Legend

	Land Suitability	Soil Mapping Unit	Left Bank	Right Bank	Total
					(Unit : ha)
(horizontal hatch)	N1td	1+2	2,752	4,939	7,691
(diagonal hatch)	S3t	3+4	16,874	7,837	24,711
(shaded)	S2tdf	5	4,756	4,178	8,934

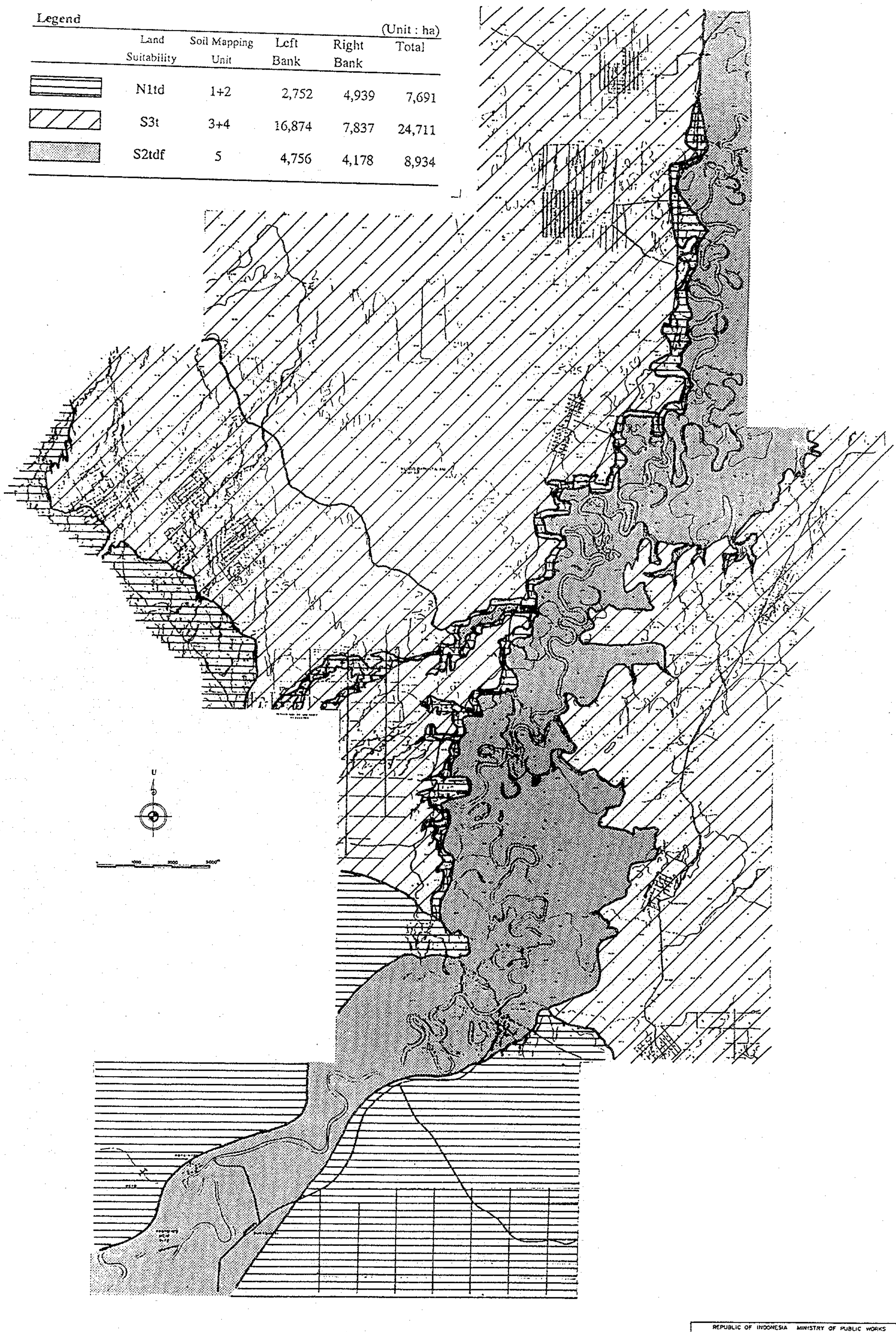


Fig. 2.3 Land Suitability Map for Paddy

REPUBLIC OF INDONESIA MINISTRY OF PUBLIC WORKS
DIRECTORATE GENERAL OF WATER RESOURCES DEVELOPMENT
FEASIBILITY STUDY ON LOWER ROKAN KIRI IRRIGATION PROJECT

LAND SUITABILITY FOR PADDY

JAPAN INTERNATIONAL COOPERATION AGENCY TOKYO (JICA) | DWG NO. 10

Legend

Land Suitability	Soil Mapping Unit	Left Bank	Right Bank	Total
S3ntc	1+2	2,752	4,939	7,691
S3n	3	5,484	7,837	13,321
S3nd	4	11,390	0	11,390
S2nedf	5	4,756	4,178	8,934

(Unit : ha)

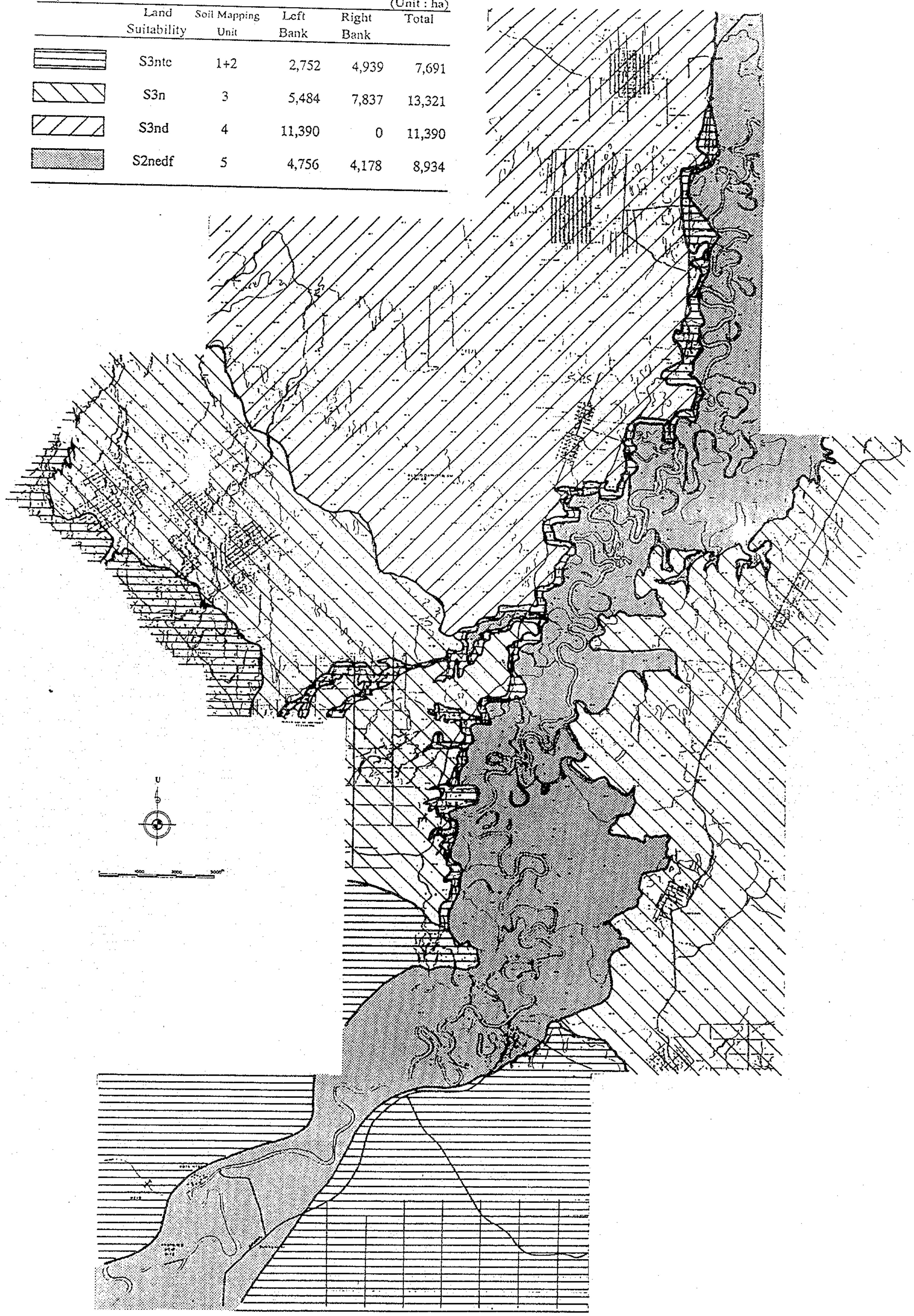


Fig. 2.4 Land Suitability Map for Upland Crops

REPUBLIC OF INDONESIA MINISTRY OF PUBLIC WORKS
DIRECTORATE GENERAL OF WATER RESOURCES DEVELOPMENT
FEASIBILITY STUDY ON LOWER ROKAN KIRI IRRIGATION PROJECT

LAND SUITABILITY FOR UPLAND CROPS

JAPAN INTERNATIONAL COOPERATION AGENCY TOKYO (JICA) | DWG NO 9

Legend (Unit : ha)

	Land Suitability	Soil Mapping Unit	Left Bank	Right Bank	Total
(horizontal lines)	S3nc	1+2	2,752	4,939	7,691
(hatch \\)	S3n	3	5,484	7,837	13,321
(hatch /)	S3nd	4	11,390	0	11,390
(stippled)	S2ned	5	4,756	4,178	8,934

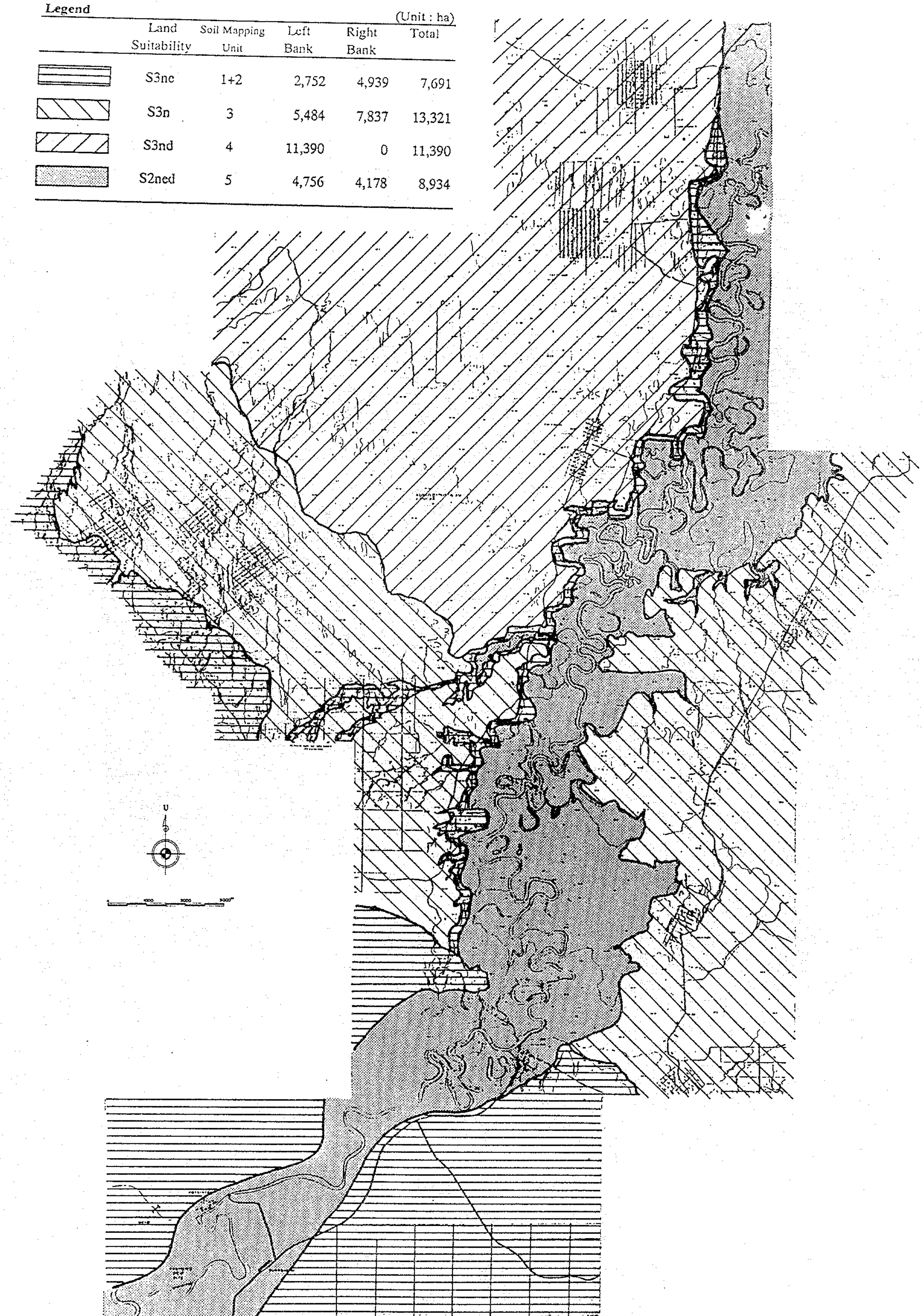


Fig. 2.5 Land Suitability Map for Perennial Crops

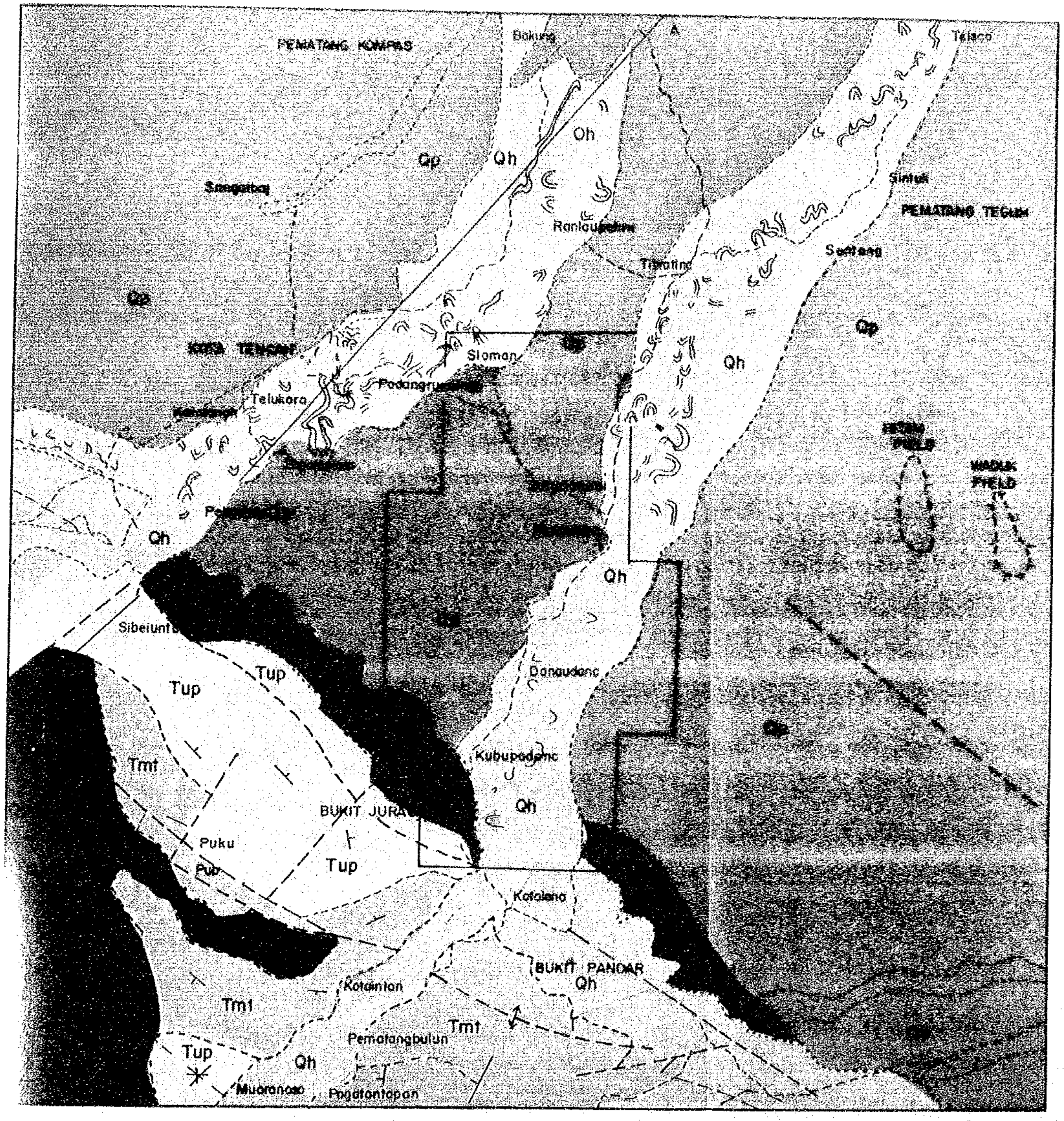
REPUBLIC OF INDONESIA MINISTRY OF PUBLIC WORKS
DIRECTORATE GENERAL OF WATER RESOURCES DEVELOPMENT
FEASIBILITY STUDY ON LOWER ROKAN KIRI IRRIGATION PROJECT

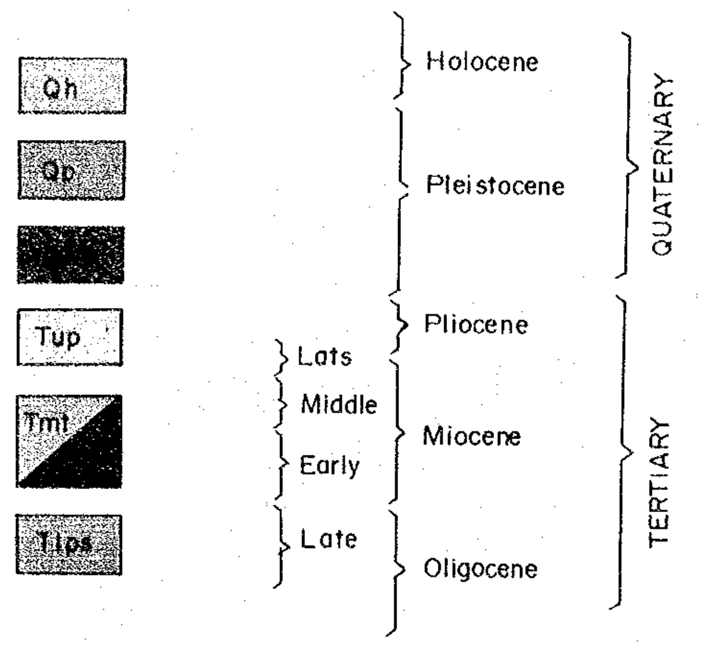
LAND SUITABILITY FOR PERENNIAL CROPS

JAPAN INTERNATIONAL COOPERATION AGENCY TOKYO (JICA) | DWG NO 8

CORRELATION OF MAP UNITS

SYSTEMATIC GEOLOGICAL
MAP INDONESIA
S= 1: 250.000





SEDIMENT

OH	YOUNG ALLUVIUM	: GRAVELS, SANDS, CLAYS.
OP	OLDER ALLUVIUM	: GRAVELS, SANDS, CLAYS VEGETATION RABTS AND PEAT SWAMPS.
OPMI	MINAS FORMATION	: GRAVELS, PEBBLS SPREADS SANDS AND CLAYS.
TUP	PETANI FORMATION	: MUD STORES, OFTER CARBONACLOUS LIGRITES, MINOR SILTSTONES AND SAND STONES.
TMT	TELISA FORMATION	: GREY CALCAREOUS MUD STONES, THE LIME STONES, SILT STONES AND MINOR GLAUCONITIC SAND STONES.
TMS	SIHAPAS FORMATION	: CONGLOMERATICE SAND STONES SILT STONE.
TIPL	PEMATANG FORMATION	: RED AND MATTLED MUD STONES BRECCIO-CONGLOMERATES AND CONGLOMERATIC SAND STONES.

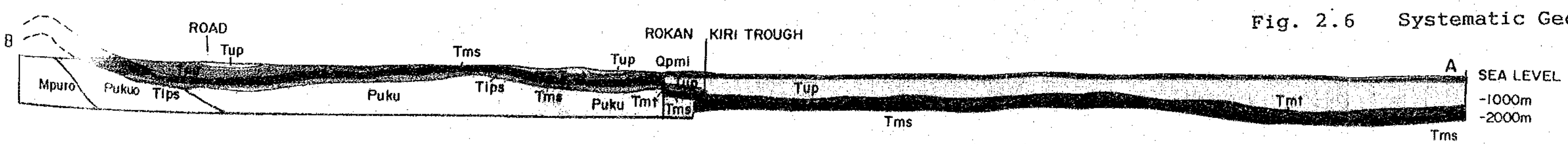


Fig. 2.6 Systematic Geological Map, Project Area

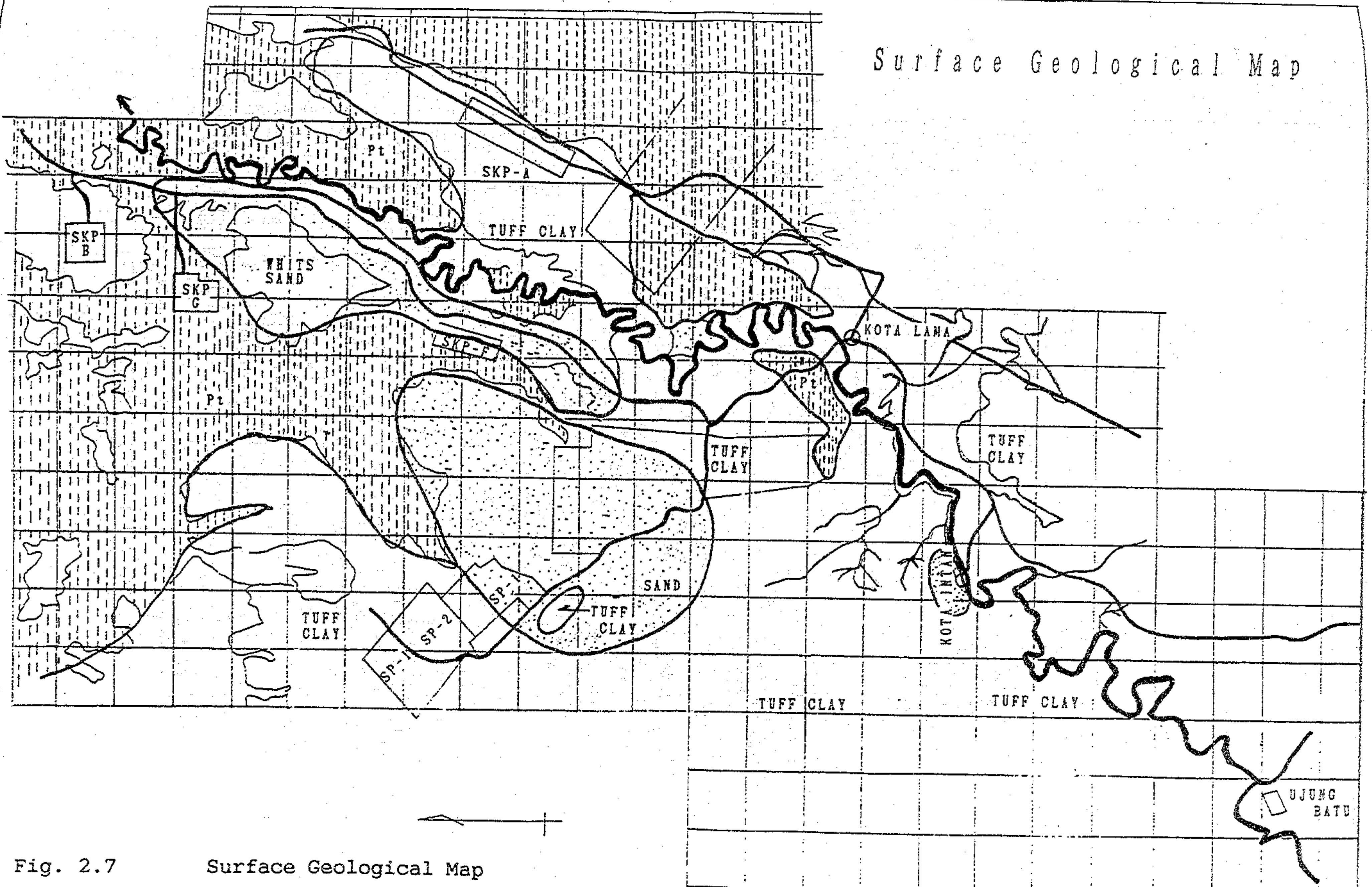


Fig. 2.7 Surface Geological Map

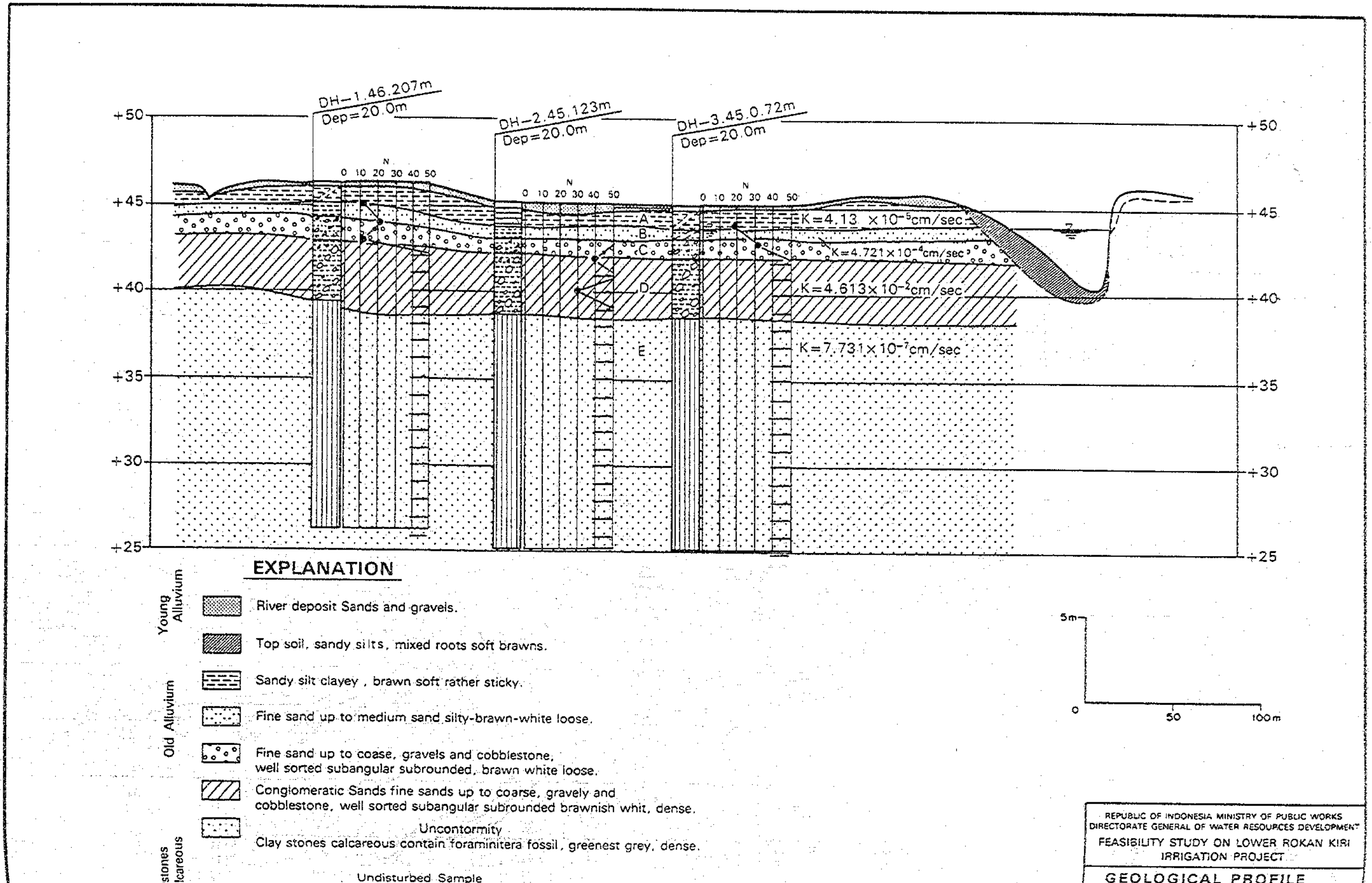


Fig. 2.8 Geological Profile at Proposed Weir Site

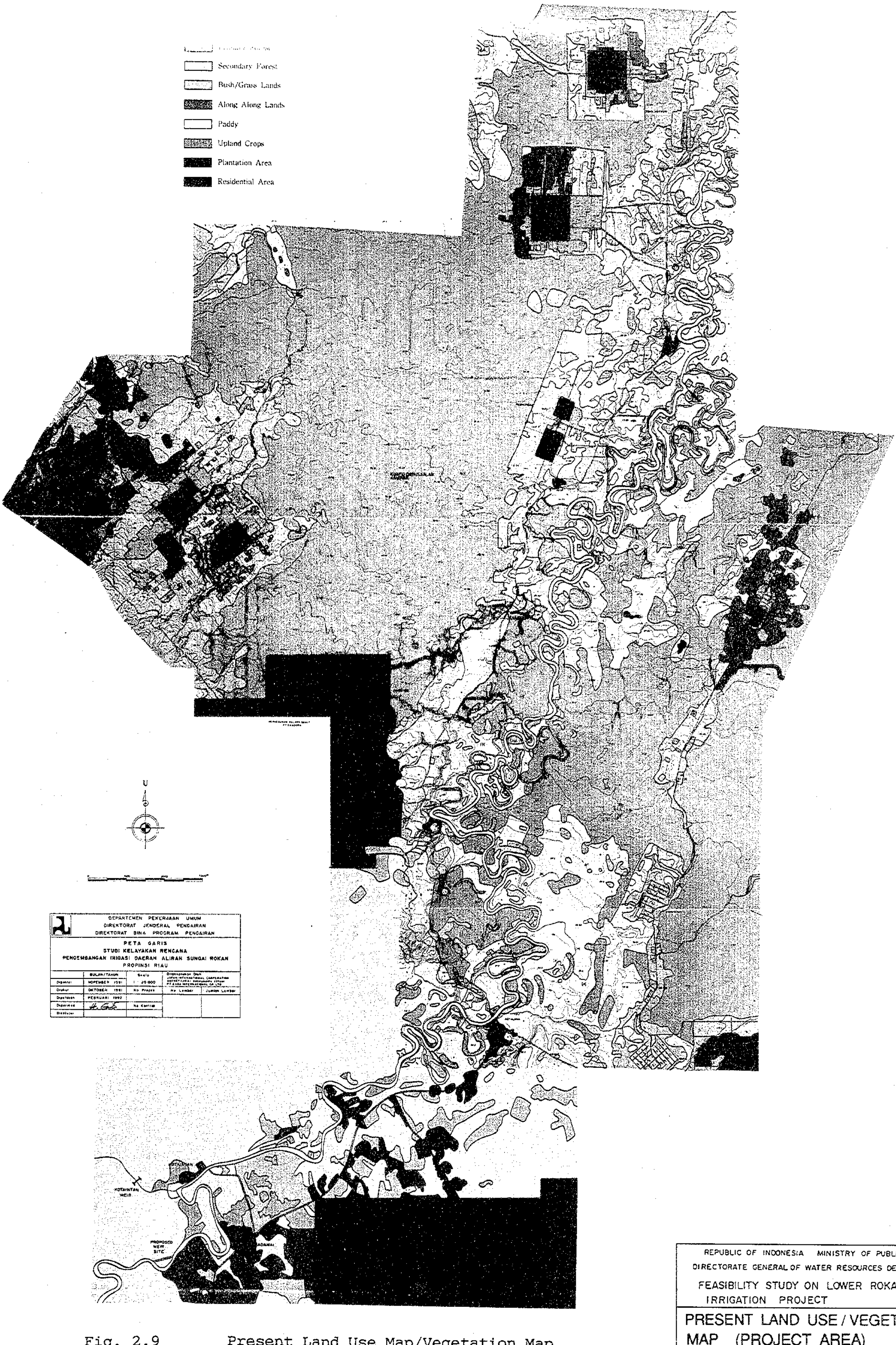


Fig. 2.9 Present Land Use Map/Vegetation Map

REPUBLIC OF INDONESIA MINISTRY OF PUBLIC WORKS
DIRECTORATE GENERAL OF WATER RESOURCES DEVELOPMENT
FEASIBILITY STUDY ON LOWER ROKAN KIRI IRRIGATION PROJECT

PRESENT LAND USE / VEGETATION MAP (PROJECT AREA)

JAPAN INTERNATIONAL COOPERATION AGENCY TOKYO (JICA)

DWG. NO. 6

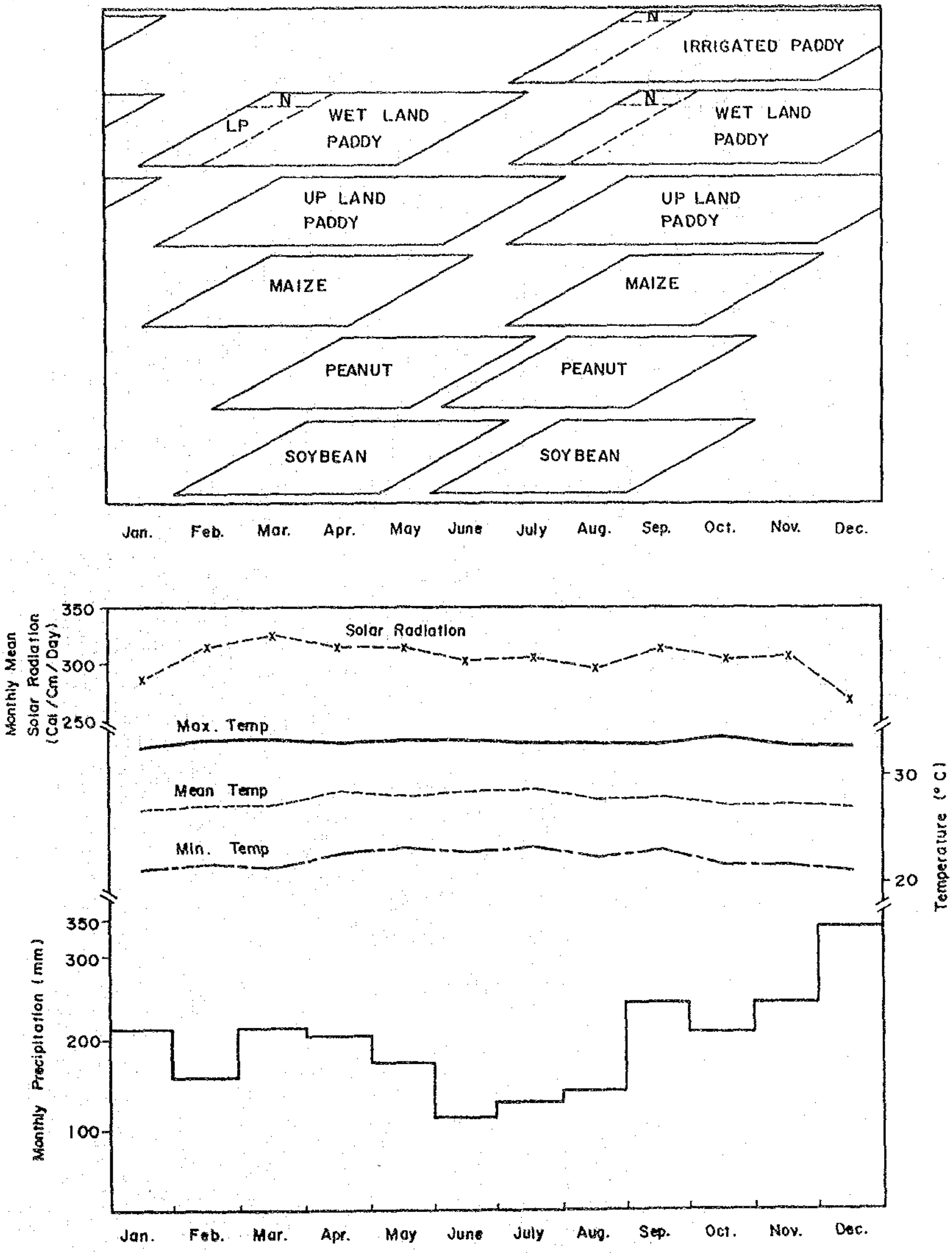


Fig. 2.10 Present Cropping Pattern

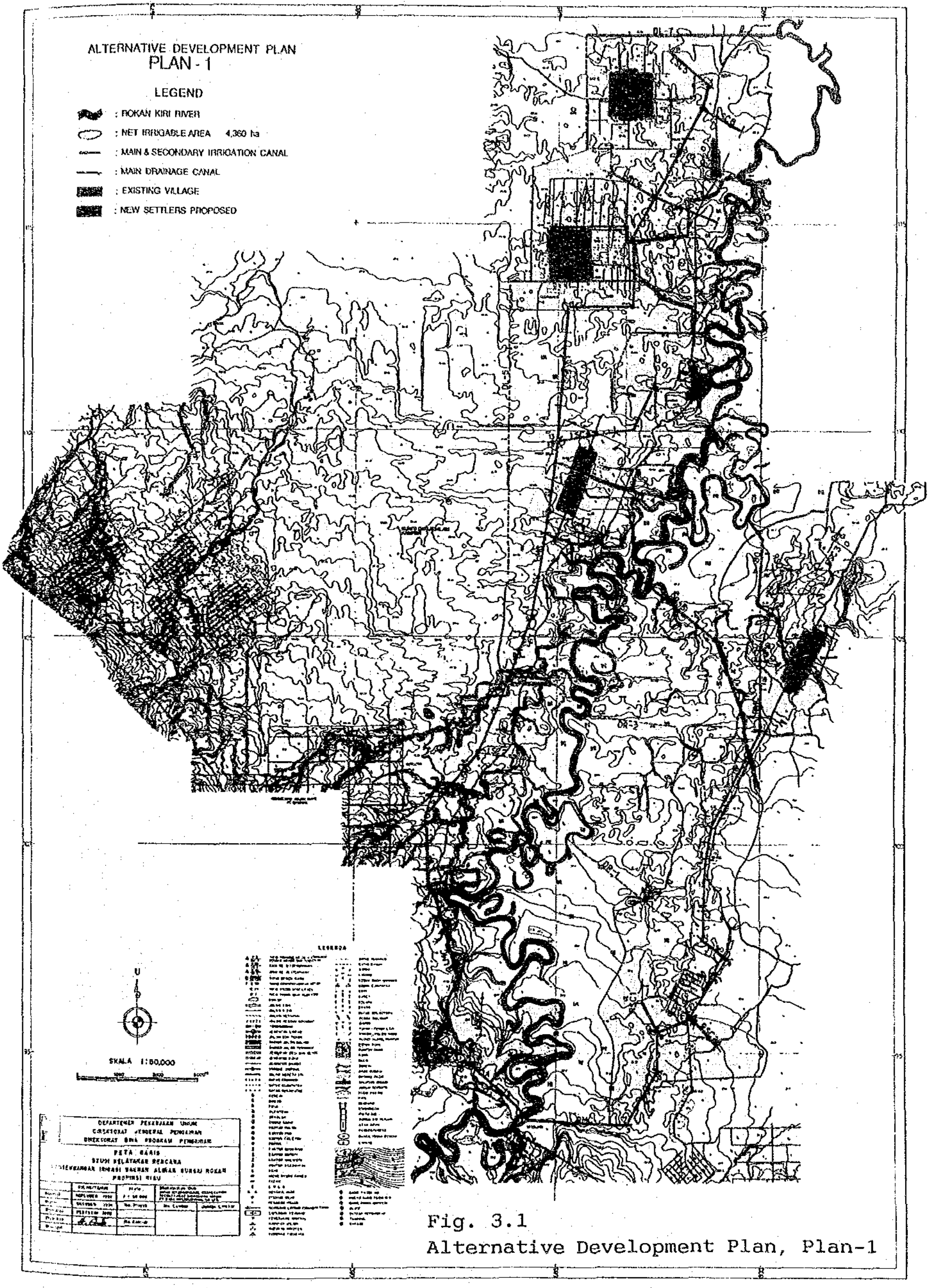


Fig. 3.1
Alternative Development Plan, Plan-1

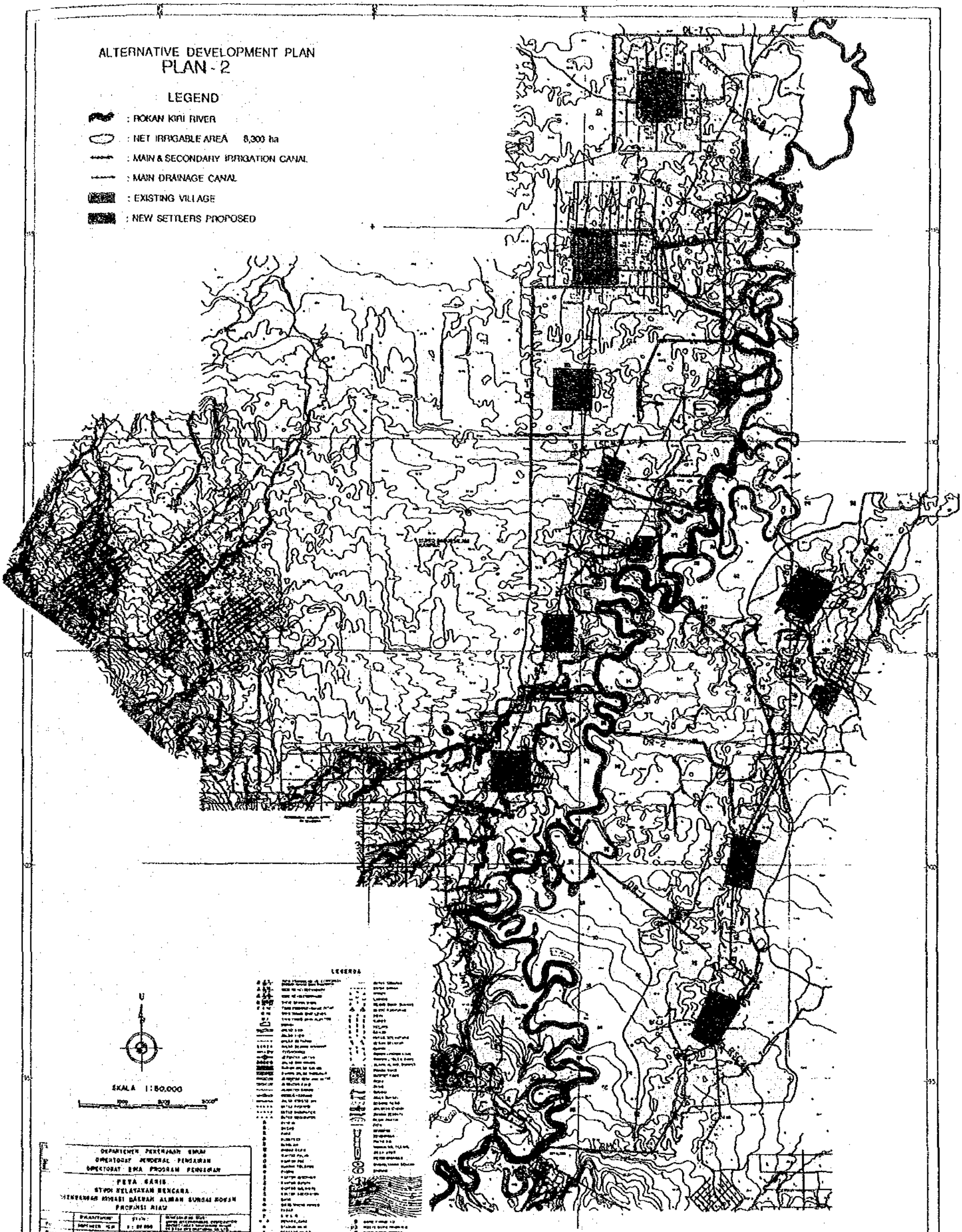


Fig. 3.2
Alternative Development Plan, Plan-2

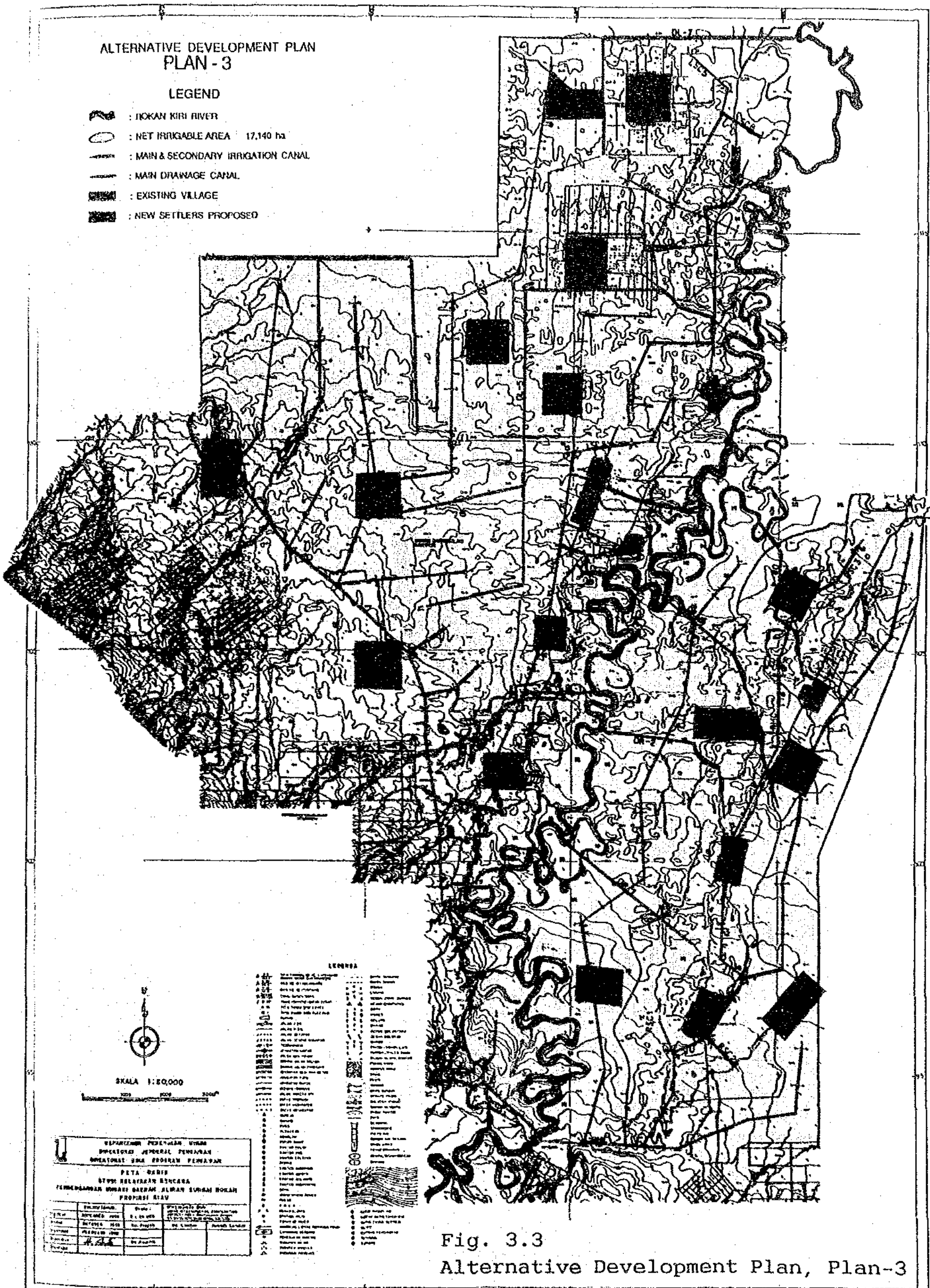


Fig. 3.3
Alternative Development Plan, Plan-3

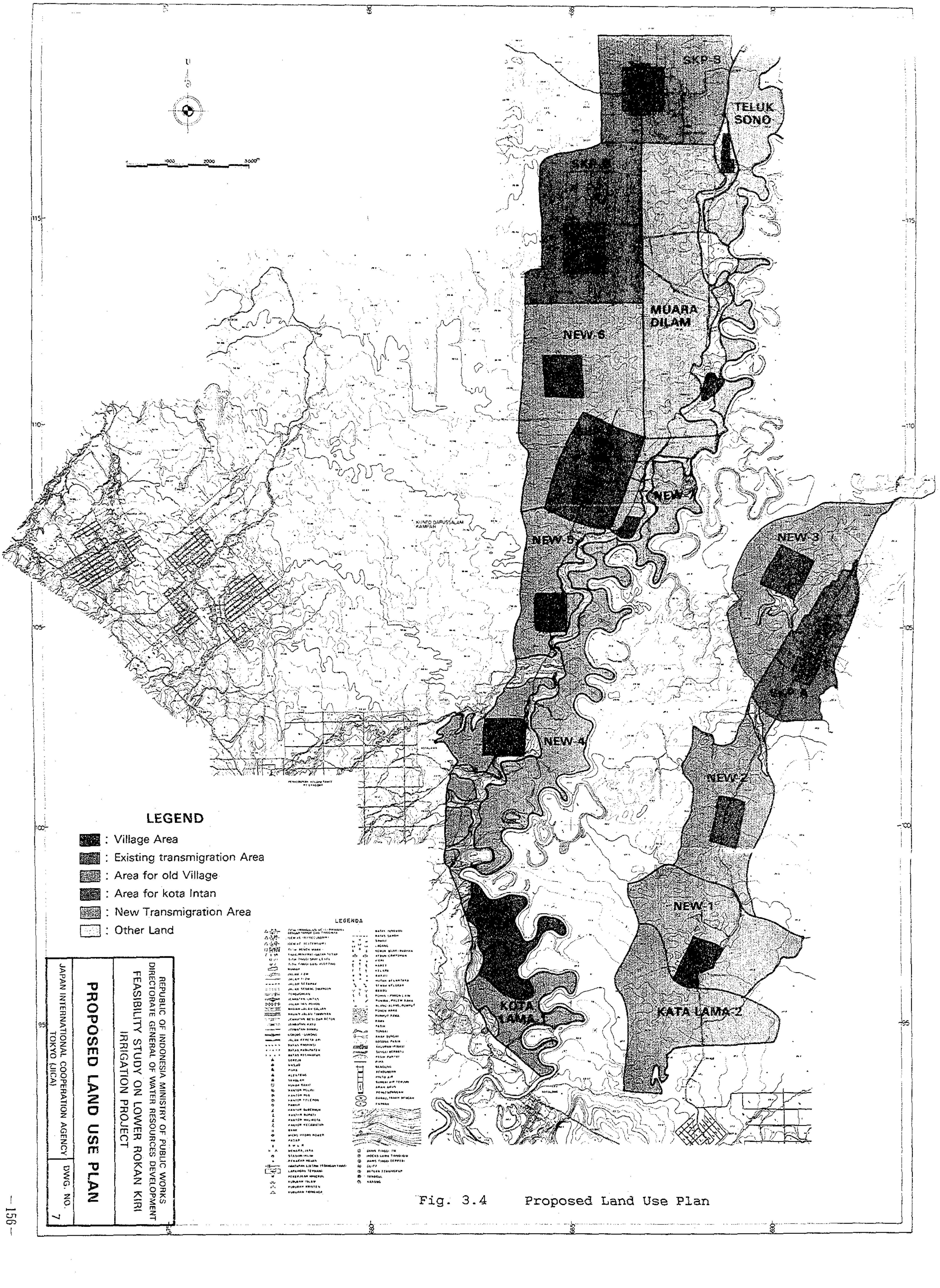


Fig. 3.4 Proposed Land Use Plan

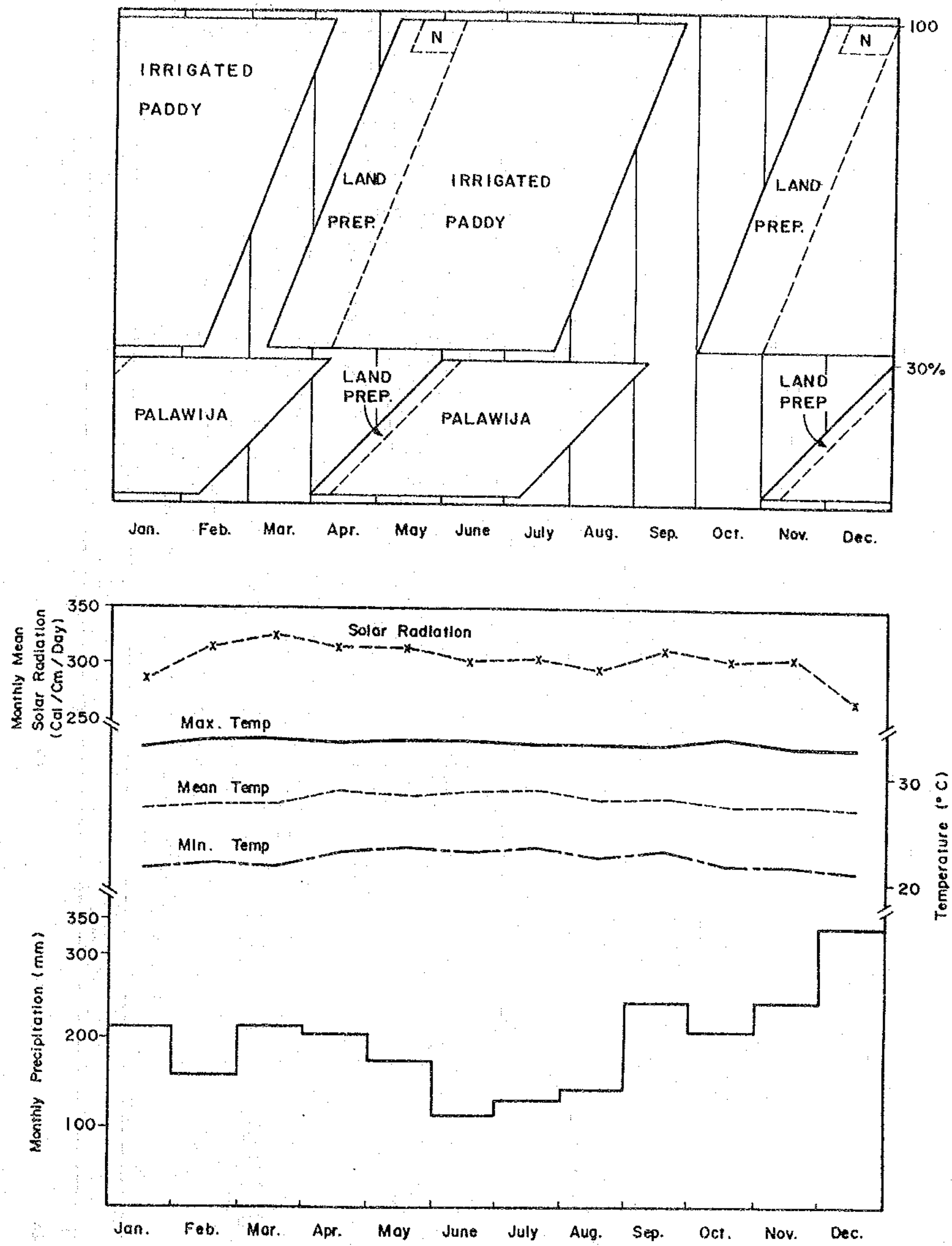


Fig. 3.5 Proposed Cropping Pattern

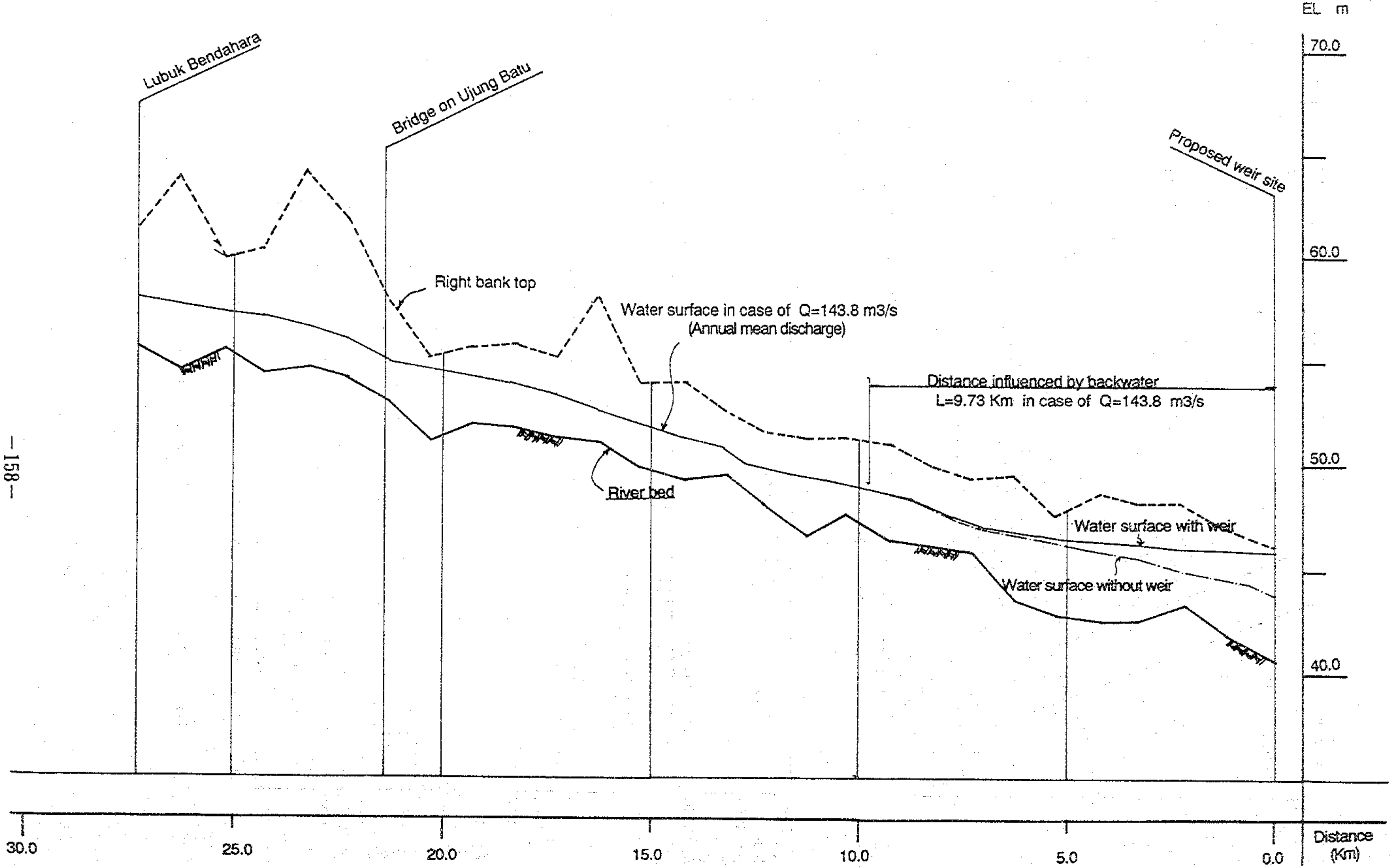


Fig. 3.6 Longitudinal Profile of Rokan Kiri River and Back Water Influenced by Proposed Weir

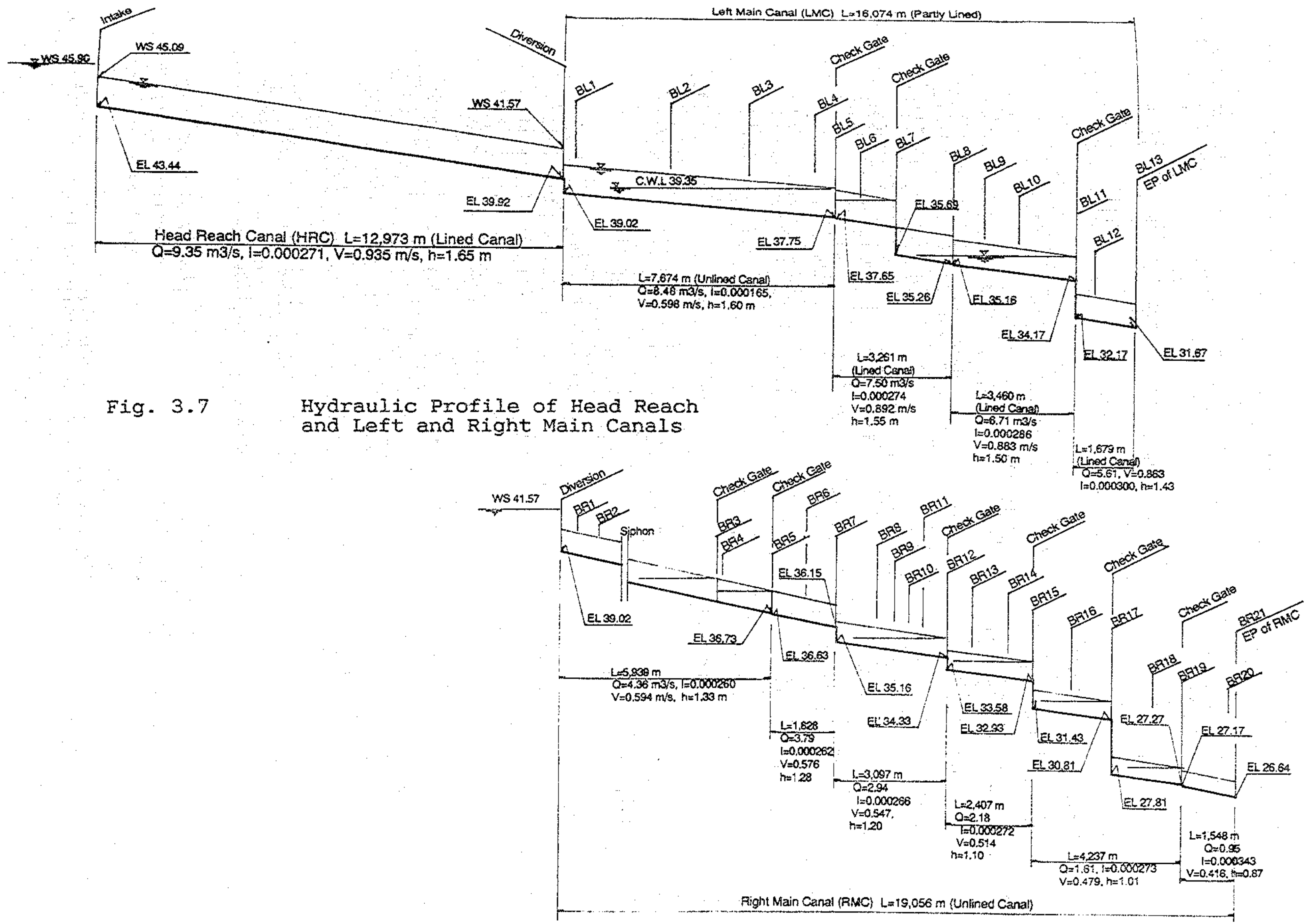


Fig. 3.7 Hydraulic Profile of Head Reach and Left and Right Main Canals

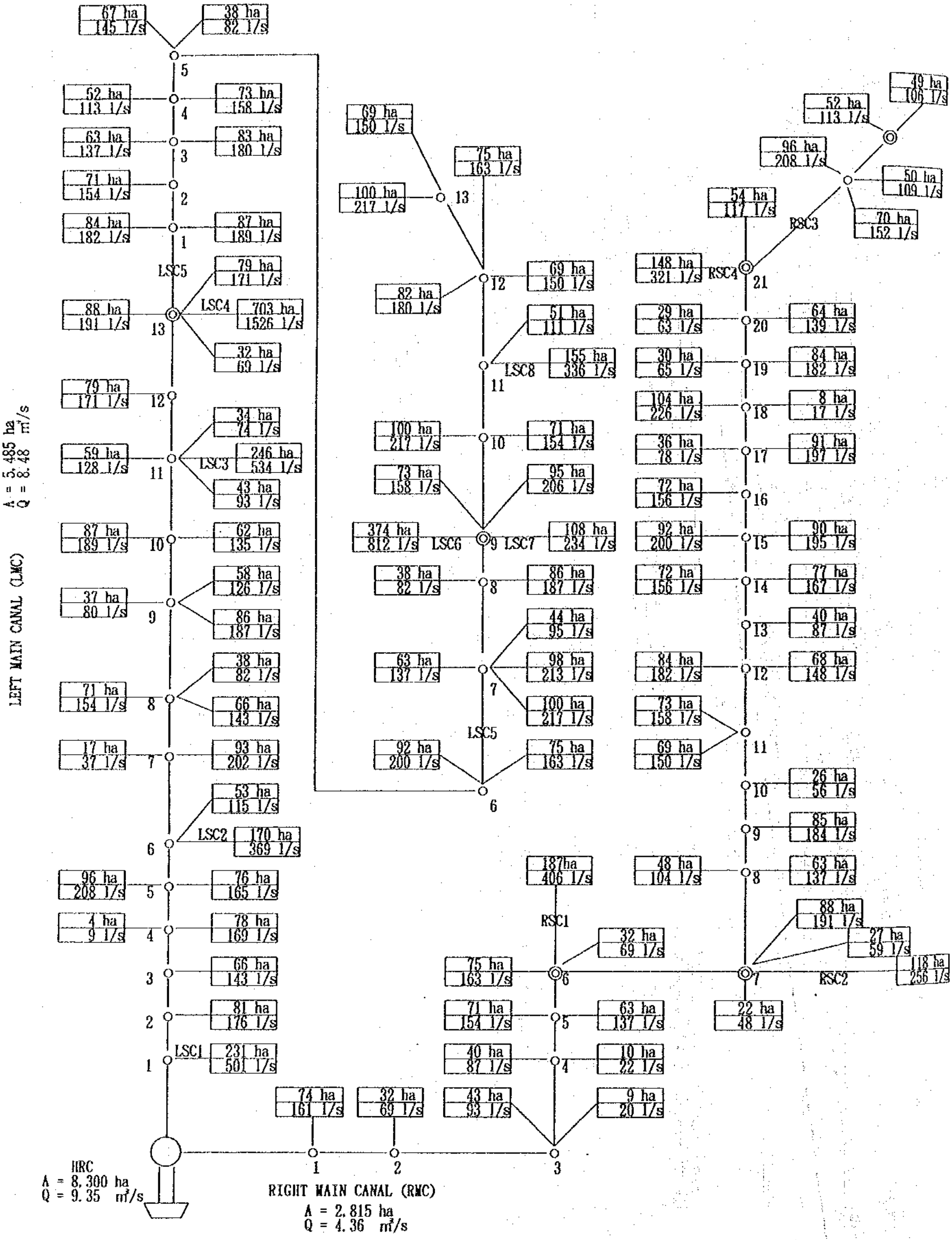


Fig. 3.8 Distribution Diagram for Main and Secondary System

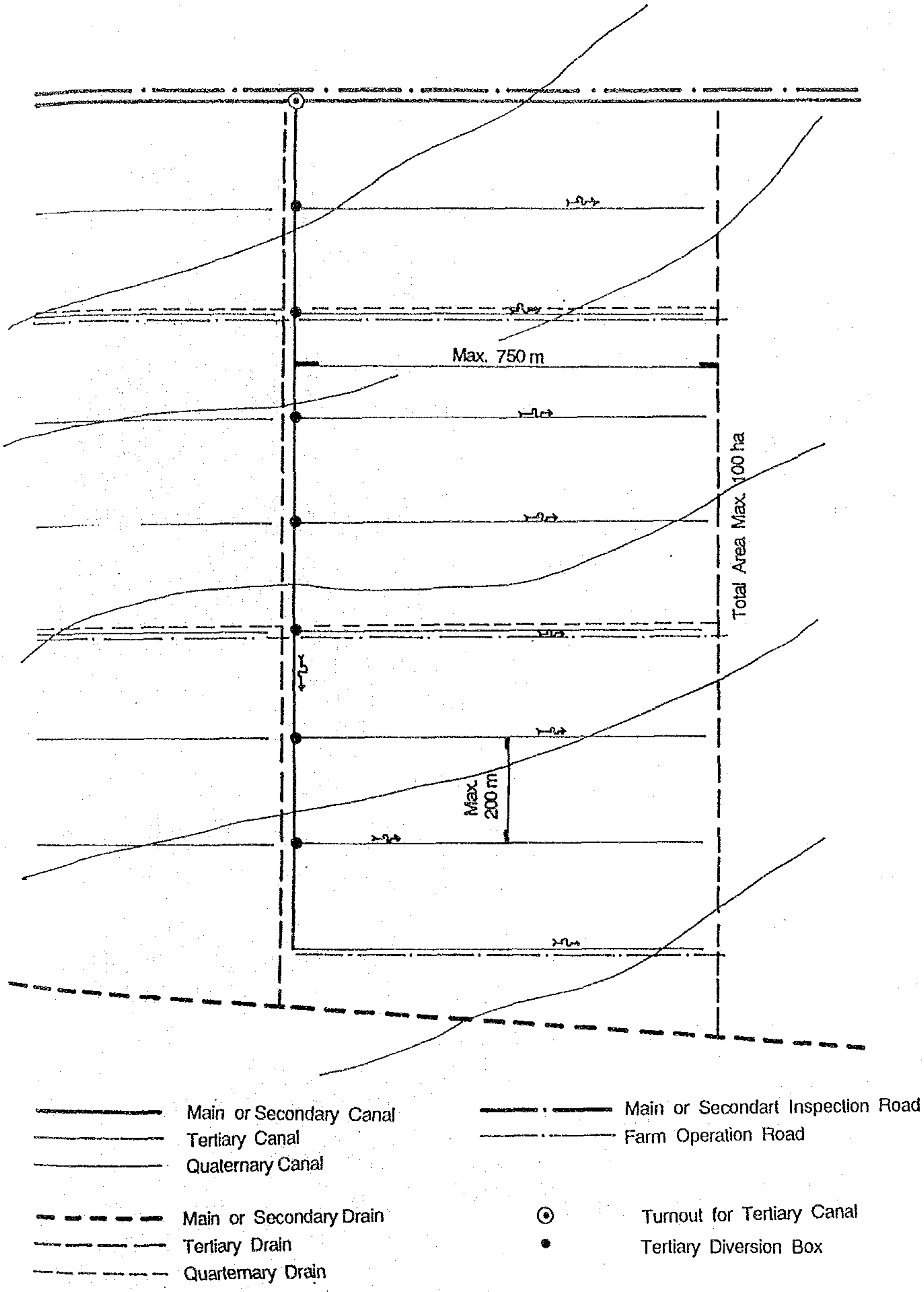


Fig. 3.9 Typical Layout of Tertiary System

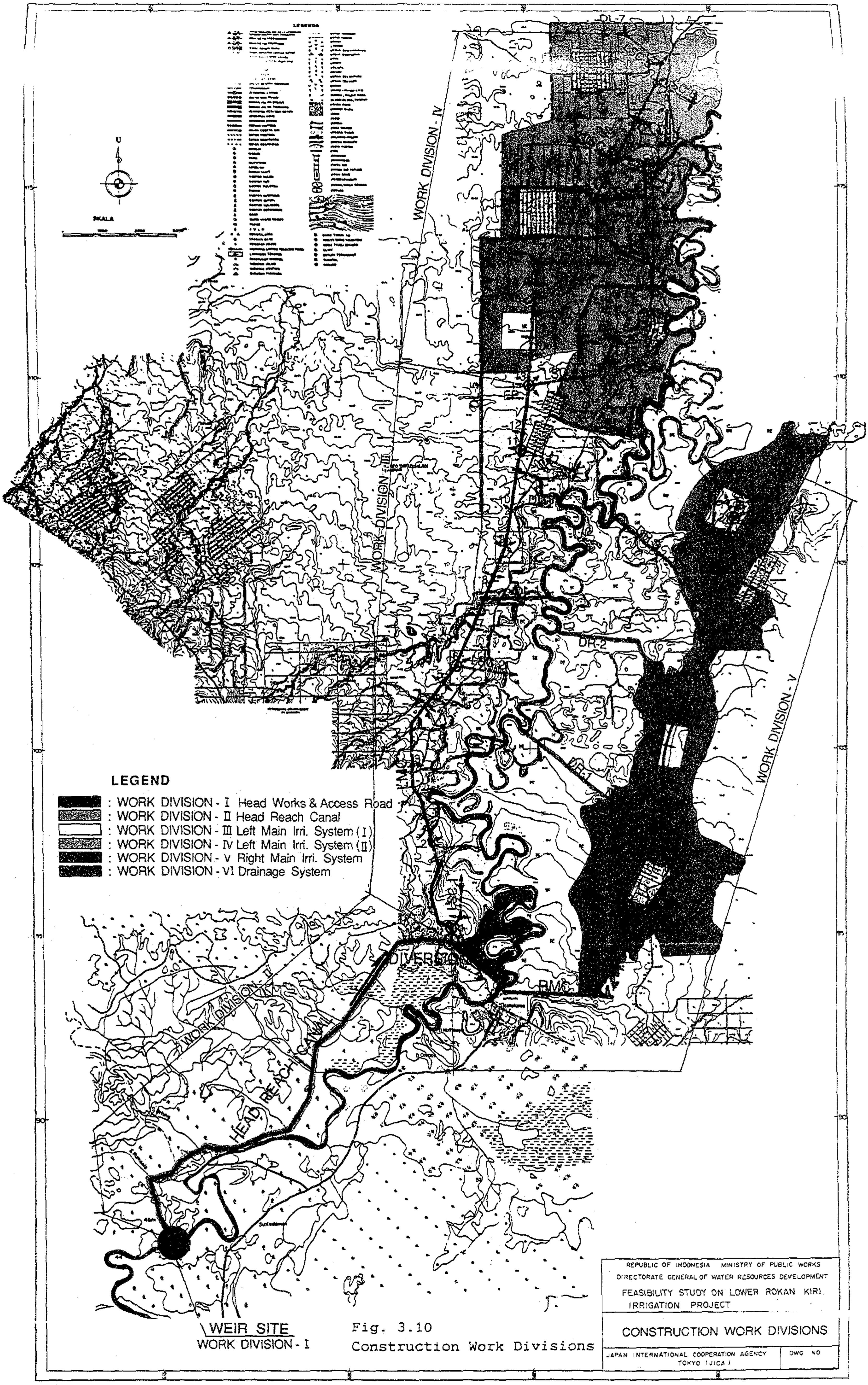
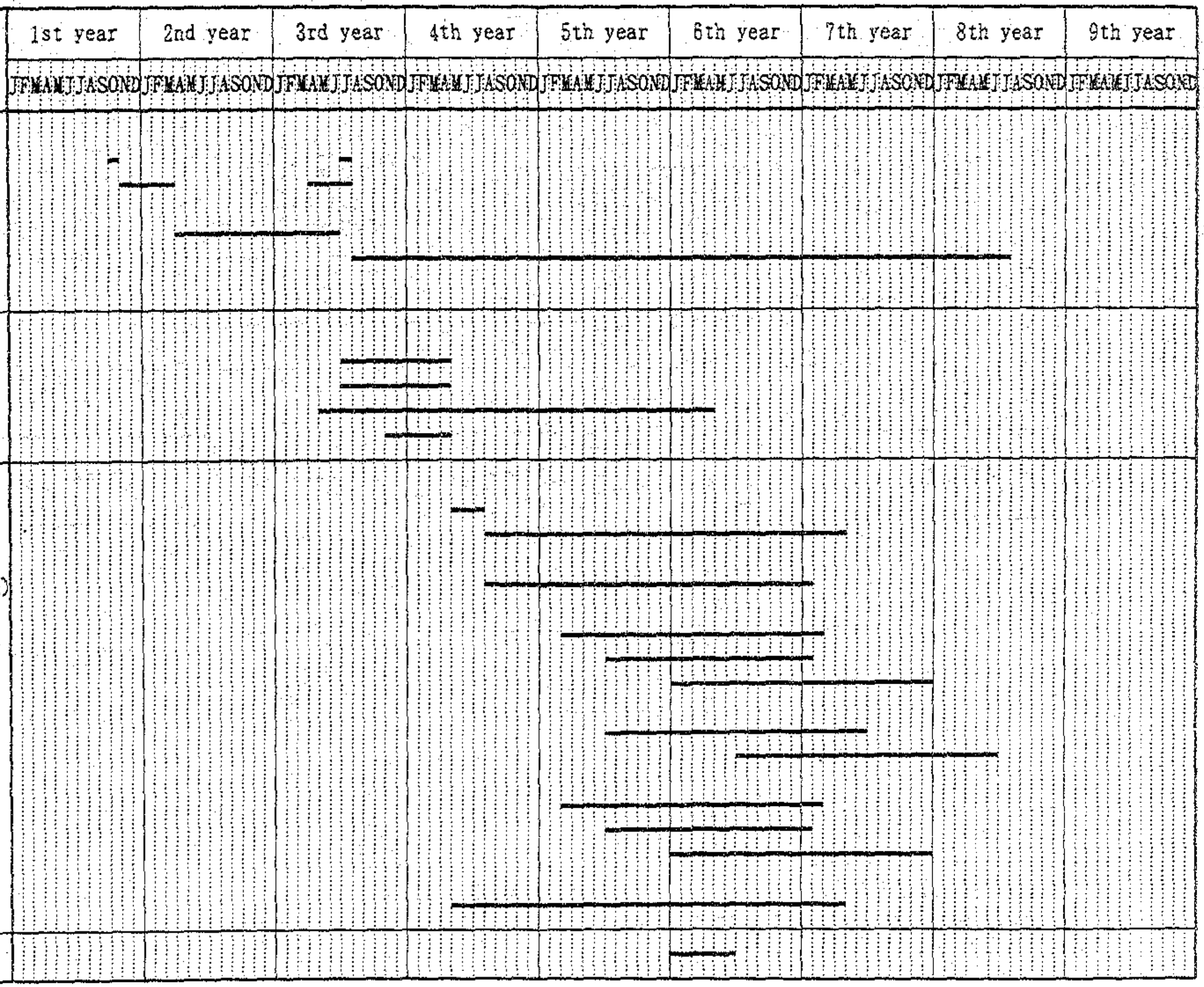


Fig. 3.10
Construction Work Divisions

Fig. 4.1 Implementation Schedule

WORK	ITEM(Quantity)
I. LOAN AGREEMENT	
1. Loan agreement	
2. Selection of consultant	
3. Detailed Design	
4. Construction supervision	
II. PREPARATORY WORK	
1. Tendering	
2. Office & quarters	
3. Land acquisition	
4. Connecting road	
III. CONSTRUCTION	
1. Work Division-I	1. Access road (2.5 Km)
	2. Weir (H=4.3m, W=106m)
2. Work Division-II	1. Head Reach C (13.0 Km)
3. Work Division-III (Left bank-1)	1. Main canal (16.1 Km)
	2. Secondary C (4.9 Km)
	3. Tertiary S (2,130 ha)
4. Work Division-IV (Left bank-2)	1. Secondary C (19.4 Km)
	2. Tertiary S (3,355 ha)
5. Work Division-V (Right bank)	1. Main canal (19.1 Km)
	2. Secondary C (5.2 Km)
	3. Tertiary S (2,815 ha)
6. Work Division-VI	1. Drainage C (56.2 Km)
IV. PILOT FARM	



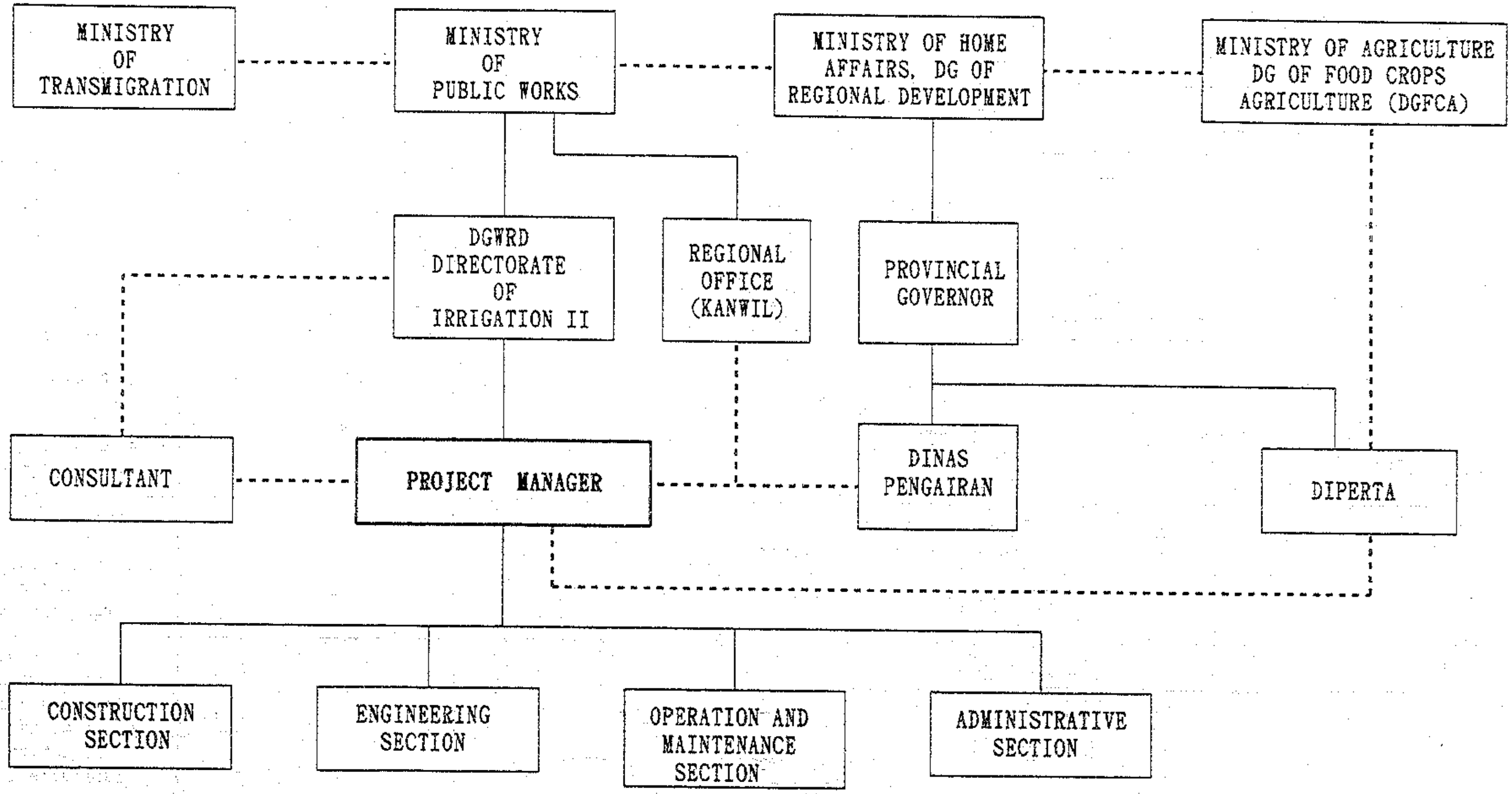


Fig. 4.2 Proposed Organization of Project executing Office

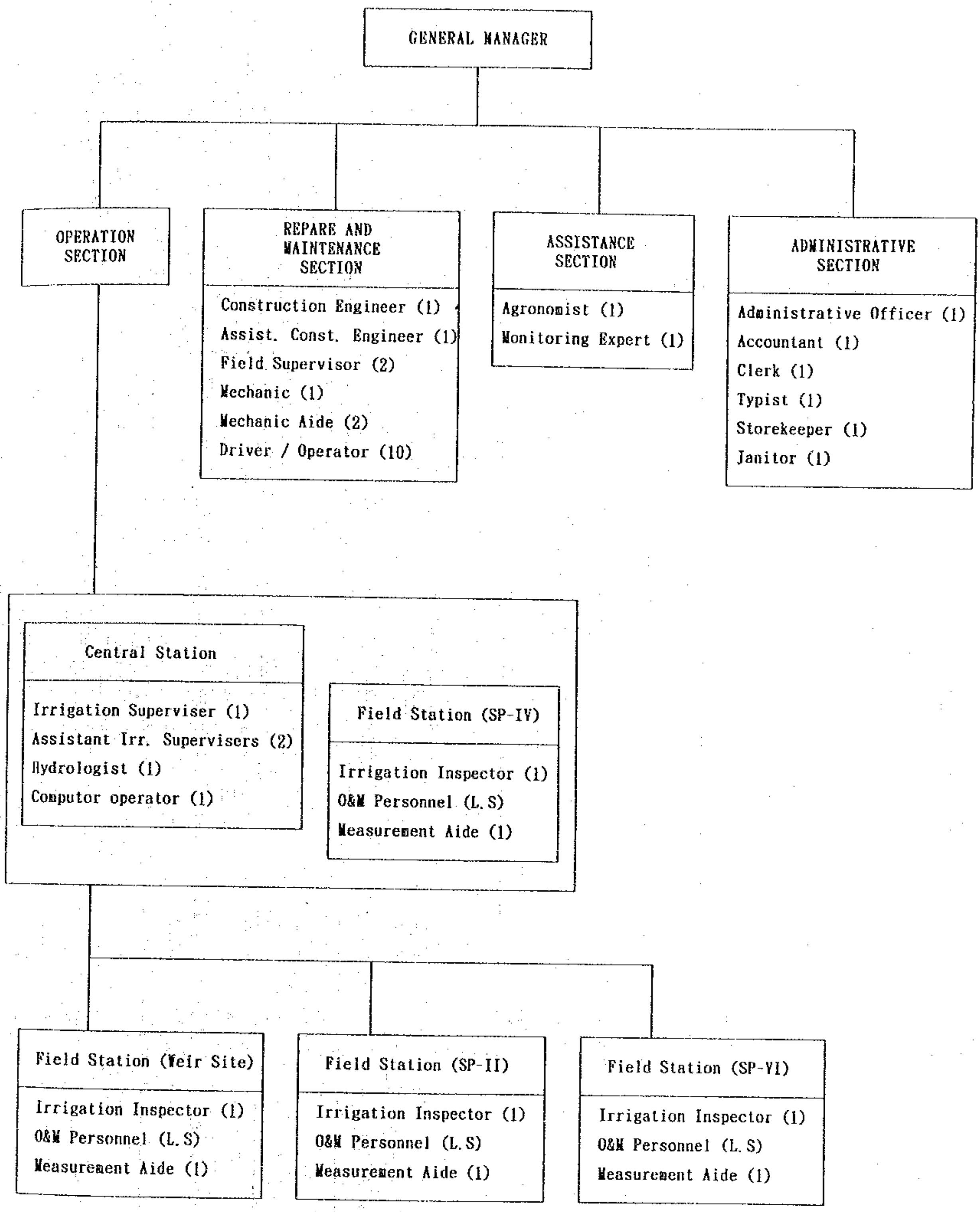


Fig. 4.3 Proposed Organization of O & M Office

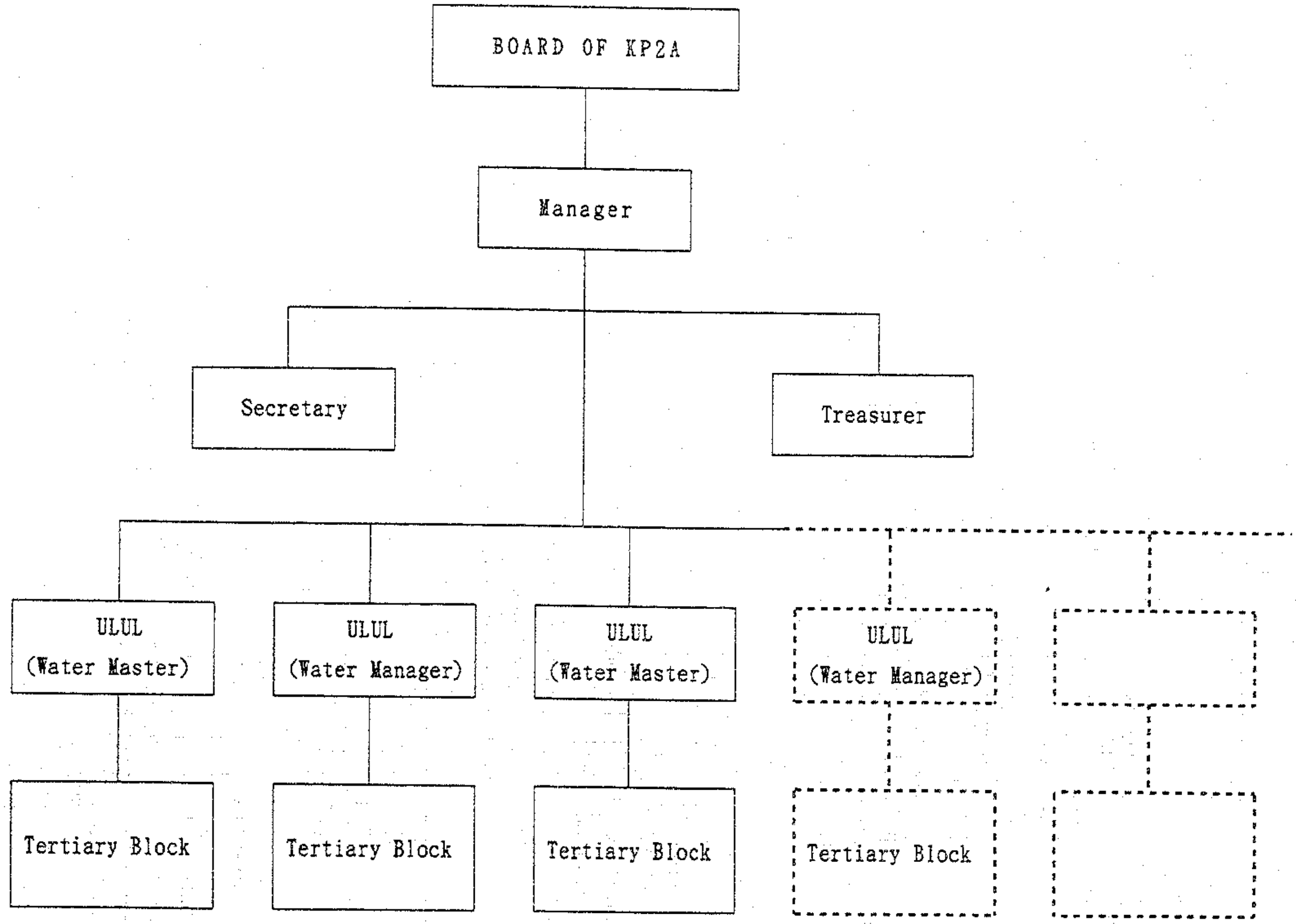
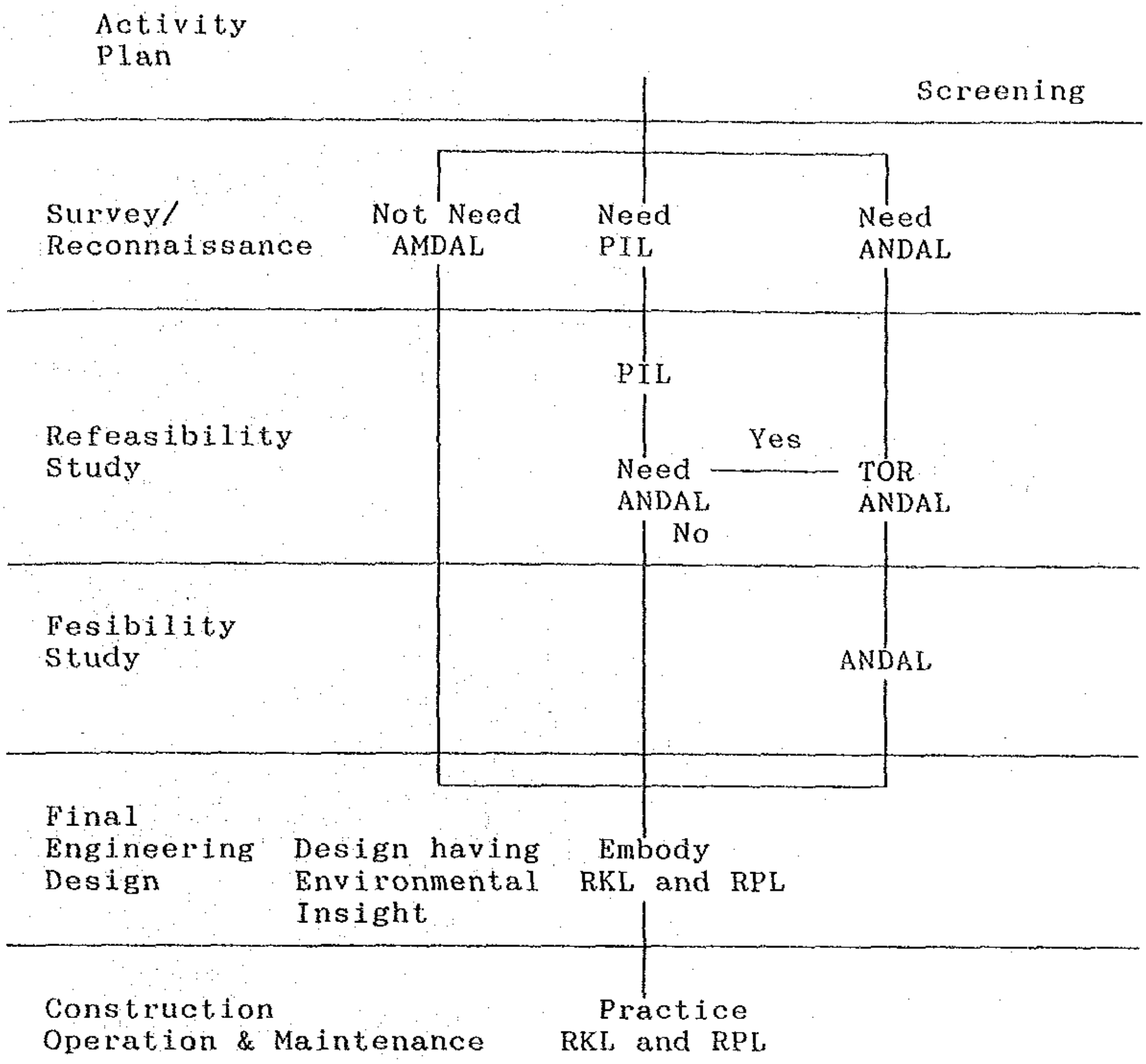


Fig. 4.4 Proposed Organization of Water Users' Association



AMDAL : Environmental Impact Assessment
PLI : Environmental Information Presentation
ANDAL : Environmental Impact Analysis
RKL : Environmental Management Plan
RPL : Environmental Monitorumg Plan

Fig. 7.1 Procedure of AMDAL for Activity Plan

ANNEXES

ANNEX A

METEOROLOGY AND HYDROLOGY

ANNEX A METEOROLOGY AND HYDROLGY

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1. METEOROLOGY

1.1 General

The objective area for the feasibility study is located around 1°00' north latitude and 100°40' east longitude. It belongs to the equator climate zone with much rainfall.

Out of total number of fourteen(14) rainfall stations and four(4) meteorological stations in the hole Rokan river basin, there exist six(6) rainfall and two(2) meteorological stations in the objective area. The locations of the existing meteorological stations are presented in Volume II.

1.2 Meteorological Conditions

The catchment area of the proposed weir site is 3,267 Km^2, While the benefitted area is about 30,000 ha in gross. The meteorological conditions in the Project area are as follows;

(1) Rainfall

The annual mean rainfall in the catchment area ranges from 3,654 mm at Rao MT of the West Sumatra Province to 2,390 mm at Lubuk Bendahara, while in the benefitted area, it is 2,370 mm approximately.

(2) Evaporation

The monthly mean evaporation in the benefitted area(Kota Lama) ranges 3.0 mm/day to 3.9 mm/day and annual mean one is 3.5 mm/day.

(3) Wind Velocity

The monthly mean wind velocity in the benefitted area is 11.8 Km/day to 20.1 Km/day and the annual mean one is 16.6 Km/day.

(4) Air Temperature

The monthly mean air temperature in the benefitted area varies 24.5°C to 26.1°C and the maximum and minimum ones are 28.9°C to 30.5°C and 20.4°C to 21.8°C respectively.

(5) Relative Humidity

The monthly mean relative humidity in the benefitted area ranges from 82.3% to 92.6% and annual mean one is 91.4%.

(6) Sunshine Ratio

The monthly mean sunshine ratio in the benefitted area is 31.0% in January to 43.4% in July, while the annual mean one is 37.6%.

(7) Solar Radiation

The monthly mean solar radiation in the benefitted area ranges from 229 cal/cm²/day in December to 285 cal/cm²/day, while the annual mean one is 264 cal/cm²/day.

The monthly mean values of meteorological data are presented in Table 1.1.

2. HYDROLOGY

2.1 Rokan Kiri River

The Rokan Kiri river originates from Barisan Range and runs to north-east direction until the confluence of the Rokan river. The Project area spreads both sides of the downstream of the Rokan Kiri river. The total river length from the mountain peak to the junction is about 205 Km with the total area of the river basin of about 4,412 Km^2. Whereas the catchment area of the proposed weir site is estimated at 3,267 Km^2.

The water levels in the river are recorded at two(2) places shown below.

Water Level Records in Rokan Kiri River

Station	Period Recorded	Remarks
Lubuk Bendahara	Jul.1977 - Feb. 1991	Installed by DPMA
Kota Lama	Jun.1991 - Feb. 1992	Installed by JICA

2.1.1 Rating Curves

Based on the river discharge observation and water level records, rating curves for both stations above are established as follows;

at Lubuk Bendahara : $Q = 30.434x(H+0.388)^2$

at Kota Lama : $Q = 17.263x(H-0.316)^2$

2.1.2 Monthly River Discharge

The monthly mean river discharges at Lubuk Bendahara and Kota Lama are estimated as shown in Table 1.2 by applying the rating curves mentioned above.

2.1.3 River Discharge at Proposed Weir Site

The proposed weir site (catchment area A = 3,267 Km^2) is located between Lubuk Bendahara (A = 3,076 Km^2) and Kota Lama (A =

3,379 Km²). Although river discharges at Lubuk Bendahara have been recorded longer period, from Jul. 1977 to Feb.1992, these at Kota Lama have been recorded from Jun. 1991 to Feb. 1992.

Comparison of daily discharges for Jun.1991 to Feb. 1992 at Lubuk Bendahara and Kota Lama is made by calculating correlation coefficient. Judging from the correlation coefficient of 0.93, relationship of river discharges at both stations is quite good.

Thus, river discharges at proposed weir site can be estimated by referring those at Lubuk Bendahara and catchment areas.

2.1.4 Flood

Observed annual peak flood discharges of the Rokan Kiri river at Lubuk Bendahara (catchment area = 3,076 Km²) are as follows;

Year	Discharge (m^3/s)	Ranking	Specific Discharge ($m^3/s/Km^2$)
1978	854.2	5	0.278
1979	995.1	3	0.324
1980	518.6	12	0.169
1981	434.4	13	0.141
1982	680.3	8	0.221
1983	402.8	14	0.131
1984	632.3	10	0.206
1985	668.9	9	0.217
1986	863.9	4	0.281
1987	1,142.9	2	0.372
1988	721.2	7	0.234
1989	1,324.9	1	0.431
1990	594.0	11	0.193
1991	736.1	6	0.239

The probable flood discharges at Lubuk Bendahara and the proposed weir site by Iwai's method are as follows;

Probable year	Flood Discharge (m^3/s) Lubuk B'hara	Weir site	Specific Discharge
1,000	2,152.9	2,286.6	0.700
100	1,625.6	1,726.5	0.528
50	1,471.5	1,562.9	0.478
20	1,269.0	1,347.8	0.413
10	1,113.8	1,183.0	0.362
5	952.6	1,011.8	0.310
2	710.5	754.6	0.231

2.1.5 Sedimentation

The study material for the sedimentation is collected at the proposed weir site on March 1992. The results are as follows;

No.	Volume of water (ml)	Weight of soil (gram)	Suspended soil (mg/l)	River Discharge on Mar.2 '92 (m^3/s)
1	3,850	0.4510	117	241.5*
2	3,625	0.1060	29	- do -
3	3,850	0.1109	29	- do -
4	4,050	0.5605	138	- do -
5	4,400	0.5889	134	- do -
6	4,100	0.8865	216	- do -
7	3,900	0.1070	27	- do -
8	4,400	0.2207	50	- do -
9	3,985	0.4136	104	- do -
Total	36,160	3.4451	-	-
Average	-	-	95	241.5

Remarks * : $Q=17.263 \times (4.12-0.316)^2 \times 3,267/3,379$

Since the study material is not enough, here shows a method of calculating amount of sedimentation out of the amount of suspended soil as an example.

Average discharge at weir site : $143.8 \times 3,267/3,076 = 152.7$ m^3/s
Amount of suspended soil : $95 \times 152.7/241.5 = 60.1$ mg/l

Density of sedimentation : $= 1.5\ t/m^3$

$$q.s = 60.1 \times 10^{-6} \times 152.7 \times 10^3 \times 86{,}400 \times 365 \div 1.5$$
$$= 192{,}943\ m^3/year$$

The amount of sedimentation (Q) is estimated with condition that the amount of run-off of suspended soil is assumed to be 20 % of the total amount;

$$Q = 1.2 \times 192{,}943 = 232{,}000\ m^3/year$$

Therefore, $q = 71\ m^3/year/Km^2$

It may be required, however, to continue the study by collecting enough seasonal study materials.

2.2 Runoff Analysis

2.2.1 Low Water Discharge Analysis

The following three(3) methods are used to applied for low water discharge analysis;

1) Correlation between discharges near the proposed weir site and the proposed weir site, in the case that enough river discharge records are available,

2) Tank model method (mathematical simulation model), in the case that enough rainfall records with insufficient river discharge records are available, and

3) Mock method, in the case that 10 years daily rainfall data from at least 1 station within the catchment and 1 year daily average flow data with 10 years half monthly evapotranspiration data are available.

Within the foregoing methods for this Project, however, low water discharge taken from correlation between discharges at Lubuk Bendahara and the proposed weir site is most reliable because the period for river discharge observation at Lubuk Bendahara is longer than period for rainfall records in the catchment area.

For the comparative use, low water discharges by the said three methods are estimated as follows;

(1) Correlation between discharges at Lubuk Bendahara and the proposed weir site

Correlation between discharges at Lubuk Bendahara and at Kota Lama for the period of Jul. 1991 to Feb. 1992 is calculated by statistical method to obtain the long term river discharges at Kota Lama for 1978 to 1991. Then, the river discharges at proposed weir site are estimated by multiplying areal proportion.

Correlation is expressed by the following equation;

$$Y = 0.887X + 39.868$$

where, Y : Discharge at Kota Lama (m^3/s)
X : Discharge at Lubuk Bendahara (m^3/s)
Correlation coefficient : 0.929

In order to estimate the low river discharges at Kota Lama in safety side, the above equation is modified as follows;

$$Y = 1.075X - 10.035$$

Therefore, the river discharges at the proposed weir site are estimated by the following equation;

$$Yw = (1.075X - 10.035)x3,267/3,379$$

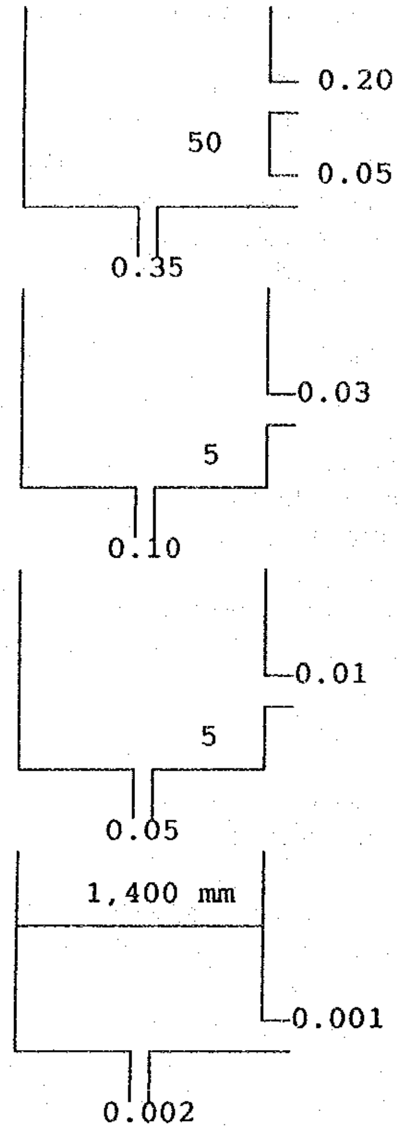
where, Yw : Discharge at the proposed weir site (m^3/s)

The correlation and both equations mentioned above are shown in Fig.2.1.

(2) Tank model method

The Tank Model simulation for Rokan Kiri river is applied to convert proper rainfall data to runoff discharge at Lubuk Bendahara which has sufficient period of runoff data. In order to establish the most adequate model, trial and error method is applied to determine the model parameters and appropriate rainfall data.

As a result, the average rainfall of Rao.MT, Jamback and Sontang and following model parameters are the most suitable for the model. Whereas, pan evaporation records at Pasir Pangarayan is adopted for evaporation value from ground surface.



The comparison of the calculated values and actual river discharges at Lubuk Bendahara for 1985 to 1990 is shown in Fig.2.2.

The river discharges at proposed weir site can be estimated by multiplying areal proportion to the catchment areas of Lubuk Bendahara.

(3) Mock method

A method of flow data synthesis was developed for Indonesia in 1973, called the Mock Method, which has been used during several irrigation projects to determine dependable flow. It is a relatively simple water balance approach to catchment modelling.

The objective of catchment modelling is to estimate dependable flow for each half month where insufficient data are available to estimate it directly from flow data, ie. where there are less than 10 years of flow data. Half monthly flows are estimated from rainfall and evapotranspiration data, with physical catchment parameters of : soil moisture capacity, initial soil moisture deficit, infiltration factor, initial groundwater storage, a groundwater recession factor and a dry season storm runoff factor.

Based on the above concept, the Mock method is applied for the Rokan Kiri river basin at Lubuk Bendahara using the same data of the tank model method above.

The calculation procedure is shown in Table 2.1 to Table 2.9.

As a result, it is harder to apply this model to this basin than the other methods.

(4) Runoff at the proposed weir site

After the comparative study mentioned above, river discharges obtained by the correlation between discharges at Lubuk Bendahara and at the proposed weir site are adopted for the estimation of low water discharges for project.

a) Annual discharge

Annual discharges at the proposed weir site from 1978 to 1991 are obtained as follows ;

1978	4.89×10^9
1979	4.22×10^9
1980	3.67×10^9
1981	3.59×10^9
1982	4.85×10^9
1983	3.74×10^9
1984	5.22×10^9
1985	4.76×10^9
1986	4.89×10^9
1987	5.65×10^9
1988	5.38×10^9
1989	4.30×10^9
1990	3.97×10^9
1991	5.67×10^9
Average	4.60×10^9 m^3

The total volume of annual runoff fluctuates from 3.59 x 10^9 to 5.67 x 10^9 m^3 and the average is 4.60 x 10^9 m^3.

b) Monthly discharge

Monthly average discharges at the proposed weir site are obtained as shown Table 2.10.

c) Ten-day discharge

Ten-day discharges at the proposed weir site are obtained as shown in Table 2.11.

(5) Dependable discharge at the proposed weir site

Ten-day flows occurring once in five years at the proposed weir site are estimated as follows ;

Month	Period	80% dependable flow (m^3/s)
Jan.	1-10	140.0
	11-20	108.0
	21-31	106.7
Feb.	1-10	99.6
	11-20	85.2
	21-28	94.2
Mar.	1-10	109.7
	11-20	97.0
	21-31	103.3
Apr.	1-10	122.0
	11-20	111.8
	21-30	107.4
May	1-10	131.7
	11-20	106.0
	21-31	86.0
Jun.	1-10	81.4
	11-20	65.7
	21-30	60.9
Jul.	1-10	58.5
	11-20	57.1
	21-31	54.4
Aug.	1-10	50.7
	11-20	49.5
	21-31	49.3
Sep.	1-10	57.3
	11-20	61.7
	21-30	69.2
Oct.	1-10	67.4

	11-20	72.6
	21-31	90.2
Nov.	1-10	113.6
	11-20	90.9
	21-30	108.9
Dec.	1-10	165.6
	11-20	151.8
	21-31	128.4

2.2.2 Flood Runoff Analysis

The following methods are named to estimate flood discharge ;

i) Rational formula
ii) Melchior method
iii) Haspers method
iv) Unit hydrograph method
v) Peak over threshold method
vi) Probability analysis using the past records

The daily rainfall data are available at six(6) stations in the catchment area and daily maximum rainfall at 6 stations are as follows ;

Daily Maximum Rainfall in the Catchment Area (Unit:mm)

Year	Rao. MT	Jamback	Sontang	Lubuk Bendahara	Ujung Batu	Kota Lama
1979	-	69.0	-	-	-	-
1980	-	66.5	-	-	85.1	-
1981	-	81.6	-	-	78.6	-
1982	-	82.0	-	-	100.2	-
1983	-	112.6	114.0	91.2	101.7	189.6
1984	-	98.5	85.3	99.0	68.0	171.7
1985	80.2	80.7	74.9	108.7	58.3	147.0
1986	94.0	78.5	52.4	91.0	140.6	68.7
1987	158.0	84.0	84.6	156.0	73.9	96.0
1988	184.2	87.2	65.0	95.0	49.0	80.0
1989	199.0	83.5	61.0	170.0	167.8	80.0
1990	175.0	-	160.0	100.0	130.9	125.0
1991	232.0	-	-	109.0	78.2	-

The probable rainfall analysis is carried out by both Iwai and

Gumbel methods. The comparison of the results are shown in Table 2.12.

Taking the location of the station and amount of rainfall into account, the probable rainfall obtained by Iwai's method at Lubuk Bendahara is applied for the flood runoff analysis as follows ;

Probable rainfall for flood runoff analysis

Probable year	Rainfall(mm)
1,000	361.9
500	317.8
200	266.8
100	233.0
50	203.1
20	169.0
10	146.8
5	127.3
2	104.8

(1) Flood runoff by Rational Formula

The peak flood discharge by Rational Formula is calculated by the following formula ;

$q = 0.2778 \times f \times r_t$

$Q = q \times A$

where, Q : the peak flood discharge (m^3/s)

q : specific peak flood discharge ($m^3/s/Km^2$)

A : catchment area (Km^2) = 3,267 Km^2 at the proposed weir site

f : runoff coefficient (=0.6)

r_t : mean rainfall intensity within arrival time of flood (mm/hr), expressed by the following equation

$r_t = (r_{24}/24) \times (24/T)^n$

where, r_{24} : maximum daily rainfall (mm)

n : constant, 1/3 to 2/3 usually = 2/3

T : arrival time of flood (hr)

$T = L/W$

W : velocity of flood (Km/hr) when Rziha's formula is applied

$$W = 72 \times (H/L)^{0.6}$$

H : altitude different (Km)

L : river length (Km)

when a river has different slopes in some sections, W is as follows;

$$Wi = (Hi/Li)^{0.6}$$

$$T = \Sigma(Li/Wi)$$

In the Rokan Kiri river, H, L, W and T above from the mountain peak to the proposed weir site are as follows ;

No.	Hi (Km)	Li (Km)	Wi (Km/hr)	Ti (hr)
1	0.160	35.0	2.84	12.32
2	0.807	49.0	6.13	7.99
3	0.020	48.0	0.67	71.64
Total	0.987	132.0	-	91.95

Therefore, the peak flood discharge by every probable rainfall can be calculated as follow ;

Probable flood discharge by Rational formula

Probable Year	Probable Rainfall r_{24}	Rainfall Intensity r_t	Specific Peak Dis. q	Peak Discharge Q=q*A
	(mm)	(mm/hr)	($m^3/s/Km^2$)	(m^3/s)
1,000	361.9	6.16	1.03	3,365
100	233.0	3.96	0.66	2,156
50	203.1	3.45	0.58	1,895
20	169.0	2.87	0.48	1,568
10	146.8	2.50	0.42	1,372
5	127.3	2.17	0.36	1,176

(2) Flood runoff by Melchior Method

The Melchior formula is expressed by the following ;

$$Q = \alpha \times q \times f$$

where, Q : peak flood discharge (m^3/s)
α : runoff coefficient (=0.6)
q : specific discharge ($m^3/s/Km^2$)
f : catchment area (=3,267 Km^2)

In the Melchior formula, the catchment area considered as ellipse shape nF is one of the important factor ;

$nF = 1/4 \times \pi \times a \times b = 1/6 \times \pi \times a^2$
where, a : large axis length (=88 Km)
b : short axis length

Therefore,
$nF = 1/6 \times 3.14 \times 88^2 = 4,053$ Km^2

The average river bed gradient is presented as follow ;

$i = H/\lambda = (10 \times H)/(9 \times L)$
where, H : altitude difference (= 987 m)
L : water course length (= 132 Km)
Therefore,
$i = (10 \times 0.987)/(9 \times 132.0) = 0.00831$

The velocity of flood is given by the following ;

$V = 1.31 \times (\beta \times q \times f \times i^2)^{1/5}$
where, β : reduction coefficient which is given by sloving the following equation ;
$f = 1,970/(\beta - 0.12) - 3,960 + 1,720 \times \beta$
$\therefore \beta = 0.423$

Approximate q is obtained using the figure.
$q = 0.7$ $m^3/S/km^2$

Therefore,

$V = 1.31 \times (0.423 \times 0.7 \times 3,267 \times 0.00831^2)^{1/5} = 0.76$ m/s
$T = 1,000 \times L/60 \times V = 2,895$ min. = 48.3 hr.

Based on the figure, nF = 4,053 Km^2 then q = 0.68 $m^3/s/Km^2$
Accordingly, V = 0.76 m/s, T = 2,895 = 48.3 hr .....O.K

The above q is the value which the maximum daily rainfall is taken to be 200 mm and the peak flood discharge of every return period is respectively calculated as follows ;

Probable flood discharge by Melchior Method

Probable Year	Probable Rainfall	Peak Discharge
	(mm)	(m^3/s)
1,000	361.9	2,412
100	233.0	1,553
50	203.1	1,354
20	169.0	1,126
10	146.8	978
5	127.3	848

Example : Q_{100} = 0.6 x 0.68 x 361.9/200 x 3,276 = 2,412 m^3/s

(3) Flood runoff by Hasper Method

The peak flood discharge by the Hasper's method is presented by the following formula ;

$$Q = \alpha \times \beta \times q \times f$$

where, Q : peak flood discharge (m^3/S)
α : runoff coefficient
β : reduction coefficient
q : specific discharge ($m^3/s/Km^2$)
f : catchment area (=3,267 Km^2)

Runoff coefficient α and reduction coefficient β can be obtained by the following formula ;

$$\alpha = (1+0.012xf^{0.7})/(1+0.075xf^{0.7})$$
$$= (1+0.012x3,267^{0.7})/(1+0.075x3,267^{0.7}) = 0.20$$

$$1/\beta = 1+(t+3.7x10^{-0.4t})/(t^2+15)xf^{3/4}/12$$

where, t : arrival time of flood

$$t = 0.1xL^{0.8}xi^{-0.3}$$
$$= 0.1x132^{0.8}x(0.987/132)^{-0.3}$$
$$= 21.6 \text{ hrs}$$

Therefore,

$$1/\beta = 1+(21.6+3.7x10^{-0.4x21.6})/(21.6^2+15)x3,267^{3/4}/12$$
$$= 2.6152$$
$$\therefore \beta = 0.38$$

On the other hand, the maximum specific discharge is obtained by the following equation ;

$q = r/(3.6 \times t)$, in which

t : mean rainfall intensity within the arrival time of flood (hr)

$r = t \times R/(t+1)$, in which

R : maximum daily rainfall for a certain return period T (mm)

$R = \underline{R} + S \times Ut$, in which

$\underline{R}$: average of the past yearly maximum daily rainfalls (mm)

$S = (Rn - \underline{R})/U$, in which

Rn: past maximum daily rainfall for recorded n years (mm)

U : STANDARD VARIABLE FOR THE RETURN PERIOD WITH RN T=1/23, THEN U=1.21

Therefore, S = (170.0-113.3)/1.21 = 46.86

Based on the concept mentioned above, the peak discharge for every return period can be calculated below ;

Probable flood discharge by Hasper's Method

Return Period	Ut	R $\underline{R}$+SxUt	r txR/(t+1)	Specific Peak Dis. q	Peak Discharge Q=αβqf
		(mm)	(mm)	($m^3/s/Km^2$)	(m^3/s)
1,000	5.92	390.7	373.4	4.80	1,192
100	3.43	274.0	261.9	3.37	836
50	2.75	242.2	231.4	2.98	739
20	1.89	201.9	192.9	2.48	616
10	1.27	172.8	165.2	2.12	527
5	0.64	143.3	136.9	1.76	437

(4) Flood runoff by Unit Hydrograph

Nakayasu offers the following equation to obtain specific values of the unit hydrograph ;

$$Q_{max} = 1/3.6 \times A \times R_0/(0.3 \times Tp + Tk)$$

- Ascending curve :

  $Q_d / Q_{max} = (t/Tp)^{2.4}$

- Recession curve :

  $Q_d / Q_{max} = 0.3^{(t-Tp)/Tk}$ in case $Q_d / Q_{max} \geq 0.3$

  $Q_d / Q_{max} = 0.3 \times 0.3^{(t-(Tp+Tk))/1.5Tk}$ $0.3 \geq Q_d / Q_{max} \geq 0.3^2$

  $Q_d / Q_{max} = 0.3^2 \times 0.3^{(t-(Tp+Tk+1.5Tk))/2.0Tk}$ $0.3^2 \geq Q_d / Q_{max}$

  where,

  Q_{max} : maximum discharge in the unit hydrograph (m^3/s)

  Q_a, Q_d : discharge on ascending curve (Q_a) or recession curve (Q_d) (m^3/s)

  A : catchment area (=3,267 Km^2)

  R_0 : effective rainfall

  T_1 : time from starting of runoff to the maximum discharge (hr)

  $T_{0.3}$: time from the maximum discharge the discharge of 0.3 times the maximum discharge (hr)

  T_r : unit time (hr)

Nakayasu assumed the unit hydrograph as mentioned above and T_1 and $T_{0.3}$ can be presented by specificity of catchment area. He also assumed a time lag (t_g = taken $0.8t_r$) from a peak rainfall in a unit time (t_r) to the maximum discharge can be presented using the maximum flow length (L Km) as mentioned below ;

in case of $L \leq 15$ Km : $t_g = 0.21 \times L^{0.7}$

in case of $L \geq 15$ Km : $t_g = 0.4 + 0.058 \times L$

T_1 and $T_{0.3}$ can be expressed applying the time lag (t_g) mentioned above as follows ;

a) in case of river with earlier runoff after rain and quick withdraw : $T_{0.3} = 1.5 \times t_g$

b) in case of river with later runoff after rain and slow withdraw : $T_{0.3} = 3.0 \times t_g$

c) in case of river with condition between a) and b) above : $T_{0.3} = 2.0 \times t_g$ or $T_{0.3} = t_g + 0.8 \times t_r$

Then, the unit hydrograph can be drawn applying

$t_r = (0.5 - 1.0) \times t_g$

The unit hydrograph using the catchment area of A=3,267 Km^2 at the proposed weir site becomes as follows ;

** Basic parameters for unit hydrograph **

- Catchment area $A = 3,267\ Km^2$
- Maximum flow length $L = 132\ Km$
- Time lag $T_g = 0.4+0.058x132 = 8.06$ hrs
- Unit time $T_0 = 5.00$ hrs
- $Tk = 3.0xT_g = 24.18$ hrs
- $Tp = T_g + 0.8xT_0 = 12.06$ hrs
- $T_{0.3} = Tp + Tk = 36.24$ hrs
- $T_{0.09} = T_{0.3} + 1.5xTk = 72.51$ hrs
- $q_p = 1.0/(0.3xTp+Tk) = 0.036$ mm/hr

Accordingly, unit discharge is calculated as follows ;

$0 \le t \le 12.06 \quad q = q_p x(t/11.34)^{2.4}$

$12.06 \le t \le 36.24 \quad q = q_p x0.3^{(t-Tp)/Tk}$

$36.24 \le t \le 72.51 \quad q = q_p x0.3x0.3^{(t-(Tp+Tk))/1.5Tk}$

$72.51 \le t \quad q = q_p x0.09x0.3^{(t-(Tp+Tk+1.5Tk))/2.0Tk}$

The Table 2.13 shows an example of calculation of flood discharge applying the probable rainfall of 1/100 year.

The peak flood discharge for every return period is summarized below ;

Probable flood discharge by Unit Hydrograph Method

Probable Year	Probable Rainfall	Peak ischarge
	(mm)	(m^3/s)
1,000	361.9	3,100
100	233.0	1,996
50	203.1	1,740
20	169.0	1,448
10	146.8	1,258
5	127.3	1,090

(5) Flood runoff by Peak Over Threshold (POT) Method

When flood records are of shorter periods or do not cover a long