GOVERNMENT OF JAMAICA
MINISTRY OF AGRICULTURE

THE AGRICULTURAL DEVELOPMENT PROJECT

ON

THE BLACK RIVER LOWER MORASS

FEASIBILITY REPORT

VOLUME II

ANNEX REPORT

MAY 1985

JAPAN INTERNATIONAL COOPERATION AGENCY

THE AGRICULTURAL DEVELOPMENT PROJECT
ON
THE BLACK RIVER LOWER MORASS

FEASIBILITY STUDY REPORT

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TOPOGRAPHIC SURVEY AND MAPPING

1. INTRODUCTION

1.1 Objectives of the Works

The objectives of the topographic survey and mapping are :

1) To revise 1 to 12,500 scale map prepared by the Government of Jamaica in 1973, covering entire project area, by means of detailed topographic survey in the field

2) To prepare 1 to 5,000 scale map for selected prospective development area, by means of detailed topographic survey such as direct and indirect levelling and aerial photogrammetric mapping.

3) To carry out additional topographic survey such as cross section and profile survey and plane table survey at major structure sites.

1.2 Activities of the Work

The topographic survey and mapping were carried out in two stages. Detailed topographic survey, mapping for 1 to 12,500 scale map and 1 to 5,000 scale map were made in the First Field Investigation Stage carried out from February to March 1984.

The additional topographic survey of major structure sites were made in the Second Field Investigation Stage from June to October 1984.

1.3 The Project Area

The project area is bordered by the Santa Cruz mountains to the east, by the Lacovia mountains to the north and by the Middle Quarters hills to the west, and faces the Black River Bay and the Pedro Plains to the south. The project area covers approximately 11,450 ha of which about 6,800 ha are marsh land covered primarily with sawgrass and at an elevation of less than 1.0 m above mean sea level.

2. IDENTIFICATION OF GROUND CONTROL POINTS

Prior to the field survey, a field reconnaissance was carried out in collaboration with Jamaican counterparts provided by the Survey Department to identify the national ground control points such as triangulation points, densification points and bench marks in and surrounding project area. As the result of field reconnaissance following points were identified;

1) Triangulation points

   Stilmore, Benmore and Cataboo

2) Densification points

   Lacovia - Slipe - Cataboo area

   197D, 198D, 199D, 202D

   203D, 204D, and 206D

   205D was found but damaged.

   Middle Quarters area

   188D and 189D

3) Bench Marks (hereinafter called "B.M.")

   DP-9, 10, 11, 12, 13, 14, 15, 15A

   16, 18, 20, 28

   DS-24, 42, 44

   DT-1, 3

   ES-1, 3

   EP-34, 35, 37

Locations of the above points are shown on Fig. A-1. Coordinates of the triangulation points and densification points are listed on Tables A-1 and A-2. Table A-3 shows elevation of all Bench Marks and 14 Temporary Bench Marks (hereinafter called "T.B.M.") established during the field survey.

3. FIELD SURVEY

3.1 Direct Levelling

3.1.1 Main levelling

The main levelling was executed in February and March 1984 to set up temporary bench marks which were the basis of spot height survey. Temporary bench marks of 30 points were established, of which 14 were clearly marked by red paint on structures or solid rocks. The location of the above 14 points are shown on Fig. A-2.

The accuracy of main levelling are as follows ;

Closure of loop and from B.M. to B.M. $10\ mm\sqrt{S}$

Closure to other T.B.M. $10\ mm + 10\ mm\sqrt{S}$

where ; S is length of running in km.

3.1.2 Spot height survey

In order to raise the accuracy of 1 to 5,000 scale topographic map for prospective agricultural development, spot height levelling was carried out in February and March 1984. The surveyed area was about 2,100 ha and total distance of levelling was about 130 km.

The accuracy of levelling are as follows;

Closure of loop $20\ mm\sqrt{S}$

Closure to other T.B.M. $20\ mm + 20\ mm\sqrt{S}$

3.2 Indirect Levelling

Indirect levelling by using of both electro - optical distance meter and theodolite were carried out in the selected area where no direct levelling was possible in February and March 1984.

1) Styx River marsh area

Observation points were connected by traverse survey with the Densification points of 204D, 206D and Bench Mark DT-3. The equipment was set at an observation point and then the distance and angle between the equipment and the reflectors, which were shifted to 39 places in about 200 ha of marsh area, were surveyed. The accuracy of traverse survey was excellent with the closure rate of coordinates being less than 1/50,000.

2) Middle Quarters - Baptist marsh area

An observation point was set up on the dike and connected by traverse survey with Densification points 188D and 189D. The Azimuth angle was also observed for the Triangulation points Stilmore and Benmore in Santa Cruz Mountains. 18 points were surveyed in about 200 ha of marsh. The accuracy of traverse survey was also satisfactory with the closure rate of coordinates being less than 1/40,000.

3) Northern Holiday Pen marsh area

An observation point was set up on an identifiable point on an aerial photograph and connected with a temporary bench mark. Prismatic reflectors were moved in three directions guided by the transceivers from the observation point as required. A total of 15 points were surveyed in about 100 ha of marsh area.

3.3 Topographic Surveys

Topographic surveys including cross-section and profile surveys were carried out from July to September 1984 to suppliment existing maps at scales of 1 to 5,000, 1 to 12,500 and 1 to 50,000 as well as aerial photos, at the following sites;

i) the Black, the Broad, the Y.S. and the Middle Quarters Rivers,

ii) Alternative diversion canal on the Black River,

iii) Proposed drainage pumping stations and irrigation pumping station,

iv) Proposed intake weir site, and

v) Main irrigation canals

In addition to the above surveys, the Broad River area was surveyed in October by means of direct levelling in order to plot adequate contour lines for proper irrigation and drainage planning in this area. All results of the above work were utilized as basic data for preliminary design of the proposed structures.

4. TOPOGRAPHIC MAPPING

The 1 to 5,000 scale maps and 1 to 12,500 scale maps were prepared on the basis of field surveys carried out in February and March 1984.

4.1 1 to 5,000 Scale Maps

1) Mapping area

The maps cover selected area of about 5,000 ha which was selected during the First Field Investigation Stage.

2) Horizontal

An enlargement from the Base Map (1 to 12,500, printed by the Survey Department of Jamaica in 1969 and 1973) to 1 to 5,000 was revised and corrected by the photogrammetric method from aerial photographs taken in 1979 at scale of 1 to 10,000.

3) Vertical

Intermediate contour lines (0.25 m) were interpolated from field spot height survey data and were supplemented by the photogrammetric method using aerial photographs (1 to 10,000 scale, taken in 1979).

4.2 1 to 12,500 Scale Maps

These maps cover entire study area of about 12,000 ha. Spot height elevations were added to the existing 1 to 12,500 scale map, and contour lines (5 m) were interpolated in place of contours in feet. Changes in physical features were corrected by the photogrammetric method based on the aerial photographs at a scale of 1 to 10,000 and 1 to 50,000.

5. LIST OF AVAILABLE DATA

The following data were provided by the Survey Department in Jamaica and were utilized in the survey work and mapping mentioned in the previous chapters in this report.

1) Aerial Photographs

i) 1 to 25,000 : Photographed in 1968

Contact prints

Line - 15C	18 - 24	
- 16A	24 - 31	
- 17	25 - 32	Total: 23

ii) 1 to 50,000 : Photographed in 1980

Contact prints and diapositives

Line - 8B	115 - 120, 123, 126	
- 9B	89 - 98	
- 10B	12 - 22	
- 11	136 - 143	Total: 37 each

iii) 1 to 10,000 : Photographed in 1979

Contact prints and diapositives

Line - 3A	27 - 34/39 - 45	
- 4	60 - 69/168 - 177	
- 5	82 - 100	
- 6	178 - 195	
- 7	207 - 212/213 - 221/228 - 237	
- 8	137 - 153	
- 9	111 - 127	Total: 131 each

2) Description of Ground Control Points in and surrounding the project area

i) Triangulation points

ii) Densification points

iii) Bench Marks

3) <u>Topographic Maps</u>

i)	1 to 12,500	6 sheets
ii)	1 to 50,000	1 sheet (Jamaican Metre Grid)
iii)	1 to 5,000	2 sheets (Sample of marginal information)

4) <u>Others</u>

i) Calculation form for Lambert Conical Orthomorphic System

ii) Explanation of Jamaica Metric Map Sheet System

Table A-1 LAMBERT CONICAL ORTHOMORPHIC PROJECTION

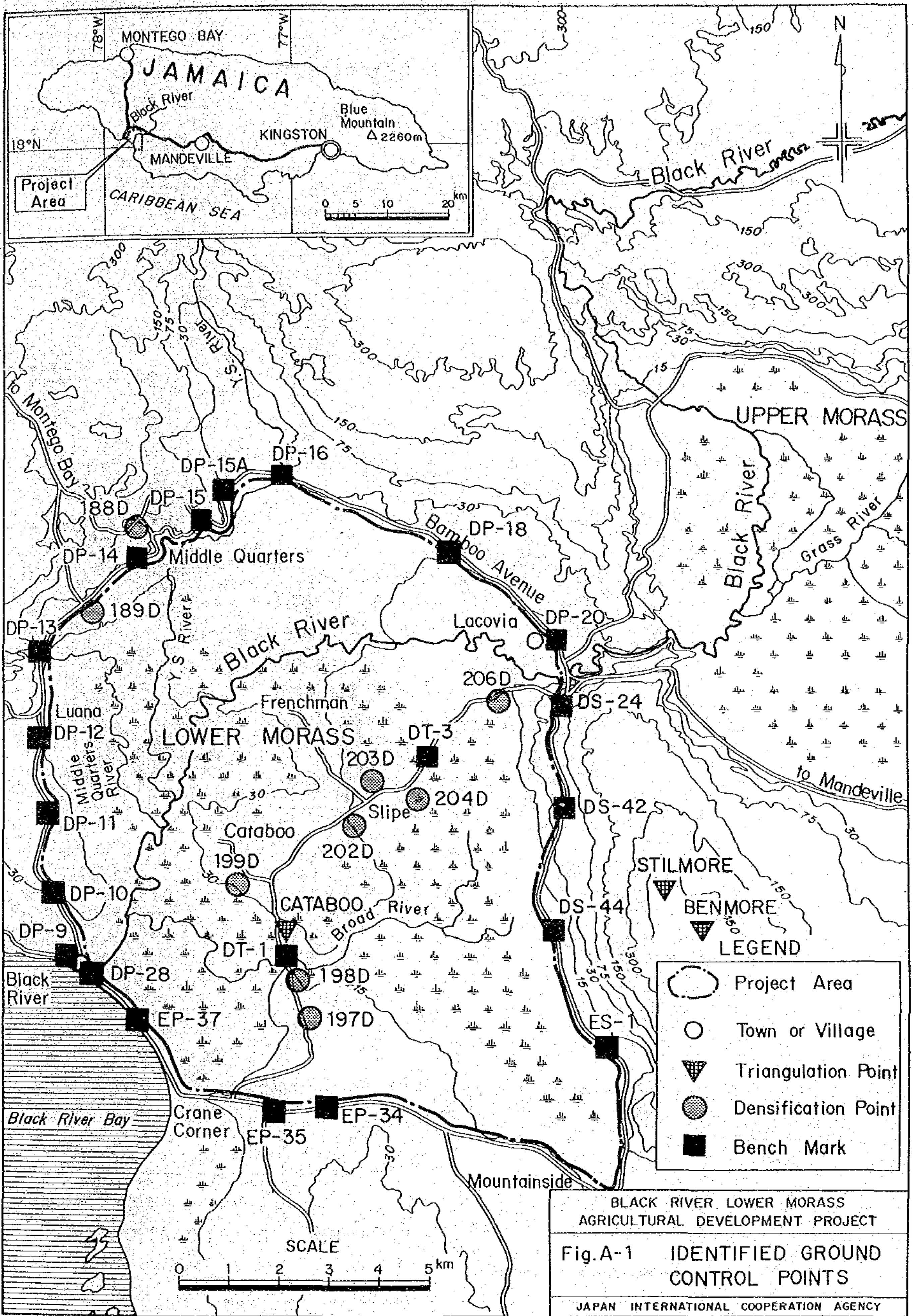
WITH ONE STANDARD PARALLEL

Spheroid	; Clarke 1866			
Scale Factor	; 1.000000			
Origin	; Latitude 18°N		Longitude	77°W
False	; Northing	150000m	Easting	250000m

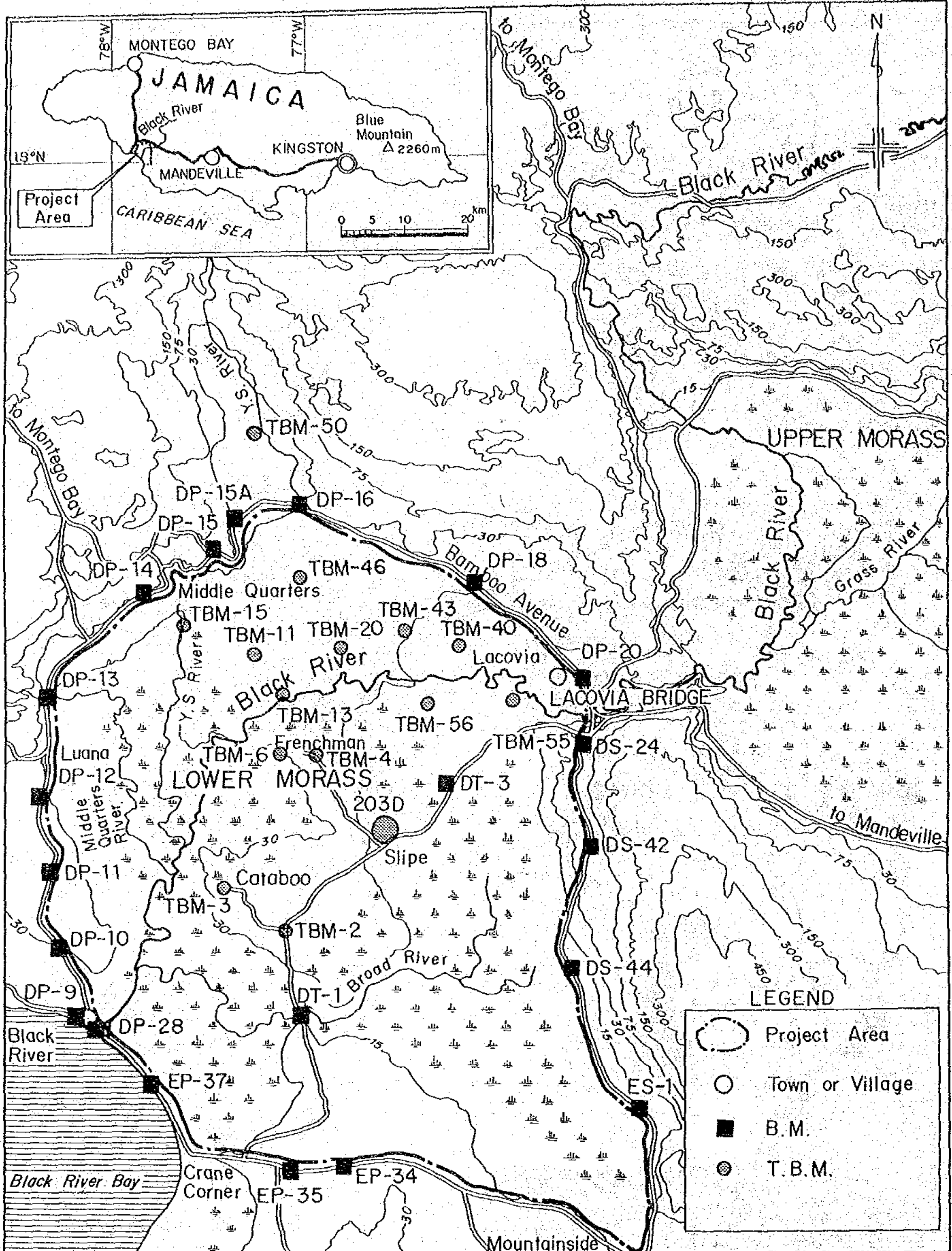
Station	Northing	Easting	Latitude	Longitude
HAUGHTON	159866.962	170497.443	18.0515712	-77.4503814
STILMORE	153513.892	171788.894	18.0149232	-77.4419033
BENMORE	152891.666	171869.352	18.0129003	-77.4416213
CATABOO	153331.438	163967.629	18.0142233	-77.4844911
RIVERSIDE	149980.724	162145.967	17.5952980	-77.4946333
MIDDLE QTR	161056.645	161442.285	18.0553148	-77.5011951
RACECOURSE	154013.661	158916.325	18.0203683	-77.5136749
10D	178896.946	190032.136	18.1536959	-77.3401440
48E	148820.353	171689.669	17.5916550	-77.4421770
144D	162738.777	163713.203	18.0648192	-77.4854967
142D	161915.932	162365.325	18.0621233	-77.4940688
143D	161039.095	162944.055	18.0552795	-77.4920872
188D	161049.185	160895.867	18.0552824	-77.5030534
189D	159920.350	160464.324	18.0516043	-77.5045036
190D	159137.578	158865.721	18.0450342	-77.5139279
186D	157915.615	158521.015	18.0410543	-77.5150807
185D	156271.471	158922.174	18.0317124	-77.5136907
184D	154072.349	159112.237	18.0205621	-77.5130098
208D	152815.784	158850.443	18.0124709	-77.5138800
207D	151988.934	160772.656	18.0058101	-77.5033324
200D	155025.293	160478.995	18.0236822	-77.5043778
199D	154573.804	163153.015	18.0222527	-77.4912792
198D	152654.755	164252.909	18.0120263	-77.4835112
197D	151901.115	164481.897	18.0055781	-77.4827215
201D	155271.739	164777.859	18.0245461	-77.4817652
202D	155629.479	165594.699	18.0257212	-77.4749931
203D	156043.835	165906.624	18.0310733	-77.4739385
204D	156118.703	166728.428	18.0313283	-77.4711453
205D	157540.656	167517.734	18.0359643	-77.4644818
206D	158013.532	168848.313	18.0415205	-77.4559638
57E	151421.381	161261.511	18.0039712	-77.5016618
56E	150755.837	161681.859	18.0018125	-77.5002227
55E	150063.815	162000.534	17.5955662	-77.4951289
54E	149763.647	163575.569	17.5946126	-77.4857706
52E	149665.685	165125.080	17.5943159	-77.4805022
53E	150992.400	164695.556	18.0026253	-77.4819818
214E	149061.099	168242.769	17.5923924	-77.4618963
212E	148215.116	170192.854	17.5856667	-77.4512563
208E	149285.977	171267.538	17.5931640	-77.4436181
end				

Table A-2 SUMMARY TABLE OF BENCH MARKS

Name of B.M.	Elevation (m)	Name of T.B.M.	Elevation (m)
DP-9	1.745	TBM-2	1.148
DP-10	5.121	TBM-3	1.446
DP-11	3.371	TBM-4	6.951
DP-12	5.382	TBM-6	1.785
DP-13	3.125	TBM-10	4.149
DP-14	3.029	TBM-11	1.301
DP-15	3.552	TBM-13	1.413
DP-15A	5.288	TBM-15	1.837
DP-16	8.776	TBM-20	0.950
DP-18	4.126	TBM-40	5.312
DP-20	12.463	TBM-46	4.488
DP-28	3.221	TBM-50	12.015
		TBM-55	1.696
DS-24	22.916	TBM-56	1.802
DS-42	37.070	Lacovia Bridge	6.116
DS-44	8.453	" (under the Bridge)	1.579
DT-1	1.985		
DT-3	1.577		
ES-1	10.078		
ES-3	5.323		
EP-34	4.039		
EP-35	1.172		
EP-37	1.396		



MONTEGO BAY
78°W
77°W
JAMAICA
Black River
Blue Mountain
Δ 2260m
KINGSTON
18°N
MANDEVILLE
Project Area
CARIBBEAN SEA
0 5 10 20 km
N
Black River
UPPER MORASS
to Montego Bay
Y.S. River
DP-16
DP-15A
DP-15
188D
DP-14
Middle Quarters
DP-18
Bamboo Avenue
DP-13
189D
Black River
Lacovia
DP-20
206D
DS-24
Black River
Grass River
to Mandeville
Luana
DP-12
Y.S. River
Frenchman
LOWER MORASS
DT-3
203D
204D
Slipe
Middle Quarters River
DP-11
Cataboo
202D
DS-42
199D
STILMORE
CATABOO
Broad River
DS-44
BENMORE
DP-10
DP-9
DT-1
198D
DP-28
Black River
EP-37
197D
ES-1
Black River Bay
Crane Corner
EP-35
EP-34
Mountainside
SCALE
0 1 2 3 4 5 km
LEGEND
Project Area
Town or Village
Triangulation Point
Densification Point
Bench Mark
BLACK RIVER LOWER MORASS
AGRICULTURAL DEVELOPMENT PROJECT
Fig. A-1 IDENTIFIED GROUND CONTROL POINTS
JAPAN INTERNATIONAL COOPERATION AGENCY



BLACK RIVER LOWER MORASS AGRICULTURAL DEVELOPMENT PROJECT

Fig. A-2 LOCATION OF BENCH MARKS

JAPAN INTERNATIONAL COOPERATION AGENCY

ANNEX B

METEOROLOGY AND HYDROLOGY

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METEOROLOGY AND HYDROLOGY

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ANNEX B

METEROLOGY AND HYDROLOGY

1. SUMMARY

The availability of surface water for irrigation was evaluated for the Black River and its tributaries in the Lower Morass. The main irrigation sources, the Black River and Y.S. River have average long term flows of 19.2 m^3/s (678 cfs) and 4.7 m^3/s (166 cfs), respectively. Critical low flows occur in March and April - 7.2 m^3/s (254 cfs) and 6.9 m^3/s (243 cfs) in the Black River at Lacovia and 0.24 m^3/s (8 cfs) and 0.29 m^3/s (10 cfs) in the Y.S. River near Middle Quarters, respectively.

The Broad River was viewed as a potential source of irrigation water for the Pedro Plains and the Middle Quarters River for the Luana area. The absence of measured stream flow data, necessitated the estimation of mean monthly flows using the water balance method. Mean annual flows of 1.5 m^3/s (53 cfs) and 0.3 m^3/s (11 cfs) were determined for the Broad and Middle Quarters Rivers, respectively. A decision to use either or both of these rivers would necessitate detailed hydrological measurements to confirm stream flows and the implementation of structures to control sea water intrusion, prior to the development of the irrigation pumping stations.

The discharge of the Y.S. and Black River and background quality of the Broad and Middle Quarters Rivers are excellently suited for irrigation, having very low salinity and alkalinity hazards.

Flood peak discharges for 10 and 50 year return periods were determined for pre and post Upper Morass Development Project flows in the Black River at Lacovia. Pre-project flood peak discharges of 73 m^3/s (2,580 cfs) and 90 m^3/s (3,180 cfs) were determined for the 10 and 50 year return events, respectively and post project discharges of 133 m^3/s (4,700 cfs) and 193 m^3/s (6,800 cfs) synthesized from available flood records 1963 to 1982. The 80% and 110% increases in flows indicated for the post-project 10 and 50 year return events, reflect the elimination of flood

storage in the Upper Morass by the diking of the Black River between Newton and Lacovia and the accentuation of peak discharge by pumping stations draining the land area behind the dikes. The 10 and 50 year flood discharges in the Y.S. River were determined by frequency analysis to be 41 m^3/s (1,450 cfs) and 55 m^3/s (1,950 cfs), respectively.

Maximum proposed development of the Lower Morass is likely to produce a slight increase in peak discharges, a significant reduction in intermediate flows and leave low flows essentially the same. Mean annual irrigation diversion of 2.0 m^3/s (71 cfs) will be roughly balanced by estimated drainage pumping of 1.8 m^3/s (64 cgs) and pre and post project evapotranspiration was estimated to be the same because of the similarity between paddy and swamp conditions. No significant net change in the water balance is anticipated.

The projected reduction in intermediate flows in the Black and Y.S. Rivers could result in longer periods of sea water intrusion but no marked change in the extent of saline intrusion. Large scale use of fertilizers and pesticides in the development area is likely to adversely affect river water quality particularly that of the Broad and Middle Quarters Rivers via irrigation return flows.

2. INTRODUCTION

The Project area conforms roughly to the Lower Morass Sub-catchment of the Black River Basin. Therefore, it will be necessary to consider the Lower Morass in context of the larger Black River Basin.

The Black River Basin located in the southwestern part of Jamaica lies mainly within the Parish of St. Elizabeth. It is located between 77°30' and 78°00' west longitude and 17°50' and 18°15' north latitude. The basin is about 40 km in length in both north-south and east-west directions. The area lies in the North East Trade Belt and has a tropical oceanic climate.

Tertiary White Limestone Formations predominate over 90% of the Black River Basin, with small exposures of Cretaceous volcanic and volcaniclastic formations in the Hector's River Valley at the extreme north east area of the Basin. Alluvial clays floor the Nassau Valley and alluviums and peat occupy the depressions which house the Upper and Lower Morasses. The highly karstic nature of the White Limestone Formations, i.e., closed 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.

FAO (1971) first defined the boundary of the Black River Basin and also identified its several component sub-catchments. The following sub-division was adopted by this Study (see Fig. B-1)

Upper Black River Basin	Lower Black River Basin
Cockpit Country Sub-catchment	Middle Quarters Sub-catchment
Essex Valley "	Y.S. River "
Upper Morass "	Pedro Plains "
	Lower Morass "

The main focus of this Annex is the Lower Morass but the other sub-catchments which drain directly into the Lower Morass are also considered.

3. METEOROLOGY

3.1 Rainfall

3.1.1 Gauging station network

There are 40 non-recording rainfall stations in and around the Black River Basin as shown in Fig. B-1. All stations are registered with the Jamaica Meteorological Services, (Ministry of Public Utilities, Communications and Transport) in Kingston. Field checks showed that most of the rainfall gauging stations were well maintained. Several stations were damaged or shadowed by trees or houses.

The rainfall is usually measured in the morning, usually between 7:00 and 9:00 a.m., and is recorded as rainfall on the previous day. Rainfall from Friday to Sunday is measured together on Monday at several stations which are located at government offices such as post offices and public works offices. The observed data are recorded on pre-franked post cards and mailed to Kingston every month. Collected data are published as monthly totals by the Meteorological Services.

Two automatic recording rainfall gauges are located within the Black River Basin. The first was installed in 1981 at Elim in the Upper Morass, by the Black River Upper Morass Development Corporation (hereinafter called "BRUMDEC"). The other is incorporated in the Petroleum Corporation of Jamaica (hereinafter called "PCJ") Salt Spring Metrorological station in the Lower Morass. This gauge was commissioned in 1983.

3.1.2 Rainfall record

Daily rainfall data for all 40 non-recording stations were collected from the Jamaica Meteorological Service and the Water Resources Division (Fig. B-2). Several stations were eliminated from the Study because of significant instances of missing data.

Complete monthly data were available for all 40 rainfall stations only for the period 1969 - 80. The reliability of these data were examined by double mass curve analyses. In this analysis accumulated rainfall of one station was plotted against the arithmetic mean of all 40 stations. These plots are shown together with the respective correlation factors as Figure B-3.

Twenty-four rainfall stations were thus selected for inclusion in the water resources study. The average monthly rainfall for each of these stations are shown as Table B-1.

3.1.3 Rainfall data

The monthly rainfall histograms of representative stations show a bimodal peak in May and October (Fig. B-4). About 70% of annual rainfall occurs during the period from May to October. The dry season usually extends from November to March.

Areal distribution in the Black River Basin was studied by annual isohyets and shown in Fig. B-5. The rainfall in the north-western part of the basin with elevation in excess of 600 m, has more than 2,500 mm per annum. The southern part has less than 1,500 mm. The rainfall in the basin decreases from north to south in accordance with decreasing elevation.

Thiessen polygons were established using the 24 base stations referred to in the previous section. The polygon network is shown in Fig. B-6. The wighted factor of each station was estimated as shown in Table B-2. The annual rainfall in the Black River Basin was determined as 2,200 mm (87 inch) at Newton, and 1,900 mm (75 inch) at Lacovia. The Y.S. River sub-catchment had 2,500 mm (98 inch) of rainfall per annum.

There are five rainfall stations in the Lower Morass as follows :

Black River,
Burnt Savannah,
Holland,
Lacovia, and
Mountainside.

The monthly rainfall data of the above stations are shown in Table B-3 and seasonal distributions are shown in Fig. B-4. The averaged annual rainfall from 1964 to 1980 vary from 1,170 mm to 1,910 mm as shown below.

Station	Average Annual Rainfall in mm
Black River	1,177
Burnt Savannah	1,694
Holland	1,912
Lacovia	1,703
Mountainside	1,286

3.2 Climate

3.2.1 Meteorological stations

Three meteorological stations are located in and around the Black River Basin, at Crawford, Elim and Salt Spring. Their locations are shown on Fig. B-1.

The Salt Spring Meteorological Station was established by PCJ in 1983. It is situated on the left bank of the Broad River about 100 metres upstream of the Salt Spring bridge. Daily data provided by PCJ are presented as monthly summaries in Table B-4. The very high rate of evopotranspiration from the evaporimeter in which the water surface is always kept below the surface of the peat is probably not representative of swamp conditions as the vegetation established within the evaporimeter is much denser than that typical of the Lower Morass.

The Elim Meteorological station has been operated by BRUMDEC since 1981. It is situated within the Upper Morass. The station was equipped to provide data on temperature, humidity, evaporation, wind and rainfall. Because some of the equipment were not properly calibrated prior to 1983 much of the data collected in 1981 and 1982 are not reliable.

The Crawford Meteorological station is located outside the Black River Basin, about 6 km north west of the town of Black River. The station has been operated since 1974. The condition of the station was good, but the usefulness of the station was limited by the many interruptions in the observations. Of the three meteorological stations, Crawford had the longest period of climatological data and was therefore used in the irrigation and agronomic studies of this project. The data from the other two stations were useful reference checks on the Crawford data. The data available for the Crawford station are summarised in Table B-5.

3.2.2 Climate data

(a) Temperature

The Lower Morass as well as the island of Jamaica lies within the Trade Wind Belt and has a tropical oceanic climate. The mean annual temperature is 25.8°C (78.4°F) with a mean annual range of 3.4°C. From January to March, the weather is cool with a mean temperature 24.4°C (75.9°F); June to September being the warm season, having a mean temperature 26.6°C (79.9°F).

Unit : °C

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
Monthly Mean Temperature												
24.6	23.5	24.8	25.4	26.2	26.9	26.6	26.4	26.6	26.4	26.2	25.3	25.8
Monthly Mean Minimum Temperature												
19.1	17.1	19.2	20.1	21.2	21.8	21.0	21.2	21.7	21.1	20.9	19.5	20.4

The absolute maximum was recorded at 35.0°C (95°F) between June and August and the absolute minimum was recorded at 12.7°C (55°F) in December as shown in Fig. B-7.

(b) Humidity

Unit : %

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ave.
75	77	76	75	76	75	76	77	77	78	76	75	76

The annual range of humidity is less than 10%. Its diurnal variation is much larger than the annual variation. Evening through early morning is high while the afternoon low, ranges more than 25%. The annual mean relative humidity is 76%.

(c) Sunshine and Evaporation

The daily sunshine hours averaged 7.6 hours/day. Evaporation from class - A pan averaged 5.35 mm/day and 1,953 mm per annum. The evapotranspiration from the swamp in the Lower Morass was assumed to be about 5.4 mm/day and 1,930 mm per annum, based on the results published for the PCJ meteorological station at the Salt Spring bridge.

Monthly Class - A Pan Evaporation Unit : mm

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
150	142	173	183	197	183	173	173	160	157	130	134	1,955

(d) Wind

The average daily wind run is about 94 km (51 nautrical miles). Besides being affected by the Trade Winds, it also has local thermal breezes. During the daytime, wind blows from the sea inland resulting from a pressure and temperature differences between sea and land. In Jamaica, the resultant wind is called a Sea Breeze. At night temperature and pressure conditions are reversed resulting a wind blowing from the land to the sea - "a land breeze".

4. SURFACE WATER HYDROLOGY

4.1 Streamflow

4.1.1 River morphology

The movement of waters within the Black River Basin was first investigated by a FAO/UNDP/GOJ Water Resources Project during 1965 to 1969. Their findings were published by the FAO in a report dated 1971 (FAO 1971).

The Black River originates in the centre of the island of Jamaica in the vicinity of an area identified as Black Ground. The river has its headwater on Cretaceous Formations which are composed of impermeable volcanic and volcaniclastic materials. In this area the river is known as the Hector's River. It flows from Black Ground eastwards some 14 km to Troy. As the river approaches Troy, it begins to disappear underground via a series of sinkholes developed in its river bed such that there is no riverflow at Troy. During periods of high river discharge, flows may persist to other sinkholes 2 km downstream of Troy.

The water sinking at Troy flows underground until it rises in the vicinity of Oxford Valley, about 3 km south of Troy and is then identified as the One Eye River. The One Eye River has a flow that is two to three times greater than the quantity of water that sinks at Troy (FAO, 1971). From the Oxford Valley rising, the river continues about 4 km southwards as surface flow, where it is joined by a semi-perennial tributary called the Rotten Cut River. At the south end of the Oxford Valley, the One Eye River turns westward and flow into Wallingford Cave.

From Wallingford Cave, the flow is underground for about one mile before rising at the Mexico Cave, a point about 45 metres lower in elevation. From the Mexico Cave, the One Eye River runs almost westward as surface flow. As the river passes Raheen 3 km westward from Mexico Cave, a portion of its flow disappears underground via a sinkhole, to rise finally as several springs which constitute the western branch of the Elim River in the Upper Morass. The One Eye River continues westward from Raheen in a meandering pattern and is joined by the Blue River in the vicinity of Windsor. The Blue River orginates at the foot of the Cockpit Country. Beyond this confluence, the river is known as the Black River.

From Windsor westward to Appleton the Black River is joined by two small tributary streams flowing southward from the foot of the Cockpit Country.

South of Appleton, at the base of the northern slopes of the Nassau Mountain are a series of sinks which accept excess surface flow, and one of which is used to dispose of dunder waste (sugar cane waste discharged from the factory) from the Appleton Distillery. This dunder is again found in one of the two risings which form the source of the North Elim River in the Upper Morass.

The Black River meanders westward from Appleton to Maggotty where it is joined by the Maggotty River, which rises as a spring a short distance northward of the confluence. At Maggotty, the river turns to the south-west and flows into the Upper Morass passing through Newton. The total length of the river at Newton is about 50 km from the farthest origin and is about 23 km from the Mexico Cave. The surface water catchment upstream of Newton was estimated about 400 km^2 (155 sq. mile).

In the Upper Morass several tributaries i.e., the North Elim, the South Elim, the Foster, the Braes, the Mt. de las Uvas, the New and the Island Rivers join the Black River. The surface water catchment area of the Upper Morass was estimated at about 430 km^2 (166 sq. mile). The Black River traverses the Upper Morass in a clock-wise path and reaches Lacovia 14 km downstream from Newton. The Black River has a surface water catchment area of about 830 km^2 (320 sq. mile) at Lacovia.

The Black River leaves the Upper Morass at Lacovia and flows through the Lower Morass in a counter clock-wise path. It is joined by the Y.S. River 14 km downstream from Lacovia by the Middle Quarters River 1 km further downstream and by the Broad

River another 4 km downstream. The Black River discharges into the sea at the town of Black River. Between Lacovia and its estuary the Black River is 20 km long and has a total length of 84 km from its farthest source.

At the estuary of the Black River, the total surface water catchment area as determined at 1,200 km^2 (463 sq. mile). The boundary of the surface water catchment area is shown on Fig. B-1 as well as the locations of the automatic water level recorder gauging stations.

The Black River exhibits the effects of tidal fluctuation several kilometer upstream of its estuary.

4.1.2 Surface water catchments

(a) Upper Morass

Water inflow to the Lower Morass from the entire Upper Black River Basin occurs via the Upper Morass.

The Upper Morass serves as the *reservoir area of the* Upper Black River Basin receiving surface and ground waters from the Cockpit Country and the Essex Valley. The Upper Morass is drained by the Black River and the several tributaries which rise within the Upper Morass itself i.e., The North Elim River, The South Elim River, Foster River, Braes River, Mt. de las Uvas River, New River and Island River. Water leaves the Upper Morass into the Lower Morass as the flow of the Black River at Lacovia.

The Upper Morass was initially a swamp into which major floods were stored when the Black River overtopped its banks. Flood magnitudes were reduced by the regulating effect of the Upper Morass resulting in significantly smaller peak discharges downstream in the Lower Morass. *In* 1981, the River was diked to halt its flooding of the Upper Morass and to convey the major flood the downstream thus eliminating the regulating effect of the Upper Morass. Furthermore, the flow in the tributaries was lifted into the Black River by three pumping stations. Consequently, the flow characteristics of the Black River have been changed significantly, particularly during periods of flood.

The discharge from the Upper Black River Basin is measured at a streamflow gauging station in the Black River at Lacovia. The mean flow for the period 1964 to 1982 was found to be 19.2 m^3/s. from a drainage area of 830 km^2 (320 sq. miles).

(b) Y.S.

The Y.S. River, a principal tributary of the Black River, originates from springs located in the vicinity of Ipswich. About 0.5 km below its source, the river enters Flat Valley. This Valley contains a number of sinkholes at various levels which serve to control the magnitude of the river flow. During period of very low flow the river disappears underground via all of the sinkholes in its river-bed and there is no surface flow until about 3 km farther south where the River again rises.

After being joined by several small branches, the Y.S. River passes over a series of water falls above Y.S. house and enters into the Lower Morass near to Middle Quarters. In the Lower Morass the river flows to the south-west towards the town of Middle Quarters where a number of seeps and rises occur. After passing through Middle Quarters, the river flows southwards to its confluence with the Black River. The total length of the river is about 20 km from Ipswich and 10 km from near Middle Quarters to its confluence with the Black River.

In the Lower Morass, the river channel is narrow but relatively deep. From the junction with the Black River upstream, the river channel is choked with vegetation.

The surface water inflow into the Lower Morass from the Y.S. sub-catchment is measured at a streamflow gauging station at the bridge where the main road linking the towns of Santa Cruz and Black River crosses the Y.S. River. The station is known as Y.S. River Near Middle Quarters. Mean river flow for the period 1955 to 1982 was determined at 4.95 m^3/s. The catchment area upstream of the gauge is 160 km^2 (62 sq. miles).

(c) Middle Quarters

The Middle Quarters Sub-catchment determined this Study, is a part (35%) of the Newmarket Sub-catchment of FAO (1971).

Recent data obtained as a result of the June 1979 flooding of the Newmarket Depression indicated that there was no surface or ground water flow from the Depression to the Lower Morass. The Newmarket area was therefore excluded from the Black River Basin. Donaldson and Walters (1981) reported that there was no significant increase in the flow of the Middle Quarters Springs, despite sub-surface losses of 4.6 m^3/s over a 46 day period from the flooded depression. These Springs drain the Middle Quarters Sub-catchment and were previously assumed (FAO 1971) to have been the exit for ground water recharge in the Newmarket Depression. Jones (1981) noted significant change in the morphology of south-west flowing streams as a result of the June - July flooding. No such change was noted for dry gullies leading from the Newmarket area to the Lower Morass.

There is no perennial or seasonal surface stream draining the Middle Quarters Sub-catchment. However, short-lived overland flow produced by particularly heavy rainfall events are believed to drain to the Lower Morass. The highly karstic limestones which make up the catchment permit only perennial ground water drainage, which appears as the Middle Quarters Springs.

The Middle Quarters Sub-catchment has an area of 50 km^2 (19 $miles^2$). FAO (1971) reported a subsurface outflow of 4 m^3/sec. Flow Net Analyses this Study determined an outflow of 1.2 m^3/s for August 1984. (Annex C, Geology and Hydrogeology).

(d) Pedro Plains

There is no integrated surface flow system in the Pedro Plains, since numerous small shallow depressions are developed. Some surface runoff occurs in these depressions, where it ponds and infiltrates into the ground. Therefore, most of the 100 km^2 (38 sq. miles) of the catchment area of the Pedro Plains was excluded from the surface water catchment area of the Lower Morass Sub-catchment.

However, the northern section of the Pedro Plains - Mountainside, Park and Fullerswood, was included in the Lower Morass catchment. Several gullies in this 20 km^2 (7.7 sq. miles) area carry storm runoff into the Lower Morass.

(e) Lower Morass

The Lower Morass sub-catchment is bounded by the Santa Cruz Mountains in the east, the Lacovia Mountain in the north the Middle Quarters Uplands in the west and the Burnt Savannah Upland in the south (see Fig. B-8). It includes 67 km^2 (26 sq. miles) of perennial swamp with elevations generally less than 1 metre a.m.s.l. and 123 km^2 of upland bordering the swamp. About 5 km^2 of upland area which attain elevation of 10 meters a.m.s.l. occur in the central area of the Lower Morass i.e. Cataboo and Frenchman.

Major surface inflows into the Lower Morass occur via the Black River and the Y.S. River. These rivers seasonally overtop their banks to flood the swamp area of the Lower Morass. Ground water inflows from the Y.S., Middle Quarters and Pedro Plains sub-catchment contribute to maintaining the perennially high water level in the swamp and to accentuating flood levels in the wet season.

Drainage of the Lower Morass occurs via the Black River and its tributaries the Y. S. River, Broad River, Middle Quarters River and the Styx River. Like the Black River, the Y.S. River originates from outside the Lower Morass sub-catchment. The other tributaries - Broad, Middle Quarters and Styx Rivers - rise from within the Lower Morass, their low flow being substained mainly by groundwater. The Broad and Styx Rivers have their sources in "blue - holes" in the eastern area of the swamp The Middle Quarters River rises as a spring at the center of the edge of the swamp in the area of Luana.

The Broad River catchment upstream of the Salt Spring bridge was estimated at 79 km^2 (31 sq. miles). No reliable measurements of the flow in the Broad River exist. A measurement carried out during this Study (July 30, 1984) proved a discharge of 6.4 m^3/sec. Crude monthly estimates of flow for an average rainfall year (i.e. 1975) suggested a mean flow of 1.5 m^3/s. This estimate also indicates the likelihood of net flow of sea water during the months of December, January and February (see Table B-8), NRCD (1981) and PCJ (1982) have reported the presence of a sea water intrusion in the bottom of the river up to distances of 9 to 10 kms upstream of the Broad River's confluence with the Black River. The Broad River has a total length of 12 km.

The Styx River drains the upper end of the Broad River, flowing westward to the Black River. Spot measurements carried out at the Slipe culvert by the Water Resources Division indicate a range of from 0.01 m^3/s (0.4 cfs) to 0.25 m^3/s (8.9 cfs) (1966 - 1970).

The catchment area of the Middle Quarters River was estimated to be 18 km^2 (7 sq. miles). No measurements of flow were available but a crude estimate prepared during this Study indicated a mean flow of 0.3 m^3/s. This estimate indicated that low flows were sustained largely by drainage of swamp storage.

The Black River itself is known to exhibit the effects of tidal fluctuations as far upstream as Lacovia. FAO (1971), NRCD (1981) and PCJ (1983) have reported the presence of saline wedges up to 10 km (6 miles) upstream of the Black River's estuary. During the wet season the increased streamflow is usually sufficient to keep the sea water out of the Black River System. This was confirmed this Study by depth/conductivity measurements on September 8, 1984.

4.1.3 Streamflow records

(a) Data Network

Automatic continuous stage recorders are installed on the Black River, Y.S. River and Broad River. The gauging station are as listed below :

River	Location of Station
Black	Appleton
Black	Newton
Black	Lacovia
Black	Black River (estuary)
Y. S.	Near Middle Quarters
Broad	Salt Spring

The station locations are shown on Fig. B-1.

Discharge measurements carried out once or twice a month are used to develop rating curves at each station. These rating curves allow computation of mean daily flows from the continuous stage recorder data. No rating curves were available for Black River at estuary and Broad River at Salt Spring because of the strong tidal effects at both stations. Discharge measurements carried out this Study at Black River at Lacovia and Y.S. River at Near Middle Quarters proved the rating curves for these stations to be of good accuracy.

A staff gauge installed on the Y.S. Diversion Canal is read twice daily. A rating curve has also been developed for this gauging station.

The network of stream gauging stations were installed and are maintained by the Water Resources Division.

(b) Discharge Records

Daily and monthly discharge records are available for Newton, Lacovia and Near Middle Quarters stations. The periods of record vary from 17 to 28 years. The monthly mean discharge record are shown in Table B-6.

The reliability of the streamflow data recorded for Black River at Lacovia and Y.S. River Near Middle Quarters were checked using double mass curve analysis. The analysis involved plots of discharge vs basin rainfall and the discharge of one station vs. another. These curves are shown as Fig. B-9. The results indicated that streamflow records for gauging stations at Newton, Lacovia and Near Middle Quarters were of acceptable accuracy, but that for Y.S. Diversion was suspect.

Headworks 1.5 km upstream of the Y.S. River Near Middle Quarters gauging station, diverts water into a canal which leads to the Holland Sugar Factory. The canal has two spillway structures so that the excess water can be returned to the Y.S. River before the river reaches the Near Middle Quarters gauging station. The canal also drains a small catchment upstream of the gauging station on the canal. Discharge measurements for this station were available from 1968. A decision not to include this data in the water resources study of the Y.S. River was based on the unacceptably low correlation between the data of the Diversion Canal and the Black River at Lacovia.

(c) Discharge Data

Mean monthly discharge for the Black River at Lacovia and Y.S. River Near Middle Quarters are presented as shown below.

Unit : m^3/sec

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
Black River at Lacovia (1964 - 1982)												
11.7	10.1	9.9	13.2	24.3	23.5	18.1	19.6	25.4	32.1	26.6	14.9	19.2
Y.S. River Near M.Q. (1964 - 1982)												
1.2	0.94	0.92	3.0	7.1	6.1	5.4	6.7	7.7	9.7	5.4	2.0	4.7

Annual minimum, maximum and mean flows in m^3/s (10^6 igpd) for both stations are summarised below :

	Minimum Flow (March)		Maximum Flow (October)		Mean Flow	
Black River at Lacovia	9.8	(182)	32.0	(608)	19.2	(365)
Y.S. River Near M.Q.	0.9	(17)	9.6	(182)	4.7	(89)

Annual rainfall in the catchments upstream of the Lacovia and Near Middle Quarters Gauging stations were determined at 1,900 mm and 2,500 mm respectively. Annual runoff coefficients for both catchments were computed at 0.38.

4.2 Water Balance of the Lower Morass

4.2.1 General

The general water balance equation can be expressed as follows:

$$I - O = dS \qquad \text{.............................} \quad (4-1)$$

where : I = Total inflow to the Lower Morass

O = Total outflow from the Lower Morass

dS = Change of storage

For the Lower Morass the components of Inflow and Outflow were identified and the water balance equation stated in more detail, as follows:

$$(I_B + I_Y + I_P + I_S + I_G) - (O_B + E + O_{GW}) = dS \qquad \text{............} \quad (4-2)$$

Where : I_B : River inflow via the Black River at Lacovia

I_Y : River inflow via the Y.S. River at Near M.Q.

I_P : Precipitation on the Lower Morass

I_S : Surface runoff from upland area of the Lower Morass Sub-catchment

I_G : Sub-surface inflow to the Lower Morass

O_B : Surface water outflow from the Black River to the sea

E : Evapotranspiration from the Lower Morass

O_{GW} : Sub-surface otuflow from the Lower Morass

dS : Change of storage

4.2.2 Inflow

(a) Precipitation (I_p)

Nine rainfall stations were used in the water balance study as follows:

1. Black River,
2. Burnt Savannah,
3. Holland,
4. Lacovia,
5. Mt. Charles,
6. Mountainside,
7. Maggotty,
8. New Market, and
9. Y.S.

The arithmetic mean of 5 stations i.e., from 1 to 5 was calculated and applied to estimation of "precipitation on the Lower Morass" (I_p) since these are located in and around the Lower Morass. The area of the swamp was determined to be 67 km^2. The arithmetic mean of all 9 stations were used in determining precipitation to the upland from which surface and groundwater runoff into the Lower Morass were estimated.

(b) River Inflows (I_B, I_Y)

River Inflows correspond to the major surface water inflows into the Lower Morass via the Black River at Lacovia and Y.S. River Near Middle Quarters. The discharge data available for these points were utilised in the water balance study.

(c) Surface and Sub-surface Runoffs (I_S, I_G)

These inflows refer to surface runoff and groundwater under flow from the upland areas within the Lower Morass and Middle Quarters Sub-catchments. This upland area is not drained by any perennial or seasonal streams but overland flow from this area reach the Lower Morass from sufficiently significant rainfall events.

The summation of both components (i.e., I_S and I_G) were determined from the following equation.

$$(P_Y + P_U) \times r_c - I_Y = I_S + I_G \qquad \text{........(4-3)}$$

Where : P_y : Areal precipitation to the Y.S. River basin (160 km^2) in m^3/sec.

P_u : Areal precipitation to the upland (122 km^2) in m^3/sec.

r_c : Total runoff coefficient

I_y : Surface runoff on the Y.S. River at Near M.Q.

I_s : Surface runoff from the Upland Area

I_G : Sub-surface inflow to the Lower Morass

A runoff coefficient of 0.44 was assumed based on that determined for the Black River at Newton.

An analysis of the streamflow hydrograph for an average year in the Black River at Newton, indicated a baseflow component of 60% and directflow component of 40%. The baseflow separation is shown as Fig. B-10. These ground and surface water runoff coefficients 0.6 and 0.4 respectively were applied to the separation of surface runoff from the upland area (I_s) and groundwater inflow (I_G) from the result of equation (4 - 3).

4.2.3 Outflow

(a) Evapotranspiration (ET)

The meteorological data observed at Crawford and FAO recommendations for determining crop water requirements for rice (FAO Irrigation and Drainage Paper 24) were used to estimate evapotranspiration from the swamp. The results are summarised below for ease of reference.

Unit : mm/day

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
4.4	4.9	5.7	6.2	6.5	6.2	6.4	6.1	5.3	5.2	4.5	4.3	5.5

The annual average of 5.5 mm/day was very similar to the 5.3 mm/day determined by PCJ (1983) from evaporimeter measurements at its Salt Spring Meteorological Station.

Ratios between the above monthly values of evapotranspiration and class - A pan evaporation at Crawford were calculated and monthly evapotranspiration from the swamp computed by multiplying the ratios and the corresponding Class - A pan record.

(b) Surface Water Outflow (O_B)

The Black River affords the only significant surface water exit from the Lower Morass. The measured flow in the Black River at its estuary would therefore constitute surface water outflow from the Lower Morass (O_B).

A continuous automatic river stage recorder installed on the Black River at the bridge in the town of Black River, has been in operation since 1955. However, it has been impossible to determine a stage-discharge rating curve because there is no recognizable relationship between river discharge and river stage. For example, only tidal fluctuations were observed for the maximum recorded flood of October 19, 1973.

Tidal integration discharge measurements were carried out by the WRD in 1980 and 1981 (NRCD 1981). Net daily discharges for the Black River at estuary were determined for a number of days and these results correlated to the discharge recorded in the Black River at Lacovia and Y.S. River Near Middle Quarters i.e., river inflow into the Lower Morass. Given net river inflow, the correlation equation was then used to determine average monthly flow at Black River (NRCD 1981).

The latter mentioned results produced runoff coefficients from 0.35 to 0.44, values that were very similar to those determined for the catchments above Lacovia and Newton. These estimates of outflow at Black River were therefore considered acceptable and applied to the water balance study.

(c) Sub-surface Outflow (O_{GW})

The hydrogeological study indicated that there was preferential groundwater flow into the Broad River and Middle Quarters groundwater depressions and little, if any, groundwater outflow directly to the sea. Sub-surface outflow (O_{GW}) was therefore assumed to be zero, in the computation of the water balance.

4.2.4 Computation of water balance

The water balance was computed on a monthly basis for the years 1974 to 1980. A hydrological flow chart graphically illustrated average component flows in the water balance (Fig. B-11). The component flows are also summarised on an annual basis in Table B-7 and the inflow/outflow results plotted as Fig. B-12.

The sub-surface inflow into the Lower Morass was determined to be 2.6 m^3/sec. (see Section 4.2.2 (c) above). This figure was very similar to the 2.8 m^3/s determined by Flow Net Analysis (ANNEX C, Geology and Hydrogeology) lending credibility to the assumptions made in that exercise.

4.2.5 Estimation of the discharge of Broad and Middle Quarters Rivers

Estimates of monthly flows in both the Broad and Middle Quarters Rivers were required in order to carry out a preliminary evaluation of their potential as sources for irrigation water for the Pedro Plains and Luana area, respectively.

There were no regular measurements of flow in either of these rivers and so the water balance methodology was applied to developing the estimates needed. Mean monthly flows were estimated for a minimum 5-year return period i.e., 1975.

The direct-flow (i.e. surface water) component of stream-flow consisted of effective rainfall on the swamp section and surface and groundwater runoff from the upland section of the respective catchments. Effective rainfall was made equivalent to precipitation less evapotranspiration. Rainfall data at Burnt Savannah and Holland were used for the Broad and Middle Quarters Rivers, respectively. Surface runoff was assumed to be 0.24 of precipitation on the upland area, an average ratio of I_s/P_u for the period 1974 - 80. The respective catchment areas are set out below in km^2.

	Catchment Area (km^2)		
	Swamp	Upland	Total
Broad River	23	56	79
Middle Quarters River	6	12	18

The results of the Flow Net Analysis (Annex C, Geology and Hydrogeology) indicated that groundwater inflow into the catchment area of the Broad and Middle Quarters Rivers accounted for 0.55 and 0.07 of total sub-surface inflow into the Lower Morass. These ratios were applied to the monthly estimates of total sub-surface inflow to decide the monthly baseflow component of the rivers.

The estimates of mean monthly flow are presented as Table B-8.

4.3 Stream Water Quality

4.3.1 Water type

FAO (1971) reported that the background quality of all surface waters within the Black River Basin conformed to a calcium bicarbonate type except for the waters of the Maiden Valley River in the Y.S. River catchment which was a magnesium bicarbonate type. The associated dolomite limestones were thought to be the likely source of the enriched levels of magnesium in the discharge of the river.

Chemical analyses of samples of the Black River, Y.S. River and Broad River carried out this study confirmed them to be calcium bicarbonate type waters. The results of these analyses are summarized in Table B-9. Sampling locations are shown on Fig. B-13.

These waters owe their character to the solution of the karstic White Limestone Formations which make up more than 90% of the Black River Basin.

4.3.2 Sediment load

PCJ (1983) reported "Turbidity Quantities" for the BLack River drainage system, presenting data on the contribution of the Black River and each of its major tributaries. Turbidity is a function both of suspended load and the colour of the water. There is the likelihood that PCJ's results were influenced to a high degree by organic colour introduced by the rum distillery waste (dunder) from the Appleton Distillery and humic acids orginating from within the swamp (particularly those areas where mangrove predominate).

The relatively intense cultivation of lands drained by the Black River (upstream of Lacovia) and the Y.S. River (upstream of Near Middle Quarters streamflow gauging station), and the significant direct flow component of those rivers (40%) contribute to relatively high suspended load inflows into the Lower Morass, particularly during periods of high river flow.

Surface runoff originating on the intensely cultivated Holland Sugar Estate within the Lower Morass also contributes to the suspended load of the Black River and Y.S. River. Suspended Load determination carried out this study for both rivers are included in Table B-10.

The effectiveness of thick water-hyacinth growth on the settling of suspended material was indicated by a reduction or suspended load from 105 ppm at the diversion on the Y.S. River at Middle Quarters to 7 ppm 1 km downstream in the Middle Quarters Canal.

No determinations were carried out on the Styx River, Broad River or Middle Quarters River because of their persistently clear discharge even after periods of intense rainfall. Their low suspended loads was thought to be a function of the relatively small area of upland catchment, the relative absence of cultivation within these areas, and the filtering effect of the swamp vegetation on surface runoff.

The limited data available on suspended load was not sufficient to permit any estimate of annual suspended load inflows into the Lower Morass.

4.3.3 Contamination of surface waters

(a) Rum Distillery Effluent (Dunder)

Distillery waste (dunder) from the Appleton Rum Distillery in the Cockpit Country sub-catchment is channeled to a sink-hole at the base of the north facing slopes of the Nassau Mountain. This dunder travels via conduit flow through the Nassau Mountain to pollute a spring of the North Elim River in the Upper Morass. The polluted North Elim River flows into the Grass River from which it is lifted into the Black River. The dunder enriched Black River flows through the Lower Morass to exit into the sea at the town of Black River.

Dunder is responsible for low dissolved oxygen levels. The affected rivers produce a foul odour and the high nutrient load caused profilic water-hyacinth growth which blocks the rivers and restricting boat travel. These effects are significant during periods of low river flow. The impact of this dunder has been the subject of a study by NRCD. The chemical and physical character of the dunder is summarised in Table B-11, reprinted from the Harza report (1977) for ease of reference.

The nutrient value of the dunder enriched Black River, particularly its nitrogen and phosporous content, may have a beneficial impact on the agricultural development of the Lower Morass. Nutrient levels in the streams which drain the Lower Morass were reported by PCJ (1983) and are considered in greater detail in Annex G, (Agriculture).

(b) Caustic Soda Enriched Effluent

The existance at one time of a bauxite/alumina plant at Revere (Cockpit Country sub-catchment) reportedly caused significant contamination of the Black River. The plant was permanently closed in 1975 and it therefore no long impacts on water quality within the Black River Basin.

4.4 Saltwater Intrusion Study

4.4.1 Tidal fluctuation

Within the Lower Morass the Black River, Broad River and probably to a lesser extent the Y.S. and Middle Quarters Rivers are affected by tidal fluctuations. The continuous automatic stage recorder on the Black River at its estuary (i.e. at the town of Black River) has essentially functioned as a tide gauge since its commissioning in 1955.

Hourly measurements taken at a non-recording tide guage within Black River Bay over a 24-hour period were compared to tide fluctuation recorded at recorder stations on the Black River at estuary and the Broad River at Salt Spring bridge. The fluctuations within Black River Bay were found to be directly equivalent in phase and amplitude to that at the Black River estuary. There was a 3-hour delay in the fluctuations recorder in the Broad River. A maximum 45 cm amplitude in tide fluctuations was observed.

The existence of river bed elevations below mean sea level and low river flow combine to permit the intrusion of seawater considerable distances inland along the bottom of these rivers. PCJ (1983) reported intrusion of saline water in the Black River and Broad River distances of up to 9 km upstream of the sea. During periods of high river flow the intruded seawater wedges are forced to retreat to the estuary of the Black River. This situation was confirmed by depth/ conductivity measurements within the Black and Broad Rivers on September 8, 1984. These latter mentioned data are summarized in Table B-12.

The back water effect resulting from the seawater intrusion has been recorded in the Black River at Lacovia, 20 km upstream of its estuary, during periods of low river flow. A 3-hour time lag between tide peaks at the Black River estuary and the Broad River at Salt Spring bridge was determined this Study. It appears likely that the Middle Quarters River and the Y.S. River also exhibit tidal fluctuations due to the back water effect.

The reduction in intermediate flows has implication for saltwater intrusion of the river system for slightly longer periods than presently observed. The study mentioned hereafter aims at estimating the extent of saltwater intrusion into the rivers under the future condition, and accordingly evaluating the impact of irrigation water intake on the rivers.

4.4.2 Basic conditions for analysis

The saltwater intrusion is influenced by the tide levels at the rivermouth, river discharge and river channel sections. The following conditions are taken into considerations for the present study :

1) Tide level : Mean high water level is observed about 0.34 m above mean sea level. Mean low water level is about 0.10 m above mean sea level.

2) River discharge : 3 cases of discharge on the Black River. Maximum monthly mean discharge 32 m^3/sec., minimum monthly mean discharge 10 m^3/sec. and minimum monthly mean discharge minus irrigation water intake (3 m^3/sec) 4 m^3/sec. 2 cases of discharge on the Broad River. Maximum monthly mean discharge 4 m^3/sec. and minimum monthly mean discharge 0.4 m^3/sec.

3) River channel : Existing channel. Cross sections are surveyed every 500 m on the Black River and every 1,000 m on the Broad River approximately.

4.4.3 Computation

In the computation of saltwater intrusion, the points to be taken into account were; resistance between freshwater and river bed and/or river sides; change of river cross sections in the river. The following equations are developed in Japan. (Reference 11)

$$eh_{1a} + \frac{Q_1^2}{2g\ A_{1a}^2} \left(1 - \frac{K_a\ (R_{1a} + R_{2a})}{2R_{1a} \cdot R_{2a}} D\right)$$

$$= eh_{1b} + \frac{Q_1^2}{2g\ A_{1b}^2} \left(1 + \frac{K_b\ (R_{1b} + R_{2b})}{2R_{1b} \cdot R_{2b}} D\right) \quad \ldots\ldots \quad (4\text{-}4)$$

$$K = \frac{f_i\ R_1 + \left(f_i\ \frac{B2}{B_1} + \frac{2\ n^2 g\ B_o}{R_1^{1/3}\ B_1}\right) R_2}{R_1 + R_2} \quad \ldots\ldots\ldots\ldots\ldots \quad (4\text{-}5)$$

where : Q_1 is freshwater discharge

A_1 is flow area of freshwater layer

B_2 is length of interface between saltwater and freshwater

B_o is length of river sides and river bed of freshwater layer

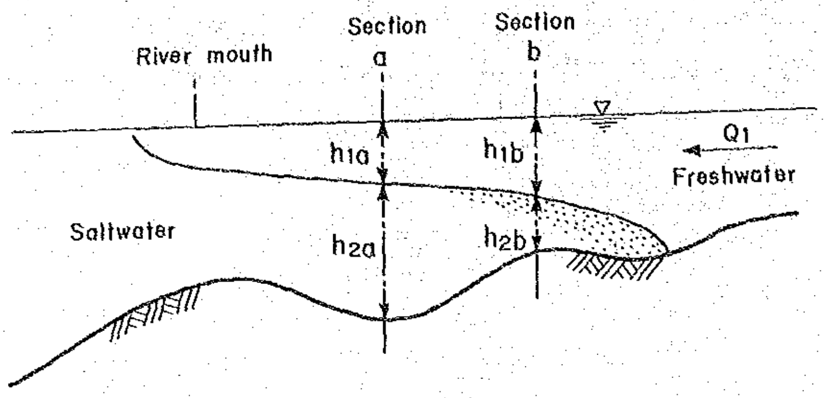
B_1 is $B_2 + B_o$, wetted perimeter of freshwater layer, nearly equal to water surface

R_1 is A_1 / B_1, R_2 is A_2 / B_2

n is roughness coefficient of river sides and river bed in Manning's formula

D is distance between section a and section b, suffix a and b indicate value at section a and section b respectively

f_i is coefficient of resistance between freshwater and saltwater layers, the value is assumed according to the observation result on the Black and Broad Rivers (Reference 7)



The computation was made by an electronic computer. Based on the results shown in Fig. B-14, the tip of saltwater wedge will reach at about 9 km upstream from the river mouth on the Black River. Accordingly, no serious problem is expected at proposed Lacovia pumping station which is located at about 18 km upstream from the river mouth.

On the other hand, the tip of the saltwater wedge on the Broad River extends about 5 km as shown on Fig. B-14. However saline water is likely to diffuse into freshwater due to the quite low river flow (0.4 m^3/sec.). Accordingly, the shape of saltwater wedge is more indistinct than that on the Black River. Based on the investigation carried out by PCJ, it would seem that saline water intrudes upto 9 km upstream on the Broad River. Therefore, use of the Broad River and Middle Quarters River as sources of irrigation water will necessitate the implementation of counter measures to control saline water intrusion at the respective intake sites.