CHAPTER 3 BASIC SURVEYS AND STUDIES

3.1 Field Surveys and Investigations

3.1.1 Installation of Hydrological Gauges and Discharge Measurements

(1) Objectives

Taking into consideration the present critical conditions of hydro-meteorological observation in the LBB basin, it is decided:

1) To install automatic rain gauges and automatic float-type water level gauges respectively at four (4) locations, and
2) To install staff gauges at ten (10) locations, and to conduct measurement there for six (6) months.

(2) Installation of Automatic Rain and Water Level Gauges

Selection of Installation Sites: Considering the inspection results of the existing gauging stations and their spatial distribution, installation sites of 4 automatic rain gauges and 4 automatic water level gauges were decided as listed below, after comprehensive discussion with counterpart agency.

(Selected Sites for Installation of Automatic Rain Gauges)

Location	River Basin	Remarks
1. Bongomeme	Pohu River	New installation for ungaged area
2. Kayumerah	Biyonga River	Upgrading of damaged gauge
3. Dulamayo Selatan	Bolango River	New installation for ungaged area (above 500 m,MSL)
4. Alale	Bone River	Upgrading of damaged gauge

(Selected Sites for Installation of Automatic Water Level Gauges)

Location	River Basin	Remarks
1. Satria Bridge	Alo River	New installation for ungaged river
2. Kayubulah Bridge	Biyonga River	New installation for ungaged river
3. Boidu Tapa	Bolango River	New installation for ungaged river
4. Alale	Bone River	Restoration of discarded gauge

Installation Works and Operation: The installation of rain gauges and water level gauges was implemented in September and October 2001 by the locally employed personnel who has experience of similar works for Bagian Proyek Pengembanan Data Sumber Air (Bagpro PDSA), North Sulawesi. All stations are to be operated and maintained initially by the Bagpro PDSA, North Sulawesi Province, then by Gorontalo Province.

(3) Installation of Staff Gauges and Discharge Measurements

Selection of Additional Flow Gauging Sites: The additional flow gauging sites were selected to collect actual flood flow and inundation data in the LBB basin. The following sites were selected for staff gauge installation and discharge measurements:

River Basin	Location	Purpose
1. Alo River	Satria Bridge	Flood flow of Alo river With an automatic recorder
2. Reksonnegoro River	Titileya	Flood flow of Reksonnegoro river
3. Pohu River	Bontula	Flood flow of Pohu river
4. Biyonga River	Kayubulah Bridge	Flood flow of Biyonga river With an automatic recorder
5. Bolango River	Boidu Tapa	Flood flow of Bolango river With an automatic recorder
6. Bolango River	Bolango Bridge	Flood flow of Bolango river
7. Bolango River	Outlet of Limboto Lake	Flow from the lake
8. Limboto Lake	Limboto Lake	Lake water level
9. Bone River	Alale	Flood flow of Bone river With an automatic recorder
10. Bone River	River mouth	Tidal gauge

Installation Works and Measurement: The installation of staff gauges at ten (10) locations was carried out by the locally employed personnel who conducts discharge measurements and water level recordings for the Study. The staff gauges were installed on October 2001 and the measurements were carried out continuously afterwards. All stations are to be operated and maintained by the Bagpro PDSA initially and then by Gorontalo Province.

3.1.2 Topographic Mapping and River Survey

General: The survey aims to conduct 1) topographic mapping including aerial photography for the surrounding areas of Lake Limboto and the flood prone areas of Gorontalo City, and 2) river survey for the major rivers in the Study Area.

The survey works were conducted by an Indonesian surveying company under a sublet contract with the Study Team. Surveying expert of the Study Team prepared survey plan and specifications, and supervised the survey works. The contract was entered into on August 20, 2001 and the delivery date is October 30, 2001.

(1) Topographic Mapping

Surrounding Area of Lake Limboto: Topographic survey was conducted for Lake Limboto and its surrounding areas. Total area of topographic survey is 8,000 ha, including lake area of about 3,500 ha. The lake was surveyed by sounding method, and the surrounding areas were surveyed by means of aerial photo survey. The aerial photo was taken in the scale of 1/25,000 and mapping scale of 1/5,000.

Sounding Survey of Lake Limboto: The sounding survey of Lake Limboto was made using a Raytheon echo sounder combined with a GPS navigator system. The depths of the lake bottom were measured and plotted at the intervals of 100 m. For the lakeside portions, the depths were sounded and plotted at the intervals of 100 to 300 m using a pole. A total of 18 measuring sections were set from south to north direction at the intervals of 400 m. According to the results of survey, water level of Lake Limboto was 4.054 m above mean sea level during the survey period. The sounding maps were prepared in the scale of 1/5,000 with intermediate contours of 1 m. Where the contour intervals are wider, supplemental contours of 0.5 m were inserted. In addition, spot elevations were indicated at the deepest bottoms.

Gorontalo City: Flood prone areas of Gorontalo City were also subject to the topographic survey by aerial photography. The survey area extends over a total area of 700 ha along the Bolango and Bone rivers for about 7 km in length and about 1 km in width. The photo scale was 1/10,000 and the mapping scale 1/1,000.

(2) River Survey

River survey was conducted for the stretches subject to flood analysis, river planning, and preliminary facility design for the master plan study. The number and approximate width of cross sectional survey are as follows:

1) Primary river such as the Bone and Bolango rivers and rivers flowing into Lake

Limboto: 100 sections with width ranging 100~500m

2) Rivers in urban area: 50 sections with width ranging 10~50m

For longitudinal and cross sectional survey of rivers, 20 rivers were selected. The number of cross sections was determined for each river considering the uses for hydraulic analysis. Where there are bridges and weirs, their upstream sections were measured. A total of 201 cross sections were surveyed.

3.1.3 Investigation of Land Use and Sediment Yield

General: Land use and sediment yield of the LBB basin were investigated using the satellite images taken in two different years, for an area of about 1,000 km^2 covering the basins of the Bolango river and Lake Limboto basins where devastation of watershed takes place.

The investigation is carried out in Japan under the sublet contract with the Study Team. The investigation was completed by the end of September, 2001.

Satellite Images Used: Satellite images were selected from the fine SPOT data with less clouds taken in different years, recently and in around 1990, as follows:

1) Latest images:
   SPOT (multi-color) K-J: 314-349 taken on Mar. 06, 1998
   SPOT (multi-color) K-J: 315-349 taken on Aug. 29, 2000
2) Images in around 1990:
   SPOT (multi-color) K-J: 314-349 taken on Apr. 22, 1990
   SPOT (multi-color) K-J: 315-349 taken on Sep. 02, 1987

Preparation of False Color Image: Two false color images were prepared in the scale of 1/50,000, joining images K-J: 314-349 and K-J: 315-349, synthesizing data of multi-color bands.

Analysis of Land Use: Land uses of the basin are analyzed on the images taken in 1998/2000 and 1990/1987. Land use is analyzed, in principle, for 8 categories such as forests, bushes, farm lands, grass lands, waste lands, villages, waters, and others. Land use maps are prepared as a result in the scale of 1/50,000. Changes in land use are also mapped in the same scale.

Analysis of Land-Slide Sites: Locations of land-slide sites were also analyzed based on the satellite images taken in 1998/2000 and 1990/1987. Location map of land-slide sites are prepared in the scale of 1/50,000. Land-slide sites smaller than 100 m^2 were disregarded due to the limit of the SPOT data resolution.

3.1.4 Investigation of Water Quality and Bottom-Sediment

General: Main objectives of water quality and bottom-sediment investigations are as follows:

1) To evaluate the current conditions of water quality and bottom-sediment as a benchmark,
2) To analyze the effect of sedimentation caused by soil erosion from upstream areas at the entrance to Lake Limboto,
3) To analyze the effect of domestic effluent and agriculture in terms of nutrients and chemical compounds, and
4) To analyze the effect of illegal mining being done in upstream area along the Bone River.

The investigation was conducted by Environmental and Natural Resources Research Center of the Sam Ratulangi University Research Center under the sublet contract in accordance with the technical specifications prepared by the Study Team.

Sampling for water quality test was conducted twice at 15 sites: one in September 2001 during dry season and another in December 2001 during rainy season, aiming to analyze the fluctuation of water quality with run-off discharge over seasons. Sampling for bottom-sediment quality test was planned once at the same 15 sites as water sampling in September 2001 during dry season, because the bottom-sediment quality does not fluctuate with run-off discharge in general.

Sampling Points: A total of 15 sampling sites were chosen commonly for water and bed-sediment samples in the LBB basin, such as Lake Limboto, Bone river including its estuary, Bolango River, Tamalate River, Biyonga River, Alo-Pohu River, etc.

Parameters for Water Quality Test:

1) Fundamental parameters: Temperature(℃), pH, BOD_5 (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), DO (Dissolved Oxygen), SS (Suspended Solid), Coliform Bacillus (Coliform Group Number), T-N (Total Nitrogen), T-P (Total Phosphorus), Electric Conductivity, Color (Chromaticity), and Turbidity.
2) Heavy metals: Cadmium (Cd), Total Mercury (T-Hg), Selenium (Se), Lead (Pb), Arsenic (As), Hexavalent Chromium (Cr^{6+}), Zinc (Zn), Iron (Fe), and Manganese (Mn).
3) Others: Cyanide (CN), Nitrate Nitrogen (NO_3-N), Nitrite Nitrogen (NO_2-N), Fluorine (F), Chloride Ion (Cl^-), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), and Phenolic Substances.

Parameters for Bottom-Sediment Quality Test:

1) Fundamental parameters: Temperature(℃), and pH.
2) Heavy metals: Cadmium (Cd), Total Mercury (T-Hg), Selenium (Se), Lead (Pb), Arsenic (As), Hexavalent Chromium (Cr^{6+}), Zinc (Zn), Iron (Fe), and Manganese (Mn).

3.1.5 Investigation of Riverbed Materials

General: Physical properties of the riverbed materials were investigated to obtain basic data for the analysis of sediment transport in the river and sedimentation in the lake. Samples were collected at 50 sites and two river bed materials at each site, from riverbed sand bar and river bank, were sampled. A total of 100 samples are subject to laboratory test i.e., grain size analysis and specific gravity test.

The investigation was carried out by a local contractor under the sublet contract in accordance with the technical specifications prepared by the Study Team. The investigation was completed by the end of October 2001.

Sampling of Riverbed Materials: Two (2) samples of riverbed materials were collected at each sampling site, from sand bar on riverbed and from nearby riverbank. The sand-bar sample was taken near the shore where the riverbed materials are exposed out of water. The sampling site was selected so that the sampled materials should represent those of typical river section.

Samples were taken out up to 80 cm deep from original surface removing surface materials by about 30 cm deep. If the maximum grain size is lager than 10 mm, the sample is subject to outdoor grain size analysis at site.

Grain Size Analysis: Grain size analysis was carried out to determine the grain size distribution of the riverbed materials. Indoor sieve analysis was carried out for the finer samples than 10 mm. Outdoor grain size analysis was carried out at site using sieve set coarser than 9.52 mm.

Specific Gravity Test: Specific gravity test was carried out indoor for about 1 kg of samples used for the sieve analysis according to ASTM or approved method by the Engineer. Specific gravity test was carried out twice dividing a sample into two.

3.1.6 Geological Investigation

General: In order to examine subsurface conditions of dams and other structures for the Study, geological investigation was carried out. The investigation includes boring at 18 holes of about 360 m in total length, and laboratory tests for 10 core samples.

Geological investigation was carried out by a local contractor under the sublet contract in accordance with the technical specifications prepared by the Study Team.

Core Drilling: Core drilling was performed with standard penetration tests and water pressure tests. The core drilling is made for bedrock, soil, gravel deposits, colluvial deposits and talus deposits that may contain boulders. The diameter of the boreholes shall be not less than 60 mm. Standard penetration tests were carried out every 1.5 meters of depth in the sections of the boreholes which are located within soils or un-cemented deposits or intensively weathered rocks, in order to evaluate the mechanical strength of those materials. Water pressure tests were carried out in the parts of boreholes through bedrock in order to evaluate the seepage potential of the foundation rocks. The permeability of the uncemented deposits is also measured by an open-end constant-head test at every three (3) meter of depth starting at the depth of 3 meters.

Laboratory Tests of Rock: Representative rock specimens selected from the drilling core samples of cylindrical form were sent to the laboratory for the purpose of confirming the basic physical, chemical and mechanical characteristics of the rocks in geotechnical aspects.

Items of the laboratory test are as listed below.

1) Water absorption and bulk specific gravity (ASTM C 127): 10 samples
2) Unconfined compression test of rock core specimen (ASTM D2938): 10 samples

3.1.7 Investigation of Flood Damages and Residents

General: In order to grasp flood damages and the present living situation of the residents, a social survey by use of questionnaire was conducted. In addition to this, existing government and previous study documents were also examined and reviewed.

Questionnaire: A questionnaire prepared for social survey has two main objectives. One is to collect information on living conditions of the residents of the study area and the other is to investigate their perception on floods. The questionnaire is composed of four parts; questions on (1) general information on the resident's living conditions, (2) past experiences related to floods, (3) residents' perception on the flood, and (4) people's observation on natural environment.

Execution of Survey: Four teams of two persons each were formed to carry out the survey. A total of 20 sites were chosen from among villages located in the flood prone areas and also those along the four principal rivers of the area, namely the Bone, Bolango, Biyonga and Alo-Pohu rivers, and their branches. Twenty (20) households are chosen for the interview at each village. The social survey was started mid August and 20 villages (Desa/ Kelurahan) were investigated to accomplish the interview of a total of 400 households by the middle of September.

3.2 Flood Runoff and Flood Flow Analyses

3.2.1 Previous Hydrological Studies

The major hydrological studies in the LBB basin were carried out in the following master plans studies through the North Sulawesi Water Resources Institutional Development Project funded by Canadian International development Agency (CIDA):

1) LBB Water Resources Development Master Plan, 1994 (the 1994-Study)
2) LBB Basin Water Management Master Plan, 1999 (the 1999-Study)

(1) LBB Water Resources Development Master Plan

The 1994-Study covers the basic study items, i.e., (1) Climate, (2) Basins and rivers, (3) Rainfall, (4) Runoff, (5) Water balance, and (6) Design flood.

In relation to the flood control study, the estimate of design floods was carried out by the empirical methods such as Haspers and Mononobe for assessing flood peaks with return periods up to 1,000 years. These methods provide the estimates of instantaneous flood peaks and are not concerned with the prediction of flood volume and hydrograph.

To determine the design flood for the Lake Limboto, a synthetic hydrograph method was applied. The peak design floods for each tributary with return periods of 50 and 100 years have been derived from the basin characteristics and calculation of unit hydrograph.

(2) LBB Basin Water Management Master Plan

The 1999-Study covers the studies on flood discharges, and probable flood peak supplementary to the 1994-Study. The 1999-study was not also concerned with the prediction of flood volume and its hydrograph because of the extreme lack of rainfall and runoff records.

3.2.2 Probable Storm Rainfall

Probable Point Rainfall for Longer Duration: Probable 1-day, 2-day and 3-day point rainfalls were estimated using 27 years (1975-2001) of records observed at Jalaluddin Airport in the west of Lake Limboto and 25 years (1972-1997) at Boidu Tapa. The following five (5) distributions are applied to the estimate.

1) Two Parameters Log Normal Distribution(LN2)
2) Three Parameters Log Normal Distribution (LN3)
3) Type I Extreme Value Distribution (T1E)
4) Pearson Type III Distribution (PT3)
5) Log Pearson Type III Distribution (LP3)

The results of the calculation are shown in Table 3.2.1, taking average value of the five distributions. According to the result, about 70 to 80 % of 3-day probable storm rainfall occurs within one day at both stations. The difference of estimated rainfall values between two stations is small within the range of 3 to 17 %.

Probable Point Rainfall for Shorter Duration: A frequency analysis for 12 years of annual maximum 1-hour to 24-hour rainfalls records from 1990 to 2001 was conducted using the said five distributions. The results of the calculation are shown in the Table 3.2.1, taking the average value of five distributions.

Rainfall Intensity Curves: The representative rainfall station shall be determined for each basin. However, in the Study Area, two stations of Jalaluddin and Boidu Tapa located around Lake Limboto are only qualified as representative stations. Considering the availability of daily and hourly records, Jalaluddin is used as a representative rainfall station for the Study. Rainfall intensity curves were prepared based on the results of the above study and shown in Figure 3.2.1.

Probable Basin Average Storm Rainfall: The average depth of storm rainfall for a given duration in a given area generally tends to decrease conversely with increasing of area. For this adjustment, a depth-area factor was employed.

3.2.3 Probable Flood Discharges

Runoff Calculation: Basin boundaries were drawn on the topographic maps and basin areas were measured as shown in Figure 3.2.2. The probable flood runoff discharges were estimated by Synthetic Unit Hydrograph Method developed by US Soil Conservation Services. The maximum of specific monthly average at Alale Weir of the Bone River and Lomaya Weir at Bolango River is applied to estimate the base flow discharge for every points of interest. Probable flood discharges were calculated for respective river basins and for various return periods of 2, 5, 10, 20, 50 and 100 years. The peak discharges are illustrated in Figure 3.2.3.

Comparison with Other Design Discharges: The discharges of the LBB basin calculated by the Synthetic Unit Hydrograph method for 20-year return period were plotted in Figure 3.2.4 showing the relationship between size of drainage area and specific peak discharge. On the other hand design discharges of other rivers in Indonesia were collected and plotted also in the Figure. As seen in the Figure, the specific discharge of the LBB basin distribute within the reasonable range in comparison with those of other rivers in Indonesia. The Synthetic Unit Hydrograph method is judged to be applicable to the LBB basin.

3.2.4 Flood Flow Analysis

Procedures for Analysis: In order to grasp the mechanism of flooding and inundation, to predict the inundated area, and to evaluate the effect of flood control project, flood flow analyses are carried out using an unsteady flow simulation model, following the procedures shown in Figure 3.2.5. In general, upper river reaches without significant flooding is modeled by runoff model, middle reaches with riverine flooding by channel model, and flooding in the lower plain reaches by flood plain model. The channel model and flood plain model constitute the flood flow model. The channel model is applied to the river reaches where flooding along riverine area is prevailing, while the flood plain model to the areas flooded water may spread over.

Results of Flood Flow Analysis: According to the procedures mentioned above, flood flows of various return periods were simulated under the present basin and river conditions and the results are shown in Figures 3.2.6. Major findings are as follows:

1) Maximum inundated areas by ranges of inundated depth are summarized below:

Depth	Max. inundated area by flood scale (km^2)				
(H: m)	2-yr.	5-yr.	10-yr.	20-yr.	50-yr.
H>0	34.3	52.1	62.4	70.9	79.7
H>0.5	23.3	37.3	46.5	54.5	63.3
H>1.0	5.3	11.6	15.3	20.3	27.6
H>1.5	0.6	0.9	1.3	2.6	9.4

2) Under the 2-year flood, extensive western areas of Lake Limboto suffer from flooding due to floodwater of the Alo-Pohu River, though riverine areas of other rivers suffer from more or less flooding.
3) Under the 5-year flood the flood waters from the Bolango River begins spread over to the left bank areas and the Bone River to the right bank areas.
4) Under the 10-year flood, southern part of Gorontalo City suffers from serious inundation damages.

3.3 Studies on River Channels and Sediment

3.3.1 Evaluation of Existing Channel Capacity

Based on the latest results of river survey in 2001, bank-full carrying capacities were estimated. Considering the steeper slopes of rivers in the Study Area, uniform flow was assumed for the channel flow calculations. Results of estimation are shown in Table 3.3.1 in comparison with 2-year probable discharges. The channel capacities of rivers in the western plain area of Lake Limboto are low in general, while the Bone and Biyonga rivers have relatively higher capacities.

3.3.2 Significant Tide Levels at River Mouth

Tide Levels at Gorontalo: Since there is no tide records and data at the river mouth of the Bone River, tide levels at Gorontalo were estimated by harmonic analysis of tides for 10 years from 1992 to 2001.

Based on the estimated tides, significant tide levels at Gorontalo were determined as follows:

Tide	(m)	(m,MSL)
HHWL	1.568	0.767
MHWL	1.474	0.673
MSL	0.801	0
MLWL	0.246	-0.555
LLWL	0.181	-0.620

3.3.3 Effects of Tides to Channel Flows

Effect of Tide to Existing Channels: In order to examine the extent of tidal influence, non-uniform flow calculations were made for the Bone and Bolango rivers under various tide levels and probable discharges. According to the results of calculation, the extent of tidal influence for 2-year flood is only up to 1.5 km from the river mouth, and it becomes shorter as the river discharge increases. This is chiefly due to the relatively steep channel slopes of the Bone and Bolango rivers.

Effect of Tide to Excavated Channel: Even in the case that riverbed of the Bone River is excavated at the river mouth so that the average riverbed can be connected in smooth bed slope with upper reaches, the extent of tidal influence for 2-year flood still remains only up to 2 km from the river mouth or only up to 1 km from the Bone confluence along the Bolango River.

3.3.4 Sediment Yield and Transport

Land Use: Land use of the Study Area and its recent change were analyzed using the following SPOT satellite images, i.e., land use in 1990 by images taken in 1990 and 1987 and land use in 2000 by images taken in 1998 and 2000 (Figure 3.3.1). The results of analysis for the land use in 1990 and 2000 are shown in Figure 3.3.2 and summarized below.

Land use	1990 (A: %)	2000 (B: %)	Ratio (B/A)
Forest land	61.8	60.3	0.98
Bush land	11.4	10.4	0.92
Farm land	20.8	22.7	1.09
Grass land	3.0	2.6	0.85
Settlement land	1.7	2.7	1.53
Other lands	1.3	1.3	1.00
Total	100.0	100.0	-

The farm and settlement lands have increased by about 3% of the total basin area, reducing the areas of forest, bush and grass lands. Most typical pattern of land use changes in the LBB basin is from forest and bush lands to farm land. During the past 10 years, 54 km^2 of bush lands and 21 km^2 of forest lands were converted to farm land.

Sediment Source in Watershed: According to the satellite images analysis and site reconnaissance, source of sediment in the watershed area is deemed to sporadic slope failures and sheet erosion on the mountain and hill slopes. Specific sub-basins and valleys yielding much sediment were not identified.

Sediment Transport Capacity: Sediment issues in the Study Area can be discussed dividing the river system into two, i.e., the Lake Limboto system and the Bone-Bolango river system, since the lake traps almost all sediment from the upstream basins and discharges little amount to the Bolango River. According to the study based on a sediment transport index (Is) shown in Table 3.3.2, the Biyonga, Meluopo and Alo-Pohu rivers are the main sources of sediment in the Lake Limboto system, though the share of the Biyonga River is by far much. In the Bone-Bolango system, the Bolango River shares 62% of total sediment and the Bone River 38%, which indicates the Lake Limboto system with basin area of about 900 km^2 transport 1.3 times more sediment than that of the Bone-Bolango system of about 1,800 km^2.

3.3.5 Sedimentation of Lake Limboto

Sedimentation of Lake Limboto is recognized as a serious problem by the local government and communities. Water depth of the lake is already shallow and vegetation in the lake encroaches toward the lake center. In order to estimate the annual sedimentation rate, attempts were made using the data as available, i.e., estimates from historical area and depth data of the lake and from sounding data of lake as shown in Figure 3.3.3.

Judging from the these estimates, annual average sedimentation volume of Lake Limboto would be approximately $1x10^6$ to $2x10^6$ m^3/year, though it must be confirmed further by sounding survey in future.

Existing Function of Lake: The Lake Limboto basin has a total catchment area of 890 km^2 excluding the Bolango River basin. All of the runoff from this area flows into the lake and drained into the Bolango River through the Tapodu River. The Lake Limboto has a surface area of about 27.8 km^2 and storage capacity of 47.4 MCM below elevation +4.0 m,MSL according to the latest survey by the Study Team. The lake plays a vital role in flood control of the lake Limboto basin and the Bolango River as well, protecting Gorontalo City located in the downstream reaches. The lake, on the other side, traps sediment from its own basin and is suffered from sever sedimentation. There would be two extreme prospects for the lake, i.e., to be left as it is or to be reclaimed. Preliminary discussions are made in the following paragraphs.

Existing Function: According to the result of hydrological analysis, times of flood concentration are almost same for the Lake Limboto and the Bolango River basins, which indicates flood peaks from the both basins meet at their confluence.

During floods of the Bolango River, floodwater from Lake Limboto basin cannot be drained due to high water level of the Bolango River. On the contrary a part of the floodwater of the Bolango River flows into the lake. The floodwater is retained in the lake until the Bolango flood passes. Due to huge area of the lake, the lake water will not rise so much. This is the primary flood control function of the existing Lake Limboto.

If Lake were Left as It Is: Existing volume of Lake Limboto is 47.4 MCM below 4.0 m, MSL and the volume is reducing at the estimated rate ranging from 1 to 2 MCM per year due to sedimentation. The lake volume is decreasing if it is measured at a fixed elevation. However, this does not mean the disappearance of the lake in near future. Since the lake Limboto is located in the depressed area and the drainage of the lake is difficult during the flood period of the Bolango River, the floodwater of the lake would remain in and around the existing lake areas forming marshes expanding its area. In such conditions, use of lakeside lands and lake water may become uncertain, and the development of the lake and surrounding areas would be constrained.

If Lake were Reclaimed: If the lake were reclaimed, radical channel works of the Bolango River is required in the urban areas of Gorontalo City for the smooth drainage of flood water from the Bolango river and the Lake Limboto. According to a preliminary estimate the Bolango River should be improved for design discharge of 1600 m^3/s even for 10 year flood, which is about 8 times of the existing capacity. Furthermore, the design high water level of the Bolango River must be set lower for the gravity drainage of lake Limboto to be reclaimed. Large volume of excavation for widening and deepening of low water channel would be necessary for the Bolango River. These channel works are required for more than 6 km of the Bolango/Bone River through densely populated urban area of Gorontalo City. Such works would not be practically acceptable. The flood storage functions of the existing lake should be conserved.

3.3.6 Design Water Levels of Lake Limboto

Water levels of Lake Limboto in the past are shown in Figure 3.4.1. Considering the past water level records, lake water use, topography and land use, and flood water retention, design water levels of Lake Limboto were proposed as follows:

1) Lowest lake water level at +4.00 m,MSL: for better and stable fish production
2) Highest lake water level at +5.50 m,MSL: for flood mitigation in lake side areas especially in the western areas of the lake. This water level is the recorded highest water level and is high enough for floodwater retention.

Table 3.2.1 PROBABLE POINT RAINFALL

Probable Point Rainfall for Longer Durationat (1 to 3 day)

Return Period (yr)	Jalaluddin (mm)			Boidu Tapa (mm)		
	1-day	2-day	3-day	1-day	2-day	3-day
2	70	87	96	72	92	102
5	89	106	121	95	118	130
10	101	118	136	110	134	147
20	113	129	150	124	148	162
50	130	143	167	143	166	180
100	142	154	180	157	180	194

Probable Point Rainfall for Shorter Duration (1- to 24-Hour)

Return period (yr)	Jalaluddin (mm)				
	1-hour	3-hour	6-hour	12-hour	24-hour
2	54	65	70	72	76
5	60	81	92	93	98
10	64	93	108	109	114
20	67	104	123	124	130
50	71	119	145	145	151
100	74	131	161	162	168

Probable Point Rainfall in the LBB River Basin (mm)

Duration	Return period (yr)					
	2	5	10	20	50	100
1hr.	54	60	64	67	71	74
3hr.	65	81	93	104	119	131
6hr.	70	92	108	123	145	161
12hr.	72	93	109	124	145	162
24hr.	76	98	114	130	151	168
1day	70	89	101	113	130	142
2days	87	106	118	129	143	154
3days	96	121	136	150	167	180

Table 3.3.1 EXISTING CHANNEL CAPACITY

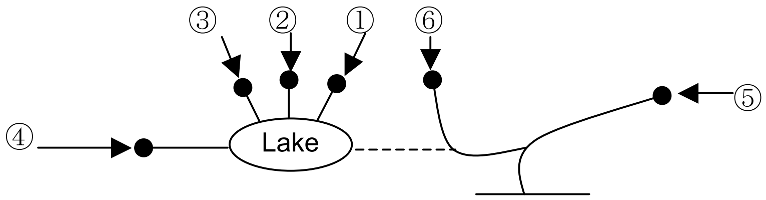
River System	River	From (m)	To (m)	Average riverbed slope (1/I)	Average width (m)	Average depth (m)	Average area (m^2)	Average carrying capacity (m^3/s)	2-year discharge Q_2 (m^3/s)	Ratio to Q_2 (Return period)
Lake Limboto System	Alopohu	0	3,618	1072	32	2.9	102	215	280	77 %
		3,618	9,003	796	33	3.0	105	258	280	92 %
	Alo	9,227	13,638	689	32	2.5	84	198	230	86 %
	Reksonegoro	0	2,818	470	19	1.5	27	55	85	64 %
	Pohu	0	3,214	737	28	2.0	56	115	65	176 % (5 yr)
	Biyonga	0	3,001	646	18	1.7	39	83	50	166 % (5 yr)
		3,001	6,585	357	27	2.1	63	186	50	372 % (36 yr)
		6,585	8,295	245	29	1.2	36	100	50	200 % (7 yr)
	Meluopo	0	2,181	686	14	0.8	12	18	35	53 %
		2,181	4,101	316	20	1.7	34	93	35	266 % (58 yr)
	Marisa	0	1,451	2476	12	0.8	9	6	55	11 %
		1,451	5,268	478	13	1.4	20	40	55	72 %
	Rintenga	0	7,020	525	9	0.7	11	21	50	42 %
Bolango River System	Bolango	0	5,981	1435	34	2.6	97	175	200	88 %
		5,981	16,884	958	58	2.4	120	247	200	123 % (3 yr)
		16,884	18,725	365	83	1.3	100	205	200	103 % (2 yr)
		18,725	19,608	153	87	1.3	99	311	200	156 % (4 yr)
	Tapodu	0	2,473	6230	24	1.9	45	31	-	-
	Siendeng	0	1,328	619	27	1.9	55	115	-	-
	Limba	0	2,306	2522	6	0.9	7	5	-	-
		2,306	8,141	466	10	0.7	8	10	-	-
Bone River System	Bone	0	969	1783	216	2.3	524	871	310	281 % (11 yr)
		969	5,572	815	129	1.5	191	301	290	104 % (2 yr)
		5,572	14,713	529	120	1.2	131	214	290	74 %
		14,713	15,824	247	123	1.1	103	232	290	80 %
	Pangimba	0	6,269	538	9	0.8	8	10	-	-
	Tamalate	0	5,653	1163	21	1.7	37	53	95	56 %
		5,653	8,318	692	23	1.6	35	60	95	63 %
		8,318	10,520	340	22	1.1	24	47	60	79 %
		10,520	10,926	112	12	1.5	23	103	60	172 % (9 yr)
	Ulanta	0	3,212	323	11	0.9	9	17	-	-
Irrigation Canal		0	1,712	1069	9	1.2	13	17	-	-

Table 3.3.2 SEDIMENT TRANSPORT CAPACITY

River	Slope (l/I)	Width (B : m)	Depth (H : m)	Bed Material (d_{60} : mm)	Index (Is)	Share (%)
Lake Limboto System						
① Biyonga River	357	27	2.1	0.48	0.1515	56
② Meluopo River	316	20	1.7	0.61	0.0679	24
③ Marisa River	478	13	1.4	0.61	0.0102	4
④ Alo-Pohu River	796	33	3.0	0.67	0.0426	16
(Sub Total)					(0.2722)	(100)
Bone - Bolango System						
⑤ Bone River	365	83	1.3	0.49	0.1282	62
⑥ Bolango River	529	120	1.2	0.38	0.0775	38
(Sub Total)					(0.2057)	(100)

Notes :

(1) Schematic Location



(2) Sediment Transport Index (Is):

Is = $B (HI)^{2.5} / d$

Where:

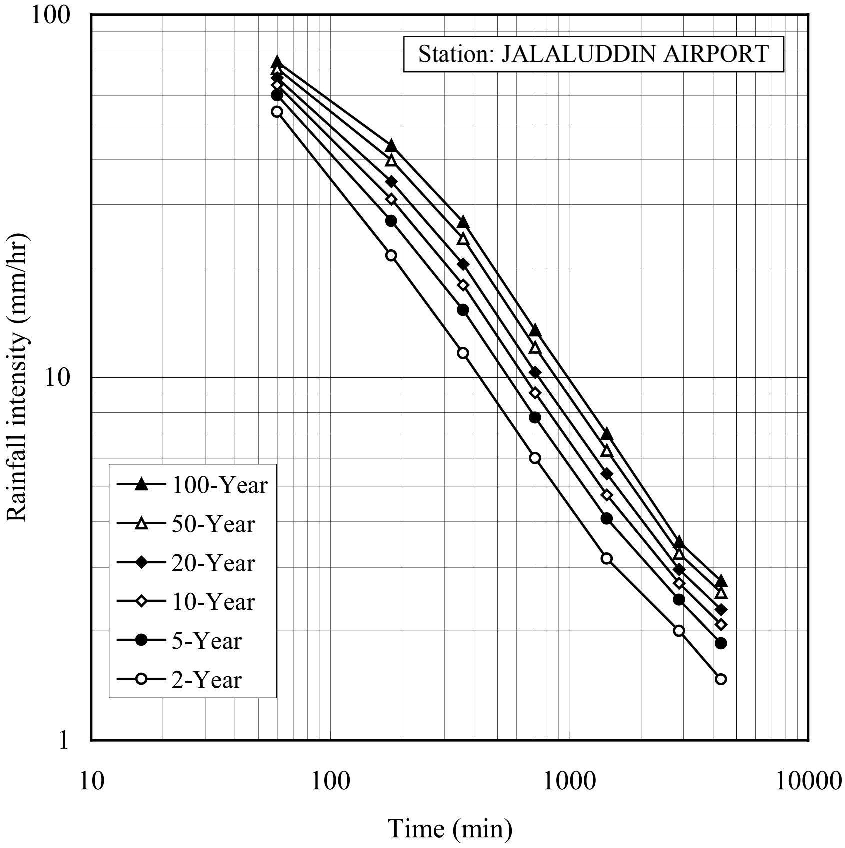
Is = Sediment transport index assumed to be proportional to sediment transport capacity

B = River width (m)

H = Mean channel width (m)

I = Riverbed slope

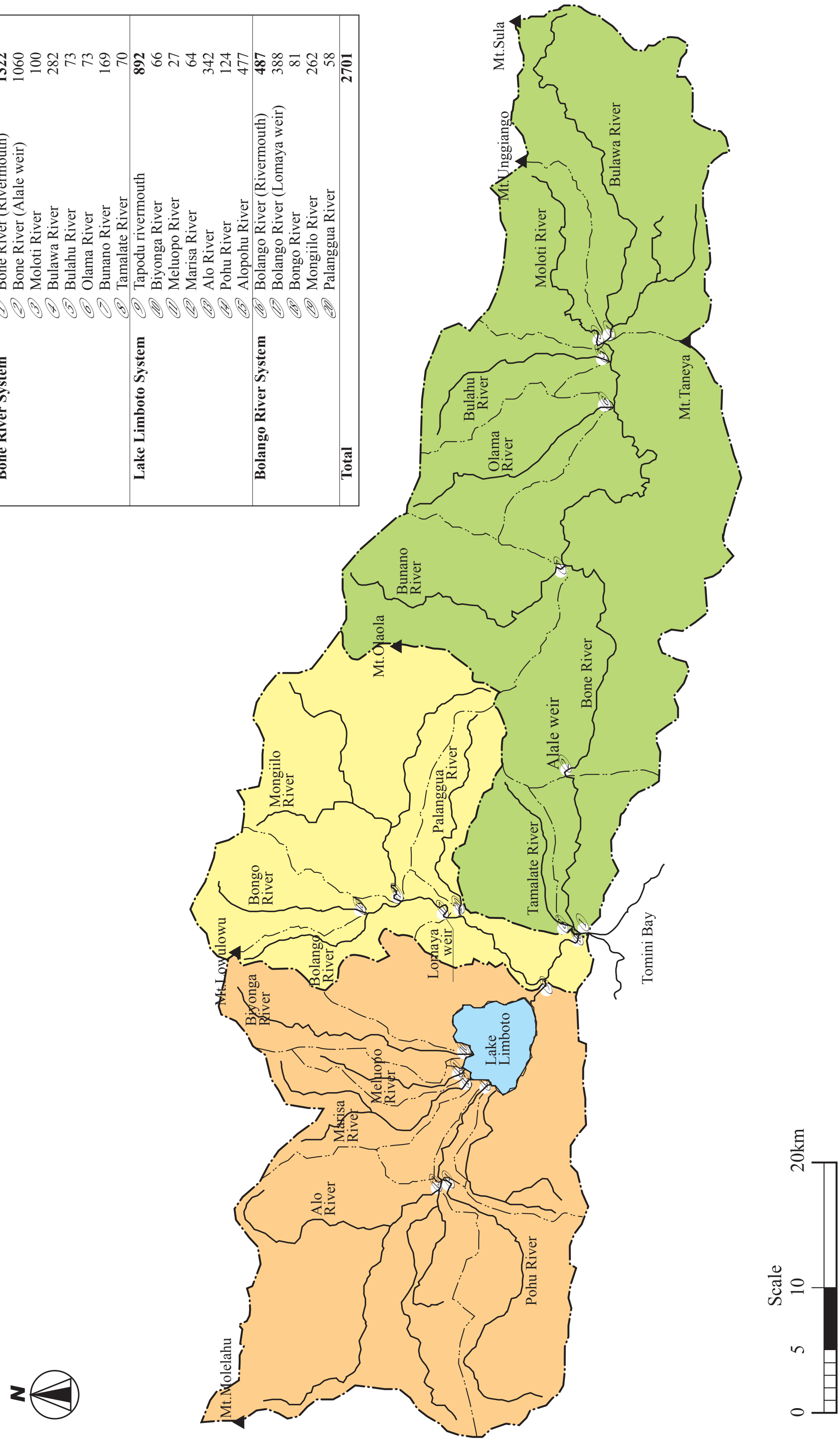
d_{60} = 60% grain size (m), 60% of the bed material is finer than this size



Duration		Rainfall (mm)					
(hr)	(min)	2	5	10	20	50	100
1	60	54	60	64	67	71	74
3	180	65	81	93	104	119	131
6	360	70	92	108	123	145	161
12	720	72	93	109	124	145	162
24	1440	76	98	114	130	151	168
48	2880	96	117	130	142	157	169
72	4320	106	133	150	165	184	198

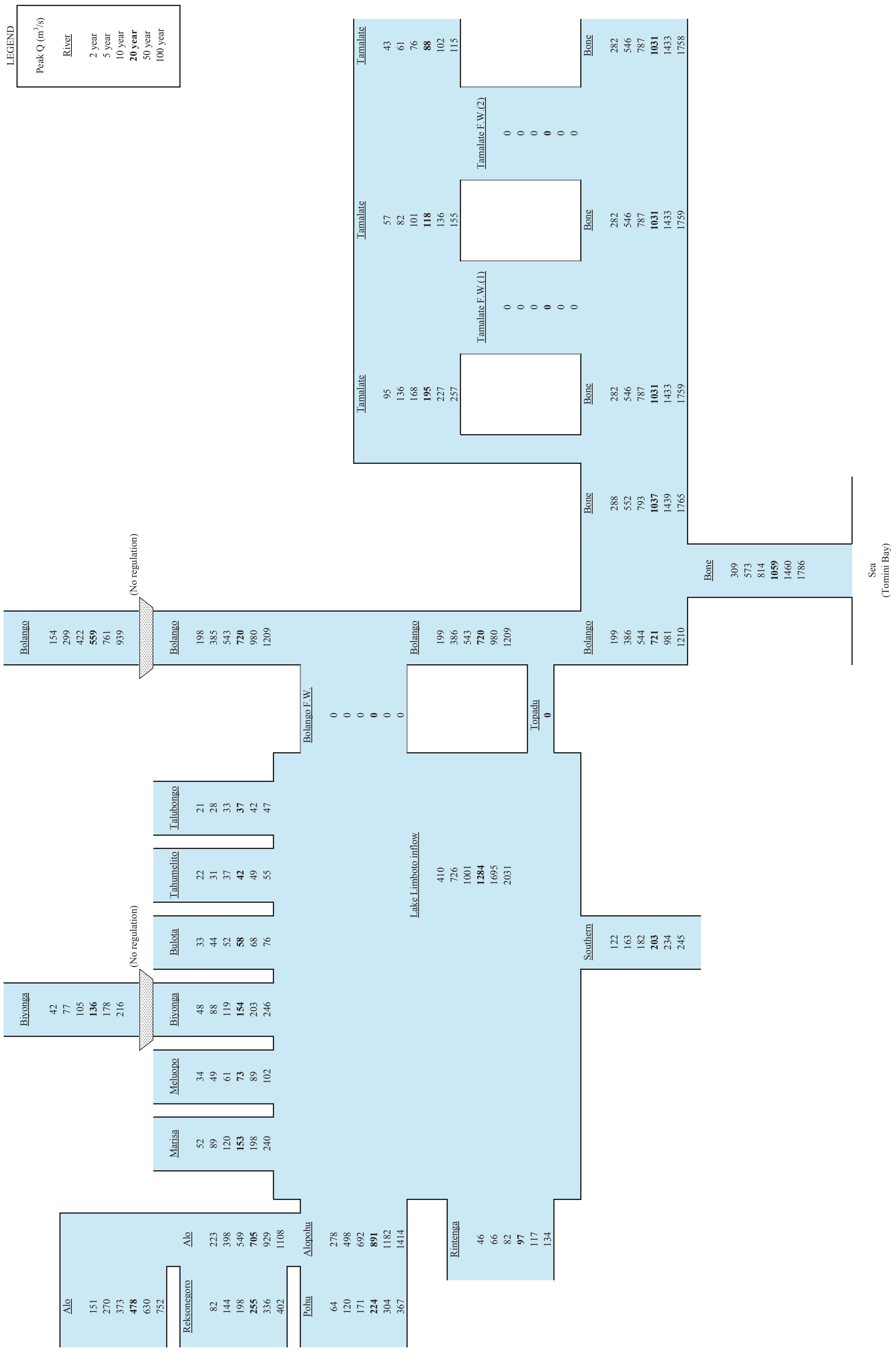
Duration		Rainfall intensity (mm/hr)					
(hr)	(min)	2	5	10	20	50	100
1	60	54.0	60.0	64.0	67.0	71.0	74.0
3	180	21.7	27.0	31.0	34.7	39.7	43.7
6	360	11.7	15.3	18.0	20.5	24.2	26.8
12	720	6.00	7.75	9.08	10.33	12.08	13.50
24	1440	3.17	4.08	4.75	5.42	6.29	7.00
48	2880	2.00	2.44	2.71	2.96	3.27	3.52
72	4320	1.47	1.85	2.08	2.29	2.56	2.75

Figure 3.2.1
RAINFALL INTENSITY CURVE AT JALALUDDIN AIRPORT

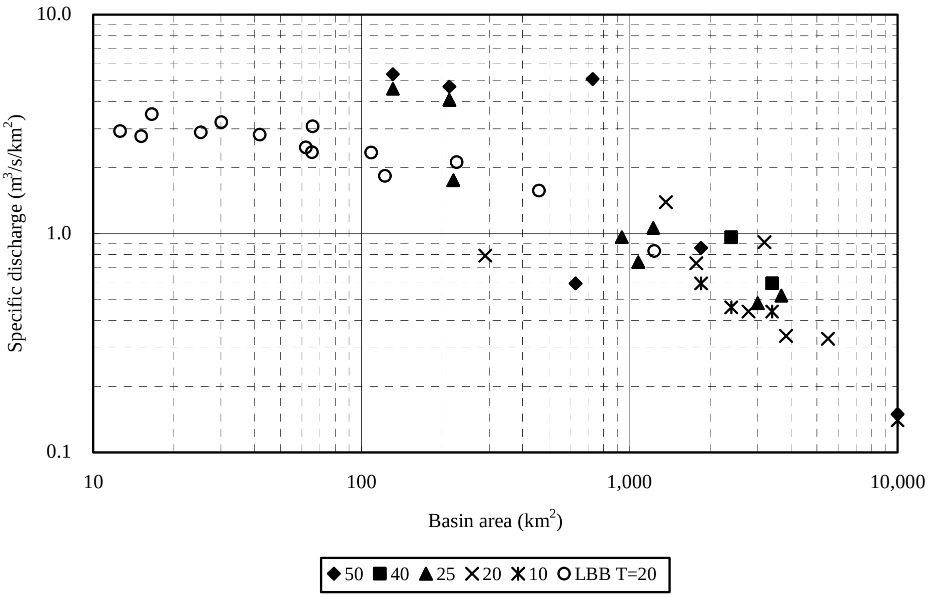


River System		River	Area (sq.km)
Bone River System	1	Bone River (Rivermouth)	**1322**
	2	Bone River (Alale weir)	1060
	3	Moloti River	100
	4	Bulawa River	282
	5	Bulahu River	73
	6	Olama River	73
	7	Bunano River	169
	8	Tamalate River	70
Lake Limboto System	9	Tapodu rivermouth	**892**
	10	Biyonga River	66
	11	Meluopo River	27
	12	Marisa River	64
	13	Alo River	342
	14	Pohu River	124
	15	Alopohu River	477
Bolango River System	16	Bolango River (Rivermouth)	**487**
	17	Bolango River (Lomaya weir)	388
	18	Bongo River	81
	19	Mongiilo River	262
	20	Palanggua River	58
Total			**2701**

The Study on Flood Control and Water Management in Limboto-Bolango-Bone Basin in the Republic of Indonesia	**Figure 3.2.2**
Japan International Cooperation Agency	**RIVER BASIN BOUNDARIES**



The Study on Flood Control and Water Management in Limboto-Bolango-Bone Basin in the Republic of Indonesia	**Figure 3.2.3**
Japan International Cooperation Agency	**BASIC PROBABLE DISCHARGES OF LBB BASIN**



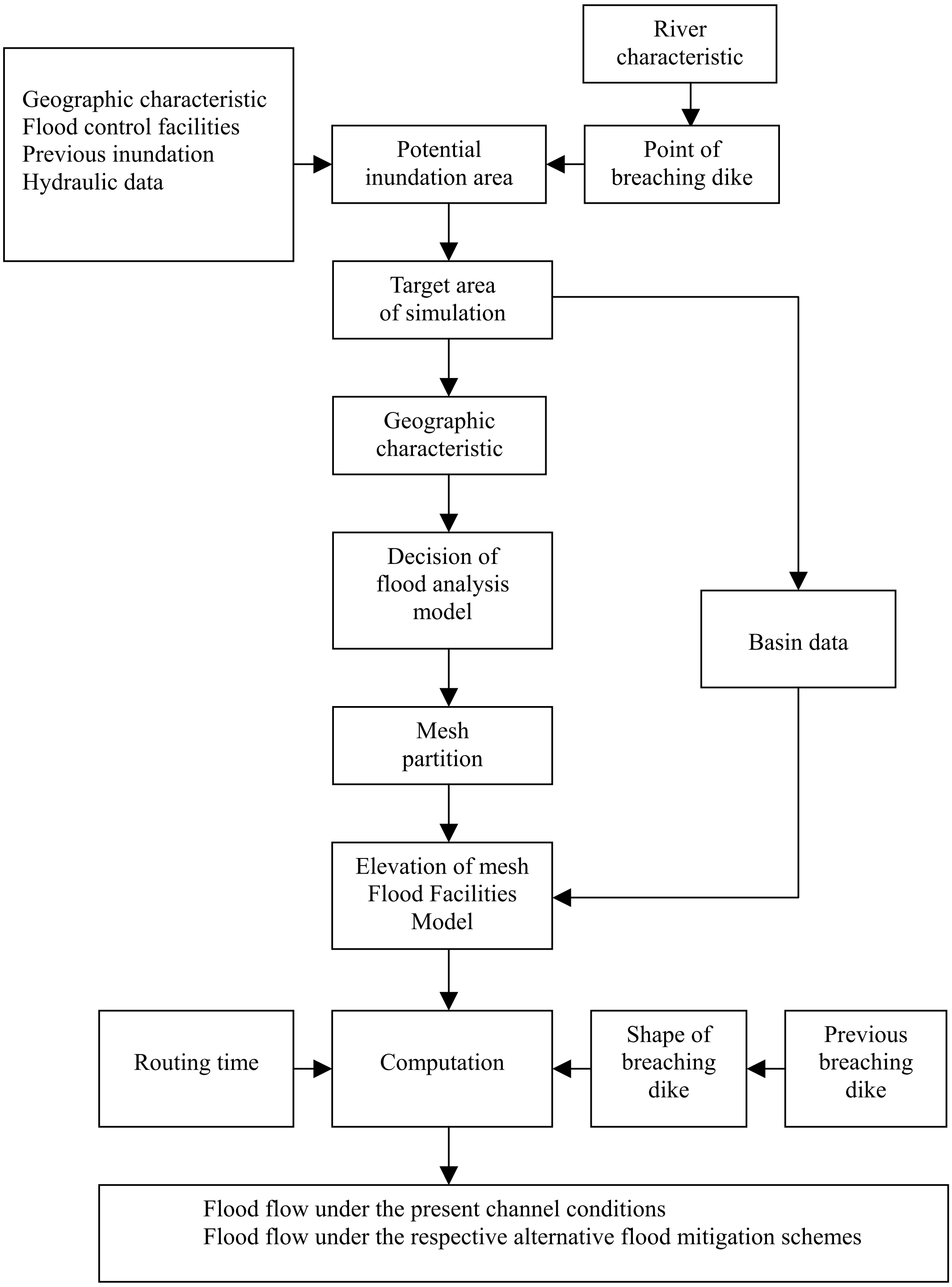
Name of River	Province	Chatchment Area (km²)	Design Flood (m³/s)	Specific Discharge (m³/s/km²)	Return Period (year)	Remarks
Brantas	East Java	10,000	1,500	0.15	50	*2
Ciujung	North Banten	1,850	1,600	0.86	50	*2
Jenebarang	South Sulawesi	729	3,700	5.08	50	
Surabaya	East Java	631	370	0.59	50	
Kuranji	West Sumatra	213	1,000	4.69	50	*2
Air Dingin	West Sumatra	131	700	5.34	50	*2
Solo	Central/East Java	3,400	2,000	0.59	40	*2
Madium	East Java	2,400	2,300	0.96	40	*2
Citanduy	West Java	3,680	1,900	0.52	25	
Cimanuk	West Java	3,006	1,440	0.48	25	
Pemali	Central Java	1,228	1,300	1.06	25	
Ular	North Sumatra	1,080	800	0.74	25	
Serang	Central Java	937	900	0.96	25	
Cipanas	West Java	220	385	1.75	25	
Kuranji	West Sumatra	213	870	4.08	25	*1
Air Dingin	West Sumatra	131	600	4.58	25	*1
Arakundo	Ache	5,495	1,800	0.33	20	
Wampu	North Sumatra	3,840	1,320	0.34	20	
Walarue	South Sulawesi	3,190	2,900	0.91	20	
Bah Bolon	North Sumatra	2,776	1,220	0.44	20	
Kring Ache	Ache	1,775	1,300	0.73	20	
Biba	South Sulawesi	1,368	1,900	1.39	20	
Marmoyo	East Java	290	230	0.79	20	
Brantas	East Java	10,000	1,350	0.14	10	*1
Solo	Central/East Java	3,400	1,500	0.44	10	*1
Madium	East Java	2,400	1,100	0.46	10	*1
Ciujung	North Banten	1,850	1,100	0.59	10	*1

Note * 1 : For short-term or urgent plan
* 2 : For long-term plan

The Study on Flood Control and Water Management in Limboto-Bolango-Bone Basin in the Republic of Indonesia

Japan International Cooperation Agency

Figure 3.2.4
DISCHARGES OF LBB BASIN AND OTHER RIVERS IN INDONESIA



The Study on Flood Control and Water Management in Limboto-Bolango-Bone Basin in the Republic of Indonesia

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Figure 3.2.5

PROCEDURES OF FLOOD FLOW ANALYSIS

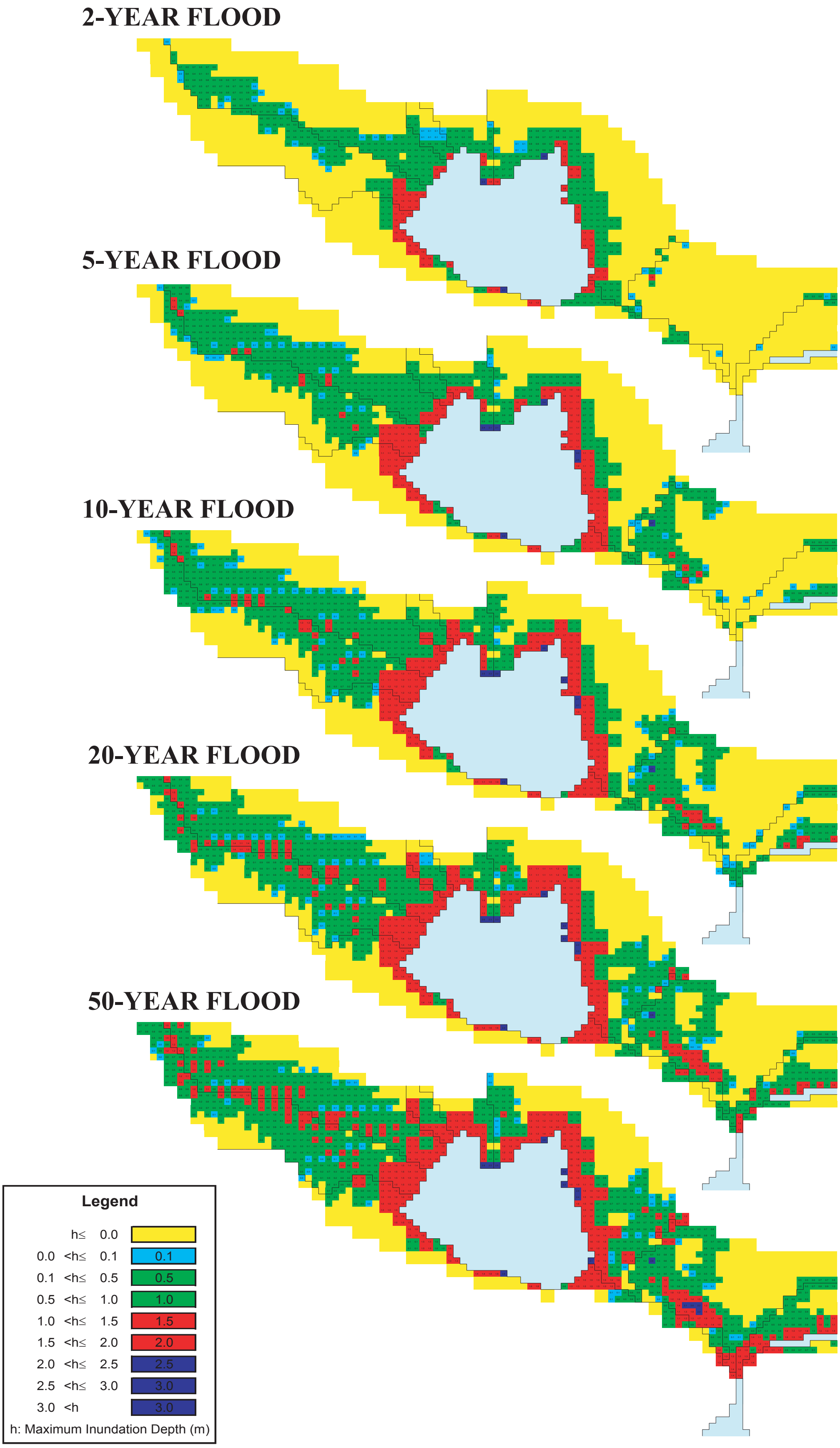

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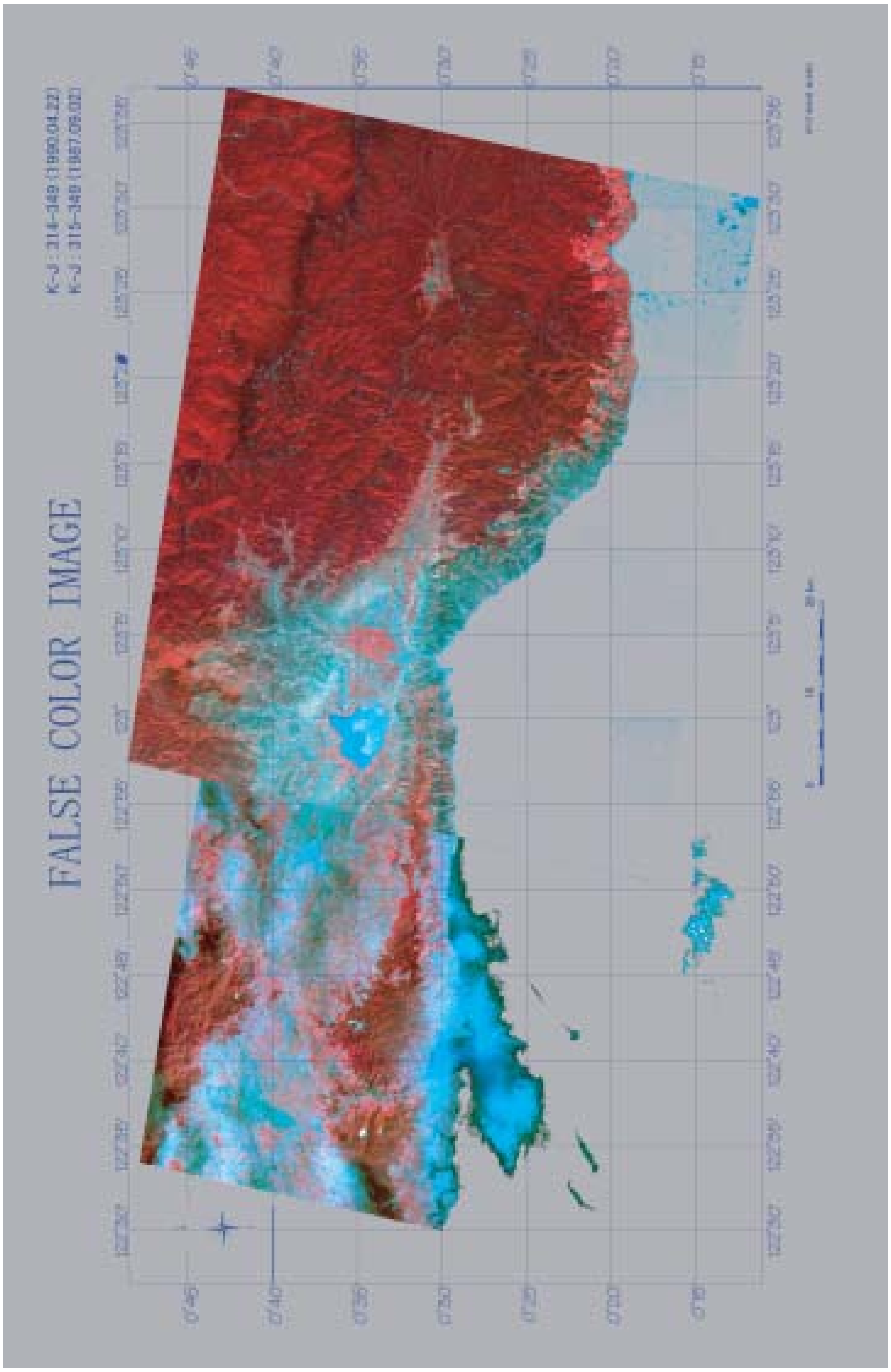
Figure 3.2.6

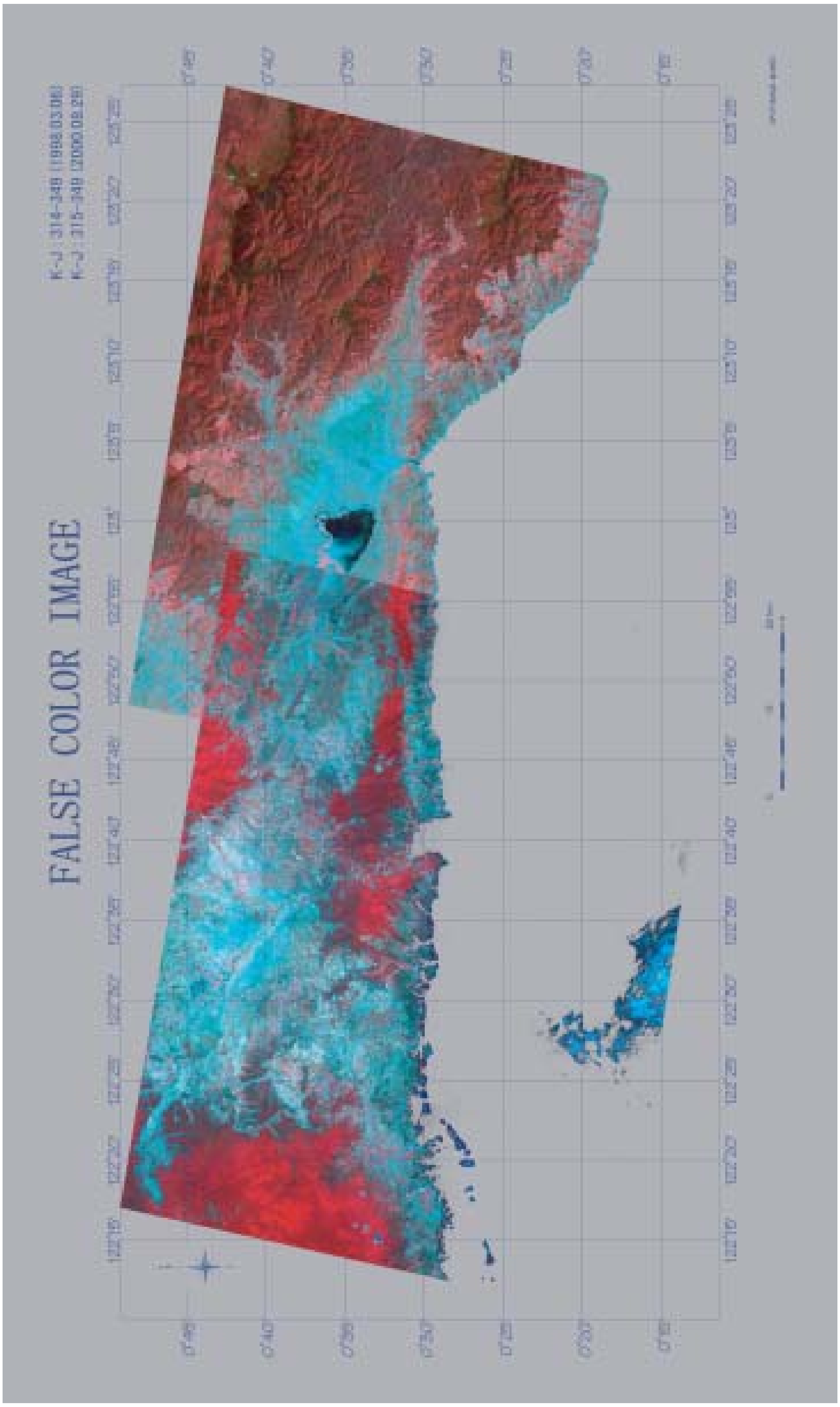
RESULT OF FLOOD FLOW ANALYSIS



Source: Sattelite Image taken in 1987.09.02/1990.04.22

SATELLITE IMAGE (1990)

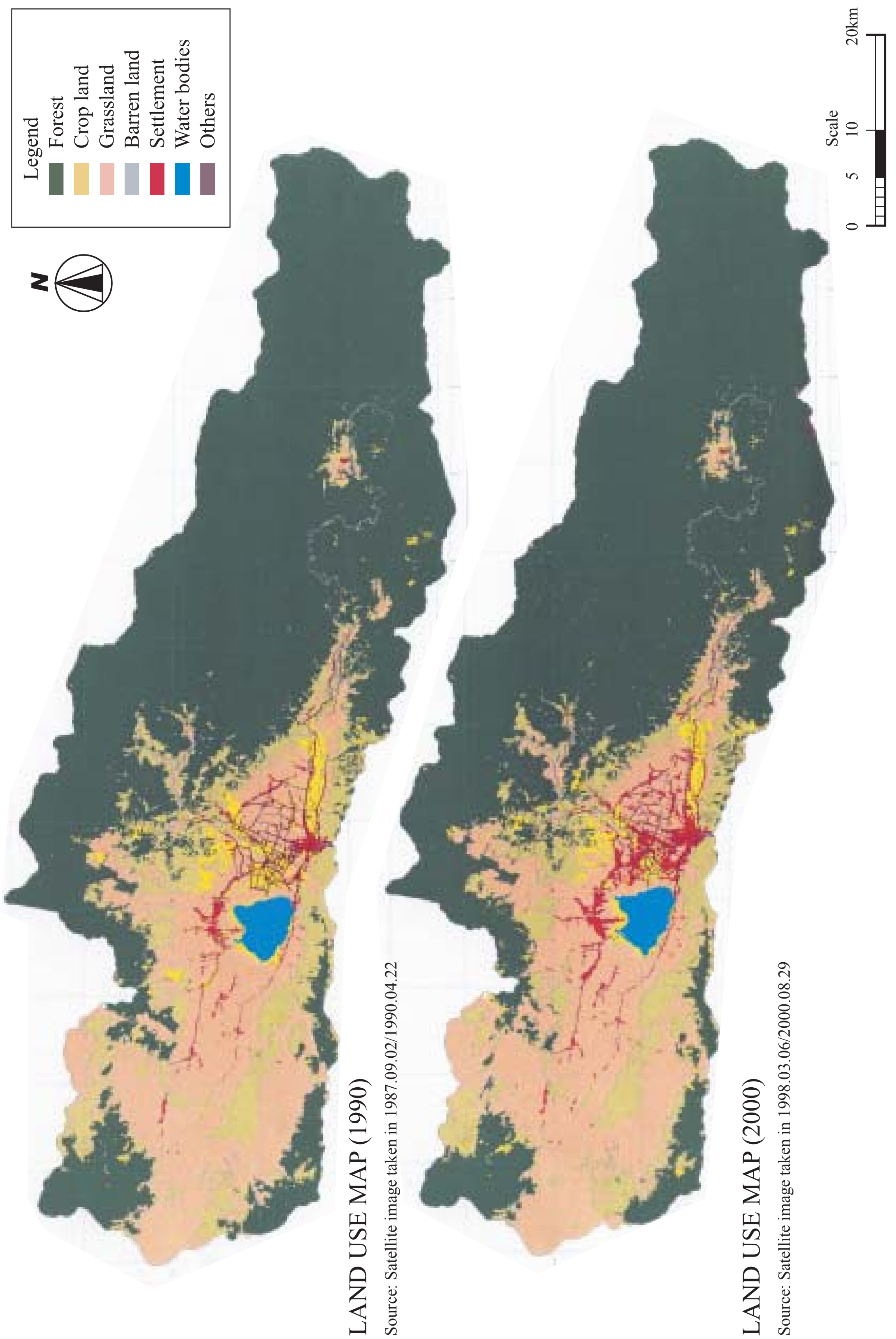
The Study on Flood Control and Water Management in Limboto-Bolango-Bone Basin in the Republic of Indonesia	**Figure 3.3.1**
Japan International Cooperation Agency	**SATELLITE IMAGE (1/2)**



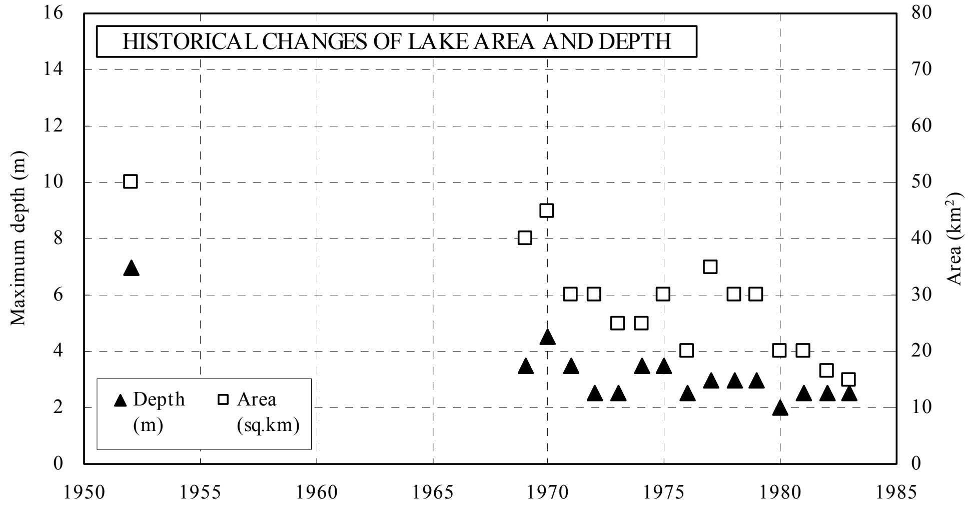
SATELLITE IMAGE (2000)

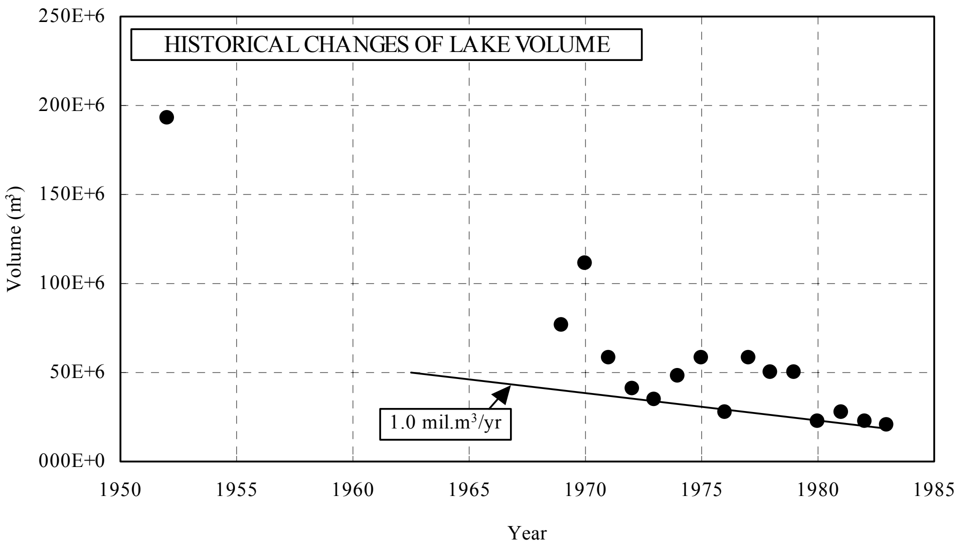
Source: Satellite Image taken in 1998.03.06/2000.08.29

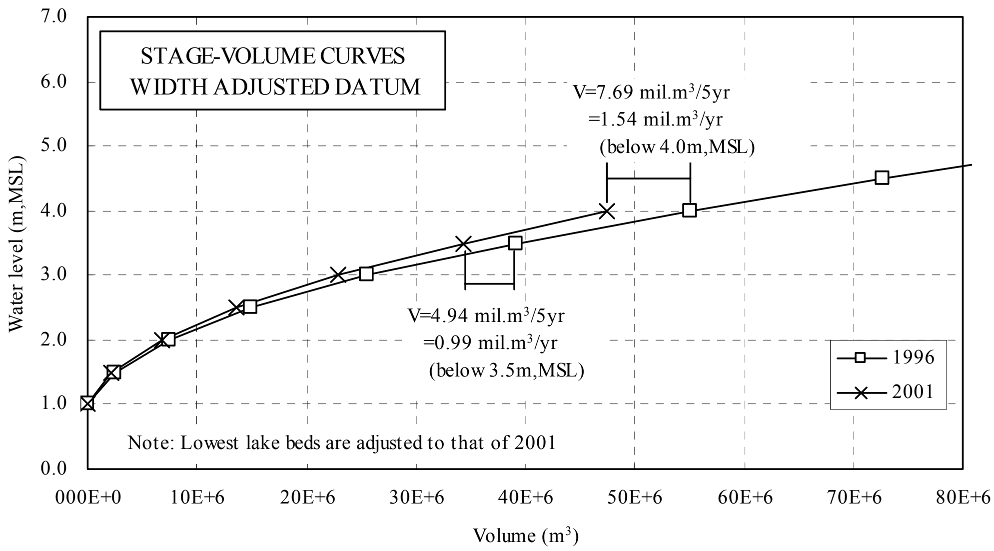
The Study on Flood Control and Water Management in Limboto-Bolango-Bone Basin in the Republic of Indonesia	**Figure 3.3.1**
Japan International Cooperation Agency	**SATELLITE IMAGE (2/2)**



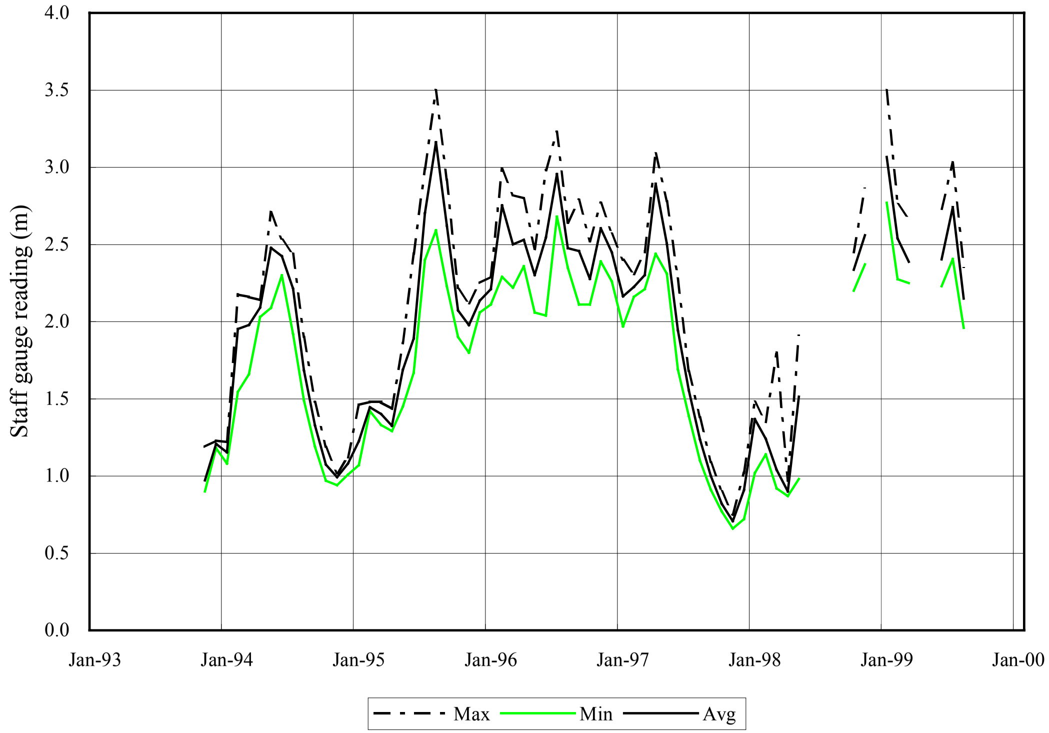
The Study on Flood Control and Water Management in Limboto-Bolango-Bone Basin in the Republic of Indonesia	**Figure 3.3.2**
Japan International Cooperation Agency	**LAND USE MAP**







The Study on Flood Control and Water Management in Limboto-Bolango-Bone Basin in the Republic of Indonesia	**Figure 3.3.3**
Japan International Cooperation Agency	**ESTIMATION OF LAKE SEDIMENTATION**



WL(m,MSL) = (Staff gauge reading) + 1.99m

Water Level of Lake Limboto

Year	Max. (m,MSL)	Min. (m,MSL)	Average (m,MSL)
1988	5.3	-	-
1989	4.8	-	-
1990	4.2	-	-
1991	4.2	-	-
1992	3.7	-	-
1993	3.2	2.9	3.0
1994	4.7	2.9	3.7
1995	5.5	3.1	4.0
1996	5.2	4.0	4.5
1997	5.1	2.7	3.7
1998	4.9	2.9	3.6
1999 (upto Aug.)	5.5	4.0	4.5

Figure 3.4.1
WATER LEVEL RECORDS OF LAKE LIMBOTO