
LAT.=Latitude LONG.=Longitude ACT.=Altitude

Table D.2.1 Summary of Available Data for Climate and Rainfall Stations (2)

Station	LAT.	LONG.	ALT.	Type
26.Vivero	04° 37'	75° 46'	1400	P
27.Maracay	04° 36'	75° 46'	1450	M
28.Yolanda	04° 37'	75° 47'	1320	P
29.El Rocio	04° 34'	75° 46'	1250	P
30.El Agrado	04° 28'	75° 49'	1350	P
31.La Ilusion	04° 36'	75° 39'	1500	P
32.Tucuman	04° 32'	75° 44'	1250	P
33.El Porvenir	04° 19'	75° 45'	1540	P
34.La Esperanza	04° 21'	75° 45'	1400	P
35.La Miranda	04° 26'	75° 50'	1220	P
36.Monaco	04° 24'	75° 40'	1300	P
37.Quebradanegra	04° 31'	75° 38'	1500	P
38.El Paraiso	04° 30'	75° 42'	1400	P
39.Sorrento	04° 32'	75° 51'	1290	P
40.La Pradera	04° 28'	75° 43'	1350	P
41.Amazonas	04° 38'	75° 39'	1750	P
42.Villa Horizaba	04° 12'	75° 44'	1540	P
43.Pueblo Tapao	04° 34'	75° 47'	1250	P
44.Pisamal	04° 26'	75° 48'	1050	M
45.Sevilla	04° 16'	75° 55'	1540	M
46.Alcala	04° 40'	75° 48'	1320	M
47.El Eden	04° 27'	75° 46'	1204	M
48.Pijao	04° 20'	75° 42'	1625	P
49.Salento	04° 38'	75° 34'	1895	P
50.El Alambrado	04° 24'	75° 52'	1100	P

Note :The location of the stations is approximate.
P=Rainfall Station M=Meteorological Station
LAT.=Latitude LONG.=Longitude ACT.=Altitude

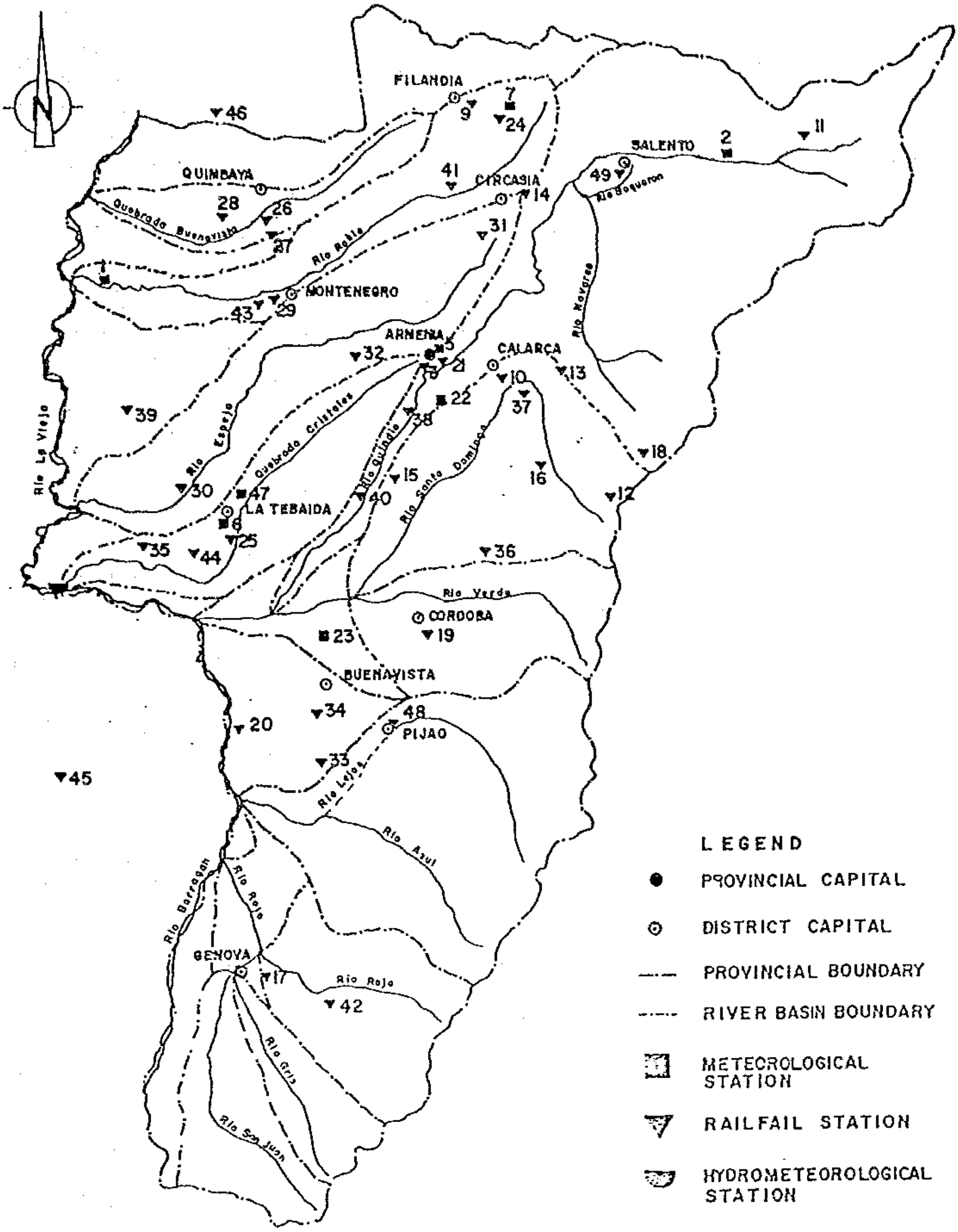


FIG D.2.1 HYDROMETEOROLOGICAL STATIONS IN QUINDIO

D.3 Meteorology

D.3.1 Climate

Except mountain areas, the climate prevailing over the Quindio is warm and humid, and two dry periods (January-February and June-August) and two wet periods (April-May and October-November) are shown in the annual rainfall pattern in general; but depending on the year and location, these characteristic seasonal pattern are not observed. The climate over the the Quindio may be classified by 5 zones as follows;

Classification	Altitude	Area	Annual Rainfall	Mean Temperature
Warm subhumid	900-1,200m	17%	1,900mm	22°C
Warm humid	1,200-1,700m	31%	2,200mm	20°C
Semiwarm humid	1,700-2,300m	21%	2,600mm	15-18°C
Cold humid	2,300-3,000m	17%	2,000mm	10-14°C
Highland cold drizzly humid	over 3,000m	14%	1,800mm	3-10°C

D.3.2 Rainfall

Approximately 2,000mm of the average annual rainfall is assumed in the Quindio, however, depending on the location, the mean annual rainfall varies from 1,500mm to 2,900mm. And the variation of annual rainfall is each year is comparatively large, i.e. sometimes over 3,500mm of annual rainfall was observed of some rainfall station. Considering the mean monthly rainfall, the seasonal rainfall pattern is seen at most of the stations, but not always every year.

Considering the correlation of monthly rainfall between stations, there is no correlation (less than 60%) with those stations located over 30 km away from each others. The rainfall in the Quindio has a tendency to concentrate intensively at small areas for a short period of time.

Examples of the annual rainfall pattern are shown below;

Annual Rainfall Patterns (mm)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
I	88	91	175	216	199	137	85	128	127	218	196	136	1,797
II	119	107	136	213	141	65	54	77	104	195	185	117	1,511
III	175	173	190	242	247	138	107	134	186	268	327	289	2,476
IV	123	116	152	166	157	102	68	90	123	247	175	125	1,643

Notes I : La Espanola (Altitude 975m) , II : Cocora (2,500m)
III: Uni.Quindio (1,550m) , IV : Gibraltar (1,650m)

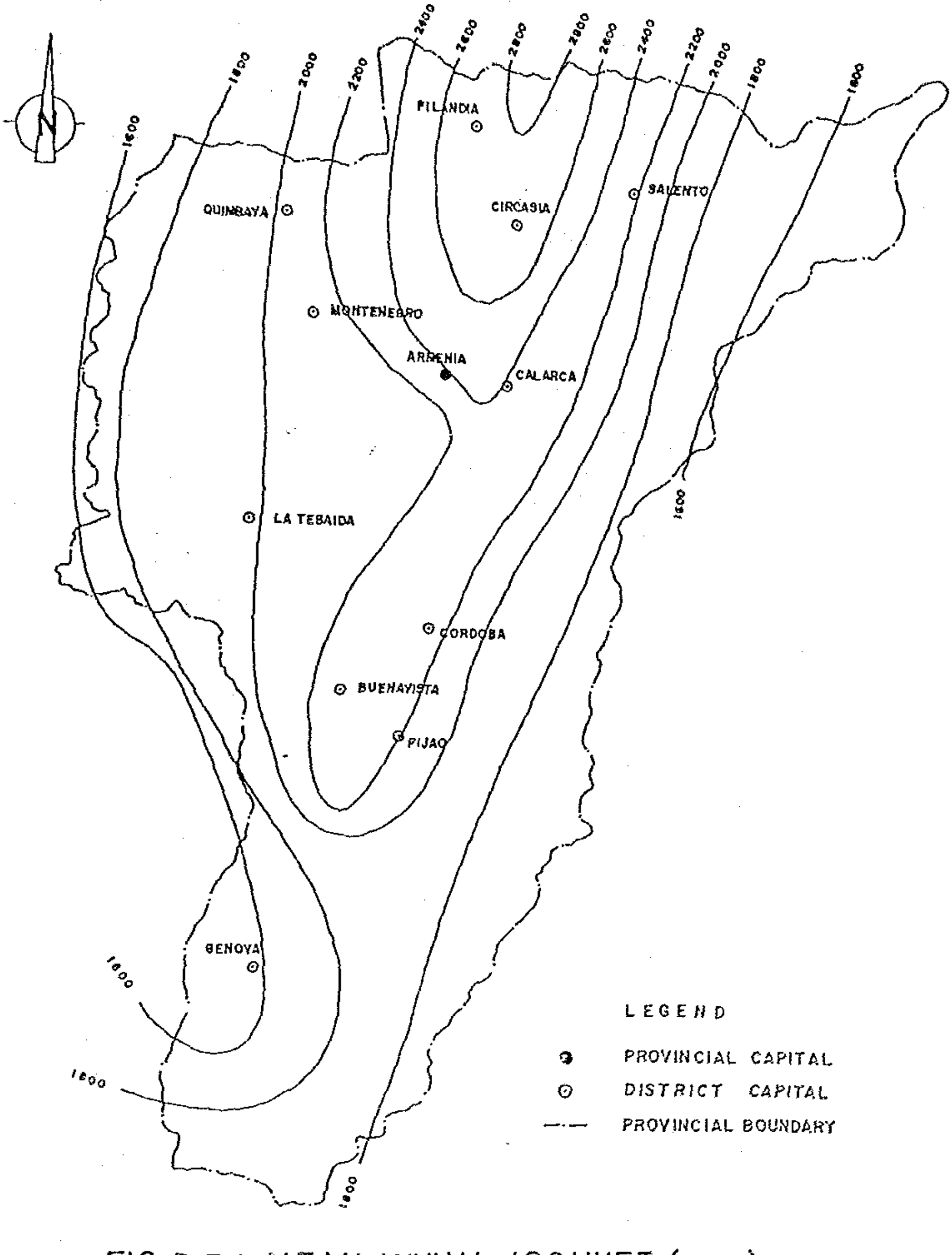


FIG D.3.1 MEAN ANNUAL ISOHYET (mm)

D.3.3 Temperatures

Mean temperatures do not vary considerably throughout the year. The mean maximum and minimum temperatures have a tendency to vary daily depending on the influence of the isolation and rainfall. The difference between the mean maximum and mean minimum temperatures is comparatively large in low altitude areas, and becomes smaller the altitude increases.

Mean Monthly Temperatures (°C)

	La Espanola			Cocora		
	Max.	Mean	Min.	Max.	Mean	Min.
JAN	27.8	21.8	18.5	18.5	13.8	11.1
FEB	27.3	22.2	17.9	18.0	14.3	11.4
MAR	27.6	22.1	18.4	17.7	14.6	11.3
APR	27.1	22.0	18.9	17.4	14.4	11.1
MAY	27.1	21.8	19.1	18.0	14.3	10.9
JUN	26.7	21.5	18.7	18.5	14.3	11.5
JUL	27.4	21.1	18.1	19.5	14.2	11.5
AUG	27.4	21.2	17.9	19.5	14.3	11.0
SEP	27.3	20.9	18.5	18.5	14.0	10.8
OCT	26.4	20.6	18.4	18.5	13.5	11.1
NOV	27.0	21.1	18.6	16.6	13.2	10.8
DEC	27.2	21.3	18.3	18.4	13.5	10.8
MEAN	27.1	21.4	18.4	18.2	14.0	11.03

Note Max. :Mean Maximum Temperature
Min. :Mean Minimum Temperature

D.3.4 Relative Humidity

The relative humidity in the Quindio is generally high, with an annual average of approximately 80%, and variation in the relative humidity is not much depending on the location. Seasonal variation in the relative humidity has a tendency to vary by more or less than 5% between the dry and wet periods, but is not much. Therefore, the relative humidity in the Department of Quindio may be considered constant throughout the year.

Mean Monthly Relative Humidities (%)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
I	81	81	81	83	84	83	79	78	81	83	84	83	82
II	80	80	81	82	82	80	75	75	79	83	86	84	80
III	78	79	80	81	82	80	75	76	80	82	84	81	80
IV	75	75	75	79	81	79	74	73	76	80	80	79	77

Note I :La Espanola (Altitude 975m) II :Cocora (2500m)
III :Uni.Quindio (1550m) IV :Paraguaycito (1250)

D.3.5 Evaporation

An approximate evaporation of 300-400 mm/year is stated in the data (La Espanola, Paraguaycito). However, this value is too low to be applied with no consideration. Based on the rough estimates from the data of river discharge and rainfall, evaporation in this area is estimated to be approximately 1,000mm/year. Therefore, it will be necessary to rectify the data or verify the methods of observation. The comparison of the evaporation data with the potential evapotranspiration calculated by CENICAFE (Garcia-Lopez Method) is as shown below;

Evaporation Data and Potential Evapotranspiration in Paraguaycito (mm)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
EVP	36	42	42	29	31	29	40	39	39	34	28	31	420
ETP	120	104	118	104	101	108	115	115	107	103	97	107	1299

Note EVP :Evaporation
ETP :Potential Evapotranspiration

D.3.6 Duration of Bright Sunshine

The duration of bright sunshine in the Department of Quindio is approximately 1,500-2,000 hours/year. The seasonal pattern of the dry period and the wet period at some stations are clear from the data, but not as are other stations. The duration of bright sunshine in the morning is shorter than that in the afternoon. Considering the longitude of the Quindio, this phenomenon may show a tendency of more cloudy in the morning than in the afternoon, in general. The monthly durations of bright sunshine at several stations are as shown below:

Duration of bright Sunshine (hour)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
I	203	172	170	157	154	168	201	195	174	167	156	170	2086
II	160	127	123	107	112	135	171	160	140	96	92	122	1545
III	139	113	107	128	109	112	142	122	104	97	76	108	1357
IV	197	164	150	134	133	148	183	170	144	139	138	162	1862

Note I :La Espanola (Altitude(75m) II :Cocora (2500m)
III :Uni.Quindio (1550m) IV :Paraguaycito (1250m)

D.3.7 Wind Speed

From the data of wind speed over the Paraguaycito Station, the wind speed in the Quindio may be estimated as 0.86m/s(NW) in the daytime and 0.33m/s(SW) in the nighttime. The maximum wind speed may be considered to be from approximately 15 to 20 m/s. However, due to a lack of the wind data, it is difficult to find out wind characteristics over all areas of the Quindio.

D.4 Hydrology

D.4.1 Rainfall Analysis

(1) Selection of Rainfall Stations

From the results of Coefficient calculation of the monthly rainfall at 50 stations, there is no correlation (less than 60%) between the stations located over 30km away from each others. Therefore, the following 14 rainfall stations were selected for rainfall analysis with consideration to the locations, the accuracy of data, etc.(See Fig.D.4.1)

	Name of Station	Annnual Rainfall (mm)	Observation Period (year)	Area of Thiessen (km2)
1	La Espanola	1,814	14	101.6
2	Cocora	1,570	13	202.0
3	Tebaida	1,972	15	219.4
4	Buenos Aires	2,258	15	96.8
5	Villadora	2,680	15	208.3
6	La Albania	1,857	15	84.7
7	Planadas	2,448	15	92.1
8	Gibraltal	1,730	14	467.2
9	Cordoba	1,942	15	112.2
10	El Sena	2,563	23	93.5
11	La Bella	2,187	35	47.0
12	Paraguaycito	2,141	23	147.6
13	Vivero	2,118	34	275.1
14	Pijao	2,279	11	185.0

(2) The Annual Rainfall Pattern and Effective Rainfall in the Drought Year

The annual rainfall at the selected stations were analyzed probabilistically by the Hazen Plot Method as shown in Fig.D.4.2 and Table D.4.1. Based on the probability of the annual rainfall, the drought design rainfall was estimated as shown in Table D.4.1.

The droughty design effective rainfall patterns were estimated by the method of U.S.Bureau of Reclamation as shown in Table D.4.2.

The average of the total area for the Department of Quindio is as shown below:

Rainfall Pattern and Effective Rainfall
for the Design Year in The Quindio (mm)

Month	Average	Return Period 1/2	1/4	1/5	1/10
JAN	140	136 (94)	114 (86)	109 (84)	98 (78)
FEB	137	133 (93)	112 (85)	107 (83)	96 (77)
MAR	186	180 (103)	151 (99)	144 (97)	129 (93)
APR	238	230 (105)	194 (103)	186 (102)	167 (99)
MAY	205	199 (104)	167 (100)	160 (99)	144 (96)
JUN	120	116 (88)	98 (79)	94 (77)	84 (71)
JUL	82	80 (69)	67 (60)	64 (58)	57 (52)
AUG	110	106 (84)	89 (75)	85 (73)	76 (67)
SEP	141	137 (97)	115 (89)	110 (86)	98 (81)
OCT	264	256 (106)	215 (105)	206 (105)	184 (102)
NOV	254	246 (103)	208 (103)	199 (102)	179 (99)
DEC	173	168 (100)	142 (94)	136 (92)	112 (87)
Annual	2050	1987 (1146)	1670 (1077)	1601 (1057)	1433 (1001)

(3) Maximum 24-hour Rainfall and Rainfall Intensity

The maximum 24-hour rainfall at the selected stations were analyzed probabilistically by the Hazen Plot Method as shown in Fig. D.4.3 and Table D.4.3. The result are summarized below:

Maximum 24-hour Rainfall (mm)

Name of Station	Return Period 1/2	1/5	1/10	1/20
1 La Espanola	61.2	70.8	76.4	81.3
2 Cocora	63.6	81.9	93.5	104.2
3 Tebaida	86.8	105.3	116.4	126.4
4 Buenos Aires	95.9	117.4	130.5	142.3
5 Villadora	99.0	126.2	143.9	159.9
6 La Albania	90.2	108.3	119.2	129.0
7 Planadas	112.0	144.3	164.7	183.6
8 Gibraltal	56.3	76.4	89.6	102.1
9 Cordoba	74.3	90.6	100.6	109.5
10 El Sena	92.9	112.3	124.0	134.5
11 La Vella	81.2	99.7	111.0	121.2
12 Paraguaycito	81.3	92.8	99.5	105.4
13 Vivero	65.2	80.6	90.1	98.6
14 Pijao	85.6	105.3	117.3	128.1

Due to a the lack of hourly rainfall data, rainfall intensity was estimated using the following formula;

i=R24/24*(24/t)^n

where i : Rainfall Intensity (mm/hour)
R24 : 24-hour rainfall (mm)

t : Duration Time (hour)
n : Coefficient from 1/2 to 2/3

(4) Continuous Drought Days

The continuous drought days at Paraguaycito and La Bella were analyzed probabilistcally by the Hazen Plot Method as shown in Fig.D.4.4 and Table D.4.4. The averages of those are approximately 20 days and the maximum data on the last 35 years is approximately 40 days. The results are summarized below:

Continuous Drought Days

Return Period	1/2	1/5	1/10	1/20
Paraguaycito	18.9	26.2	31.2	35.9
La Vella	19.3	26.8	31.9	36.7

(5) Rainfall Trend

The rainfall mass curves of Paraguaycito, La Bella and Vivero Stations were plotted in Fig.D.4.5 for understanding of the rainfall trend of the past 30 years. It can be assumed that there is approximately 20-year intervals in the rainfall trend and the same characteristics can be seen in the same period at these stations. Now (1986-1987) may be the time when the for the tendency is changing from decrease to increase and it may be expected that the rainfall in the Quindio will increase as compared with the the past 10 years.

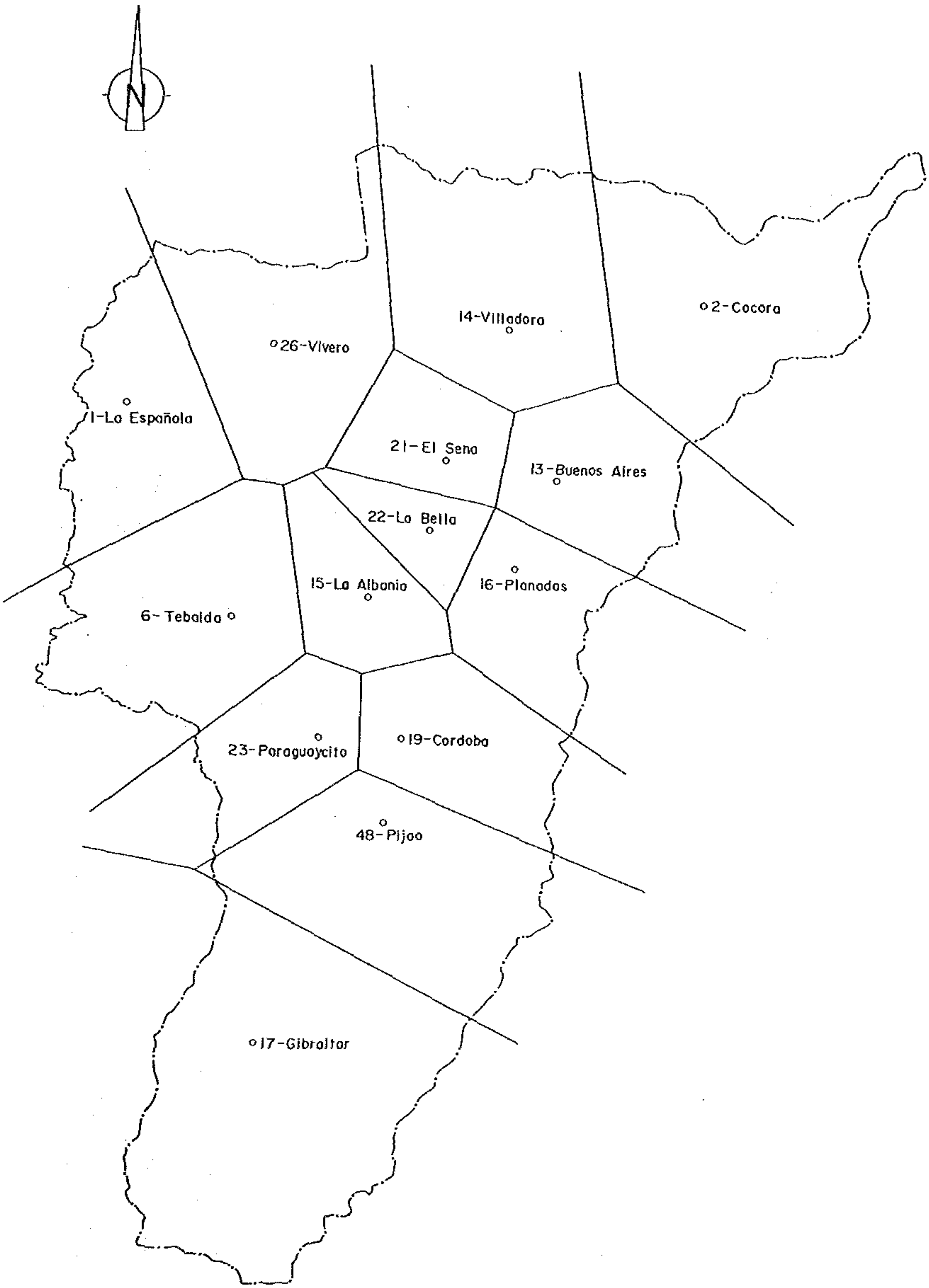


FIG. D.4.1 LOCATION OF RAINFALL STATION SELECTED

Table D.4.1 Probability of Annual Rainfall (Station LA ESPANOLA)

Year	Annual Rainfall [mm]	No.	Data(year) [mm]	Ratio Xi/Xo	Probability [%]
1972	1379	1	1379(1972)	0.760	3.85
1973	----	2	1518(1985)	0.837	11.54
1974	2272	3	1552(1980)	0.856	19.23
1975	1961	4	1591(1976)	0.877	26.92
1976	1591	5	1651(1979)	0.910	34.62
1977	1912	6	1690(1978)	0.932	42.31
1978	1690	7	1707(1983)	0.941	50.00
1979	1651	8	1912(1977)	1.054	57.69
1980	1552	9	1925(1982)	1.061	65.38
1981	1964	10	1961(1975)	1.081	73.08
1982	1925	11	1964(1981)	1.083	80.77
1983	1707	12	2272(1974)	1.253	88.46
1984	2457	13	2457(1984)	1.355	96.15
1985	1518				

Total Xs= 23579 mm Average Xo= 1813.8 mm

Probability [mm]	Return Period [year]	Ratio Xi/Xo	Rainfall [mm]
5%	20	0.748	1358
10%	10	0.795	1443
20%	5	0.857	1554
25%	4	0.881	1598
33%	3	0.917	1662
50%	2	0.987	1791

Rainfall Patern and Effective Rainfall for Design Year at LA ESPANOLA

Month	13 Years Average	Return Period			
		1/2	1/5	1/10	1/20
1	89	88(76)	76(68)	71(64)	67(60)
2	92	91(78)	79(70)	73(65)	69(62)
3	177	174(103)	151(102)	141(99)	132(96)
4	218	215(106)	187(104)	174(103)	163(103)
5	201	198(105)	172(103)	160(103)	150(102)
6	138	137(97)	119(91)	110(88)	104(85)
7	86	85(74)	74(66)	68(62)	64(58)
8	129	128(94)	111(88)	103(85)	97(81)
9	128	127(94)	110(88)	102(85)	96(81)
10	220	217(106)	189(105)	175(103)	165(103)
11	198	195(105)	170(103)	157(103)	148(101)
12	137	136(97)	118(91)	109(88)	103(85)
Annual	1814	1791(1135)	1554(1079)	1443(1047)	1358(1018)

( ) : Effective Rainfall [mm]

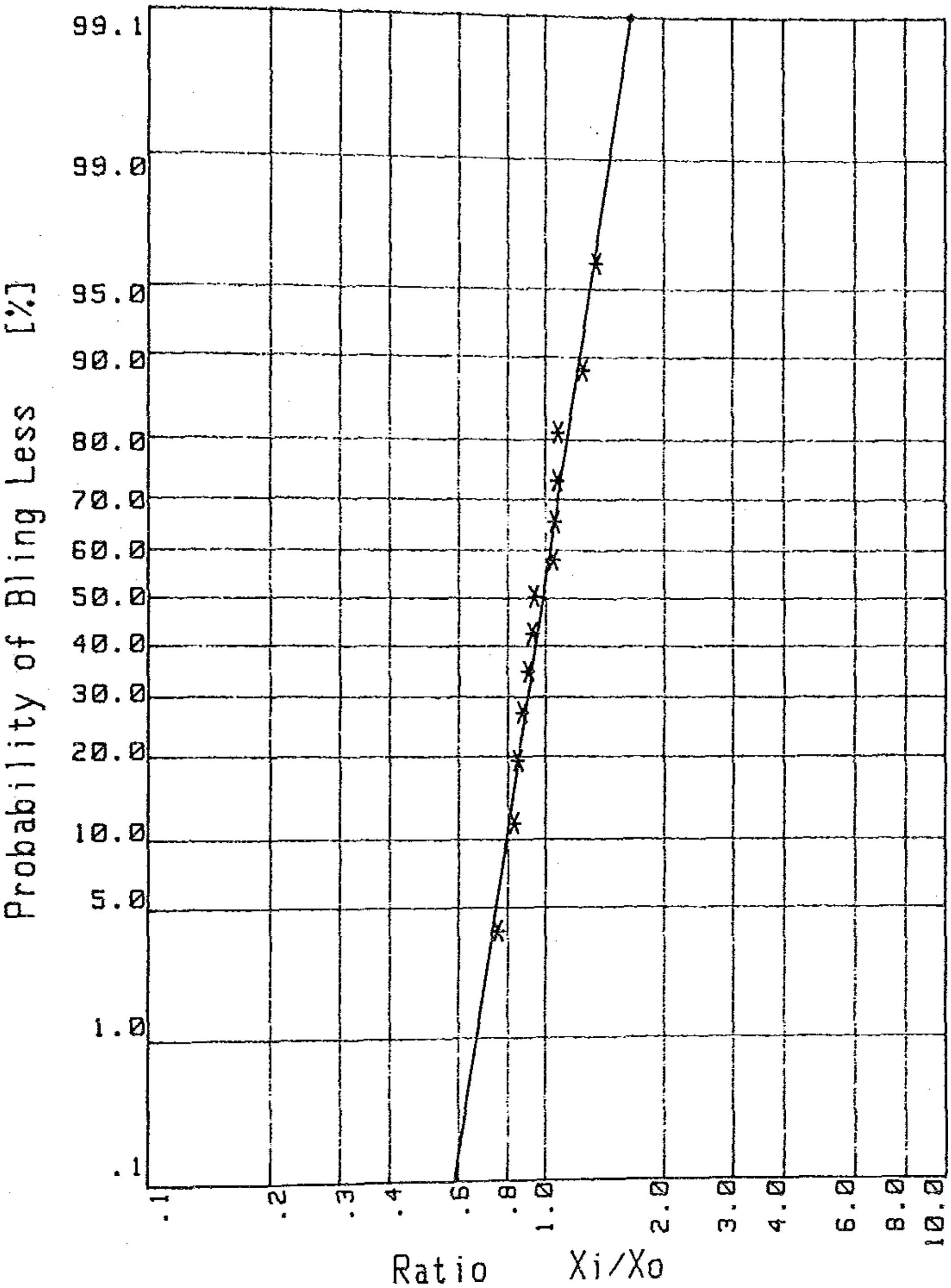
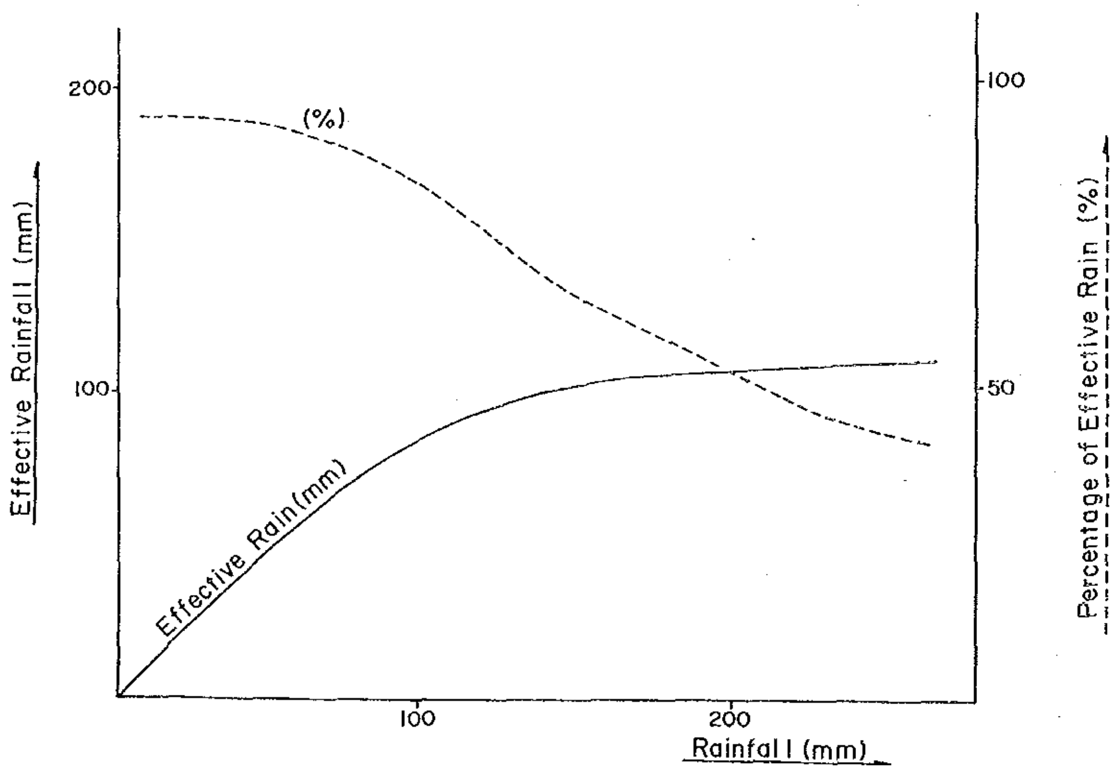


FIG.D.4.2 Probability of Annual Rainfall
(Station LA ESPANOLA)

TABLE D.4.2 RELATIONSHIP BETWEEN RAINFALL AND EFFECTIVE RAINFALL

Rainfall		Effective Rainfall		
inches	mm	inches	mm	%
1	25.4	0.95	24.13	95
2	50.8	1.85	46.99	93
3	76.2	2.67	67.82	89
4	101.6	3.32	84.33	83
5	127.0	3.79	96.87	74
6	152.4	4.02	102.11	67
7	177.8	4.07	103.38	58
8	203.2	4.12	104.65	52
9	228.6	4.17	105.92	46
10	254.0	4.22	107.19	42



EFFECTIVE RAINFALL

Table D.4.3 Probability of Maximum 24-hour Rainfall (Station LA ESPANOLA)

Year	24 Max. Rainfall [mm]	No.	Data(year) [mm]	Ratio Xi/Xo	Probability [%]
1972	58.5	1	85.0(1974)	1.370	3.85
1973	----	2	79.0(1979)	1.273	11.54
1974	85.0	3	70.0(1978)	1.128	19.23
1975	46.5	4	68.3(1981)	1.101	26.92
1976	52.9	5	62.7(1982)	1.011	34.62
1977	55.1	6	60.0(1985)	0.967	42.31
1978	70.0	7	58.5(1972)	0.943	50.00
1979	79.0	8	57.0(1983)	0.919	57.69
1980	56.3	9	56.3(1980)	0.908	65.38
1981	68.3	10	55.2(1984)	0.890	73.08
1982	62.7	11	55.1(1977)	0.888	80.77
1983	57.0	12	52.9(1976)	0.853	88.46
1984	55.2	13	46.5(1975)	0.750	96.15
1985	60.0				

Total Xs= 806.5 mm Average Xo= 62.0 mm

Hazen Plot

Probability	Return Period [year]	Ratio Xi/Xo	Rainfall [mm]
5%	20	1.311	81.3
10%	10	1.232	76.4
20%	5	1.141	70.8
25%	4	1.109	68.8
33%	3	1.065	66.1
50%	2	0.987	61.2

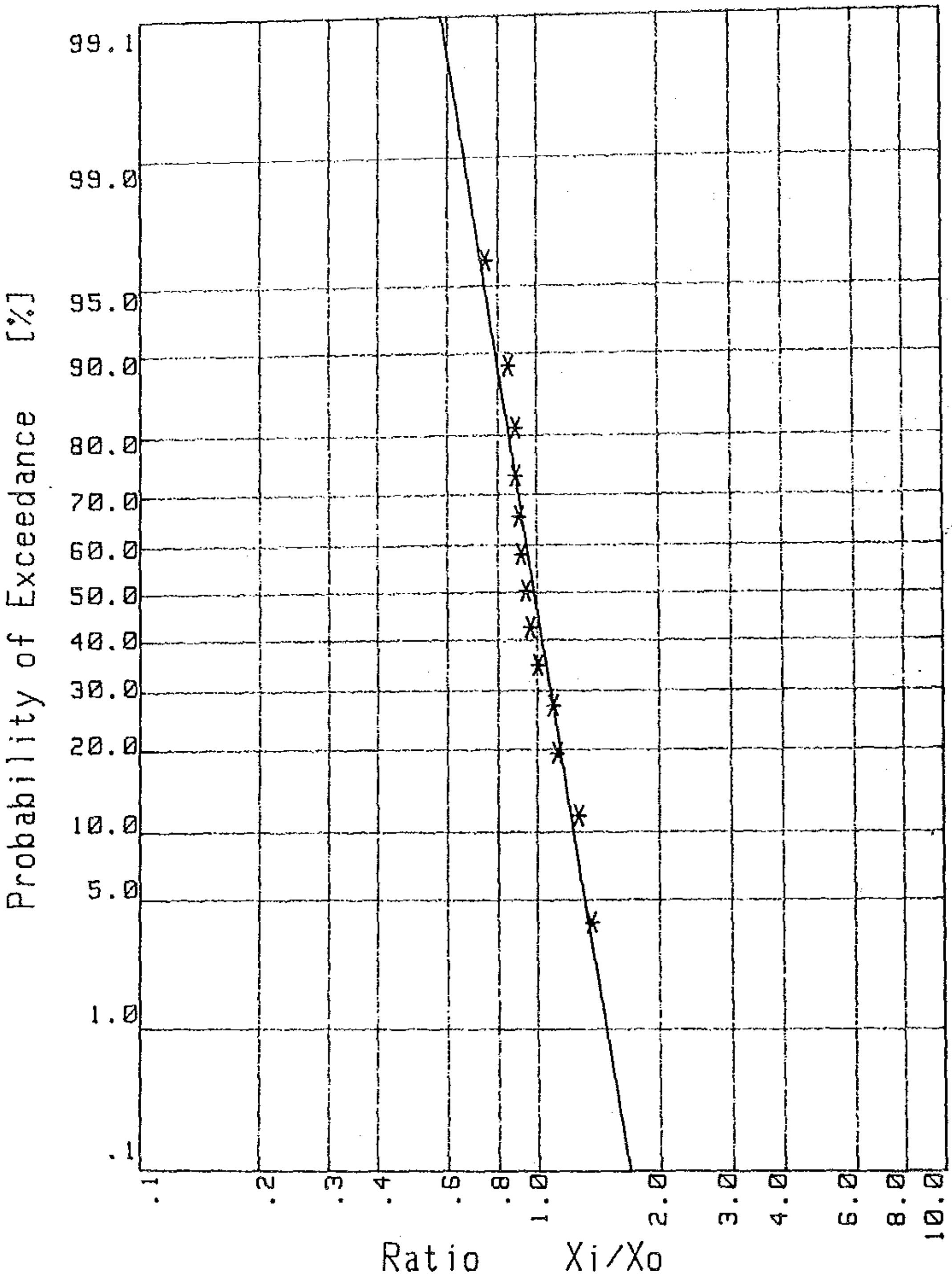


FIG.D.4.3 Probability of Maximum 24-hour Rainfall
(Station LA ESPANOLA)

Table D.4.4 Probability of Continuous Drought Days (Station LA BELLA)

Year	Maximum [days]	No.	Data(year) [days]	Ratio Xi/Xo	Probability [%]
1951	17	1	8(1971)	0.385	1.56
1952	20	2	11(1962)	0.529	4.69
1953	31	3	12(1980)	0.577	7.81
1954	15	4	13(1975)	0.626	10.94
1955	13	5	13(1955)	0.626	14.06
1956	16	6	14(1967)	0.674	17.19
1957	16	7	14(1966)	0.674	20.31
1958	38	8	15(1954)	0.722	23.44
1959	17	9	15(1974)	0.722	26.56
1960	----	10	16(1956)	0.770	29.69
1961	20	11	16(1970)	0.770	32.81
1962	11	12	16(1957)	0.770	35.94
1963	19	13	16(1984)	0.770	39.06
1964	----	14	17(1959)	0.818	42.19
1965	21	15	17(1951)	0.818	45.31
1966	14	16	18(1981)	0.866	48.44
1967	14	17	19(1963)	0.914	51.56
1968	27	18	20(1952)	0.962	54.69
1969	----	19	20(1961)	0.962	57.81
1970	16	20	20(1979)	0.962	60.94
1971	8	21	21(1965)	1.011	64.06
1972	30	22	23(1985)	1.107	67.19
1973	24	23	24(1973)	1.155	70.31
1974	15	24	25(1978)	1.203	73.44
1975	13	25	25(1977)	1.203	76.56
1976	39	26	27(1968)	1.299	79.69
1977	25	27	30(1972)	1.444	82.81
1978	25	28	31(1953)	1.492	85.94
1979	20	29	33(1982)	1.588	89.06
1980	12	30	38(1958)	1.829	92.19
1981	18	31	39(1976)	1.877	95.31
1982	33	32	39(1983)	1.877	98.44
1983	39				
1984	16				
1985	23				

Total Xs= 665 days Average Xo= 20.8 days

Probability	Return Period [year]	Ratio Xi/Xo	Maximum [days]
5%	20	0.489	10
10%	10	0.563	12
20%	5	0.669	14
25%	4	0.714	15
33%	3	0.782	16
50%	2	0.930	19

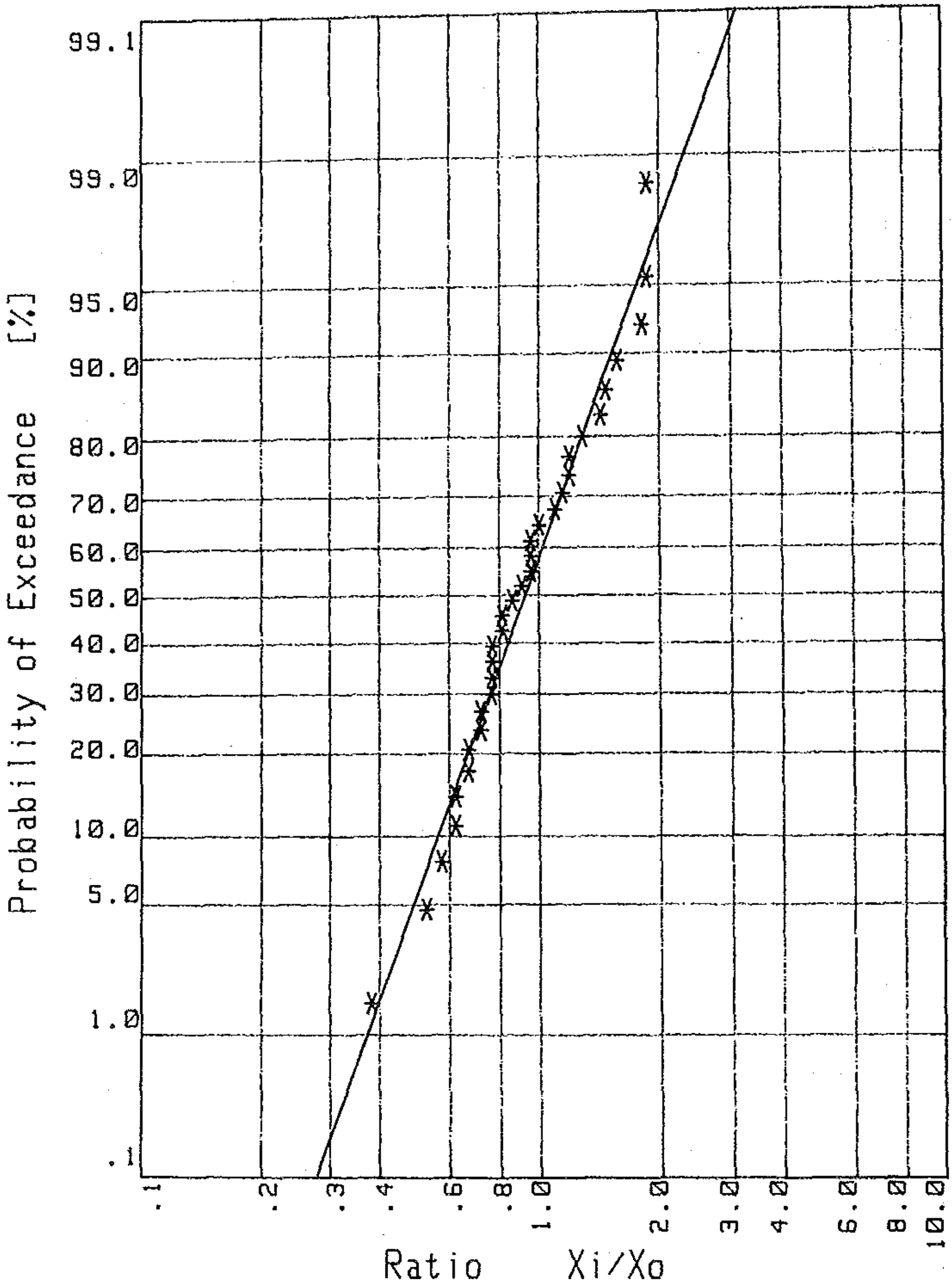


FIG.D.4.4 Probability of Continuous Drought Days
(Station LA BELLA)

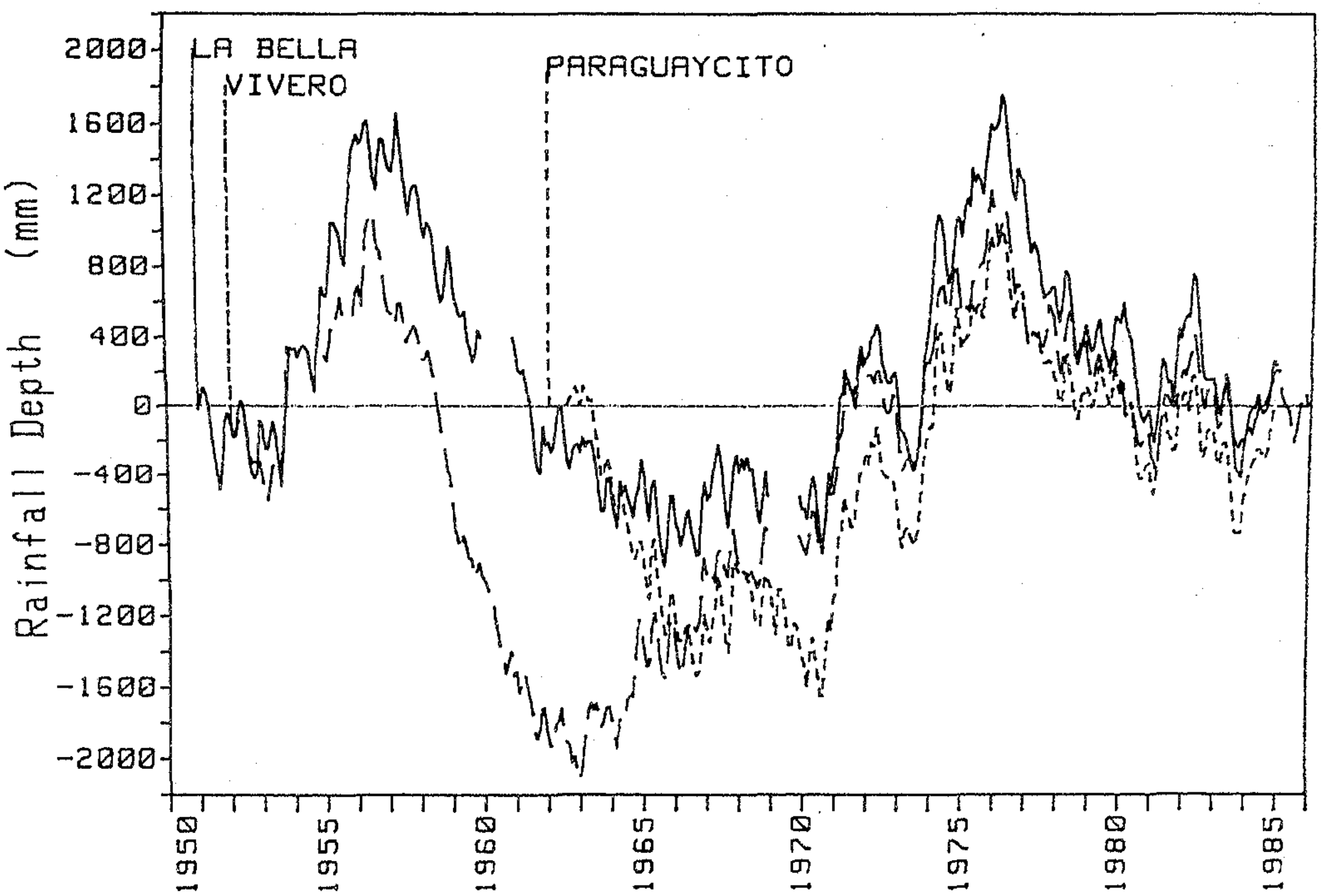
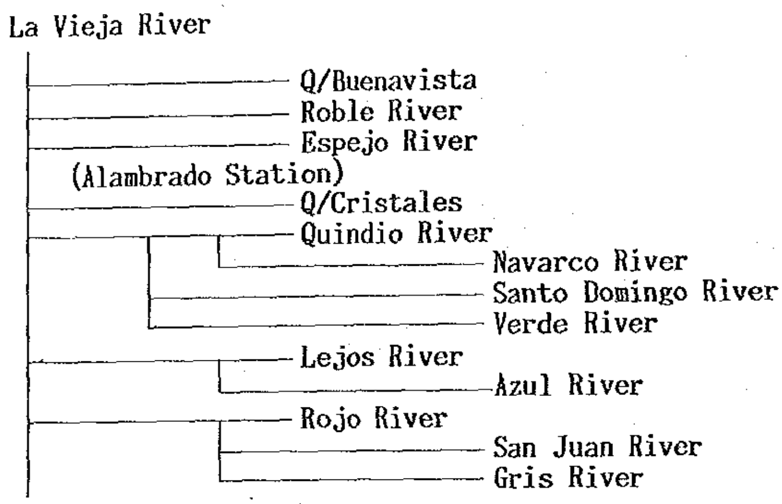


FIG.D.4.5 Rainfall Mass Curve

D.4.2 Runoff Analysis

(1) The Basin of the Quindio

All river in the Quindio belong to the La Vieja River System, and this area may be divided into thirteen(13) main catchment areas as follows(See Fig.D.4.6). The hydrological station at the Alambrado bridge over the La Vieja River covers ten(10) of those areas (70% of the total area of the Department of Quindio), and, except Q/Cristales, all the main rivers in these nine(9) catchment areas originate in the Central Range of the Andes.



For altitude, these catchment areas can be divided into three(3) zones, as follows;

a) Low area : Under approximately 1,200m of altitude
b) Middle area : Approximately 1,200 - 2,000m of altitude
c) Mountain area : Over approximately 2,000m of altitude

The river profile varies by point from 1,500 to 2,000m of altitude, and the longitudinal river slope is approximately 2% downstream and 20% upstream.

(2) Low Flow Analysis

The data of river discharge at the Alambrado bridge (1974-1985) was analyzed for low flow, and the droughty water discharge was estimated by using the specific discharge.

1) Discharge Data

The Daily discharge data of the last twelve(12) years was summarized below:

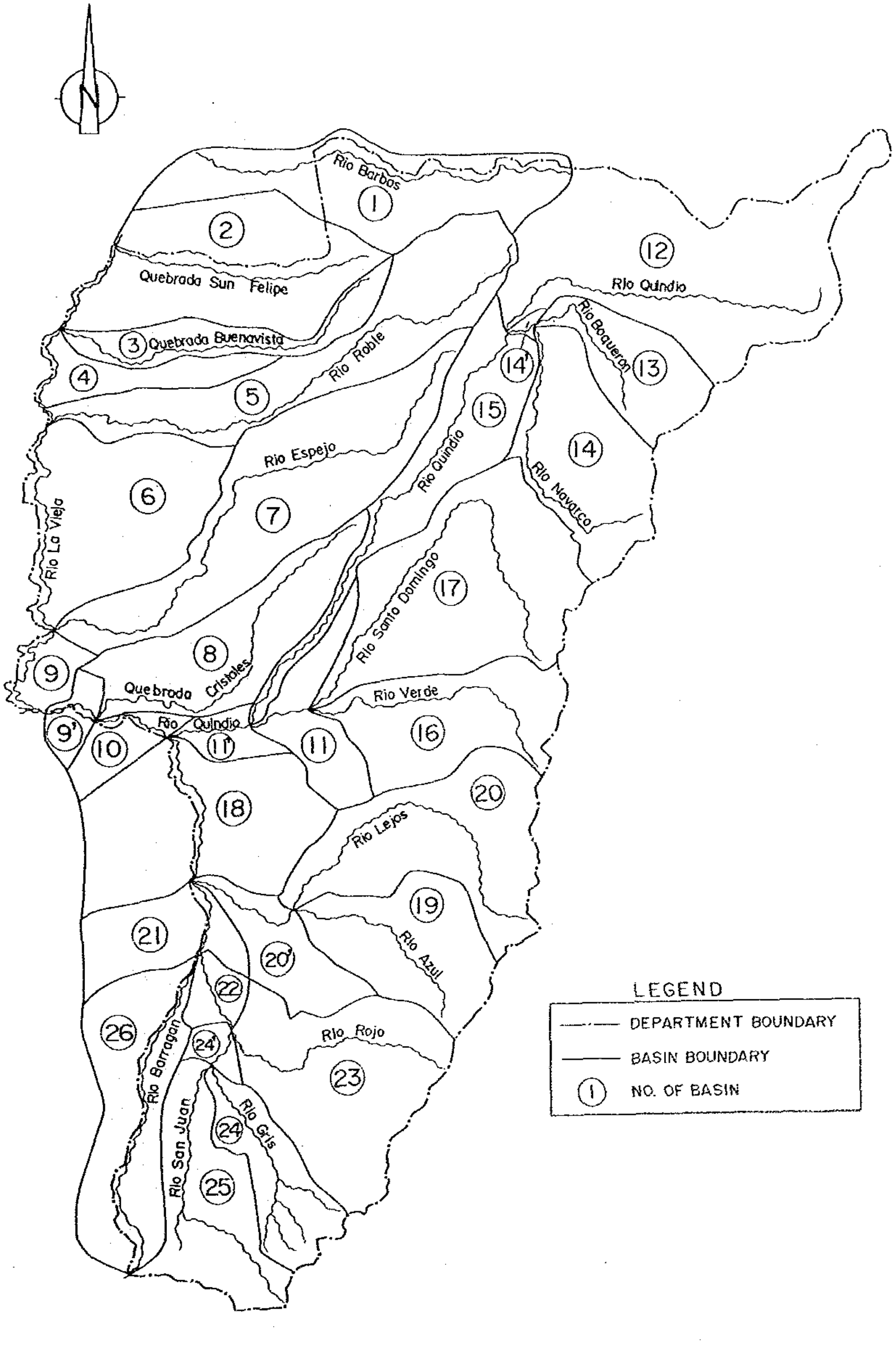


FIG. D.4.6 THE CATCHMENT BASIN OF THE QUINDIO

Summaly of River Discharge at Alambrado (m3/s)

Month	Mean	Maximum	Minimum
JAN	69.3	435.0	19.0
FEB	59.6	299.0	11.8
MAR	57.0	352.0	10.1
APR	74.9	386.2	15.0
MAY	75.5	253.5	17.0
JUN	50.6	271.5	22.4
JUL	32.4	144.8	13.6
AUG	21.2	78.5	7.8
SEP	22.5	92.0	7.5
OCT	52.3	340.5	6.8
NOV	88.3	348.5	15.2
DEC	71.4	313.0	21.0
ANNUAL	56.1	435.0	6.8

2) Droughty Water Discharge

The droughty water discharge was analyzed probabilistically by the Hazen Plot Method as shown in Fig.D.4.7 and Table D.4.5. The result are summarized below:

Droughty Water Discharge

Return Period	1/2	1/5	1/10	1/20
Discharge (m3/s)	11.6	8.3	6.9	6.0
Specific Discharge (l/s/km2)	7.14	5.08	4.25	3.68

3) Runoff Pattern of the Droughty Year

The annual mean runoff discharge was analyzed probabilistically by the Hazen Plot Method as shown in Fig.D.4.8 and Table D.4.6 for the estimation of the runoff pattern of the droughty year. The results are summarized below:

Runoff Pattern of the Droughty Year (m3/s)

Return Period	1/2	1/4	1/5	1/10
JAN	66.2(40.8)	53.4(32.9)	50.6(31.2)	44.0(27.1)
FEB	57.0(35.1)	45.9(28.3)	43.5(26.8)	37.8(23.3)
MAR	54.5(33.6)	43.9(27.0)	41.6(25.6)	36.2(22.3)
APR	71.6(44.1)	57.7(35.5)	54.7(33.7)	47.5(29.3)
MAY	72.2(44.8)	58.2(35.8)	55.2(34.0)	47.9(29.5)
JUN	48.4(29.8)	39.0(24.0)	37.0(22.8)	32.1(19.8)
JUL	31.0(19.1)	25.0(15.4)	23.7(14.6)	20.6(12.7)
AUG	20.3(12.5)	16.3(10.1)	15.5(9.5)	13.5(8.5)
SEP	21.5(13.2)	17.3(10.7)	16.4(10.1)	14.3(8.8)
OCT	50.0(30.8)	40.3(24.8)	38.2(23.5)	33.2(20.4)
NOV	84.4(52.0)	68.0(41.9)	64.5(39.7)	56.0(34.5)
DEC	68.2(42.0)	55.0(33.9)	52.2(32.1)	45.3(27.9)
ANNUAL	53.8(33.1)	43.3(26.7)	41.1(25.3)	35.7(22.0)

Note :( ) represents Specific Discharge l/s/km2

Table D.4.5 Probability of Droughty Water Discharge (Station ALAMBRADO)

Year	Minimum Discharge [m3/S]	No.	Data(year) [m3/s]	Ratio Xi/Xo	Probability [%]
1974	15.0	1	6.8(1978)	0.544	4.17
1975	26.4	2	8.0(1976)	0.640	12.50
1976	8.0	3	8.0(1983)	0.640	20.83
1977	10.1	4	9.4(1979)	0.751	29.17
1978	6.8	5	10.1(1977)	0.807	37.50
1979	9.4	6	10.7(1982)	0.855	45.83
1980	10.8	7	10.8(1980)	0.863	54.17
1981	12.3	8	12.3(1981)	0.983	62.50
1982	10.7	9	12.9(1985)	1.031	70.83
1983	8.0	10	15.0(1974)	1.199	79.17
1984	19.7	11	19.7(1984)	1.575	87.50
1985	12.9	12	26.4(1975)	2.111	95.83
Total	Xs=	150.1 m3/s	Average	Xo=	12.5 m3/s

Probability [%]	Return Period [year]	Ratio Xi/Xo	Minimum Discharge [m3/s]	[l/s/km2]	[mm/day]
5%	20	0.477	6.0	3.677	0.318
10%	10	0.552	6.9	4.254	0.368
20%	5	0.660	8.3	5.083	0.439
25%	4	0.706	8.8	5.435	0.470
33%	3	0.776	9.7	5.975	0.516
50%	2	0.927	11.6	7.141	0.617

* Area of Basin = 1623.88 km2

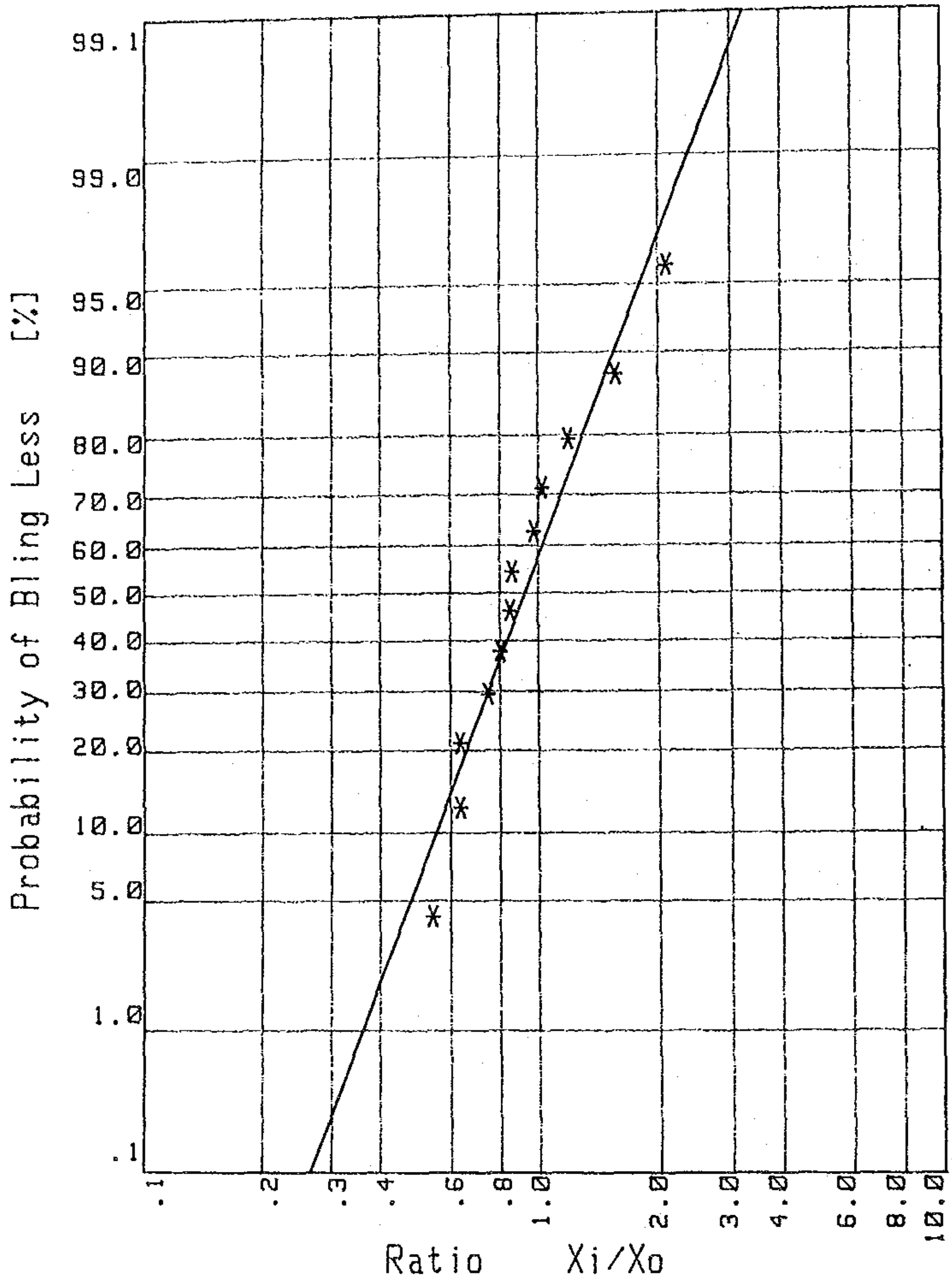


FIG.D.4.7 Probability of Droughty Water Discharge
(Station ALAMBRADO)

Table D.4.6 Probability of Mean River Discharge (Station ALAMBRADO)

Year	Mean Discharge [m3/S]	No.	Data(year) [m3/s]	Ratio Xi/Xo	Probability [%]
1974	88.9	1	30.8(1977)	0.548	4.17
1975	77.1	2	36.8(1983)	0.655	12.50
1976	53.1	3	40.1(1978)	0.713	20.83
1977	30.8	4	43.2(1980)	0.769	29.17
1978	40.1	5	51.8(1979)	0.922	37.50
1979	51.8	6	53.1(1976)	0.945	45.83
1980	43.2	7	57.7(1981)	1.027	54.17
1981	57.7	8	60.0(1985)	1.067	62.50
1982	65.9	9	65.9(1982)	1.172	70.83
1983	36.8	10	69.1(1984)	1.229	79.17
1984	69.1	11	77.1(1975)	1.372	87.50
1985	60.0	12	88.9(1974)	1.582	95.83

Total Xs= 674 m3/s Average Xo= 56.2 m3/s

Probability [%]	Return Period [year]	Ratio Xi/Xo	Mean Discharge [m3/s]
5%	20	0.566	31.8
10%	10	0.635	35.7
20%	5	0.731	41.1
25%	4	0.771	43.3
33%	3	0.831	46.7
50%	2	0.957	53.8

Discharge Patern and Specific Discharge for Design Year at ALAMBRADO

Month	12 Years Average	Return Period			
		1/2	1/5	1/10	1/20
1	69.2	66.2(40.8)	50.6(31.2)	44.0(27.1)	39.2(24.1)
2	59.6	57.0(35.1)	43.5(26.8)	37.8(23.3)	33.7(20.8)
3	57.0	54.5(33.6)	41.6(25.6)	36.2(22.3)	32.2(19.9)
4	74.8	71.6(44.1)	54.7(33.7)	47.5(29.3)	42.4(26.1)
5	75.4	72.2(44.4)	55.2(34.0)	47.9(29.5)	42.7(26.3)
6	50.6	48.4(29.8)	37.0(22.8)	32.1(19.8)	28.6(17.6)
7	32.4	31.0(19.1)	23.7(14.6)	20.6(12.7)	18.3(11.3)
8	21.2	20.3(12.5)	15.5(9.5)	13.5(8.3)	12.0(7.4)
9	22.5	21.5(13.2)	16.4(10.1)	14.3(8.8)	12.7(7.8)
10	52.3	50.0(30.8)	38.2(23.5)	33.2(20.4)	29.6(18.2)
11	88.2	84.4(52.0)	64.5(39.7)	56.0(34.5)	49.9(30.8)
12	71.3	68.2(42.0)	52.2(32.1)	45.3(27.9)	40.4(24.9)
Annual	56.2	53.8(33.1)	41.1(25.3)	35.7(22.0)	31.8(19.6)

( ) : Specific Discharge [l/s/km2]

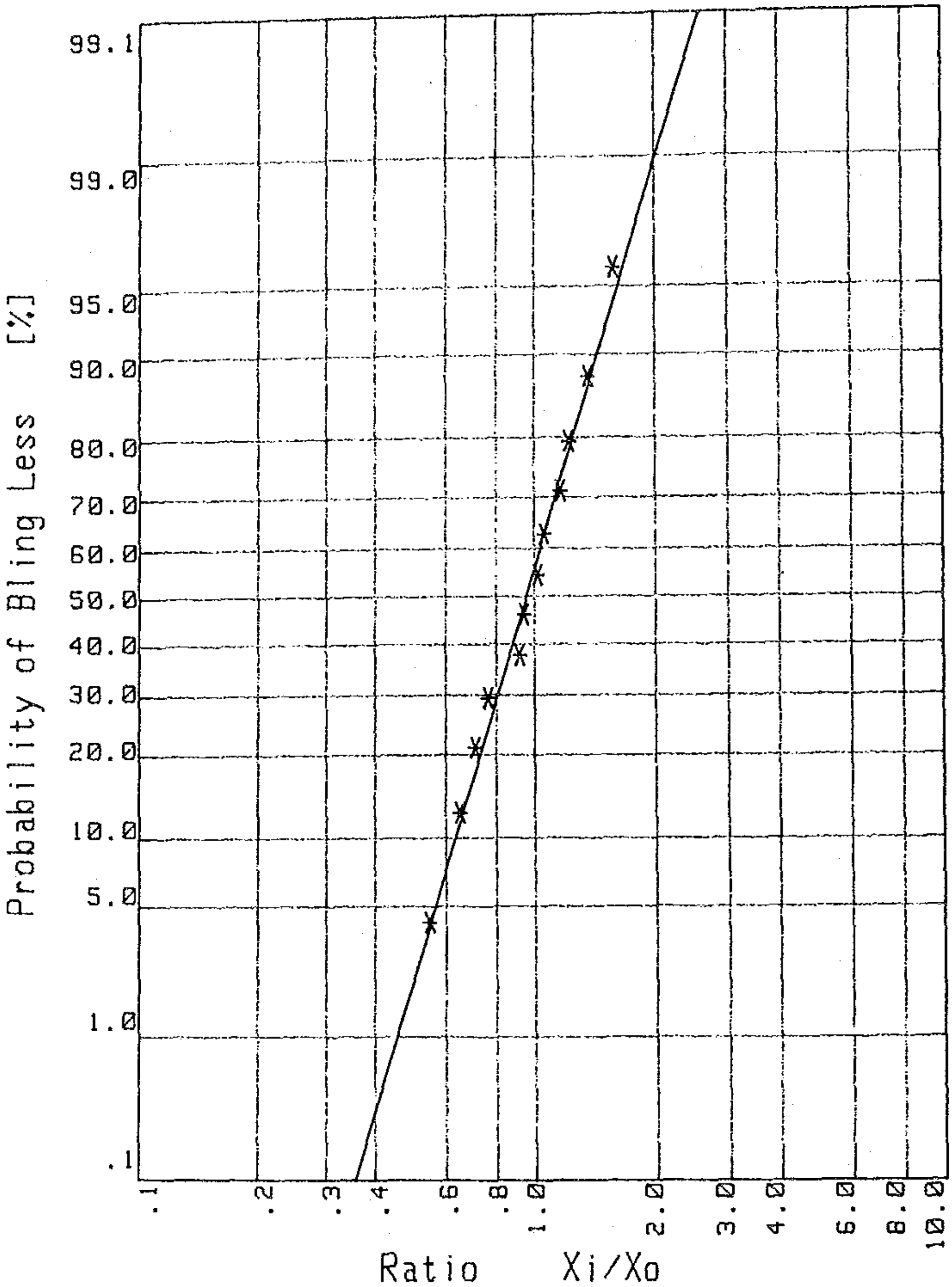


FIG.D.4.8 Probability of Mean River Discharge (Station ALAMBRADO)

Approximately 2000mm of the annual rainfall in the Quindio can be stimated. Approximately 1000mm of the annual runoff at the Alambrado Station is observed. It can be assumed that 50% of the rainfall will became surface runoff.

4) Correlation with Other Data Observed by CRQ

The discharge data, not dominated by rainfall, was selected from the data observed by CRQ at other points, and compared with the data of Alambrado by using specific discharge and the correlation coefficient was calculated as 87% (See Fig.D.4.9). Because of the consideration that the droughty water discharge may not be influenced by rainfall, the result of these low flow analysis can be applied for the estimation of the droughty water discharge at other points in the Quindio, using specific water.

(3) Flood Analysis

Flood analysis was carried out by applying the Rational Formula, considering 27 of the catchment areas with the main rivers (See Fig.D.4.6).

1) Treatment of Rainfall

Basically the compound rainfall by the Thiessen Method was applied, but each rainfall station is probabilistically independent, therefore, in the case of using plural rainfall stations, but following probability was applied.

P'=(P^(1/N))^(1/2)

where P': the Probability Applied
P : the Probability of the Return Period
N : the Number of Rainfall Stations

2) Runoff Coefficient

With account taken into the characteristics of the catchment areas, the following runoff coefficient was applied;

Mountain Area	:	0.8
Middle Area	:	0.5
Low Area	:	0.3

In the case of the compound catchment area, the compound runoff coefficient was applied.

3) Analysis Results

Analysis results are shown in Table D.4.7 and summarized as follows;

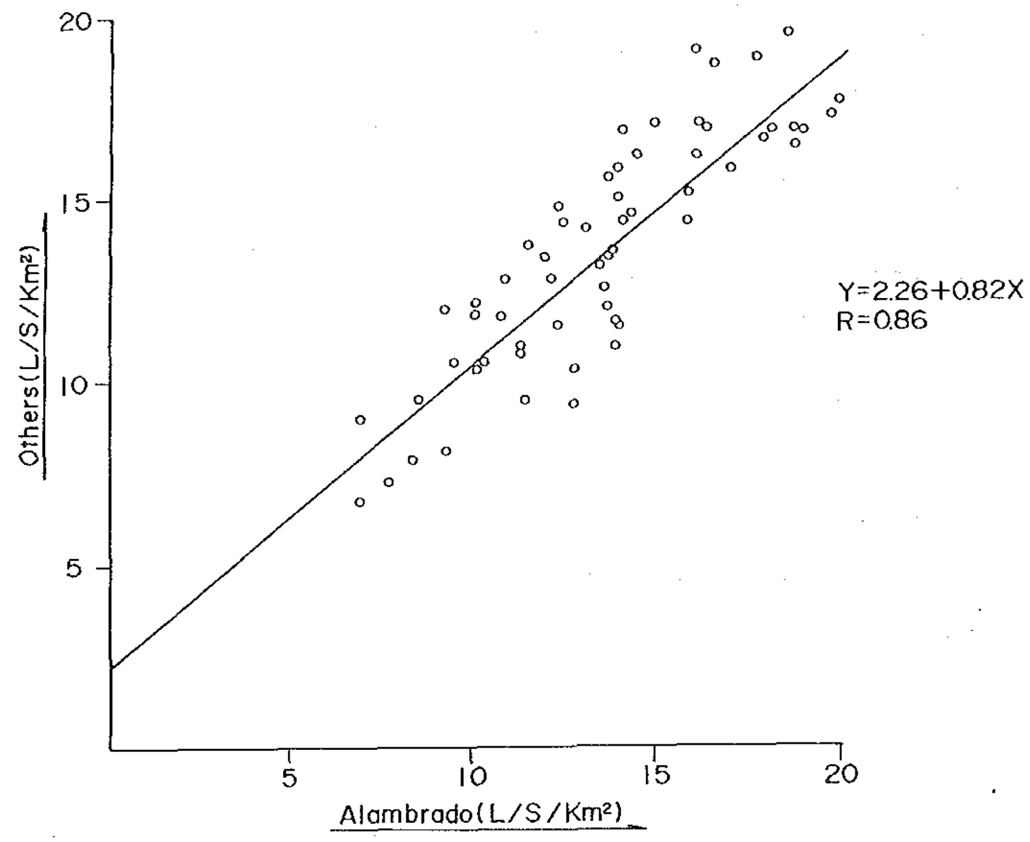


FIG. D.4.9 RELATIONSHIP OF THE SPECIFIC DISCHARGE BETWEEN ALAMBRADO STATION AND OTHERS

Table D.4.7 Flood Discharge (1)

BASIN	DIMENSIONS	ITEM	RETURN PERIOD 1/2	1/3	1/4	1/5	1/10	1/20
12	A= 185.98km2	R24 (It)	63.2 (16.3)	71.0 (18.3)	75.8 (19.5)	79.2 (20.4)	89.0 (22.9)	98.0 (25.3)
	F= .80	Qpeak(mean)	673.7 (336.8)	756.2 (378.1)	807.2 (403.6)	843.8 (421.9)	947.6 (473.8)	1044.0 (522.0)
	T= 1.560hr	qs (mean)	3.622 (1.811)	4.066 (2.033)	4.340 (2.170)	4.537 (2.268)	5.095 (2.548)	5.614 (2.807)
13	A= 51.81km2	R24 (It)	61.0 (39.0)	67.9 (43.4)	72.1 (46.1)	75.1 (48.0)	83.5 (53.4)	91.1 (58.3)
	F= .80	Qpeak(mean)	449.5 (224.8)	500.2 (250.1)	530.8 (265.4)	552.9 (276.4)	614.7 (307.4)	670.9 (335.4)
	T= .399hr	qs (mean)	8.677 (4.338)	9.654 (4.827)	10.246 (5.123)	10.671 (5.335)	11.865 (5.932)	12.949 (6.475)
14	A= 74.35km2	R24 (It)	83.9 (23.1)	91.5 (25.3)	96.1 (26.5)	99.3 (27.4)	108.3 (29.9)	116.1 (32.0)
	F= .80	Qpeak(mean)	382.4 (191.2)	417.2 (208.6)	438.0 (219.0)	452.7 (226.4)	493.5 (246.8)	529.2 (264.6)
	T= 1.409hr	qs (mean)	5.143 (2.571)	5.611 (2.806)	5.891 (2.946)	6.089 (3.045)	6.638 (3.319)	7.118 (3.559)
14'	A= 128.16km2	R24 (It)	73.9 (19.8)	81.1 (21.7)	85.4 (22.9)	88.4 (23.7)	96.9 (25.9)	104.3 (27.9)
	F= .80	Qpeak(mean)	563.8 (281.9)	618.4 (309.2)	651.1 (325.5)	674.3 (337.2)	738.9 (369.5)	795.8 (397.9)
	T= 1.473hr	qs (mean)	4.399 (2.200)	4.825 (2.412)	5.080 (2.540)	5.262 (2.631)	5.766 (2.883)	6.209 (3.105)
16	A= 82.01km2	R24 (It)	73.7 (21.0)	80.8 (23.0)	85.1 (24.3)	88.1 (25.1)	96.6 (27.6)	104.3 (29.7)
	F= .80	Qpeak(mean)	383.0 (191.5)	420.1 (210.0)	442.3 (221.1)	458.2 (229.1)	502.3 (251.2)	542.0 (271.0)
	T= 1.340hr	qs (mean)	4.670 (2.335)	5.122 (2.561)	5.393 (2.697)	5.587 (2.793)	6.125 (3.063)	6.609 (3.304)
17	A= 155.14km2	R24 (It)	81.5 (11.0)	88.9 (12.0)	93.3 (12.6)	96.4 (13.0)	104.9 (14.1)	112.4 (15.1)
	F= .80	Qpeak(mean)	378.5 (189.2)	412.6 (206.3)	433.0 (216.5)	447.5 (223.7)	487.0 (243.5)	521.8 (260.9)
	T= 4.132hr	qs (mean)	2.440 (1.220)	2.660 (1.330)	2.791 (1.396)	2.884 (1.442)	3.139 (1.570)	3.363 (1.682)
19	A= 74.93km2	R24 (It)	73.9 (31.7)	81.8 (35.1)	86.6 (37.2)	90.0 (38.6)	99.7 (42.8)	108.6 (46.6)
	F= .80	Qpeak(mean)	527.9 (264.0)	584.3 (292.1)	618.8 (309.4)	643.4 (321.7)	712.7 (356.4)	776.4 (388.2)
	T= .726hr	qs (mean)	7.046 (3.523)	7.798 (3.899)	8.258 (4.129)	8.587 (4.293)	9.512 (4.756)	10.362 (5.181)
20	A= 114.73km2	R24 (It)	76.4 (19.6)	83.9 (21.5)	88.5 (22.7)	91.8 (23.5)	100.8 (25.8)	109.1 (27.9)
	F= .80	Qpeak(mean)	499.0 (249.5)	548.1 (274.1)	578.0 (289.0)	599.1 (299.6)	658.3 (329.2)	712.2 (356.1)
	T= 1.575hr	qs (mean)	4.350 (2.175)	4.778 (2.389)	5.038 (2.519)	5.222 (2.611)	5.738 (2.869)	6.207 (3.104)
23	A= 115.37km2	R24 (It)	50.9 (19.3)	58.6 (22.2)	63.4 (24.0)	66.9 (25.4)	77.0 (29.2)	86.5 (32.8)
	F= .80	Qpeak(mean)	494.9 (247.4)	569.2 (284.6)	616.0 (308.0)	649.9 (325.0)	748.0 (374.0)	841.1 (420.5)
	T= .875hr	qs (mean)	4.289 (2.145)	4.934 (2.467)	5.339 (2.670)	5.633 (2.817)	6.483 (3.242)	7.290 (3.645)
24	A= 45.91km2	R24 (It)	56.3 (29.6)	65.8 (34.6)	71.9 (37.8)	76.4 (40.2)	89.6 (47.1)	102.1 (53.7)
	F= .80	Qpeak(mean)	302.2 (151.1)	353.4 (176.7)	386.0 (193.0)	409.9 (205.0)	481.0 (240.5)	548.2 (274.1)
	T= .535hr	qs (mean)	6.582 (3.291)	7.698 (3.849)	8.408 (4.204)	8.929 (4.465)	10.476 (5.238)	11.940 (5.970)
25	A= 64.68km2	R24 (It)	56.3 (43.8)	65.8 (51.3)	71.9 (56.0)	76.4 (59.5)	89.6 (69.8)	102.1 (79.5)
	F= .80	Qpeak(mean)	630.2 (315.1)	737.1 (368.6)	805.2 (402.6)	855.0 (427.5)	1003.2 (501.6)	1143.3 (571.7)
	T= .297hr	qs (mean)	9.744 (4.872)	11.396 (5.698)	12.448 (6.224)	13.220 (6.610)	15.510 (7.755)	17.676 (8.838)
25'	A= 118.17km2	R24 (It)	56.3 (13.9)	65.8 (16.3)	71.9 (17.8)	76.4 (18.9)	89.6 (22.2)	102.1 (25.3)
	F= .78	Qpeak(mean)	356.9 (178.5)	417.5 (208.7)	456.0 (228.0)	484.3 (242.1)	568.2 (284.1)	647.5 (323.8)
	T= 1.659hr	qs (mean)	3.021 (1.510)	3.533 (1.766)	3.859 (1.930)	4.098 (2.049)	4.808 (2.404)	5.480 (2.740)
26	A= 120.17km2	R24 (It)	56.3 (12.9)	65.8 (15.1)	71.9 (16.5)	76.4 (17.5)	89.6 (20.5)	102.1 (23.4)
	F= .80	Qpeak(mean)	344.8 (172.4)	403.2 (201.6)	440.4 (220.2)	467.7 (233.9)	548.8 (274.4)	625.4 (312.7)
	T= 1.859hr	qs (mean)	2.869 (1.434)	3.355 (1.678)	3.665 (1.833)	3.892 (1.946)	4.567 (2.283)	5.204 (2.602)

Table D.4.7 Flood Discharge (2)

BASIN	DIMENSIONS	ITEM	RETURN PERIOD 1/2	1/3	1/4	1/5	1/10	1/20
15	A= 393.56km2	R24 (lt)	63.2 (4.1)	68.8 (4.4)	72.2 (4.7)	74.5 (4.8)	81.0 (5.2)	86.7 (5.6)
	F= .69	Qpeak(mean)	307.6 (153.8)	335.1 (167.6)	351.4 (175.7)	363.0 (181.5)	394.6 (197.3)	422.3 (211.1)
	T=11.313hr	qs (mean)	.782 (.391)	.852 (.426)	.893 (.446)	.922 (.461)	1.003 (.501)	1.073 (.537)
11	A= 279.93km2	R24 (lt)	75.4 (6.0)	81.7 (6.5)	85.4 (6.8)	88.0 (7.0)	95.2 (7.6)	101.5 (8.1)
	F= .70	Qpeak(mean)	329.0 (164.5)	356.3 (178.2)	372.6 (186.3)	384.0 (192.0)	415.3 (207.7)	442.7 (221.3)
	T= 7.896hr	qs (mean)	1.175 (.588)	1.273 (.636)	1.331 (.665)	1.372 (.686)	1.484 (.742)	1.581 (.791)
11'	A= 689.04km2	R24 (lt)	66.8 (3.9)	72.5 (4.2)	75.7 (4.4)	78.0 (4.5)	84.3 (4.9)	89.8 (5.2)
	F= .69	Qpeak(mean)	511.5 (255.7)	554.4 (277.2)	579.5 (289.7)	597.1 (298.6)	645.3 (322.6)	687.0 (343.5)
	T=13.523hr	qs (mean)	.742 (.371)	.805 (.402)	.841 (.420)	.867 (.433)	.936 (.468)	.997 (.499)
18	A= 796.15km2	R24 (lt)	56.3 (3.9)	62.1 (4.3)	65.6 (4.5)	68.0 (4.7)	75.0 (5.2)	81.1 (5.6)
	F= .62	Qpeak(mean)	535.2 (267.6)	589.8 (294.9)	622.9 (311.5)	646.4 (323.2)	712.3 (356.1)	770.9 (385.4)
	T=10.170hr	qs (mean)	.672 (.336)	.741 (.370)	.782 (.391)	.812 (.406)	.895 (.447)	.968 (.484)
21	A= 423.23km2	R24 (lt)	51.1 (4.9)	58.8 (5.7)	63.6 (6.1)	67.1 (6.5)	77.2 (7.5)	86.8 (8.4)
	F= .70	Qpeak(mean)	404.2 (202.1)	464.6 (232.3)	502.7 (251.4)	530.3 (265.2)	610.0 (305.0)	685.7 (342.9)
	T= 5.672hr	qs (mean)	.955 (.477)	1.098 (.549)	1.188 (.594)	1.253 (.626)	1.441 (.721)	1.620 (.810)
20'	A= 229.14km2	R24 (lt)	70.2 (8.5)	77.1 (9.4)	81.3 (9.9)	84.2 (10.2)	92.6 (11.3)	100.0 (12.2)
	F= .70	Qpeak(mean)	379.2 (189.6)	416.7 (208.4)	439.3 (219.6)	455.4 (227.7)	500.3 (250.1)	540.7 (270.4)
	T= 3.827hr	qs (mean)	1.655 (.827)	1.819 (.909)	1.917 (.958)	1.987 (.994)	2.183 (1.092)	2.360 (1.180)
22	A= 247.19km2	R24 (lt)	50.8 (6.4)	58.5 (7.3)	63.3 (7.9)	66.8 (8.4)	76.9 (9.6)	86.5 (10.9)
	F= .72	Qpeak(mean)	317.2 (158.6)	365.0 (182.5)	395.0 (197.5)	416.8 (208.4)	479.8 (239.9)	539.6 (269.8)
	T= 3.626hr	qs (mean)	1.283 (.642)	1.476 (.738)	1.598 (.799)	1.686 (.843)	1.941 (.971)	2.183 (1.092)

Table D.4.7 Flood Discharge (3)

BASIN	DIMENSIONS	ITEM	RETURN PERIOD 1/2	1/3	1/4	1/5	1/10	1/20
1	A= 101.32km2	R24 (lt)	76.5 (9.1)	85.2 (10.1)	90.6 (10.8)	94.4 (11.2)	105.1 (12.5)	115.0 (13.7)
	F= .50	Qpeak(mean)	128.0 (64.0)	142.5 (71.2)	151.4 (75.7)	157.7 (78.9)	175.7 (87.8)	192.2 (96.1)
	T= 4.986hr	qs (mean)	1.263 (.632)	1.406 (.703)	1.494 (.747)	1.557 (.778)	1.734 (.867)	1.897 (.949)
3	A= 51.23km2	R24 (lt)	63.0 (11.0)	69.0 (12.1)	72.6 (12.7)	75.2 (13.2)	82.4 (14.5)	88.8 (15.6)
	F= .30	Qpeak(mean)	47.1 (23.6)	51.7 (25.8)	54.4 (27.2)	56.3 (28.2)	61.7 (30.8)	66.5 (33.3)
	T= 2.779hr	qs (mean)	.920 (.460)	1.009 (.504)	1.062 (.531)	1.099 (.550)	1.204 (.602)	1.299 (.649)
5	A= 124.29km2	R24 (lt)	74.2 (7.5)	81.4 (8.2)	85.8 (8.7)	89.0 (9.0)	97.6 (9.9)	105.3 (10.6)
	F= .50	Qpeak(mean)	129.4 (64.7)	142.1 (71.1)	149.8 (74.9)	155.2 (77.6)	170.4 (85.2)	183.7 (91.9)
	T= 6.350hr	qs (mean)	1.041 (.521)	1.144 (.572)	1.205 (.603)	1.249 (.625)	1.371 (.685)	1.478 (.739)
7	A= 155.65km2	R24 (lt)	73.2 (6.9)	79.0 (7.4)	82.5 (7.7)	85.0 (8.0)	91.7 (8.6)	97.5 (9.1)
	F= .30	Qpeak(mean)	89.0 (44.5)	96.2 (48.1)	100.4 (50.2)	103.4 (51.7)	111.5 (55.8)	118.6 (59.3)
	T= 7.106hr	qs (mean)	.572 (.286)	.618 (.309)	.645 (.323)	.664 (.332)	.716 (.358)	.762 (.381)
8	A= 91.95km2	R24 (lt)	77.3 (9.1)	83.6 (9.8)	87.4 (10.3)	90.0 (10.6)	97.3 (11.5)	103.7 (12.2)
	F= .30	Qpeak(mean)	69.7 (34.9)	75.5 (37.7)	78.8 (39.4)	81.2 (40.6)	87.8 (43.9)	93.5 (46.8)
	T= 5.052hr	qs (mean)	.758 (.379)	.821 (.410)	.858 (.429)	.884 (.442)	.955 (.478)	1.017 (.509)
9	A=1639.59km2	R24 (lt)	59.7 (2.3)	64.8 (2.5)	67.8 (2.6)	69.9 (2.6)	75.6 (2.9)	80.6 (3.0)
	F= .57	Qpeak(mean)	586.9 (293.5)	637.1 (318.6)	666.3 (333.1)	686.8 (343.4)	743.1 (371.5)	791.9 (395.9)
	T=29.098hr	qs (mean)	.358 (.179)	.389 (.194)	.406 (.203)	.419 (.209)	.453 (.227)	.483 (.241)
9'	A=1623.88km2	R24 (lt)	59.6 (2.5)	64.7 (2.7)	67.7 (2.9)	69.8 (3.0)	75.5 (3.2)	80.5 (3.4)
	F= .57	Qpeak(mean)	654.8 (327.4)	710.9 (355.5)	743.5 (371.8)	766.4 (383.2)	829.4 (414.7)	884.0 (442.0)
	T=23.100hr	qs (mean)	.403 (.202)	.438 (.219)	.458 (.229)	.472 (.236)	.511 (.255)	.544 (.272)
10	A=1518.54km2	R24 (lt)	58.8 (2.6)	63.9 (2.8)	66.9 (2.9)	69.0 (3.0)	74.7 (3.3)	79.7 (3.5)
	F= .60	Qpeak(mean)	649.7 (324.8)	706.1 (353.1)	738.9 (369.5)	762.0 (381.0)	825.4 (412.7)	880.5 (440.3)
	T=21.574hr	qs (mean)	.428 (.214)	.465 (.233)	.487 (.243)	.502 (.251)	.544 (.272)	.580 (.290)

The Peak Flood Discharge (Specific Discharge Unit:m3/s/km2)

Catchment Area	Return Period 1/2	1/5	1/10	1/20
Over 500 km2 (mean)	0.521	0.614	0.668	0.714
200 - 500 km2 (mean)	1.170	1.444	1.610	1.763
Under 200 km2 (mean)	3.967	5.004	5.650	6.249

The annual maximum daily mean discharge at Alambrado was analyzed probabilistically by the Hazen Plot Method. The results of this analysis were compared with the results of the Rational Formula as follows and the difference between these results are approximately 5%.

The Annual Maximum Daily Mean Discharge at Alambrado (m3/s)

Return Period	1/2	1/5	1/10	1/20
The Hazen Plot Method	308	363	395	424
The Rational Formula	327	383	415	442

D.4.3 Sediment Runoff Analysis

Suspended sediment has been observed at the Alambrado bridge since 1982 and approximately 2.6 million tons/year of suspended sediment was calculated by using these data. Because the runoff sediment can be assumed two or three times as much as the suspended sediment, 1,500 m3/km2/year of the sediment runoff can be estimated. (Analysis detail is described in Annex K.)