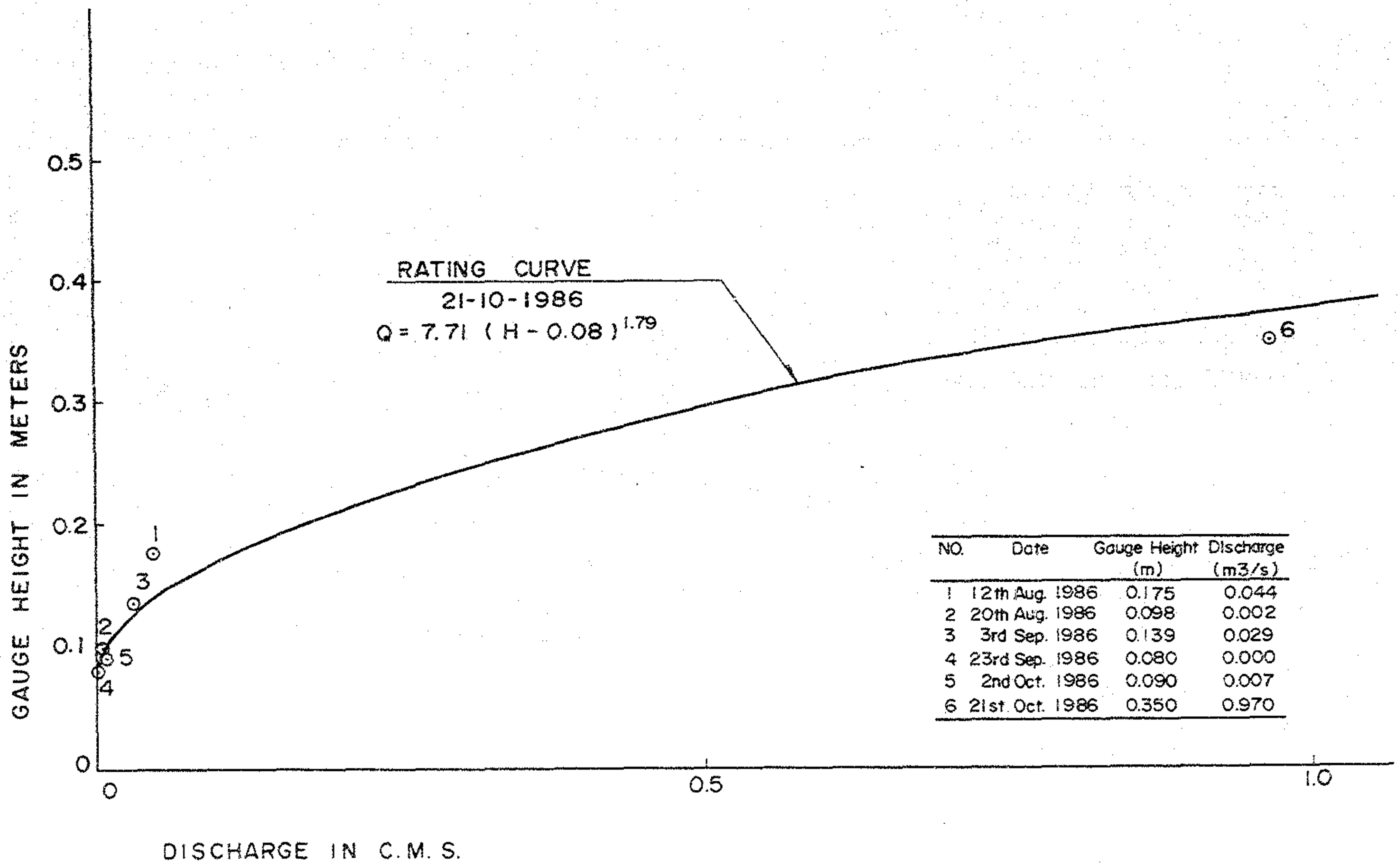
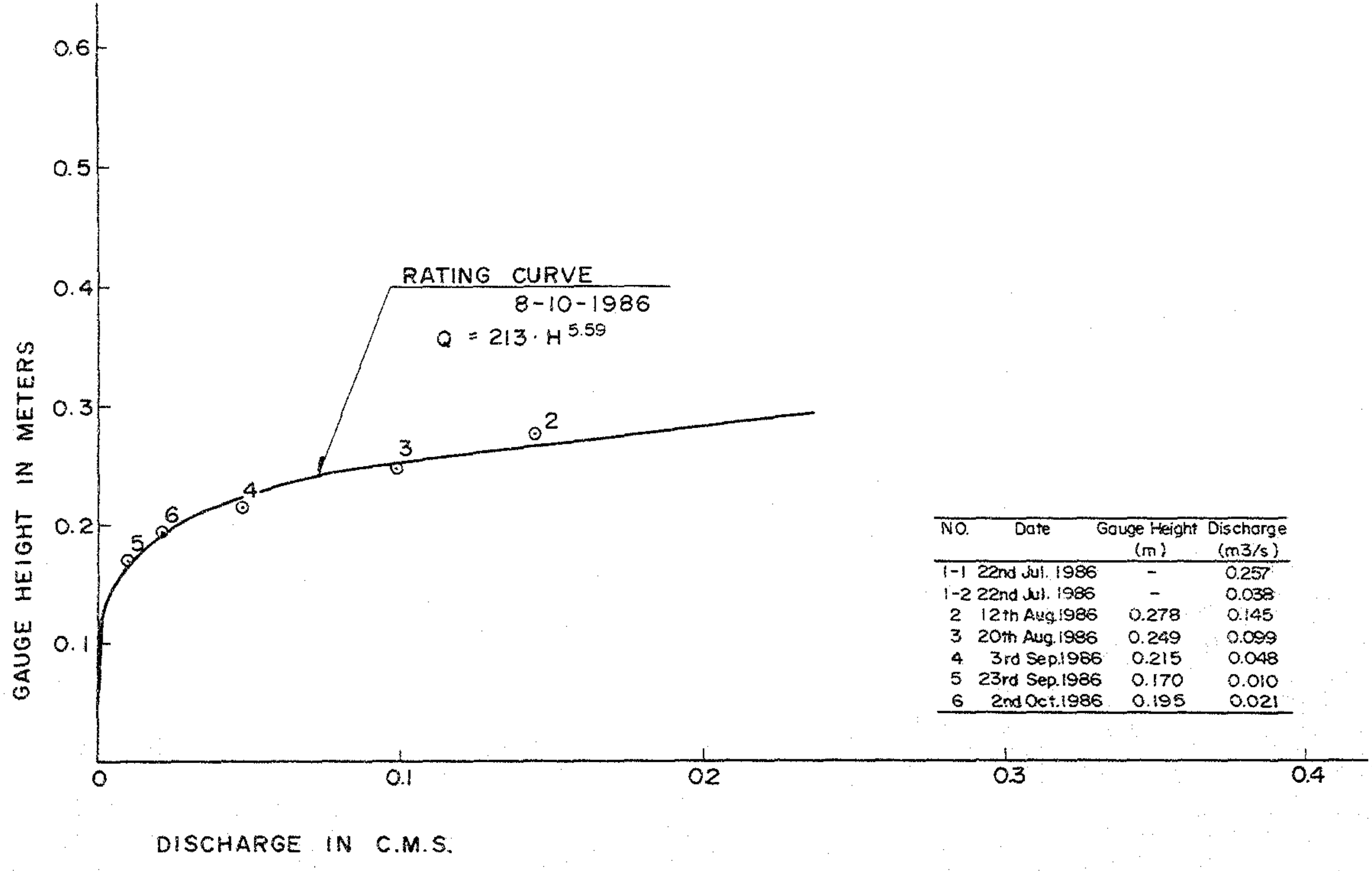


NO.	Date	Gauge Height (m)	Discharge (m3/s)
1	12th Aug. 1986	0.175	0.044
2	20th Aug. 1986	0.098	0.002
3	3rd Sep. 1986	0.139	0.029
4	23rd Sep. 1986	0.080	0.000
5	2nd Oct. 1986	0.090	0.007
6	21st. Oct. 1986	0.350	0.970

THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. B-15
RATING CURVE ON THE COLEBURNS GULLY AT BRIDGE SPRING GARDEN ROAD

JAPAN INTERNATIONAL COOPERATION AGENCY

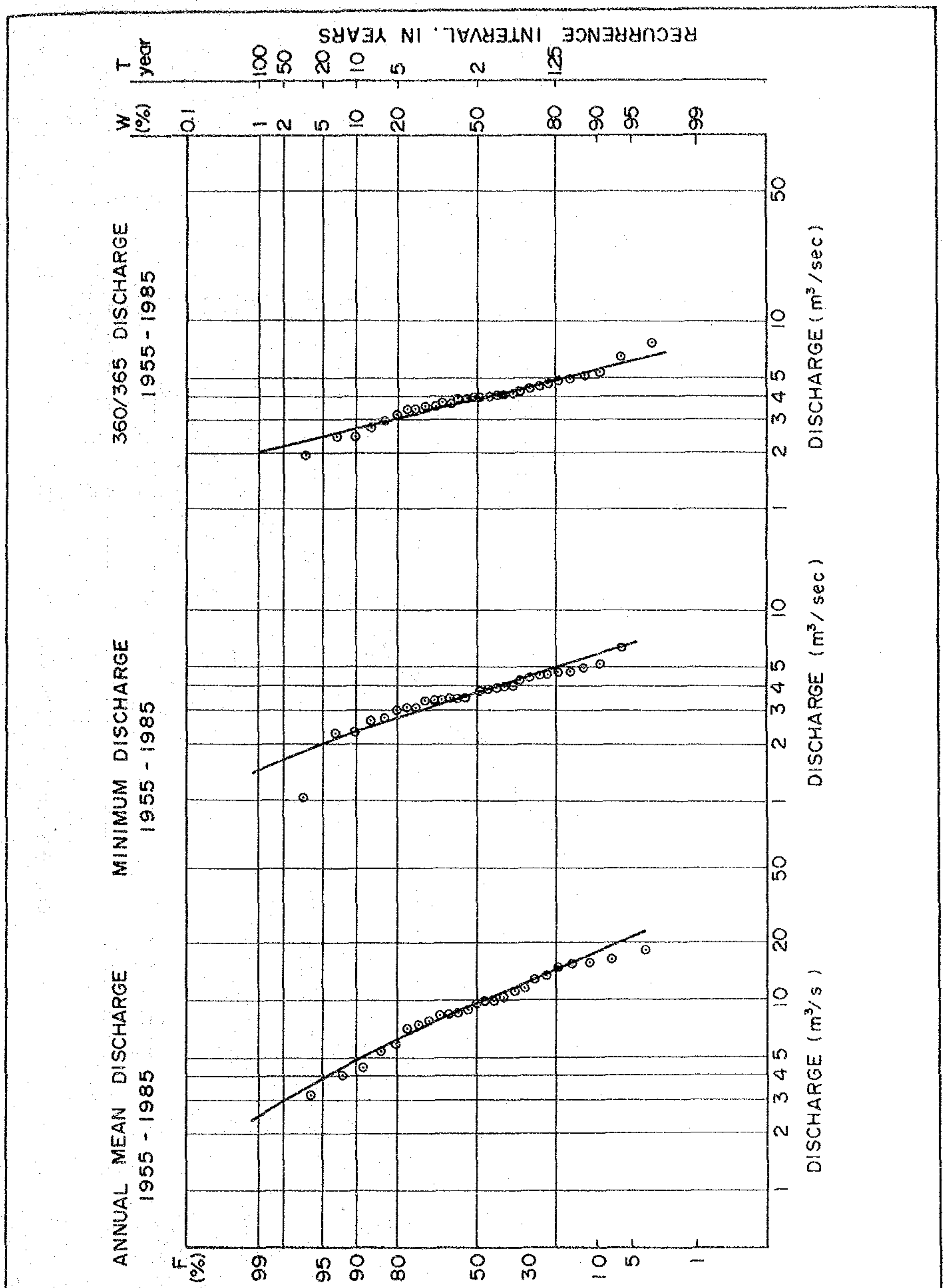


NO.	Date	Gauge Height (m)	Discharge (m3/s)
1-1	22nd Jul. 1986	-	0.257
1-2	22nd Jul. 1986	-	0.038
2	12th Aug.1986	0.278	0.145
3	20th Aug.1986	0.249	0.099
4	3rd Sep.1986	0.215	0.048
5	23rd Sep.1986	0.170	0.010
6	2nd Oct.1986	0.195	0.021

THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. B-16
RATING CURVE ON THE COLEBURNS GULLY AT RESOURCES SPRING

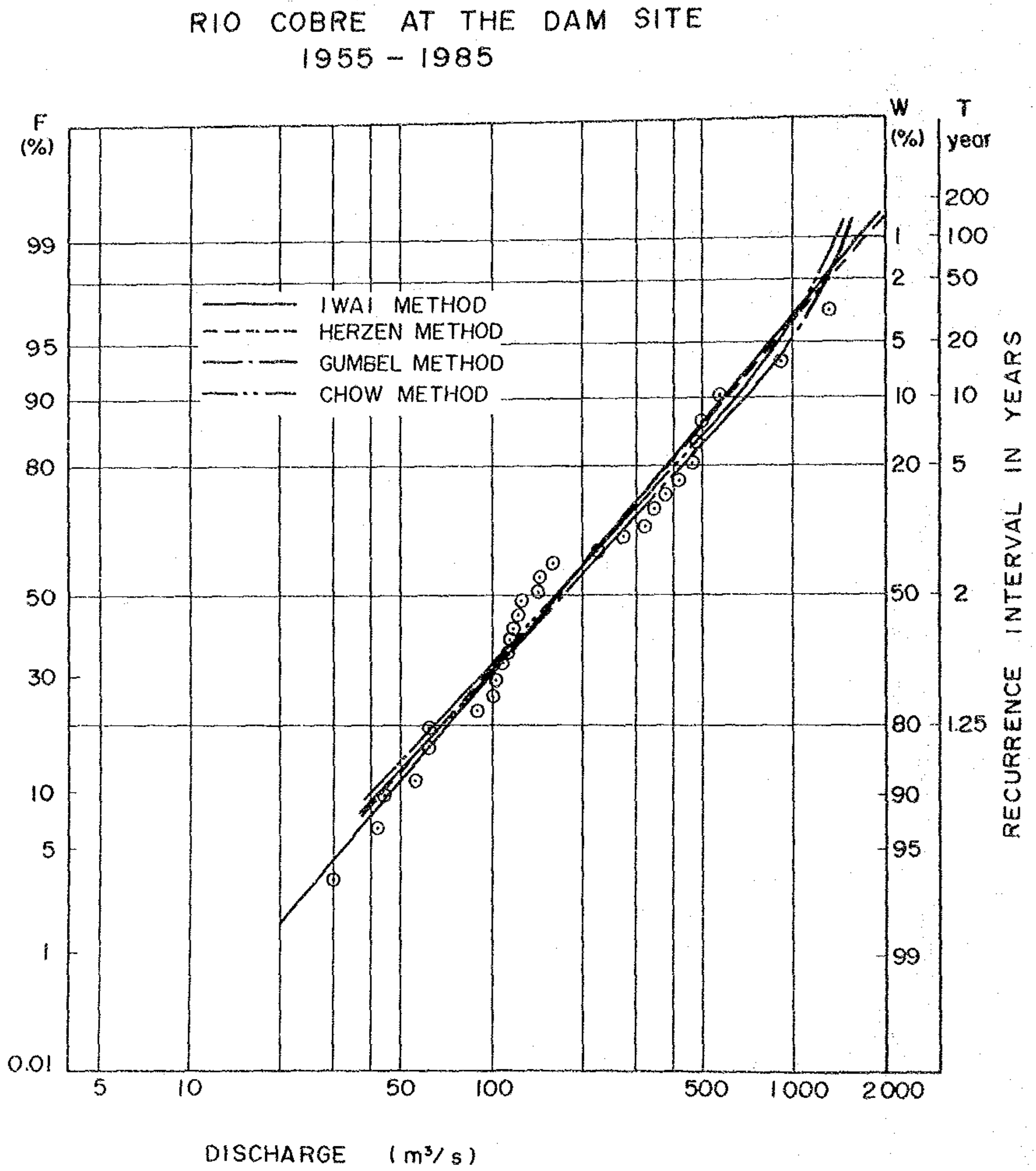
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. B-17
DISCHARGE FREQUENCY ON THE RIO COBRE AT THE DAM SITE

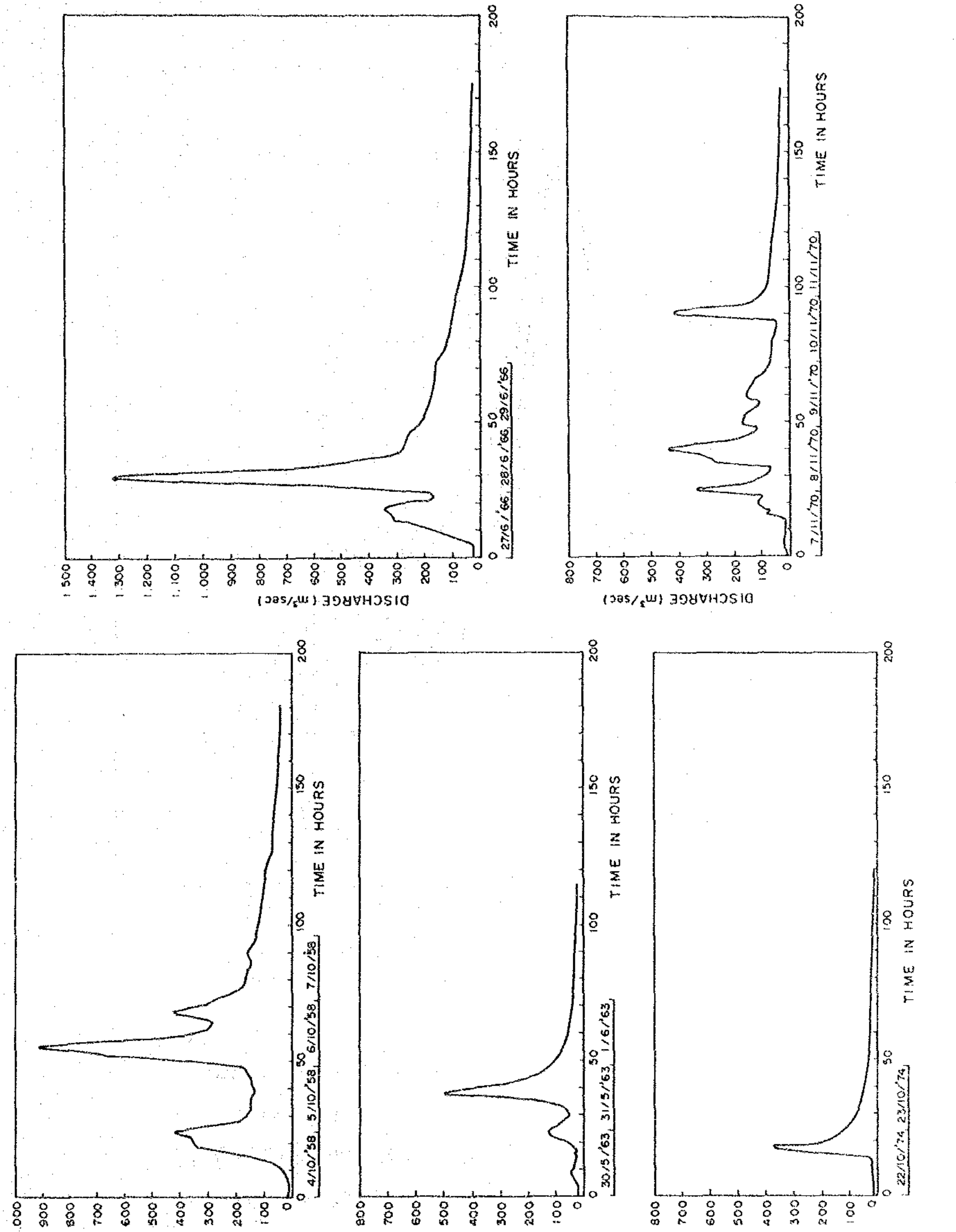
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. B-18
PEAK DISCHARGE FREQUENCY

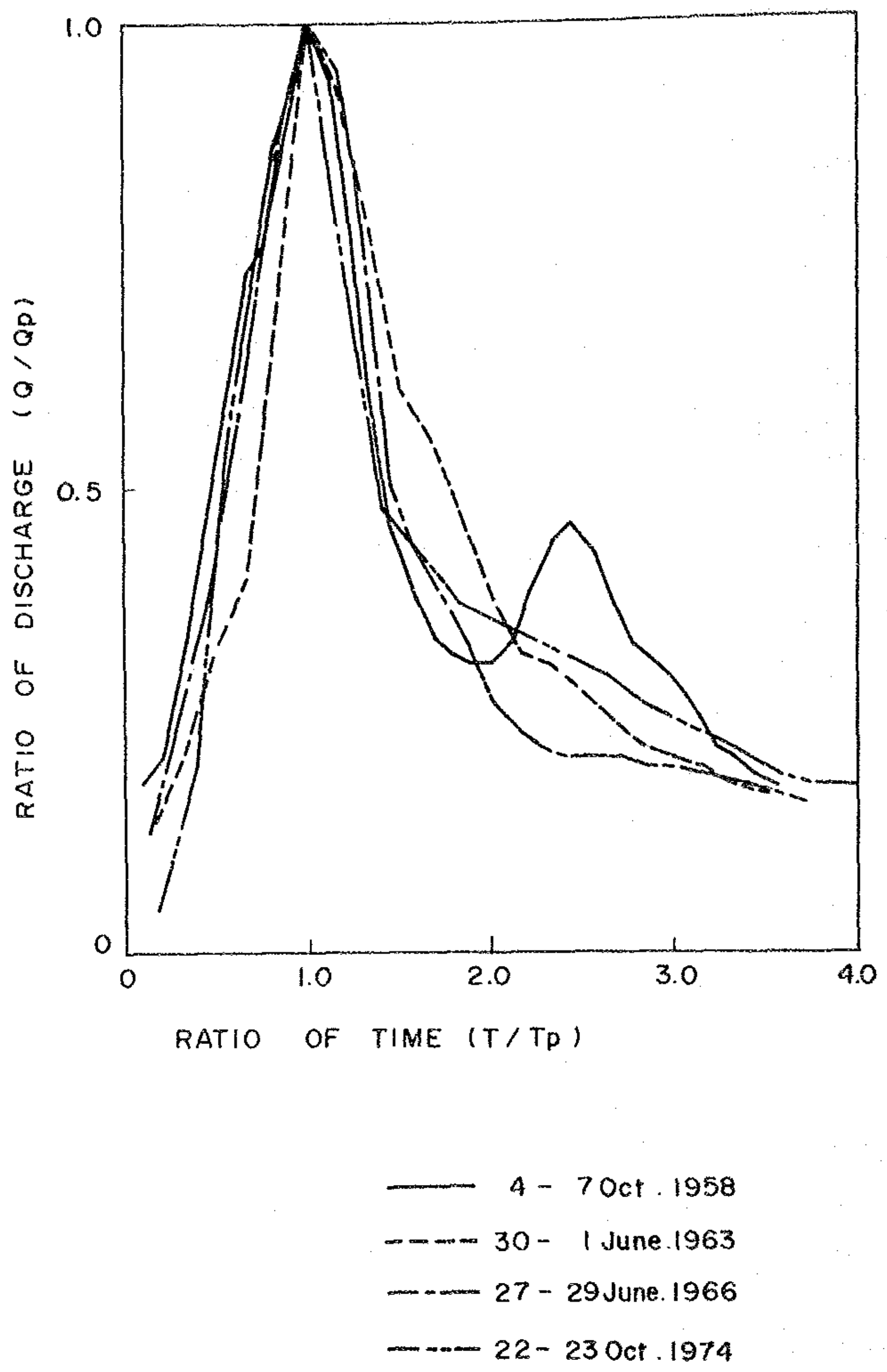
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. B-19
REPRESENTATIVE MAJOR FLOOD HYDROGRAPHS ON THE RIO COBRE

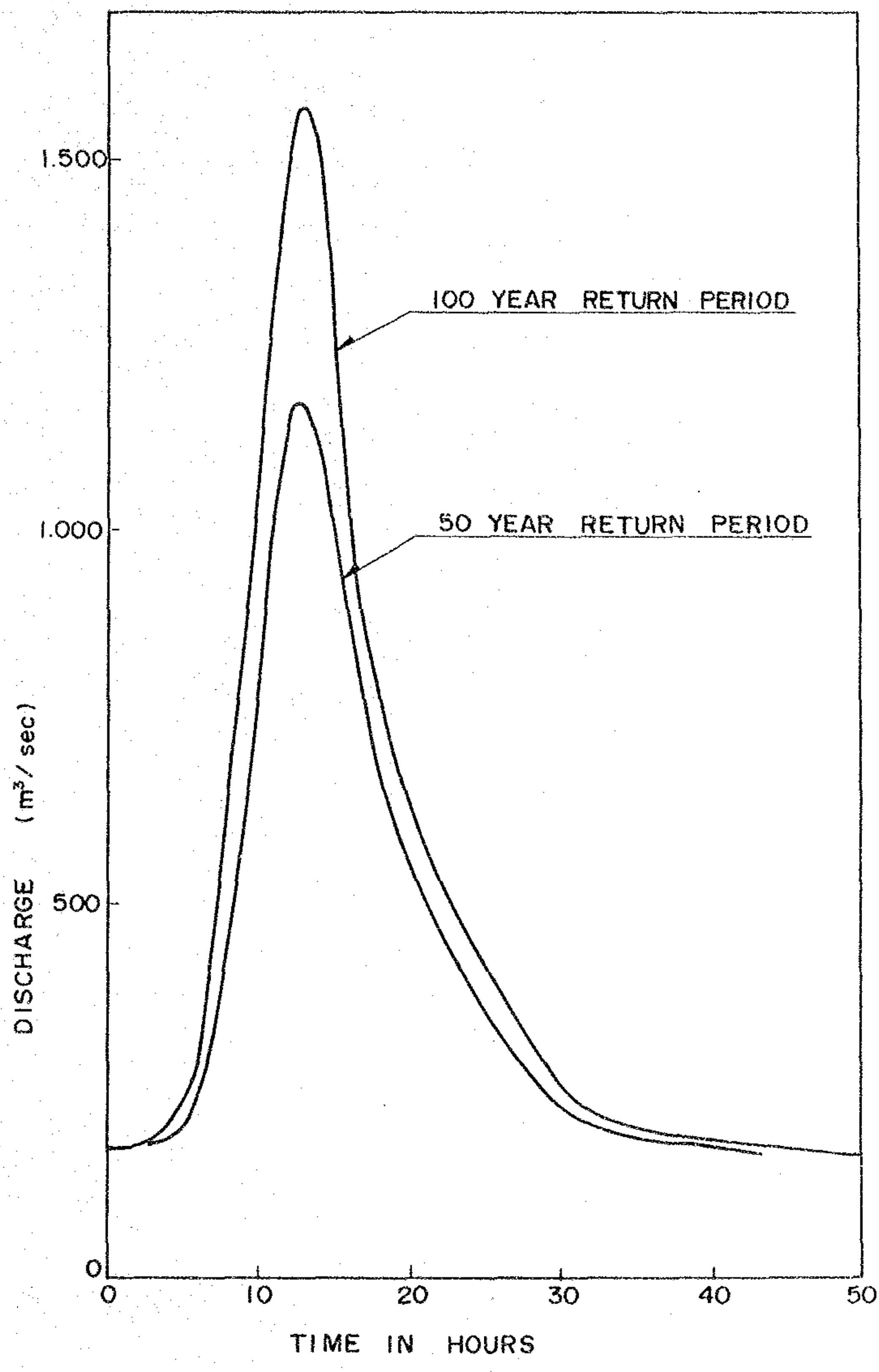
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF
THE RIO COBRE IRRIGATION SCHEME

Fig. B-20
DIMENSIONLESS FLOOD HYDROGRAPHS

JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. B-21
PROBABLE FLOOD HYDROGRAPH ON THE RIO COBRE

JAPAN INTERNATIONAL COOPERATION AGENCY

ANNEX - C

GEOLOGY AND HYDROGEOLOGY

ANNEX C

GEOLOGY AND HYDROGEOLOGY

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

The study area is composed of alluvium of the Rio Cobre and small rivers and covers approximately 27,400 ha of which about 12,000 ha is presently irrigated in net by both the Rio Cobre Irrigation Scheme and the St. Dorothy Irrigation Scheme.

The Rio Cobre basin located in the central part of Jamaica lies within the Parish of St. Catherine. It is located between 76°48' and 77°10' west longitude and 17°50' and 18°14' north latitude. The basin is about 40 km in length in the east - west direction and about 45 km from north to south. It covers an area of approximately 1,180 km^2 and can be divided into two district parts, the Lower Rio Cobre basin in the south and the Upper Rio Cobre basin in the north. (see Annex-B) The area lies in the North East Trade Belt and has a tropical oceanic climate.

Tertiary White Limestone Formation predominates over 50% of the Rio Cobre basin and alluvium occupies the study area. The highly karstic nature of the White Limestone Formations, i.e. the close surface depressions, the absence of surface drainage and well developed sub-surface drainage, made definition of the exact position of the surface water boundaries uncertain.

The main focus of this Annex is the Lower Rio Cobre basin, but the other sub-catchments which drain directly into the Lower Rio Cobre basin are also surveyed.

2. GEOLOGY

2.1 Geomorphology

The three major geomorphological features identified in and around the area include:

- dissected highlands (volcaniclastic areas)
- karstlands (limestone outcrops)
- flat areas (alluvial plains)

The dissected highlands include impermeable Cretaceous deposits. Surface run-off has denuded the area to form steep sided 'V' shaped valleys. During floods there is direct drainage to the sea but normally, river channels are dry as flow is lost to the limestone aquifer at the impermeable boundary. The karstlands comprise the Tertiary carbonate formations and include all the area north of the plains and also the Hellshire and Port Henderson Hills, which have very rugged topography, formed by numerous deep dolines, collapse structures, sinkholes and solution cavities. Considerable surface flow is therefore percolates into the ground. The alluvial plains form a gently sloping area between the limestone foothills in the north and the shore in the south excluding the Hellshire and Port Henderson Hills. The numerous irrigation channels contribute to drainage by the Rio Cobre and Ferry rivers in the east, the Salt Island Creek in the central area, and the Coleburns Gully in the west.

2.2 Geology

The most complete works on geology of the Lower Rio Cobre basin have been officially reported by V.A.Zans et al. (1962) and UNDP/FAO (1974), which were quoted in this chapter.

2.2.1 Stratigraphy

Fig. C-1 and C-2 provide maps of the geology and stratigraphic sequence around the Rio Cobre basin as used in this study, and a correlation of these units with the traditionally accepted units used by previous writers.

The Cretaceous rocks outcrop in the northwest near Bartons and Macca Tree and in the north central area around Giblatore. They are overlain unconformably by the Tertiary rocks, mostly limestone, the oldest of which is of Middle Eocene age and outcrop over much of the area north of Spanish Town. The Tertiary rocks are overlain by limestone, marls and sandy clays of Plio-Pleistocene age, constituting the Liguanea Formations.

(1) Cretaceous rocks

Rocks of Cretaceous age outcrop around Bartons and Water Mount and in the small inlayer at Giblatore. The rocks are primarily reworked volcaniclastics and subsidiary intrusives. Erosion of these sediments provided the bulk of the sediment in the lowest part of the overlying Tertiary rocks.

(2) Tertiary rocks

(a) Yellow Limestone Group

The part of the Yellow Limestone which occurs in this area is called the Chapleton Formation and comprises the lower Guys Hill member and the Ham Walk member. The upper unit is continuous and consists primarily of hard shelly limestones, yellow to brownish marls and patchily dolomitized limestones. Rocks belonging to the Yellow Limestone Group outcrop around the Cretaceous Inliers. The total thickness of the group varies from about 15 m where the lower member is missing to a maximum of about 150 m.

(b) White Limestone Group

Rocks belonging to the White Limestone Group are exposed in the northern hilly areas and the southern Hellshire and Port Henderson Hills and are covered by alluvium in the coastal plain. This group of limestones has been subdivided into five members by other writers but will be treated as two units, the Lower White Limestone, primarily of Eocene age, and the Upper White Limestone, of Oligocene to Middle Micocene age.

(i) Lower White Limestone

The Lower White Limestone includes the Troy and Somerset Limestone. The Troy is the most distinctive of the group and represents the basal sediments of the White Limestone Group. For the most part it overlies the Yellow Limestone rocks conformably. The Troy sediments are essentially dolomites, often well-bedded but sometimes massive. Bedding in the lower part is usually good, but becomes much less marked in the upper part. Jointing is one of the most important characteristics of the Troy Limestone and the texture varies from a very dense fine-grained dolomite to rubbly and coarse grained. The Troy Limestone ranges in thickness from 100 m to 250 m. The post Troy Limestone consists of hard, fine-grained biomicrites and coarse-grained biosparites to soft, chalky rubbly limestones. It is believed that these Limestones vary in thickness between about 30 m to 200 m.

(ii) Upper White Limestone

The Upper White Limestone includes the Brown's Town and Newport Limestones. The sequence consists of chalky, poorly bedded, mainly massive, partly recrystalized, and rubble limestones. Accurate measurement of the thickness of the Upper White Limestone sediments is unavailable but it is obvious that there are variations in thickness of the sequence. Comparing the Oligocene-Miocene limestones with the Clarendon sequence it is possible that there may be as much as 1,200 m of this limestone beneath the St. Catherine Plains near the southern edge.

(c) Alluvium

The alluvium represents fluviatile deposition from Pleistocene times in response to the rapid denudation of the newly exposed Cretaceous rocks. The alluvial deposits consist of a thick sequence of intercalated sands, sandy gravels and clays. The bulk of the sediments is made up of igneous derived material with a very small fraction of limestone grains. The alluvium has been deposited on a strongly karstified limestone surface, hence there are considerable variations in thickness from only a few meters at the border of the plain to about 180 m.

2.2.2 Structure

Structure in and around the area is quite simple. The old Cretaceous depositional surface had much relief, the Giblatore and Lazarcito Inliers being obvious positive areas during much of the depositional cycles from Eocene through to the present. Post-Cretaceous rocks dip off the Cretaceous remnant hills in all directions, the dominant direction of dip in and around the area being to the south from the edge of the central and Blue Mountain Inliers. It appears that this dip is due to supratenous folding and post depositional earth movements, with the former dominant immediately around the inlayer areas. Several faults dissect the area. The unconformity at the top of the Cretaceous is the most pronounced in the area. There is evidence to suggest earth movements at the end of Miocene times and again, locally, during the Pliocene.

(1) Faults

The hilly area of the Lower Rio Cobre basin is dissected by faults, primarily normal tension faults with little throw. There are two major sets; a dominant northwest-southeast set including the Red Ground-Marlie Mount Fault, the Caymanas, Glade, Wreck Point and Manatee Bay Faults; and an east-west set including the Half Moon Bay, Molynes Mountain and Bog Walk Faults. The faults seem to fall naturally into groups based on mode of origin, as described below:

(a) Group 1: Basement faults

These are rejuvenated pre-Eocene faults along which movement has taken place possibly during and after the deposition of the carbonate sediments. The resulting faults or fractures are usually expressed as rather long linear features with small scarps and prominent gullying along the line of strike. The Bog Walk, Cudjoe Hill and Caymanas Faults seem to be of this origin although the first one seems to have nearly 500 m of throw around the centre.

(i) Bog Walk Fault

This fault forms the most imposing topographical feature seen in the Rio Cobre basin. Trending west to east the main fault is marked by a very steep scarp slope, some 300 m at its highest point. In the east the faults split up into a series of splayed smaller faults.

(ii) Cudjoe Hill Fault

This fault is marked by a sinuous linear feature extending from Spring Vale to Cocoa Walk. There is an impression of down faulting on the south side, the north block sometimes having a very marked scarp as at Cudjoe Hill.

(iii) Red Ground-Marlie Mount Fault

This fault is expressed as a marked scarp east of Bannister but passes into a valley feature near Marlie Mount. There are smaller faults associated with this fault near Red Ground. At Bartons it can no longer be identified.

(iv) Molynes Mountain Fault

This is a very marked linear feature extending from Belvedere to Caymanas Bay. It takes the form of a narrow "V" having a thin cover of alluvium.

(v) Ferry Hill Fault

This is a very distinct east-west trending structure passing north of Ferry Hill. It forms the scarp, bounding the Liguanea Plains, around the Duhaney river area, then passes north towards the Queen Hill. It probably extends westwards beneath the alluvium. The throw on this fault is not great, probably of the order of 60 m.

(b) Group 2: Tension faults

The second group of faults seems to have been generated by tensional forces in response to uplift after deposition. The Hellshire Hills Faults are prime examples of this mode of fault origin. These faults have been developed mainly in the two prominent directions, one north-south trend dominating in the west and east-west in the east.

2.3 Geology of Headworks

Core drilling was carried out by JICA Team on the existing dam site and the proposed dam site about 170 m downstream of the existing dam to investigate the geological and hydrogeological, soil and foundation conditions of the existing dam and for design purposes of the proposed alternative dam. Standard penetration tests and permeability tests were also carried out at both sites.

2.3.1 Result of drilling and laboratory test

The following field works and laboratory tests were carried out by the Contractor in Jamaica.

Work item	Unit	Quantity
1) Field works		
Drilling works	site	7
Drilling depth	m	181.6
Standard penetration test	Nos.	33
Permeability test		
- Falling head test	Nos.	2
- Packer test	Nos.	23
2) Laboratory test		
For alluvial deposit		
- Specific gravity test	Nos.	4
- Grain size analysis	No.	1
For limestone formation and dam concrete		
- Specific gravity test	Nos.	10
- Unit weight test	Nos.	10
- Uniaxial compression test	Nos.	10

The field works commenced on 3rd August and ended 21st September 1986. The locations of drilling points are shown in Fig. C-3.

(1) Drilling works

Seven holes were drilled to a total depth of 181.6 m. Geologic sections at the existing dam and the proposed alternative dam sites are shown in Fig. C-4 and C-5. It is found that the typical formation consists of alluvium and limestone formation.

(a) Existing dam site

The existing dam at B-3 consists of boulders and gravels covered with concrete. No cement mortar could be observed between the mounded boulders and gravels, but foundations of brick and concrete were observed between 8.0 m and 9.1 m. At B-2 the dam construction consists of concrete both of limestone gravels and bricks. The thickness of the concrete material is 9.6 m at which depth there is an iron plate about 10 mm in thickness. The total thickness of the dam construction varies from 9.1 m to 9.6 m. The surface concrete ranges in thickness from 3 cm to 60 cm at the crest.

The alluvial deposit mainly consists of gravel and sand with N value over 40. Clay with sand is found up to 4 m in thickness from the surface at B-1 and a clay bed of 9.1 m having a range of N values from 9 to 23 at B-4. The top portion of the sediment at B-4 is considered to be recent dam sediments. Drilling investigations have indicated that the left side of the dam is founded on the alluvium. At B-2 and B-3 the dam is founded on alluvial gravel and sand bed or Tertiary sheared limestone.

The bedrock is the Tertiary limestone, well fractured and having many cavities filled with clay.

(b) Alternative dam site

The alluvial deposit comprises gravel and sand on the riverbed. The N values show a wide scatter from four (4) to over 50. Red clay with gravel is found at the surface of B-5 on the left bank. The deposit is from 7.6 m to 14.0 m in thickness on the riverbed and about 3.1 m at B-5. The alluvial deposit overlies the Tertiary limestone formation.

The bedrock is limestone which outcrops at the left bank of the river. It is well fracture, jointed and cavernous.

(2) Standard penetration test

Standard penetration test is performed on each bore hole at one and half meter intervals principally in the alluvium. The result are shown in Fig. C-4. The average N value at each layer is as follows:

Sand and gravel	10 to 50
Clay with sand	19 to 24
Fractured limestone	24 to over 50 (at B-2 and B-4)

(3) Permeability

The results of field permeability tests indicate that coefficient of permeability of each part of the formation as shown in Fig. C-4 and Fig. C-5. The groundwater level of each bore hole is below the water level of reservoir or river.

The average permeability of each formation is estimated as follows:

Sand gravel and boulder	5×10^{-3} to 5×10^{-1} cm/sec
Limestone formation	1×10^{-4} to 5×10^{-2} cm/sec

(4) Laboratory tests

Rock and soil samples were taken by drilling in the dam site and subjected rock and soil tests in the laboratory. The results of tests are shown in Table C-1.

(a) Rock tests

(i) Concrete material of dam

The dam concrete was sampled at B-2 and B-3. The specific gravity is in the range of 2.16 and 2.50. The unit density is in the range between 2.16 and 2.50 g/cm^3. The uniaxial compression strength is 46 to 152 kg/cm^2.

(ii) Limestone (bed rock)

The specific gravity of the limestone shows a wide range from a low 2.19 in the cavernous state, to a high 2.89 in the solid compact state. The unit density has a same tendency of the specific gravity, the value is from 2.19 to 2.88. The uniaxial compression strength is 152 to 527 kg/cm^2.

(b) Soil tests

The specific gravity of sand is 2.66 and 2.77. The value of silt/clay is 2.55 and 2.57. The grain size of the sample (B-1, Depth from 3.2 to 3.5 m) indicates coarse to very coarse sand.

2.3.2 Conclusion of investigation

The investigations lead to the conclusion that the geological and hydrogeological, soil and foundation conditions of the existing dam site are better than the proposed alternative dam site. As compared with the later, the alluvium of the former is thinner, the permeability is smaller, etc. The condition of the existing dam may be summarized as follows:

(1) The existing dam, constructed about 100 years ago, seems to be sound but its upstream slope could not be observed due to deposit of sediments in the reservoir.

(2) The dam is founded on Tertiary sheared limestone or alluvial gravel and sand, some of which is very permeable (permeability $K = 1 \times 10^{-4}$ to 5×10^{-2} cm/sec). The amount of leakage through the dam foundation however is small.

(3) The sediment in the reservoir reduces the pondage but reduces leakage.

(4) If the sediment is to be dredged leakage must also be prevented, for which it will be necessary to reduce the permeability of the foundation to less than 1×10^{-4} cm/sec by grouting after detailed investigation. Suitable treatment will have to extend to a depth of about 10 m and over a length of about 120 m along the crest and abutments.

2.4 Geology of the Canal Network

Most of the canal network is located on the alluvial plain where the top soil consists mainly of silt and clay. Sticky clay soil is found especially around the ends of the Old Harbour Branch and the Hartlands Branch in the west of the study area.

The upper part of main canal is located at the apex of the alluvial fan where the Rio Cobre enters the plains from the hills. More coarse material is found in this part of the alluvial fan.

Some parts of the Old Harbour and Caymanas Branch canals pass through the limestone foothills where there are many sink holes, Where the canals are not lined some water is lost as leakage which recharges the groundwater table.

3. HYDROGEOLOGY

3.1 General

The studies on hydrogeology of the Lower Rio Cobre basin are published by UNDP/FAO (1974), Botbol (1982), etc., which give the information of hydrogeological features, aquifer lithofacies, aquifer characteristics, etc.

3.2 Outline of Groundwater

The area of the Lower Rio Cobre basin is about 650 km^2. It is drained mainly by the Rio Cobre and the Ferry river in the east which flow into Kingston Harbour. There are also a number of less important and intermittent streams in the west which discharge into Old Harbour Bay.

The study area has two principal aquifers, the limestone aquifer and the alluvial aquifer from which water is produced by wells.

The hydrogeological basement rocks outcrop in Giblatore and around Bartons and Water Mount to the northwest of the study area. These rocks are the Cretaceous volcaniclastics and the Tertiary yellow impure muddy limestones. These older rocks are usually impermeable and are unimportant as aquifers and no successful wells have been developed in this type of rock. The limestone aquifer consists mainly of the White Limestone. The White Limestone outcrops occur in the upland areas, north of the alluvium except for the isolated Hellshire and Port Henderson Hills which lie south of the alluvium and border the coast. The White Limestone outcrop region is noted for the absence of any well-developed surface drainage pattern. Instead there are many closed depressions within which water is channelled underground through centrally located sinks or laterally draining caverns and eventually infiltrated to the groundwater table. This area is therefore one of the primary recharges.

The alluvial plain region is important agriculturally because of favourable soil development and is therefore the area over which agricultural use is greatest. Water is withdrawn both from the limestone and alluvial aquifers for irrigating the alluvial plains.

There are about 230 wells in the South St. Catherine area most of which have been drilled for abstraction of groundwater. At present, most of the wells are used for irrigation. The location and names of the wells are shown in Fig. C-6 and Table C-2 and C-3.

3.3 Hydrogeological Features

Springs and sinks are prominent surface expressions of connection between surface water and groundwater.

3.3.1 Springs

Spring flow forms a fairly large part of the groundwater discharge from the basin. Details of all known springs in the area are given in Table C-4 (from FAO, 1974). The springs of the Spring Garden and the Resource Spring are famous gravity springs.

3.3.2 Sinks

Closed depressions are a conspicuous feature of the karstified landscape. The depressions range from 1 meter to 100 m from the lowest part to the top of the surrounding hills. They may be sub-circular or elongate and cover up to 1 km^2. After heavy precipitation transient ponding of water may take place, usually all surface water has disappeared within a few hours.

A source of recharge to the limestone is water which flows off the highly dissected impermeable rock, on the north highlands. A well developed dendritic surface drainage system is developed on these impermeable rocks and the runoff flows via well-developed river channels into the limestone where some of all the water usually sinks underground. In many rivers in this area through-flow to the river mouths is sustained only as long as precipitation on the impermeable rocks is high. In a number of cases during low flow the entire streamflow is absorbed into the river bed and percolated to the limestone aquifer close to the boundary between the impermeable rocks and the limestone. The Myttins river, Old Harbour river and St. Faith's river all behave in this manner.

3.4 Limestone Aquifer

3.4.1 Lithofacies

The limestone aquifer consists exclusively of rocks of the White Limestone Group, divided into a lower and an upper stratigraphic unit. There is no well production from the older Yellow Limestone Formation which is, for the most part, impure and has little secondary permeability development. However, only a small amount of water yields from the Yellow Limestone as a spring. Two units in the White Limestone Group consist of a complex series of bio- and litho-facies which reflect different depositional conditions and those result in local variations in the hydraulic properties of the aquifer. The upper limestone units are mainly rubbly or chalky and consequently more likely to develop secondary permeability through solution than through fracturing. This results in a more even distribution of permeability. The lower units are hard, recrystalized and dolomitized and fracturing controls the development of secondary permeability. In the upper units there may be some primary permeability, but little in the lower units.

Basically the White Limestone Rock acts as a single hydrological unit which is non-homogeneous and non-isotropic. However, the properties of the aquifer may vary by many order of magnitudes over short distances so that water levels often appear inconsistent. For example, in the upland areas water level elevations rise steeply and the water table stands a few meters above the sea level in the lowlands.

In a horizontal plain the development of secondary permeability is controlled not only by the lithology of the rocks but also by previous sea level stands. Because sea levels were both below and above the present levels at various times in the past, there are discrete horizontal zones with appreciably higher permeability than the intervening layers.

3.4.2 Water levels

Water levels and changes in levels reflect aquifer characteristics and changes in storage. The water level contours in limestone aquifer for January and August 1972 is presented by on Fig. C-7 and Fig. C-8 and the contour for February 1986 on Fig. C-9 and the contours between June and September 1986 on Fig. C-10.

In the southern part of the aquifer the groundwater gradient is relatively uniform trending south to south-easterly toward the sea. Superimposed on this regional gradient are local variations in outflow directions caused by local abstraction centres.

Water levels in the limestone aquifer fluctuate in response to variation in recharge and discharge and the amount of fluctuation is also related to differences in the hydraulic characteristics of the aquifer. The well hydrographs were drawn by using the data of automatic water level recorders on Crescent well and Hartlands Exploratory well between March and September 1986 as shown in Fig. C-11. At Hartlands in the southern part of the aquifer the fluctuation is about 1 m, while at Crescent in the limestone hills the fluctuation is more than 10 m. Both water levels were raised after the heavy rain in early June 1986. The response of the water level in the upper area to recharge from rain is much more rapid than in the lower area.

3.4.3 Aquifer characteristics

The ability of the aquifer to transmit and store water is assessed quantitatively in terms of its coefficient of transmissibility (T) and storage coefficient (S). To determine values of T and S, ten pumping tests were run and analysed by FAO (1974). The results of these, together with values obtained from previous investigations, are shown in Table C-5 and C-6.

It is apparent that there is wide variation in the transmissibility of the unconfined section of the aquifer. Geological investigations indicate that the highest transmissibility values are confined to fault and fracture zones where secondary permeability is enhanced by solution phenomena as, for example at Bamboo where T = 15,000 m^2/day. The intervening areas have low transmissibility, for example T = 20 m^2/day at Crescent. The ranges of aquifer characteristics are as follows:

Transmissibility	T (m^2/day)	:	20 to 15,000
Storage coefficient	S	:	1.1×10^{-6} to 3.8×10^{-4}

3.4.4 Well production

There are about 80 producing wells in the limestone aquifer in the study area. The wells are listed in Table C-2 and the locations are shown in Fig. C-6. According to Botbol

Report (1982), the total discharge from 77 wells was 91.5 million m^3 in 1980 and an average of 1.19 million m^3 per well annually. The location of the production wells and the annual production in 1980 of each grid mesh on the map are shown in Fig. C-12. The annual total production for the years between 1970 and 1980 is listed in Table C-7 and the average ten (10) years is calculated 85.9 million m^3/year.

Abstraction is localized around heavily irrigated areas of sugar cane cultivation. The Caymanas, Bernard Lodge and Innswood Estates and the St. Dorothy Irrigation Scheme are the principal water users. The agricultural abstraction is roughly 134,000 m^3/day, about 53% of the total limestone abstraction. Domestic supply is the next in importance, accounting for 95,000 m^3/day which is 38% of the total abstraction. A relatively small amount of water is used for industrial purposes.

According to FAO (1974), the volume of water in usable storage is about 860 million m^3, while from Botbol (1982) the safe yield is about 197,000 m^3/day (72 million m^3/year), the value being a little smaller than the 235,000 m^3/day (85.9 million m^3/year) average 10 years abstraction (1970 to 1980).

3.4.5 Water quality

Samples were collected from 13 wells and three (3) springs in the limestone aquifer shown as in Fig. C-13. The results of their analysis are presented in Table C-8 and Fig. C-14. There are seven groundwater samples (Free Town, Whim, New Market Pen, Bushy Park Hendrick, Mango Walk No.5, White Marl No.2 and Ferry Spring) which contain chloride more than 250 ppm.

3.5 Alluvial Aquifer

3.5.1 Lithofacies

The alluvial aquifer overlies the limestone aquifer in the central part of the study area, and is about 6 km wide running between Old Harbour and Caymanas. The northern boundary is formed by the limestone outcrop and the southern boundary by Kingston Harbour and Old Harbour Bay in the east and west and centrally by the Hellshire and Port Henderson Hills. The total surface area is about 130 km^2 and the elevation ranges from sea level to about 50 m.

The materials forming the aquifer are unconsolidated deposits consisting of interstratified clays, sands and gravels. The hydrogeologic sections around the Bernard Lodge area are shown in Fig. C-15 which shows how the two aquifers are distributed almost horizontally with a thickness of 10 m to 30 m. Below these aquifers salty aquifers are presumed to exist.

The alluvium was deposited on the limestone basement when karstification was well advanced and there is much variation in the thickness of alluvium as shown in Fig. C-16. At Amity Hall a thickness of over 170 m of alluvium was penetrated while at Hartlands the thickness was 126 m.

3.5.2 Water levels

The groundwater level contour maps for January and August 1972 are shown in Fig. C-17 and C-18, which give the general pattern. The highest water levels occur around the Sydenham/ Innswood area, extending as far south as Fellowship Hall as shown in the above map. From this high ground, water flows very gently due south, southeast and southwest

The groundwater level contour map for February 1986 is shown in Fig. C-19. This shows some depressions around heavily pumping wells. The most important depressions are seen at Bernard Lodge, Caymanas and Braeton. The contours between June and September 1986 give the pattern of high water level for the non-pumping condition after the heavy rains in early June 1986, as shown in Fig. C-20.

The Fig. C-11 shows the well hydrograph at Cookson #2 in Bernard Lodge area. The gentle water levels arose by about 2 m immediately after the heavy rains.

According to FAO (1974) the water level of the aquifer varies from ground level to over 9 m, but in more than 75 % of the area the water table is less than 3 m below the surface. There are localized areas within the aquifer where confined conditions exist and water levels are above ground level or at ground level. These areas are found at Caymanas and in the east Gregory Park area.

3.5.3 Aquifer characteristics

Pumping tests were performed and analysed by FAO (1974) and Versley (1962). The results of these tests are shown in Tables C-9 and C-10.

Calculated transmissibility values (T) range from 160 m^2/day to 8,200 m^2/day. These values are representative of what may be regarded as successful wells in the aquifer, and no doubt more clayey areas are characterized by lower values. The calculated values of storage coefficient (S) vary from 3.3×10^{-1} to 1.8×10^{-2}.

Generally speaking, there are three areas where high yields and accompanying high values of T and S are experienced. These are the plains encompassing the Bernard Lodge and South Caymanas area, the Cherry Gardens/Bushy Park areas and the Whim area.

3.5.4 Well production

There are about 60 production wells in the alluvial aquifer. The name and the location of the wells are shown in Table C-3 and Fig. C-6. The wells are concentrated mainly in the Bernard Lodge and Caymanas areas, on the right bank of the Rio Cobre, downstream of Spanish Town. The annual production in 1972 of each grid mesh on the map is shown in Fig. C-21.

Table C-11 shows the total annual abstractions from the alluvial wells for the years from 1970 to 1972 (after FAO, 1974). The total annual abstraction from the aquifer has increased over this three year period from 35.71 million m^3 to 40.04 million m^3.

According to FAO (1974) the total volume of water in storage in the alluvial aquifer is calculated as 1,300 million m^3.

3.5.5 Water quality

Groundwater samples from the alluvial aquifer were collected from three wells shown in Fig. C-13. The result of these analysis are indicated in Table C-8 and Fig. C-14. The samples from well at Amity Hall contains chloride more than 250 ppm.

3.6 Problem of Groundwater

3.6.1 Saline water intrusion

According to Botbol (1984) and White (1980), the limestone aquifer has been contaminated by subsurface saline inflow in response to the development of the groundwater resources of this aquifer since the year 1930. Uncontrolled development has resulted in deteriorating groundwater quality, and all the south coastal area - almost all the confined section - contains poor quality water for domestic or irrigation usage (chlorides as high as 20,000 ppm).

In the active production zone, the groundwater salinity lies in the range 20 to 300 ppm chlorides. The salinity is higher in the Innswood and Woodlands areas (300 to 600 ppm) and in the Caymanas - Ellis - White Marl areas (500 to 1,000 ppm). Fig. C-22 and C-23 show isochloride contours for September - October 1972, and December 1980. There are two main mechanisms of salt water intrusion and contamination; frontal intrusion (Caymanas - Half Way Tree) and upconing (Innswood wells). Frontal intrusion is caused by overpumping, low water levels and small seaward flow. Upconing is caused by high drawdowns.

3.6.2 Fresh saline water boundary

For investigating saline water intrusion condition and fresh saline water boundary, electrical conductivity measurement were carried out on several wells by using an electrical conductivity meter with a 150 m long cable. The sharp interfacial boundary between fresh and saline water could not be observed in the results of field survey and a brackish transition zone of finite thickness separated the two (2) fluids. The electrical conductivities and its profiles are very different at each well and the brackish transition zones are also dissimilar. This all seems to indicate that the above mentioned saline water intrusion, is caused by upconing and pre-existing brackish water springs.

The results of measurements shows only four wells namely Hartlands Expl. Well, Little Windsor Expl. Well, Half Way Tree Expl. II Well and Caymanas Expl. Well were able to pick up the saline water face. Extraporated sections across electrical conductivity profiles are shown in Fig. C-24. This work indicates that more electrical conductivity profile must be made across the St. Catherine Plains to get a clearer understanding of the position of the fresh water saline water interface. In other words, more wells must be made available for this electrical conductivity profiling exercises.

3.7 Artificial Recharge

3.7.1 Purpose and previous study

Artificial recharge is generally performed in order to increase the natural supply of groundwater, and artificial recharge projects are designed to serve one or more of the following purposes:

- to maintain or augment the natural groundwater as an economic resource.
- to coordinate operation of surface and groundwater reservoirs.
- to overcome adverse conditions such as progressive lowering of groundwater level, unfavourable salt balance, and saline water intrusion.
- to provide subsurface storage for local or imported surface water.

In the study area artificial recharge studies were carried out by Water Resources Division (1980-1982) at Innswood on the artificial recharge of surplus surface water into the limestone aquifer through sinkholes. A pilot plant at Innswood has been in operation since September 1981. During the year May 1981 to March 1982, 3.2 million m^3 (9,700 m^3/day) surface water was recharged through two sinkholes by gravity as a result of which a 0.5 to 1 m groundwater mound had been created near some recharge area and apparently as a consequence some regression of the saline front has been observed.

3.7.2 Artificial recharge in the study area

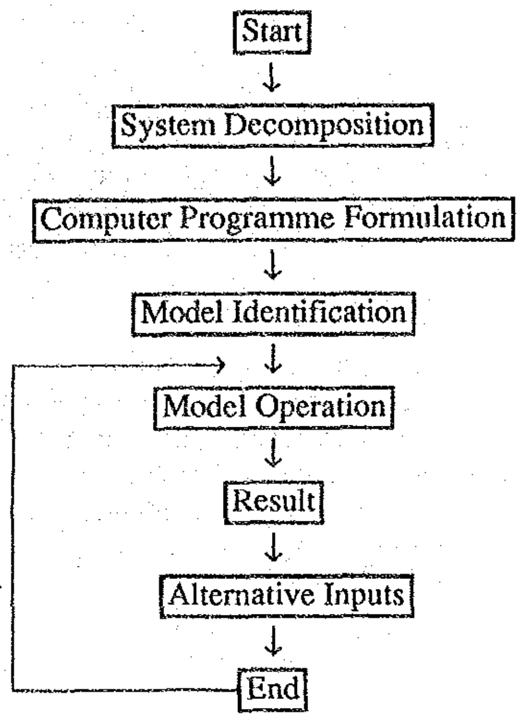
Artificial recharge is considered to be necessary in the study area to make use of surplus surface water that can be recharged through sinkholes by gravity in rainy season, unused time, etc. The sinkhole method is most economical one but silting above the hole limits the recharge capacity. The well method which is now used in Cuba and other countries is another suitable method in the area. Recharge of dirty or polluted water will contaminate the groundwater, therefore it is necessary to investigate the volume available for recharge, the quality of the recharge water, and existing groundwater conditions beforehand and to assess the impact of one on the other. When recharge is undertaken the operation has to be managed.

3.8 Groundwater Simulation

3.8.1 Approach and procedure of simulation

In order to evaluate the groundwater potential of the Lower Rio Cobre Basin the analysis must be performed by using a simulation model on the basis of hydrogeological investigation. Simulation can be defined as reproducing the essence of a system without reproducing the system itself. The essential characteristics of the system are reproduced in a model which is studied in an abbreviated time scale.

A general procedure of simulation is shown in following chart and the procedure of the Lower Rio Cobre Basin is explained in order of the chart:



(1) System decomposition

To use a simulation approach on a system. The first step is to decompose the system into components and subsystems which are held together by linkage. Before the behaviour of an aquifer can be examined using a simulation model, a great deal of information must be specified. Though there may be considerable difficulty in obtaining reliable data, yet the problem must be completely formulated with estimates made of relevant parameters. The following parameters are distilled in this study and explained in following chapter.

(a) Boundary and conditions of the groundwater basin
(b) Unit condition and its area of groundwater basin
(c) Transmissibility of aquifer (T)
(d) Storage coefficient of aquifer (S)
(e) Initial water level (Initial water head) of aquifer (ho)
(f) Discharge (Qd)
(g) Recharge (Precipitation (P), Evapotranspiration (E), Irrigation efficiency (I)
(h) River flow (A)

(2) Computer programme formulation

The second step is to formulate the computer programmes for each subsystem and their linkages. This may involve writing computer programmes for the algebraic and logical relationships of subsystems and linkages.

There are two principle aquifers in the Lower Rio Cobre basin. The limestone aquifer and the alluvial aquifer, which are considered to be hydrogeologically discontinuous. Therefore two different simulation models were formulated for the two aquifers. These models were programmed using the finite element method for a digital computer.

(3) Model identification

The third step is to identify the model. This is accomplished by using known inputs and outputs for each subsystem. Inputs and outputs must be received and sent through the correct linkages and must be acceptable to their appropriate subsystems. In this study the hydrological and hydrogeological data in 1972 by FAO were considered to be the most reliable of the observational records and groundwater levels in August 1972 were adopted for the identification.

If the good conformity is not achieved through the inspection of interpretation, the parameters must be adjusted in the model. Generally the adjustment is carried out on recharge from precipitation, transmissibility, etc. Such trials with adjustment of parameters has to be made many times until the model conforms with the groundwater configuration of the basin. When conformation is achieved between the observations and calculated results, the model, its parameters and the boundary conditions are fixed to obtain prediction of future trends.

(4) Model operation and results

The completed simulation model is now ready for processing the input parameters of the system.

The parameters (probable precipitation, future abstraction, etc.) are set in the fixed model and the future groundwater level is predicted.

(5) Alternative inputs and evaluation

Groundwater levels are changed in accordance with the discharge rate input. In the simulation the optimal yield is the estimated the annual abstraction for which the groundwater level after one year's abstraction is almost same (less than ±1 m) of the primary water level. After several trials of discharge rate input, the annual discharge rate will be analysed.

3.8.2 Simulation model of the lower Rio Cobre basin

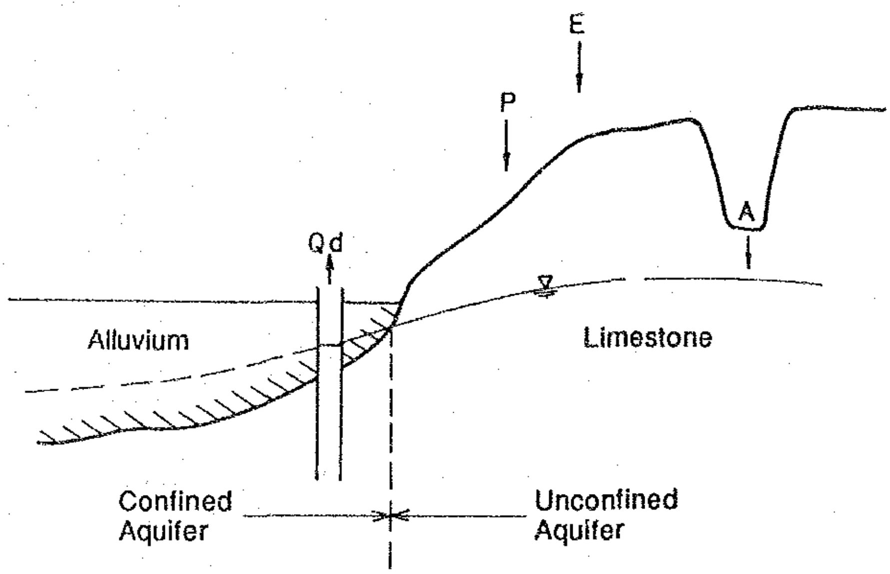
Two simulation models were formulated on the basis of above mentioned basic procedure: for the limestone aquifer and the alluvial aquifer in the Lower Rio Cobre Basin.

(1) Conceptional models of the aquifers

(a) Limestone aquifer model

The limestone aquifer, which extends almost throughout the Lower Rio Cobre Basin, is considered as continuous aquifer which is recharged by surface water (precipitation, river flow, etc.).

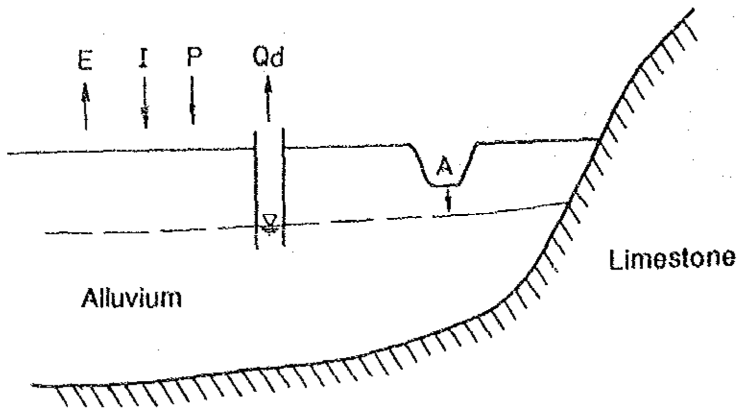
(i) The limestone aquifer is hydrogeologically discontinuous from the alluvial aquifer.
(ii) The aquifer is presumed as be unconfined in the hilly area and confined in the alluvial area.
(iii) The aquifer is regarded as being recharged with surface water (precipitation, river flow, etc.).



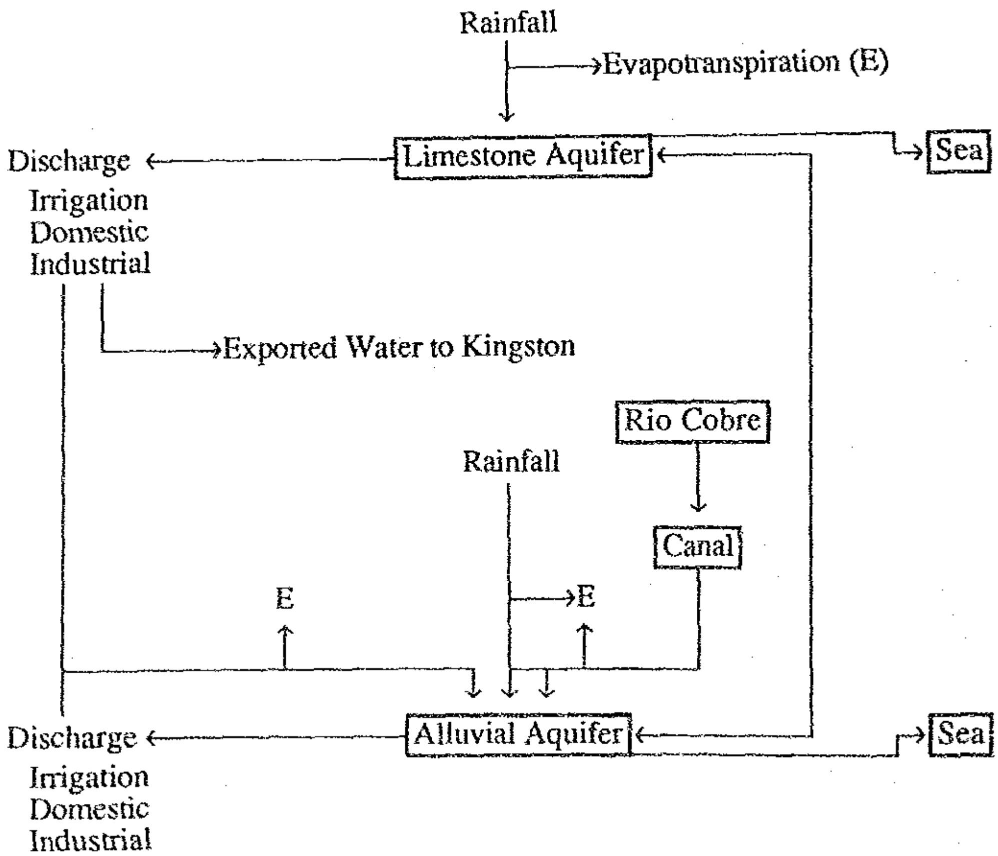
(b) Alluvial aquifer model

In the model the alluvial aquifer is distributed only on the coastal alluvial flat plain and is considered as a continuous aquifer.

(i) The alluvial aquifer is hydrogeologically regarded as discontinuous from the limestone aquifer.
(ii) The aquifer is considered to be recharged with surface water (precipitation, irrigation water, river flow, etc.).



The hydrologic cycle is illustrated schematically by the flow chart shown below:



(3) Simulation equation

The simulation models of the two basins are two dimensional plain distributed parameter models and are analysed numerically using the finite element method.

The groundwater flow is expressed by the following equation based on Darcy's Law and the condition of continuity of flow.

$$S\, dh/dt = \partial/\partial x\, (T\, \partial h/\partial x) + \partial/\partial y\, (T\, \partial h/\partial y) + W\, (x,y,t)$$

where, T : Transmissibility
S : Storage coefficient
h : Hydraulic head (water level) in aquifer
W : Recharge rate

The above equation is modified in the Lower Rio Cobre Groundwater Basins as follows:

$$S\, dh/dt = \partial/\partial x\, (T\, \partial h/\partial x) + \partial h/\partial y\, (T\, \partial h/\partial y) - Qd + P + I + A$$

where, Qd : Discharge rate or pumping rate
P : Recharge rate from precipitation
I : Recharge rate from irrigation water
A : Recharge rate from river flow

(4) Data processing for simulation

(a) Boundary and its condition of groundwater basin

The area of groundwater basin is considered as the area of the continuous aquifer and the in and out flow of groundwater from the basin is limited on the boundary.

The limestone groundwater basin is almost same area of the Lower Rio Cobre Basin. The north boundary runs mostly on the hydrological watershed through around Bog Walk. The some of the east and west boundaries are along almost same line of the parish boundary. The south boundary is coast line and the boundary between the plains and the Hellshire and Port Henderson Hills. The groundwater level of the south boundary is almost zero in altitude.

The alluvial groundwater basin has the same area of alluvial coastal basin surrounded by north limestone hills, south coast line and the Hellshire and Port Henderson Hills. The groundwater level of coast line is almost zero in altitude.

(b) Element grid

The groundwater basin is divided into unit areas. The scale of dividing unit areas depends on the purpose, the accuracy of the data and the capacity of the computer. In this case, the form of the unit area is the square element grid with 1.5 km sides as shown in Fig. C-25.

(c) Aquifer characteristics

(i) Transmissibility (T)

The existing aquifer characteristics are shown in Table C-5, C-6 and C-9. The numbers of the data are limited in the study area. The information is used together with information on stratigraphy and specific capacity (the ratio of discharge rate to drawdown) to estimate the distribution of transmissibility.

- Limestone aquifer:
  A lineament map of the limestone outcrop area was drawn by air photographic interpretation and was used to subdivide the area of transmissibility. The transmissibility map was made as shown in Fig. C-26.

- Alluvial aquifer:
  The transmissibility map of alluvial aquifer was made as shown in Fig. C-27.

(ii) Storage coefficient (S)

The data was not enough for deriving the storage coefficients. These were therefore estimated as follows:

- Limestone aquifer	
Confined area	1×10^{-4}
Unconfined area	1×10^{-2}
- Alluvial aquifer	5×10^{-2}

(d) Initial condition

Groundwater levels (ho) of the aquifer as initial condition in each grid element were read from the groundwater contour maps made from observations of groundwater level in the wells.

In model identification the groundwater level for each aquifer on January 1972 was set as the initial water level as shown in Fig. C-7 and C–17.

(e) Discharge rate

Annual discharge from the limestone and alluvial aquifers are shown in Fig. C-12 and C-21. Data on monthly discharge being inadequate, monthly discharge rates of two or three portions had been estimated by using the monthly discharge data as shown in Table C-12.

(f) Parameters of recharge

Groundwater of the Lower Rio Cobre Basin is considered to be recharged partly by precipitation, partly by river flow and partly by irrigation water.

(i) Precipitation

The areal distribution of precipitation is determined by the use of Thiessen networks. The stations and data on rainfall were those from Botbol report (1982), which are shown in Fig. C-28 and Table C-13.

(ii) Recharge to limestone aquifer

FAO (1974) and Botbol (1982) correlated annual rainfall and natural replenishment from rainfall and produced the function shown in Fig. C-29. It is used for the simulation. The recharged-area is assumed to be the limestone outcrop area. Recharge from the river Rio Cobre seems to be relatively small and is omitted in the study. As regards recharge from the Rio Minho Basin, although the details were obscure after several trials the groundwater level of the boundary between the two basins was given a constant head to represent groundwater flow from the Rio Minho Basin.

(iii) Recharge to alluvial aquifer

Recharge from surface water was assumed to follow the relationship shown in Fig. C-30 as derived by FAO investigation (1974). The recharged water includes irrigation water, industrial water and domestic water, which are obtained from the limestone and alluvial wells, as well as from canal water as shown in above flow chart. But some of the domestic water exported to the Kingston is not included. The quantity of the above mentioned water is shown in Table C-14. The recharge area is assumed to be the irrigated area as shown in Fig. C-31.

In addition there was leakage water to the alluvial aquifer from the river Rio Cobre between the dam and Crum Ewing in 1972 to 1973 as shown in Table C-15. This is put into the recharge of alluvial aquifer directly.

3.8.3 Model identification and operation

(1) Model identification

For the model identification the observed groundwater data in 1972 were used. The observed recharge and discharge parameters in each element grid from January to August are put in the groundwater condition in January on each limestone and alluvial groundwater basin. After operation the calculated groundwater levels in August were obtained. When there was any difference between the observed and calculated groundwater levels, the parameter of transmissibility was adjusted in the model and it was operated again. After the number of iteration of the adjustment, conformation was achieved between the observed water levels and the calculated water levels. And then the model, its parameters and the boundary conditions were fixed.

The identified transmissibility and groundwater levels in the models are shown in Fig. C-32 and C-33 and Fig. C-34 and C-35 respectively. The boundary which has a constant head of groundwater is shown in Fig. C-34 and C-35.

(2) Operation and alternative input

The simulation was operated as follows:

(a) The purpose of the simulation was to obtain the optimal yield of each element grid in a probable drought year.

(b) Groundwater level were changed in the simulation model in relation to discharge. The optimal yield, also called the safe yield or the perennial yield in terms of the water balance was determined as the annual abstraction after which the groundwater is almost same of the primary water level, and the difference between the primary water level and the water level after one year discharging will be less than ± 1 m after several trials.

(c) In the limestone aquifer system a further criteria was that the water level should always be above sea water level, because saline water will be abstracted when discharge water level is below sea water level.

(d) For inspecting the recharge to the aquifers in the rainy season, the operating year was assumed to begin from September.

(e) The calculated groundwater levels on August 1972 were used as the initial water levels at each element as shown in Fig. C-34 and C-35.

(f) The discharge volume was investigated from the designed irrigation water volume monthly on each element grid.

(g) The rainfall in 1975 was used in the calculation as provable rainfall.

(h) The canal flow is shown in Table C-16.

(i) The industrial and domestic water was assumed as shown in Table C-17, referring for the Reports of Water Resources Inventory, Water Demand Inventory and Analysis of Water Balance and Developments Alternatives by UNDP (1985/1986).

(3) Results of operation

The result of the simulation indicated optimal annual discharge volumes for each element grid from both aquifers as shown in Fig. C-36 and C-37. The total monthly abstraction is summarized as follows:

(Unit: 10^3 m^3/month)

	Limestone Basin	Alluvial Basin
September	7,690	1,690
October	7,110	1,670
November	7,890	1,730
December	8,410	2,200
January	8,410	2,630
February	9,300	3,960
March	9,510	4,050
April	9,410	4,050
May	8,270	3,970
June	8,950	3,970
July	9,650	4,040
August	9,150	2,130
Total	103,750	36,090

The water levels after one year discharge are shown in Fig. C–38 and C-39. In the limestone basin the abstractable areas are Old Harbour, Innswood, etc. along the boundary between limestone hills and plains. On the other hand the main abstracting area in the alluvial basin is around the Bernard Lodge area.

The annual water supply volumes for agriculture demand on wells include supplies for outside the study area for Agricultural, Industrial and Domestic use in the Lower Rio Cobre Basin estimated as shown in following table:

(Unit: million m^3/year)

Source	Agriculture	Industrial	Domestic*	Total
Limestone basin	60.7	5.9	37.2	103.8
Alluvial basin	31.0	2.6	2.5	36.1
Total	91.7	8.5	39.7	139.9

Remarks: *; includes the exported water to the Kingston
17 million m^3

3.9 Evaluation of Groundwater

(1) Present condition of groundwater

There are two aquifers (Tertiary limestone and alluvial aquifers) in the study area and from which about 130 million m^3 of groundwater seems to be produced. But the saline water intrusion is caused by upconing and frontal intrusion in Old Harbour, Innswood, etc. The groundwater salinity from several limestone wells is over 300 ppm in dry season.

(2) Evaluation of groundwater simulation result

From the results of the groundwater simulation 103.6 million m^3 of optimal discharge from the limestone aquifer and 36.1 x 10^3 m^3 from the alluvial aquifer are calculated annually. At present the abstraction wells are concentrated in certain areas (Innswood, Caymanas, etc. on the limestone wells and Bernard Lodge on the alluvial wells) and to avoid interference it is recommended that the well field must be reconstructed in order to reduce pumping depressions and to have a uniform well field.

(3) Application of simulation model

Since good correlation has been obtained for the groundwater levels and discharges between present conditions and simulation results in both aquifers it is considered that fluctuation of groundwater levels should provide the judgement data in planning future groundwater abstraction.

The simulation model may also be used as a valuable tool for expressing future groundwater conditions and should be modified regularly with results of observation and monitoring data.

(4) About UNDP/Water Resources Development Master Plan Report No. 4 (1986)

The subtitle of the report is Analysis of the Water Balance and Development Alternatives for the Lower Rio Cobre Sub-Basin by a Simulation Model. The volume of surface and groundwater was predicted using the data of two rainfall stations and river flow data by probability theory, after which the water balance was analysed with the provided water and several water demands. The prediction of rainfall and river flow was based on data from only a few data, but it is noteworthy that the authors state that the best prospects for development of the area will lie in crop diversification and improvement of the main canal.

3.10 Groundwater Basin Management

3.10.1 Appropriate usage and maintenance of groundwater

(1) The safe yield of the groundwater basin is the amount of water which can be withdrawn annually without causing an undesirable influence in the Basin (Todd, 1959). The undesired influence means usually increase of pumping costs due to decline of groundwater level, sea water intrusion and subsidence. It is noticed that this definition includes perennial water balance, no risk to economical use, and no trouble to groundwater development. This definition is called as perennial yield by the characters of perennial water balancing.

(2) In the Lower Rio Cobre Basin, rainfall distribution is strongly seasonal and the rainfall pattern is intensely localized. Therefore unrestricted usage of groundwater at any time would lead to a fall groundwater level and saline water intrusion to the aquifer in the part of the Basin.

(3) The irrigation water must be used effectively by:

- (a) Economy and management of irrigation water use.
- (b) Maximizing the use of canal water.
- (c) Conservation of excess surface water in reservoirs and recharging some of it into the aquifers especially in the rainy season.
- (d) Keeping drawdown levels above sea water level, to preventing saline water intrusion.
- (e) Formulating a system that by which well owners must observe their wells and submit the groundwater data to UWA.
- (f) Better management of the groundwater well field by reconstruction.

3.10.2 Groundwater management

The groundwater management should include:

(1) Collection of observational data

This needs to be carried out continuously including the observation of groundwater levels, pumping water levels, discharge and water quality of the index wells. Many more observation wells must be installed in addition to the present monitoring system as shown below:

- (a) Increase the numbers of the monthly groundwater observation wells on both limestone and alluvial aquifers.
- (b) Set more than 5 automatic water level recorders on the limestone wells of Old Harbour, Innswood and Caymanas, etc. and on the alluvial wells of Bushy Park and Bernard Lodge etc.
- (c) Take and analyze the water quality samples from 25 limestone wells and 15 alluvial wells in dry and wet seasons a year for monitoring saltwater intrusion and groundwater contamination.
- (d) Investigate the fresh-saline water boundary on several wells in dry and wet season each year. Now only 4 wells can be observed and more 5 wells must be made available for electrical conductivity profiling exercises. Sites of new observation wells are proposed in Old Harbour, Longville Park, Brampton Farm, Bushy Park and Salt Pond.

(2) Hydrogeological investigation

The groundwater conditions in the Lower Rio Cobre Basin are so complex that much more hydrogeological investigation should be carried out before new wells are constructed, in order to grasp the continuity of aquifers, the aquifer characteristics, the relationship between limestone and alluvial aquifers, conditions of saline water intrusion, effects of artificial recharge, groundwater sub-basins, etc.

(3) Obligatory system of groundwater data submission

To establish a reliable monitoring system for the groundwater system, it is necessary to systematize an obligatory system of well data and groundwater observation from the well owners or users. The items of data required are: Name of well, Name of orner, Place (co-ordinate), Drilled date, Drilled method, Depth, Datum level, Well structure (diameter and depth of casing and screen), Well condition (water level, pumping water level and discharge on the constructed and each month, water quality semi-yearly), Pump (name, type, stage, diameter of discharge pipe, HP (kwA), discharge, capacity and total head) Trouble (sady, salinity, etc.).

(4) Filing system of groundwater data

Above-mentioned data must be filed in a data bank accessible by computer at any time.

(5) Intensive groundwater monitoring

Intensive groundwater monitoring is necessary not only to detect critical groundwater levels but to provide more detailed data for the purpose of improving groundwater simulation models, planning and management.

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Annex II	Water Resource Appraisal
Annex III	Water Quality
List of Table	
List of Plates	

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Table C-1 RESULT OF LABORATORY TEST

(1) Unaxial Compression Test of Core Sample, Rio Cobre Dam, 6 Oct., 1986

No. (Depth in mm)			Sample Size Diameter (cm)	Sample Size Length (cm)	Area (cm2)	Weight (g)	Unit Weight (g/cm3)	Uniaxial Compressin Strength Load (kg)	Uniaxial Compressin Strength Strength (kg/cm)
B-1	(26.2 - 27.4)	limestone	4.445	10.16	15.52	430.83	2.73	8,181.14	527.14
B-2	(3.0 - 4.6)	concrete	4.445	6.35	15.52	213.15	2.16	1,269.80	81.82
B-2	(6.1 - 7.6)	concrete	4.445	8.89	15.52	308.38	2.24	725.60	46.75
B-2	(21.3 - 22.9)	limestone	4.445	8.89	15.52	399.08	2.89	6,711.80	432.41
B-3	(TOP)	concrete	4.445	8.89	15.52	344.66	2.50	2,358.20	151.95
B-3	(23.2 - 24.1)	limestone	4.445	10.16	15.52	453.50	2.88	7,074.60	455.84
B-4	(24.4 - 25.0)	limestone	4.445	10.16	15.52	453.50	2.88	6,167.60	397.40
B-5	(9.1 - 12.2)	limestone	4.445	10.16	15.52	421.76	2.68	3,664.28	263.10
B-5	(12.2 - 15.2)	limestone	4.445	10.16	15.52	344.66	2.19	3,628.00	233.76
B-7	(15.5 - 17.0)	limestone	4.445	10.16	15.52	448.97	2.85	5,442.00	350.64

(2) Specific Gravity of Rock, Rio Cobre Dam, 2 Oct., 1986

Bore Hole No.	B-1	B-2	B-2	B-2	B-3	B-3	B-4	B-5	B-5	B-7
Depth of Sample (m)	26.2-27.4	3.0-4.6	6.1-7.6	21.3-22.9	TOP	23.2-24.1	24.4-25.0	9.1-12.2	12.2-15.2	15.2-17.0
Weight of Sample in Air A	430.8	213.2	308.6	399.1	344.7	453.7	453.5	422.2	347.0	449.0
Weight of Sample in Water B	272.9	113.9	170.5	260.3	206.8	296.1	294.7	264.4	188.4	291.2
A - B	157.2	98.0	138.1	137.4	139.9	157.6	158.8	157.8	158.6	157.5
Specific Gravity	1.735	2.162	2.235	2.894	2.500	2.878	2.878	2.676	2.188	2.849

(3) Specific Gravity of Soil Solids (Gs), Rio Cobre Dam Site, 3 Oct., 1986

Sample No.	B -1		B - 2		B - 4		B - 5	
	Sand		Sand		Silt		Clay	
Depth of Sample	(3.20 - 3.50 m)		(13.87 - 14.17 m)		(12.35 - 12.65 m)		(1.68 - 1.98 m)	
Test no	1	2	1	2	1	2	1	2
Wt. Flask + water + soil = W bws	993.80	997.80	980.00	984.00	87.53	87.56	88.87	88.92
Wt. Flask + water b = W bw	868.00	868.00	868.00	868.00	71.56	71.56	71.56	71.56
Wt.evap dish + dry soil	506.40	510.50	486.60	490.70	47.97	48.00	50.33	50.38
Wt. of evap. dish	305.90	305.90	305.90	305.90	21.82	21.82	21.82	21.82
Wt. of dry soil = W s	200.50	204.60	180.70	184.80	26.15	26.18	28.51	28.56
Ww = Ws + Wbw - Wbws	74.70	74.80	68.70	68.80	10.18	10.18	11.20	11.20
Gs = ∝ Ws/Ww (for 15oC)	2.68	2.74	2.63	2.69	2.57	2.57	2.55	2.55
Specific gravity (for 15oC)	Average 2.71		Average 2.66		Average 2.57		Average 2.55	

(4) Grain Size Distribution, Rio Cobre Dam B-1, Depth 3.2-3.5 m, 2 Oct., 1986

Diametre (mm)	50.8	38.1	25.4	19.1	9.52	4.76	2.00	0.84	0.42	0.25	0.105	0.074
% Passing	100.0	100.0	100.0	100.0	96.1	91.7	77.3	59.5	46.3	37.5	24.6	21.6

Table C.3(1/3) LIMESTONE AQUIFER (WELL LIST)

No	Name of Well	Reference E	Reference N	Drilled Date	Drilled By	Depth (m)	Datum (m ASL)	Log	Casing Pipe (m)	Diameter (cm)	Screen (m)	Diameter (cm)	OPEN (m)	Diameter (cm)
1	BODLES NOSE HALL	E5301	N3745	1972	Perc	93.4	-	L	0-27.1	30.6	27.1-42.4	30.8	42.4-53.4	50.8
2	BODLES NO. 2	E3017	N3734		-	40.5	24.62	L	-		-	-		
3	COLBECK MACHADO	E5229	N3457	1930	Tool	100.7	46.72	L	0-16.3	30.9			18.2-32.3,32.3-100.7	30.8,40.6
4	COLBECK CLARK	E5032	N3449	-	-	62.5	58.10	-	-	30.5	-	-	-	-
5	BODLES LIVESTOCK	E3052	N3186	1946	Perc	61.0	77.05	L	0-29.3, 42.1-43.9	30.8, 30.8	29.3-41.5	30.5	42.9-61.0	
6	COLBECK CASTLE	E5057	N3815	1962	Perc	60.3	47.05	L	0-46.1	40.6	46.1-57.4	40.6	55.8-68.3	45.7
7	WHIM Abd	E5057	N3685	-	Perc	-	13.90	-	-	-	-	-	-	-
8	MANDOR TERMINALS	E5059	N3720	1942	Tool	56.6	22.86	L	0.6-28.1	30.8	-	-	28.1-56.6	30.8
9	BODLES EXPERIMENTAL	E5059	N3721	-	Tool	58.0	20.53	L	-		-	-		-
10	BODLES IPS 1	E5041	N3738	-	Perc	56.6	-	-	-	-	-	-	-	20.3
11	BODLES IPS 2	E5041	N3739	-	Perc	50.4	-	-		-	-	-	-	20.3
12	BODLES DOMESTIC	E5044	N3784	1959	-	55.4	-	L	0.2-4.0,5-37.2	203.2,30.8,30.5	34.4-77.2	30.8	77.2-53.4	-
13	BODLES CITRUS	E5049	N3793	-	Dug Drill	-	-	L	-		-	-	-	-
14	LODGE FARM No.1	E5057	N3702		Perc	36.6	23.01	L	0.6-11.3	20.3	11.3-29.4	20.3	29.8-36.6	20.3
15	LODGE FARM No.2	E5057	N3701		Dug	-	19.73	-	-		-	-	-	-
16	SHOGGINS	E5060	N3736	-	Dug Drill	26.7	26.24	L					0-26.5	182.9
17	BOWERS	E5072	N3405	1936	Tool	91.5	49.50	L	0.3-2.7	20.3	-	-	58.0-91.5	20.3
18	WHIM NO. 3 Mead Shed	E5074	N3715	-	Perc	36.6	19.19	-	-		-	-	-	-
19	BANNISTER	E5073	N3674	1971	Perc	80.8	34.50	L	0.0-42.7	40.6	42.7-67.1	42.7	67.1-80.8	50.8
20	RED GROUND	E5077	N3949	1971	Rot	122.0	115.40	L	0-21.3,30.2-32.8,72-76.6	20.3,20.3,20.3	21.3-30.2,32.8-72.0,76.6-82.4	20.3,20.3,20.3	-	-
21	COLBECK PUBLIC	E5078	N3794	-	-	62.5	30.80	L	0-39.0	40.6	0-39.0-51.2	40.6	51.2-62.5	-
22	CLAREMONT	E5090	N3414		Perc	42.6	-	-		35	-	-	-	-
23	OLD HARBOUR (BURKES)	E5085	N3702	-	Perc	61.0	27.05	-	-	-	-	-	-	30.5
24	WHIM NO. 1 (Railway)	E5092	N3745	-	Perc	45.8	22.15	-			-	-	-	-
25	OLD HARBOUR (VAZ)	E5093	N3776	-	Dug Drill	35.7	-	-	-		26.5-35.7	20.3	0-26.5	182.9
26	LITTLE ASCOT	E5100	N3794	-	Perc	-	30.50	-		-	-	-	-	-
27	BALLY PEN NO. 1	E5102	N3692	-	Dug	-	13.90	-	-	-	-	-	-	-
28	NEW MARKET PEN	E5127	N3742	-	Tool	37.4	19.30	-	-	-	-	-	-	-
29	MORRANT PEN	E5127	N3743	-		-	-							
30	RED GROUND CH	E5127	N3943	-	Core	-	-	-	-				-	-
31	BRAMPTON FARM	E5135	N3720	-	Tool	67.1	14.57	L	13.4-57.3	30.5	-	-	0-13.4,57.5-67.1	182.9,30.5
32	MAHLIE MOUNT	E5142	N3703	1973	Dug	37.7	23.20	-	0-23.5,12.5-26.5,32.6-34.2	40.6,50.8,40.6	23.5-32.6	40.6	-	-
33	THETFORD OLD HARBOUR	E5160	N3811	1970	Perc	30.5	29.30	L	0.5-20.7	35.6	20.7-30.5	35.6	-	-
34	THETFORD HALL	E5160	N3411	1970	Perc	30.5	29.25	L	0-20.7	35	20.7-30.5	35.0	-	-
35	CHURCH PEN	E5174	N3779	1972	Perc	48.8	20.90	L	0-18.3	61	18.3-30.8	61.0	36.6-48.8	61.0
36	ASHBOURNE CORRISOLS	E5183	N3943	-	-	71.7	54.30	L	0-71.7	3.0	0-71.7	3.8	-	-
37	THETFORD (DUG WELL)	E5204	N3638	1970	Dug	67.1	-	-	18.3-22.9	1.8	22.9-42.1	1.8	0-18.3,42.1-67.1	20.3,1.8
38	THETFORD 3	E5209	N3657	1975	Perc	109.8	-	L	0.6-3.0	40.6	3.0-30.7,31.7-75.6	40.6,30.5	73.6-109.8	30.5
39	THETFORD 2	E5209	N3630	1974	Perc	77.8	-	-	-	-	0-30.3	40.6	30.3-77.8	40.6
40	HINKOCKS (Bushy Park)	E5239	N3705	1948	Tool	100.3	19.30	L	0-70.2	30.5	-	-	-	20.3
41	KILBY PEN	E5241	N3799	1970	Perc	-	21.10	-	-	-	-	-	-	-
42	SPRING GARDEN FARM	E5244	N3676	1958	Tool	76.3	30.49	L	0-18.3, 23.2-40.6	50.8,40.6	18.3-24.4	50.8	40.6-76.3	40.6
43	LORDS (Bushy Park)	E5245	N3610	1946	Perc	105.1	24.00	L	0-61.0	30.5	61.0-105.2	20.3	-	-
44	SPRING VILLAGE NO. 1	E5242	N3673		Perc	-	30.00	-	-	-	-	-	-	-
45	SPRING VILLAGE NO. 2	E5245	N3673		Perc	-	30.00	-	-	-	-	-	-	-
46	GROVE FARM 1	E5246	N3423	1930	Tool	76.3	21.60	L	0-43.7,43.7-72.3	50.5,30.5	-	-	72.3-76.3	20.3
47	GROVE FARM 2	E5249	N3424	1975	Perc	104.3	-	L	0.6-37.7	40.6	17.7-61.0,52.5-75.0	40.6,35.6	75.0-104.3	30.5
48	SPRING VILLAGE NO.3	E5277	N3480	-	Perc	-	28.91	L	-	20.3	-		-	-
49	NIGHTINGALE GROVE	E5297	N3443	1973	Perc	55.8	-	L	0-20,0.3-21	50.8,30.5	21.0-42.4	30.5	42.4-55.8	40.6
50	GUANABOA VALE	E5280	N4137	-	Drill	-	151.40	-	-	-	-	-	-	-
51	SUTTON TOWN 1	E5299	N4022	1969	-	54.3	-	-	-	-	-	-	0-54.3	10.2
52	ST. HELEN 2	E5302	N3915	1963	Drill	91.5	17.20	L	0-12.2,0-18.3	50.8,40.6	12.2-21.3,18.3-37.2,30.5-57.9	50.8,40.6,30.5	57.9-91.5	40.6
53	ST. HELEN EXPL. 1	E5305	N3464	1972	Rot	131.6	-	L	-	-	-	-	-	-
54	ST. HELEN EXPL. 2	E5305	N3464	1972	Rot	259.3	11.60	L	0-73.8	34		-	73.8-170.2,170.2-259.3	26.9,21.8
55	ST. HELENS NO. 4	E5305	N3464	1954		76.2	11.64	L	-		53.4-61.0	-	61.0-99.1	
56	ST. HELEN (Abd)	E5308	N3890	-	Dug	8.5	-	-	-	-	-	-	-	-
57	ST. HELENS NO. 5	E5317	N3893	1954	Tool	24.4	15.01	L	-	-	-	-	-	-
58	COTTON TREE NO. 2	E5332	N3965	1955	Tool	87.8	20.12	L	0-21.0	30.8	21.0-42.1,41.2-48.2,48.2-55.3	50.8,30.5,25.4	55.5-87.8	25.4
59	COTTONS TREE NO. 1	E5333	N3972	1955	Perc	87.8	-	L	-	-	-	-	-	-
60	SYLES	E5337	N4022	1970	Perc	71.7	-	L	0-40.3	25.4	-	-	40.3-71.7	25.4
61	RIO COBRE LEASE 1	E5393	N3939	1954	Perc	61.0	18.90	-	0-7.3,7.3-22.6,30.2-44.5	61.0,50.8,40.6	22.6-30.2, 44.5-52.5	50.8, 40.6	32.5-61.0	40.6
64	RIO COBRE LEASE NO.2	E5393	N3936	1954	Perc	61.0	13.90	L	0-7.3,7.3-22.6,30.2-44.0	61.0,50.8,40.6	22.0-30.2,44.0-52.5	50.8,40.6	32.5-61.0	40.6
65	RIO COBRE LEASE 2	E5393	N3936	1954	Perc	125.0	17.70	L	0-16.3,0-17.7,30.6-45.70.6-109.6	61.0,50.8,40.6,20.3	17.7-39.0,43.0-53.2,51.8-76.2,109.8-122.0	50.8,40.6,50.5,20.3	-	-
66	HAREBERRY GROVE	E5401	N4042	1973	Rot	111.3	-	-	0.3-80.8	22.3	80.8-90.1	22.3	90.1-111.3	44.4
67	HAREBERRY GROVE 2	E5410	N4040	-	Perc		-	L	-	-	-	-	-	-
68	HAREBERRY GROVE 1	E5411	N4041	-	Drill		17.70	-	-	30.5		-	-	-
69	INNSWOOD CH 9	E5425	N3926	1981	Rot	76.5	21.90	L	0-21.3	5.1	21.3-76.2	5.1	-	-
70	INNSWOOD FACTORY 1	E5428	N3936	1965	Tool	36.6	21.30	L	-	-			-	-
71	INNSWOOD FACTORY	E5428	N3938	-	Tool	36.6	20.77	L	0-24.4	50.8			-	-
72	INNSWOOD FACTORY 2	E5430	N3939	1977	Perc	36.6	22.00	L	0-11.6	50.8	11.6-28.8	50.8	26.8-36.6	61.0
73	INNSWOOD FACTORY NO.3	E5430	N3941	1965	Drill	36.6	21.90	L	0-11.6	50.8	11.6-26.8	50.8	26.8-36.6	50.8
74	INNSWOOD CH 10	E5432	N3937	1981	Rot	83.8	22.20	L	0-47.3	5.1	47.3-83.9	5.1	-	-
75	INNSWOOD FACTORY 4	E5434	N3943	1965	Tool	36.6	21.70	L	0-12.2	50.8	12.2-27.5	50.8	27.5-36.6	50.8
76	INNSWOOD CH 7/1	E5442	N3921	1980	Rot	93.6	21.20	L	0-63.1	5.1	63.1-93.6	5.1	-	-
77	INNSWOOD CH 7/2	E5442	N3921	1980	Rot	55.7	21.30	L	0-32.9	5.1	32.9-57.3	5.1	-	-
78	INNSWOOD CH 4	E5444	N3933	1981	Rot	103.7	21.30	L	0-39.7	5.1	39.7-103.7	5.1	-	-
79	BELLEVUE	E5447	N4002	-	Drill	-	72.00	-	-	-		-	-	-
80	INNSWOOD CH 3	E5448	N3944	1981	Rot	73.2	24.20	L	0-30.3	5.1	30.3-73.2	5.1	-	-
81	MANGO WALK NO. 2	E5451	N3973	1964	Tool	84.0	25.83	L	0-23.0	30.8	24.1-39.7	50.8	39.7-84.2	50.8
82	MANGO WALK NO. 4	E5451	N3973	1965	Tool	84.0	27.71	-	0-24.4	50.8	24.4-39.7	50.8	-	-
83	MANGO WALK NO. 5	E5452	N3974	1966	Perc	84.3	27.03	-	-	-	24.4-39.7	50.8	39.7-84.2	20.8
84	MANGO WALK NO. 3	E5454	N3976	1956	Tool	84.0	27.71	L	0-24.4	-	21.0-39.7	50.8	39.7-84.2	50.8

Table C-2(2/3) LIMESTONE AQUIFER (WELL LIST)

No	Name of Well	Reference E	Reference N	Drilled Date	Drilled Rig	Depth (m)	Datum (m ASL)	Log	Casing Plain (m)	Diameter (cm)	Screen (m)	Diameter (cm)	OPEN (m)	Diameter (cm)
85	INNSWOOD CH 41	E5433	N3950	1980	Rot	73.8	24.70	L	0-54.9	5.1	54.9-73.2	5.1	-	-
86	INNSWOOD CH 42	E5453	N3950	1980	Rot	54.9	25.00	L	0-36.6	5.1	36.6-54.9	5.1	-	-
87	MANGO WALK NO. 1	E5458	N3982	1949	Tool	61.0	26.52	L	0-24.1	30.8	24.4-39.7	30.8	39.7-54.2	30.8
88	INNSWOOD CH 8	E5465	N3914	1981	Rot	213.0	23.10	L	0-70.1	5.1	155.4-213.0	5.1	-	-
89	INNSWOOD CH 5	E5469	N3941	1980	Rot	78.4	26.60	L	0-48.8	5.1	48.8-78.4	5.1	-	-
90	DOVECOT PARK	E5469	N4008	1974	Pure	53.4	33.50	L	0-29	40	29.0-47.3	40.6	47.3-53.4	50.8
91	E.R. INTAKE	E5476	N4319	1967	Core	47.3	77.00	-	-	-	-	-	-	-
92	FRUIT HILL	E5485	N4116	1973	Core	199.1	118.50	-	-	2.54	-	-	-	25.4
93	MELVIN PARK	E5493	N4008	1975	Pure	70.2	-	L	0-32.8, 0-48.2	30.5, 25.4	-	-	48.2-70.2	25.4
94	HARTLANDS EXPL. 1	E5495	N3983	1972	Rot	245.3	19.80	L	0-75	34	-	-	75.0-107.1	47.0
95	HARTLANDS EXPL. 2	E5495	N3883	1972	Rot	214.1	19.40	L	0-10.4,0-79.6	34, 16.8	-	-	79.6-214.2	14.2
96	HARTLANDS EXPL. 2	E5495	N3883	1980	Cement	214.1	20.00		0-10.4, 0-79.6, 0-79.6	34, 16.8, 5.1	79.6-214.1	5.1	-	-
97	GORGE	E5505	N4317	1968	Core	64.0	79.60		-	-	-	-	-	25.4
98	WYNTERS PEN	E5516	N4056	1970	Pure	73.2	44.60	L	0-25.3	40.6	25.3-47.3	40.6	47.3-73.2	30.8
99	KENT VILLAGE	E5525	N4307	1967	Core	94.9	78.50	-	-	2.54	-	-	-	-
100	ST. JOHNS ROAD	E5531	N4015	1951	Perc	70.1	36.80	L	0.3-48.5	30.8	47.3-69.2	40.6	48.8-70.1	40.6
101	ARDENNE FARM EXPL. 1	E5532	N4090	1970	Pure	72.0	31.20	L	0-38.4	40.6	38.4-61.0	40.6	61.0-68.6	40.6
102	ARDENNE FARM	E5542	N4056	1955	Tool	88.5	46.73	L	0-36.6	40.6	36.6-51.8	40.6	51.8-73.0	40.6
103	FLAT BRIDGE	E5546	N4207	1957	Core	29.0	48.60	-	-	-	-	-	-	-
104	ARGUANABOA EXPL. 1	E5550	N4130	1970	Rot	67.4	52.10	L	0-39.9	40.6	39.9-64.4	40.6	64.4-67.4	47.0
105	CHUNG'S	E5550	N4092	-	Drill	-	49.40	-	-	-	-	-	-	40.6
106	O'TOOLES	E5553	N4066	-	Drill	-	44.70	L	-	40.6	-	-	-	40.6
107	ARGUANABO	E5554	N4121	-	Tool	-	54.70	L	-	-	-	-	-	-
108	TOP PIPE SOUTH	E5554	N3764	1973	Core	91.5	-	L	0-85.4	2.54	85.4-91.5	2.5	-	-
109	ARGUANABOA TEXTILES	E5554	N4121	-	Tool	-	54.70	-	-	-	-	-	-	-
110	CRESCENT EXPL.	E5555	N4154	1969	Rot	76.2	59.20	L	0-44.8	40.6	64.8-75.3	40.6	75.3-76.2	47.0
111	ANGELS NO. 7	E5566	N4135	-	-	-	-				-	-	-	-
112	HEADWORKS	E5567	N4130	1949	Drill	92.7	47.20	L	39.0-43.9	61	39.0-43.9	61.0	42.9-92.7	30.8
113	LITTLE WINDSOR EXPL.	E5568	N3827	1973	Rot	248.5	12.30	L	0-132.7	34	-	-	132.7-248.5	27.0
114	LITTLE WINDSOR EXPL.	E5568	N3827	1981	Cement	225.7	-		0-132.7	34	-			
115	ANGELS 1	E5569	N4136	1941	Tool	67.1	55.40	L	0-57.3	30.5	-	-	57.3-68.3	30.5
116	GOLDEN ACRES	E5573	N4078	-	Pure	-	47.40	L	-	-	-	-	-	40.6
117	CONTENT EXPL. H	E5580	N4149	1970	Rot	71.9	-	L	0.3-44.7	34	44.7-72.1	34.0	71.1-72.3	47.0
118	CONTENT WELL	E5580	N4149	-	Rot	73.8	55.20	L	0-49.4	40.6	49.4-73.8	40.6	-	-
119	ANGELS 2	E5594	N4108	1937	Tool	91.5	49.30	L	0-34.8	30.8	45.7-64.0,32.3-45.7	40.6,40.6	64.0-91.5	30.5
120	CROSS PEN (W)	E5622	N4120	1973	-	61.9	-	L	0-44.8	40.6	44.8-61.0	40.6	-	-
121	CROSS PEN	E5623	N4115	1973	Drill	37.9	49.20	-	-	-	44.8-61.0	-	-	-
122	BAMBOO EXPL. E	E5633	N4173	1970	Rot	61.0	40.50	L	0-37.2	34	37.2-61.0	34.0	-	-
123	KENSINGTON CH	E5643	N4232	-	Core	-	-	-	-	-	-	-	-	-
124	CROSS PEN EXPL. P	E5640	N4114	1970	Rot	72.3	35.10	L	0-32.8	34	32.8-72.3	34.0	-	-
125	ENSOM CITY	E5640	N4028	1943	Tool	61.0	33.60	L	0-21.3, 0-26.8	33.3, 30.5	26.8-48.5	30.5	48.5-61.0	30.5
126	TREDEGAR PARK NO. 2	E5675	N4044	1958	Pure	67.1	37.20	L	0-24.4	30.5	24.4-30.5	30.5	30.5-67.1	30.5
127	TREDEGAR PARK NO. 1	E5680	N4032	-	Drill	60.7	36.20	-	-	-	-	-	-	-
128	GREENDALE	E5698	N4034	-	Pure	-	-	-	-	-	-	-	-	-
129	WOODLANDS EXPL.	E5677	N3924	1972	Rot	183.0	21.30	L	0-33.2, 33.2-102.2	34-6.8	-	-	102.2-183.8	15.0
130	GRAHAM PEN	E5691	N4011	1955	Pure	64.1	34.60	L	0-22.9	30.8	32.9-32.5	30.8	32.5-64.1	30.8
131	WATERLOO VALLEY	E5697	N4087	1970	Rot	75.0	49.40	L	0-47	34	47.0-74.7	34.0	-	-
132	WATERLOO VALLEY EXPL.	E5697	N4087	1949	Drill	54.9	48.90	-	-	-	-	-	-	15.2
133	CRAIGALACHIE 3	E5700	N3926	1964	Tool	65.6	22.80	L	6.1-16.5	30.8	16.5-28.7	30.8	28.7-65.6	30.8
134	CRAIGALACHIE NO.2	E5702	N3912	1939	Tool	67.4	21.10	L	0-14.6	33	14.6-51.2	33.0	51.2-67.4	33.0
135	JONES DAM	E5710	N3940	1949	Tool	76.2	22.50	L	0-41.5	30.8	41.5-46.4	30.8	46.4-76.2	30.8
136	TWICKENHAM PARK	E5712	N3996	1939	Tool	75.0	30.40	L	0-24.4	30.8	24.4-36.6	30.8	36.6-75.0	61.0
137	WATERLOO FARM	E5714	N4061	-	Drill	30.8	62.70	L	-	-	-	-	-	-
138	KEYSTONE	E5714	N4061	-	Drill	30.8	62.70	-	-	-	-	-	-	30.2
139	CRAIGALLACHIE NO. 1	E5718	N3929	1933	Tool	84.3	21.40	L	0-30.0	30.8	29.0-54.3	30.5	-	-
141	TWICKENHAM PARK NO. 1	E5724	N3979	1946	Tool	58.0	30.20	L	-	-	-	-	-	61.0-40.6
142	TWICKENHAM PARK NO.2	E5722	N3985	-	Pure	-	27.85	L	0-24.4	30.8	24.4-26.6	30.8	-	-
142	TWICKENHAM PARK NO.3	E5724	N3979	-	Tool	58.0	25.70	-	-	-	-	-	-	-
143	RIFLE RANGE CH.	E5730	N4001	-	-	-	23.10	-	-	2.5	-	-	-	-
144	CENTRAL VILLAGE	E5732	N3984	1940	Pure	61.0	17.80	L	0-34.8	30.8	34.8-47.0	30.8	47.0-61.0	30.8/40.6
145	MOUNT GOTTHAM CH.	E5799	N4078	-	Core	-	26.90	-	-	-	-	-	-	-
146	GLADE (Pump)	E5791	N4210	1943	Tool	79.6	34.20	L	0-30.8,23.5-30.8	30.8,40.6	30.8-30.1	40.6	30.6-39.6	40.6
147	GOLF COURSE	E5797	N4075	1953	Tool	10.2	7.60	L	0.5	40.6	30.0-9.1	40.6	9.1-19.2	40.6
148	ELLIS FACTORY 4	E5798	N4007	1934	Tool	35.4	6.34	L	0-32.0	-	32-35.4	30.5	-	-
149	TOP ELLIS	E5799	N4079	-	Pure	-	-	-	-	-	-	-	-	-
150	H.W.T. EXPL. NO. 2	E5805	N3916	1972	Rot	276.9	14.60	L	0-95.2	34	-	-	95.2-276.9	27.0
151	H.W.T. EXPL. 1	E5805	N3916	1972	Rot	242.5	14.40	L	0-127.2	7.6	127.2-151.6	7.6	151.6-242.5	14.2
152	WHITE MARL NO. 3	E5813	N4001	1962	Tool	36.4	11.30	L	0-10.4,0-19.5	61.0,40.6	10.4-19.5,19.5-36.1	61.0,40.6	-	-
153	WHITE MARL NO. 1	E5814	N4001	1960	Tool	34.9	12.40	L	0-8.5	61	8.5-17.7	61.0	17.7-34.9	61.0
154	DAWKINS POLO FIELD	E5815	N4040	1960	Tool	25.3	11.60	L	0-10.7	61	10.7-12.2	61.0	12.2-34.4	61.0
155	WHITE MARL NO.2	E5816	N4002	1961	Tool	35.5	12.40	L	0-6.1	61	6.1-15.2	61.0	15.2-35.5	24.0
156	ELLIS NO. 1	E5817	N4003	1953	Tool	19.8	8.15	L	-	-	0-19.5	30.8	-	-
157	ELLIS NO. 3	E5817	N4036	1959	Tool	20.7	7.06	L	0-4.0	33	4.0-11.3	33.0	4.0-11.3	33.0
158	ELLIS NO. 2	E5818	N4035	1959	Tool	19.8	7.84	L	0.5-4.6	61	4.6-16.8	61.0	16.8-19.2	30.2
159	CAYMANAS CH 4	E5820	N4003	1960	Tool	25.0	-	L	0.3-6.1	10.2	6.1-18.0	10.2	18.0-25.0	20.3
160	MUNDEZ CEMENT	E5821	N4019	-	Pure	-	10.40	-	-	-	-	-	-	-
161	GLADE CK	E5848	N4147	-	Core	-	20.60	-	-	-	-	-	-	-
162	CAYMANAS CH 1	E5850	N4105	1973	-	80.8	4.00	L	0-80.8	3.8	0-80.8	3.8	-	-
163	CAYMANAS EXPL. 1	E5853	N4010	1972	Rot	318.1	-	L	0-40.3	34	-	-	40.3-318.1	26.9
164	CAYMANAS EXPL. 2	E5853	N4010	1972	Rot	213.0	9.00	L	0-106.7	34	-	-	106.7-213.0	26.9
165	CAYMANAS EXPL. 3	E5853	N4010	1972	Rot	183.0	-	-	0-4.6, 4.6-122, 0-94.6	34, 26.9, 16.8	-	-	94.6-183.0	14.2

Table C-3 ALLUVIAL AQUIFER (WELL LIST)

No	Name of Well	Reference E	Reference N	Date of Drilled	Depth (m)	Datum (m ASL)	Log	Plain (m)	Diameter (cm)	Screen (m)	Diameter (cm)	Discharge (lit/min)	Water (m)	Draw (m)
1	Wham No. 2	E5095	N3729	-	-	-	A	-	-	-	-	-	-	-
2	Old Harbour/Bypass	E5098	N3770	-	-	-	A	-	-	-	-	-	-	-
3	Kelly Pen NO. 2	E5110	N3688	-	-	-	A	-	-	-	-	-	-	-
4	Home Pen	E5132	N3701	-	-	-	A	-	-	-	-	-	-	-
5	Villa	E5151	N3757	-	-	-	A	-	-	-	-	-	-	-
6	Mignon (Bushy Park)	E5228	N3739	-	-	-	A	-	-	-	-	-	-	-
7	Ricketts (Bushy Park)	E5264	N3740	1956	21.3	8.5	A	6.4-14.6,18.0-20.2	30.5	0-6.4,14.6-18.0	30.5	1135, 1362	12.5	9.4,11.0
8	Khans (Bushy Park)	E5274	N3784	-	-	-	A	-	-	-	-	-	-	-
9	Cherry Gardens No. 1	E5287	N3793	-	-	-	A	-	-	-	-	-	-	-
10	Cherry Gardens No. 2	E5296	N3777	1959	36.0	12.9	A	0.3-13.1, 23.5-29.6	30.5	13.1-23.5,29.6-36.0	30.5	1324, 2082	26.5	7.9,22.3
11	St. Helens Domestic	E5310	N3827	-	-	-	A	-	-	-	-	-	-	-
12	Amity Hall CH. 1	N5330	N3772	1954	30.8	8.1	A	0.8-9.9	40.6	9.9-30.8	40.6	1366, 1450	24.4	13.1,22.9
13	Amity Hall North	E5331	N3824	1954	61.0	10.8	A	0-8.5	40.6	8.5-45.7,45.1-61.0	40.6,30.5	318, 2245	36.6	21.,35.1
14	Smallwood	E5499	N3826	-	-	-	A	-	-	-	-	-	-	-
15	Featherbed Lane Ch	E5514	N3941	-	30.5	-	A	-	-	-	-	-	-	-
16	Little Windsor CH	E5538	N3773	-	-	-	A	-	-	-	-	-	-	-
17	Windsor Park	E5545	N3886	1964	33.5	21.8	A	-	-	-	-	1274 , 5097	16.5	2.1,7.9
18	Tamarind	E5593	N3919	-	-	-	A	-	-	-	-	-	-	-
19	Fellowship Hall 1	E5599	N3847	-	-	-	A	-	-	-	-	-	-	-
20	St. John's Road CH.	E5609	N3989	1973	24.4	29.5	A	-	-	-	-	-	-	-
21	Fellowship Hall No.2	E5618	N3818	1964	11.6	-	A	-	-	0.6-11.6	50.8	637, 1784	9.2	1.5,8.2
22	Blair Pen	E5663	N3826	1959	33.5	19.5	A	0-6.1	50.8	6.1-33.5	50.8	1266, 3803	14.9	4.8,10.1
23	March Pen No. 2	E5676	N3833	1961	30.5	14.9	A	15.2-16.8	30.5	0-15.2,16.8-30.5	40.6,30.5	2839	3.7	4.9,6.4
25	Woodlands No. 1	E5677	N3924	1952	30.8	22.3	A	0.3-9.1	50.8	9.1-30.5	50.8	2271	17.4	3.7
26	Woodlands No. 2	E5689	N3905	1962	24.4	20.9	A	0-2.4	50.8	2.4-23.8	50.8	1274, 3823	9.8	0.6,4.6
27	Campeche	E5691	N3806	1973	17.7	11.2	A	0.6-1.2	50.8	1.2-17.7	50.8	2082, 3785	9.7	4.0,7.3
28	Phoenix Park No. 4	E5695	N3844	1963	33.6	13.9	A	-	-	0.6-33.6	50.8	2979, 4247	11.4	7.2,10.1
29	Phoenix Park No. 3	E5700	N3879	1960	30.5	18.6	A	0.6-2.4	50.8	2.4-29.9	50.8	1274, 5097	7.0	1.5,2.4
30	Phoenix Park No. 1	E5723	N3857	1959	10.7	-	A	-	-	-	-	3558	7.3	1.8
31	Bernard Lodge No. 1	E5727	N3885	1959	47.3	16.9	A	0-6.1	50.8	6.1-30.5, 30.5-46.7	50.8,30.5	5390	13.6	10.1
32	Bernard Lodge No. 2	E5727	N3885	1959	47.3	16.3	A	0.61	50.8	6.1-30.5, 29.0-45.7	50.8,30.5	5640	11.6	11
33	Lime Tree No. 1	E5736	N3927	1959	27.4	22.7	A	0-6.1	50.8	6.1-27.4	50.8	3342, 1392	16.5	4.6,10.5
34	Salt Pond No. 2	E5742	N3805	1964	25.9	-	A	-	-	0.6-21.3	50.8	1274, 5097	10.7	2.7,10.7
34	March Pen No. 1	E5676	N3822	-	-	-	A	-	-	DRY	-	ABANDONED IN 1985		
35	Salt Pond No. 3	E5744	N3827	1961	30.5	11.6	A	0.6-1.7	50.8	1.7-30.5	50.8	2347, 4754	12.0	4.6,10.8
36	Government Park	E5748	N3860	1959	24.4	15.0	A	0-3.1	50.8	3.1-24.4	50.8	1268, 4054	3.1	0.6,1.8
37	Lime Tree No. 2	E5761	N3922	1959	27.4	18.0	A	0-6.1	50.8	6.1-27.4	50.8	7467, 11099	10.4	3.6,5.5
38	Clifton	E5762	N3887	1961	29.0	16.1	A	0.3-2.1	50.8	2.1-29.0	50.8	2725, 4375	17.1	4.3,14.6
39	Salt Pond NO.1	E5764	B3807	1960	30.5	11.6	A	-	-	0.3-14.9,13.4-30.5	50.8,40.6	3043, 5072	11.9	5.5,11.0
40	Orange Pen No. 5	E5774	N3901	-	-	-	A	-	-	-	-	-	-	-
41	Reid's Pen No.1	E5780	B3800	1960	24.4	8.2	A	0-9.1	50.8	9.1-24.4	50.8	378, 1893	15.3	2.7,14.0
42	Osbon No. 5	E5781	N3848	1962	13.7	-	A	-	-	-	-	1295	4.6	1.2
43	Orange Pen No. 4	E5783	N3848	-	-	-	A	-	-	-	-	-	-	-
44	Lawrencefield	E5785	N3942	-	-	-	A	-	-	-	-	-	-	-
45	Orange Pen No. 3	E5788	N3887	-	-	-	A	-	-	-	-	-	-	-
46	Orange Pen No. 2	E5792	N3887	-	-	-	A	-	-	-	-	-	-	-
47	Reid's Pen No. 2	E5795	N3805	1966	32.6	-	A	-	-	-	-	1003, 1949	10.7	5.5,8.8
48	Orange Pen No. 1	E5799	N3882	1960	30.5	13.4	A	0.6-4.3	50.8	4.3-30.5	50.8	2256, 3421	5.0	2.3,3.3
49	Congreve Park 4	E5799	N3746	1967	19.8	-	A	0.6-0.6	50.8	0.6-24.4	50.8	637, 3823	4.6	0.4,3.7
50	Reid's Pen No. 3	E5802	N3868	-	-	-	A	-	-	-	-	-	-	-
51	Cow Park No. 1	E5806	N3957	-	-	-	A	-	-	-	-	-	-	-
52	H.W.T. No. 5	E5806	N3892	1959	24.4	13.0	A	0-3.1	50.8	3.1-24.4	50.8	1268, 3804	7.4	0.9,5.6
53	Cookson No. 1	E5814	N3875	-	-	-	A	-	-	-	-	-	-	-
54	Cookson No. 3	E5814	N3875	1962	23.8	12.7	A	-	-	0.6-23.8	50.8	1274, 5097	11.5	1.4,9.3
55	H.W.T. 2	E5818	N3907	-	-	-	A	-	-	-	-	-	-	-
56	North Syndicate	E5822	N3938	1957	18.6	12.2	A	0-9.1,0-12.5	61.0,50.8	12.5-18.6	50.8	632, 4436	11.7	1.5,9.9
57	Cookson No. 2	E5830	N3862	-	-	-	A	-	-	-	-	-	-	-
58	H.W.T. No. 4	E5842	N3910	1959	26.4	11.3	A	0.6-2.4	50.8	2.4-23.8	50.8	2638, 3804	5.8	3.0,4.3
59	Caymanas CH.2	E5850	N4105	1973	24.4	3.8	A	-	-	-	-	-	-	-
60	Watson Grove No. 2	E5854	N3971	1963	23.5	13.1	A	-	-	0.9-11.3, 11.3-23.5	69.4	637, 1618	8.2	0.3,3.0
61	Phoenix Park No. 1	E5865	N3998	-	-	-	A	-	-	0-17.1	50.8	-	-	-
62	South Syndicate	E5871	N3717	-	19.8	8.1	A	-	-	-	-	2252	5.4	10.2
63	Phoenix Park No. 2	E5872	N3997	1972	20.7	9.3	A	-	-	0.19.5	50.8	3785	5.8	5.2
64	Belmore No. 3	E5873	N3964	-	11.0	11.3	A	-	-	-	-	2080		
65	Cedar Grove NO. 1	E5875	N3950	-	-	-	A	-	-	-	-	-	-	-
66	Belmore No. 1	E5885	N3969	-	-	-	A	-	-	-	-	-	-	-
67	Cedar Grove No. 2	E5898	N3942	-	26.8	12.2	A	-	-	-	-	3790	7.0	2.5
68	Ferry	E5900	N4052	1970	30.3	6.9	A	6.1-12.2,21.3-22.9	30.5,30.5	0-6.1	30.5	191, 1146	15.8	3.0,10.1
69	Cumberland Pen	E5913	N3996	1957	18.6	7.0	A	0.6-12.5	50.8	12.5-18.6	50.8	632, 4436	11.7	1.5,9.9
70	Portmore No. 1	E5915	N3923	1957	29.3	5.7	A	1.2-23.2	50.8	23.2-29.3	50.8	632, 4436	9.8	11.7,3

Table C-4 LIST OF SPRINGS

Location	Reference		Aquifer	Altitude	Discharged	Use	Remarks
	E	N		(m)	(lit/min)		
Resource	E5182	N3941	Troy Limestone	76.3	19,180	No used	Flows into Cab Gully
Spring Garden	E5255	N3942	Troy Limestone	76.3	1,591	Village supply + irrigation	Head of Spring Garden River
Red Ground	E5056	N4026	Troy Limestone	229.0	9.1-45.46	Water supply	
Salt Island Lagoon	E5046	N3597	Young Limestone	30.5		Not used	Very salt water only flows in rainy season
Salt Island Lagoon	E5050	N3610	Young Limestone	30.5		Not used	Very salt water
Ferry Springs	E5798	N4128	Young Limestone	30.5	90.9-891	Supply main water	Head of Ferry River
Giblatore	E5418	N4300	Troy Limestone	305.0	13.6-45.46	Village supply	Head of Giblatore River
Cocoa Walk	E5020	N4026	Jpper Young Limeston	152.5	45.40-136.4	Local supply	Flows into Myttins River
Browns Hall	E5070	N4149	ower Young Limeston	427.0	22.7-90.9	Local supply	Source of St. Faiths River
Mogans Spring	E5302	N3915	Troy Limestone			Irrigation	Rises in swamp passes openings

Table C-5 AQUIFER CHARACTERISTICS, LIMESTONE WELLS (After Howard Humphreys, Jamaica Ltd.)

Name of Well	Reference		Type of	Pumped Well	Observation	Well
	E	N	Test	(m3/d/m)	T	S
Bellevue	E5447	N4002	Recovery	1,490	-	-
St. Johns Road	E5531	N4015	Recovery	7,460	-	-
Chungs	E5550	N4092	Recovery	708	-	-
O'Toole's	E5553	N4056	Recovery	4,680	-	-
ArIguanabo Textile	E5554	N4121	Recovery	1,270	-	-
Angels	E5566	N4135	Recovery	2,100	-	-
Headworkds Dam	E5567	N4150	Recovery	37.8	-	-
Content Expl.	E5580	N4149	Recovery	4,470	-	-
Cross Pen	E5623	N4115	Recovery	1,940	-	-
Cross Pen Expl.	E5640	N4114	Recovery	35.1	-	-
Waterloo Valley Expl.	E5697	N4087	Recovery	4,400	-	-
Twickenham No. 2	E5722	N3985	Recovery	2,010	-	-
Twickehnham No. 3	E5724	N3979	Recovery	952	-	-

Table C-6 AQUIFER CHARACTERISTICS, LIMESTONE WELLS (After FOA Project)

Name of Well	Reference		Type of Test	Pumped Well T (m3/d/m)	Observation T
Bodles Livestock	E5033	N3786	Drawdown	5,800	-
Bodles Citrus	E5049	N3793	Drawdown	3,520	-
Old Harbour					
Perrie's	E5085	N3762	Drawdown	32.1	-
Bushy Park (Hend)	E5238	N3785	Recovery	31.9	-
St. Helens No. 4	E5305	N3864	Drawdown	312	1,690
			Recovery		155
St. Helens Expl.	E5305	N3864	Drawdown		175
			Recovery		175
Cotton Tree No. 2	E5352	N3965	Drawdown	204	-
			Recovery	294	-
Ariguanabo Expl.	E5550	N4130	Drawdown	3,970	-
Crescent Expl.	E5555	N4154	Recovery	20	-
Little Windsor Expl.	E5568	N3827	Drawdown	1,400	-
Bamboo Expl.	E5633	N4173	Recovery	15,100	-
Tredegar Park 1	E5660	N4032	Drawdown	680	-
Half Way Tree Expl.	E5805	N3916	Recovery	952	-
Caymanas Expl	N5853	N4010	Drawdown	197	180
			Recovery		245

Name of Well	Reference		T (m3/d/m)	Q/d	Specific Capacity (m3/min/m)
Chungs	E5550	N4092	701	5.64/ 9.91	0.57
Ariguanabo Expl.	E5550	N4130	254	3.27/ 5.18	0.63
Crescent Expl.	E5555	N4154	16.9	0.77/31.39	0.02
Headworks Dam	E5567	N4150	82.0	2.27/22.71	0.10
Content Expl.	E5580	N4149	4,590	6.00/ 1.25	4.80
Cross Pen	E5623	N4115	1,940	6.14/ 2.13	2.88
Bamboo Expl.	E5623	N4173	13,600	7.82/ 0.73	10.71
Cross Pen Expl.	E5640	N4114	7,830	6.77/ 2.44	2.77
Waterloo Valley Expl.	E5697	N4087	3,670	7.82/ 5.97	1.31

Table C-7 ANNUAL ABSTRACTION FROM LIMESTONE AQUIFER

No	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
1. Irrigation											
Million US gallon	12,877	16,907	16,256	13,308	13,880	16,568	16,288	15,534	10,849	10,849	12,905
Million cubic metre	48.7	64.0	61.5	50.4	58.5	62.7	61.7	58.8	41.0	41.1	48.8
Number of Wells	43	44	45	41	44	46	46	44	43	42	39
2. Domestic											
Million US gallon	2,651	2,766	3,252	3,851	6,121	8,201	9,049	7,854	9,053	9,604	9,203
Million cubic metre	10.0	10.5	12.3	14.6	23.2	31.0	34.3	29.7	34.3	36.4	34.8
Number of Wells	15	17	17	17	25	27	27	28	28	29	30
3. Industrial											
Million US gallon	592	1,130	1,196	2,455	2,335	1,790	2,706	2,510	2,510	2,510	2,060
Million cubic metre	2.3	4.2	4.6	9.2	8.8	6.8	10.3	9.4	9.4	9.4	7.9
Number of Wells	7	7	7	7	6	7	7	8	8	8	8
4. Total Abstraction											
Million US gallon	16,120	20,805	20,705	19,613	22,337	26,559	28,097	25,893	22,384	22,949	24,168
Million cubic metre	61.0	78.7	78.4	74.2	84.5	100.5	106.3	98.0	84.7	86.9	91.5
Number of Wells	65	68	69	65	75	80	80	79	79	78	77

Remarks: after Botbol (1982)

Table C-8 RESULTS OF WATER QUALITY ANALYSES FOR WELLS AND SPRINGS IN THE LIMESTONE AQUIFER

No	Location	Coordinate E	Coordinate N	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	HCO3 (ppm)	SO4 (ppm)	Cl (ppm)	Fe (ppm)	NO3 (ppm)	SiO2	Total PO4	T.D.S. (ppm)	Hardness (ppm)	Alkalinity(ppm)	BOD/ DO	COD	EC	PH	T (C)	Date Collected
1. Limestone Aquifer																							
	Free Town No 1 and 2	4,971.0	3,700.0	92.0	29.7	172.0	5.7	-	26.8	311.0	-	4.8	-	-	-	-	-	-	-	1,800.0	7.1	30.0	7.9.86
	Marine Terminal	5,039.0	3,780.0	95.0	33.0	117.0	2.0	296.0	24.0	195.0	0.0	6.5	16.0	0.2	720.0	149.0	296.0	0/7.0	2.8	1,300.0	7.0	28.0	9.9.86
	Whim (Railway)	5,095.0	3,743.0	124.0	28.0	147.0	2.2	325.0	32.0	300.0	0.0	9.9	21.0	0.2	1,040.0	457.0	325.0	0.1/63	5.6	1,570.0	6.9	29.0	9.9.86
	New Market Pen	5,127.0	3,742.0	92.0	58.0	146.0	1.6	303.0	40.0	278.0	0.0	7.9	14.0	0.3	990.0	470.0	303.0	0.2/6.6	2.8	1,560.0	6.9	28.0	9.9.86
	Bushy Park Hendrick	5,238.0	3,785.0	152.0	64.0	122.0	0.7	368.0	90.0	315.0	0.0	15.1	36.0	-	1,400.0	643.0	368.0	0/6.0	2.8	1,860.0	6.9	29.0	9.9.86
	Mount Moreland	5,257.0	3,885.0	86.0	30.7	27.5	0.8	256.0	3.6	42.0	0.0	17.1	9.7	0.1	310.0	269.0	256.0	0/7.4	5.6	811.0	7.1	28.0	7.9.86
	St. Helens No.4	5,305.0	3,864.0	65.0	26.0	11.0	0.5	256.0	5.2	15.8	0.0	5.9	9.7	0.1	310.0	269.0	256.0	0/7.4	5.6	530.0	7.2	28.0	9.9.86
	Innswood factory No.3	5,430.0	3,941.0	104.0	18.0	32.0	33.0	321.0	13.0	74.0	1.6	0.9	10.4	0.6	520.0	332.0	321.0	2.1/6.2	25.0	890.0	7.1	29.0	9.9.86
	Mango Walk No.1	5,458.0	3,982.0	161.0	33.0	150.0	3.0	270.0	30.0	405.0	0.0	9.9	7.6	0.1	1,340.0	538.0	270.0	0/6.8	2.8	1,850.0	7.0	28.0	9.9.86
	Cross Pen (Ric Well W)	5,623.0	4,115.0	77.0	11.6	10.0	1.0	-	4.6	13.0	-	3.6	-	Nil	-	-	-	0.5/7.4	-	520.0	7.3	-	2.9.86
	Ensom City	5,640.0	4,028.0	103.0	20.4	57.5	1.4	-	20.0	110.5	-	5.3	-	Nil	-	-	-	2.0/4.7	-	936.0	7.1	-	2.9.86
	Twickenham Park Well	5,724.0	3,979.0	77.0	14.8	85.0	2.5	-	27.6	87.0	-	6.2	-	Nil	-	-	-	8.2/3.8	-	915.2	7.1	-	2.9.86
	White Marl No. 2	5,816.0	4,002.0	125.0	24.0	150.0	3.2	-	46.5	291.0	-	8.5	-	0.0	-	-	-	0.8/5.3	-	1,580.8	7.0	-	2.9.86
	Ferry Spring *	5,298.0	4,128.0	113.0	88.0	656.0	24.4	248.0	120.0	1,180.0	0.1	4.0	6.8	0.2	2,720.0	643.0	248.0	0.2/7.8	1.4	4,380.0	7.4	27.0	9.9.86
	Coleburn Gully *	5,182.0	3,941.0	78.0	14.6	10.0	0.6	-	6.0	12.9	-	6.9	-	-	-	-	-	-	-	561.6	6.9	-	7.9.86
	Spring Gardens No.1 *	5,255.0	3,942.0	73.0	13.0	8.1	0.4	-	13.1	10.9	-	3.1	-	-	-	-	-	-	-	499.2	7.6	-	7.9.86
2. Alluvial Aquifer																							
	Amity Hall North	5,331.0	3,824.0	186.0	87.3	185.0	1.1	-	214.0	421.0	-	4.4	-	-	-	-	-	-	-	2,496.0	6.9	30.0	7.9.86
	March Pen No.2	5,675.0	3,833.0	74.0	17.0	67.0	0.6	305.0	31.0	38.0	0.0	2.3	37.0	0.3	470.0	257.0	305.0	0/4.8	-	740.0	6.9	29.0	10.9.86
	Reid's Pen No.1	5,780.0	3,800.0	79.0	27.0	74.0	1.2	337.0	25.0	65.0	0.0	0.8	37.0	0.2	530.0	307.0	333.0	0/5.8	2.8	870.0	7.2	29.0	9.9.86

Remark : * ; Spring

Table C-9 AQUIFER CHARACTERISTICS, ALLUVIAL WELLS (After FAO Project)

Name of Well	Reference		Type of Test	Pumped Well	Observation	
	E	N		T (m3/d/m)	T (m3/d/m)	S
Salt Pond No. 2	E5742	N3805	Drawdown	274	1,790	0.0180
			Recovery		3,070	0.3330
Half Way Tree No. 4	E5842	N3910	Drawdown		3,280	0.0436

Table C-10 TRANSMISSIVILITY VALUES CALCULATED FROM RECOVERY TESTS, ALLUVIAL AQUIFER (After Versey, 1962)

Name of Well	Reference		Pumping Well
	E	N	T (m3/d/m)
Amity Hall No. 1	E5331	N3824	177
March Pen No. 2	E5676	N3833	400-480
Blair Pen	E5698	N3877	370-670
Jones Dam	E5709	N3940	390-4000
Bernard Lodge	E5727	N3885	1509-2390
Government Park	E5748	N3860	6640
Lime Tree No. 2	E5761	N3922	1270-1550
Half Way Tree No. 5	E5808	N3892	1600
Cookson No. 1	E5814	N3875	162
Half Way Tree No. 2	E5818	N3907	768-1110
Half Way Tree No. 4	E5842	N3910	700-2100
Watson Grove	E5854	N3971	8200
Belmore No. 2	E5880	N3954	838

Table C-11 ANNUAL ABSTRACTION FROM ALLUVIAL AQUIFER

	1970	1971	1972
1 Irrigation			
Million US gallon	8,984	10,287	10,136
Million cubic metre	34.00	38.90	38.40
Number of wells	50	51	52
2 Domestic			
Million US gallon	5	5	4
Million cubic metre	0.02	0.02	0.02
Number of wells	4	4	4
3 Industrial			
Million US gallon	447	450	438
Million cubic metre	1.70	1.70	1.70
Number of wells	2	2	2
4 Total Abstraction			
Million US gallon	9,436	10,742	10,578
Million cubic metre	35.70	40.70	40.00
Number of wells	56	57	58

Table C-12 MONTHLY RAINFALL DATA

(Unit: mm)

Staion	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1. 1972													
Above Rocks	77.7	31.0	81.5	122.7	289.1	90.2	127.5	196.3	207.5*	180.3*	81.5*	218.9*	1704.2*
Bodles Agr	24.1	57.2	101.3	29.0	40.4	122.0	3.3	20.1	96.0	122.9	15.5	108.5	740.5
Caymanas C	8.9	106.7	64.8	27.9	146.1	165.1	33.0	72.4	81.8*	225.3*	94.0*	74.4*	1100.4*
Cocoa Walk	103.9	47.0	94.7	52.1	245.9	147.1	5.8	136.1	129.0	140.2	35.6	143.3	1,280.7
Guanaboa Vale	75.7	85.1	135.6	112.0	89.7	193.0	0.0	125.0	150.4*	239.3	12.7	136.1	1354.6*
Harmony Pen	11.9	101.9	106.2	18.3	85.6	206.2	0.0	0.0	11.4	263.4	31.8	38.4	875.1
Innswood 2	27.2	65.3	126.7	79.5	44.7	130.3	0.0	33.8	122.7	259.3	11.4	230.9	1,131.8
Innswood 5	6.4	66.0	53.8	25.9	48.8	94.5	0.0	48.8	78.7	178.1	0.0	152.7	753.7
Kensingtan	26.2	61.2	137.2	35.8	216.2	176.3	51.6	297.9	165.9	219.5	104.1	185.4	1,677.3
Old Harbour	27.9	69.6	124.2	40.9	43.9*	101.1	0.0	12.7	96.5	87.1	5.6	96.0	705.5*
Sligoville	35.3	56.6	28.7	139.2	225.3	151.6	77.0	263.7	189.0	161.5	61.2*	200.7	1589.8*
Spanish T. Woodlands	4.3	46.7	99.3	100.0	65.5	146.6	0.0	19.3	63.5	141.2	0.0	188.2	874.6
Springvale	70.1	32.0	44.5	73.9	155.4	170.9	149.1	173.2	150.9	142.5*	101.3	202.9	1466.7*
Watermont	62.2	51.6	90.9*	45.2	128.3*	174.5*	27.7*	51.6*	75.4*	45.0*	106.7*	196.3*	1055.4*
Brown's Hall School	45.2	57.7	62.0	79.8	153.2	215.9	64.8	78.5	152.9	249.7	25.9	183.4	1,369.0
Innswood 1	21.3	80.3	103.9	65.8	56.1	153.7	0.0	31.5	99.3	222.3	22.9	225.0	1,082.1
Bemard Lodge	7.9	47.0	35.6	73.9	75.9	153.9	0.0	36.8	23.6	189.7	0.0	93.0	737.3
Bodles Rose Hall	22.1	69.9	149.6	64.8	41.7	138.9	1.8	17.5	117.6	134.4	8.9	109.5	876.7
Bybrook	98.3	40.9	26.4	118.9	151.4	125.2	225.6	157.5*	157.2	174.8	146.1	183.1	1605.4*
Dawkins	15.0	66.0	73.7	34.3	96.3*	111.8	22.9	33.0	96.5	135.4	39.4	96.5	820.8*
Dawkins Bog	12.7	76.2	45.0	87.6	59.7	127.0	17.8	20.3	73.2	181.4	60.2	72.6	833.7
Farm 2	7.6	59.7	57.2	45.7	94.0	163.8	30.5	17.8	69.9	187.5	35.6	83.1	852.4
Great Salt pond	12.2	46.2	9.7	26.4	18.3	155.2	0.0	13.7	18.0	123.4	0.0	56.4	479.5
Hartlands 2	22.9	13.5	94.0	8.4	23.1	126.5	0.0	0.0	30.7	80.3	9.1	99.6	508.1
Lagoon	21.6	129.5	85.1	33.0	148.6*	148.6	10.2	115.6	87.6	237.0	100.3	80.0	1197.1*
Little Windsot	27.7	66.8	92.2	30.2	86.1	170.9	0.0	0.0	19.6	168.9	5.8	69.3	737.5
March pen	26.7	79.5	40.9	45.2	86.1	174.0	0.0	5.1	18.8	209.6	8.9	112.0	806.8
South syndicate	6.4	57.7	6.6	18.0	45.0	140.7	0.0	22.1	44.7	151.6	20.1	31.2	544.1
Tulloch Estate	73.7	33.0	58.2	78.5	207.8	123.7	120.9	146.8	177.5	188.7	169.2	191.3	1,569.3
Warwick Castles	24.4	46.5	93.2	47.0	57.7	162.1	0.0	36.6	137.2	210.3	13.2*	147.6	975.8*
Ferry	12.7	114.3	119.4	111.8	114.3	137.2	27.9	22.9	68.3*	188.2*	65.5*	78.0*	1060.5*
Half way tree	6.6	47.8	27.2	54.6	71.1	212.9	0.0	34.0	27.9	253.2	3.0	45.0	783.3
2. 1975													
Above Rocks	0.0	0.0	0.0	5.8	127.8	102.1	157.5	241.0	578.9	195.6	191.8	28.4	1,628.9
Bodles Agr	9.7	1.5	9.4	17.5	33.0	0.0	66.5	70.6	157.2	118.4	75.4	47.0	606.2
Caymanas C	5.1	0.0	6.4	25.4	22.9	8.9	82.6	53.3	194.3	138.4	95.3	47.0	679.6
Cocoa Walk	12.7	24.6	28.4	39.1	78.2	1.3	64.3	212.6	259.1	151.6	83.6	60.7	1,016.2
Guanaboa Vale	10.4	30.5	14.5	69.1	70.4	9.1	116.3	143.0	214.1	184.4	119.1	27.9	1,008.8
Harmony Pen	11.4	0.0	0.0	5.1	27.9	0.0	40.4	0.0	270.3	87.6	31.2	34.3	508.2
Innswood 2	0.0	1.3	0.0	35.8	44.7	0.0	93.2	113.3	190.0	106.9	55.9	47.2	688.3
Innswood 5	0.0	1.0	0.0	24.6	51.3	0.8	48.5	55.1	152.4	68.8	50.3	65.8	518.6
Kensingtan	2.8	87.9	56.4	103.1	173.7	34.8	172.5	161.5	373.4	204.0	268.2	80.0	1,718.3
Old Harbour	16.0	5.1	0.0	23.6	42.9	0.0	78.0	113.3	162.8	82.6	61.5	39.9	625.7
Sligoville	8.4	68.1	21.1	126.5	95.5	119.4	234.7	156.5	317.0	312.2	376.2	49.0	1,884.6
Spanish T. Woodlands	9.9	0.0	0.0	9.1	66.3	0.0	17.0	11.7	163.8	116.3	22.9	18.0	435.0
Springvale	7.6	57.7	30.0	79.0	53.3	94.0	135.9	133.4	184.9	137.4	89.4	31.0	1,033.6
Watermont	17.8	51.1	38.4	33.3	80.5	17.0	76.7	106.7	224.8	183.1	5.1	39.1	873.6
Brown's Hall School	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	485.4	268.2	12.2	58.4	824.2
Innswood 1	6.1	2.5	0.5	23.1	56.4	2.8	86.1	56.6	188.0	89.2	41.4	50.0	602.7
Bemard Lodge	2.8	0.0	0.0	2.0	33.3	0.0	13.5	16.8	156.5	79.2	83.8	20.1	408.0
Bodles Rose Hall	16.3	3.0	22.9	20.1	32.3	0.8	58.2	88.9	194.8	130.6	56.9	46.5	671.3
Bybrook	24.1	49.5	47.5	67.1	54.9	91.7	202.2	131.3	183.1	121.4	146.1	38.4	1,157.3
Dawkins	1.3	0.0	6.4	16.5	20.3	19.1	78.7	29.2	147.3	97.8	81.3	26.7	524.6
Dawkins Bog	4.1	2.5	3.8	19.1	20.3	0.0	53.8	15.2	188.7	161.8	104.1	41.9	615.3
Farm 2	4.1	2.5	3.8	14.0	8.9	0.0	50.8	25.9	193.0	129.5	99.8	41.9	574.2
Great Salt pond	0.0	0.0	0.0	8.9	21.1	0.0	36.6	23.6	193.3	30.2	21.3	34.0	369.0
Hartlands 2	8.9	0.0	10.2	6.4	50.8	0.0	40.6	15.2	176.3	115.3	29.5	55.9	509.1
Lagoon	0.0	0.0	6.4	31.8	14.0	7.6	86.4	69.9	223.5	146.1	120.7	48.3	754.7
Little Windsot	10.2	0.0	0.0	9.1	50.8	0.0	56.9	12.7	218.2	139.7	35.6	41.9	575.1
March pen	5.1	0.0	0.0	7.6	27.4	0.0	27.2	13.2	208.3	67.6	40.6	17.3	414.3
South syndicate	0.0	0.0	0.0	6.9	11.4	1.5	27.4	3.0	190.2	91.2	73.9	33.0	438.5
Tulloch Estate	5.3	26.9	32.0	108.7	58.9	84.1	204.0	147.8	188.0	176.0	177.0	36.1	1,248.8
Warwick Castles	2.5	30.5	1.3	31.0	42.7	0.0	113.8	96.5	210.3	67.3	48.8	64.3	709.0
Ferry	5.1	3.8	3.8	11.4	19.1	0.0	34.3	17.8	193.0	167.6	108.0	45.7	609.6
Half way tree	4.1	0.0	0.0	4.1	24.1	0.0	15.7	12.4	151.9	81.8	67.1	30.2	391.4

Remarks: *; Calculated rainfall after Botbol Report (1982)

Table C-13 MONTHLY DISCHARGE RATE IN 1972

(Unit: %)

Aquifer	Area*	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Limestone	A	11.4	7.8	8.5	11.6	5.9	5.7	9.6	10.4	9.2	5.7	7.7	6.5
"	B	9.9	7.9	5.1	5.6	10.3	9.6	8.3	10.3	9.6	7.2	2.9	13.3
"	C	8	8.1	3.4	6.3	7.5	12.3	10.6	9.6	8.5	8.7	8.2	8.8
"	D	7.6	8.4	8.4	8.7	7.3	6.2	9.3	8.6	9	8.4	10.1	8
Alluvial	A	9.3	9.7	9.4	9.2	6.5	6.3	7.2	10.7	10.5	5.1	7.7	8.4
"	B	7.1	9.6	8.9	11.4	7.3	7.7	6.7	10.2	10.1	5.3	7.5	8.2

Remarks: Limestone Aquifer Area:
A; N-Coordinate 5600-6000, Simulation Grid Number 16-24
B; N-Coordinate 5300-5600, Simulation Grid Number 10-15
C; N-Coordinate 5150-5300, Simulation Grid Number 7-9
D; N-Coordinate 4900-5150, Simulation Grid Number 2-6
Alluvial Aquifer Area:
A; N-Coordinate 5500-6000, Simulation Grid Number 14-24
B; N-Coordinate 4900-5500, Simulation Grid Number 3-13

Table H-14 WATER SUPPLY IN THE LOWER RIO COBRE BASIN IN 1972

(Unit: million m3/year)

	Agriculture	Industrial	Domestic	Export	Total
River Rio Cobre	141.1	-	2.7	-	143.8
Limestone Wells	61.5	4.6	8.3*	4.0*	78.4
Alluvial Wells	38.4	1.6	0.02	-	40.0
Total	241.0	6.2	11.0	4.0	262.2

Remark: *: Estimated value

Table C-15 MONTHLY STREAMFLOW DATA AT RIO COBRE CANAL

(Unit: m3/sec)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual million m3
Obeserved in 1972	4.42	4.85	4.75	4.11	4.88	3.77	4.65	4.57	4.99	4.29	4.94	4.46	143.8
Planned Flow*	7.11	5.92	4.9	4.09	4.67	4.82	4.8	5.48	5.18	4.74	6.35	7.27	169.3

Remarks: *; Estimated on Water Balance Study for Irrigation.

Table C-16 MONTHLY RECHARGE FROM RIO COBRE TO ALLUVIAL AQUIFER

(Unit: m3/sec)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Yearly Mean
A. Headworks (03BY002-03BA003)	7.64	5.93	5.71	5.44	6.59	6.83	5.65	7.35	11.10	39.87	12.94	15.09	10.85
B. Crum Ewing (03BA11)	2.9	0.90	0.82	0.81	1.94	2.69	0.90	2.28	5.83	32.84	6.79	10.81	5.79
C. Rio Cobre Main Canal (03BY002)	4.51	4.96	4.90	4.36	4.47	4.03	4.48	4.65	4.66	4.02	4.88	4.04	4.50
Recharge Rate (A-B-C)	0.23	0.07	-0.01	0.27	0.18	0.11	0.27	0.42	0.61	3.01	1.27	0.24	0.56

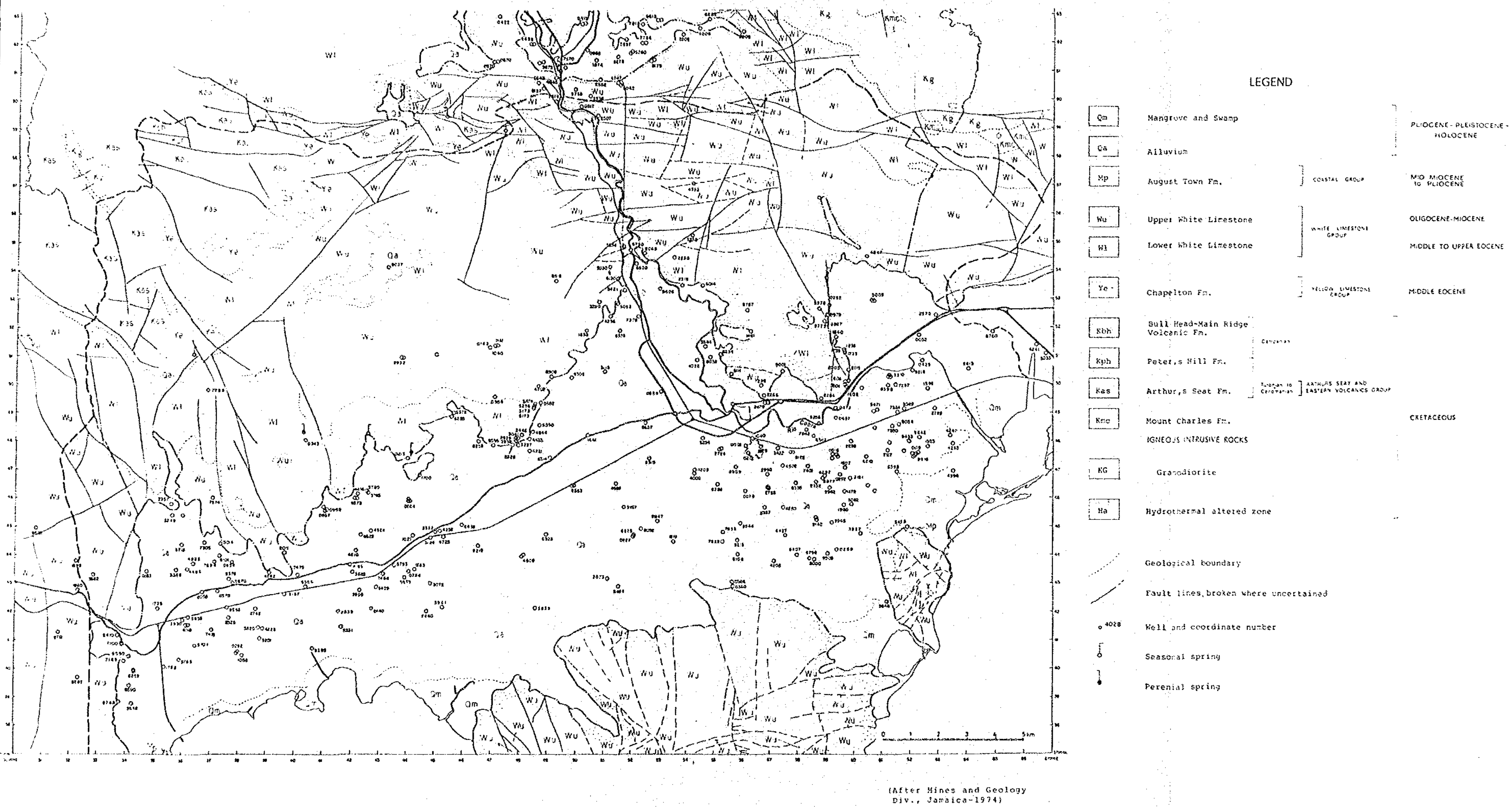
Remarks:
A&B; After Table B- , Comparative Table of Mean Streamflow (1972-1973) for Rio Cobre River.
C; Monthly Mean Streamflow (1972-1973)
Recharge; Recharged to Alluvial Aquifer from Rio Cobre River betwen A and B for Calibration and Operation of Simulation.

Table C-17 ESTIMATED WATER SUPPLY IN THE LOWER RIO COBRE BASIN

(Unit: million m3/year)

Source	Agriculture	Industrial	Domestic	Export	Total
River Rio Cobre	157.6	3	8.7	-	169.3 *2
Limestone Wells	60.7	5.9	20.2	17.0	103.8 *3
Alluvial Wells	31	2.6	2.5	-	36.1 *3
Total	249.3	11.5 *1	31.4 *1	17.0 *1	309.2

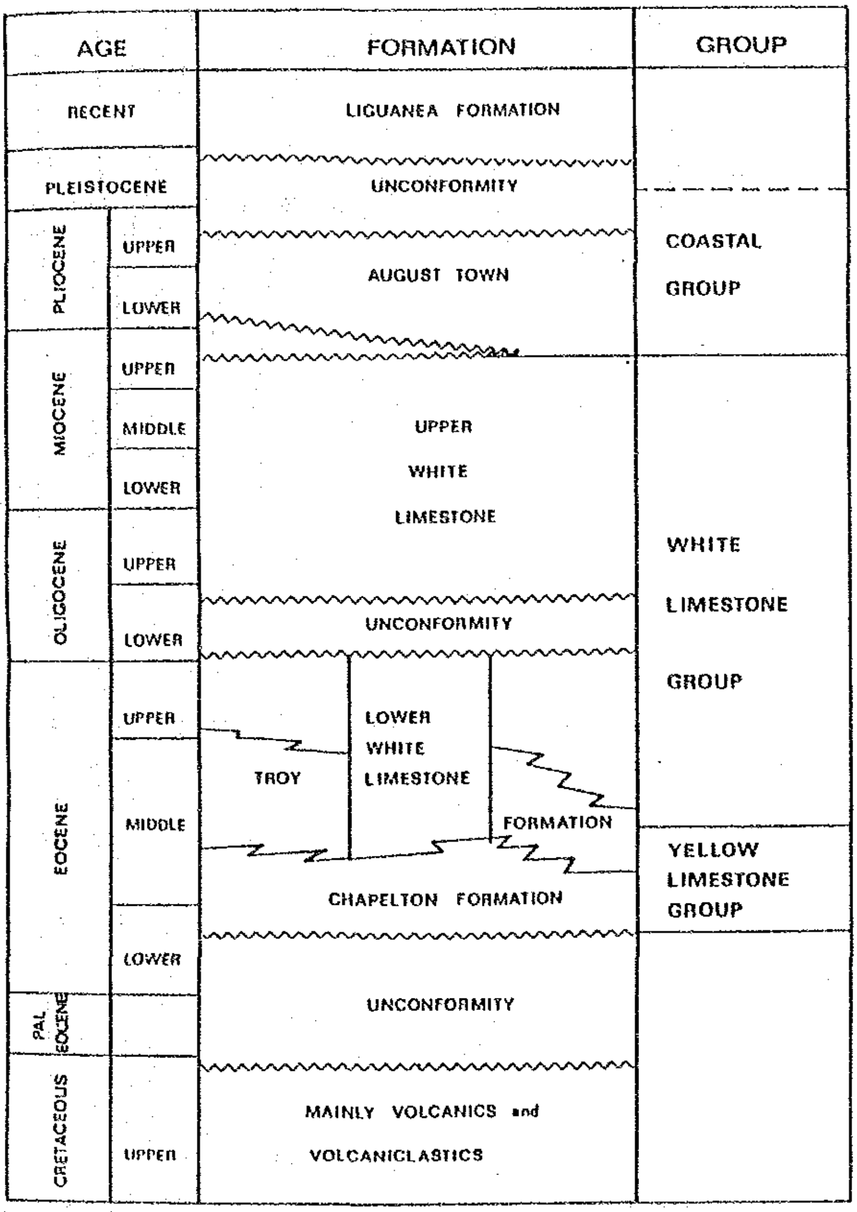
R *1; Estimated from the data of UNDP (1986)
*2; Based on the Result of Water Balance Study.
*3; Based on the Result of Groundwater Simulation.



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-1 GEOLOGICAL MAP

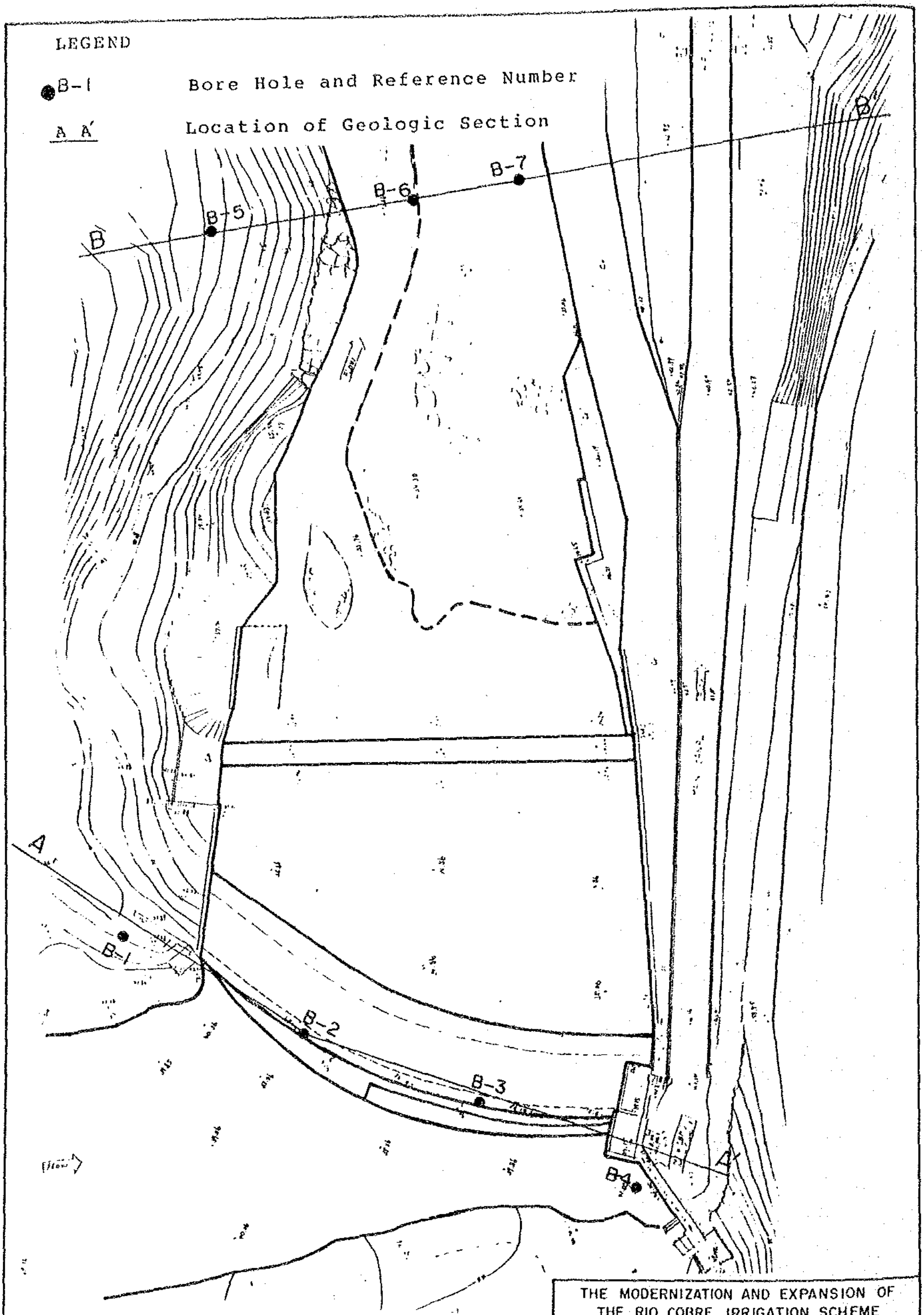
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF
THE RIO COBRE IRRIGATION SCHEME

Fig. C-2
STRATIGRAPHIC FRAMEWORK OF
RIO COBRE

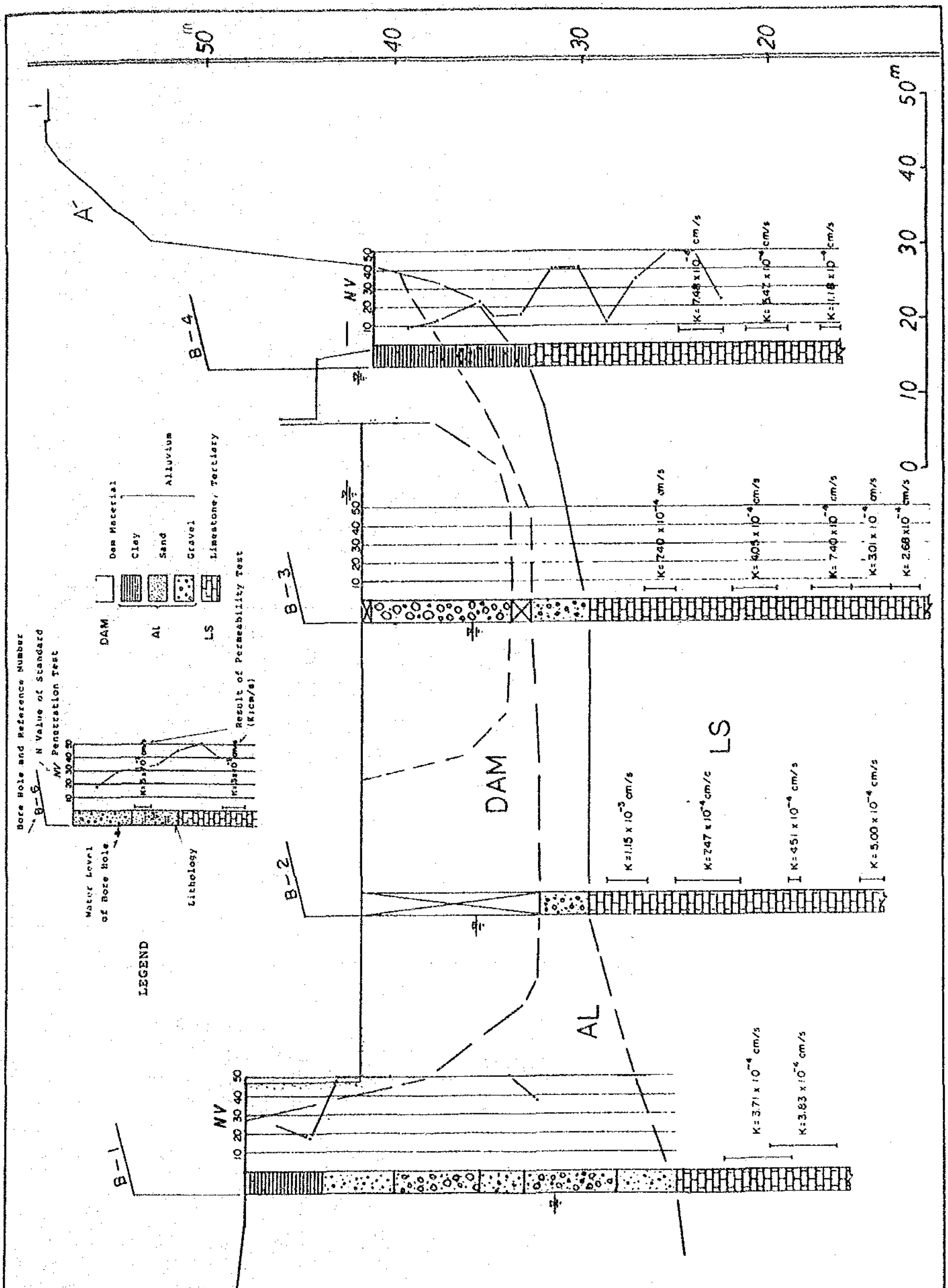
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-3
LOCATION MAP OF DRILLING POINT

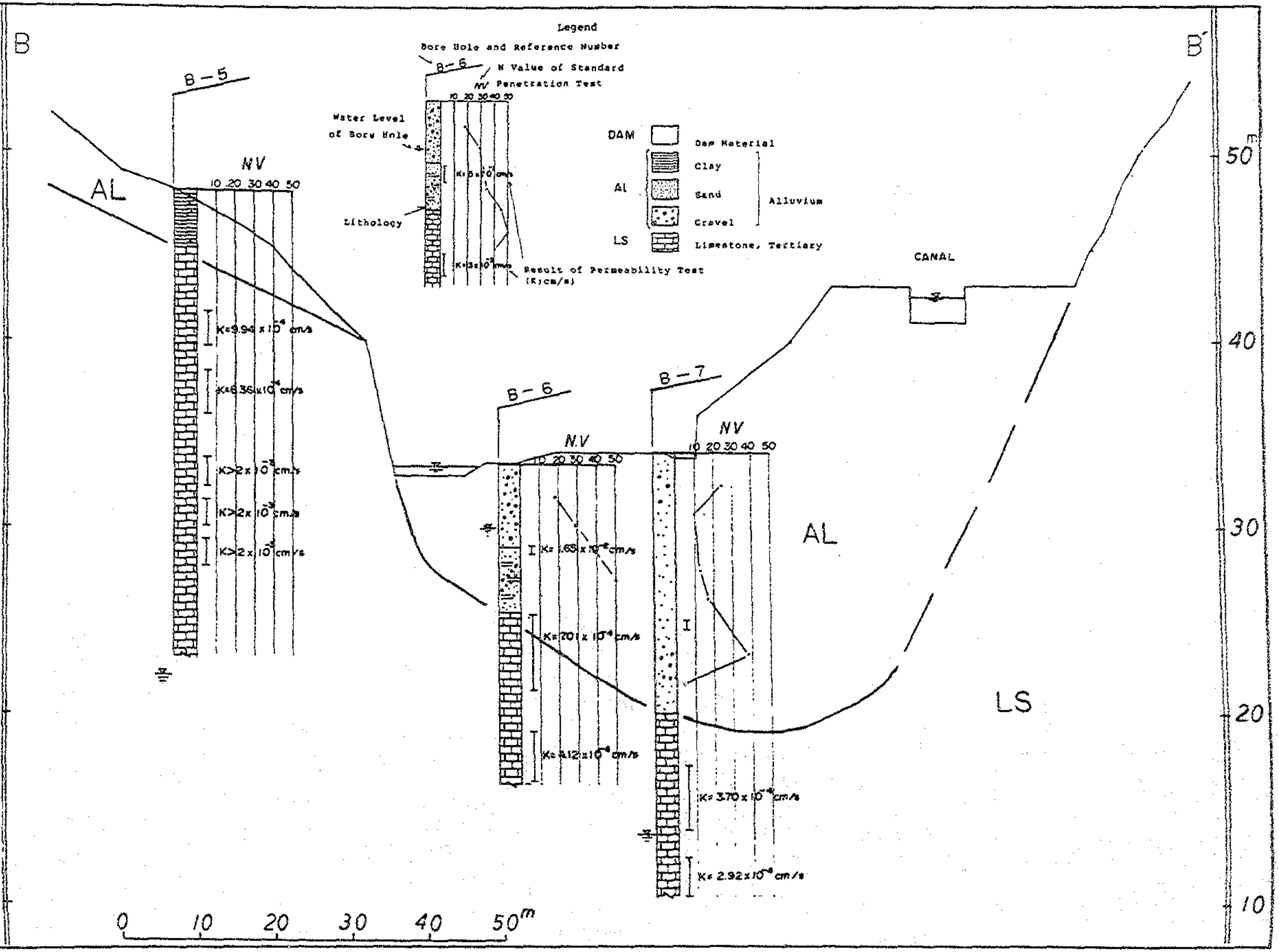
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-4
GEOLOGIC CROSS SECTION OF THE EXISTING DAM SITE

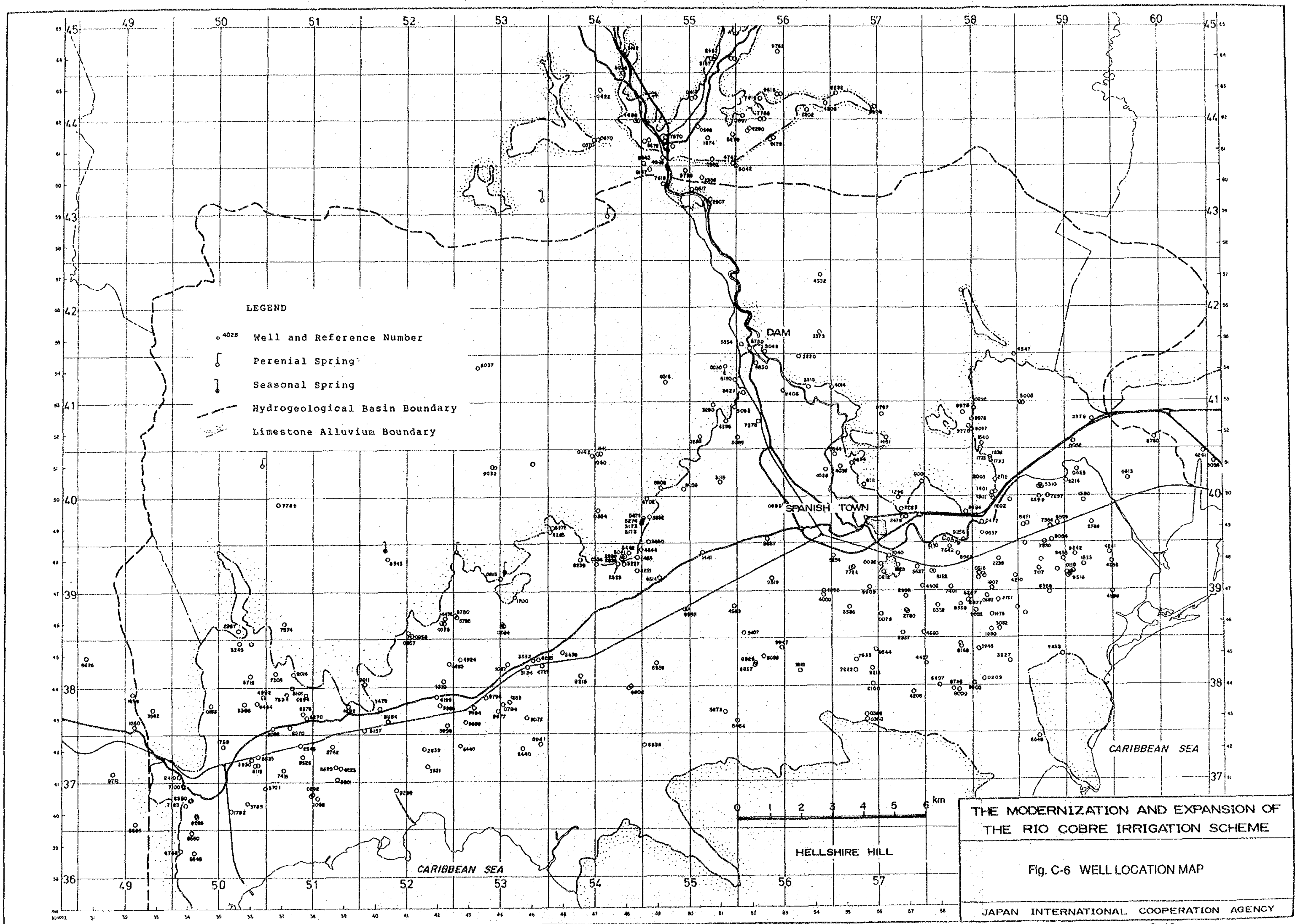
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-5
GEOLOGIC CROSS SECTION OF THE ALTERNATIVE DAM SITE

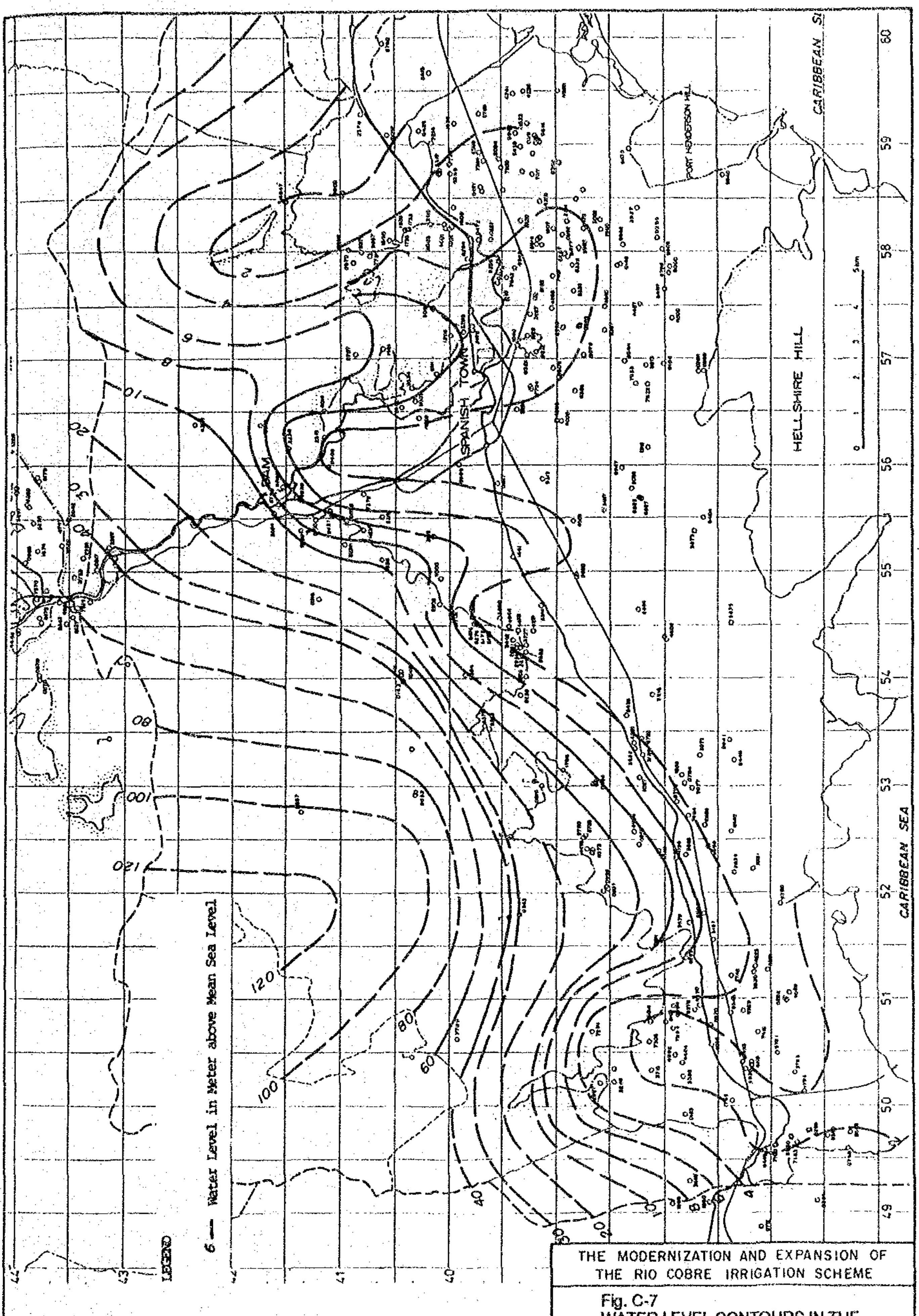
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-6 WELL LOCATION MAP

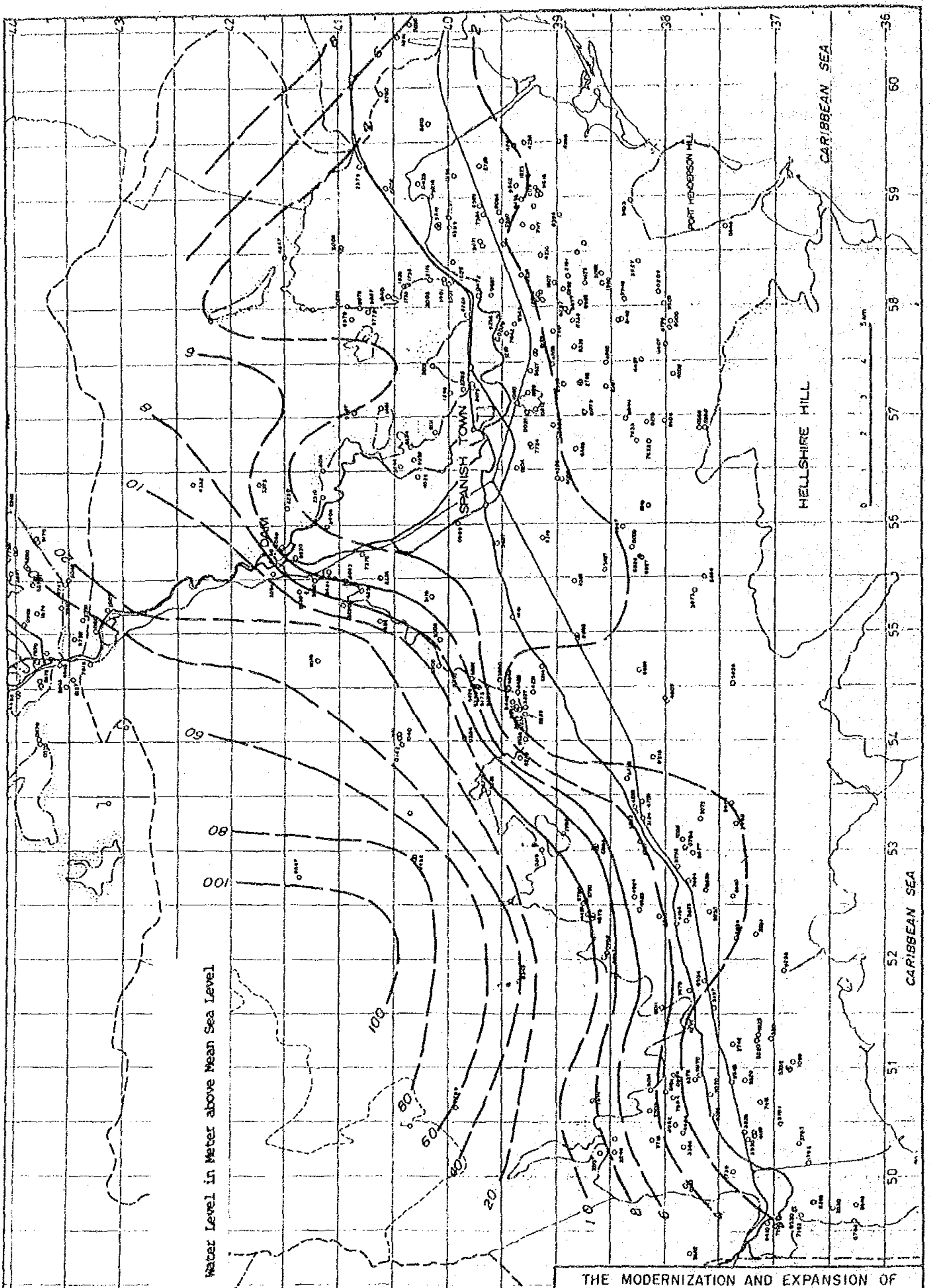
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-7
WATER LEVEL CONTOURS IN THE LIMESTONE AQUIFER JAN. 1972

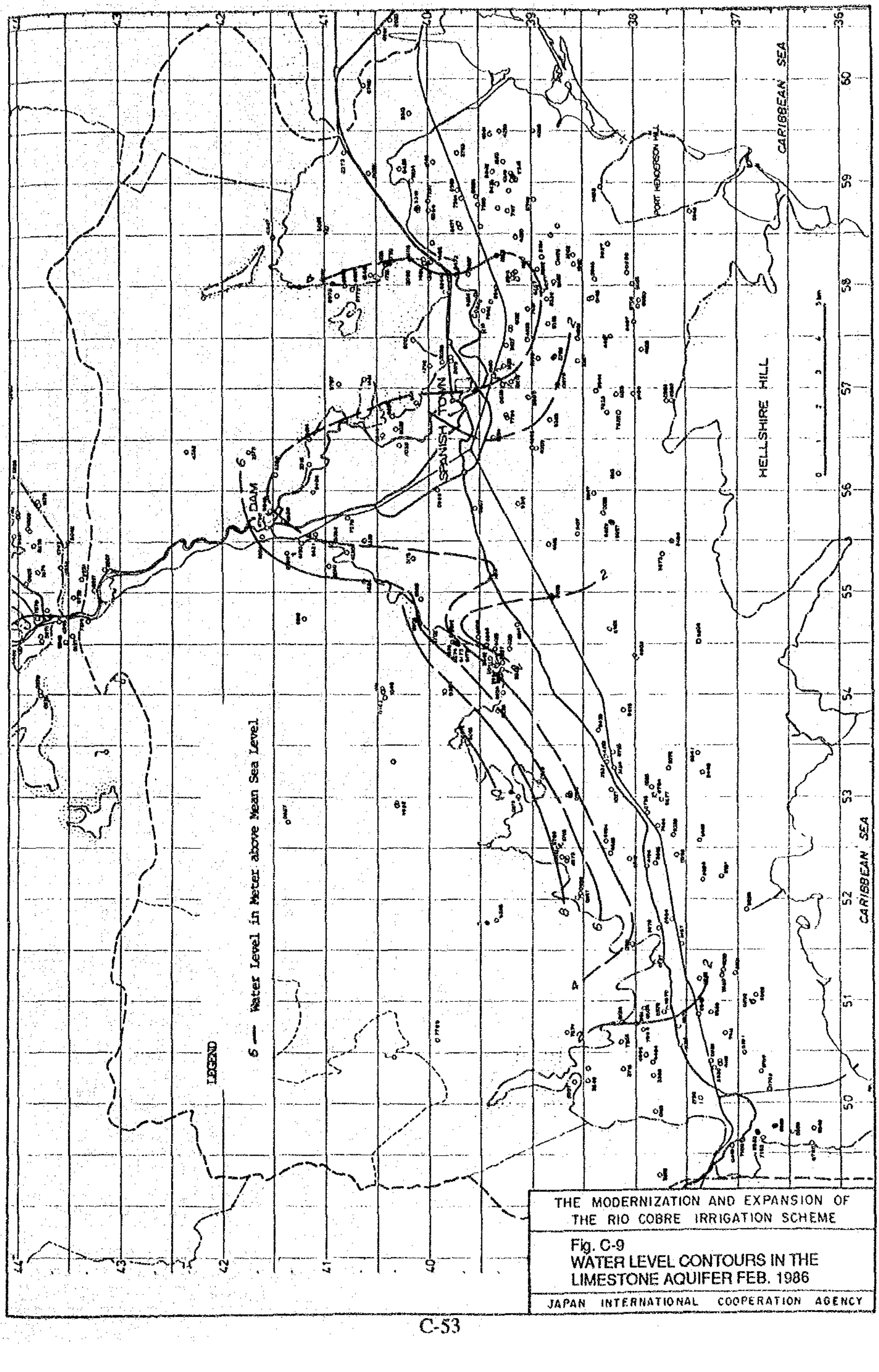
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-8
WATER LEVEL CONTOURS IN THE LIMESTONE AQUIFER AUG. 1972

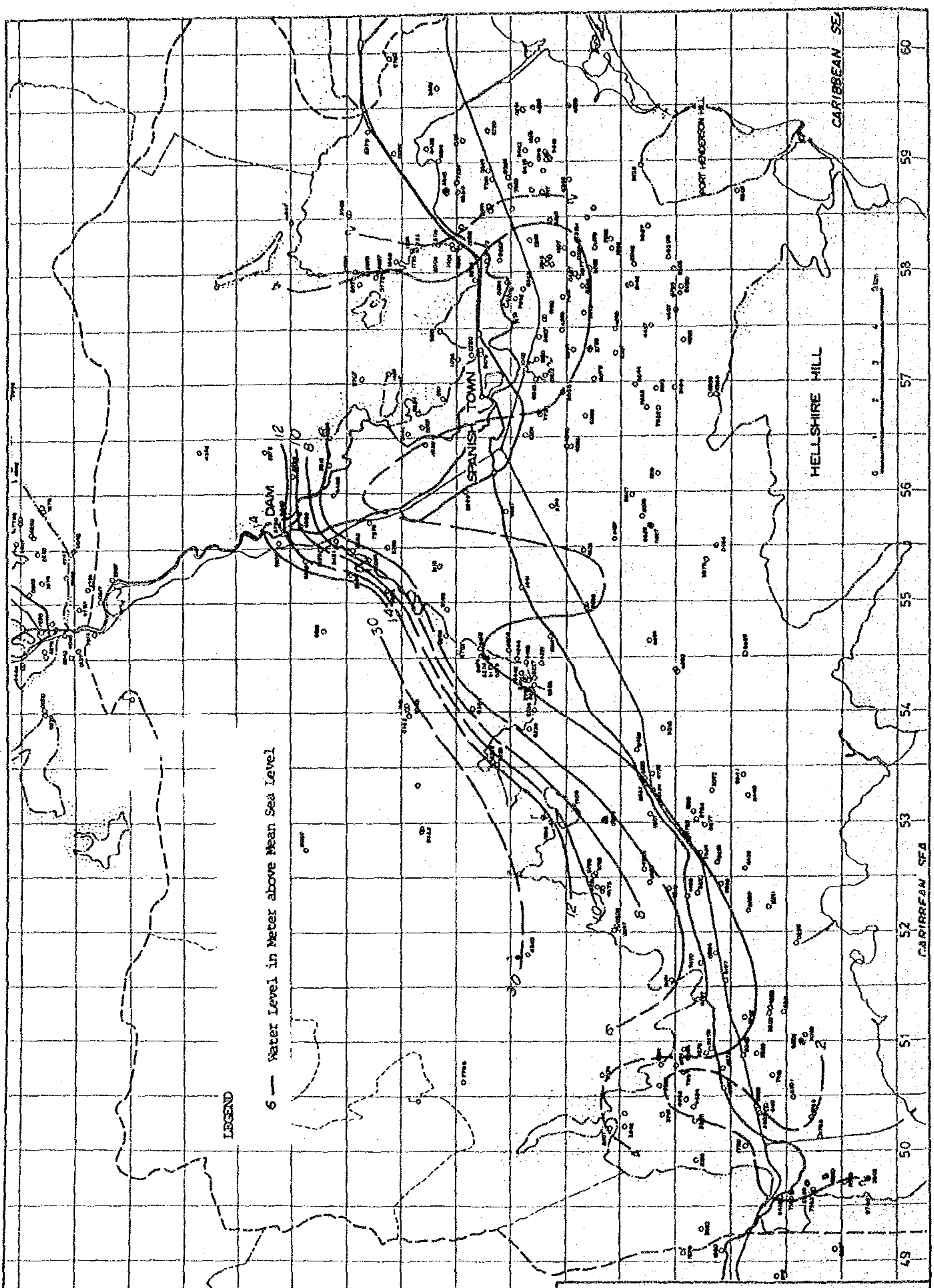
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF
THE RIO COBRE IRRIGATION SCHEME

Fig. C-9
WATER LEVEL CONTOURS IN THE
LIMESTONE AQUIFER FEB. 1986

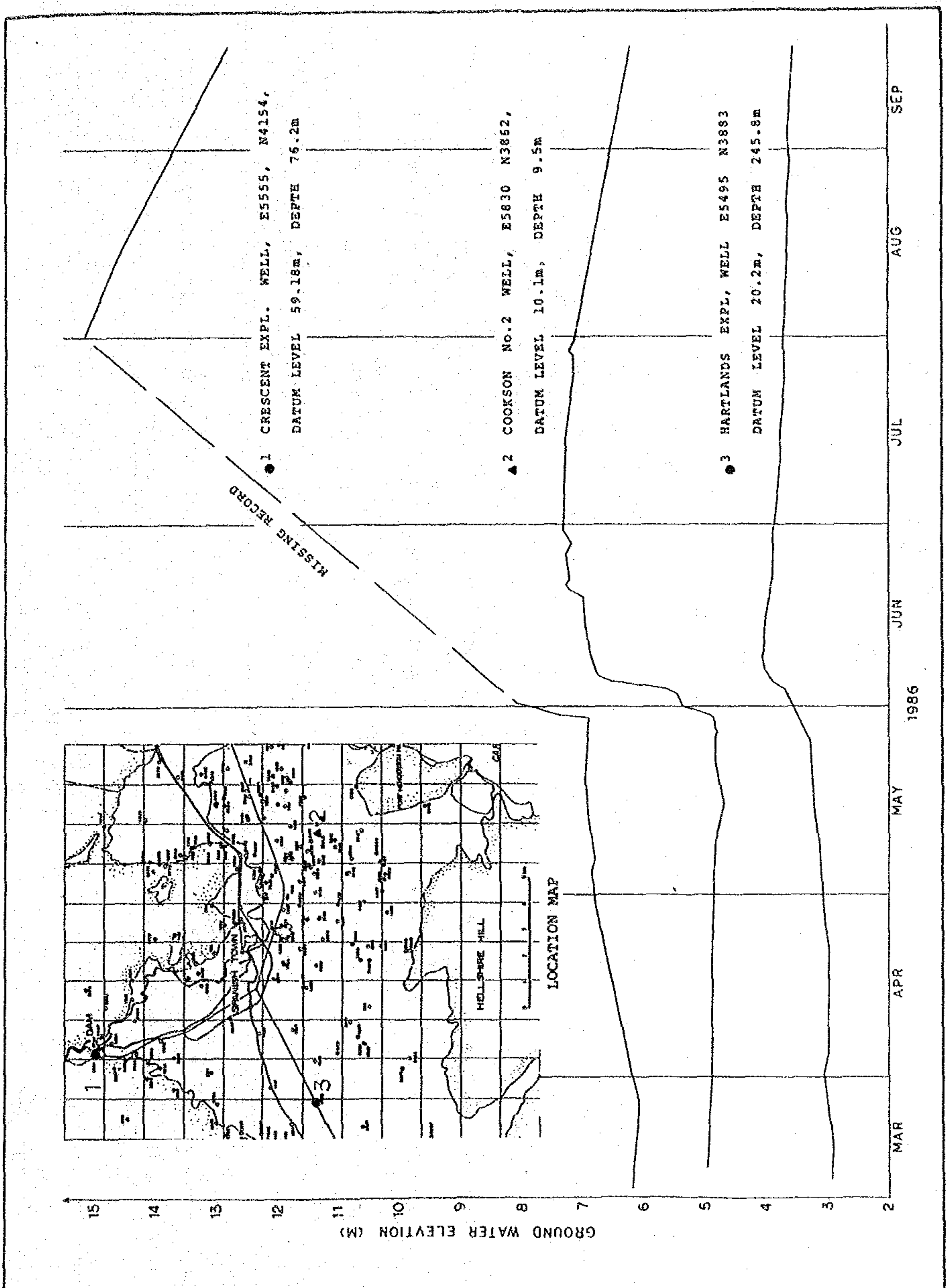
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-10
WATER LEVEL CONTOURS IN THE LIMESTONE AQUIFER JUN.-SEP. 1986

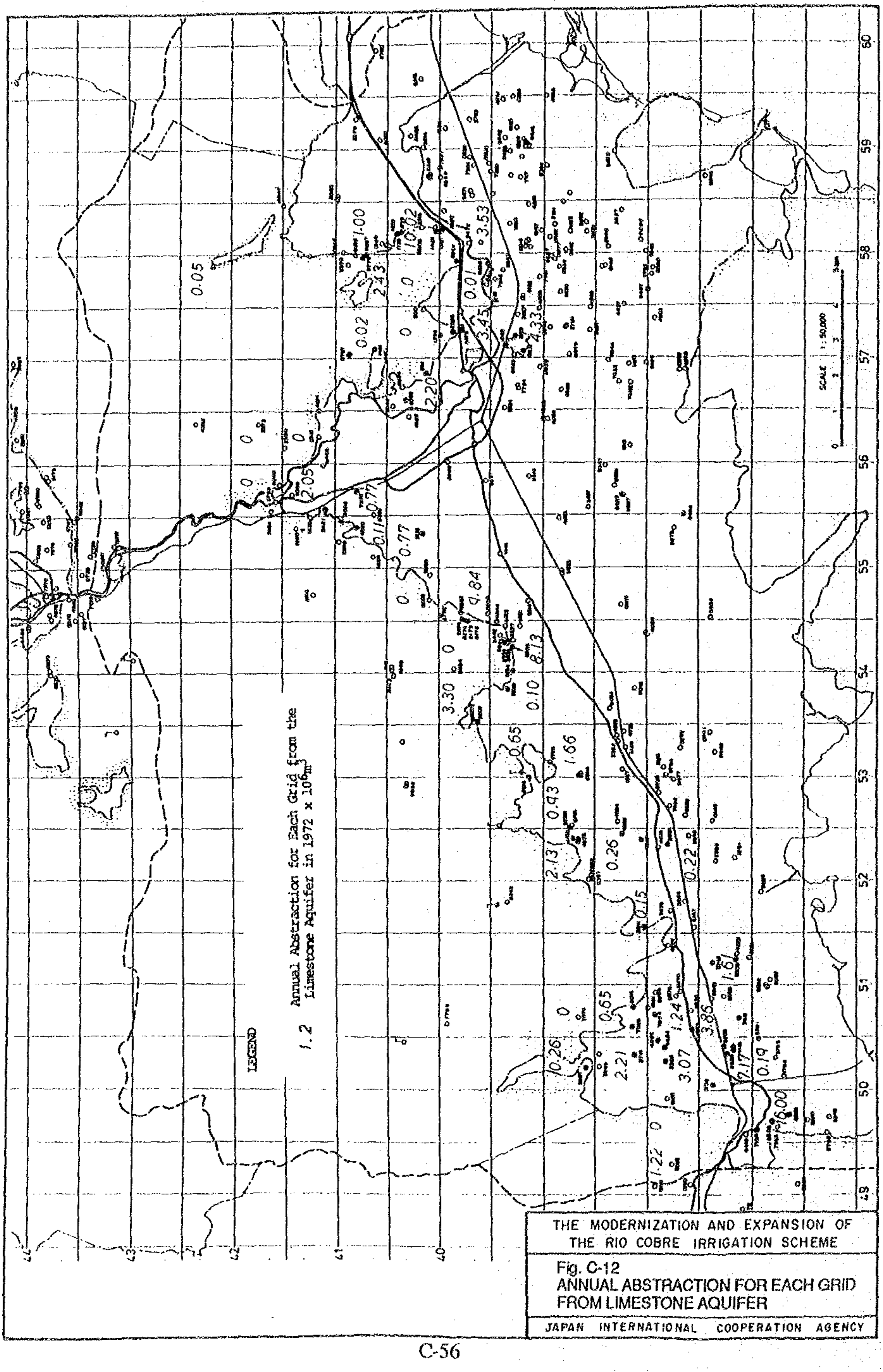
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-11
WELL HYDROGRAPHS

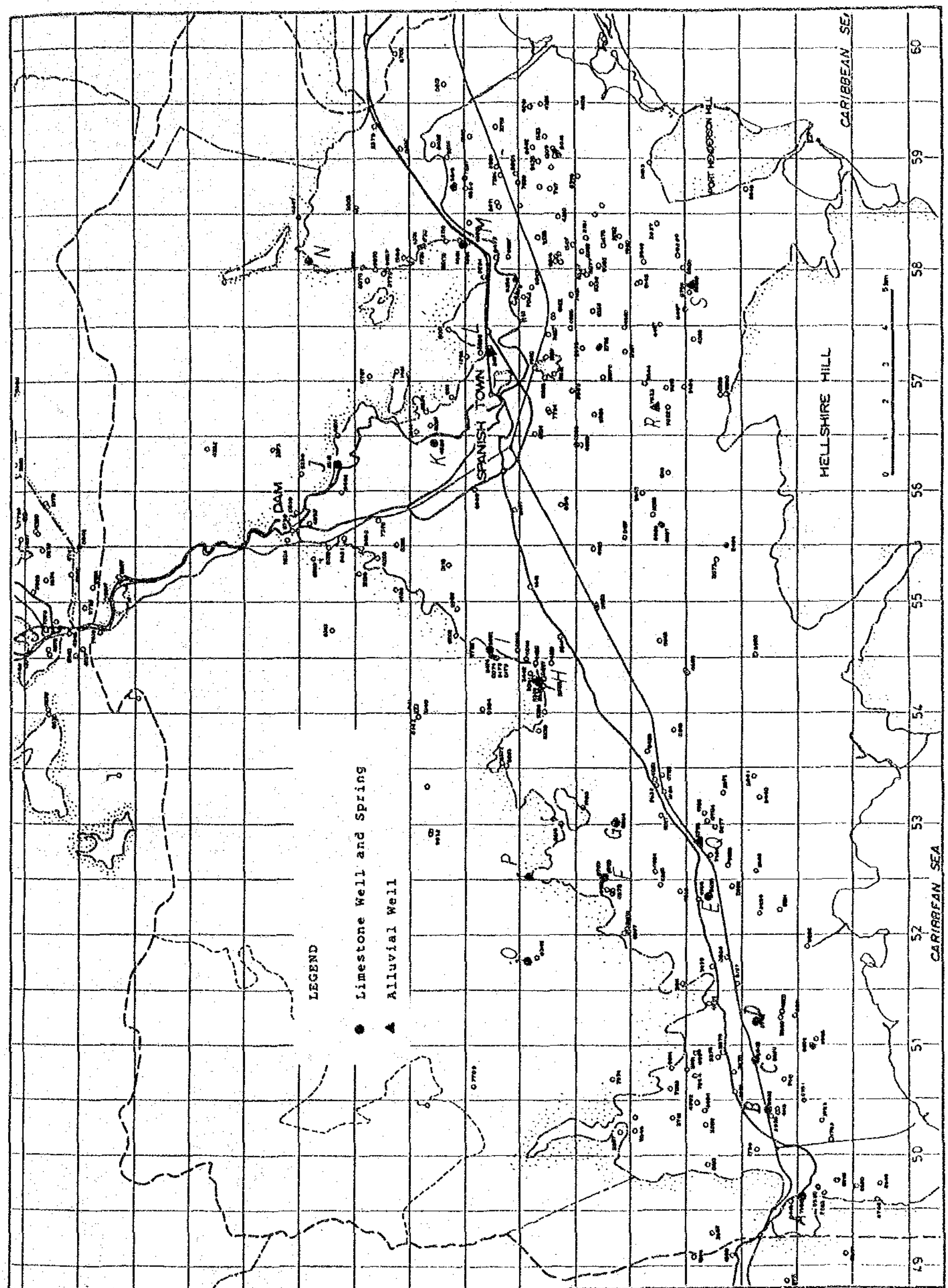
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-12
ANNUAL ABSTRACTION FOR EACH GRID FROM LIMESTONE AQUIFER

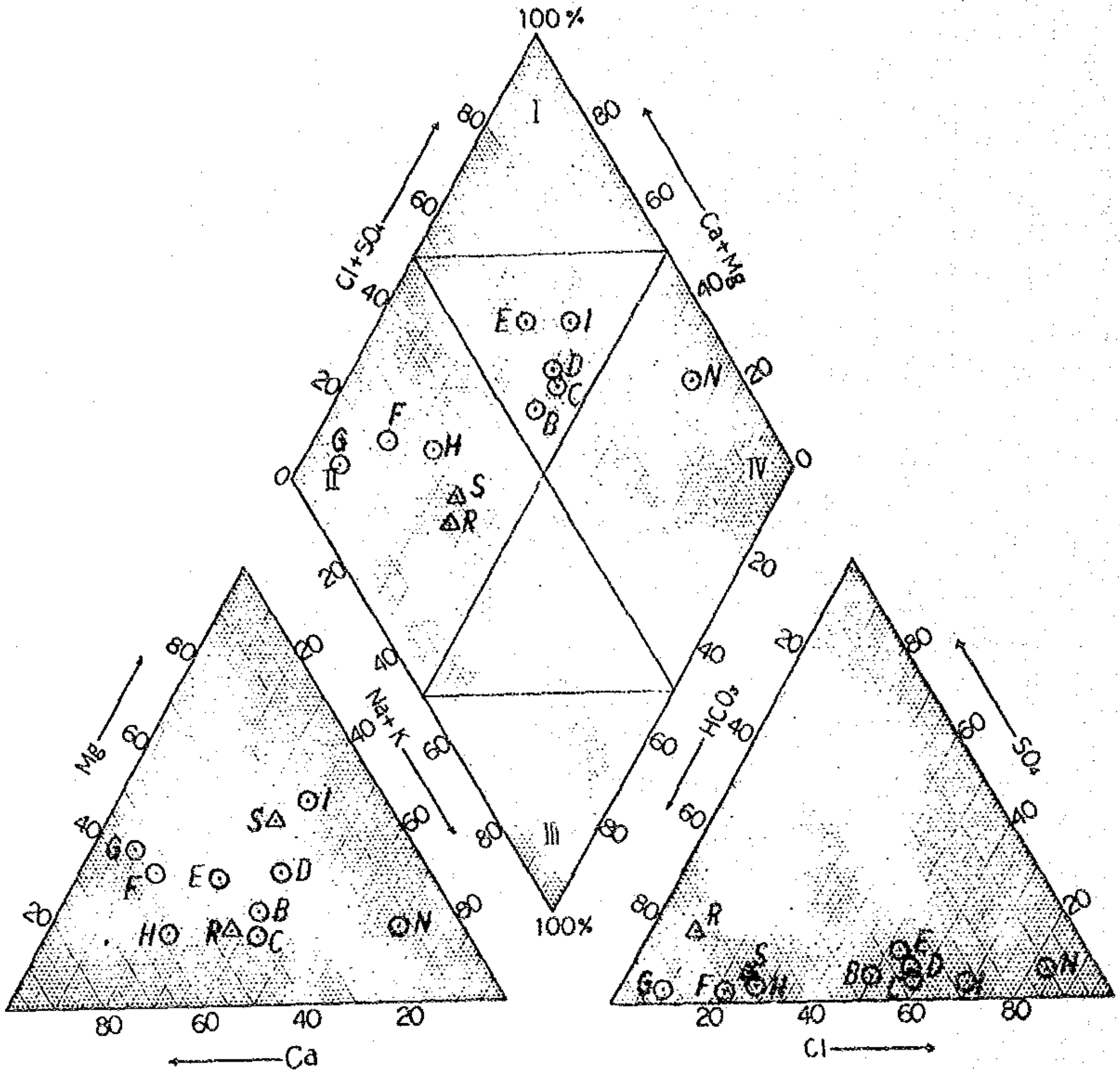
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF
THE RIO COBRE IRRIGATION SCHEME

Fig. C-13
LOCATION OF WATER SAMPLE

JAPAN INTERNATIONAL COOPERATION AGENCY



LEGEND

○ Groundwater from Limestone Aquifer

△ Groundwater from Alluvial Aquifer

I Noncarbonate Hardness

II Carbonate Hardness

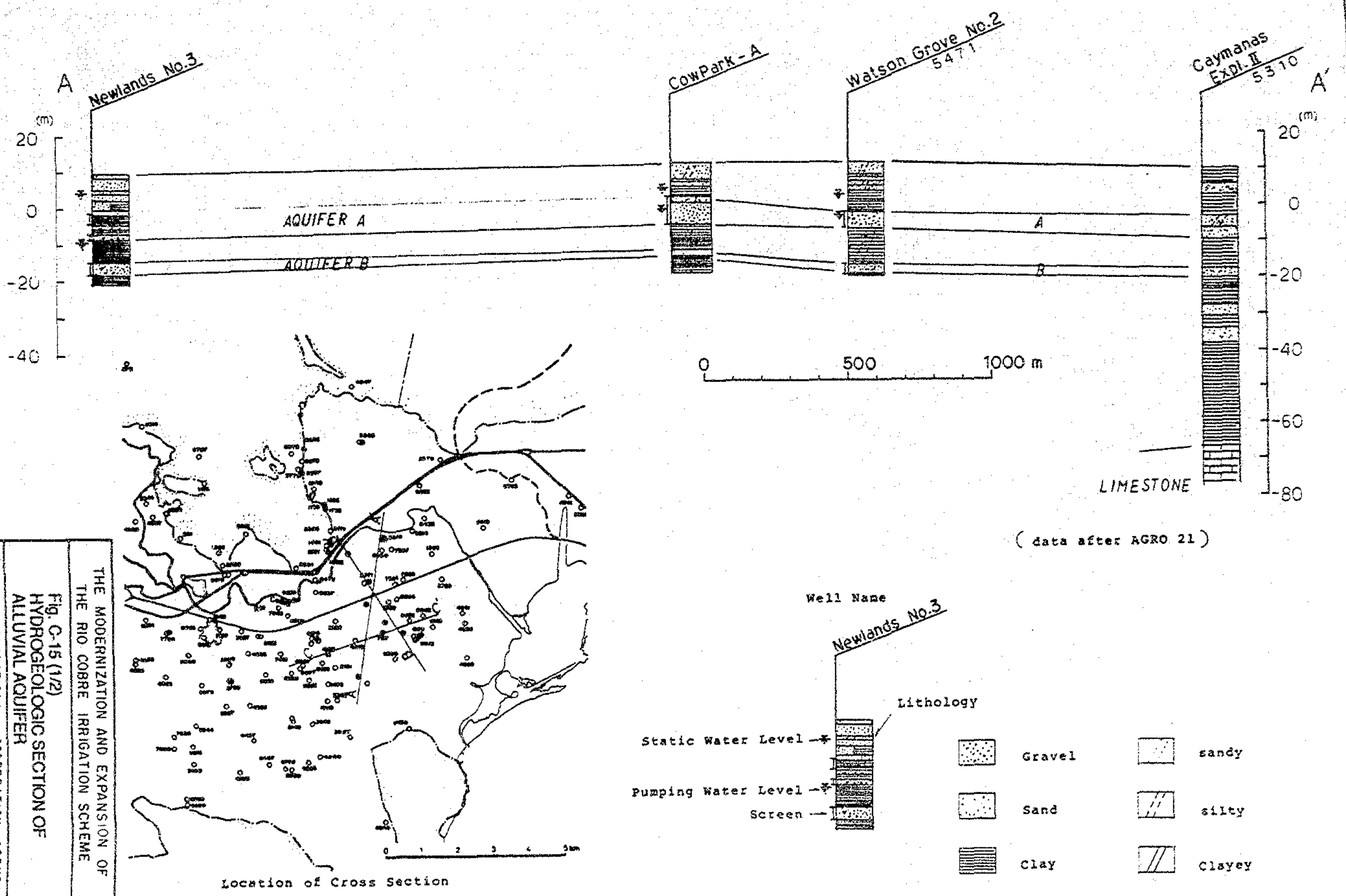
III Carbonate Alkali

IV Noncarbonate Alkali

THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-14
TRILINEAR DIAGRAM OF GROUNDWATER QUALITY

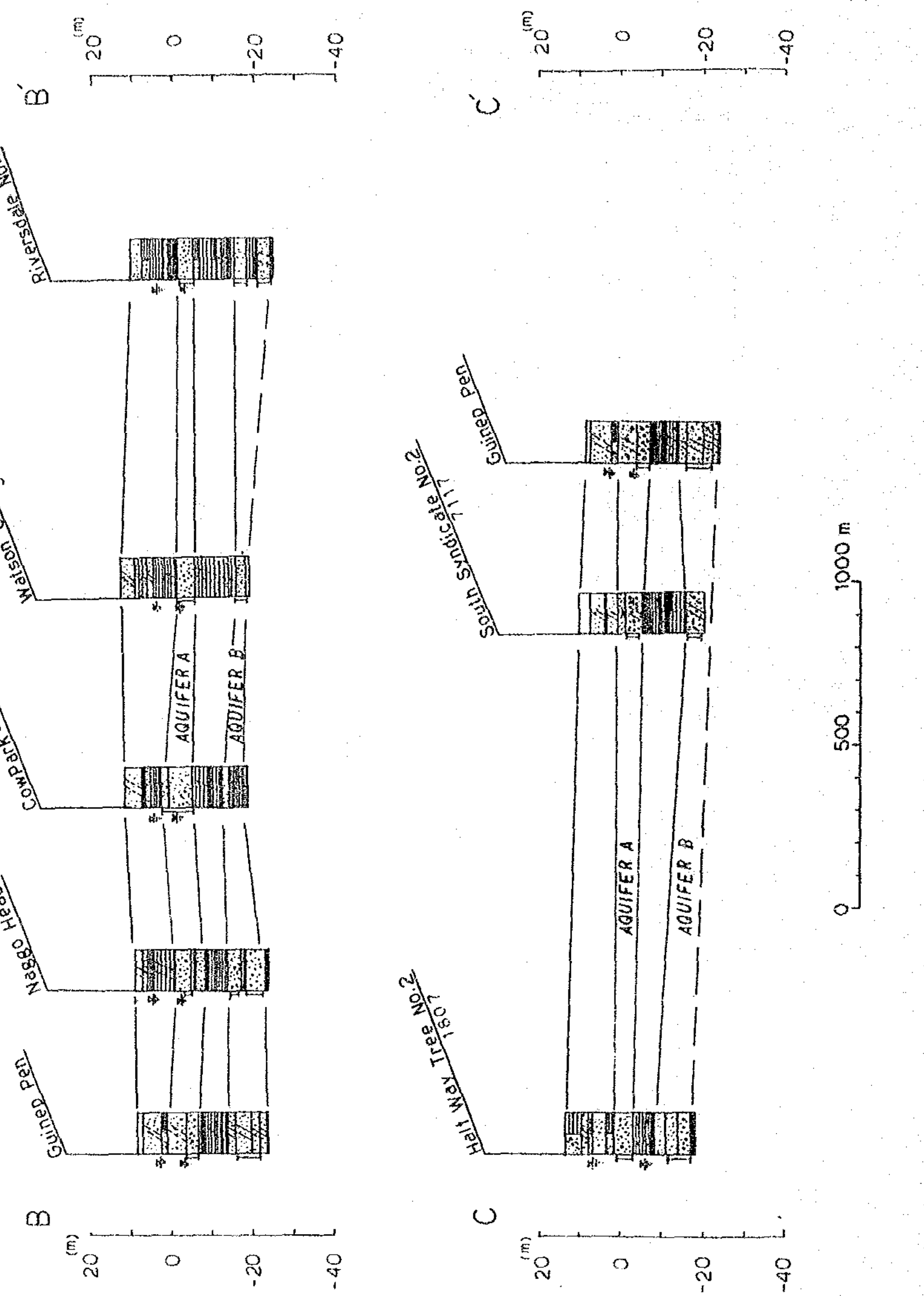
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-15 (1/2)
HYDROGEOLOGIC SECTION OF ALLUVIAL AQUIFER

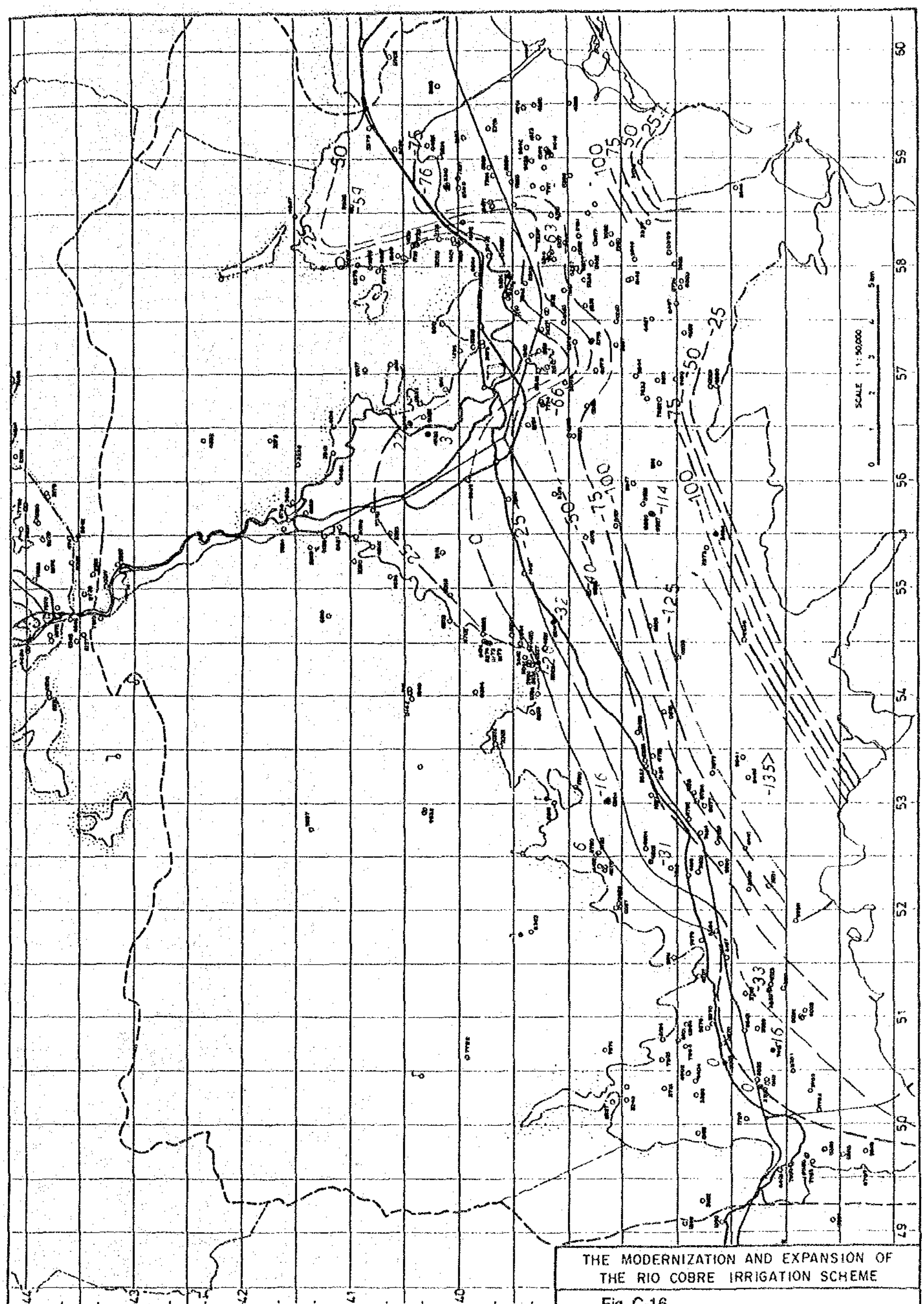
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-15 (2/2)
HYDROGEOLOGIC SECTION OF ALLUVIAL AQUIFER

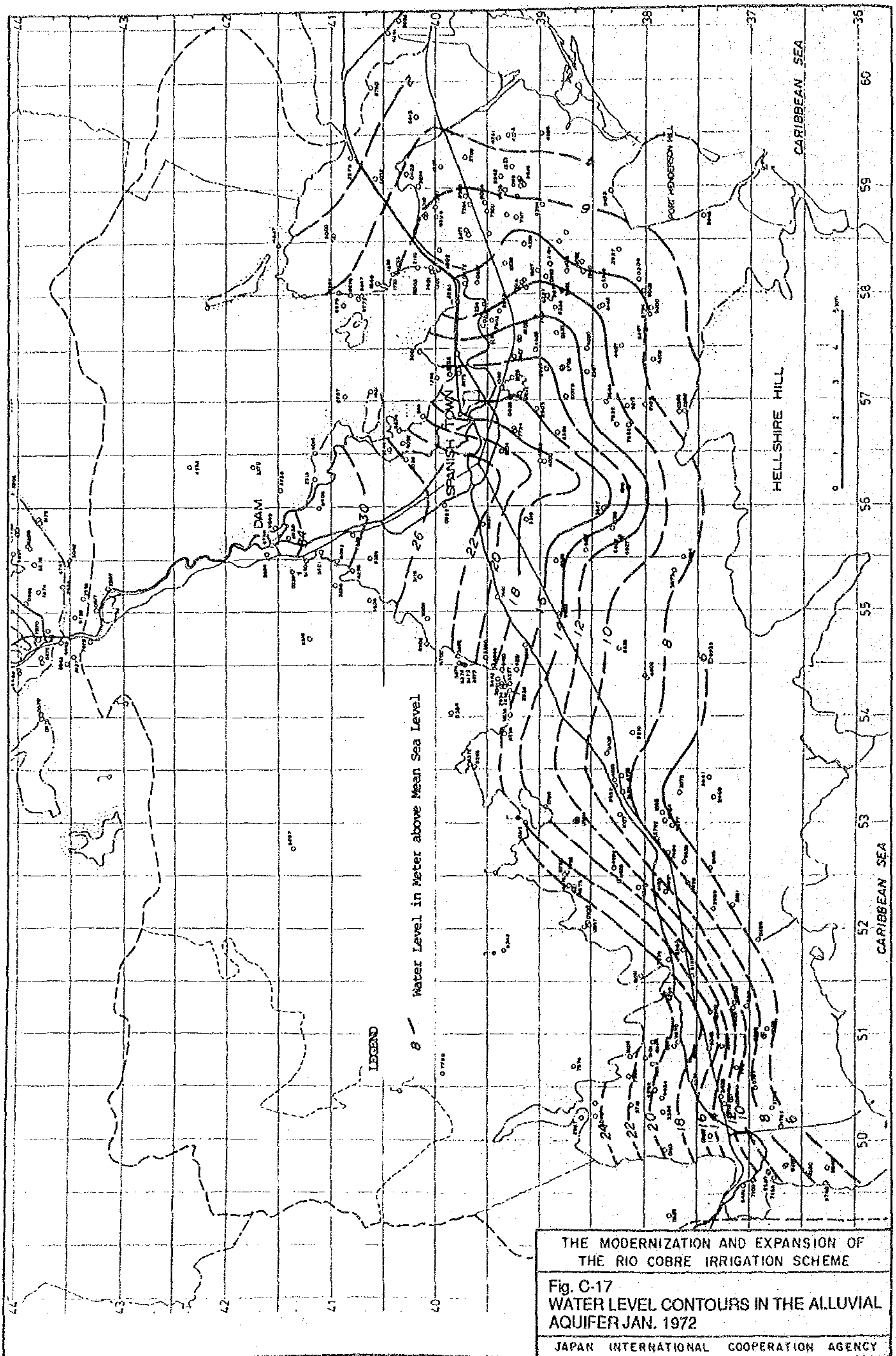
JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF
THE RIO COBRE IRRIGATION SCHEME

Fig. C-16
CONTOURS ON THE BOTTOM OF THE ALLUVIUM

JAPAN INTERNATIONAL COOPERATION AGENCY



THE MODERNIZATION AND EXPANSION OF THE RIO COBRE IRRIGATION SCHEME

Fig. C-17
WATER LEVEL CONTOURS IN THE ALLUVIAL AQUIFER JAN. 1972

JAPAN INTERNATIONAL COOPERATION AGENCY