REPUBLIC OF INDONESIA
MINISTRY OF PUBLIC WORKS
DIRECTORATE GENERAL OF WATER RESOURCES DEVELOPMENT

THE STUDY ON
[illegible] PADANG
[illegible] BASIN DEVELOPMENT

FINAL REPORT

([illegible])

MARCH [illegible]

JAPAN INTERNATIONAL COOPERATION AGENCY
(JICA)

REPUBLIC OF INDONESIA
MINISTRY OF PUBLIC WORKS
DIRECTORATE GENERAL OF WATER RESOURCES DEVELOPMENT

THE STUDY ON
BELAWAN - PADANG
INTEGRATED RIVER BASIN DEVELOPMENT

FINAL REPORT

(SUPPORTING)

MARCH 1992

JAPAN INTERNATIONAL COOPERATION
AGENCY

SUPPORTING REPORTS

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SE	SOCIO-ECONOMY
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TOPOGRAPHIC SURVEY

STUDY ON BELAWAN-PADANG
INTEGRATED RIVER BASIN DEVELOPMENT

SUPPORTING REPORT

TOPOGRAPHIC SURVEY

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TOPOGRAPHIC SURVEY

1. INTRODUCTION

In order to carry out the Master Plan Study on integrated river basin development and the Feasibility Study on urgent projects, topographic information such as aerial photography, photogrammetric mapping and river survey are needed as the basic data.

To attain the above, various survey works were carried out in the following two stages:

(1) Master Plan Stage

Aerial photographic survey of the whole study area and photogrammetric mapping of the flood prone area were the main items of work carried out with financing from the Japan International Cooperation Agency (JICA).

(2) Feasibility Study Stage

Photogrammetric mapping and river survey work were the main items of work conducted for the urgent project components such as Lausimeme Dam, Medan Floodway and the river improvement works, also with financing from the Japan International Cooperation Agency (JICA).

2. SCOPE OF WORK

2.1 Master Plan Stage

The scope of work for photogrammetric mapping and river survey in the Study Area are tabulated as follows:

(1) Photogrammetric Mapping

Aerial Photography	5,800 km^2 at 1:25,000
Monumentation	42 points
Control Point Survey (GPS)	45 points
Minor Order Leveling	300 m
Field Verification	1,000 km^2
Aerial Triangulation	300 models
Plotting/Editing	1,000 km^2 at 1:5,000; Contour interval 2.0 m
Drawing	1,000 km^2

(2) River Survey

<u>Belawan River</u>

Longitudinal Profile Survey		40 km
Cross Section Survey	@1 km	48 secs

<u>Percut River</u>

Longitudinal Profile Survey		30 km
Cross Section Survey	@1 km	39 secs

<u>Belutu River</u>

Longitudinal Profile Survey		40 km
Cross Section Survey	@1 km	48 secs

<u>Padang River</u>

Longitudinal Profile Survey		30 km
Cross Section Survey	@1 km	38 secs

2.2 **Feasibility Stage**

The volume of work for photogrammetric mapping and river survey for urgent project sites are summarized as follows:

(1) Photogrammetric Mapping

<u>Lausimeme Damsite</u>

Monumentation	9 points
Control Point Survey (GDS)	9 points
Leveling	20 km
Aerial Triangulation	4 models
Plotting/Editing	3 km^2 at 1:5,000 and 1:2,000

<u>Deli River</u>

Field Verification	6.5 km^2
Plotting/Editing	6.5 km^2 at 1:5,000

(2) River Survey

<u>Deli River</u>

Longitudinal Profile Survey		4.5 km
Cross Section Survey	@400 m	7 secs
	@200 m	46 secs

<u>Percut River</u>

Longitudinal Profile Survey		30.0 km
Cross Section Survey	@200 m	140 secs

<u>Padang River</u>

Longitudinal Profile Survey		30.0 km
Cross Section Survey	@200 m	140 secs

(3) Leveling Survey

Six Water Gauging Stations	10 km

3. EXECUTION OF WORK

3.1 Master Plan Stage

Fieldwork

The following work was conducted by a local survey company in accordance with a contract with the JICA Study Team and the technical specifications provided.

(1) Aerial Photography

The location of aerial photography is shown in Fig. 3-1 and its specifications are as follows:

Item	Volume
Area	5,800 km^2
Camera and Film	Wide angle lens, Monochrome film
Scale	1:25,000
Flight Altitude	3,750 - 4,000 m
Flight Length	Approx. 1,700 km
Number of Sheets	Approx. 106 sheets
Sidelap and Overlap	Sidelap: 30% + 10% Overlap: 60% + 5%

(2) Control Point Survey (GPS)

Forty-two (42) new ground control points were set for aerial triangulation. Planimetric positioning of the ground control point was determined by GPS (Global Positioning System).

(3) Mirror Order Leveling and Monumentation

Mirror order leveling was conducted by direct leveling method. Monumentation of control points was established at places suitable for maintenance, and monumentation was carried out in conformity with Indonesian specifications. Results of survey and records are filled in description forms.

Spot elevations at approximately 500 m intervals by direct leveling were pricked on twice-enlarged aerial photos for aerial triangulation.

(4) Field Verification

Field verification for approx. 1,000 km^2, which is subject for mapping as shown in Fig. 3-2, was made using twice-enlarged photos. Field verification was performed in accordance with the map symbols and their application rules, by using aerial photos and available data based on the preliminary photo interpretation.

(5) Longitudinal Profile and Cross Section Survey

Longitudinal profile and cross section survey for four (4) river courses were carried out. Each cross section was extended by 300 m from both the left and right banks. Location of river survey work is shown in Fig. 3-3.

Indoor Work

Aerial triangulation, plotting/editing and drawing were performed based on the field survey results. They are subject to change depending on the results of the succeeding study.

(1) Aerial Triangulation

A total of 300 models were adjusted by block adjustment method using independent models.

Pass points, tie points and kilometer posts on aerial photos and the orientation elements required for succeeding plotting/editing and cartography shall be computed by using survey results of the control point survey and minor order leveling.

(2) Plotting/Editing

Based on the results of aerial triangulation, control point survey and field verification, topographic features necessary for mapping were measured and delineated by plotting machines with colored ball-point pens to produce the manuscript sheets and orientation records.

(a) Mapping scale and work volume (1:5,000 and 1,000 km^2)

(b) Control interval (2 m: 1 m for half interval contours)

(c) Format of manuscript sheet (80 cm x 60 cm; 106 sheets)

(d) Map symbols and their application rules, and cartographic standards were agreed upon based on the results of field verification.

(3) Fair Drawing

Fair drawings were performed on the marginal design sheets of 1:5,000 scale topographic maps in accordance with the rules of annotations discussed with Indonesian counterparts.

Original drawings were performed in the order given below by a standard drafting (fair drawing) method based on the compilation manuscript, as well as the map symbols and their application rules.

(a) Spot height
(b) Annotations

(c) Linear features
(d) Building symbols
(e) Building, planimetric features
(f) Vegetation symbols
(g) Vegetation boundary
(h) Contourlines

Index maps to adjoining sheets are shown in Fig. 3-4.

3.2 Feasibility Study Stage

The same datum as described in Section 3.1 was basically adopted in the Feasibility Study Stage.

Photogrammetric Mapping

Locations of photogrammetric mapping for urgent project sites such as Lausimeme reservoir and Medan floodway are shown in Fig. 3-5.

River Survey

Locations of river survey are shown in Fig. 3-3.

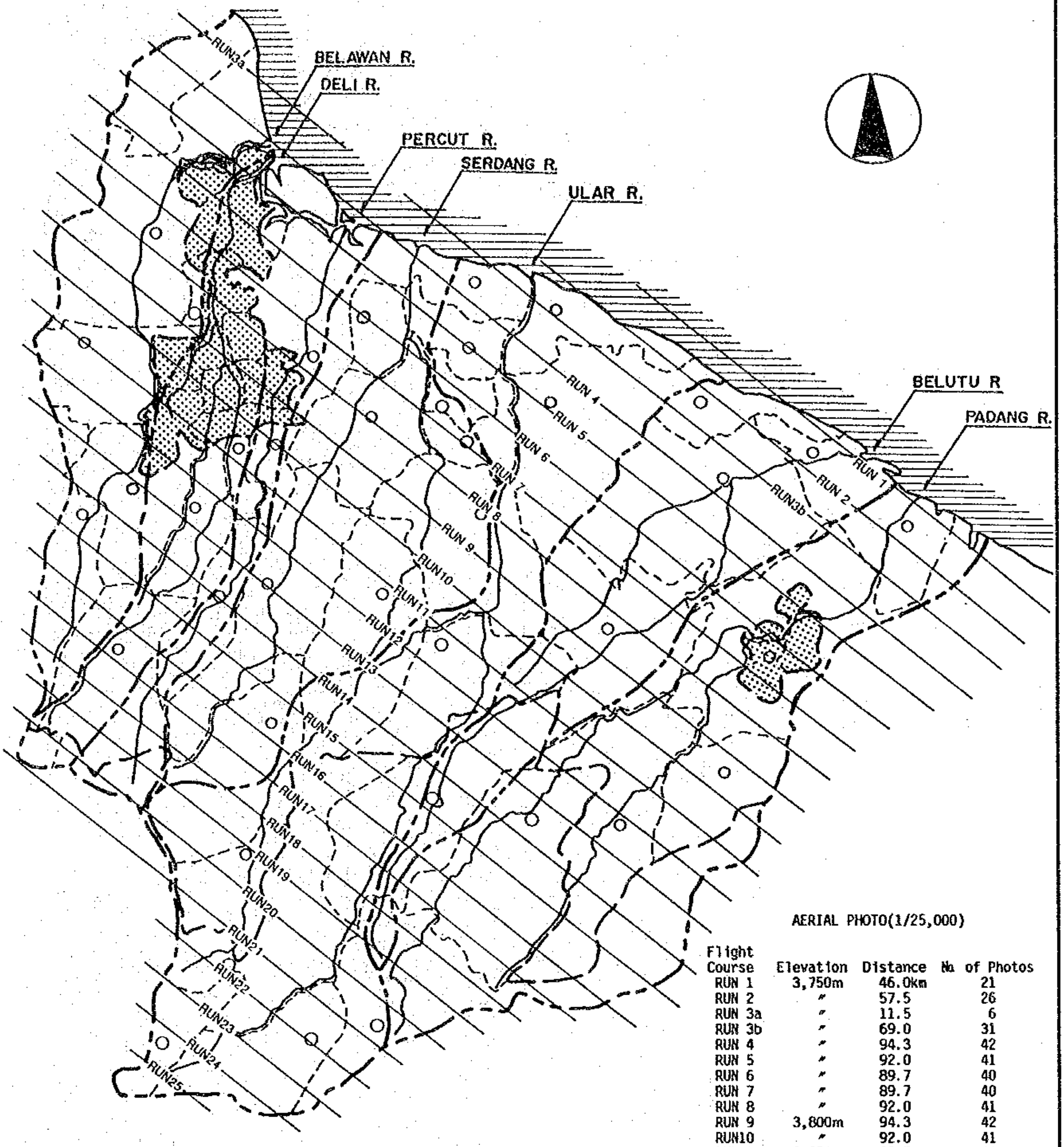
Leveling Survey

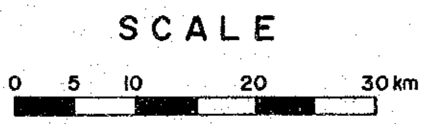
Leveling survey for the six (6) water gauging stations installed in this JICA study were conducted to confirm each fixed point of ground elevation. (Refer to Fig. 3-5.)

4. RESULTS

All the results of the foregoing survey work were submitted to the JICA Jakarta Office.

FIGURES





AERIAL PHOTO(1/25,000)

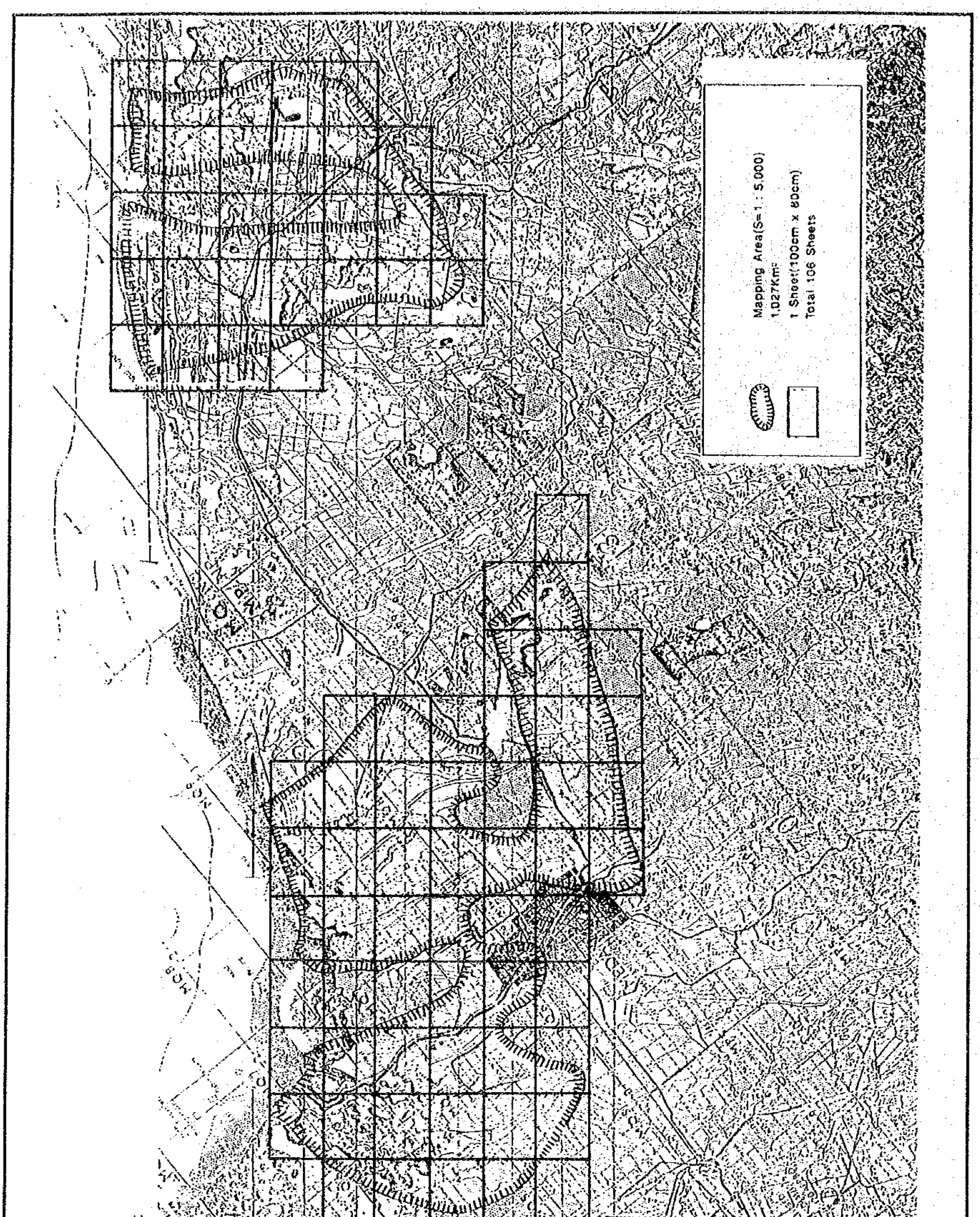
Flight Course	Elevation	Distance	№ of Photos
RUN 1	3,750m	46.0km	21
RUN 2	〃	57.5	26
RUN 3a	〃	11.5	6
RUN 3b	〃	69.0	31
RUN 4	〃	94.3	42
RUN 5	〃	92.0	41
RUN 6	〃	89.7	40
RUN 7	〃	89.7	40
RUN 8	〃	92.0	41
RUN 9	3,800m	94.3	42
RUN10	〃	92.0	41
RUN11	3,850m	89.7	40
RUN12	〃	85.1	38
RUN13	3,900m	82.8	37
RUN14	4,000m	82.8	37
RUN15	4,150m	78.2	35
RUN16	4,350m	73.6	33
RUN17	4,400m	66.7	30
RUN18	4,700m	59.8	27
RUN19	〃	52.9	24
RUN20	〃	50.6	23
RUN21	4,500m	48.3	22
RUN22	4,300m	27.6	13
RUN23	4,100m	23.0	11
RUN24	〃	27.6	13
RUN25	〃	27.6	13
Total 26 Course		1704.3km	767

THE STUDY ON BELAWAN-PADANG INTEGRATED RIVER BASIN DEVELOPMENT IN THE REPUBLIC OF INDONESIA

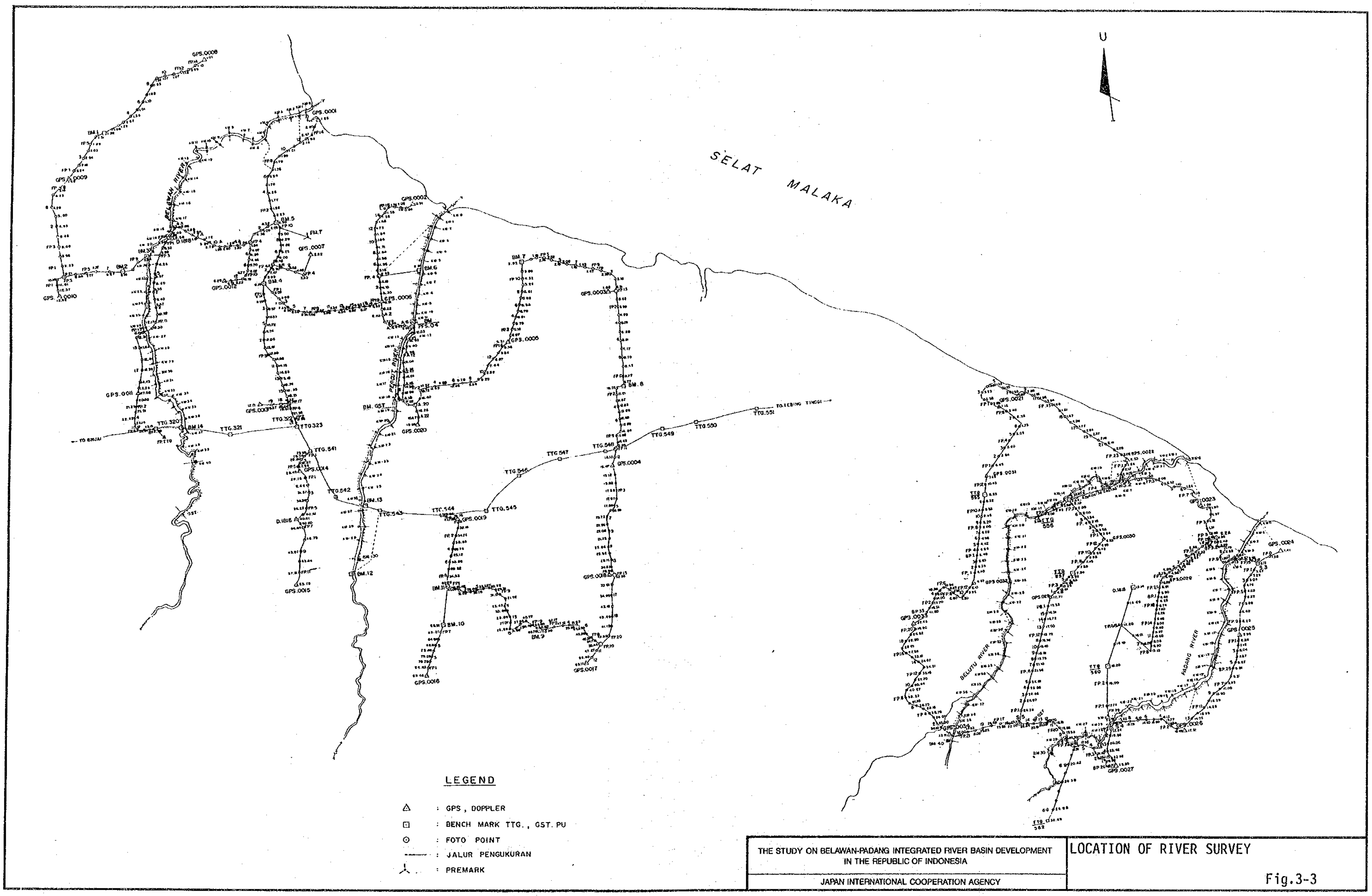
JAPAN INTERNATIONAL COOPERATION AGENCY

LOCATION OF AERIAL PHOTOGRAPHY

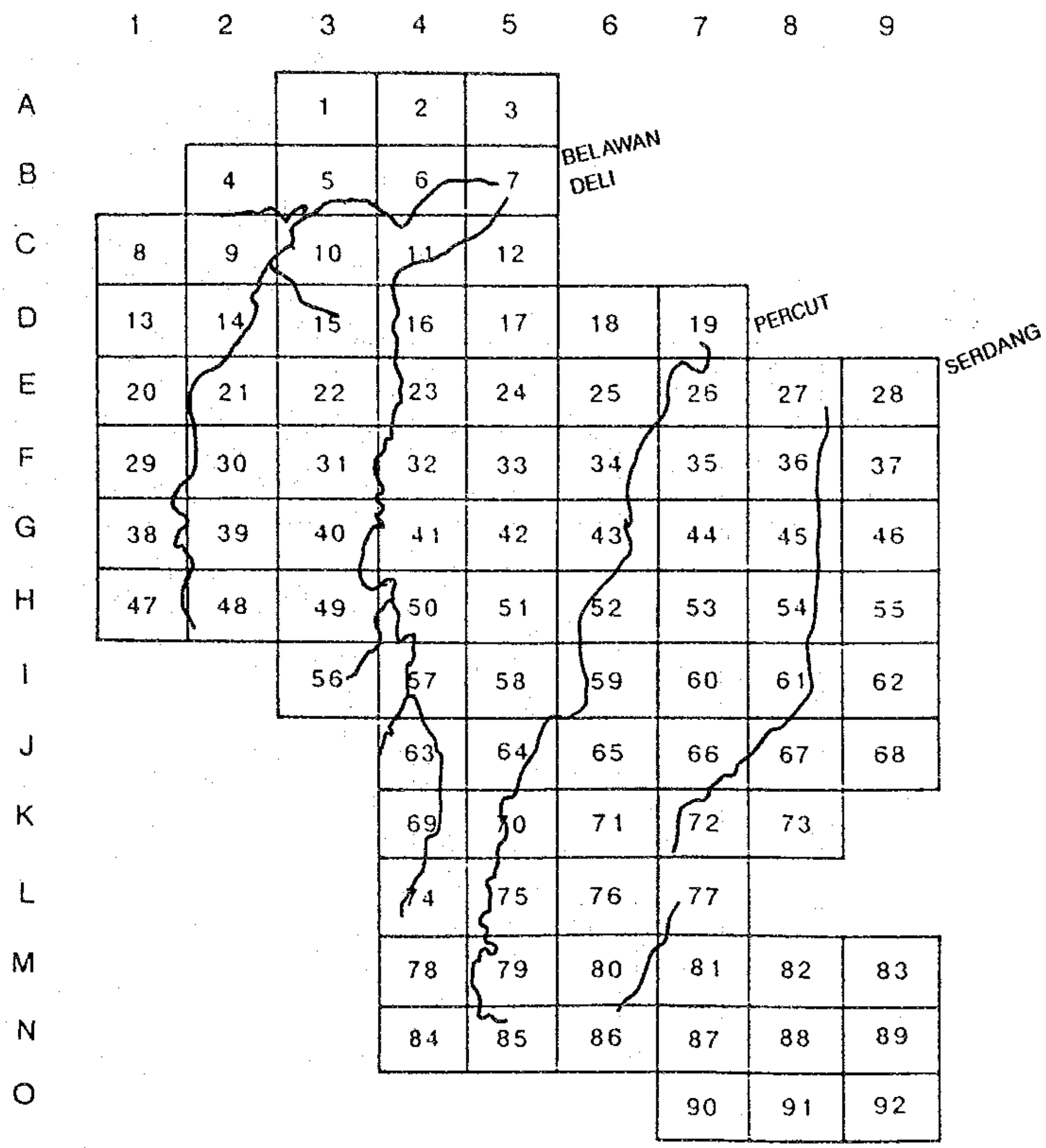
Fig.3-1



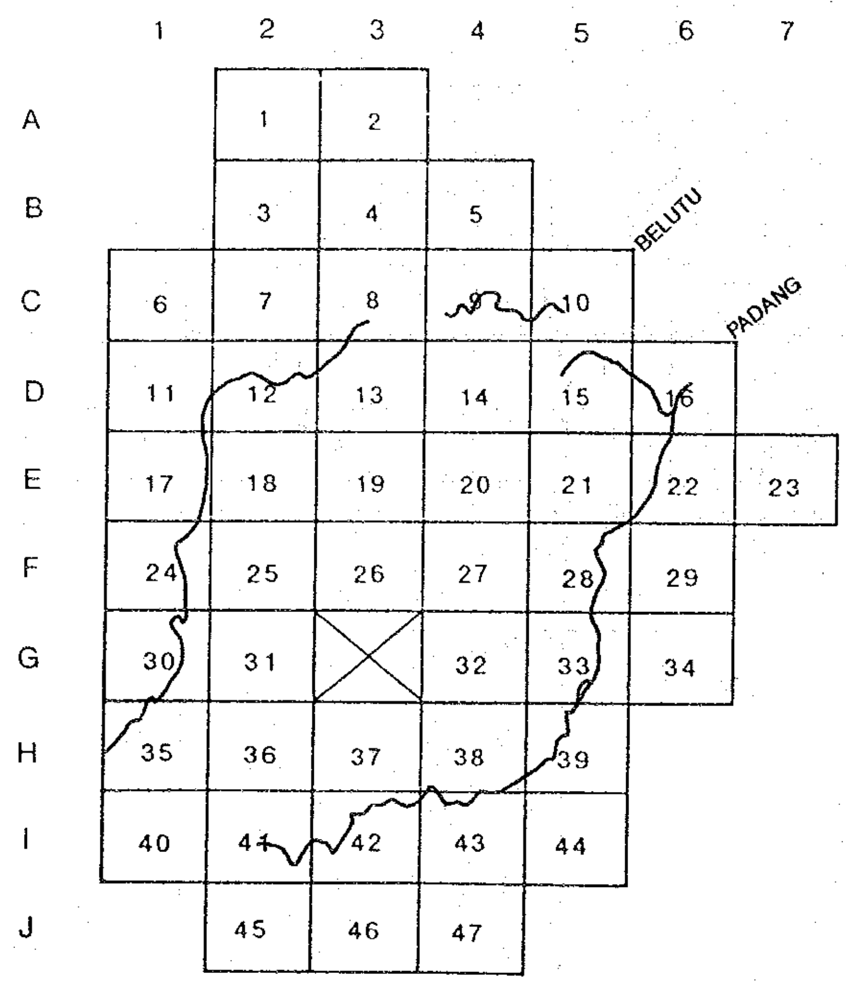
THE STUDY ON BELAWAN-PADANG INTEGRATED RIVER BASIN DEVELOPMENT IN THE REPUBLIC OF INDONESIA	LOCATION OF MAPPING AREA
JAPAN INTERNATIONAL COOPERATION AGENCY	Fig.3-2



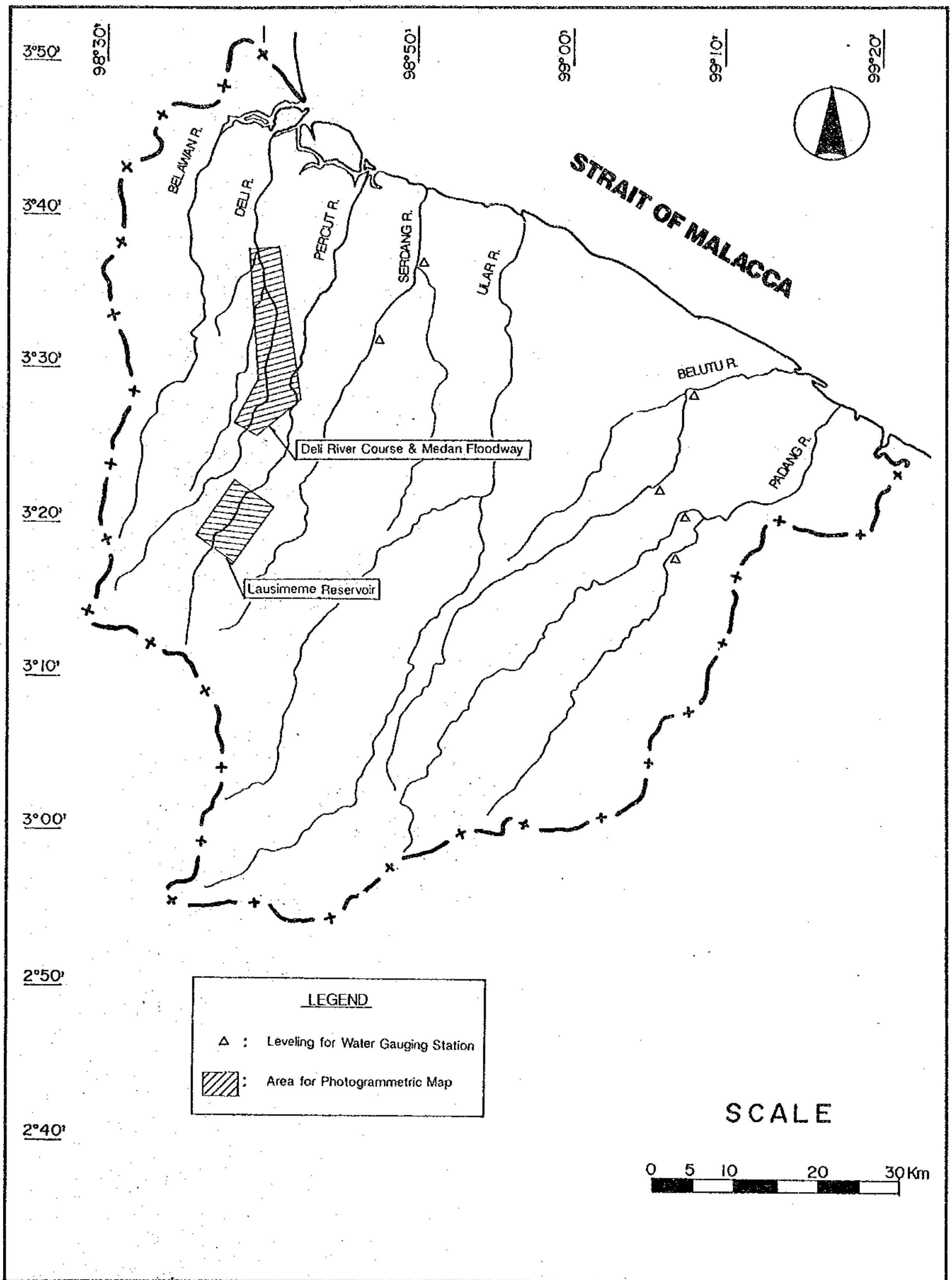
THE STUDY ON BELAWAN-PADANG INTEGRATED RIVER BASIN DEVELOPMENT IN THE REPUBLIC OF INDONESIA	LOCATION OF RIVER SURVEY
JAPAN INTERNATIONAL COOPERATION AGENCY	Fig.3-3



THE STUDY ON BELAWAN-PADANG INTEGRATED RIVER BASIN DEVELOPMENT IN THE REPUBLIC OF INDONESIA	INDEX OF PHOTOGRAMMETRIC MAP
JAPAN INTERNATIONAL COOPERATION AGENCY	Fig.3-4(1/2)



THE STUDY ON BELAWAN-PADANG INTEGRATED RIVER BASIN DEVELOPMENT IN THE REPUBLIC OF INDONESIA	INDEX OF PHOTOGRAMMETRIC MAP
JAPAN INTERNATIONAL COOPERATION AGENCY	Fig.3-4(2/2)



THE STUDY ON BELAWAN-PADANG INTEGRATED RIVER BASIN DEVELOPMENT IN THE REPUBLIC OF INDONESIA	LOCATION OF PHOTOGRAMMETRIC MAPS AT LAUSIMEME DAM AND MEDAN FLOODWAY
JAPAN INTERNATIONAL COOPERATION AGENCY	Fig.3-5

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HYDROLOGY

STUDY ON BELAWAN-PADANG
INTEGRATED RIVER BASIN DEVELOPMENT

SUPPORTING REPORT

HYDROLOGY

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HYDROLOGY

1. INTRODUCTION

This Supporting Report on Hydrology presents the results of the hydrologic and hydraulic investigation and analysis for the Belawan-Padang integrated river basins.

Seven (7) major rivers originating in the steep slope of the mountains flow down generally in north to northeastern direction. They are from northwest to southeast, the Belawan, Deli, Percut, Serdang, Ular, Belutu and Padang rivers, as shown in Fig. 1-1.

The features of each river basin are as follows:

Features of Rivers in the Study Area

River	Catchment Area (km2)	Longest Stream (km)	Maximum Elevation (m)	Minimum Elevation (m)	Average Gradient (1/I)
Belawan	647	76	1,100	0	69
Deli	358	82	1,500	1	55
Percut	186	64	1,520	8	42
Serdang	671	63	1,450	4	44
Ular	1,081	91	1,330	30	70
Belutu	500	76	1,000	4	76
Padang	919	82	1,020	6	81

2. CLIMATE AND RAINFALL

2.1 Existing Observatory

There are four (4) meteorological stations (Sampali, Polonia, Belawan and Tanjung Morawa) operated by the Center of Meteorology and Geophysics (PMG) for the observation of temperature, relative humidity, sunshine duration, wind velocity, evaporation and rainfall. The other stations are the 91 stations maintained by the Research Institute of Sumatra Planter's Association (RISPA) for the observation of daily rainfall and the 25 rainfall stations related to the Ular River Project. Although all RISPA stations are operated manually, observation has been continued for a long time and rainfall data are available from 1948. Location and data of these rainfall stations are as shown in Figs. 2-1 and 2-2 and in Tables 2-1 to 2-3.

2.2 Climatic Characteristics

The climate of North Sumatra Province, unlike that of other Indonesian regions south of the equator, is characterized by a little difference between the wet and dry seasons. Since Sumatra is located near the southern side of the continent across the Strait of Malacca, the study area is not greatly affected by northeasterly monsoons and trade winds.

This region is located in the area known as the Intertropical Convergence Zone, and due to its topographical structure and geographical location the air over the region is warm and relatively humid. Therefore, unstable air occurs along the doldrums of low pressure. The water content of the air, together with orographical lifting, may cause heavy rain; and, diurnal heating over land areas produce convective showers.

Meteorological records at Sampali Station are considered representative in the study area. Climatological data recorded at this station are shown in Table 2-4. Rainfall data show low values from January to March and high values from September to December.

Temperature ranges between 21°C and 33°C and annual temperature averages 26°C. Relative humidity ranges between 83% and 87% and the average is 85%. The temperature and humidity in this area is very high throughout the year with the annual pan evaporation as high as 1,566 mm.

Mean monthly sunshine duration ranges between 43% and 60% and the average is 53%. These values appear relatively low due to a layer of cumulonimbus clouds caused by diurnal heating and convection.

Mean wind velocity is 0.82 m/s. Higher velocities have been recorded exceeding 15 m/s at ground surface. Northerly or northeasterly monsoons blow throughout the year, but the area is located outside of the region affected by tropical depressions or cyclones.

Rainfalls in the southern mountainous area and the northern coastal plain are 2,900 mm and 1,700 mm, as shown in Fig. 2-3. The isohyetal map of annual rainfall is as shown in Fig. 2-4. The higher elevation the area is located, the more rainfall is observed.

3. RIVER FLOW AND FLOOD CONDITIONS

3.1 Existing Observatory

Water level stations under operation are the ten (10) stations (Kampung Lalang, Asam Kumbang, Helvetia, Simeme, Tembung, Kp. Serdang, Tanjung Morawa, Silau Dunia, Tebing Tinggi and Pulau. Tagor) under the Hydrology Section of DPUP and the seven (7) stations related to the Ular River Project as shown in Table 3-1. Their locations are as shown in Fig. 3-1.

Records of daily water level have been collected and processed by the Hydrology Section since 1972, and data of the automatic water level stations are available from 1980. Observation under the Ular River Project was started in late 1971, but it was discontinued in 1986. The available data from these water level stations are as shown in Tables 3-2 and 3-3.

3.2 River Discharge

Discharge Rating Curve

Daily discharge data for low flow analysis and the rating curves used for conversion from daily water level were provided by the Institute of Hydraulic Engineering (IHE) in Bandung. As for flood runoff analysis, the hourly levels are converted into hourly discharges using the same rating curves. However, the rating curves prepared by the IHE were constructed using only the low flow data. Therefore, flood discharges calculated by the rating curves extrapolated to high flow area are rather small compared to the actual ones.

As a consequence of the above, the rating curves are set up as follows:

(a) The rating curves prepared by the IHE are applied to the low flow area.

(b) Rating curves for the high flow area are set up using the cross section at water level stations and estimates obtained from Manning's Uniform Flow Calculation.

(c) The low flow and high flow areas are connected in consideration of the observed discharge data.

(d) Since the connection between the low flow and high flow areas are not available in the three (3) automatic water level stations of Tumbung, Silau Dunia and Kp. Serdang, the parameters for the rating curve are calculated by the least square method. River cross sections and rating curves are drawn, as shown in Fig. 3-2 together with the results of hydraulic calculations.

Flow Regime

Flow regimes in observed discharges at the following stations are presented in Table 3-4, and each specific discharge and non-exceedence probability at the gauging stations are drawn as shown in Fig. 3-3.

Flow Regime at Discharge Gauging Stations

River	Station	Catchment Area (km2)	Period
Belawan	Asam Kumbang	209	1982-1988
	Kampung Lalang	254	1980-1988
Deli	Simeme	158	1980-1988
	Helvetia	341	1980-1988
Serdang	Tanjung Morawa	250	1972-1978
Ular	Pulau Tagor	1,031	1972-1988 (except 1979)
Padang	Tebing Tinggi	919	1977-1986

Flood Records

The annual maximum water level is extracted from the recording charts of automatic water level stations and converted into the maximum flood discharge. It is noted that the maximum water levels of three (3) water level stations (Kp. Lalang, Helvetia and Pulau Tagor) which were not equipped with an automatic recorder were observed manually, usually three (3) times per day. Table 3-5 shows the annual maximum flood discharges for each station.

4. RAINFALL ANALYSIS

4.1 Selection of Representative Stations

The availability of daily rainfall data collected at the different rainfall stations have been described earlier. In view of the length of observation periods and areal distribution, 15 rainfall stations representing two periods are selected. The first period is 15 years (1954 to 1968) and the second period is 20 years (1969 to 1988), as shown in Fig. 4-1. Their monthly rainfalls are presented in Table 4-1.

Rainfall stations are densely distributed in the northern flat land, but limited in the southern mountainous area. Therefore, the rainfall stations in the mountainous area are used to the possible extent, and stations in the flat land are selected roughly to one in 100 km^2.

4.2 Compensation of Missing Data

All rainfall stations, except Balai Penelitian Station, have a few missing data. Therefore, linear regression analysis is conducted to compensate the missing data. The correlation coefficient gives a higher value when the distance between the respective stations is closer. Compensation of missing data is made using the data of the closest station.

4.3 Calculation of Basin Rainfall

Based on the Thiessen polygons drawn for each river basin from the 15 representative stations as shown in Fig. 4-2, the average daily rainfall for 35 years is calculated. Their maximum daily rainfall are presented in Table 4-2.

4.4 Probable Daily Rainfall

Probable daily rainfalls in each river basin are estimated using the Gumbel Method as shown in Table 4-3. Probability graphs of exceedence drawn on a extreme value probability paper which are given the plotting position by the Thomas Plot are presented in Fig. 4-3.

4.5 Model Hyetograph

The actual rainfall pattern during a flood is commonly used for the rainfall pattern to obtain the probable hydrograph. There is only one (1) rainfall gauging station in the study area, namely Sampali, where hourly rainfall data have been recorded; hence, a model hyetograph is applied.

To define a typical rainfall pattern in the study area, the biggest 20 daily rainfalls for 13 years from 1977 to 1989 are extracted from all records, converted into accumulative rate (refer to Table 4-4) and centralized putting in order the occurrence time of hourly maximum precipitation. Duration of storms causing flood usually continue for 12 hours on average since their rainfall distribution is standardized by the hourly rate as presented in Fig. 4-4. Based on this typical rainfall pattern and the aforementioned probable daily rainfall, the design storm is prepared.

5. FLOOD RUNOFF ANALYSIS

5.1 Flood Runoff Model

The Storage Function Method is employed for the flood runoff analysis because the method can express non-linearity of rainfall-runoff relation, and it has been used widely for a long time to generate hydrographs and to calibrate parameters. A basin runoff model is constructed for each river based on the subbasin divisions and the topographic conditions. The model also includes the possible dams which are discussed in the Supporting Report on Dam and Reservoir.

The Storage Function Model was developed to express the non-linear characteristics of runoff phenomena, introducing the following function between the storage volume (S_l) of a basin and the discharge (Q_l) from the same.

$$S_l = KQ_l^p$$

where,

K and p are parameters.

This equation is used with the equation of motion which expresses runoff as proportional to the exponent of storage volume. In this equation, runoff phenomena is considered to be similar to the runoff from the notch of a container filled with water.

Runoff calculation is performed in combination with the following equation of continuity for basin.

$$\frac{dS_l}{dt} = \frac{1}{3.6} f r_{ave} A - Q_l$$

where,

S_l : apparent storage volume in the basin ($m^3/s/hr$)
f : inflow coefficient
r_{ave} : basin's average rainfall (mm/hr)
A : area of the basin (km^2)
$Q_l(t) = Q(t+T_l)$: direct runoff height with lag time (m^3/s)
T_l : lag time (hr)

The Storage Function of the channel is expressed as follows:

$$S_l = K \times Q_l^P - T'_l \times Q_l$$

where,

K and p : parameters
T'_l : lag time for river channel

5.2 Division of Basin

Each river basin is divided into several subbasins for constructing a flood runoff model. The division into subbasins is made in such that a subbasin area is approximately 100 km^2 taking into consideration the catchment of tributaries and topographic conditions (refer to Fig. 5-1). Based on this division into subbasins, the basin runoff model is developed (refer to Fig. 5-2).

5.3 Model Calibration

Objective Flood

Objective floods for the estimation of parameters are selected from the annual maximum flood records by automatic water level stations (refer to Table 3-5) considering available hourly rainfall data. The following 11 floods, except in the Belawan and Ular river basins, are selected for the estimation of parameters.

Floods for Estimation of Parameters

River	Station	Date
Deli	Simeme	30-31 OCT 1980 06-07 DEC 1986
Percut	Tembung	20-21 MAY 1985 06-07 DEC 1986
Serdang	Kampung Serdang	18-20 DEC 1985 06-07 DEC 1986
Belutu	Silau Dunia	07-08 NOV 1984 18-19 DEC 1985 17-19 APR 1986 09-10 DEC 1987
Padang	Tebing Tinggi	16-17 DEC 1985

Setting of Parameters

Setting of parameters for the flood runoff model is made as follows:

(1) Parameters of Basin

The values for K and p of basin are determined from actual flood records. As for the Belawan River, because of no available records, K and p of basin are determined to be the same as those of the Deli river basin except K of the downstream basins of Belawan River. Considering the flat and plain land in the downstream area, K of these basins are determined by raising the average gradient of basin to the minus zero point three (-0.3) power. On the other hand, the values for

K and p of the Ular River Basin are calculated to be most suitable to the probable flood discharge of the Ular River Project.

The value for T_l of subbasins is determined from an experimental formula (Rziha Formula) as follows:

$$T_l = \frac{L}{72} \times \left(\frac{h}{L}\right)^{0.6} \times \frac{L_s}{L}$$

where,

T_l : lag time of subbasin (hr)

L : distance from the point under consideration to the farthest point in the basin along the river course (km)

h : altitude difference of L

L_s : distance from the point under consideration to the farthest point in the subbasin along the river course

Lag time of basins and subbasins are as shown in Tables 5-1 and 5-2, respectively.

(2) Base Flow (Q_B)

Base flow for each subbasin is determined as 0.035 $m^3/s/km$ from the 80% of flow regime in the study area discussed in Low Flow Analysis.

(3) Primary Runoff Rate (f_1) and Saturation Rainfall Depth (R_{sa})

f_1 and R_{sa} are fixed at 0.3 and 300 mm, respectively, which are the average values calculated from actual flood records.

(4) K, p and T_l of River Channel

K and p for river channels are determined assuming the flow as Manning's uniform flow.

T_l for river channels is determined from an experimental formula proposed by Sasama in Japan; namely,

$$K = B^{0.4} \times n^{0.6} \times I^{-0.3} \times L / 3.6$$

$$P = 0.6$$

$$T_l = 0.00076 \times L \times I^{-0.5}$$

where,

K, p : parameters for river channel

T_l : lag time
B : average width (km)
n : Manning's roughness coefficient (0.035)
I : average gradient
L : channel length (km)

K and T_l of river channels calculated are as shown in Table 5-3.

Calibration of Constants

Calibration of the constants is conducted by comparing observed and calculated hydrographs. As presented in Fig. 5-3, the constants of storage function are determined to be most suitable to simulate the calculated hydrograph to the observed one. Summaries of parameters for the Storage Function Model for each river basin and river channel are obtained, as shown in Table 5-4.

5.4 Verification by New Hydrological Stations

In the master plan study stage, a total of six (6) water level stations and six (6) rainfall stations were installed in the three (3) river basins of Serdang, Belutu and Padang, i.e., two of each kind in each river basin. The locations of these hydrological stations are as shown in Fig. 5-4.

Available Records of New Hydrological Stations

Observation was started from September 1990 at most of the stations. Periods of available data for the respective stations are presented in Table 5-5.

Operation and Maintenance

The rainfall stations have been maintained in good condition, because they are located at sites where continuous monitoring can be made by school teachers or plantation employees. Only the rain recorder requires close attention on operation and maintenance.

As for water level stations, however, water levels at Pekapahan, Rampah, Basumbu and Brohol were observed to have the tendency to lower from the beginning of 1991 which may be due to degradation of the riverbed caused by the floods from September to December 1990. On the other hand, relatively higher water levels were observed at Simpang Station, because the riverbed has risen due to sediment deposition.

In view of the above, it is necessary to conduct periodical river cross-section survey and river discharge observations at the stations. Rating curves, the relation between water level and river discharge, shall have to be updated from time to time. For reference, the station house floor and "zero" gauge elevations are shown in Table 5-6.

Flood Discharge

River cross-sections at the water level stations and their rating curves derived from Manning's Uniform Flow Formula are shown in Fig. 5-5. For flood analysis, water level records of 13 floods are extracted from automatic recording charts of the water level station. Hourly flood discharge is derived by means of rating curves. The peak discharges at the respective stations are as tabulated in the following table.

Peak Flood Discharge at Water Level Stations

Item No.	Water Level Station	River	Peak Discharge (m3/s)	Occurrence Time	
1	Bedimbar	Belumai (Serdang)	210 (81)	17/03 (17/24)	Sep.
2	- do -	- do -	120 (101)	03/09 (06/08)	Oct.
3	Pekapahan	Batugingging (Serdang)	36	16/14-17	Dec.
4	Rampah	Belutu	117	20/15-19	Oct.
5	Simpang	- do -	78	02/18-19	Nov.
6	Basumbu	Padang	134 (98)	26/06 (27/22)	Sep.
7	- do -	- do -	110	06/06	Oct.
8	- do -	- do -	123 (116)	17/05 (18/23)	Oct.
9	- do -	- do -	130 (122)	14/04 (12/10)	Dec.
10	Brohol	- do -	169 (141)	26/13 (28/01)	Sep.
11	- do -	- do -	141	06/10	Oct.
12	- do -	- do -	193 (166)	19/08 (17/11)	Oct.
13	- do -	- do -	179 (168)	14/10 (12/15)	Dec.

Note: Figures in parentheses show the second peak discharge and its occurrence time; Date/Time.

Basin Rainfall

Thiessen coefficients for the respective river basins are computed, based on two of the rainfall stations. The hourly rainfall data of the 13 floods mentioned above are taken from the recording charts, and the mean hourly rainfall data for each river basin are then calculated based on the computed Thiessen coefficient.

Parameter Analysis of Flood Runoff Model

Parameter analysis by the storage function method is conducted, applying the hydrological data collected for the 13 floods. The results are summarized in Table 5-7. The parameters mentioned in Section 5.3 generally show very similar characteristics.

However, the parameters for Rampah, Simpang, Pekapahan and Tembung cannot be well adjusted because the flood hydrographs in the Belutu, Batugingging and Percut rivers become flat due to flooding in the upstream areas. The average value of runoff ratio is estimated to be 0.26 and this value is not so different from the value of 0.3 determined in Section 5.3.

Verification of Runoff Model

The results show conformity with the runoff analysis for the runoff model mentioned above, as shown in Fig. 5-6.

5.5 Flood in November 1990

The upper reaches of the Deli and Percut rivers in the Medan city area suffered serious damage from the flood on November 25 to 26, 1990. To verify the flood runoff model, the actually recorded hydrological data are applied.

River Discharge

Among the existing automatic water level stations located in and around the flooding area, Simeme Station in the upper reaches of the Deli River and Tembung Station in middle reaches of the Percut River have been operated. Their hourly water level data are as shown in Fig. 5-7.

The peak discharges were recorded at 240 m^3/s and 194 m^3/s at Simeme and Tembung, respectively. They correspond to about a 10-year return period flood.

Rainfall

Daily rainfall data of the flood in November 1990 has been recorded at 30 manual rainfall stations and at three (3) automatic rainfall stations, as tabulated in Table 5-8. The location of rainfall stations is as shown in Fig. 5-8. Hourly rainfall data have been recorded at only three (3) automatic rainfall stations, namely Sampali, Tg. Morawa and Kutajurung.

Runoff Simulation

In the Thiessen division analysis, the rainfall data at Sampali Station is regarded as the representative rainfall of the two (2) river basins. Therefore, the flood runoff simulation is conducted using the hourly rainfall at Sampali Station.

The computed hydrographs at Simeme and Tembung are presented together with the observed ones in Fig. 5-9 and the parameters of flood runoff model are summarized in Table 5-9. The hydrograph of Simeme shows that the runoff model and its parameters are well calibrated, while that of Tembung shows that the computed peak discharge is bigger than the observed one. This is caused by the flooding in the upstream area of Tembung Station.

6. LOW FLOW ANALYSIS

6.1 Low Flow Model

The Tank Model method which has a simple structure designed to calculate daily discharges over a long time and is the most commonly used, is employed as a low flow model. Calculation is made for a period of at least 20 years (1969 to 1988), and the parameters are evaluated in the low flow analysis, especially average basin daily rainfall and loss in runoff which indicates evaporation.

(1) Input Rainfall

The Tank Model is defined as a single basin model encompassing basins covered by existing water level stations. Rainfall input into this model is daily basin rainfall which is calculated by the Thiessen Method, as described before.

(2) Loss in Runoff

In the Tank Model, daily rainfall is input and daily loss in runoff is mandatorily subtracted. The annual total loss can be obtained as the annual basin rainfall height minus annual runoff height.

As shown in Table 6-1 summarizing flow regime and annual water balance, the smallest and the second smallest values of average runoff loss during the observation period are 169 mm/year (Asam Kumbang) and 442 mm/year (Tanjung Morawa), while the greatest and the second greatest values are 1,140 mm/year (Pulau Tagor) and 1,070 mm/year.

Since the climates of these basins are similar, the loss in runoff (evaporation) from each river can be considered as almost the same. As described, pan evaporation at Sampali Station is 1,566 mm/year (refer to Table 6-2), and because actual basin evaporation is about 70% of pan evaporation, basin evaporation is estimated at 1,100 mm/year.

Annual losses at Pulau Tagor and Tebing Tinggi stations are close to this 1,100 mm/year. Therefore, the annual loss of 1,100 mm/year is used. The daily loss is determined from the monthly variation pattern of pan evaporation, and all values are scaled down to 70%.

6.2 Model Calibration

The parameters of the Tank Model as shown in Table 6-3 are determined by trial and error until the calculated flow regime show good agreement with the observed flow regime. Constants for outlets of the Tank Model are presumed, so that a lower outlet is assigned a number of fewer figures. In this specific case, where there is no discharge component for the fourth tank, a three-staged tank model is applied because the observed flow regime is relatively flat. The schematic model and parameters are given in Fig. 6-1.

The observed and calculated flow regimes are compared as shown in Table 6-4 and in Fig. 6-2. In evaluating the degree of similarity in flow regime, low flow portions (80 to 95% exceedence discharge) and annual variation patterns are emphasized. The calculated flow regime, mean monthly discharge and annual flow regimes at the existing water level stations (refer to Fig. 3-3) are given in Tables 6-5 and 6-6, respectively.

From the low flow analysis, flow regimes and their distributions are plotted for the 20% non-exceedence discharge in the respective rivers and their major tributaries as shown in Fig. 6-3.

7. PROBABLE FLOODS

7.1 Design Storm

The design storm of each river basin is applied to calculate the pattern of design storm as described in Section 4.5 (refer to Fig. 4-4) and the probable rainfall of each river basin as estimated in Section 4.4 (refer to Table 4-3).

7.2 Probable Flood Discharge

Probable flood discharges of 2-year up to 100-year return period are calculated for each river basin applying the probable design storm to the flood runoff model, as shown in Table 7-1. In calculating the flood runoff model, the probable flood discharge is determined taking into consideration the drainage basin. The probable flood discharges at the reference point of each river basin are shown in the following table and their distribution in each river system are presented in Fig. 7-1.

Probable Flood Discharge at Reference Point

River/ Reference Point		Catchment Area (km2)	Probable Flood Discharge (m3/s)						
			2-yr	5-yr	10-yr	20-yr	30-yr	50-yr	100-yr
1.	Belawan	674							
	- Lalang	254	250	340	410	470	510	550	610
2.	Deli	358							
	- Titi Kuning	180	160	220	260	300	320	340	380
	- Helvetia*	341	280	390	460	530	570	620	690
3.	Percut	186							
	- Tembakau	171	140	190	230	260	280	300	340
4.	Serdang	671							
	- Baru	671	470	590	680	750	800	850	940
	Batu-gingging - Gang Melaya	343	280	340	390	420	450	480	520
	Belumai - Buntu	262	190	230	270	290	310	330	360
5.	Ular	1,081							
	- Pulau Tagor	1,013	430	600	710	820	890	970	1,07
6.	Belutu	500							
	- Bakaran Batu	243	110	140	160	180	190	210	230
	- Sei Rampah*	423	180	220	260	290	310	340	370
7.	Padang	919							
	- Brohol	759	390	530	620	720	770	840	940

* Sub-Reference Point

Fig. 7-2 shows a specific discharge plot for 50-year return period probable discharge in Indonesia. Specific discharge of each river is an appropriate value.

8. INUNDATION ANALYSIS

It is necessary to identify the inundation condition to provide an effective control measure and to estimate the benefit which may accrue from the flood control project. The inundation analysis method is selected, and the analysis procedure is made as described hereinafter.

8.1 Inundation Analysis Method

Generally, inundation is classified into two (2) types, the storage type and the flow or diffusion type. Inundation analysis is made by either the Two-Dimensional Unsteady Flow Model, the Muskingum Model, the Simplified Unsteady Flow Model, or some other models.

The flood prone area in the study area is flat with a slight slope towards the sea. Overbank flow usually spreads along the river course and is somewhat retained in the shoreline area. Since this condition falls under both the storage type and the flow/diffusion type, the Two- Dimensional Unsteady Flow Model is selected for the flood inundation analysis.

8.2 Considerations for the Inundation Model

The following procedures are made, and parameters are taken into account in the flood inundation model as follows:

(a) The whole inundation area is divided into several cells called mesh, as shown in Fig. 8-1. The size of a mesh is set at 1.0 km by 1.0 km on account of the rather flat topography and the large-scale land use condition.

(b) The average ground height of each mesh is obtained using the topographic maps with the scale of 1/5,000 which were prepared from the aerophotographs.

(c) Structures such as tollways that may hamper the smooth flow of inundation water are taken into consideration assuming them as weirs between the mesh blocks.

(d) Flood discharge overtops at points with low flow capacity and spreads over the inundation area.

8.3 Basic Equation

The basic equations applied to the inundation model are derived from the following equations:

(a) Euler's Equation of Motion

$$
\begin{cases}
\dfrac{\partial u}{\partial t} + u\dfrac{\partial u}{\partial x} + v\dfrac{\partial u}{\partial y} + w\dfrac{\partial u}{\partial z} = X - \dfrac{1}{\rho}\dfrac{\partial P}{\partial X} \\
\dfrac{\partial v}{\partial t} + u\dfrac{\partial v}{\partial x} + v\dfrac{\partial v}{\partial y} + w\dfrac{\partial v}{\partial z} = Y - \dfrac{1}{\rho}\dfrac{\partial P}{\partial Y} \\
\dfrac{\partial w}{\partial t} + u\dfrac{\partial w}{\partial x} + v\dfrac{\partial w}{\partial y} + w\dfrac{\partial w}{\partial z} = Z - \dfrac{1}{\rho}\dfrac{\partial P}{\partial z}
\end{cases}
$$

where,

u, v, w	: velocity of x, y and z direction
X, Y, Z	: gravity of x, y and z direction
ρ	: water density (= 1.0)
P	: pressure

(b) Equation of Continuity

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

For actual application to the two-dimensional model, the above expressions are expressed as follows:

(a) Equation of Motion

$$\frac{1}{gA_x}\frac{\partial Q_x}{\partial t} - \frac{Q_x B_x}{gA_x^2}\frac{\partial H}{\partial t} + \frac{\partial H}{\partial x} + \frac{|Q_x|Q_x}{F_x^2} = 0$$

$$\frac{1}{gA_y}\frac{\partial Q_y}{\partial t} - \frac{Q_y B_y}{gA_y^2}\frac{\partial H}{\partial t} + \frac{\partial H}{\partial y} + \frac{|Q_y|Q_y}{F_y^2} = 0$$

$$F_x = \frac{1}{n}R_x^{2/3}A_x$$

$$F_y = \frac{1}{n}R_y^{2/3}A_y$$

(b) Equation of Continuity

$$\frac{\partial(Bh)}{\partial t} + \frac{\partial Q_x}{\partial x} + \frac{\partial Q_y}{\partial y} = 0$$

where,
Q_x, Q_y : discharge of x and y direction
A_x, A_y : current area of x and y direction
B_x, B_y : width of x and y direction
R_x, R_y : hydraulic depth of x and y direction
g : acceleration of gravity
n : roughness coefficient
H : water level
h : water depth

The above equations are finally transformed into finite difference form for numerical computation, as follows:

(a) Finite Difference Form of Equation of Motion

$$\frac{1}{gA_{I,J}^{n-1/2}} \frac{Q_{I,J}^{n} - Q_{I,J}^{n-1}}{\Delta t} - \frac{\left(\frac{Q_{I,J}^{n} - Q_{I,J}^{n-1}}{2}\right)\Delta y}{g\left(A_{I,J}^{n-1/2}\right)^2} \frac{H_{I,J}^{n-1/2} - H_{I,J}^{n-3/2}}{\Delta t}$$

$$+ \frac{H_{I+1/2,J}^{n-1/2} - H_{I-1/2,J}^{n-1/2}}{\Delta x} + \frac{\left|Q_{I,J}^{n-1}\right| Q_{I,J}^{n}}{\left\{\frac{1}{n}\left(\frac{A_{I,J}^{n-1/2}}{\Delta y}\right)^{2/3} \cdot A_{I,J}^{n-1/2}\right\}^2} = 0$$