4) Estuary - Middle Quarters

This area consists of three sub-areas, i.e. (1) the wetland of about 660 ha on the right bank of the Middle Quarters River, (2) the wetland of about 1,460 ha spreading over the estuary of the Black River including the wetland along the Broad River downstream of Salt Spring Bridge and (3) the upland Luana area of about 560 ha including Black River town (40 ha). Both weltlands are covered with Morass Peat of two types. One is in a low decomposition phase and the other is in a sulfidic phase. Both of them are classified as marginally suitable for cultivation. In Luana, there are four major soil types. About 380 ha covered with such clayey soils as Four Paths loam are classified as suitable for irrigated farming for both rice culture and upland crops. In most of these lands, at present, pastures are predominant by grown for not only livestock farming but also dairy-farming. Thus, this area was excluded from the selection of area to be developed under this proejct.

2.3 Water Resources Development

2.3.1 Water resources

In the Lower Morass area, there flow four major rivers, i.e., the Black River as a main stream in the area, Y.S. River, Middle Quarters River and Broad River. Among them, the Black and Y.S. Rivers have a stable surface runoff. The annual mean runoff of the Black River was estimated at 19.2 m^3/sec (678 cusec) or 650 x $10^6 m^3$ at Lacovia and that of the Y.S. River as 4.7 m^3/sec (166 cusec) or 148 x $10^6 m^3$ at a place near the Middle Quarters through the hydrological analysis (see Annex B) for the period from 1964 to 1982.

Many springs, so called blue holes and wells are observed in the project area. One group of such blue holes is to be found by the Middle Quarters River in the western part and another by the Broad River in the eastern part of the project area. No discharge data are available for either the Middle Quarters River or the Broad River. The annual mean discharge was roughly estimated at about 0.2 m^3/sec for the Middle Quarters River and about 1.4 m^3/sec for the Broad River as given in Annex B. For six months in the year there is virtually no discharge at all. Thus due to the small and irregular discharge of these two rivers it is questionable whether these essentially groundwater sources can be used except for irrigating small isolated plots.

Furthermore there would be even more saltwater intrusion from the sea during the dry season that at present due to irrigation water uptake. Construction costs would be very high in relation to the benefits obtainable. Therefore these two rivers will not be employed as sources of irrigation.

The net irrigable area was estimated to be about 560 ha on the right bank of the Black River. The main water source for this area would be the Y.S. River. The water taken from the Y.S. River would flow down to the area by gravity.

The Black River would be the water source for the area on its left bank as well as for the areas on both banks of the Broad River. Pumping up of water to a height of about 5 m would be required since the water level of the Black River is lower than the ground surface elevation during low flow period.

2.3.2 Water balance

1) The Y.S. River

Although the annual average runoff of the Y.S. River was estimated to be about 4.7 m^3/sec, its monthly runoff varies widely. The minimum 5-year 20-day low flows in a month are estimated to be as low as 0.24 m^3/sec in March, 0.29 m^3/sec in April and so on. On the other hand, the maximum 5-year monthly mean diversion requirement for paddy and soya beans of the Black River right bank area was estimated to be 0.45 m^3/S in June as described in the following Section 3.2. A balance has to be struck between the minimum 5-year 20-day low flows and maximum 5-year monthly mean diversion requirement as shown in following table. In April, the river flow would only be enough to irrigate, 500 ha of spring rice fields. But 560 ha of fall rice and soya beans could be fully irrigated.

Unit: m^3/sec

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Minimum 5-year 20-day low flows											
0.63	0.42	0.24	0.29	1.79	1.93	2.20	3.48	4.09	4.43	2.60	1.28
Maximum 5-year monthly mean diversion requirement											
0.27	0.40	0.24	0.27	0.38	0.45	0.24	0.27	0.34	0.16	0.22	0.21
Balance											
0.36	0.02	0.00	0.02	1.41	1.48	1.96	3.21	3.75	4.27	2.38	1.07

2) The Black River

The minimum 5-year 20-day low flows were estimated at 6.9 m^3/sec at Lacovia in April, which is about two times the total diversion requirement for the Black River left bank area and the Broad River right and left bank areas. The monthly water balance is shown below.

Unit: m^3/sec

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Minimum 5-year 20-day low flows											
8.8	7.6	7.2	6.9	11.6	11.2	10.8	13.0	18.0	17.9	17.5	11.5
Maximum 5-year monthly mean diversion requirement											
0.11	0.15	0.61	3.16	3.42	3.40	0.73	1.20	2.80	2.43	1.95	0.13
Balance											
8.6	7.4	6.5	3.7	8.1	7.8	10.0	11.8	15.2	15.4	15.5	11.3

As seen above, the Black River, would have ample water after supplying irrigation water for the whole development area in the Lower Morass and meet the requirements in the Pedro Plains Agricultural Development Project (about 1.7 m^3/sec).

2.4 Study of Alternative Development Plans

2.4.1 Basic considerations

In the project formulation, the following basic considerations were made:

1) Water resources

In the Lower Morass area, there flow four major rivers, i.e. the Black River main stream, the Y.S. River, the Middle Quarters River and the Broad River. Among them, both the Black River and the Y.S. River have an ample perennial flow for irrigation water supply, while the Middle Quarters and Broad Rivers have a quite limited flow.

2) Pedro Plain Agricultural Development Project

The Pedro Plain has quite a high potential for agricultural development if irrigation water is available. Because of a severe shortage of irrigation water, the present area developed for agriculture has to be limited to about 670 ha only. Consequently, diversion of water from the Black River to the Pedro Plain has been contemplated but the plan was suspended due to the considerable cost of the necessary headreach canal from the Black River to project area.

The net area proposed for irrigation in the surface water alternative is about 1,840 ha (4,600 acres) in total, including the Eastern Region (1,320 ha) and the Western Region (520 ha)[1/]. According to NWC, the maximum diversion water requirement for the Pedro Plains is 1.70 m^3/sec (60 cusec) consisting of 1.13 m^3/sec (40 cusec) for the Eastern Region and 0.57 m^3/sec (20 cusec) for the Western Region for the critical net irrigation requirements 4.3 mm/day or 0.5 lit/sec/ha (5.26 inch/month) in May. These diversion water volumes have to be pumped up at the proposed Lacovia pump station. The design discharge of pumps is about 5.12 m^3/sec (3.42 m^3/sec for the Lower Morass and 1.70 m^3/sec for the Pedro Plains).

1/: A Review of Irrigation Proposals for the Pedro Plains, May 1982, A.B. Hall, J.M.L. Mehra and D.G. Henry, Irrigation and Drainage Department, National Water Commission (hereinafter called "NWC").

2.4.2 Economic comparison on alternative plans

1) Alternative 1 (Full development plan)

This alternative plan covers four sub-areas to be developed as mentioned in the previous Section 2.2. The total irrigation area would be about 3,080 ha (7,700 ac) in net, of which 560 ha (1,400 ac) would be irrigated with water of the Y.S. River to be conveyed by gravity through the proposed Holland Main Canal (3.2 km). The peak diversion water requirement of this area of 560 ha was estimated to be 0.45 m^3/sec in June and would be taken by the proposed intake weir on the Y.S. River. Irrigation water for the left bank area of the Black River and the area located on both banks of the Broad River would be pumped up by the proposed Lacovia pump station and then diverted to the field through irrigation canals. The peak diversion requirement of these areas of 2,520 ha (6,300 ac) was estimated to be 3.42 m^3/sec in May. The irrigation water taken by the Lacovia pumping station on the Black River would be diverted to two main irrigation canals, i.e. Slipe Main Canal and Mountainside Main Canal. The Slipe Main Canal covers the Hatfield area, Styx River area, Frenchman-Holiday Pen area and a part of the Broad River right bank area. The Mountainside Main Canal covers the Broad River left bank area and the remaining Broad River right bank area. The irrigation canal layout is shown in Fig. I-2 and Alternative 1 is shown in Fig. I-3. The length of the Slipe Main Canal is estimated to be about 5.2 km and total length of secondary canals branched off from the Slipe Main Canal was estimated to be about 15.4 km. The length of the Mountainside Main Canal would be 8.8 km and total length of secondary canals would be 5.1 km approximately.

In addition to the above, irrigation water for the Pedro Plains (1.7 m^3/sec) would be taken at the Lacovia pumping station and be conveyed by the Slipe Main Canal and the Mountainside Main Canal of which flow capacities would have to be increased. The discharge of 0.57 m^3/sec for the Western Region would be released at Salt Spring Bridge into the Broad River via the Slipe Main Canal. An additional secondary canal of about 2.4 km long would be necessary. The remaining 1.13 m^3/sec for the Eastern Region would be conveyed to Mountainside via the Mountainside Main Canal. This will require approximately 1.5 km of additional secondary canal branching off from the Mountainside Main Canal. The major irrigation facilities required and construction cost estimated for this plan are shown in Tables I-3 and I-4 respectively as the Alternative 1-a.

2) Alternative 2 (Medium scale development plan)

Both the Black River right and left bank areas would be developed as same as the Alternative 1. The Broad River right bank area is to be developed while, from the environmental conservation viewpoint, the Broad River left bank area is to be maintained as it is. Total irrigation area is 2,280 ha (5,700 ac) in net, including 560 ha of the Black River right bank area. The peak diversion requirement for remaining area, which is to be pumped up by the proposed Lacovia pumping station, was estimated to be 2.27 m^3/sec. The length of the Slipe Canal would be about 5.2 km and the total length of secondary canals would be about 8.7 km. Irrigation water for the Pedro Plain, if required, would be diverted to the Broad River through the Slipe Main Canal.

3) Alternative 3 (Small scale development plan)

In order to minimize the environmental impact due to the agricultural development in the Lower Morass area, only both banks of the Black River will be developed. Total irrigation area would be about 1,480 ha (3,700 ac). The Black River right bank area (560 ha) is developed as same as the Alternative 1.

The remaining 920 ha comprise the Hatfield, Styx River and Frenchman-Holiday Pen areas. The peak diversion requirement would be about 1.16 m^3/sec which is to be pumped up by the proposed Lacovia pumping station. The Slipe Main Canal of 5.2 km long and secondary canals of about 12.3 km in total were proposed. No measures on diverting water to the Pedro Plain area were envisaged.

4) Alternative 4 (Black River diversion plan)

This alternative was derived from the Alternative 3. In order to maximize total irrigation area on both banks of the Black River, the Black River main stream is to be diverted to the Broad River at about 1 km downstream of the Lacovia bridge by constructing a diversion dike and canal. The required height and width of the dike on both sides of the Black River would be lower than those for Alternatives 1 to 3. Accordingly, there would be an increase of about 20 ha in net irrigation area. Although the height of the dike along both banks of the Black River can be lowered by about 1.0 m, considerable amounts of embankment for a diversion dike and rock excavation for diversion channel to the Broad River basin would be required, resulting in substantial increase in construction cost. Moreover, because the flood flow from the Black River would have a quite high sediment load, the unique ecosystem of the Broad River basin, in particular, the aquatic vegetation associated with the Blue Holes could be seriously damaged. On the other hand, the Pedro Plain could benefit from increased irrigation water in the Broad River if an inlet channel were provided.

5) Economic comparison

A comparative study on the development scale was made for the above four alternative plans as shown in Fig. I-3. The major required irrigation facilities are described in Table I-3, and construction costs are summarized in Table I-4. The net benefits to be expected are shown in Table I-5. The economic comparison was made in terms of EIRR, NPV and B/C for three alternatives, 1, 2 and 3. The Alternative 4 was omitted from the economic comparison since extremely high construction cost would be required for diversion works from the Black River to the Broad River. The following table shows the result of the economic comparison.

	Unit	Alternative Development Plan		
		1	2	3
Net irrigation area	ha	3,080	2,280	1,480
Net irrigation area	acre	7,700	5,700	3,700
Economic construction cost	10^3US$	33,570	25,480	17,110
Annual benefit	10^3US$	8,130	6,120	4,380
EIRR	%	13.4	14.1	15.6
NPV (at 10%)	10^3US$	11,010	9,840	8,660
B/C (at 10%)	10^3US$	1.3	1.4	1.5
Production of paddy	ton/year	29,000	21,800	14,600
Foreign exchange saving	10^3US$/year	3,000	2,300	1,500

As shown in the above table, the economic viability of "Alternative 1" is slightly lower than that of "Alternative 2" and "Alternative 3". The total production of rice (unhusked) after the full development in case of "Alternative 1" is, however, expected to be substantially greater than that of the other two alternatives. Besides, additional benefits to the Pedro Plain Project could be expected through diverting irrigation water from the irrigation facilities of "Alternative 1". Consequently, it is recommended that "Alternative 1" be developed.

3. IRRIGATION PLAN

3.1 General

3.1.1 Irrigation method

The crops proposed for the Project are paddy and soya bean. The flood irrigation method is recommended for rice cultivation and furrow irrigation method for soya bean.

In general, for both flood and furrow irrigation methods, it is preferable to adopt the gravity irrigation. Various diversion plans were first studied for gravity irrigation in the light of available water, geographic location of water source and seasonal distribution of the riverflow of both the Y.S. and Black Rivers.

Based on the results of the analysis of the data on hydrology, topography, soils, geology, etc., a gravity irrigation system diverting water from the Y.S. River was planned to be provided for lowlying area in the Holland Estate. Another gravity system with low head pumps taking water from the Black River for both the Broad River Basin and the left bank area of the Black River would be practicable.

Following are the irrigation systems proposed:

(Unit: ha)

Irrigation System/Area	Area to be Developed	
	Gross	Net
1. Y.S. Intake System	680	560
2. Lacovia Pump System	3,200	2,520
2.1 Black River Left Bank area	1,200	920
2.1.1 Hatfield sub-area	300	220
2.1.2 Styx River sub-area	400	300
2.1.3 Frenchman-Holiday pen sub-area	500	400
2.2 Broad River Right Bank area	1,000	800
2.3 Broad River Left Bank area	1,000	800
Total	3,880	3,080

In addition to the above, an alternative plan (Alternative 1-a) for conveyance of irrigation water to the Pedro Plain Project was also studied in Section 2.4.2.

3.1.2 Function and requirement of canal

1) Main canal

The principal function of the main canal would be to deliver irrigation water from an intake or a pump station to the development area in the shortest or in the most economical way. The main canal would have a trapezoidal cross section lined with concrete.

2) Secondary and sub-secondary canal

A secondary canal would branch off from the main canal and command a secondary unit which would be divided into one to several tertiary units. The size of a secondary unit area would vary from place to place depending on the topography. A sub-secondary canal would branch off from the secondary canal and cover a tertiary unit located far from the secondary canal due to topographic conditions. Both the secondary and sub-secondary canals would be lined with concrete like the main canal.

3) Tertiary canal

A tertiary unit would include a tertiary canal and one to several farm ditches. The appropriate maximum size of one tertiary unit was judged to be 100 ha. In any case, each farm ditch would be branched off from a tertiary canal and not from a secondary or a main canal. All tertiary canals would be lined with soil cement.

4) Farm ditch

A farm ditch would cover a farm unit of 20 ha, in which rotation irrigation would be made for about 5 days. The design discharge was estimated to be a constant 40 ℓ/sec from the beginning end point. The length of the farm ditch would depend on topography but, on an average, it would be 1,000 m approximately. Based on the comparative study mentioned in Annex J, all farm ditches would be lined with soil cement.

3.2 Irrigation Water Requirement

3.2.1 Measurement of water consumption

The crops proposed for the project are paddy and soya beans. There were no data on evapotranspiration (ET) and percolation rate (Pr) in and around the project area. During the paddy growing period from late July to mid-October 1984, measurement of both evapotranspiration and percolation in the paddy field were made to collect data for estimation of water requirement by using portable measuring pans. Measuring pans were installed in two places. One was in the paddy field beside the meteorological station of BRUMDEC and the other in a lowlying land in the Holland Estate where rice is planted. The measurement was made every day. However, un-controlled irrigation and drainage interrupted often the measurement, especially in the Holland Estate. The results of the measurement are shown in Table I-6.

As may be seen in Table I-6, evapotranspiration from paddy ranges from 3.5 to 6.7 mm/day which is close to the normal level usually observed in paddy growing countries. The percolation rate in BRUMDEC and Holland Estate is as low as 1.1 mm/day and 0.9 mm/day respectively, even lower than that in Meylersfield, which is 1.4 mm/day according to "Recommendations for Soil and Water Management of the Meylersfield Wet Polder", Rural Physical Planning Unit (hereinafter called "RPPU"), Ministry of Agriculture (hereinafter called "MOA"), October 1980.

3.2.2 Methodology

The measurement data of evapotranspiration were available for 2 - 3 months only, but they are reasonably close to the amounts estimated hereunder. The irrigation water requirements were therefore estimated on the basis of climatic data for the proposed crops, paddy rice and soya beans. Irrigation water requirements for these crops were individually estimated by the following procedure.

1) Paddy

- Estimate consumptive use of water (Cu) by paddy by the product of potential evapotranspiration (ETo) and crop coefficient (Kc) varying with growth stage.
- Estimate percolation loss (Pr) in paddy field for flood irrigation.
- Estimate effective rainfall (ER) and pre-irrigation water requirement (Pi), as the direct-sowing method after pre-germination will be adopted.
- If the transplanting method be adopted, estimated water requirements for the nursery period (Nw) and puddling works (Pw) would be used instead of Pi.
- Calculate total water demand (Dw) as follows:

$$Dw = Cu + Pr + Pi$$

$$\text{or } Dw = Cu + Pr + Nw + Pw$$

- Calculate net water requirement (Nr) as,

$$Nr = Dw - ER$$

- Calculate diversion water requirement (gross water requirement in other words = Gr) dividing Nr by overall irrigation efficiency (Ei).

$$Gr = Nr/Ei$$

2) Upland Crops (soya beans)

- Estimate consumptive use of water (Cu) by crop by same method as for paddy.
- Estimate effective rainfall (ER) and pre-irrigation water requirement (Pi)
- Estimate net irrigation requirement (Nr), as

$$Nr = Cu + Pi - ER$$

- Estimate diversion water requirement (Gr) dividing (Nr) by overall irrigation efficiency (Ei).

3.2.3 Consumptive use of water by crops

Consumptive use of water by crops is estimated from the potential evapotranspiration (ETo) calculated from climatic data and crop coefficient (Kc) relating crop growth stages. To estimate potential evapotranspiration for water requirement from climatic data, four methods are suggested in "Irrigation and Drainage Paper No.24 - Guidelines for Predicting Crop Water Requirement" revised issue by FAO in 1977. They are "Modified Blaney - Criddle", "Radiation", "Modified Penman" and "Pan Evaporation" methods.

The climatic data necessary for estimating the potential evapotranspiration in the project area are available at Crawford Meteorological Stations, and summarized in Annex B. Using these climatic data, potential evapotranspiration is estimated and shown on Table I-7 together with Class -A pan evaporation as well as recommended evapotranspiration from both open water surface and non crop land.

The choice of method to be used for calculating water requirements depends upon the availability of reliable data. It is generally said that the Modified Penman method (annual average is 5.0 mm/day ranging from 3.9 mm/day in December to 5.9 mm/day in May) offers the best results for predicting mean crop water requirements for a period as short as 10 days, while Blaney-Criddle method (annual averages is 3.8 mm/day ranging from 3.2 mm/day in December to 4.4 mm/day in June) should not be used either in equatorial regions where temperatures remain fairly constant but other weather parameters will change or for small islands where air temperature is generally a function of the surrounding sea temperature showing little response to seasonal change in radiation. Accordingly, the following potential evapotranspiration (ETo) were estimated for project study using the Modified Penman method (see Table I-8).

Unit : mm/day

	J	F	M	A	M	J	J	A	S	O	N	D
ETo	4.0	4.4	5.2	5.6	5.9	5.6	5.8	5.5	4.8	4.7	4.1	3.9

Taking FAO's recommendation in above mentioned "Irrigation and Drainage Paper" into consideration, the crop coefficient (Kc) for proposed crops were estimated for each month based on the proposed cropping pattern in Annex G and results are given in Table I-9.

Consumptive use of water by proposed crops is estimated as the product of ETo and Kc, as shown in Tables I-10 to I-13 for paddy and Table I-17 for soya beans.

3.2.4 Percolation rate and other requirement

As described in section 3.2.1, the percolation rate in the paddy field was measured to be about 1.0 mm/day. However, the observed field was clay soils in which the infiltration ratio is usually as low as 10^{-5} cm/sec in terms of permeability. Most of the irrigable land is covered with either clayey mineral soil or peat. In general, permeability of peat ranges from 10^{-3} to 10^{-5} cm/sec and its moisture holding capacity is as high as 700 to 1,200%. The percolation rate of peat will be as high as 10 - 50 mm/day. However, when standing water in the field is kept as low as possible or head between water surfaces of the field and drain is low, percolation rate could be maintained as low as necessary with high moisture holding capacity. It is usually recommended that the percolation rate be kept between 5 to 10 mm/day for paddy cultivation. As these percolated water discharges finally into drains in the project area, it is desirable to keep percolation rate as low as possible to reduce drainage pump capacity as well as costs of operation.

Taking these conditions into account, the percolation rate is estimated at 1.0 mm/day for mineral soil and 5.0 mm/day for peat/peaty soil in the project area.

On the rained paddy fields without irrigation facilities, paddy cultivation is usually commenced after sufficient rainfall for soil on the paddy field to become saturated and suitably for rice cultivation.

On the other hand, in irrigated agriculture, land preparation and sowing should be commenced without awaiting such rainfall.

Water requirement for pre-saturation and standing water for paddy rice as well as pre-irrigation for upland crops were estimated as follows:

1) Mineral soil for paddy

- Soil depth	300 mm
- Void ratio (Porosity) of soil	50 %
- Soil vapour phase after saturation	5 %
- Soil moisture before water supply	15 %
- Water required to saturate soil	
300 x (50 - 5 - 15)/100 =	90 mm
- Standing water	30 mm
Total water requirement	120 mm

2) Peat soil for paddy

- Soil depth	300 mm
- Void ratio of peat at natural dry condition*	92.3 %
- Solid materials of peat in dry condition	7.7 %
- Density of solid materials	1.3 g/cm^3
- Water content at natural dry condition	
(before water supply) In weight	700 %
In volume 700 x 0.077 x 1.3	70 %
- Void ratio of peat in water	94.9 % 1/
- Solid materials of peat in water	5.1 %
- Vapour phase after saturation	5 %
- Water required to saturate peat	
300 x (94.9 - 70 - 5)/100 = 59.7 say	60 mm
- Standing water	30 mm
Total water requirement	90 mm

1/: Average of all samples tested (see Annex H)

3) Mineral soil for Upland crops

- Soil Depth	300 mm
- Field capacity of soil	35 %
- Soil moisture before irrigation (After rice cultivation)	25 %
- Water required for first irrigation in paddy field 300 x (35 - 25)/100	30 mm
- Soil moisture before regular irrigation	22 %
- Water required for regular irrigation 300 x (35 - 22)/100	40 mm
- Soil moisture before irrigation after fallow	15 %
- Water required for first irrigation 300 x (35 - 15)/100	60 mm

3.2.5 Effective rainfall

There are various methods for estimating effective rainfall. In general, effective rainfall estimated from daily water/moisture balance method offers the best result for predicting water requirements. The dependable rainfall efficiency of each soil and each crop was computed by this method based on the daily rainfall data of several rainfall stations. The computation was done in all years of data available, then results obtained were averaged. As a result, for paddy rainfall efficiency of peat soil area is higher than that of mineral soil area and that of fall crop than spring crop. For soya beans, the rainfall efficiency varies from 65% to 75%.

Basic conditions for water/moisture balance calculation are;

1) A daily rainfall of more than 5 mm and less than 100 mm for paddy fields and of more than 5 mm and less than 40 mm for upland fields are effective,

2) 25 mm for paddy and 0 mm for upland field are adopted as a lower limit of field water/moisture level to be kept, and 100 mm for paddy and 60 mm for upland field are adopted as the upper limit,

3) 75 mm for paddy and 40 mm for upland fields are irrigation water applications to one interval,

4) Irrigation intervals are estimated as 5 days for paddy and 10 days for upland crop (soya bean),

5) Percolation rate, potential evapotranspiration, water requirements for pre-irrigation and standing water and crop coefficients (Kc) have been discussed in previous sections.

The average rainfall efficiency was estimated as shown in the following table.

Rainfall Efficiency

Unit: %

Soils/Crop	Rainfall Station			
	Holland	Lacovia	Black River	Burnt Savannah
Mineral Soil				
Spring rice	70	80	90	85
Fall rice	75	75	80	70
Soya bean	70	65	75	75
Peat Soil				
Spring rice	75	80	90	90
Fall rice	85	85	85	80

To meet the varied climatic conditions over the project area and the Lower Morass area, the effective rainfall at each following station is applied for the respective sub-areas shown in Fig. I-1.

Rain gauge station	Sub-area of irrigation area
Holland	Holland (mineral soil)
	Frenchman-Holiday Pen (peat soil)
Lacovia	Hatfield (mineral soil)
	Styx River basin (peat soil)
Burnt Savannah	Broad River basin (peat soil)

Monthly effective rainfall was estimated as product of monthly dependable rainfall and rainfall efficiency for each crop of each area. The dependable monthly and annual rainfall is given in Annex B and the estimated effective rainfall in Table I-18.

3.2.6 Irrigation efficiency

Irrigation efficiency depends on the irrigation methods used for application and both operation and conveyance efficiencies. The irrigation efficiency for each crop is assessed as follows:

1) Application loss

The proposed land use plan of the project is paddy field. Flood irrigation methods with continuous water supply will be practised for rice cultivation. As percolation loss is included in the net water requirement, no application losses are considered. Whereas, for upland crops (soya bean) in paddy fields of mineral soil, the furrow irrigation method is recommended. It is assumed for the present study that 30% of water supplied will be lost during application.

2) Conveyance loss and operation loss

During conveyance of water from an intake to field, seepage or leakage and evaporation from canal and canal operation losses occur. The magnitude of such losses depends on the type of canal and canal operation and maintenance. Taking into account these conditions for the project the following losses are adopted.

- Main canal with provision of lining 5%
- Lateral open channel 10%

3) Overall irrigation efficiency

On the above assumptions, the overall irrigation efficiency (Ei) is estimated as a product of Application efficiency (Ea), operation efficiency (Eo) and conveyance efficiency (Ec) on Table I-14 and summarized below.

(Unit : %)

Irrigation Method	Ea	Eo	Ec	Ei
Flooding	100	80	85	68 say 70
Furrow	70	80	85	48 say 50

3.2.7 Diversion water requirement

The diversion water requirements, gross water requirements in other words, for the proposed cropping pattern in the project area are estimated based on the effective rainfall with dependability of 80%.

Unit diversion water requirement (Gr) of respective crops are calculated by dividing the net water requirement (Nr) by the overall irrigation efficiency (Ei) as shown in Tables I-15 to I-17.

Monthly peak diversion water requirements, which should be used as unit design discharge per ha for determination of the capacity of the proposed irrigation facilities, range from 0.90 lit/s/ha to 1.45 lit/s/ha depending on the soil and effective rainfall as shown below:

Sub-area	Monthly peak "Gr" Lit/s/ha	Occurrence
Holland (mineral soil)	0.90	June
Hatfield (mineral soil)	0.96	June
Styx River basin (peat soil)	1.45	May
Frenchman-Holiday Pen (peat soil)	1.29	Apr.
Broad River basin (peat soil)	1.44	May

The peak diversion water requirement is, thus, estimated at 0.45 m^3/sec for Holland from the Y.S. River in June, and 3.42 m^3/sec for whole area locating on the left bank of the Black River which have to be served by water pumped up from the Black River at Lacovia in May, as shown in Table I-19.

3.3 Irrigation Systems

3.3.1 Y.S. intake system

There is an existing intake structure about 1.5 km upstream of the highway (Bamboo Avenue) crossing of the Y.S. River. The intake structure is a simple primitive concrete weir of rectangular shape of which crest level is about El. 10.00 m. There is no intake gate at the head of the canal. Upstream reaches of the canal have an adequate carrying capacity for the large amount of water flowing into the canal but all of the water which flows into the canal returns to the Y.S. River through two diversion channels and a broken syphon at about 700 m from the intake.

The existing canal is located along the hill skirt on the left bank of the Y.S. River. Near the highway crossing of the Y.S. River, the canal crosses the highway at about 1.5 km downstream from the intake. Canal bed level at the highway crossing was observed to be El. 7.00 m.

With rehabilitation of these existing canal systems, about a net 560 ha in Holland can be brought under gravity irrigation. As described in section 2.3.2, however, the available discharge in April is limited and only 500 ha of spring rice field can be safely irrigated. While 560 ha of fall rice and soya beans can be fully irrigated.

The system proposed consists of an intake structure to be constructed newly, a concrete lined main canal of 3.2 km and twelve secondary and sub-secondary canals of 11.1 km in total length. The design discharge of the main canal would be 0.45 m^3/sec based on the peak diversion water requirement in the month of May, as shown in Fig. I-4.

3.3.2 Lacovia pump up system

1) Pump station

Three alternative sites i.e., Lacovia, Frenchman and Holiday Pen were studied for a pumping station. Both Frenchman and Holiday Pen sites are rather far from the Black River main stream where construction of an intake channel is necessary. In addition, irrigation water for

Hatfield will need to be boosted again at the hill skirt of Hatfield. At Holiday Pen, it is expected that river water will be affected by salinity intrusion from the estuary during the dry season. Taking above circumstances into consideration, site proposed at the Lacovia pump station is on the left bank of the Black River about 1.6 km downstream from the Lacovia Bridge on the Santa Cruz - Black River Road.

The peak diversion water requirement to be pumped is estimated to be 3.42 m^3/sec in May, while an additional 1.7 m^3/sec would be required for pedro plain. Four 700 mm pumps diameter would be necessary with two additional pumps of the same diameter for the Pedro Plain water supply.

2) Irrigation canals

The irrigation water pumped up would be distributed to respective irrigation area through two main irrigation canals i.e., the Slipe Main Canal and the Mountainside Main Canal of about 14.0 km in total and 14 major secondary canals.

The Slipe Main Canal which convey irrigation water to Hatfield, Styx River basin, Frenchman-Holiday Pen and most of Broad River right bank areas will be aligned on the ridge of hills lying between the Black River and Lacovia - Cataboo Road and then along this road across the Styx River and swamps along the Styx River. Three secondary canals would branch off in Hatfield for both Hatfield and Styx River basin. Another secondary canal for the Styx River basin and 3 secondary canal for Frenchman Holiday Pen would branch off to the right, while 2 secondary canals for Broad River right bank area would branch off to the left side. Length of the Slipe Main Canal is about 5.2 km and total length of secondary canals branching off from it will be about 15.4 km.

The Mountainside Main Canal for remaining Broad River right bank area and left bank area of the Broad River will run on the mountain skirt along Lacovia - Mountainside Road. Three secondary canals will branch off from it. The length of the Mountainside Main Canal is 8.8 km and total length of secondary canals is 5.1 km approximately. Irrigation network is shown in Fig. I-5.

Table I-1 IRRIGABLE AREA IN THE BLACK RIVER LOWER MORASS

(Unit: ha)

Area/Sub-Area	Project Area	Total Irrigable Area	Area to be developped (Paddy) Gross	Area to be developped (Paddy) Net	Upland Gross
1. Black River Right Bank					
Lacovia	260	-	-	-	-
Holland	1,700	1,200	680	560	520
(Elevated land)	(730)	(550)	(30)	(20)	(520)
(Lowlying land)	(970)	(650)	(650)	(540)	(0)
Y.S. River Basin	580	-	-	-	-
Total	2,540	1,200	680	560	520
2. Black River Left Bank					
Hatfield	370	300	300	220	-
Styx River Basin	410	400	400	300	-
Frenchman-Holiday Pen	800	500	500	400	-
Island (Slipe-Cataboo)	740	-	-	-	-
Total	2,320	1,200	1,200	920	0
3. Broad River Basin					
Right Bank	1,290	1,000	1,000	800	-
Left Bank	1,300	1,000	1,000	800	-
Mountain Skirt	760	-	-	-	-
Vineyard/Arlington	560	-	-	-	-
Total	3,910	2,000	2,000	1,600	0
4. Estuary-Middle Quarters					
M.Q. River Right Bank	660	-	-	-	-
Luana (with Black River Town)	560	315	-	-	315
Black/Broad Estuary	1,460	-	-	-	-
Total	2,680	315	0	0	315
Grand Total	11,450	4,715	3,880	3,080	835

Table I-2 PRESENT LAND USE OF HOLLAND ESTATE

(Unit: ha (Acres))

Description	Low Lying	Flat/Slope Elevated				Total
	Below	El. 1.00 - 3.00 m			Above	
	El. 1.00 m	Flat	Slope	Sub-total	El. 3.00 m	
Whole Area of the Estate	670	300	190	490	740	1,900 (4,750)
Northern Area than Bamboo Ave.	0	0	0	0	200	200 (500)
Area in the Project Area	670	300	190	490	540	1,700 (4,250)
Present Land Use in the Project Area						
Factory and quarters	0	0	0	0	20	20 (50)
Cane field	70	220	160	390	460 2/	910 (2,275)
Paddy/Swamp fallow	90	20	0	20 1/	0	110 (275)
Grassland/fallow	40	50	30	80	60	180 (450)
Swamp	170 3/	10	0	10	0	180 (450)
Sub-total	370	300	190	490	540	1,400 (3,500)
Undeveloped swamp and forest between the Y.R. River and the Black River	300	0	0	0	0	300 (750)

Remarks: 1/: Paddy field along the Y.S. River

2/: Inclusive of cane field (50 ha) on the right bank of the Y.S. River

3/: Inclusive of undeveloped swamp (40 ha) along the Black River at east end

Table I-3 IRRIGATION FACILITIES OF ALTERNATIVES

Description	Unit	Case 1	Case 2	Case 3	Case 1-a
1. Total irrigation area	ha	3,080	2,280	1,480	4,380
2. Lacovia pump station					
2.1 Design discharge	m^3/s	3.42	2.27	1.12	5.12
2.2 Irrigation pump					
- Type		Mixed flow			
- Diameter	mm	700	700	500	700
- Number	set	4	3	3	6
- Capacity of power unit	kW	120	120	60	110
- Total capacity	kW	360	240	120	550
3. Main canal					
3.1 Mountainside main canal					
- Design discharge	m^3/s	1.44-0.59	-	-	2.57-0.59
- Total length	km	8.8	-	-	8.8
3.2 Slipe main canal					
- Design discharge	m^3/s	1.98-0.63	1.98-0.63	1.16-0.24	2.55-1.20
- Total length	km	5.2	5.2	5.2	5.2
3.3 Holland main canal					
- Design discharge	m^3/s	0.45-0.31	0.45-0.31	0.45-0.31	0.45-0.31
- Total length	km	3.2	3.2	3.2	3.2
4. Secondary canal					
4.1 Design discharge	m^3/s	0.57-0.02	0.57-0.02	0.57-0.02	1.28-0.02
4.2 Total length	km	31.6	30.1	21.4	35.5

Table I-4 THE PROJECT COST OF ALTERNATIVES

(Unit: $1x10^3$US$)

Capital Cost		Case 1		Case 1-a (with Pedro Plain)		Case 2		Case 3	
		F.C.	L.C.	F.C.	L.C.	F.C.	L.C.	F.C.	L.C.
1. Direct construction cost									
Holland	560 ha	2,300	1,510	2,300	1,510	2,300	1,510	2,300	1,510
Black River Left	920 ha	5,060	2,390	5,170	2,430	5,060	2,390	5,060	2,390
Broad River Right	800 ha	3,840	1,760	4,060	1,850	3,840	1,760	-	-
Broad River Left	800 ha	3,870	1,910	4,040	2,090	-	-	-	-
Office & Quarters		720	780	720	780	580	620	360	390
Sub-total		15,790	8,350	16,290	8,660	11,780	6,280	7,720	4,290
2. O & M equipment		830	-	830	-	660	-	580	-
3. General expense		-	400	-	400	-	320	-	280
4. Compensation cost for land acquisition		-	730	-	730	-	480	-	400
5. Engineering services		4,316	745	4,316	745	3,453	596	2,158	373
Sub-total		5,146	1,875	5,146	1,875	4,113	800	2,738	1,053
Total		20,936	10,225	21,436	10,535	15,893	7,080	10,458	5,343
6. Physical contingency		2,094	1,025	2,144	1,055	1,587	0.700	1,042	537
Total		23,030	11,250	23,580	11,590	17,480	7,780	11,500	5,880
(F.C + L.C)		(34,280)		(35,170)		(25,260)		(17,380)	

Table I-5 ANNUAL BENEFITS OF EACH ALTERNATIVE

(Unit: J$$10^3$)

Section	1 (3,080 ha)	2 (2,280 ha)	3 (1,480 ha)
I. Black River Right			
1. Net Production Value			
- Without project	263	263	263
- With project	8,169	8,169	8,169
2. Net Incremental Benefit	7,906	7,906	7,906
II. Black River Left			
1. Net Production Value			
- Without project	41	41	41
- With project	10,101	10,101	10,101
2. Net Incremental Benefit	10,060	10,060	10,060
III. Broad River Right			
1. Net Production Value			
- Without project	0	0	-
- With project	7,691	7,690	-
2. Net Incremental Benefit	7,691	7,690	-
IV. Broad River Left			
1. Net Production Value			
- Without project	0	-	-
- With project	7,691	-	-
2. Net Incremental Benefit	7,691	-	-
V. Total Net Incremental Benefit	33,348	25,656	17,966

Table I-6 OBSERVED EVAPOTRANSPIRATION AND PERCOLATION RATE

	BRUMDEC					HOLLAND		
	A-Pan	ET	ET/Pan rate	Pr.	Rainfall	ET	Pr.	Rainfall
	mm/d	mm/d		mm/d	mm	mm/d	mm/d	mm
	Measurement commenced on 29 July, 1984					Commenced on 19 July, 1984		
Late July	n.a.	3.5	*	1.5	53.4	4.4	0.6	122
Early Aug.	n.a.	4.9	*	0.8	28.2	6.7	1.3	75
Mid Aug.	6.8	6.6	0.97	1.1	75.0	6.4	1.1	41
Late Aug.	4.6	5.0	1.09	0.9	11.8	6.5	1.2	39
Monthly/Average	5.6	5.5	0.98	0.9	115.0	6.5	1.2	155
Early Sept.	4.7	5.1	1.09	0.5	56.4	6.1	1.0	36
Mid Sept.	5.2	6.1	1.17	1.2	84.6	5.7	0.6	81
Late Sept.	3.7	6.0	1.62	1.2	52.0	5.5	0.5	96
Monthly/Average	4.5	5.7	1.27	1.0	193.0	5.8	0.7	213
Early Oct.	6.6	6.7	1.02	1.1	169.2	5.0	1.0	186
Mid Oct.	3.7 1/	4.7 1/	1.27	1.4 1/	33.0 1/	*	*	*
Total/Average	5.6 1/	6.0 1/	1.07	1.2 1/	202.2 1/	5.0 2/	1.0 2/	186 2/
Average	5.1	5.4	1.06	1.1	-	5.8	0.9	-

Remarks: 1/: As of 15 Oct., 1984.
2/: As of 10 Oct., 1984.

Table I-7 POTENTIAL EVAPOTRANSPIRATION (ETo)

(Unit: mm/day)

Methods	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Average
Modified Blaney-criddl method	3.3	3.2	3.6	3.9	4.2	4.4	4.3	4.1	4.0	3.6	3.4	3.2	3.77
Radiation method	3.8	4.1	4.7	5.0	5.1	4.8	5.1	4.9	4.4	4.4	3.8	3.6	4.48
Modified Penman method *	4.0	4.4	5.2	5.6	5.9	5.6	5.8	5.5	4.8	4.7	4.1	3.9	4.96
Pan evaporation method	3.6	3.8	4.2	4.6	4.8	4.6	4.2	4.2	4.0	3.8	3.2	3.2	4.02
A - Pan Evaporation	4.8	5.1	5.6	6.1	6.4	6.1	5.6	5.6	5.3	5.1	4.3	4.3	5.36
ETo from Open water surface	4.4	4.9	5.7	6.2	6.5	6.2	6.4	6.1	5.3	5.2	4.5	4.3	5.48
ETo from Non crop land	1.8	1.9	2.3	3.6	4.3	3.2	3.7	4.1	3.8	3.7	2.6	2.0	3.08

Remarks: ETo is estimated based on the climate date at Crawford described in Annex A.

*: ETo estimated by the modified Penman method is used for the study.

Table I-8 CALCULATION OF POTENTIAL EVAPOTRANSPIRATION

Modified Penman Method	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1. Data[1/]												
1) Mean Temperature, Tmean (°C)	24.9	23.5	24.8	25.4	26.2	26.9	26.6	26.4	26.5	26.4	26.1	25.3
2) Relative Humidity, RHmax. (%)	87	89	89	87	88	85	88	90	91	91	90	89
RHmin. (%)	75	77	76	75	76	75	76	77	78	77	76	75
3) Wind Speed, U (km/day)	89	113	102	106	107	126	98	89	76	67	74	91
4) Sunshine Duration (hrs/day)	7.8	7.8	7.9	8.1	8.1	7.3	8.1	7.5	6.6	7.6	7.3	7.6
2. Calculation												
1) Vapour Pressure												
i) ea at Tmean (mbar)[2/]	31.5	29.0	31.3	32.5	34.0	35.5	34.9	34.4	34.7	34.4	33.8	32.3
ii) ed = ea x RHmean/100 (mbar)	23.6	22.3	23.3	24.3	25.7	26.6	26.5	26.3	26.9	26.5	25.7	24.2
iii) ea − ed (mbar)	7.9	6.7	7.5	8.2	8.3	8.9	8.4	8.1	7.8	7.9	8.1	8.1
2) Wind Function, f(u) = 0.27(1+u/100)	0.51	0.58	0.15	0.56	0.56	0.61	0.53	0.51	0.48	0.45	0.47	0.52
3) Weighting Factor												
i) W at Tmean[2/]	0.74	0.73	0.74	0.74	0.75	0.76	0.76	0.75	0.76	0.75	0.75	0.74
ii) 1-W	0.26	0.27	0.26	0.26	0.25	0.24	0.24	0.25	0.24	0.25	0.25	0.26
4) Net Radiation												
i) Extra Terrestrical Radiation, Ra (mm/day)[2/]	11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1
ii) Solar Radiation,[3/] Rs = (0.25+0.5·n/N)·Ra (mm/day)	7.0	7.6	8.5	8.9	9.1	8.5	9.0	8.6	7.7	7.8	6.9	6.6
iii) Net Short Wave Radiation, Rns = 0.75·Rs (mm/day)	5.2	5.7	6.3	6.7	6.8	6.4	6.8	6.5	5.8	5.8	5.2	4.9
iv) f (Tmean)[2/]	15.5	15.2	15.5	15.6	15.8	16.0	15.9	15.8	15.9	15.8	15.8	15.6
v) f (ed)[2/]	0.13	0.13	0.13	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.12	0.12
vi) f (n/N)[2/]	0.73	0.71	0.69	0.68	0.66	0.60	0.66	0.63	0.58	0.68	0.68	0.72
vii) Net Long Wave Radiation, Rnl = f(Tmean)·f(ed)·f(n/N) (mm/day)	1.4	1.4	1.3	1.3	1.2	1.1	1.2	1.1	1.0	1.2	1.3	1.4
viii) Net Radiation, Rn = Rns − Rnl (mm/day)	3.8	4.3	5.0	5.4	5.6	5.3	5.6	5.3	4.8	4.6	3.9	3.6
5) Adjustment Factor, c[2/]	1.04	1.06	1.08	1.09	1.09	1.07	1.09	1.09	1.07	1.07	1.05	1.04
6) Potential Evapotranspiration, ETo = C·[W·Rn+(1-W)·f(u)·(es−ed)] (mm/day)	4.0	4.4	5.2	5.6	5.9	5.6	5.8	5.5	4.8	4.7	4.1	3.9

Remarks: 1/: Data at Crawford, average during 9 years from 1974 to 1982.

2/: Refer to tables in Crop Water Requirements FAO Irrigation and Drainage Paper No. 24.

3/: n/N is assumed in accordance with above reference.

Table I-9 CROP COEFFICIENT (Kc)

Rice

Spring Rice

(1) In mineral soil

	Apr.	May	Jun.	Jul.	Aug.
Early plant	1.10	1.10	1.05	0.98	-
Late plant	-	1.10	1.10	1.08	1.00
Average	1.10	1.10	1.08	1.03	1.00

(2) In peat soil

	Mar.	Apr.	May	Jun.	Jul.	Aug.
Early plant	1.10	1.10	1.08	1.00	-	-
Late plant	-	1.10	1.10	1.05	0.98	0.95
Average	1.10	1.10	1.09	1.03	0.98	0.95

Fall Rice

	Aug.	Sep.	Oct.	Nov.	Dec.
Early plant	1.10	1.10	1.03	0.95	-
Late plant	-	1.10	1.10	1.08	1.08
Average	1.10	1.10	1.07	1.02	1.00

Soy Bean

	Dec.	Jan.	Feb.	Mar.	Apr.
Early plant	0.5	0.90	0.85	-	-
Late plant	-	0.40	0.75	1.00	0.70
Average	0.5	0.65	0.80	1.00	0.70

Table I-10 NET WATER REQUIREMENT OF SPRING RICE ON MINERAL SOIL

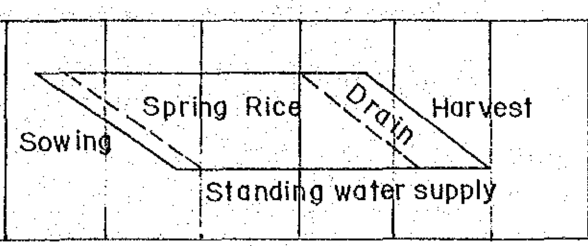
Description		Apr.	May	Jun.	Jul.	Aug.	Sep.	Total
Holland Hatfield								
Planting Area (1)		1/6	5/6	1.0	23/24	3/8	0	
Irrigating Area (2)		1/6	5/6	1.0	5/8	1/24	0	
Eto (3)	mm/day	5.6	5.9	5.6	5.8	5.5	4.8	
Kc (4)		1.10	1.10	1.08	1.03	1.00	-	
Cu. (3) x (4)	mm/day	6.2	6.5	6.0	6.0	5.5	-	
Monthly Cu. (5)	mm	186	202	180	186	171	-	
(2) x (5)	mm	31	168	180	116	7	-	502
(1) x (5)	mm	(31)	(168)	(180)	(178)	(64)	-	(621)
Pr. (6)	mm	30	31	30	31	31	-	
Monthly demand								
(7) = (5) + (6)	mm	216	233	210	217	202	-	
Effective rainfall (8)								
Holland	mm	61	129	51	77	107	114	
Lacovia	mm	43	93	40	56	134	127	
Net water requirement (7) - (8)								
Holland (9)	mm	155	104	159	140	95	-	
(2) x (9)	mm	26	87	159	88	4	-	364
Pre-irrigation & standing water	mm	68	52	-	-	-	-	120
Total	mm	94	139	159	88	4	-	484
Hatfield (10)	mm	173	140	170	161	68	-	
(2) x (10)	mm	29	117	170	101	3	-	420
Pre-irrigation & standing water	mm	68	52	-	-	-	-	120
Total	mm	97	169	170	101	3	-	540

Table I-11 NET WATER REQUIREMENT OF FALL RICE ON MINERAL SOIL

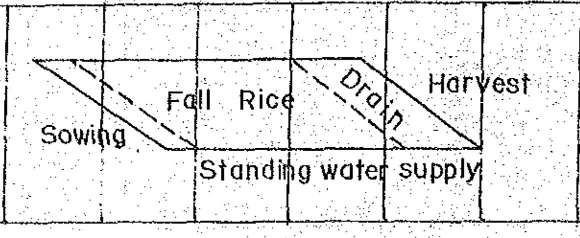
Description		Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Total
Holland Hatfield								
Planting Area (1)		1/6	5/6	1.0	23/24	3/8	0	
Irrigating Area (2)		1/6	5/6	1.0	5/8	1/24	0	
Eto (3)	mm/day	55	48	4.7	4.1	3.9	4.0	
Kc (4)		1.10	1.10	1.07	0.99	0.95	-	
Cu. (3) x (4)	mm/day	6.1	5.3	5.0	4.1	3.7	-	
Monthly Cu. (5)	mm	189	159	155	123	115	-	
(2) x (5)	mm	32	133	155	77	5	-	402
(1) x (5)	mm	(32)	(133)	(155)	(118)	(43)	-	(481)
Pr. (6)	mm	31	30	31	30	31	-	
Monthly demand								
(7) = (5) + (6)	mm	220	189	186	153	146	-	
Effective rainfall (8)								
Holland	mm	115	123	133	42	23	16	
Lacovia	mm	126	119	155	39	6	15	
Net water requirement (7) - (8)								
Holland (9)	mm	105	66	53	111	123	-	
(2) x (9)	mm	18	55	53	69	5	-	200
Pre-irrigation & standing water	mm	68	52	-	-	-	-	120
Total	mm	86	107	53	69	5	0	320
Hatfield (10)	mm	92	70	31	114	140	-	
(2) x (10)	mm	15	58	31	71	6	-	181
Pre-irrigation & standing water	mm	68	52	-	-	-	-	120
Total	mm	83	110	31	71	6	0	301

Table I-12 NET WATER REQUIREMENT OF SPRING RICE ON PEATY SOIL

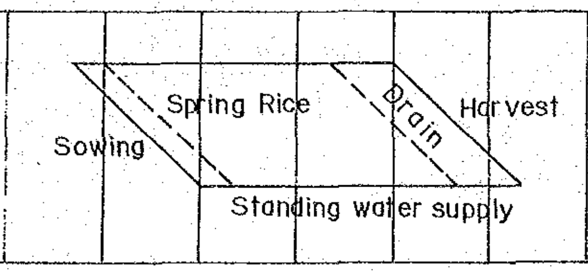
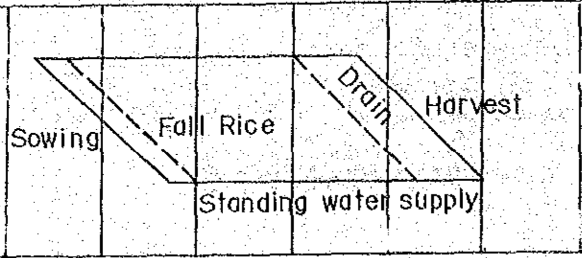
Description		Mar.	Apr.	May	Jun.	Jul.	Aug.	Total
Frenchman-Holiday Pen Styx River Basin Broad River Basin		 						
Planting Area (1)		1/24	5/8	1.0	1.0	5/8	1/24	
Irrigating Area (2)		1/24	5/8	1.0	5/6	1/6	0	
Eto (3)	mm/day	5.2	5.6	5.9	5.6	5.8	5.5	
Kc (4)		1.10	1.10	1.09	1.03	0.98	0.95	
Cu. (3) x (4)	mm/day	5.7	6.2	6.4	5.8	5.7	5.2	
Monthly Cu. (5)	mm	177	186	198	174	177	161	
(2) x (5)	mm	7	116	198	145	30	-	496
(1) x (5)	mm	(7)	(116)	(198)	(174)	(111)	(7)	(613)
Pr. (6)	mm	155	150	155	150	155	155	
Monthly demand (7) = (5) + (6)	mm	332	336	353	324	442	316	
Effective rainfall (8)								
Holland	mm	15	69	138	54	82	115	
Lacovia	mm	11	43	93	40	56	134	
Burnt Savannah	mm	36	57	94	24	46	122	
Net water requirement (7) - (8)								
Frenchman (9)	mm	317	270	215	270	250	201	
(2) x (9)	mm	13	169	215	225	42	0	664
Pre-irrigation & standing water	mm	28	58	4	-	-	-	90
Total	mm	41	227	219	225	42	0	754
Styx River (10)	mm	321	293	260	284	276	182	
(2) x (10)	mm	13	183	260	237	46	0	739
Pre-irrigation & standing water	mm	28	58	4	-	-	-	90
Total	mm	41	241	264	237	46	0	829
Broad River (11)	mm	296	270	259	300	286	144	
(2) x (11)	mm	12	174	259	250	48	0	743
Standing water	mm	28	58	4	-	-	-	90
Total	mm	40	232	263	250	48	0	833

Table I-13 NET WATER REQUIREMENT OF FALL RICE ON PEATY SOIL

Description		Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Total
Frenchman-Holiday Pen								
Styx River Basin								
Broad River Basin								



Description		Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Total
Planting Area (1)		1/6	5/6	1.0	23/24	3/8	0	
Irrigating Area (2)		1/6	5/6	1.0	5/8	1/24	0	
Eto (3)	mm/day	5.5	4.8	4.7	4.1	3.9	4.0	
Kc (4)		1.10	1.10	1.07	0.99	0.95	-	
Cu. (3) x (4)	mm/day	6.1	5.3	5.0	4.1	3.7	-	
Monthly Cu. (5)	mm	189	159	155	123	115	-	
(2) x (5)	mm	32	133	155	77	5	-	402
(1) x (5)	mm	32	133	155	(118)	(43)	-	(481)
Pr. (6)	mm	155	150	155	150	155	-	
Monthly demand (7) = (5) + (6)	mm	344	309	310	273	270	-	
Effective rainfall (8)								
Holland	mm	130	139	151	48	26	18	
Lacovia	mm	142	135	175	45	6	17	
Burnt Savannah	mm	108	104	102	44	12	3	
Net water requirement (7) - (8)								
Frenchman (9)	mm	214	170	159	225	244	-	
(2) x (9)	mm	36	142	159	141	10	-	488
Pre-irrigation & standing water	mm	49	41	-	-	-	-	90
Total	mm	85	183	159	141	10	-	578
Styx River (10)	mm	202	174	135	228	264	-	
(2) x (10)	mm	34	145	135	143	11	-	468
Pre-irrigation & standing water	mm	49	41	-	-	-	-	90
Total	mm	83	186	135	143	11	-	558
Broad River (11)	mm	236	205	208	229	258	-	
(2) x (11)	mm	39	171	208	143	11	-	572
Standing water	mm	49	41	-	-	-	-	90
Total	mm	88	212	208	143	11	-	662

Table I-14 IRRIGATION EFFICIENCY

(Unit: %)

Description	Flood	Furrow
Conveyance Losses		
In main canal		
Concrete lining canal	5	5
Pipeline	-	-
In lateral canals		
Open channel	10	10
Pipeline	-	-
Total losses	15	15
Conveyance Efficiency, Ec	85	85
Operation Losses	20	20
Operation Efficiency, Eo	80	80
Application Losses	0 1/	30
Application Efficiency, Ea	100	70
Overall Irrigation Efficiency		
Ei = Ec x Eo x Ea	68	48

Remarks: 1/: Percoration loss is included in net water requirement.

Table I-15 GROSS IRRIGATION WATER REQUIREMENT OF SPRING RICE

Mineral Soil		Apr.	May	Jun.	Jul.	Aug.	Total
Holland							
Nr.	mm	94	139	159	88	4	484
Gr. = Nr/Ei	mm	138	204	234	129	6	711
	mm/day	4.60	6.58	7.80	4.16	0.19	-
	lit/s/ha	0.53	0.76	0.90*	0.48	0.02	-
Hatfield							
Nr.	mm	97	169	170	101	3	540
Gr. = Nr/Ei	mm	143	249	250	149	4	795
	mm/day	4.77	8.03	8.33	4.81	0.13	-
	lit/s/ha	0.55	0.93	0.96*	0.56	0.02	-

Peat		Mar.	Apr.	May	Jun.	Jul.	Total
Frenchman & Holiday Pen							
Nr.	mm	41	227	219	225	42	754
Gr. = Nr/Ei	mm	60	334	322	331	62	1,109
	mm/day	1.94	11.13	10.39	11.03	2.00	
	lit/s/ha	0.22	1.29	1.20	1.28	0.23	
Styx River Basin							
Nr.	mm	41	241	264	237	46	829
Gr. = Nr/Ei	mm	60	354	388	349	68	1,219
	mm/day	1.94	11.80	12.52	11.63	2.19	
	lit/s/ha	0.22	1.37	1.45*	1.35	0.25	
Broad River Basin							
Nr.	mm	40	232	263	250	48	833
Gr. = Nr/Ei	mm	59	341	387	368	71	1,226
	mm/day	1.90	11.37	12.48	12.27	2.29	
	lit/s/ha	0.22	1.32	1.44*	1.42	0.27	

Remarks: *: Peak monthly requirement in a year

Irrigation Efficiency Ei = 68%

Table I-16 GROSS IRRIGATION WATER REQUIREMENT OF FALL RICE

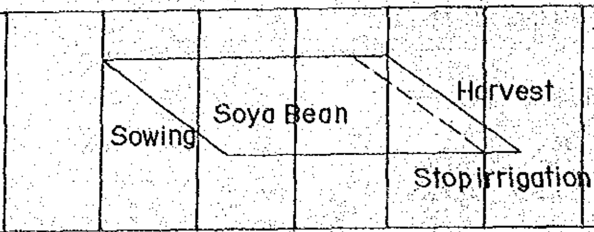
Mineral Soil		Aug.	Sep.	Oct.	Nov.	Dec.	Total
Holland							
Nr.	mm	86	107	53	69	5	320
Gr. = Nr/Ei	mm	126	157	78	101	7	469
	mm/day	4.06	5.23	2.52	3.37	0.23	
	lit/s/ha	0.47	0.61	0.29	0.39	0.03	
Hatfield							
Nr.	mm	83	110	31	71	6	301
Gr. = Nr/Ei	mm	122	162	46	104	9	443
	mm/day	3.94	5.40	1.48	3.47	0.29	
	lit/s/ha	0.45	0.63	0.17	0.40	0.03	

Peat		Aug.	Sep.	Oct.	Nov.	Dec.	Total
Frenchman & Holiday Pen							
Nr.	mm	85	183	159	141	10	578
Gr. = Nr/Ei	mm	125	269	234	207	15	850
	mm/day	4.03	8.97	7.55	6.90	0.48	
	lit/s/ha	0.47	1.04*	0.87	0.80	0.06	
Styx River Basin							
Nr.	mm	83	186	135	143	11	558
Gr. = Nr/Ei	mm	122	274	199	210	16	821
	mm/day	3.94	9.13	6.42	7.00	0.52	
	lit/s/ha	0.46	1.06	0.74	0.81	0.06	
Broad River Basin							
Nr.	mm	88	212	208	143	11	662
Gr. = Nr/Ei	mm	129	312	306	210	16	973
	mm/day	4.16	10.40	9.87	7.00	0.52	
	lit/s/ha	0.48	1.20	1.14	0.81	0.06	

Remarks: *: Peak monthly requirement in a year.

Irrigation Efficiency Ei = 68%

Table I-17 WATER REQUIREMENT OF SOYA BEAN

Description		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total
Holland Hatfield								
Planting area (1)		-	3/8	23/24	1.0	5/8	1/24	
Irrigating area (2)		-	3/8	23/24	23/24	3/8	0	
Eto (3)	mm/day	4.1	3.9	4.0	4.4	5.2	5.6	
Kc (4)		-	0.50	0.65	0.80	1.00	0.70	
Cu (3) x (4)	mm/day	-	2.0	2.6	3.5	5.2	3.9	
Monthly Cu. (5)	mm	-	62	81	98	161	117	
(2) x (5)	mm	-	(23)	(78)	94	60	0	255
(1) x (5)	mm	-	23	78	(98)	(101)	(5)	(305)
Effective rainfall (6)								
Holland	mm	39	21	15	10	14	61	
Lacovia	mm	34	5	13	18	9	35	
Net water requirement (5) - (6)								
Pre. irrigation	mm	-	30	-	-	-	-	30
Holland (7)	mm	-	41	66	88	147	56	
(1) x (7)	mm	-	15	63	84	55	0	
Total	mm	-	45	63	84	55	-	247
Hatfield (8)	mm	-	57	68	80	152	82	
(1) x (8)	mm	-	21	65	77	57	0	
Total	mm	-	51	65	77	57	-	250
Gross water requirement								
Holland								
Monthly	mm	-	94	131	175	115	0	515
Daily	mm/day	-	3.03	4.23	6.25	3.71	0	
	(lit/s/ha)	-	0.35	0.49	0.72	0.43	0	
Hatfield								
Monthly	mm	-	106	135	160	119	0	520
Daily	mm/day	-	3.42	4.35	5.71	3.84	0	
	(lit/s/ha)	0	0.40	0.50	0.66*	0.44	0	

Remarks: Irrigation efficiency = 48% for furrow irrigation

*: monthly maximum

Table I-18 MONTHLY EFFECTIVE RAINFALL

(Unit: mm)

Station/Description		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Rainfall
Holland (80% Dependable)		22	15	20	88	185	73	110	154	164	178	57	31	1,640
Mineral Soil Paddy	1st crop	15	10	14	61	129	51	77	107	114	124	39	21	-
Mineral Soil Paddy	2nd crop	16	11	15	66	138	54	82	115	123	133	42	23	-
Peaty Soil Paddy	1st crop	16	11	15	66	138	54	82	115	123	133	42	23	-
Peaty Soil Paddy	2nd crop	18	12	17	74	157	62	93	130	139	151	48	26	-
Soya Bean		15	10	14	61	129	51	77	107	114	124	39	21	-
Lacovia (80% Dependable R.)		21	29	14	54	117	50	70	168	159	207	53	8	1,387
Mineral Soil Paddy	1st crop	16	23	11	43	93	40	56	134	127	166	42	6	-
Mineral Soil Paddy	2nd crop	15	21	10	40	87	37	52	126	119	155	39	6	-
Peaty Soil Paddy	1st crop	16	23	11	43	93	40	56	134	127	166	42	6	-
Peaty Soil Paddy	2nd crop	17	24	11	45	99	42	59	142	135	175	45	6	-
Soya Bean		13	18	9	35	76	32	45	109	103	134	34	5	-
Black River		4	14	16	27	93	24	56	102	80	87	57	6	973
Mineral Soil Paddy	1st crop	3	12	14	24	83	21	50	91	72	78	51	5	-
Mineral Soil Paddy	2nd crop	3	11	12	21	74	19	44	81	64	69	45	4	-
Peaty Soil Paddy	1st crop	3	12	14	24	83	21	50	91	72	78	51	5	-
Peaty Soil Paddy	2nd crop	3	11	13	22	79	20	47	86	68	73	48	5	-
Soya Bean		3	10	12	20	69	18	42	76	60	65	42	4	-
Burnt Savannah		4	25	40	64	105	27	52	136	130	128	55	15	1,340
Mineral Soil Paddy	1st crop	3	21	34	54	89	22	44	115	110	108	46	12	-
Mineral Soil Paddy	2nd crop	2	17	28	44	73	18	36	95	91	89	38	10	-
Peaty Soil Paddy	1st crop	3	22	36	57	94	24	46	122	117	115	49	13	-
Peaty Soil Paddy	2nd crop	3	20	32	51	84	21	41	108	104	102	44	12	-
Soya Bean		3	18	30	48	78	20	39	102	97	96	41	11	-

Table I-19 MONTHLY DIVERSION WATER REQUIREMENT

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Remarks
1. Y.S. River Intake													
Holland, 560 ha													
Unit requirement													
Spring Rice (500 ha)	-	-	-	0.53	0.76	0.90	0.48	0.02	-	-	-	-	
Fall Rice	-	-	-	-	-	-	-	0.47	0.61	0.29	0.39	0.03	
Soya Bean	0.49	0.72	0.43	0	-	-	-	-	-	-	-	0.35	
Total (lit/sec/ha)	0.49	0.72	0.43	0.53	0.76	0.90*	0.48	0.49	0.61	0.29	0.39	0.38	
Diversion requirement (m^3/sec)	0.27	0.40	0.24	0.27	0.38	0.45*	0.24	0.27	0.34	0.16	0.22	0.21	
Dependable discharge of the Y.S. River (m^3/sec)	0.63	0.42	0.24	0.29	1.79	1.93	2.20	3.48	4.09	4.43	2.60	1.28	1/
2. Black River Pump-up													
Black River Left Bank Area, 920 ha													
-Hatfield, 220 ha													
Unit requirement													
Spring Rice	-	-	-	0.55	0.93	0.96	0.56	0.02	-	-	-	-	
Fall Rice	-	-	-	-	-	-	-	0.45	0.63	0.17	0.40	0.03	
Soya Bean	0.50	0.66	0.44	0	-	-	-	-	-	-	-	0.40	
Sub-total (lit/s/ha)	0.50	0.66	0.44	0.55	0.93	0.96*	0.56	0.47	0.63	0.17	0.40	0.43	
Diversion requirement (m^3/sec)	0.11	0.15	0.10	0.12	0.20	0.21*	0.12	0.10	0.14	0.04	0.09	0.09	
-Styx River Basin, 300 ha													
Unit requirement													
Spring Rice	-	-	0.22	1.37	1.45	1.35	0.25	0	-	-	-	-	
Fall Rice	-	-	-	-	-	-	-	0.46	1.06	0.74	0.81	0.06	
Sub-total (lit/s/ha)	0	0	0.22	1.37	1.45*	1.35	0.25	0.46	1.06	0.74	0.81	0.06	
Diversion requirement (m^3/sec)	0	0	0.07	0.41	0.44*	0.41	0.08	0.14	0.32	0.22	0.24	0.02	
-Frenchman-Holiday Pen, 400 ha													
Unit requirement													
Spring Rice	-	-	0.22	1.29	1.20	1.28	0.23	0	-	-	-	-	
Fall Rice	-	-	-	-	-	-	-	0.47	1.04	0.87	0.80	0.06	
Sub-total (lit/s/ha)	0	0	0.22	1.29	1.20	1.28*	0.23	0.47	1.04	0.87	0.80	0.06	
Diversion requirement (m^3/sec)	0	0	0.09	0.52*	0.48	0.51*	0.09	0.19	0.42	0.35	0.32	0.02	
Total (Diversion requirement)	0.11	0.15	0.26	1.05	1.12	1.13*	0.29	0.43	0.88	0.61	0.65	0.13	
Broad River Basin, 1,600 ha													
Unit requirement													
Spring Rice	-	-	0.22	1.32	1.44	1.42	0.27	0	-	-	-	-	
Fall Rice	-	-	-	-	-	-	-	0.48	1.20	1.14	0.81	0.06	
Total (lit/s/ha)	0	0	0.22	1.32	1.44*	1.42	0.27	0.48	1.20	1.14	0.18	0.06	
Diversion requirement													
Right bank, 800 ha	0	0	0.17	1.05	1.50	1.13	0.22	0.33	0.96	0.91	0.65	0.05	
Left bank, 800 ha	0	0	0.18	1.06	1.50	1.14	0.22	0.34	0.96	0.91	0.65	0.05	
Total (m^3/sec)	0	0	0.35	2.11	2.30*	2.27	0.44	0.77	1.92	1.82	1.30	0.10	
Total Diversion Requirement for Lacovia Pump Station (m^3/sec)	0.11	0.15	0.61	3.16	3.42	3.40*	0.73	1.20	2.80	2.43	1.95	0.13	
Dependable discharge of the Black River (m^3/sec)	8.8	7.6	7.2	6.9	11.6	11.2	10.8	13.0	18.0	17.9	17.5	11.5	1/

Remarks: 1/: See Annex A

* : Peak monthly requirement

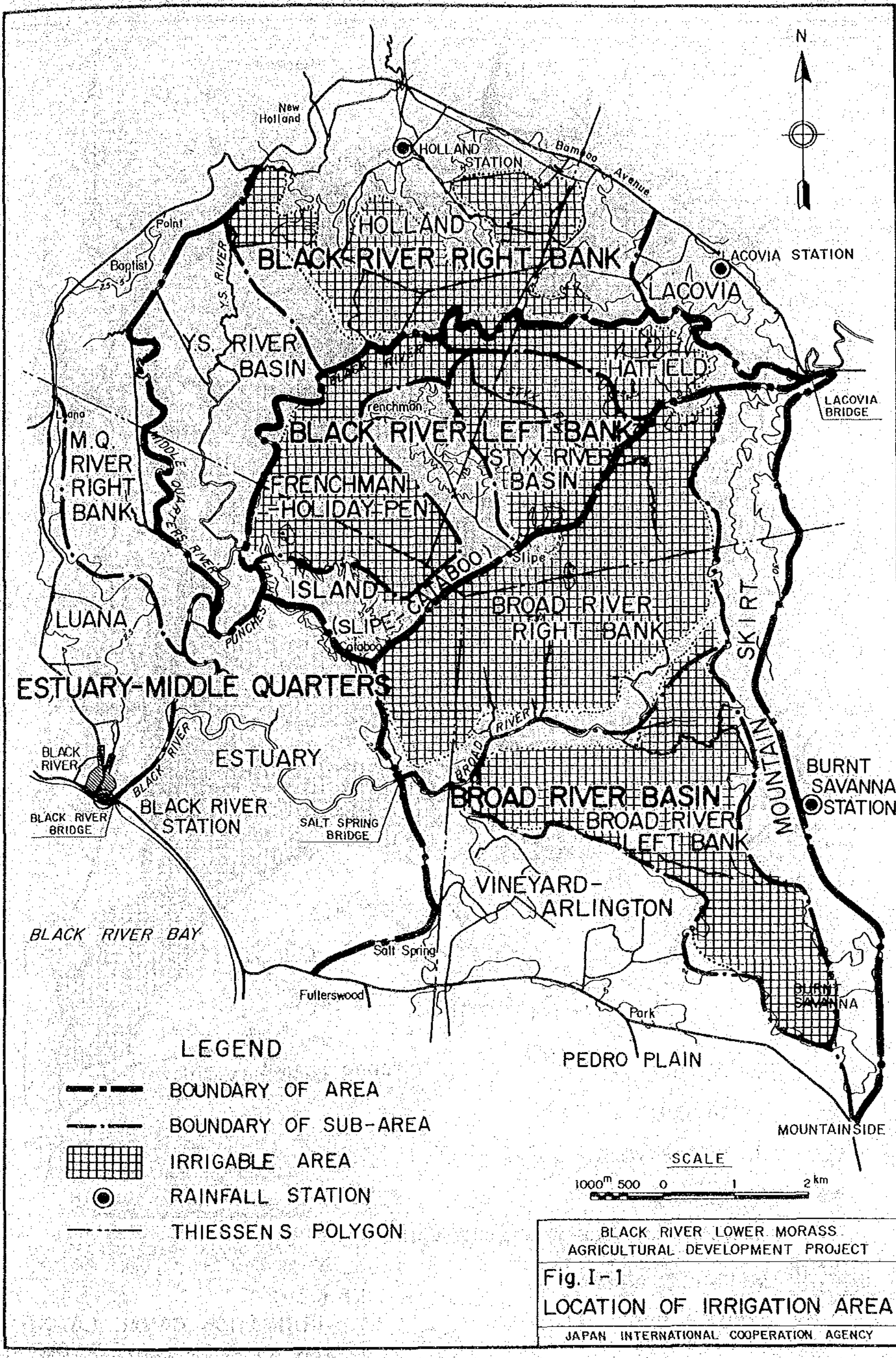
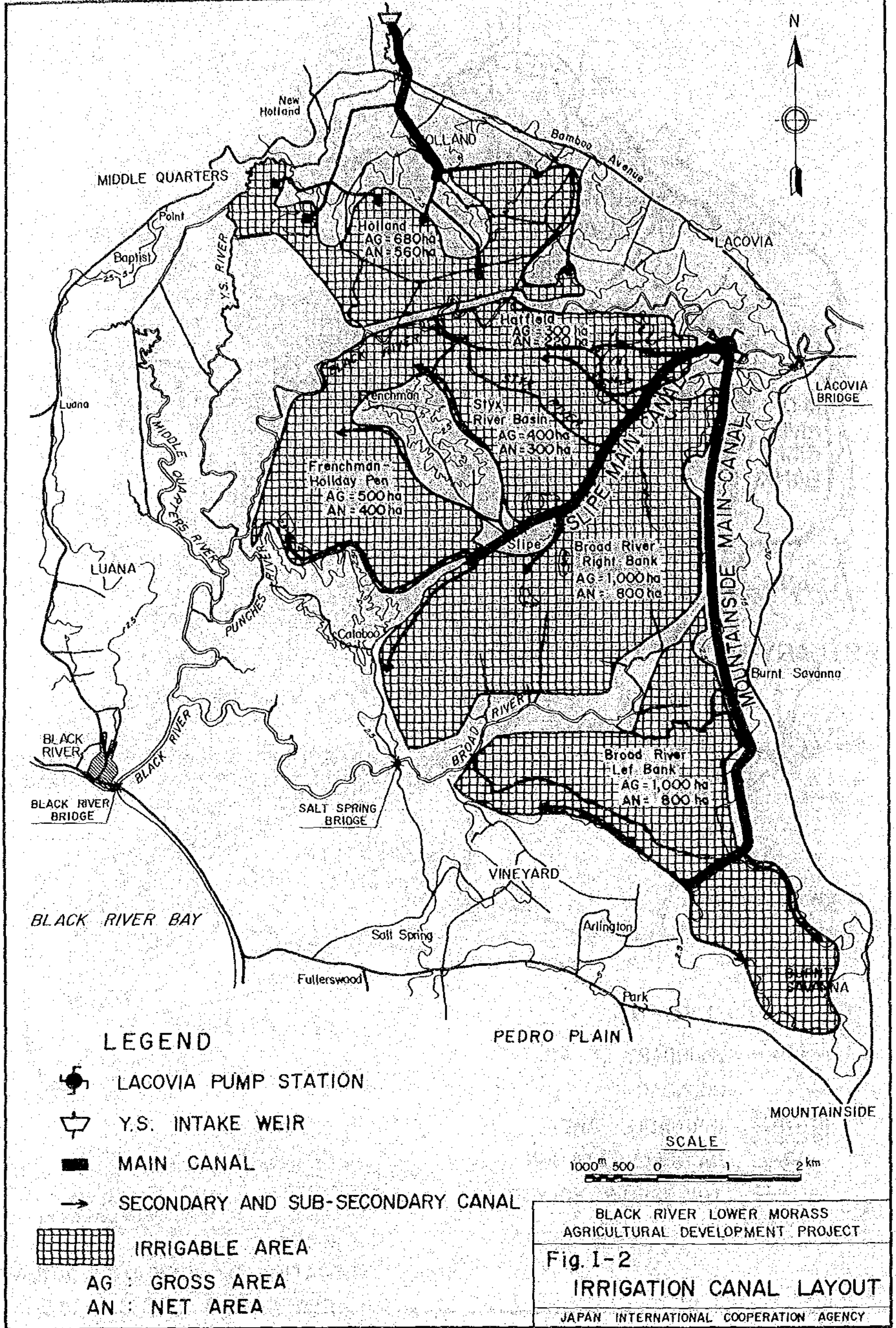


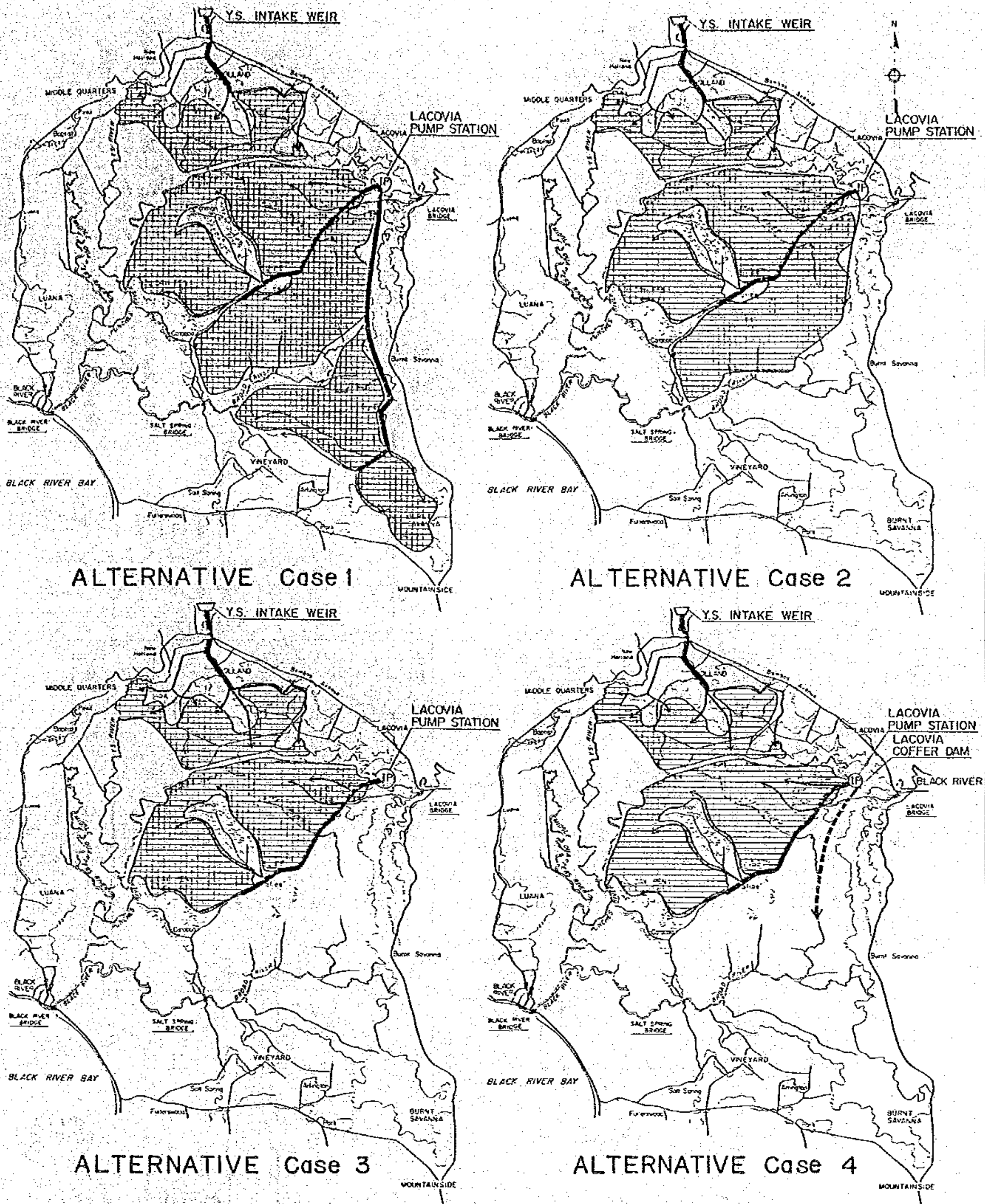
Fig. I-1
LOCATION OF IRRIGATION AREA



BLACK RIVER LOWER MORASS AGRICULTURAL DEVELOPMENT PROJECT

Fig. I-2 IRRIGATION CANAL LAYOUT

JAPAN INTERNATIONAL COOPERATION AGENCY



LEGEND

- INTAKE WEIR
- (IP) IRRIGATION PUMP STATION
- MAIN IRRIGATION CANAL
- SECONDARY AND SUB-SECONDARY IRRIGATION CANAL
- BLACK RIVER DIVERSION CANAL
- DEVELOPMENT AREA

SCALE
1000m 0 1 2km

BLACK RIVER LOWER MORASS AGRICULTURAL DEVELOPMENT PROJECT

Fig. I-3
ALTERNATIVE PLANS

JAPAN INTERNATIONAL COOPERATION AGENCY