3. HYDROGEOLOGY

3.1 Previous Investigations

Systematic hydrogeologic investigations of the Black River Lower Morass have been reported by FAO (1971). Their reconnaissance level investigation of the Lower Morass presented information on the geology, groundwater catchment boundaries, the permeability of the limestone aquifer, its water table and ground water quality. FAO's field study was carried out between April 1965 and March 1967.

3.2 Hydrostratigraphy

3.2.1 Impermeable basement

The Cretaceous formations and the Yellow Limestone Group, because of their low permeability, function as aquiclides i.e., they may store water but will not transmit water in sufficient quantities to support economic yields from wells and springs. These formations serve as the hydrogeological basement within the Black River Basin.

3.2.2 White limestone aquifer

All members of the White Limestone Group function as aquifers where secondary permeability is moderately or well developed.

Primary permeability is generally poorly developed within the Limestone Aquifer. In the Troy/Claremont and Gibratlar/ Bonny Gate Formations, it has been largely destroyed by recrystallisation and is initially low in the soft chalky limestones of the Newport Formation.

The Limestone Aquifer owes its permeability to the development of secondary permeability. In the Troy/Claremont and Gibraltar/Bonny Gate Formations the bulk permeability of the limestone is controlled by the development of solution enlarged bedding plane, joint and fracture permeability. These features result as a response to stresses on these incompetent limestones. The absence of these micro-features from the more competent Newport Formation account for its apparent lower bulk permeability.

However, the effective permeability of the White Limestone Aquifer is controlled by the presence of faults aligned in the direction of major groundwater movement.

Diffuse flow is associated with the bulk permeability of the Limestone Aquifer and conduit flow with the fault controlled movement of groundwater. Aquifer Tests, carried out this study on the Burnt Savanna, and Luana wells, located within the Lower Morass, produced transmissivity values characteristic of conduit flow i.e., 4.82×10^5 m^2/d (3.23×10^7 igpd/ft) and 5.26×10^3 m^2/d (3.53×10^5 igpd/ft), respectively. Both wells are sited on faults aligned in the direction of major groundwater flow. The blue holes of the Broad and Styx Rivers and the Middle Quarters springs are also similarly located on faults.

FAO (1971) reports a range of transmissivity 400 - 4,800 m^2/d (2.6×10^4 to 3.22×10^5 igpd/ft) for the Limestone Aquifer of the adjoining Pedro Plains area (see Table C-2). A similar range is reported by White (1983) for other groundwater basins in Jamaica (see table C-3).

The development of this karstic secondary permeability is believed to result from solution/abrasion enlargement of initial micro-permeability - Versey (1960). White (1983), concentrated within the zone of groundwater level fluctuations. Karstic permeability tend therefore to be absent from newly uplifted limestones as is exposed at Cataboo and Slipe. The inner core of the limestone mountains (e.g., Santa Cruz and Lacovia Mountains) appear to have also escaped karstification, serving as barriers to groundwater flow and ponding groundwater as in the Upper Morass.

In the bottom of the Lower Morass depression the water level in the Limestone Aquifer is confined by the overlying Alluvium (clay) Aquiclude, except in the upper Broad River Basin where windows in the clay allow direct hydraulic continuity between the Limestone and Peat Aquifers.

3.2.3 Alluvium aquiclude

The alluvium covers most of the floor of the Lower Morass depression, resting directly on the underlying limestone. Borings made during this study confirmed maximum clay thickness of 6 m (20 ft) in the Lacovia area (BH # 2) and in the swamp in the Middle Quarters catchment clay interbedded with peat was proved to a maximum depth of 16, (B H # 8). See Annex E, Figs. E-2 to 14

In the eastern upper section of the Broad River Basin, the clay is believed to be generally thin. Groundwater issues vertically through windows in the clay as the Broad River and Styx River blue holes. In the western area of the Lower Morass the clay appears to be much thicker, such that groundwater is ponded in the Limestone Aquifer of the Middle Quarters sub-catchment, issuing as springs at or near the outcropping of the limestone/alluvium boundary.

Where the clay is intact it functions as an aquiclude, confining groundwater levels in the Limestone Aquifer and preventing direct hydraulic contact between the underlying limestone and the overlying peat.

3.2.4 Peat aquifer

P.C.J. (1983) reported that peat covers almost the total area of the swamp, with maximum thickness of 12 m (40 ft) in the Middle Quarters River catchment area in the western section and about 5 m (16 ft) in the eastern section of the Lower Morass.

No measurements of the permeability of the peat in the Lower Morass are known to exist. However, rates of 0.01 to 0.108 m/day (24 to 256 igpd/ft^2) were reported for peats in Japan (Umeda and Nagasawa, 1977). The absence of the accumulation of organic acid throughout much of the swamp suggest a regular flushing of the peat. These organic acids in more stagnant swamp situations produce a characteristic brown coloured water, which is confied to the southern margins of the swamp in the Lower Morass.

The peat is apparently in hydraulic continuity with the surface streams which drain the Lower Morass, the water in the peat (or more commonly above the peat surface) being at approximately the same elevation as that of the water surface of the rivers. It is hydraulically separated from the Limestone Aquifer, throughout most of the Lower Morass by Alluvium Aquiclude.

3.3 Boundary of Groundwater Catchment

FAO (1971) reported a boundary for the Black River Basin and identified the several sub-catchment boundaries within this Basin. The basis of the selection of the boundaries choosen were not discussed and it is here assumed that the FAO identified the surface water boundaries. WRD (1982) presumed that the groundwater boundaries coincided with the surface water boundaries.

In the present study, the groundwater boundaries for the Lower Black River Basin and its sub-catchments were defined. They are shown in Fig. C-3.

3.3.1 Southern boundary

This boundary coincides with the northern groundwater boundary of the Pedro Plains Sub-catchment of the Black River Basin. This boundary was drawn along the crest of the groundwater high in the Fullerswood-Mountainside areas, based on water level contours for the Pedro Plains reported by WRD (1981a).

3.3.2 South-eastern boundary

The groundwater divide in the eastern section of the Lower Black River Basin coincides with the alignment of the Santa Cruz Fault from Carisbrook to Hounslow. Low permeability Newport Formation is brought to the surface at the base of the Santa Cruz and Lacovia Mountains on the eastern up-thrown side of the Fault, preventing underflow from the Upper Morass and Essex Valley sub-catchments of the Upper Black River Basin into the Lower Morass. The 20 m (65 ft) difference of groundwater level elevation on either side of the Santa Cruz mountains attest to the lack of hydraulic continuity i.e., less than 1 m (3 ft) in the Lower Morass and 21 m (69 ft) in the Essex Valley. The ponding of groundwater in the Upper Morass imply little, if any, underflow into the Lower Morass.

3.3.3 North-eastern and north-western boundaries

These boundaries were made to coincide with impermeable basement rocks which outcrop or are close to the ground surface. This boundary coincides with the surface water boundary.

3.3.4 Mid-western boundary

The boundary proposed by FAO (1971) was redrawn to exclude the catchment area of the closed Newmarket surface depression.

Data resulting from the June 1979 flooding of the Newmarket depression indicated that there was no significant, if any, groundwater underflow from the Newmarket depression to the Lower Morass. Donaldson and Walters (1981) reported that despite a 4.6 m^3/s (88 migd) leakage from the flooded depression to the sub-surface there was no significant increase in the flow of the Middle Quarters Spring in the Lower Morass. These Springs were previously assumed (FAO, 1971) to have been the exit for groundwater recharge in the Newmarket area.

The size of the FAO (1971) Newmarket Sub-catchment was also assumed this study to be too large, based on the absence of perennial or seasonal surface water drainage and the estimated discharge of the Middle Quarters Springs. Given average annual rainfall over the Newmarket sub-catchment (after FAO) of 2.367 m, catchment area of 140 km^2 and a runoff coefficient of 0.4, then the discharge of the Middle Quarters Spring should be of the order of 4.2 m^3/s (80 migd). Flow net evaluation of groundwater flow estimate total spring flow to be of the order of 1.0 m3/s (19 migd, section 6.1.1. (a)), much more in keeping with the 50 km^2 catchment area decided this study and annual rainfall of 1.58 m.

3.3.5 South-western boundary

The groundwater boundary was assumed to coincide with the crest of an anticline in the Mount Charles and Luana areas of the Basin.

3.4 Hydrogeological Features

3.4.1 Groundwater levels

Water level elevation data from 5 springs and 20 wells were used to prepare a groundwater level contour map in the Limestone Aquifer of the Black River Lower Morass. The map is presented as Fig. C-4. The datum for each point was accurately determined by field survey carried out during this Study. These datum elevations are listed in Table C-4.

Ground water level contours were drawn to a maximum elevation of 2.0 m above mean sea level. The main features of the map were the presence of two groundwater depressions - the Broad River and Middle Quarters depressions, separated by a low ground water ridge in the Frenchman - Cataboo area of limestone upland. Groundwater from the Luana, Middle Quarters and Frenchman flow-tubes discharged into the Middle Quarters Depression and the Fullerswood, Mountainside, Burnt Savannah and Lacovia flow-tubes emptied into the Broad River depression. There was little evidence of direct groundwater outflow to sea. The extent of the respective flow-tubes are shown on Fig. C-5.

A water table exists in the upland areas but the groundwater surface is confined in the swamp area of the Lower Morass.

3.4.2 Water table fluctuations

The water level in wells and springs of the Limestone Aquifer were monitored once per week for a 4 week period - July 17 to August 15, 1984. The resulting water level fluctuations are presented as Fig. C-6.

The groundwater levels showed a general trend to increasing elevation in response to the onset of the main rainy season.

The extent of the fluctuations observed appear to be directly related to the variation of permeability within the aquifer. Wells and springs known to be associated with high permeability conduit flow along faults showed fluctuations an order of magnitude less than the others which reflected the lower permeability diffuse flow.

See Table C-4. Note also that the highest change in groundwater levels were observed at Frenchman, on the groundwater ridge. This ridge is developed in that area of the Limestone recently emerged and believed to be least affected by karstic processes i.e., area of lowest permeability within the Lower Morass.

The existence of groundwater levels being below mean sea level in the Vineyard - Arlington - Fullerswood area implied that groundwater levels in the Lower Morass sub-catchment responded to tidal fluctuations. Fluctuations of maximum pumping water levels in the Luana and Burnt Savanna wells observed during aquifer testing were also thought to reflect the effect of tidal fluctuations.

3.4.3 Springs and blue-holes

Groundwater is discharged from the Limestone Aquifer at the margins of the Lower Morass as springs (e.g., the Middle Quarters Springs) or as vertical upwelling through "windows" in the Alluvium and Peat which floor the Lower Morass (e.g. Broad River and Styx River Blue holes).

The Middle Quarters Springs issue at or near the outcropping of the boundary between the Limestone Aquifer and the Alluvium Aquiclude in the north western section of the Lower Morass. It appears likely that the relatively thick sequence of alluvium and peat overburden (16 m) limit the development of blue holes within the swamp, ponds the groundwater in the Limestone Aquifer, which overflows at the limestone/alluvium boundary. The Middle Quarters Springs drain the 50 km^2 Middle Quarters sub-catchment at a rate of about 1.0 m^3/s (see section 4.3.4 and 6.1.1(a)). The springs appear to be associated with the down-stream end of faults orientated in the direction of major ground-water flow, a relationship which implies that they are fed by conduit flow. The relatively low range of fluctuations observed at these springs was consistent with the assumption of conduit flow (see section 3.4.2 above).

FAO (1971) reported the existence of some 18 sinkholes in the bed of the Broad River, of which only those in the Upper reaches of the river appeared to actively support groundwater discharge i.e., functioned as blue holes. During this study, the Broad River and Styx River blue holes were investigated. The Broad River blue hole which is located about 4.5 km upstream of the Salt Spring bridge, exhibited a depth of about 10 m below the water surface, with limestone rock exposed at its base. The bottom of the Styx River blue hole was covered with a thick growth of aquatic plants. No turbulence was observed in either blue hole. Direct measurement of their respective flows was not attempted as there was no obvious way that a distinct groundwater flow could have been identified. Flow Net Analysis (section 6.1.1. (a)) determined groundwater inflow into the Broad River depression to be of the order of 1.5 m^3/s (29 migd). Estimates developed by the water balance method indicated a mean annual inflow of 1.8 m^3/s (34 migd) Annex A, Section 4.2.2. Both the Broad and the Styx River blue holes are located within close proximity to the alignment of the Santa Cruz Fault.

The main hydrogeological features are summarised on a map included as Fig. C-7.

4. GROUND WATER QUALITY

4.1 Water Types

Samples collected from 11 wells and 4 springs were analysed for major cation and anion concentrations and physical quality. The results of these analyses are presented in Table C-5.

Three water types were identified with the aid of stiff, trilinear and hexa diagrams. These diagrams are included as Figs. C-8, C-9 and C-10.

4.1.1 Calcium bicarbonate type

The background quality of the karstified section of the Limestone Aquifer corresponded to a calcium bicarbonate type water. This water type is associated with groundwaters in the Broad and Styx River blueholes, wells in the Mountainside - Burnt Savanna - Lacovia areas, the Middle Quarters Springs and the Luana and Ashton wells. These waters owe their quality to their interaction with the calcium carbonate rich Limestone Aquifer.

4.1.2 Magnesium bicarbonate type

This water type was identified in the Frenchman-Slipe area and in the overflowing artesian discharge from the Fullerswood Corehole. These waters occured in sections of the Limestone Aquifer of particularly low permeability, either at the surface as at Frenchman - Slipe, or at depth as at Fullerswood. The enrichment in magnesium may reflect the presence of dolomitic limestones in these sections and the longer contact time of the water with the aquifer.

4.1.3 Calcium chloride type

This water is exhibited by the Vineyard well. Its proximity to that section of the Broad River affected by seawater intrusion and which had groundwater level fluctuations below sea level implied the influence of seawater on the water quality in this well. This conclusion is supported by - sulphate/chloride and magnesium/ chloride ratios which are similar to those expected to result from seawater contamination.

4.2 Sea Water Contamination

FAO (1971), NRCD (1981), Hydrocon (1982) and PCJ (1983) all reported the presence of seawater wedges in the beds of the Black and Broad Rivers during periods of seasonally low flow. The wedge has been confirmed up to 7 km upstream from the sea (PCJ, 1983). A potential exists for contamination of the Limestone and Peat Aquifers to the extent that they are in direct hydraulic contact with the contaminated river bed. Both aquifers may also be contaminated by direct inflow from the sea where they have a common sub-surface boundary, with the sea.

4.2.1 Contamination of the limestone aquifer

FAO (1971) identified that area of the Limestone aquifer believed to be contaminated by seawater intrusion. See Fig. C-11. Their conclusion was apparently based largely on the position of the sea water wedges in the bed of the Black and Broad Rivers.

Electrical conductivity measurements were carried out this study in wells and springs within the Lower Morass Sub-catchment. A map showing the distribution of electrical conductivity within the Limestone Aquifer, as indicated by these measurements, is presented as Fig. C-12. Groundwater of background quality have values of electrical conductivity less than 600 micro.mhos/cm. A general increase in electrical conductivity towards the sea is modified by higher values being associated with that area of the aquifer in the vicinity of the Black and Broad Rivers. A maximum value of 2,500 micro.mhos/cm was determined for the discharge of the Black River Spa, a limestone spring located less than 100 m from the shoreline.

Given an electrical conductivity of about 50,000 micro.mhos/cm for seawater (WRD 1981b) a maximum value of less than 3,000 micro. mhos/cm within the Limestone Aquifer indicated moderate to low seawater contamination. This conclusion suggested significant subsurface discharge out to sea a situation not supported by groundwater flow lines indicated by the groundwater level contour map (Fig. C-4). It appeared more likely that the groundwater sampled, reflected the presence of a thin surface layer of relatively fresh groundwater flowing seaward above more saline groundwater at depth.

The Limestone Aquifer is in direct contact with seawater in the bed of the Broad River about 1.5 km upstream of the Salt Spring bridge, where limestone is exposed in a 1 km reach of the river bed. The aquifer is also assumed to be in direct hydraulic contact with the sea at depth off-shore. Both these situations provide significant opportunity for seawater intrusion of the aquifer.

Hydrocon (1982) reported the presence of slight saline contamination of the 76 m deep Luana well, and referred to the absence of a proper Ghyben-Herzberg response within the Limestone Aquifer of the Lower Morass i.e., given such a low groundwater level elevation much higher levels of salinity aught to be present within the wells and springs in the Lower Morass.

A definitive interpretation of saline contamination of the Limestone Aquifer will require the drilling of several deep wells in the vicinity of the lower reaches of the Black and Broad Rivers to obtain depth/conductivity information on the aquifer.

4.2.2 Contamination of the peat aquifer

The Peat Aquifer is in direct contact with those sections of the Black and Broad Rivers invaded by the seawater wedge. Continuity between river water level and the peat water level have been interpreted to indicate hydraulic continuity between the river and peat. Sea water contamination of the Peat Aquifer is therefore likely.

The apparent net outflow of fresh water from the Peat Aquifer ant its apparent low permeability are believed to significantly limit the extent of seawater contamination of the peat in the Lower Morass. The presence of mangrove was used to indicate saline contamination of the peat 4.5 and 8.0 km upstream from the sea in the Black and Broad Rivers, respectively. Mangrove forests were also found in areas not regularly flushed by the flood waters of the Black and Y.S. Rivers i.e., the right bank of the Black River below its confluence with the Middle Quarters River and the left bank area between the Broad River and the sea, downstream of Salt Spring bridge.

The flushing of seawater from the river system during the wet season is not believed to cause any significant reduction in the area of the Peat Aquifer contaminated by seawater, as the fresh flood waters are drained off by the Black and Broad Rivers before reaching these areas.

The areas of the Peat Aquifer assumed to be contaminated by sea water are shown on Fig. C-13.

4.3 Groundwater pH and Temperature

Field measurements of pH and temperature of wells and springs in the Lower Morass were monitored once per week for a 4 week period (July 17 to August 14, 1984). The pH measurements were carried out by colourimeter pipe method and temperature with a mercury thermometer with 0.2°C gradations. The resulting pH and temperature data are presented in Table C-5.

The pH values obtained for the wells ranged from 7.1 to 7.6, while that of the springs and blueholes showed a slightly lower range i.e., 7.0 to 7.4.

Water temperatures ranged from 25 to 28°C, that of the springs and blueholes generally being 1 or 2°C less than the temperature of well water.

5. IMPACT OF HYDROGEOLOGY ON THE PROPOSED DEVELOPMENT PROJECT

5.1 Impact on Groundwater Inflows

A quantitative evaluation of groundwater inflow into the Lower Morass was required to determine the implications for the drainage plan and also to assess the impact of drainage on wells established in and around the Lower Morass.

5.1.1 Pre-project groundwater inflow

(a) Flow Net Determination

The following modification of Darcy's Equation governing groundwater flow was used to estimate sub-surface inflow into the Lower Morass :-

$$Q = T \times I \times L$$

where Q = groundwater flow (m^3/s)

T = transmissivity of the aquifer (m^2/d)

I = hydraulic gradient of the water table (dimensionless

L = length of the water table contour through which the groundwater flow occured (m)

The groundwater level contour map determined this study was used in the determination. A number of flow tubes were identified and the groundwater flow in each determined. Total groundwater inflow was obtained by summing the inflow from each flow tube. The flow tubes are shown in Fig. C-5.

The values for I and L were obtained by direct measurement on the map. Flow tubes with apparently high transmissivities were assigned a value of 7.45×10^3 m^2/d (5×10^5 igpd/ft) - Mountainside and Middle Quarters Flow tubes, and the others assigned a value, a order of magnitude lower i.e., 7.45×10^2 m^2/d (5×10^4 igpd/ft). These assumed values of transmissivity were decided after considering the published data on the Limestone Aquifers in Jamaica (Tables C-2 and C-3) and the results of aquifer tests on the Luana and Burnt Savanna wells carried out this study (section 3.2.2. above)

The results of the Flow Net Analysis is summarised in Table C-6 and presented graphical as Fig. C-14. Groundwater inflow into the Broad River depression was determined to be 1.6 m^3/s (52%), that into the Middle Quarters Depression 1.4 m^3/s (48%) amounting to an inflow of 2.0 m^3/s (57 migd) on August 18, 1984. Conduit flow accounted for 2.2 m^3/s (74%) of the total inflow.

(b) Water Balance Determination

A determination of the mean ground water inflow to the Lower Morass for the period 1974 to 1980, by the water balance method is reported in Annex B section 4.2.2. A value of 2.6 m^3/s was estimated.

This result compared favourable with the 3.0 m^3/s estimated by NRCD (1981) and the 2.4 m^3/s of FAO (1971).

Given the relatively small changes in water table gradients that are characteristic of groundwater systems, this result lent credibility to the assumptions used and result obtained in the Flow Net Analysis described above (Section 5.1.1 (a)).

The revised FAO result used assumed an adjustment in the catchment area to the smaller catchment of the Middle Quarters sub-catchment of this Study. Both NRCD and FAO determinations utilised the water balance method.

5.1.2 Post-project groundwater inflow

Maximum proposed development includes four main blocks of land - the Black River Right Bank (Holland), Black River Left Bank (Holiday Pen-Hatfield), Broad River Right Bank and Broad River Left Bank. Each development block has a dike, a main drainage canal and a pumping station. These areas and their associated drainage control structures are shown in Fig. C-15.

The exclusion of the Y.S. River and Middle Quarters River swamp area from the proposed development area means that there should be no significant change in the pre-project hydraulic relationship between the Limestone Aquifer and the swamp after implementation of the proposed development project. The small inflows from such blue holes as may exist in these areas would be unchanged. In any event, the main inflow into the Middle Quarters groundwater depression via the Middle Quarters Spring, would be unaffected by drainage of the swamp as their flow is geologically controlled at elevations at or above the level of the swamp.

On the other hand, the drainage plans are likely to have a significant impact on groundwater inflows into the Broad River groundwater depression. Present ground surface elevation in the swamp is an average 0.3 m. Drainage is expected to cause settlement such that post-project ground surface elevation is reduced to 0 m i.e., the mean sea level. The water table in the Peat Aquifer will be controlled at -0.8 m. Pre-project water level in the Broad River depression was estimated to be about elevation 0 m (Sea level). Post-project water level would be reduced to -0.8 m at the maximum.

The maximum elevation along the groundwater high that forms the groundwater boundary between the Lower Morass and the Pedro Plains is about 4 m (WRD, 1981a). The lower post-project base level of -0.8 m elevation in the Lower Morass, would thus increase the groundwater head difference by 0.8 m (20%). An initial high increase in groundwater flow would result from the increased groundwater gradient. To support this increased flow, the groundwater boundary would tend to shift outwards, increasing the size of the groundwater catchment of the Lower Morass, mainly at the expense of the Pedro Plains. Accompanying this expansion would be a tendency to establish a new groundwater boundary with a lower maximum elevation. This situation would eventually lead to the establishment of a final hydraulic gradient likely to be higher than the pre-project gradient but less than the initial post-project gradient. The net effect would be a less than 0.3 m^3/s (20%) increase in groundwater inflow into the Broad River depression and a corresponding decrease in the amount of groundwater available from the Pedro Plains.

However, above mentioned controlled ground water level is at most critical situation, the normal height of the ground water is to be mentioned at the ground surface of EL. $\pm$ 0 m in an average (the lowest ground surface level is EL. -0.5 m at the drainage pump station), because this area is used for paddy field.

The changing of hydrogeological regime such as increase of groundwater inflow toward Broad River Depression, lowering the groundwater level in the Pedro Plains can be predicted by computer model simulation. In order to establish proper simulation model, water level in wells have to be observed for at least one year. In this event about 15 new wells should be dug in the Broad River basin and the Pedro Plains. A hydraulic constant to be applied to the simulation model, which is very important to obtain an accurate result of computer simulation, is to be determined based on the results of pumping test at the wells. Based on the data obtained by the investigations, a model in which present hydrogeological regime is simulated adequately is established through try and error. (see Table C-8)

The expected drainage condition in the Broad River basin in post-development condition is inputted to the above model and thus the future hydrogeological regimes in the Pedro Plains can be predicted properly.

5.2 Effect on Existing Production Wells

5.2.1 Effect on deep wells

There are 3 tube-wells in active production, located near to the edge of the swamp areas of the Lower Morass i.e., the Burnt Savanna well to the east, Holland well to the north and the Luana well to the west. See Fig. C-4. The Burnt Savanna and Luana wells are public water supply sources and the the Holland well was used to meet domestic and industrial demands on the Holland Sugar Estate. Data on these wells are summarised in Table C-7 (Hydrocon, 1982).

Transmissivity results obtained from aquifer tests carried out this study on the Luana and Burnt Savanna wells indicated that both wells tapped conduit flow i.e., a high proportion of their flow are obtained from relatively large fissures or caves intercepted by the wells. The exclusion of the swamp area of the Middle Quarters River catchment from the proposed development area, would leave the Luana well largely unaffected by drainage activities within the development area. However, the proposed reduction of base level within the Broad River basin to -0.8 m elevation, is likely to produce a similar reduction in static and pumping water levels in the Burnt Savanna well. These expected reductions in well water levels would affect well yield only in the event that the conduit(s) feeding into the well are dewatered by the projected 0.8 drop in water level. Given its location along the Santa Cruz Fault this is hardly likely to be the case. A 0.8 metre increase in the total dynamic head of the pumping plant installed in the Burnt Savanna well is likely to cause at worst a very marginal reduction in output. Therefore no significant post-project change in the yield of the Burnt Savanna well is expected.

In the absence of specific capacity data on the Holland well, it was assumed that its production was supported by diffuse flow. This assumption was based on its location within the Frenchman Flow-tube, where groundwater flow in the Limestone Aquifer is believed to reflect diffuse flow rather than conduit flow. The well also occurs in an area where groundwater levels in the Limestone Aquifer are confined by the overlying Alluvium Aquiclude. This absence of direct hydraulic contact between the Peat and Limestone Aquifers implies that water levels and therefore the yield of the Holland well would be unaffected by reductions in the water table in the Peat Aquifer, caused by the draining of the swamp in the Black River Right and/or Left Bank development blocks. The likely expansion of the Broad River catchment towards the Holland well could cause a maximum 0.5 metre fall in well water level. The resulting reduction in saturated aquifer tapped by the well and the increase in total dynamic head of the pumping plant are likely to combine to produce a marginal reduction in the optimum yield of the well.

5.2.2 Effect on shallow dug wells

Several low yielding shallow hand dug wells are established within the Lacovia - Cataboo groundwater ridge and in the upland area of the Lower Morass area. These wells serve as semi-active production wells, providing household water supplies and water for livestock. These wells are generally used for household supply in the event of a failure of the public water supply system.

The bottom of these wells rarely extend greater than 1.5 m below the water table. A maximum 0.5 m reduction in the water table within the catchment of the Broad River basin, which is expected to result from a post-project drainage induced base level of -0.8 m elevation, would therefore reduce the depth of water in the bottom of these shallow dug wells. Their continued use would necessitate deepening to compensate for the fall in the water table.

5.3 Post-project Groundwater Quality

5.3.1 Limestone water quality

A drainage induced reduction in the groundwater levels within the Broad River depression to an average elevation of -0.8 m is certain to increase the potential for seawater contamination of the depression. The groundwater gradient with respect ot the sea would be reversed with a resulting increased inflow of saline groundwater.

The absence of information on the fresh/saline groundwater interface in the vicinity of the Broad River depression precluded even the crudest quantitative estimation of the extent of the water quality change. A quantitative evaluation would necessitate the construction of several exploratory deep wells into the limestone and the definition and characterisation of the fresh/saline groundwater interface by a study of water quality changes in these wells.

5.3.2 Peat water quality

No significant change in annual surface water outflow from the Lower Morass is likely under post-project conditions, as it is estimated that irrigation diversions will be balanced by a near equivalent amount of drainage water discharged into the Black and Broad Rivers. Correspondingly, no significant change in the extent of saline intrusion along the river beds is expected (see Annex B section 4.4).

The sections of the Peat Aquifer within the development area although protected by dikes from flooding by the rivers, will continue to be flushed by fresh irrigation water infiltrated into the peat via paddy fields and subsequently removed by drainage pumping.

Therefore no significant post-project changes in the water quality of the Peat Aquifer is likely to occur.

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Table C-1 SUMMARY DESCRIPTION OF HYDRO-STRATIGRAPHIC UNITS IN THE BLACK RIVER BASIN

Age		Formation	Group	Maximum Thickness (metres)	Lithology	Hydrogeologic Character	
Recent to Quaternary		Peat (Qm)		12	Very soft, fibrous partially decomposed plants.	Peat Aquifer	Low permeability aquifer
Recent to Quaternary		Alluvium (Qa)		10	Mainly clay, with minor amounts of sand and gravel	Alluvium Aquiclude	Aquiclude which separates peat and limestone aquifers.
Tertiary	Miocene	Newport Limestone (Mn)	White Limestone Group	1,500	Soft, chalky, nodular limestone sandy and marly in Cataboo-Slipe area	Upper White Limestone Aquifer	Primary permeability low. Secondary permeability moderately developed. Major ground water movement associated with faults.
Tertiary	Oligocene	Walderston Browns Town Limestone (Owb)	White Limestone Group	215	Massive bioclastic limestone in chalky matrix.	Upper White Limestone Aquifer	
Tertiary	Eocene	Bonny Gate Gibraltar Limestone (Egb)	White Limestone Group	460	Hard well bedded chalks with few clay and flint layers.	Lower White Limestone Aquifer	Moderate to well developed secondary permeability. Character essentially that of Etc. Original porosity destroyed by recrystallisation. Well developed secondary permeability controlled by fracture rather than solution features.
Tertiary	Eocene	Somerset Limestone (Est)	White Limestone Group	60	Bio-clastic limestone with micritic matrix rich in forams.	Lower White Limestone Aquifer	
Tertiary	Eocene	Swanswick Limestone (Es)	White Limestone Group	90	Bio-clastic limestone in sparry matrix.	Lower White Limestone Aquifer	
Tertiary	Eocene	Troy Claremont Limestone (Etc)	White Limestone Group	460	Well bedded to massive, recrystallised limestones and dolomites.	Lower White Limestone Aquifer	
Tertiary		Yellow Limestone Group		300	Impure limestones calcareous mudstones and sandstones.	Basement Aquiclude	Low permeability rocks which act as the lower stratigraphic limit to ground water movement in the Limestone Aquifer.
Cretaceous		Undifferentiated		3,500	Mudstones, sandstones, tuffs, lavas and volcanic conglomerates.	Basement Aquiclude	

Table C-2 SUMMARY OF AQUIFER TEST DATA FOR WELLS IN THE PEDRO PLAINS* AND LOWER MORASS SUB-CATCHMENTS

No.	Total Drilled Depth (metre)	Tested Aquifer Thickness (metre) 1)	Static Water Level Elevation (metre)	Pump Test Data				Specific Capacity (ℓ/s per metre)	Transmissivity $m^3/s/m$ Method Used		
				Dis-charge (ℓ/s)	Drawdown (metre)				Non-equi-librium Drawdown Curve	Non-equi-librium Recovery Cruve	Step Draw-down
					Pumped Well	Obs. Well No.1 (Distance to Obs. Well)	Obs. Well No.2				
Exp. I	307	61	1.0	74	1.5	0.6 (12.2)	0.7 (24.4)	49.3	5,770	5,960	
Exp. II	113	34	0.6	37	0.9	0.01 (16.5)		41.1	2,980		
Exp. III	309	274 - 335	0.9	16	1.5			10.7	8,690		
Exp. IV	153	23	0.9	58	13.4	0.2 (14.0)		4.3	1,090		
Exp. V	168	30	0.7	68	1.2	0.6 (12.1)		56.7	5,340	5,340	
Exp. VI	184	6	3.2							1,068 5)	
Exp. VIIA	91	9	1.0	71	4.3	0.4 (12.1)	0.1 (38.0)	16.5	9,690	8,690	
Exp. VIIB	91	13	1.0	27	29.0	0.4 (54.9)		0.9	2,980	4,100 4)	
Exp. VIII	277	91	6.1	52	13.1	3.7 (12.1)		4.0	596	397	
Exp. IX	94	94	12.9	63	3.7	0.9 (12.1)		17.0	3,970	4,220	
Luana	76	55	2.4	18	7.6			2.4	6,332	4,187	
Burnt Savanna	30	24	4.3	18	0.3			60.0	200,700	762,600	

1) "Tested Aquifer Thickness" refers to the thickness of the water-bearing white limestone.
2) No calculation possible because of too small or too rapid change in water level during test.
3) Calculated on drawdown data from the observation well.
4) Calculated on recovery data from the pumped well.
5) Well tested by bailing test.
* FAO (1971)

TABLE C-3 SUMMARY OF THE RESULTS OF DETERMINATIONS OF AQUIFER CONSTANTS FOR THE SHALLOW WATER FACIES OF THE WHITE LIMESTONE GROUP - JAMAICA (WHITE 1982)

Organization	Basin	Method	Transmissivity gpd/ft.	Specific Yield
Howard Humphreys & Sons (1972)	Lower Rio Cobre	Aquifer Tests	$2.4 \times 10^3 - 5.0 \times 10^5$	
	Upper Rio Cobre	Aquifer Tests	$2.0 \times 10^4 - 5.0 \times 10^5$	0.08 - 0.02
		Digital Computer	$1.1 \times 10^5 - 3.8 \times 10^5$	0.0022
		Laboratory Technique (Centrifuge)		0.026 - 0.006
		Water Balance		0.028
UNDP (1971)	Pedro Plains	Aquifer Tests	$2.4 \times 10^5 - 7.8 \times 10^5$	0.15 - 0.10
(1974)	Rio Minho	-	-	0.10 - 0.02
(1974)	Lower Rio Cobre	Aquifer Test	$1.0 \times 10^4 - 3.9 \times 10^5$	-
Water Resources Division (1978)	Upper Rio Cobre	Aquifer Test	$1.9 \times 10^3 - 1.9 \times 10^5$	0.05 - 0.01
		Flow Net	$1.3 \times 10^5 - 3.0 \times 10^5$	-
		Water Balance	-	0.03

Table C-4 GROUNDWATER LEVEL ELEVATIONS AT WELLS AND SPRINGS IN THE LIMESTONE AQUIFER LOWER MORASS (JULY 18 to AUGUST 15, 1984)

Field No.	Well Location	Elevation of Datum	Water Level Elevation				Maximum Fluctuation Aug.1-15
			Jul* 18	Aug. 1	Aug. 8	Aug. 15	
1	Aston #1 Well	15.086	1.96	2.16	2.24	2.34	+ 0.18
2	Fullerswood Corehole	1.674		Overflowing		Artesian	
3	Vineyard Well	2.820	-0.30	-0.1	0.06	0.06	+ 0.16
4	Arlington Well	4.217	0.02	-0.1	0.10	0.06	+ 0.11
5	Fullerswood #2 Well	5.122	0.42	0.40	-	0.24	- 0.16
6	Fullerswood #1 Well	5.374	0.67	0.59	-	0.62	+ 0.03
7	Park #1 Well	3.605	0.83	0.80	-	0.93	+ 0.13
8	Park #2 Well	2.313	0.61	0.67	0.79	0.78	+ 0.11
9	Mountainside Well	4.157	0.77	0.77	-	0.79	+ 0.02
10	Islington Well	10.071	-	-	0.86	0.87	+ 0.01
11	Hope River Well	3.446	0.85	0.95	0.93	0.97	+ 0.04
12	Lacovia Corehole	36.139	1.51	1.53	-	1.61	+ 0.08
13	Slipe #2 Well	5.180	0.88	1.05	1.07	1.18	+ 0.13
14	Frenchman #1 Well	3.090	0.89	1.92	-	2.44	+ 0.51
15	Frenchman #2 Well	3.860	0.16	0.59	-	0.88	+ 0.29
16	Middle Quarters #1 Spring	3.460	-	2.33	-	2.45	+ 0.12
17	Middle Quarters #2 Spring	2.716	-	1.92	-	2.01	+ 0.09
18	Middle Quarters #3 Spring	3.264	-	1.78	1.81	1.81	+ 0.03
19	Luana Well	5.171	-	-	-	-	-
20	Vineyard Corehole	1.020	0.01	-	-	0.28	-
21	Burnt Savanna Well	-	-	-	-	-	-
22	Middle Quarters Well	5.259	-	2.14	-	2.23	+ 0.09
23	Slipe #1 Well	5.050	0.78	0.94	-	1.09	+ 0.15

* Decimal point estimated

Table C-5 RESULTS OF WATER QUALITY ANALYSES FOR SPRINGS AND WELLS IN THE LIMESTONE AQUIFER, LOWER MORASS (COLLECTED AUGUST 8, 1984)

No.	Location	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	HCO_3 (ppm)	SO_4 (ppm)	Cl (ppm)	Fe (ppm)	NO3 (ppm)	T.D.S. (ppm)	Hard. Total (ppm)	Alk. Total (ppm)	EC*	pH	T (°C)
1.	Ashton #1 Well	135	22	14	40.6	476	0	38	0.85	0.7	630	430	476	940	7.2	27.0
3.	Vineyard Well	160	42	122	15.8	332	9	390	0.01	2.4	1,190	574	332	1,190	7.4	27.5
4.	Arlington Well	38	18	26	13.0	170	13	49	0.14	3.8	280	170	170	420	7.5	27.0
8.	Park #2 Well	90	17	17	0.41	282	9	36	0.03	2.5	360	296	282	650	7.3	26.7
10.	Islington Well	44	2	4	3.29	120	0	12	1.24	0.3	160	116	120	270	7.2	27.5
11.	Hope River Well	67	2	7	1.55	166	6	16	0.01	10.8	220	176	166	390	7.5	26.0
13.	Slipe #2 Well	76	61	3	1.92	434	11	64	0.13	4.6	550	440	434	970	7.4	26.2
15.	Frenchman #2 Well	78	38	15	1.59	348	13	31	0.21	0.07	400	354	348	720	7.3	26.0
19.	Luana Well	88	11	20	1.11	238	12	47	0.02	9.8	340	262	238	610	7.1	26.2
2.	Fullerswood Corehole	62	47	9	1.72	248	108	8	0.31	0	460	350	248	700	7.4	22.0
21.	Burnt Savanna Well	75	8	7	1.79	204	12	18	0.02	9.8	270	222	204	500	7.5	27.7
18.	Middle Quarters Spring #3	76	7	5	0.44	216	4	11	0.02	3.0	250	220	216	440	7.2	24.5
24.	M.Q. Spring #4	74	6	3	0.39	212	4	10	0.01	7.4	240	212	212	420	7.2	27.0
25.	Broad River Blue Hole	67	10	5	0.46	206	4	13	0.01	4.4	230	208	206	420	7.2	25.0
26.	Sytx River at Culvert	82	7	3	0.26	240	0	9	0.05	3.9	260	236	240	460	7.2	25.0

Remarks: *: micro.mhos/cm

Table C-6 SUMMARY OF RESULTS OF FLOW NET METHOD DETERMINATION OF GROUNDWATER INFLOW INTO THE BLACK RIVER LOWER MORASS

Groundwater Flow-tube	Assumed Transmissivity m^2/d (igpd/ft)	Water table Gradient	Length of Groundwater Contour metre (feet)		Groundwater Inflow		
					m^3/d	m^3/s	migd
Broad River Depression							
Fullerswood	(50,000)	0.002	6,870 (22,550)		10,236	0.12	2.25
Mountainside	7,450 (500,000)	0.003	4,350 (13,940)		94,988	1.10	20.90
Burnt Savanna	745 (50,000)	0.004	3,370 (11,070)		10,043	0.12	2.21
Lacovia	745 (50,000)	0.003	8,250 (27,070)		18,439	0.21	4.06
				Sub-total	133,706	1.55	29.42 (52%)
Middle Quarters Depression							
Luana	745 (50,000)	0.004	6,870 (22,500)		20,473	0.24	4.50
Middle Quarters	7,450 (500,000)	0.002	6,500 (21,300)		96,850	1.12	21.31
Frenchman	745 (50,000)	0.003	3,250 (10,660)		7,264	0.08	1.60
				Sub-total	124,587	1.44	27.41 (48%)
				Total	258,293	2.99	56.83 (100%)

MIGD - million imperial gallons per day.

Table C-7 SELECT DATA ON DEEP WELLS IN THE BLACK RIVER LOWER MORASS

		Burnt Savanna Well	Holland Well	Luana Well
1.	Grid Reference		E 2685 N 4376	E 2527 N 4293
2.	Owner	Parish Council	Holland Estate	National Water Commission
3.	Aquifer	Limestone	Limestone	Limestone
4.	Well Diameter (cm)	25	33	30
5.	Well Depth (m)	30	61	76
6.	Static Water Level (Elevation in metres)	1.0*	2.5	2.7**
7.	Pumping Water Level (Elevation in metres)	0.7*	-	-4.8**
8.	Discharge (l/s)	17.0	-	17.0
9.	Maximum Recorded Chloride Content (mg/l)	15*	17	43*

* August, 1982

** August, 1984

Table C-8 PROPOSED INVESTIGATION OF POST PROJECT GROUND WATER INFLOW

I. Wells and Facilities for Investigation:

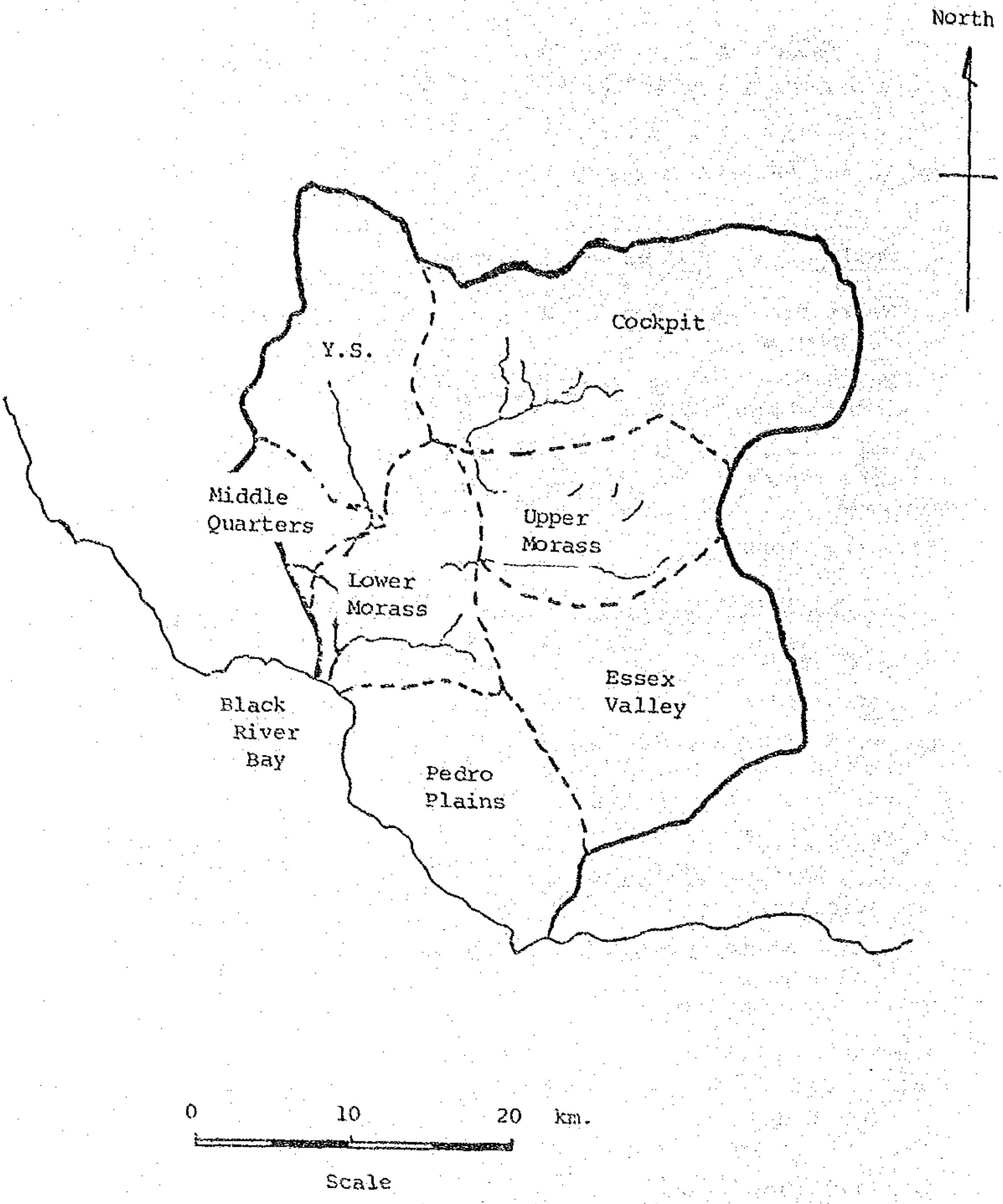
Wells	Nos.	Dimension	Installed Facilities
a. Wells for Pumping up	2	ø250 mm, 20 m	automatic water gauge
b. Wells for observation	3	ø150 mm, 15 m	automatic water gauge
c. Wells for observation	10	ø50 mm, 15 m	

II. Investigations:

Investigation	Nos. of Points and Times
a. Pumping up test	2 points continuously
b. Water quality test	2 points continuously
c. Overall observation (Water level, Temperature, pH, Electric conductivity, etc.)	30 points, 6 times (including other wells installed)
d. Water level	5 points continuously
e. Data collecting beside the investigations	Continuously
f. Data processing and computer model simulation	

III. Schedule

Investigation	2nd Year				3rd Year			
I. digging wells and installing facilities		━━	━━					
II. a				━━	━━	━━	━━	
b				━━	━━	━━	━━	
c				o o	o	o o	o	
d				━━	━━	━━	━━	
e		━━	━━	━━	━━	━━	━━	
f							━━	━━



BLACK RIVER LOWER MORASS
AGRICULTURAL DEVELOPMENT PROJECT

Fig.C-1 POSITION OF THE LOWER MORASS WITHIN THE BLACK RIVER BASIN

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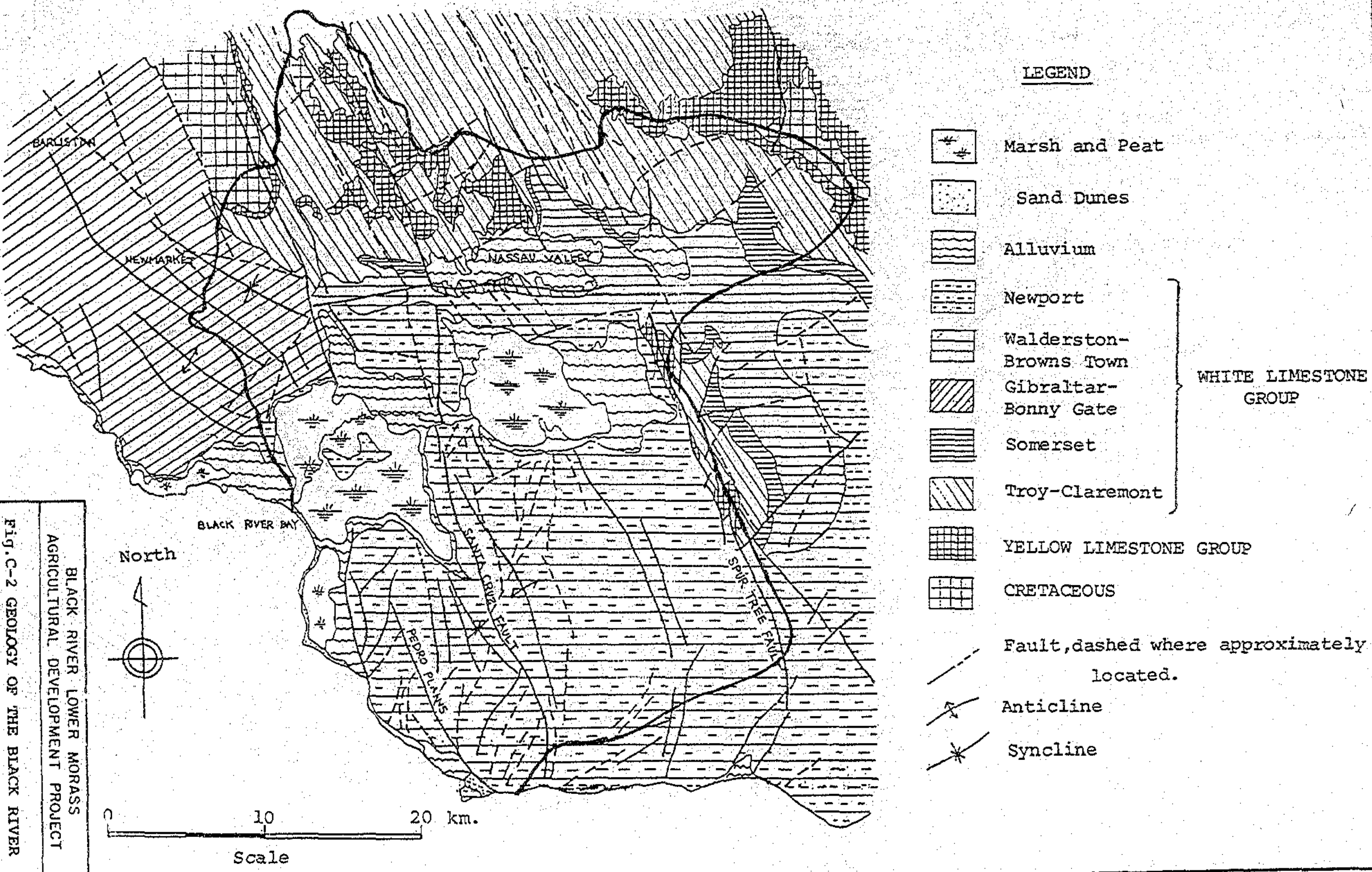

BLACK RIVER LOWER MORASS
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Fig.C-2 GEOLOGY OF THE BLACK RIVER BASIN

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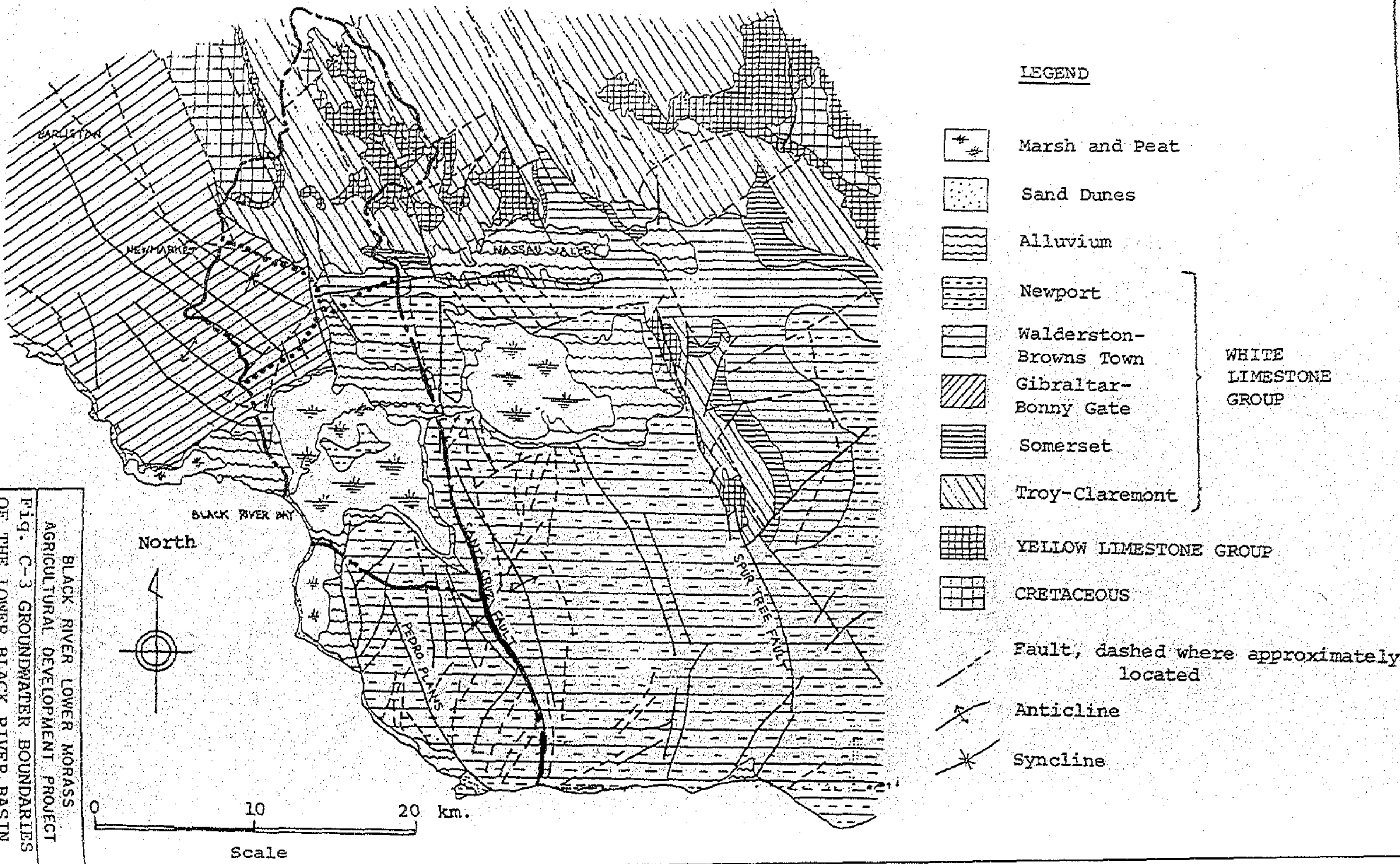

BLACK RIVER LOWER MORASS
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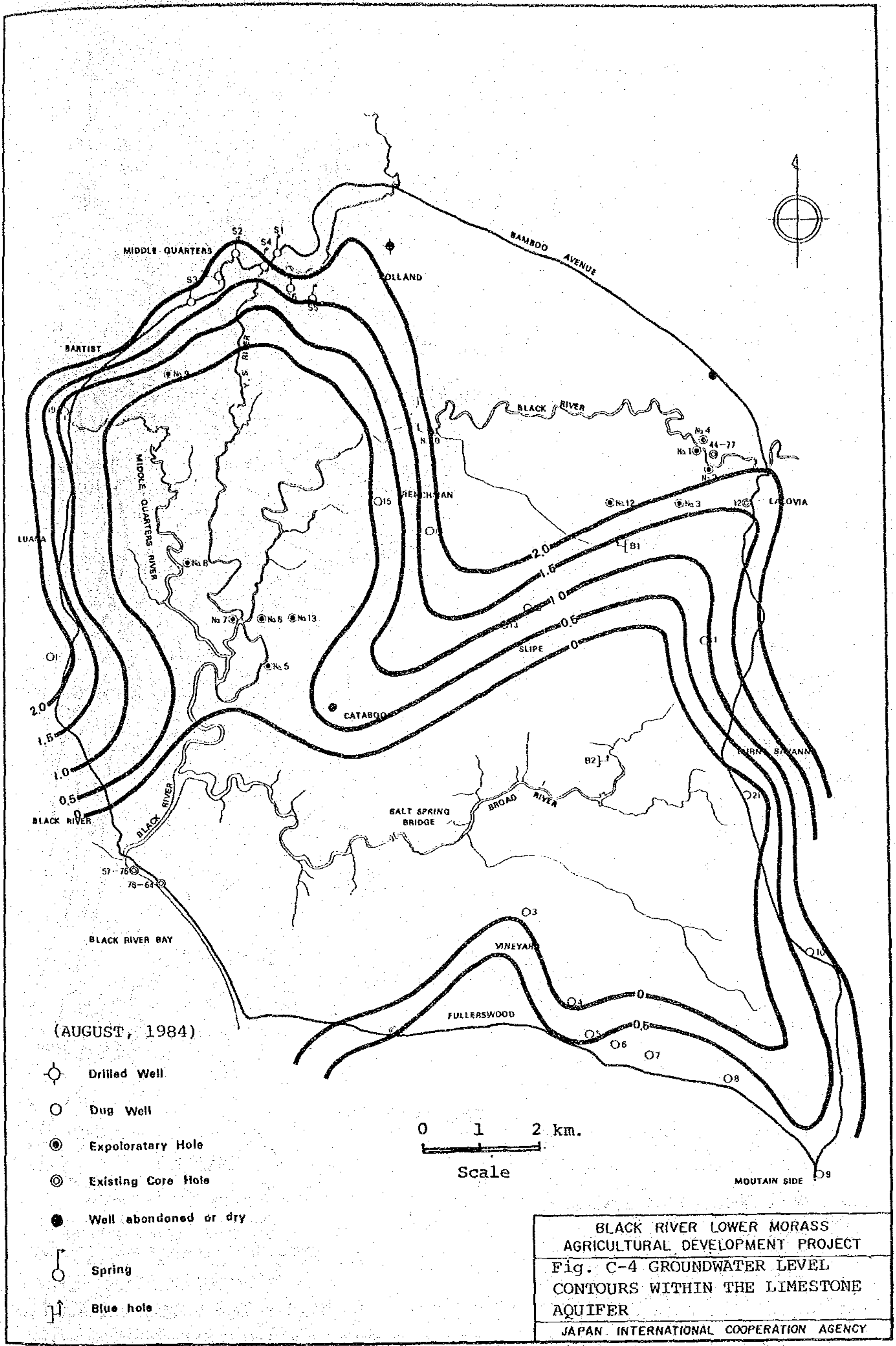
Fig. C-3 GROUNDWATER BOUNDARIES OF THE LOWER BLACK RIVER BASIN AND ITS SUB-CATCHMENTS

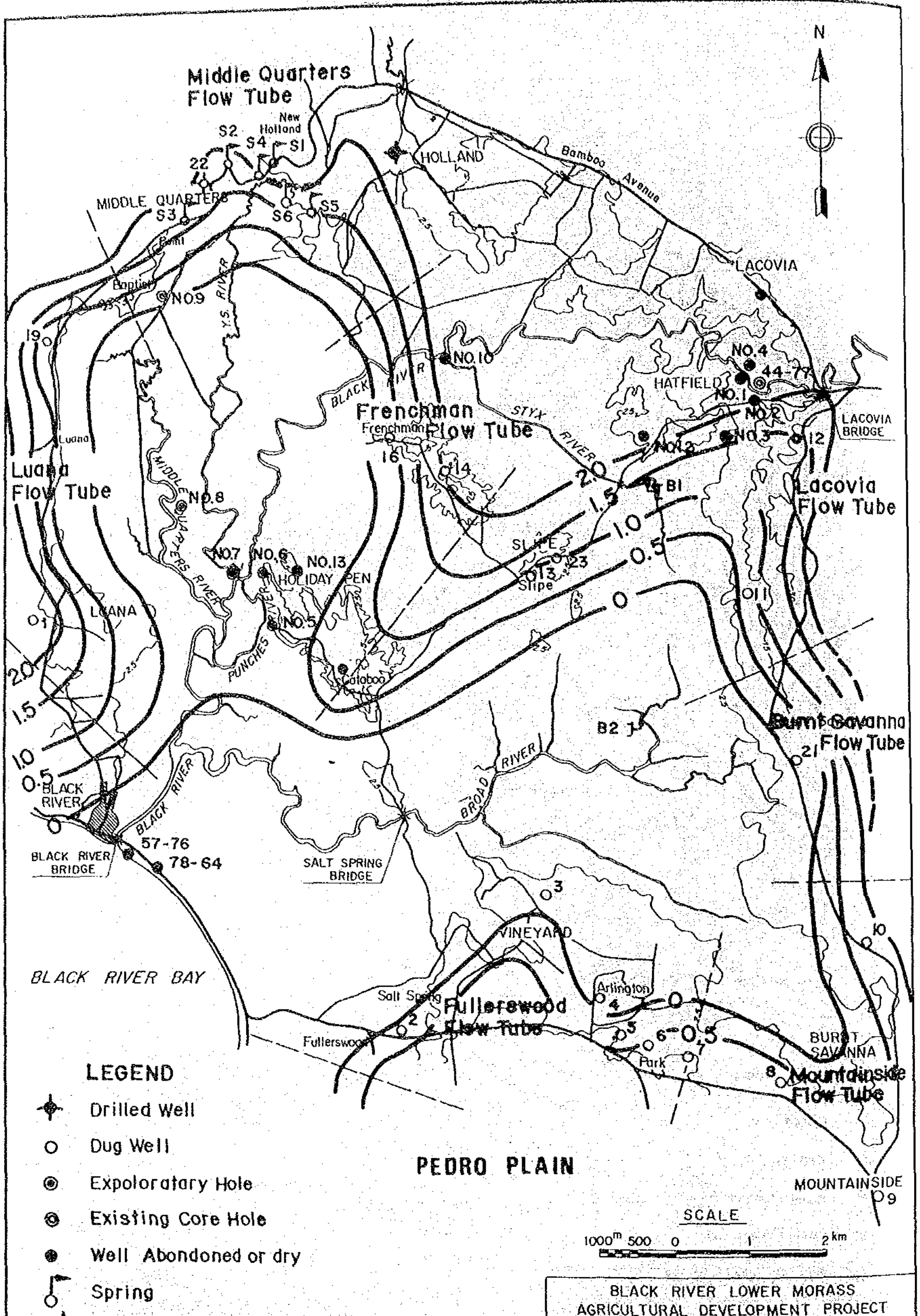
JAPAN INTERNATIONAL COOPERATION AGENCY



BLACK RIVER LOWER MORASS AGRICULTURAL DEVELOPMENT PROJECT

Fig. C-4 GROUNDWATER LEVEL CONTOURS WITHIN THE LIMESTONE AQUIFER

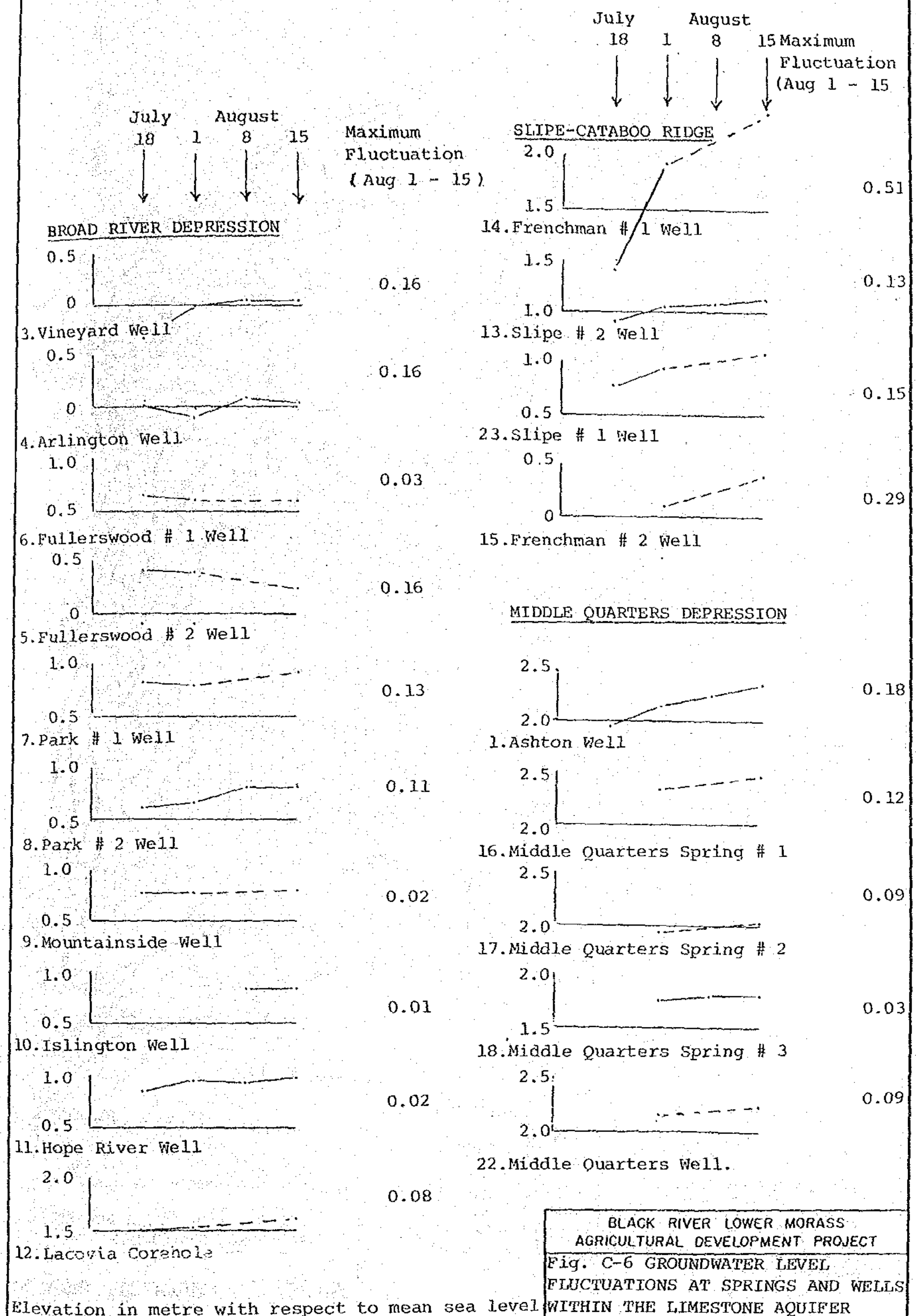
JAPAN INTERNATIONAL COOPERATION AGENCY



BLACK RIVER LOWER MORASS AGRICULTURAL DEVELOPMENT PROJECT

Fig. C-5 GROUNDWATER FLOW-TUBES IN THE LIMESTONE AQUIFER

JAPAN INTERNATIONAL COOPERATION AGENCY



BLACK RIVER LOWER MORASS AGRICULTURAL DEVELOPMENT PROJECT

Fig. C-6 GROUNDWATER LEVEL FLUCTUATIONS AT SPRINGS AND WELLS WITHIN THE LIMESTONE AQUIFER

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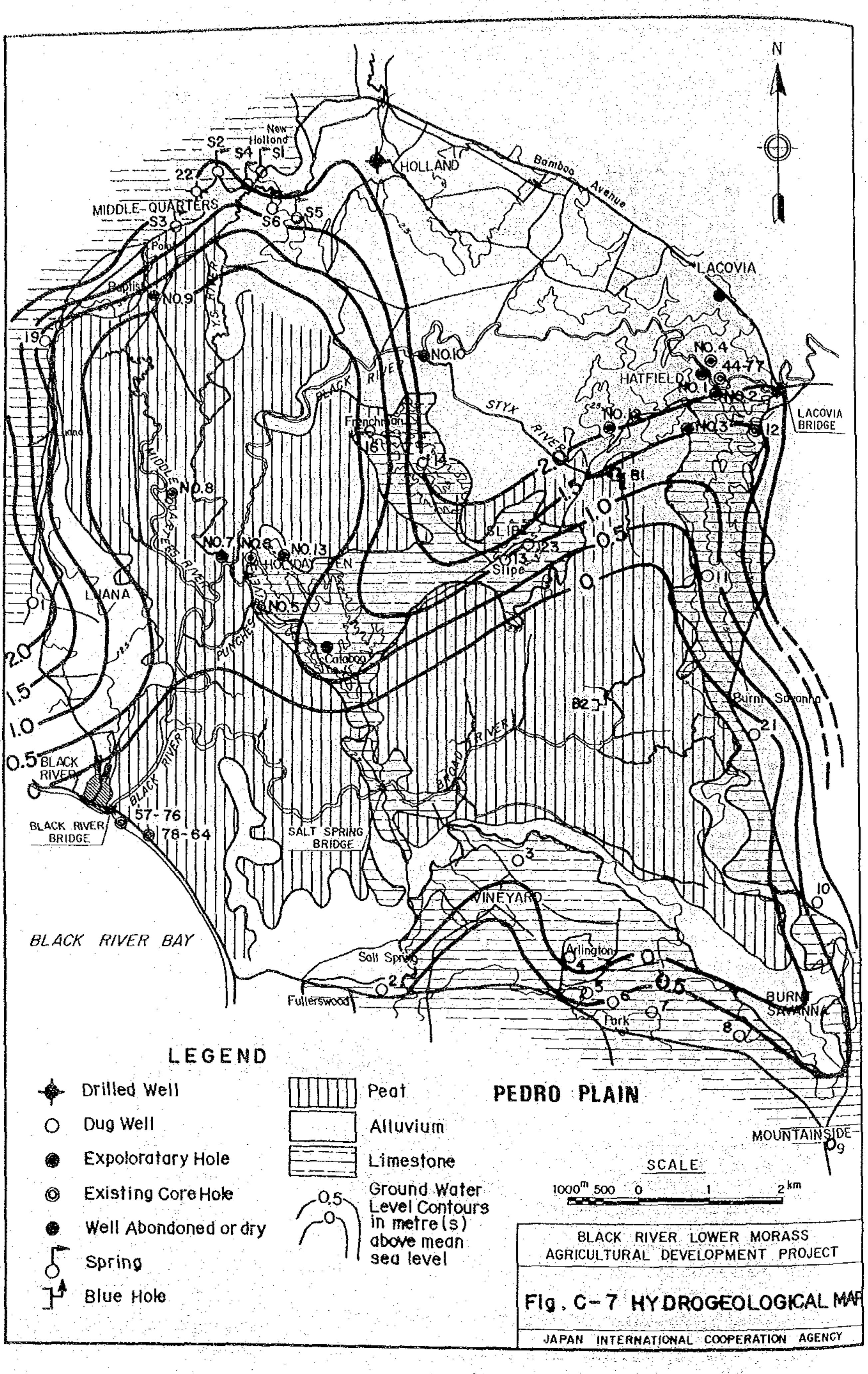

N
New Holland
S2
S4
S1
22
HOLLAND
Bamboo Avenue
MIDDLE-QUARTERS
S3
S6
S5
LACOVIA
NO.9
19
NO.10
NO.4
44-77
HATFIELD
NO.1
NO.2
LACOVIA BRIDGE
BLACK RIVER
STYX RIVER
NO.18
NO.3
12
Frenchman
16
14
NO.8
B1
2.0
1.5
1.0
0.5
NO.7
NO.6
NO.13
HOLIDAY PEN
23
Slipe
0
11
LUANA
NO.5
Cataboo
B2
Burnt Savanna
21
2.0
1.5
1.0
0.5
BLACK RIVER
BLACK RIVER
BROAD RIVER
BLACK RIVER BRIDGE
57-76
78-64
SALT SPRING BRIDGE
3
VINEYARD
10
BLACK RIVER BAY
Arlington
Salt Spring
2
Fullerswood
5
6
7
Park
8
BURNT SAVANNA
LEGEND
Drilled Well
Dug Well
Expoloratary Hole
Existing Core Hole
Well Abondoned or dry
Spring
Blue Hole
Peat
Alluvium
Limestone
Ground Water Level Contours in metre(s) above mean sea level
0.5
0
PEDRO PLAIN
MOUNTAINSIDE
9
SCALE
1000m 500 0 1 2 km
BLACK RIVER LOWER MORASS AGRICULTURAL DEVELOPMENT PROJECT
Fig. C-7 HYDROGEOLOGICAL MAP
JAPAN INTERNATIONAL COOPERATION AGENCY

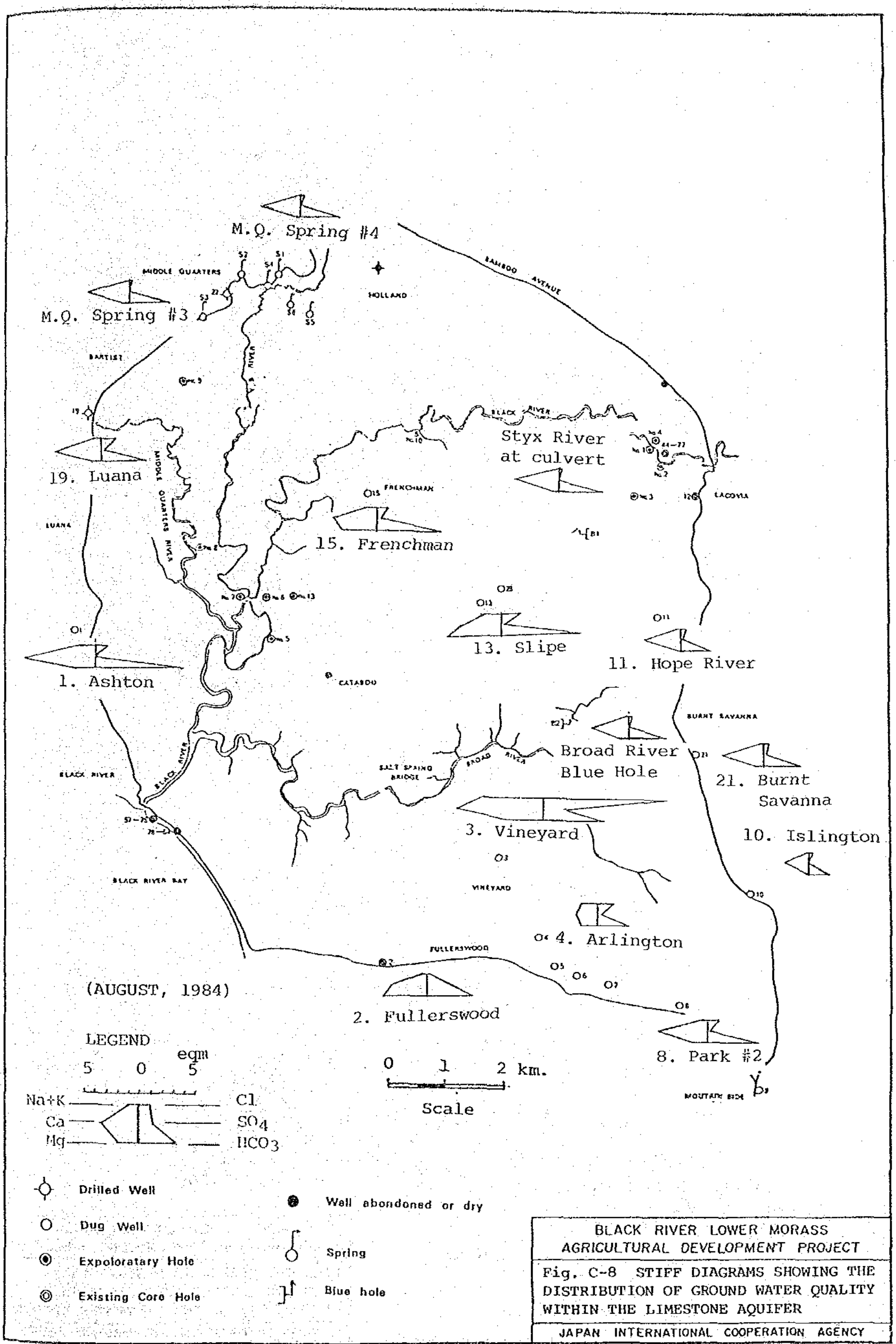
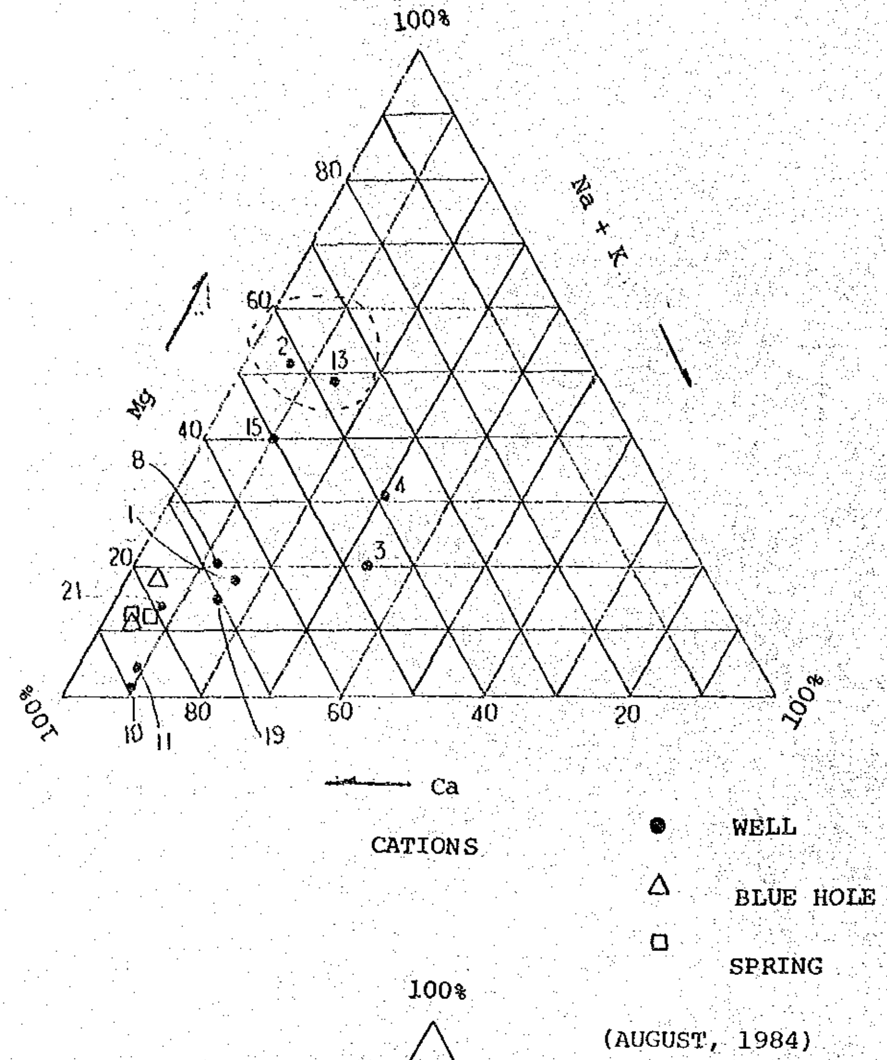
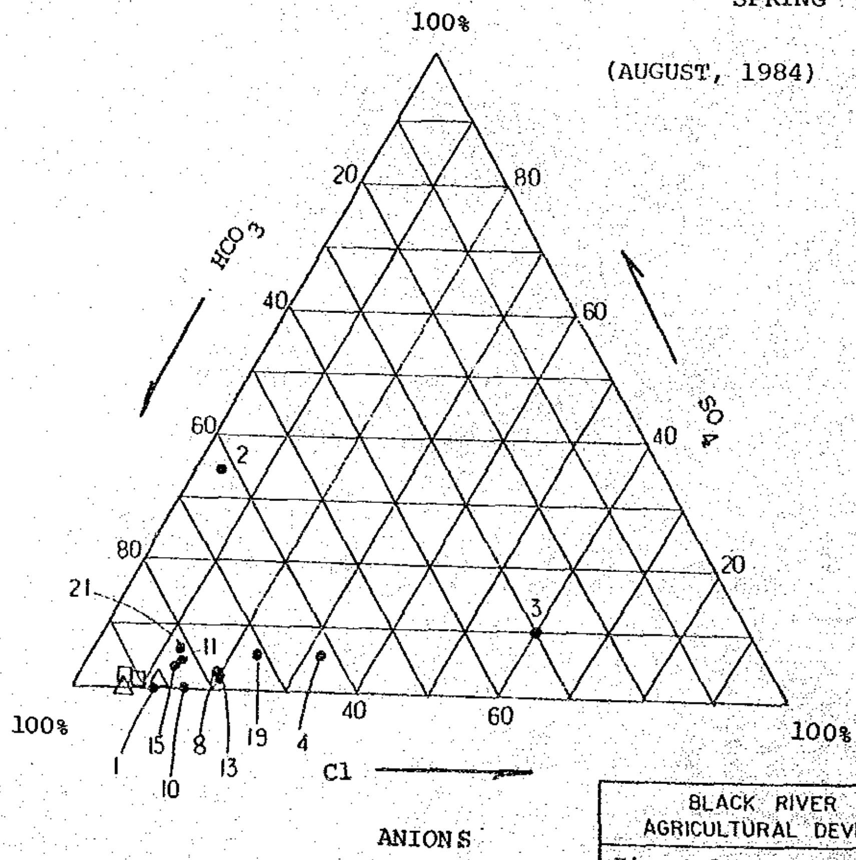


Fig. C-8 STIFF DIAGRAMS SHOWING THE DISTRIBUTION OF GROUND WATER QUALITY WITHIN THE LIMESTONE AQUIFER





BLACK RIVER LOWER MORASS
AGRICULTURAL DEVELOPMENT PROJECT

Fig. C-9 TRILINEAR DISTRIBUTIONS OF MAJOR CATIONS AND ANIONS IN GROUNDWATER OF THE LIMESTONE AQUIFER

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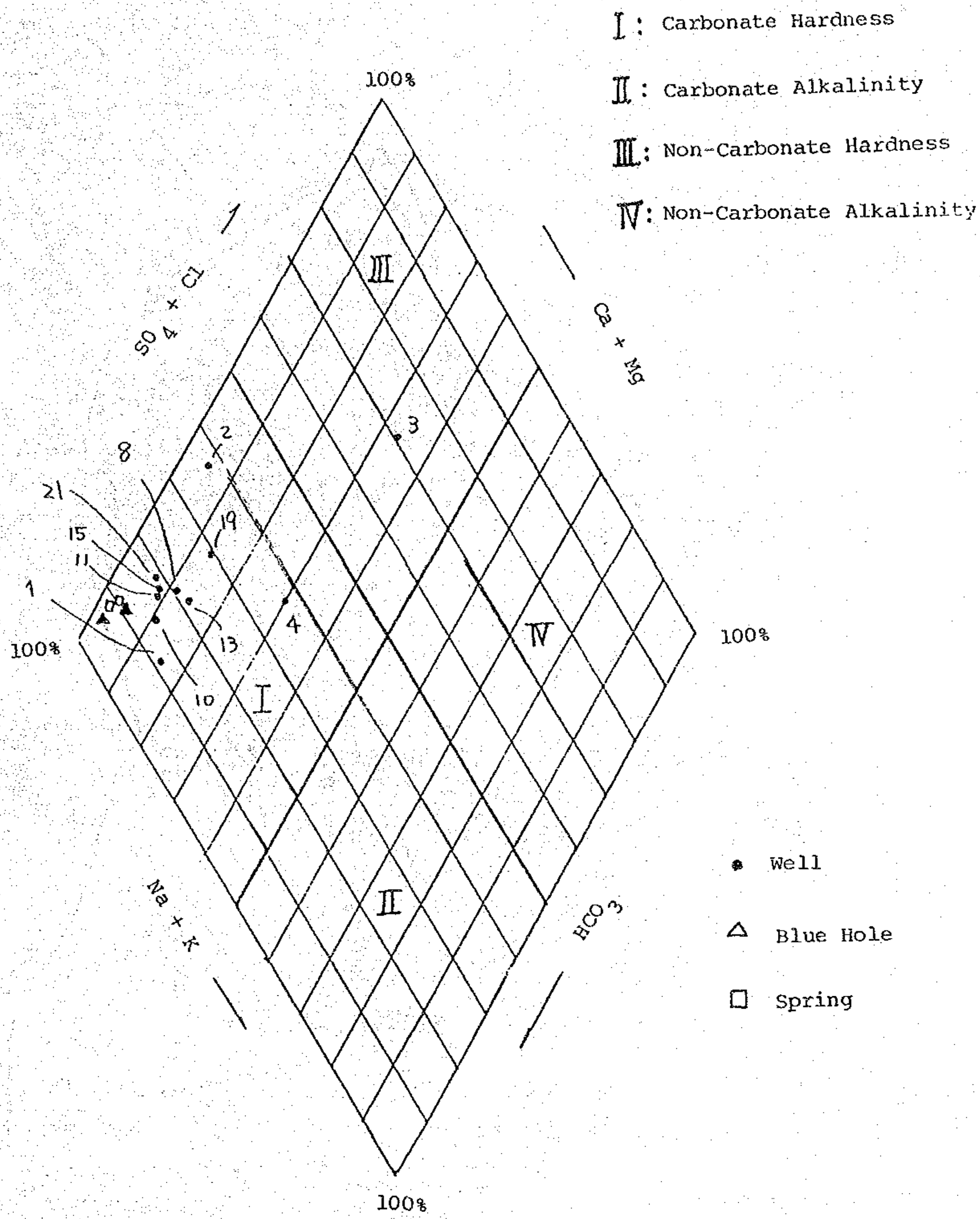

BLACK RIVER LOWER MORASS AGRICULTURAL DEVELOPMENT PROJECT

Fig.C-10 WATER QUALITY CLASSIFICATION OF GROUND WATERS OF THE LIMESTONE AQUIFER

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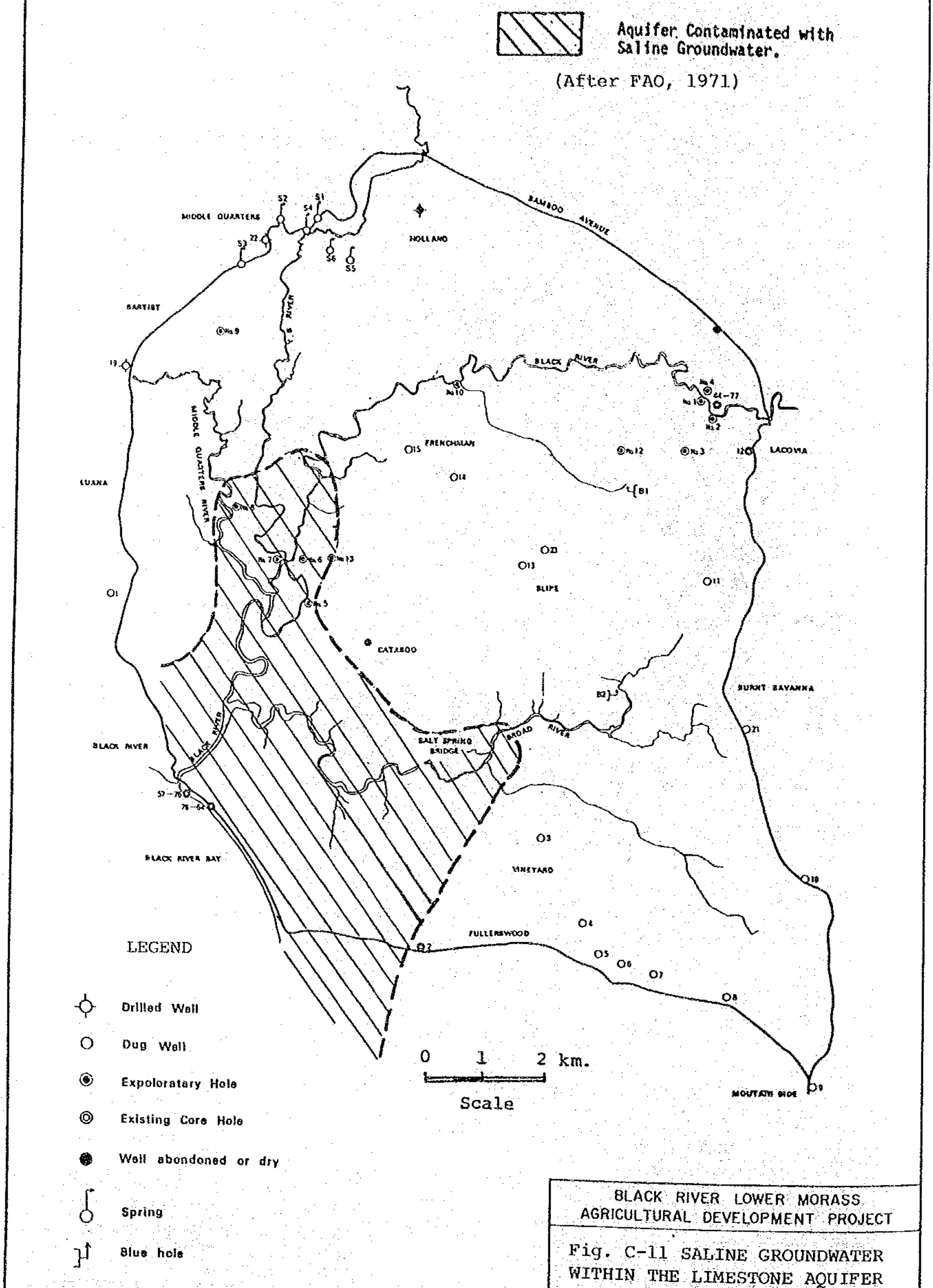

BLACK RIVER LOWER MORASS AGRICULTURAL DEVELOPMENT PROJECT

Fig. C-11 SALINE GROUNDWATER WITHIN THE LIMESTONE AQUIFER

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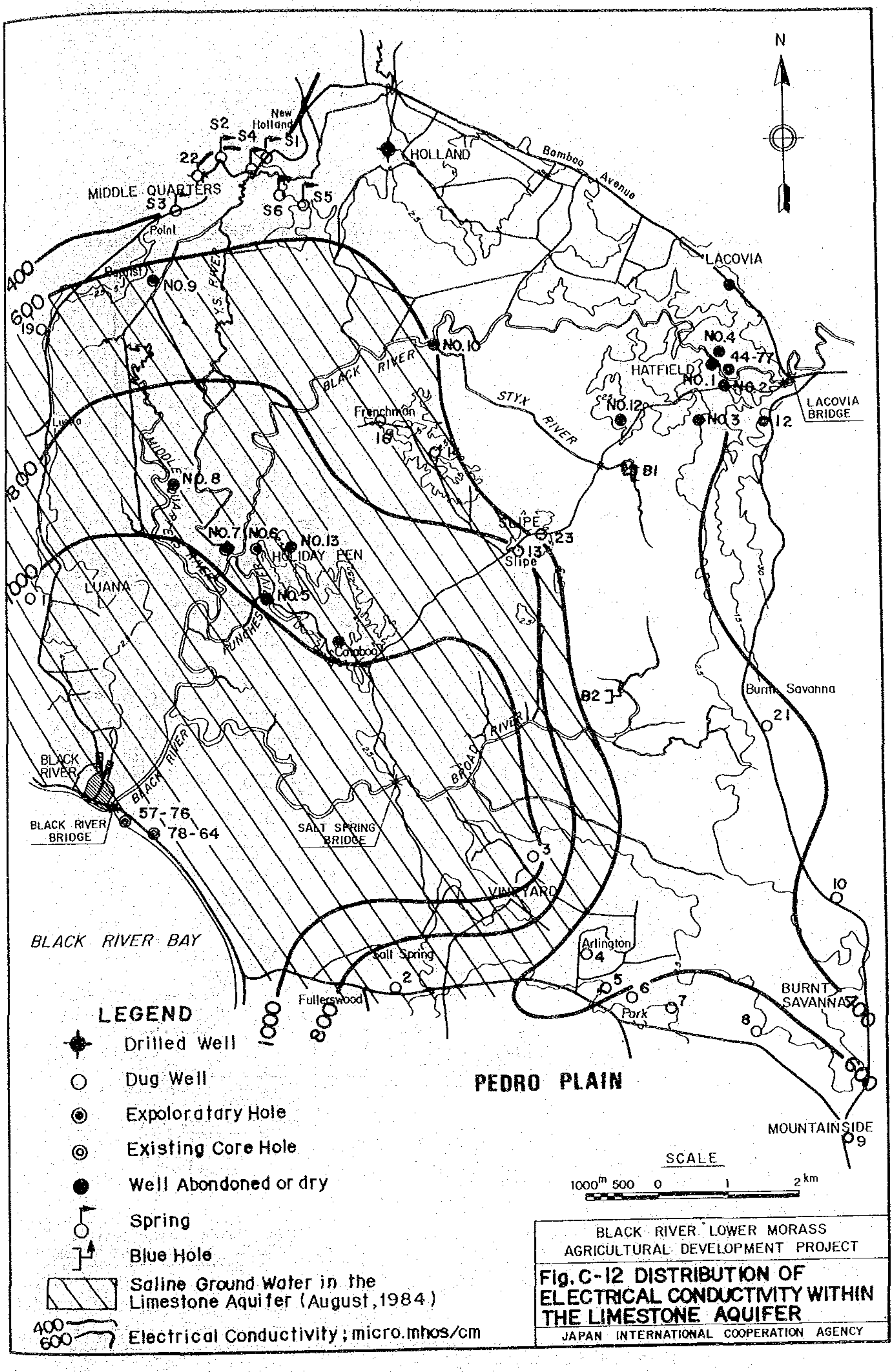
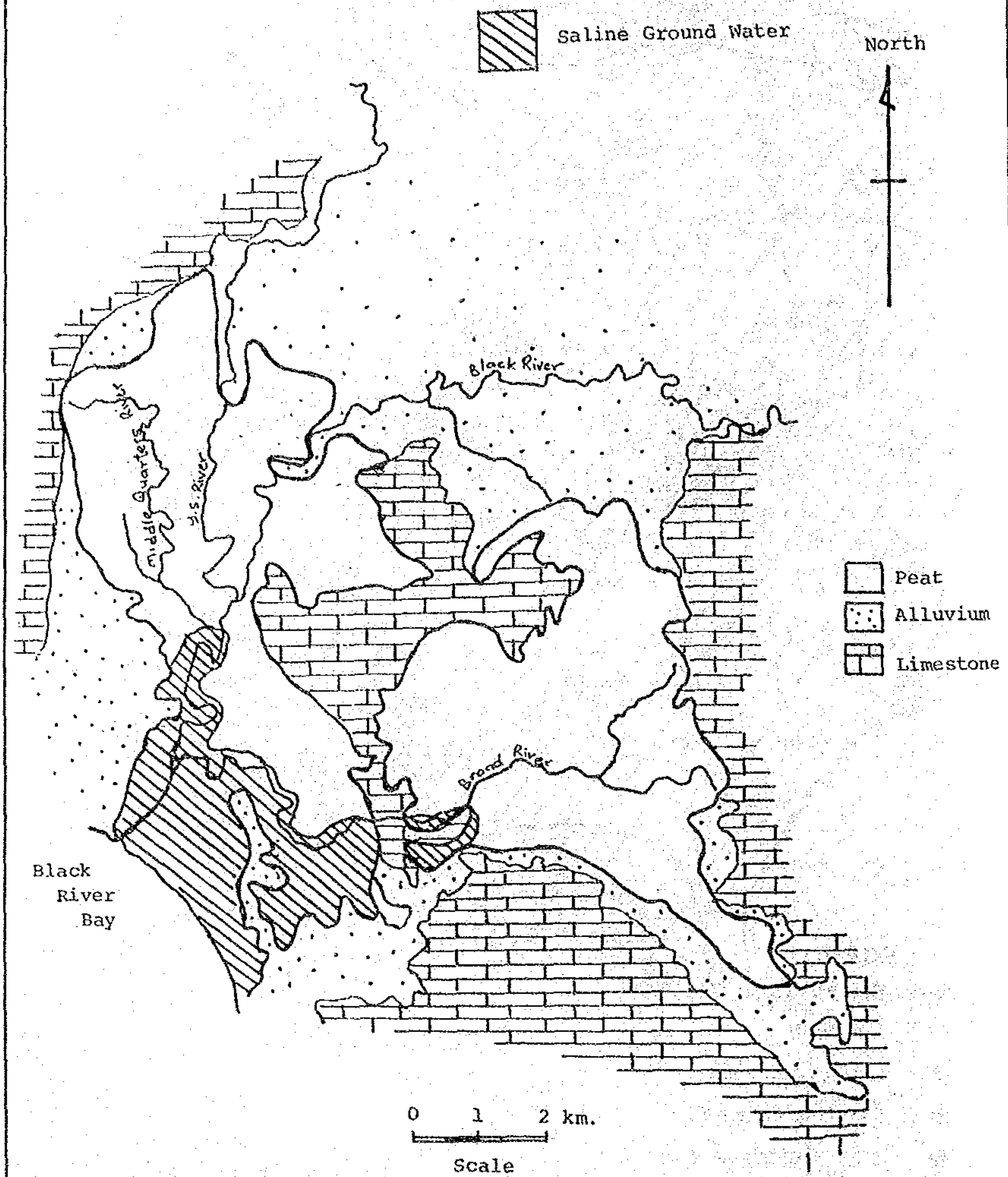


N
New Holland
S1
S2
S4
S3
S5
S6
22
MIDDLE QUARTERS
Point
HOLLAND
Bamboo Avenue
LACOVIA
NO.9
NO.10
NO.4
44-77
HATFIELD
NO.1
NO.2
LACOVIA BRIDGE
NO.12
NO.3
12
BLACK RIVER
STYX RIVER
Y.S. RIVER
Frenchman
MIDDLE QUARTERS RIVER
NO.8
NO.7
NO.6
NO.13
HOLIDAY PEN
SLIPE
23
13
Slipe
B1
LUANA
NO.5
PUNCHES RIVER
Caraboo
B2
Burnt Savanna
21
BROAD RIVER
BLACK RIVER
BLACK RIVER BRIDGE
57-76
78-64
SALT SPRING BRIDGE
3
VINEYARD
10
BLACK RIVER BAY
Arlington
4
Salt Spring
2
5
6
7
Park
8
BURNT SAVANNA
Fullerswood
PEDRO PLAIN
MOUNTAINSIDE
9
400
600
800
1000
19
1
SCALE
1000m 500 0 1 2 km
LEGEND
Drilled Well
Dug Well
Expoloratory Hole
Existing Core Hole
Well Abondoned or dry
Spring
Blue Hole
Saline Ground Water in the Limestone Aquifer (August, 1984)
Electrical Conductivity ; micro.mhos/cm
BLACK RIVER LOWER MORASS AGRICULTURAL DEVELOPMENT PROJECT
Fig. C-12 DISTRIBUTION OF ELECTRICAL CONDUCTIVITY WITHIN THE LIMESTONE AQUIFER
JAPAN INTERNATIONAL COOPERATION AGENCY



BLACK RIVER LOWER MORASS
AGRICULTURAL DEVELOPMENT PROJECT

Fig.C-13 ASSUMED EXTENT OF SALINE CONTAMINATION OF THE PEAT AQUIFER

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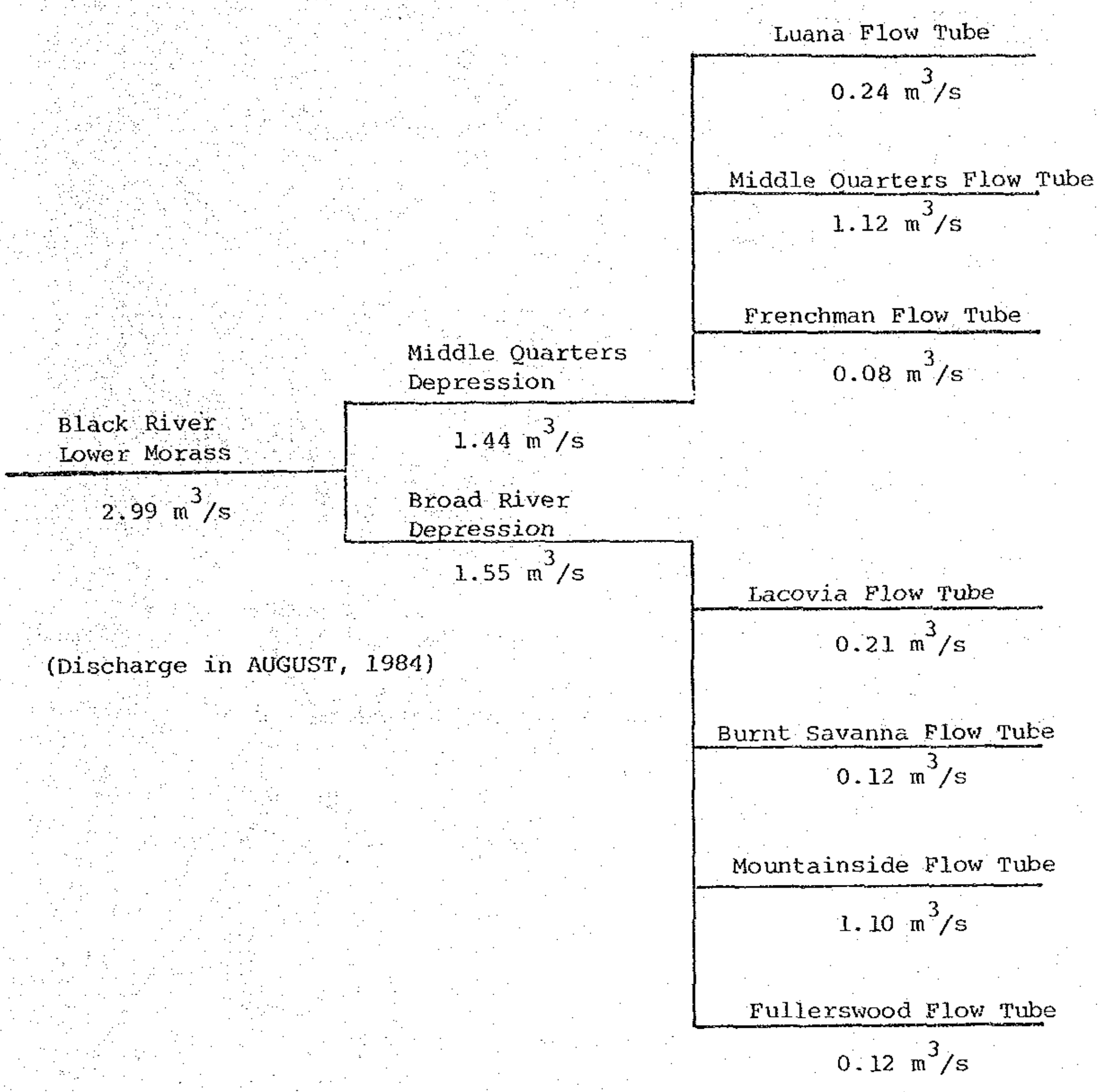
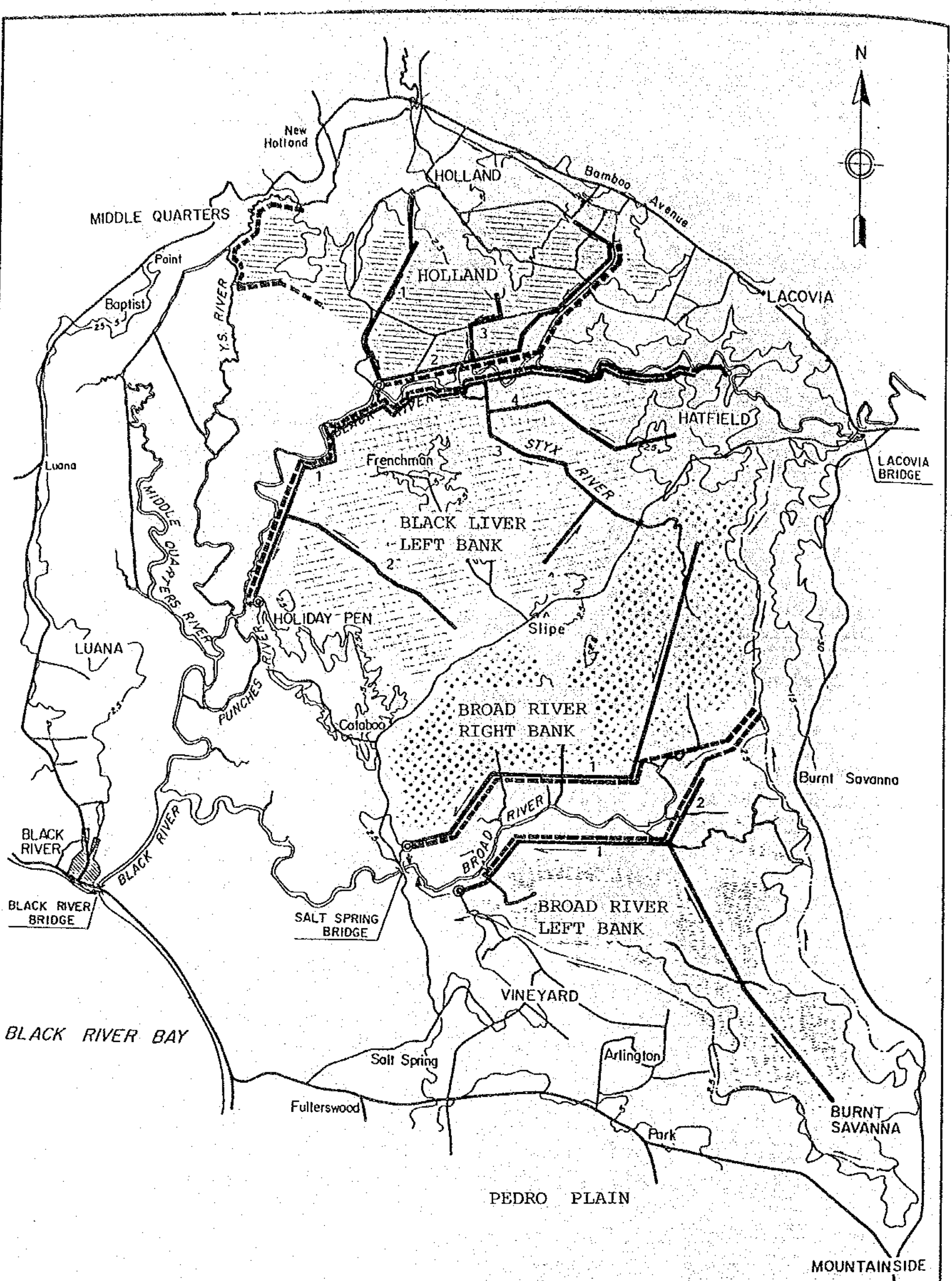


BLACK RIVER LOWER MORASS AGRICULTURAL DEVELOPMENT PROJECT

Fig. C-14 GROUNDWATER INFLOW INTO THE LOWER MORASS FROM THE LIMESTONE AQUIFER

JAPAN INTERNATIONAL COOPERATION AGENCY



LEGEND

- Dike
- Main Drainage Canal
- Catch Drain
- Main Drainage Pump Station
- 2 Main Drainage Canal Number

SCALE

1000 m 500 0 1 2 km

BLACK RIVER LOWER MORASS AGRICULTURAL DEVELOPMENT PROJECT

Fig.C-15 LOCATION OF THE PROPOSED DEVELOPMENT AREAS AND ASSOCIATED FLOOD CONTROL AND DRAINAGE STRUCTURES

JAPAN INTERNATIONAL COOPERATION AGENCY

ANNEX D

SOILS AND LAND CAPABILITY CLASSIFICATION

ANNEX D

SOILS AND LAND CAPABILITY CLASSIFICATION

TABLE OF CONTENTS

Page

1. SOILS D-1

1.1 Introduction D-1

1.2 General Condition of Soil and Land D-1

1.3 Soil Survey Method D-3

1.3.1 Upland area survey D-3

1.3.2 Inundated area survey D-4

1.4 Soil Classification D-5

1.4.1 Basic consideration for classification D-5

1.4.2 Soil classes D-7

1.5 Soil Series Description D-8

1.5.1 General description D-8

1.5.2 Description of individual soil series D-9

1.6 Chemical Properties of Major Soils D-27

1.6.1 Method of soils analysis D-27

1.6.2 Identification of clay mineral composition D-27

1.6.3 Physical properties of soils D-28

1.6.4 Chemical properties of soils D-29

1.6.5 Chemical deficiency of soils in the study area . D-34

1.7 Soil Mapping Unit D-36

2. LAND CAPABILITY CLASSIFICATION D-37

2.1 Basic Consideration on Land Classification D-37

2.2 Criteria of Land Classification D-40

2.3 Land Capability Classification D-41

2.3.1 *Land capability of soil groups by parent materials* D-41

2.3.2 Land capability for rice culture D-42

2.3.3 Land capability for upland crops D-43

2.3.4 *Land capability for specific crops* D-43

2.4 Demarcation of Potential Arable Land D-44

REFERENCES D-46

LIST OF TABLES

		Page
Table D-1	EVALUATION OF THE PEAT DECOMPOSITION	D-47
Table D-2	SOIL CLASSIFICATION IN THE PROJECT AREA BY SOIL TAXONOMY	D-48
Table D-3	LEGEND FOR THE UPLAND SOILS ON THE PROJECT AREA	D-49
Table D-4	IDENTIFICATION OF THE CLAY MINERAL COMPOSITION ...	D-50
Table D-5	WATER RETAINTIVITY OF UPLAND SOILS	D-51
Table D-6	FIBRIC MATERIALS IN UNDISTURBED PEAT SOILS OF SURFACE LAYER	D-52
Table D-7	PEAT COMPOSITION OF SUB-SURFACE LAYER	D-53
Table D-8	CHEMICAL PROPERTIES OF MINERAL SOILS COLLECTED FROM OPEN PITS	D-54
Table D-9	CHEMICAL PROPERTIES OF UPLAND SOILS	D-55
Table D-10	CHEMICAL PROPERTIES OF PEAT SOILS ON THE BASE LINES	D-57
Table D-11	CHEMICAL PROPERTIES OF INUNDATED SOILS	D-59
Table D-12	MINOR ELEMENTS AND BASES OF PEAT SOILS	D-61
Table D-13	CHEMICAL DEFICIENCY OF SOILS IN THE PROJECT AREA ..	D-62
Table D-14	CORRELATION OF MAP UNIT ON SOIL MAP AND JAMAICAN MAP SYMBOL	D-63
Table D-15	TOTAL HECTARE OF EACH MAP UNIT	D-64
Table D-16	CRITERIA FOR RATING OF LAND FACTORS	D-65
Table D-17	TERM OF LAND CLASSIFICATION AND THEIR SPECIFIC DEGREE FOR RICE CULTURE	D-66
Table D-18	LAND SUITABILITY SPECIFICATION FOR JAMAICA - (GENERAL FOR ALL LOCALLY GROWN CROPS EXCLUDING RICE)	D-67
Table D-19	LAND CAPABILITY OF SOIL UNITS	D-68
Table D-20	DISTRIBUTION OF LAND CAPABILITY	D-69
Table D-21	LAND CLASSIFICATION FOR SPECIFIC CROPS IN PROJECT AREA	D-71
Table D-22	DISTRIBUTION OF SOIL UNITS IN PROJECT AREA	D-72
Table D-23	DISTRIBUTION OF LAND CAPABILITY CLASSES FOR RICE CULTURE IN PROJECT AREA	D-73
Table D-24	DISTRIBUTION OF LAND CAPABILITY CLASSES FOR UPLAND CROPS IN PROJECT AREA	D-73

LIST OF FIGURES

Page

Fig. D-1 LANDSCAPE OF LOWER MORASS D-74

Fig. D-2 SOIL SURVEY SITES IN THE PROJECT AREA D-75

Fig. D-3 SOIL PROFILE (OPEN PIT) DIAGRAM IN UPLAND AREA D-76

Fig. D-4 SOIL COLUMN DIAGRAM IN UPLAND AREA D-77

Fig. D-5 SOIL PROFILE DIAGRAM OF PEAT SOILS D-78

Fig. D-6 SOIL COLUMN DIAGRAM IN INUNDATED AREA D-83

Fig. D-7 X-RAY DIFFRACTION PATTERNS D-85

Fig. D-8 CLAY MINERAL COMPOSITION OF TYPICAL SOILS IN THE PROJECT AREA D-86

Fig. D-9 SOIL THREE PHASES IN UPLAND AREA D-87

Fig. D-10 CHEMICAL PROPERTIES OF MINERAL SOILS D-88

Fig. D-11 CHEMICAL PROPERTIES OF PEAT SOILS D-89

Fig. D-12 SOIL MAP D-90

Fig. D-13 LAND CAPABILITY MAP FOR RICE CULTURE D-91

Fig. D-14 LAND CAPABILITY MAP FOR UPLAND CROPS D-92

ANNEX D

SOILS AND LAND CAPABILITY CLASSIFICATION

1. SOILS

1.1 Introduction

Soil survey and land classification was introduced into Jamaica with the Publication of a Technical Guide Sheet for the main soil types in the island in 1955. The soil survey was followed in the late 50's by a National Soil Survey conducted by the Soil Survey and Research Section of the Regional Research Center, Imperial College of Tropical Agriculture, Trinidad, W.I. Soil Survey in the parish of St. Elizabeth were carried out during the period from 1958 to 1961 by the Regional Research Center and updated in 1982 by the Comprehensive Resource Inventory and Evaluation System (hereinafter called "CRIES") Project. Soil classification in the Project was made in accordance with the Soil Taxonomy which was defined by Soil Survey Staff of USDA and soil types in Jamaica were recognized to be approximately 350 soil series in the Project.

The extensive swamp or morass area which occupies about one third of the parish of St. Elizabeth was surveyed by the Government of the Netherland in view of reclamation in 1964. On the other hand, in order to determine the extent of peat reserves in the Lower Morass of the Black River Basin, the peat survey was carried out by the Petroleum Corporation of Jamaica during the period from 1979 to 1981. Reconnaissance soil survey by Japan International Cooperation Agency (hereinafter called "JICA") Team was carried out in the Lower Morass and its immediate upland districts during February to March 1984. Furthermore, semidetailed soil survey was continuously carried out during June to October, 1984.

As mentioned above, various peat surveys in the Lower Morass were carried out, however, it is considered that peat survey from a view point of the soil formation is not enough, especially on the peat decomposition.

1.2 General Conditions of Soils and Land

The project area covers approximately about 11,450 ha of upland and inundated areas including marsh physiographic conditions. The inundated area of the project could be physiographically classified into two (2) main basins, South Eastern and North Western, which are separated by a low ridge of upland with limestone outcrops. Within the North Western basin are a number of smaller basins separated by a few low ridges.

Geomorphological characteristics in the study area are as shown in Fig. D-1. The project area is a basin which is surrounded by the Santa Cruz and Lacovia Mountains. Elements of geomorphological features in the upland area can be as follows:

1. Sloping plain which exposed limestone outcrops in the Mountainside district which is used mainly for pasture and residential section
2. Undulating plain with exposed limestone bedrocks in Vineyard district which is used mainly as pasture
3. Undulating plain with low limestone hills in Cataboo district which is used mainly as pasture land
4. Undulating alluvial plain with low limestone hills in Slipe district which is used mainly as pasture land and residential section
5. Undulating deep alluvial plain in Holland district which is mainly used for growing of sugar cane,
6. Undulating alluvial plain in Luana district which is used mainly as pasture land,
7. Rolling alluvial plain in Hatfield which is used mainly as pasture land and natural forest.

The basin of the Lower Morass is characteristically of a Newport Limestone base with various depths of clay overlain by varying thickness of peat formation. Fig. D-1 also indicates a negative relationship between the clay and peat deposits, that is, the thicker the peat the thinner the level of clay deposit and vice versa. The nutritional status of such mineral deposits is reduced by constant uptake by the morass vegetations.

Peat thickness along the Black River is deeper than that of the Broad River and surfaces of the exposed limestone of the basin shows very irregular roughness while the depth of soil varies widely from place to place.

Various soil formations are identified on the limestone bedrocks of the Lower Morass basin, which comprise alluvial and limestone mineral soils, clayey peat and peat. The alluvial sediments are found in the North Western basin, which had been transported into the project area particularly by the Black and Y.S. Rivers which flow from areas of Cretaceous volcanic rocks in the upper parts of the drainage basin. The alluvial soils of various ages are found mainly along the Y.S. River. Mineral sediments transported by these rivers are also deposited further down stream mixing with peats.

The geology and lithology of the above mentioned formation could therefore be classified into recent and old allivial soils. Peat formation in the lower basin had been started at the end of the glacial epoch and it is considered that peat thickness is being increased according to heightening of the sea water level.

1.3 Soil Survey Method

1.3.1 Upland area survey

The survey are carried out through a program of field operation comprising exhaustive examination of soils and their environment in the survey sites decided and based on the interpretation of aerial photographs of 1/50,000 scales, 1980 and topographic map 1/10,000 scales. Field survey method and descriptive terms used have been those given in the USDA. Soil Survey Manual and in the F.A.O. Guideline for the Soil Profile Description.

Soil survey procedures are carried out in accordance with the free method, in which the soil surveyor uses his judgement in siting soil observations in relation to land form and other environmental features. The sites of soil survey based on a number of parallel traverses are laid down 100 to 200 meters apart so as to examine the major landscape units differentiated by study of the aerial photos and the topographic maps. Total number of auger boring observations are one hundred and fifty (150), corresponding to one site in every thirty (30) hectares. Typical soil profiles are described from open pits supplemented by the spot identification from auger holes. Soil Samples for laboratory analysis are taken from typical profile of each soil series. Soil survey points in the project area are shown in Fig. D-2.

The main soil unit recognized in the field is the soil series. For convenience of use of soil series, names used have been those given in the "so called green book," (1963) and Jamaican Resource Assessment, (1982). Where the land and soil pattern are so intricate that the soil change at very close intervals, such unit is mapped as a soil complex. The boundaries of individual soil series are transferred on the topographic map of 1/10,000 scale.

1.3.2 Inundated area survey

The peat soil survey in the inundated area is also carried out on the survey lines and spots as shown in Fig. D-2. The soils of the survey lines are examined by peat auger boring, usually as interval of 100 meters. Important items of peat survey are the degree of peat decomposition by the Post Method, peat colour and peat compositions. The degree of peat decomposition are shown in Table D-1.

The soil unit recognized in the inundated area are soil series and soil phases. For convenience of use, soil series names used are those given in the "so called green book" (1963). But the soil series that have been newly identified are named after the neighbouring two major rivers in the project area. The important sub-divisions of individual soil series that have been recognized here are necessary as Soil Phase to show the differences among soils in respect of the degree of peat decomposition. Boundaries between peat soil types are mapped out precisely on soil series, type and phase levels using the arial photographs and vegetation map.

From each boring site wherever possible, peat samples are collected at depth of 0 - 50 cm and 50 - 100 cm. Chemical analysis of mineral and peat soils are carried out at the soil chemical laboratory in Kingston. Their analytical items are as follows; pH, E C, sulphur, nitrogen, phosphate, potassium, calcium, magnesium, silica, C E C , ignition loss, pF - moisture curves and minor elements.

1.4 Soil Classification

1.4.1 Basic consideration for classification

The soils are classified in terms of the U.S.D.A. Soil Taxonomy . In reference to the Soil Taxonomy System, the following terms of soil features and properties are taken into account for the present soil classification and mapping in the study area.

1) Parent material and/or lithological materials

From the lithological view point, the soils in the project area derive from the following three types of parent materials.

- Limestone

These materials are primarily the diluvium originated from gneissose in the precambrian. Because of steep topography in some places, finer fractions of these materials have been outwashed by heavy showers. Thus, the present texture quality of these places is sandy in general. Various boulder cobbles, coarse fragments or stony layers intercalate few positions in the shallow profile.

- Old Alluvium

These are primarily the fine depositions. The specific particle size shows a rather wide range from 15 to 50%

clay, 25 to 45% silt and 5 to 65% sand. Fine to small gravel and/or fragments are also found in certain shallow layer but less than 20% in common.

- Recent Alluvium

Generally, these materials are deeply deposited in the flood plain of the project area which had been transported by the Black River and Y.S. River. These materials have 35 to 40% clay, 10 to 15% silt and 45 to 50% sandy particles. With small exceptions, deep sandy sediments are also found in the natural levee.

2) Lithological sequence in the specific soil depth (150 cm)

All the soils of the project area except for those in the dissected higher terrace and flat hills have deep soil profiles of more than 2 m. These profiles generally consist of several strata characterized by different sedimentations, of which sandy and/or gravel stratification in the profile are the essential factor for definition as the lower categories of soil groups. Seasonal formation (perched water) or fluctuation of the ground water table in the shallow profiles are also important factors for defining the classes of the soil moisture regime in the higher categories of soil classification.

In the small exception, outcrops and/or shallow profile limited by bedrock is the factor for classifying in the dissected hilly area.

3) Specific soil formation and diagnostic profile feature

Hydromorphic weathering, such as leaching process of inherent bases, gleization and mottling caused by the seasonal fluctuation of ground water and/or water logging in certain period is the essential feature of soils in the low lying and inundated area.

4) Environment

The predominant feature of the area is a monsoon savannah climate directly subject to the soil formation in which soil moisture regime is specified as Aquatic in the lowlying and inundated area and as Ustic in the elevated area.

Soil temperature regime is grouped into Iso-thermic in specific class for all over the soils, according to the seasonal variation of air temperature, relative humidity, solar radiation, evaporation, etc.

1.4.2 Soil classes

Based on the unique soil properties and the soil profile features, the soils in the project area are provisionally classified into seven orders, eleven sub-orders, twelve great groups and twelve sub-groups in the higher categories of classification as shown in Table D-2. Distribution of twelve sub-groups are as follows:

Typic Eutrorthox mainly developed on the side slopes of limestone hill and lower slopes of the alluvial fan formation. Udic Haplustalfs are developed over a hard white limestone formation and occurs mainly on foot slopes of hill.

Lithic Ustorthents are erodible soils in the dissected limestone hills. Generally, these soils are shallowly bottomed by the gneissose basement and have skeleted conditions. These soils are generally associated with Typic Eutrorthox.

Typic Quartzipsamments are the typical sandy alluvial soils developed narrowly along the river and swamp. These soils are generally associated with Typic Chromusterts.

Typic Chromuderts mainly developed over a flat limestone formation. These soils are generally associated with Typic Chromusterts.

Typic Chromusterts are the alluvial soils developed on both elevated and lower part of the alluvial fan formation.

Aquic Hapludoll are the predominant soils developed on the narrow river trails and extended over the alluvial depression in the lowlying alluvial plain. These soils are associated with Hydric Troposaprists in some places.

Aeric Tropaquepts are the predominant soils developed on the lowlying alluvial plain. These soils are generally in wet condition throughout most of the year.

Hemic Troposaprists, Hydric Tropohemists, Hydric Tropofibrists and Typic Sulfihemists are the organic (peat) soils developed under marsh physiographic condition on the alluvial swamp.

1.5 Soil Series Description

1.5.1 General description

Thirteen soil series are recognized in the study area, ten (10) in upland and three (3) in inundated areas. The technical descriptions of soil series indicate the major differentiating features of the soil, its parent materials, a detail description of a representative profile, range of characteristics, distribution and extent.

The descriptive terms used for the profile description are those given in the FAO Guideline for Soil Profile Description. Colour notation is according to the "Munsell Soil Colour Charts". Soil reactions (pH) are recorded on the soil suspension of 1:5.

1.5.2 Description of individual soil series

1.5.2.1 Upland soils

Characteristics of soil profiles in upland area are shown in Table D-3, Fig. D-3 and Fig. D-4.

i) Chudleigh Series

Chudleigh series comprises well to somewhat excessively drained, dark yellowish brown, moderately fine textured (fine loady) soils developed over a hard white limestone. These soils occupy about 249 ha of the project area.

Description of Typical Profile

Profile No. : P 8

Soil Name : Chudleigh Clay Loam # 73

Location : Exeter, about 500 meters west of the main road from Point near road junction

Topography : Gently convex slope (slope 3 - 5%)

Vegetation and Land Use : Fairly dense cover of short grasses and low shrubs

Drainage : Well drained

Profile Description

Depth in cm	Description
0 - 30	Dark yellowish brown (10 YR.3/4) moist and (10 YR.4/4) dry, clay loam, weak fine sub-angular blocky, slightly sticky slightly plastic firm most slightly hard dry, common fine, terbular and few fine interstitial pores, common medium and fine roots, few worm casts, few small hard white limestone gravels, clear smooth boundary, pH 8.0.
30 - 40	Dark brown (7.5 YR.3/4) moist, clay loam, moderate to weak medium and fine angular and subangular blocky, slightly sticky, slightly plastic friable moist slightly hard dry, few fine tubular pores, common

fine and few medium roots, many small hard rounded black iron and manganese nodules, pH 8.0

Range in Characteristics

a. Profile characteristics : Profile is uniform in texture and has an almost uniform brown colour throughout, occasionally yellowish brown subsoil. Structure is weak to moderate throughout. Profile reacts to acid throughout its depth.

b. Environmental characteristics : This soil is developed mainly on limestone hills and occurs on slopes and summits of hills. In some places, this soil has bedrock that limits root penetration. The dominant slopes range from 2 to 50%. The erosion hazzard is moderate to high on this soil.

ii) Lucky Hill Series

This series comprises moderately well to well drained soil developed over a hard white limestone. This soil occupies about 91 ha. of the project area.

Description of Typical Profile

Profile No.	:	P 7
Soil Name	:	Lucky Hill clay loam # 74
Location	:	Exeter, about 100 meters west of main road
Topography	:	Very gently convex slope
Vegetation and Land Use	:	Fairly dense cover of short grasses and low shrubs
Drainage	:	Well drained

Profile Description

Depth in cm	Description
0 - 37.5/47.5	Dark brown (7.5 YR.3/4) moist and brown to dark brown (7.5 YR.4/4) dry, clay