Department of Public Works and Highway
The Republic of Philippines

DATA COLLECTION SURVEY ON FLOOD MANAGEMENT PLAN IN METRO MANILA

Final Report

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Japan International Cooperation Agency (JICA)

Yachiyo Engineering Co., Ltd.

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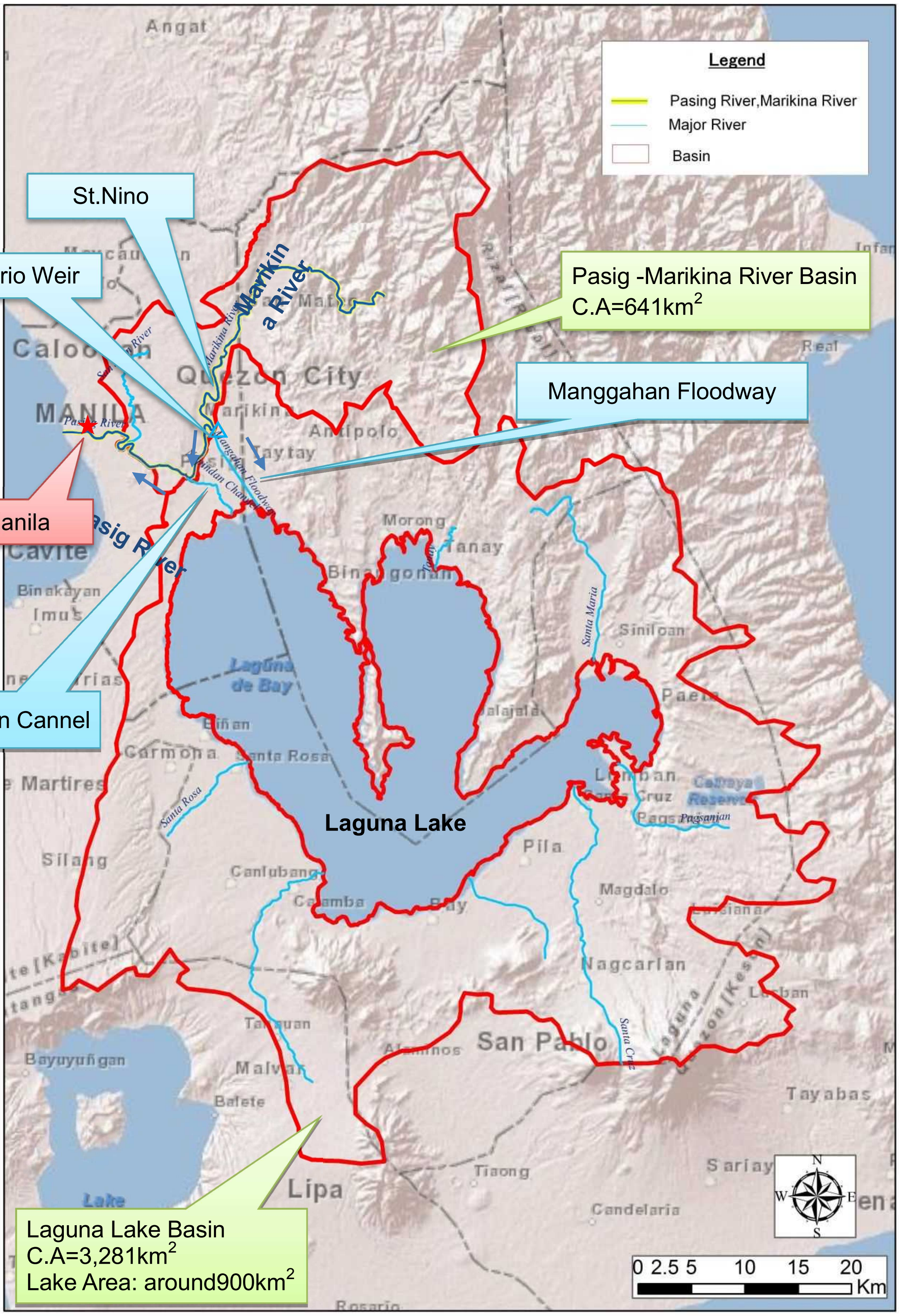
Legend
Pasing River,Marikina River
Major River
Basin
St.Nino
Rosario Weir
Marikina River
Pasig -Marikina River Basin
C.A=641km2
Manggahan Floodway
Manila
Pasig River
Napindan Cannel
Laguna Lake
Laguna Lake Basin
C.A=3,281km2
Lake Area: around900km2
0 2.5 5 10 15 20
Km

Study Area

PHOTOS

Manggahan Floodway and Densely Urbanized Area (2009)[1]

2009

1988

Landuse Change around Outlet of Manggahan Floodway [1]

Flood Disaster in 2009 [2]

Rosario Weir [3]

1 Preparatory Study for Pasig-Marikina River Channel Improvement Project (JICA)
2 Flood Disaster caused by Ondoy Typhoon in 2009
3 Post Evaluation Report on "the Project for Rehabilitation of the Flood Control Operation and Warning System in Metro Manila"

SYNOPSIS

1 INTRODUCTION

(1) Background

The Pasig-Marikina-San Juan River System, of which total catchment area is 621 km^2, runs through the center of Metro Manila and flows out to the Manila Bay. Its Main tributaries, the San Juan River and Napindan River, join the main stream at about 9.9 km and 19.9 km upstream from the Pasig River mouth, respectively. The three largest waterways contribute largely to the flooding in the metropolis brought about by the riverbank overflow of floodwaters. Metro Manila, which encompasses 16 cities and 1 municipality having a total projected population of over 11.5 million in 2010, is the economic, political and cultural center of the Philippines.

The department of Public Works and Highways (DPWH) conducted an updated Master Plan (M/P) for flood control and drainage improvement in Metro Manila and a Feasibility Study (F/S) on the channel improvement of the Pasig-Marikina River from January 1988 to March 1990, under a technical assistance from the Japan International Cooperation Agency (JICA), called "The Study on Flood Control and Drainage Project in Metro Manila (JICA M/P Study)" and PMRCIP has been implemented based on the Master Plan.

On the other hand, the World Bank conducted the study "Master Plan for Flood Management in Metro Manila and Surrounding Areas" ("WB Study") under the objective to establish the vision, which will be the blue print or road map, for a sustainable and effective flood risk management in Metro Manila and surrounding areas until 2035.

The WB Study has shown the results; 1) Review of current situation and arrangement of flood risk management, 2) Study on the mechanism of floods and flood damage, 3) Identification of constraints and barriers for flood risk management and directions for improvement, and 4) Formulation of the macro-framework for integrated flood risk management plan.

Based on the results of the WB Study and JICA M/P Study, JICA conducts "Data Collection Survey on Flood Management Plan in Metro Manila" to further examine with the detailed flood control measures in Pasig-Marikina River Basin.

(2) Objective and Study Items

The objective is to reexamine the technical validity of the proposed structural measures in Pasig-Marikina River Basin under the WB Study by utilizing the hydrological and hydrodynamic flood simulation model which is to be refined and updated with appropriately selected dataset in consideration of the future climate change. Main work items are 1) Collection and Utilization of Previous Study Results, 2) Establishment of Flood Analysis Model, 3) Analysis of Design High-water Discharge, 4) Analysis of Water Level Fluctuation in Laguna Lake during Flood in Pasig-Marikina River and 5) Analysis of Climate Change Effects. The counterpart agency is Department of Public Works and Highway (DPWH) of the Republic of Philippine. Study area is Pasig-Marikina River Basin and Laguna Lake Basin in Metro Manila.

2 ESTABLISHMENT OF FLOOD ANALYSIS MODEL

(1) Establishment of Flood Analysis Model

Runoff Analysis Model was established using "Water and Energy Budget-based Distributed Hydrological Model" (WEB-DHM) which can describe spatial variations of basin such as topography, dynamic behavior of rainwater, soil characteristics, spatial variation of rainfall and so on.

Inundation Analysis Model is formulated by combining river hydraulic model utilizing one-dimensional unsteady flow analysis model with inundation model utilizing two-dimensional unsteady flow analysis model which can reproduce compound inundation phenomena of inland water and river flood, flow resistance due to land use and density of building, effects of channels, embankment, micro-topography, drainage and pump drainage and so on. Based on the survey conducted from December 2010 to January 2011, LiDAR data surveyed from December 2010 to

January 2011 is utilized which is the newest and most accurate data.

(2) Calibration of Model with Past Floods

Validity of established flood analysis model was calibrated comparing the observed discharge and water level data with simulation results such as discharge, river water level and inundation level.

Verification of H-Q Equations

Since the H-Q curves in previous studies (JICA MP and WB Study) have low reliability in high water level while the accuracies in low water level is high. Thus, the new H-Q curve which is recalculated by the Study are applied. Using the H-Q of this Study, the largest discharge in 2009 is estimated as 2,900m^3/s.

Peak Water Level by Typhoon Ondoy at Sto.Nino Station

During the flood by Typhoon Ondoy, water level was not recorded at Sto.Nino Station after 18:00 on September 26 with the record of 22.16m, and the peak water level is uncertain. Based on the comparison of the peak discharges of past floods, the peak time of Sto.Nino during the flood by Typhoon Ondoy was estimated at 17:00 and water level is almost same as 22.16m which was observed at 18:00.

Selection of Past Floods for Model Calibration and Verification

The 3 floods in Typhoon Ondoy in 2009, November 2004 and August 2008 were selected for calibration and verification of the flood analysis model as the 3 largest basin daily rainfalls were recorded.

Establishment of Flood Analysis Model

Model calibration was conducted as the following procedure.

- Discharge to river course without inundation in upstream basin estimated by the runoff model (WEB-DHM) is given to the inundation model as a boundary condition.
- Water level in river course and inundation area is estimated by the inundation model
- Parameters are evaluated comparing estimated discharge, water level and inundation area to the observed ones.

The 2009 Flood (Typhoon Ondoy) was selected for calibration. The established model shows good reproductivity for relatively small peak flood such as the 2004 Flood and multi-peak flood such as 2012 Flood.

3 ANALYSIS OF DESIGN FLOOD DISCHARGE

(1) Preconditions for Analysis

As preconditions for analysis of design flood discharge, existing facilities, plans f are confirmed.

Existing Facilities

Manggahan Floodway was constructed in 1988 to protect the center of Metro Manila from 100 years probable flood with design discharge of 2,400m^3/s.

Currently, the original flow capacity has been reduced mainly due to illegal houses in the course of floodway and sedimentation.

Current Flow Capacity

The average ratio of current flow capacities against design discharges are about 50% in Pasig, 80% in lower Marikina and 20% in upper and upper-upper Marikina. Flood control ratio is especially low in upper and upper-upper Marikina.

Pasig-Marikina River Channel Improvement Project (Phase III)

The objective of the overall project is to increase flood safety of Pasig-Marikina River to 1/30 years probable flood. The Phase III Project covers the sections which are not covered by the ongoing Phase II Project. Design discharges are set assuming MCGS will be constructed in the future. The design discharges are 2,900m^3/s at Sto.Nito. It is diverted to Manggahan Floodway with 2,400m^3/s and Lower

Marikina with 500m^3/s by MCGS at Rosario, and the river discharges increase to 600m^3/s at upstream and to 1,200m^3/s at downstream of Pasig River.

Proposed Projects by WB Study

The Proposed projects by the WB Study consists the improvement of Upper and Upper-Upper Marikina River, Marikina Large Dam, re-improvement of Pasig River and Lower Marikina River and improvement of San Juan River and Napindan Channel with design flood discharge of 1/100 years return period and the target year of 2035. In the WP Plan, the current diversion system using both Manggahan Floodway and Napindan Channel is applied without construction of MCGS. , which is against the concept of PMRCIP. The design discharge is 2,900m^3/s at Sto.Nito by controlling by a Marikina large dam. It becomes 3,000m^3/s at Rosario and is diverted to Manggahan Floodway with 2,000m^3/s and Lower Marikina with 1,000m^3/s and the design discharge of 1,200m^3/s at NHCS is further diverted to Napindan Channel with 600m^3/s, and the design discharge becomes 850m^3/s at Upper Pasig and 1,800m^3/s at Lower Pasig.

(2) Review of Rainfall Analysis

Conditions for calculation and its results as 30 years and 100 years return periods rainfall which obtained by the Study of Water Security Master Plan for Metro Manila and its Adjoining Areas (hereinafter referred to as the JICA Water Security Study) are examined.

The JICA Water Security Study applied 1 day rainfall based on the analysis for correlation between rainfall duration and peak water level at Sto.Nino, while the previous studies applied 2 days rainfall.

Besides, the JICA Water Security Study applied several design hyetographs based on the observed hyetographs while the previous studies applied only milled-peak fictional hyetograph and the hyetograph of Typhoon Ondoy.

(3) Basic Design Discharge

Based on the established flood analysis model, basic design discharge is estimated using the hyetographs. The largest discharge at Sto.Nino is estimated using the hyetograph of Typhoon Ondoy of which discharges are 3,575m^3/s with natural retarding function (inundation in upstream) and 4,980m^3/s without inundation in upstream. Thus, the basic design discharge is determined using the hyetograph of Typhoon Ondoy. It is noted that probability 1 day rainfall of the hyetograph of Typhoon Ondoy is evaluated as 1/110 years, however, it is not cut down to meet the 1/100 years rainfall since the both values are almost same.

Water Level of Laguna Lake

Since there is a possibility that the peak discharges at Marikina River and Laguna Lake occur at same time, the highest water level after 1989 when Manggahan Floodway constructed, 13.90m is applied in this Study. For water level rise of Laguna Lake in the case of Typhoon Ondoy, inflow from Manggahan Floodway and Napindan Channel contributes to 0.18m which is only 17% of total water level rise during the Typhoon Ondoy.

(4) Design Flood Discharge

Operation of NHCS

With the following reasons, it is judged as appropriate that NHCS shall be closed during flood to avoid uncertain phenomena in flood management plan.

- Diversion through Napindan Channel to Laguna Lake is uncertain since reverse flow will happen depending on water level in Laguna Lake.
- If NHCS would open during flood, channel improvement of Napindan Channel is inevitable to protect surrounding dense urbanized area resulting difficulty of land acquisitions.

Necessity of MCGS

MCGS is necessary for sure diversion of design discharge to Laguna Lake. Besides, excess flood also can be diverted to Manggahan Floodway by MCGS resulting mitigation of flood risk at the center of Metro Manila.

Without MCGS, re-improvement of channel downstream of Rosario Weir since HWL increases. Rise of HWL leads to increase of flood disaster potentials.

Evaluation of Probability of Design Flood Discharge by PMRCIP

PMRCIP is to divert the design discharge equivalent to 1/30 years probable flood at Sto.Nino of 2,900m^3/s to Manggahan Floodway with 2,400m^3/s and Pasig-Marikina River with 500m^3/s. Based on the review of hydrological analysis referring the observed floods in recent years, the design flood discharge of PMRCIP of 2,900 m^3/s is reevaluated as 1/20 years flood.

Alternatives of Flood Management Plan for 1/30 Flood

As the urgent flood management measures until the completion of Phase IV Project, the following 3 alternatives are proposed.

- Alt-O: 1/30 years flood (as of 2002) measures by Phase IV component (Q=2,900m^3/s at Sto.Nino)
- Alt-A: 1/30 years flood measures by Phase IV components with improvement of Manggahan Floodway (Q=3,100m^3/s at Sto.Nino)
- Alt-B: 1/30 years flood measures by Phase IV components with improvement of retarding basin in upper-upper Marikina (Q=2,900m^3/s at Sto.Nino)

Flood Management Plan for 1/100 Years Flood

Based on the above mentioned 3 alternatives for 1/30 years flood management plan, 10 alternatives are proposed considering step-wise development.

Implementing “dam” or “dam + retarding basin” development after the Phase IV Project completed, flood safety degree can be increased up to 1/100 years without re-investment to the past developed section.

- “Dam + Retarding Basin” options can increase safety degree by stages.
- “Dam” options can be taken if geological conditions in upstream basin is good enough. Since retarding basin is not required or can be reduced after completion of dam, land use such as urban development is available.

Comparison with WB Proposal

The alternatives for 1/100 years flood and the WB proposed measures are compared and the following differences are found.

- The WB proposal utilizes the current flood management system without MCGS by which step-wise improvement of flood safety is impossible.
- It includes the uncertain function of natural diversion at NHCS which might not always occur.
- It requires large scale of dredging work in Lower Pasig River and it will be repeatedly conducted.
- Re-investment is required to PMRCIP such as heightening of dykes and replacement of bridges.

Investigation of Appropriateness of Measures to Floods

The appropriateness of measures to floods is investigated by Economic Evaluation taking into consideration this project forms a part of the public investment in order to reduce floods damage in the Metro Manila. As shown in the table below, economic feasibility is confirmed for all alternatives.

- It varies depending on the alternatives, however, EIRR exceeds 15% in all cases.
- In all cases, NPV is largely surplus the cost.
- It varies depending on the alternatives, however, B/C exceeds 1.00 in all cases.

4 WATER LEVEL FLUCTUATION IN LAGUNA LAKE DURING FLOOD IN PASIG-MARIKINA RIVER

In order to examine the validity of water level fluctuation of Laguna Lake, and the measure against floods, data collection and its arrangement are performed about flow regime of the water fluctuation data of Laguna Lake lake and both Manggahan Floodway and Napindan Channel during the floods, and the water level fluctuation analysis model of Laguna Lake is built based on the water level fluctuation characteristic of Laguna Lake as follows.

(1) Water Level Fluctuation of Laguna Lake

Secular change of monthly variation of water level at Anogono Station from 1994 to 2012 is summarized. Water level of Laguna Lake becomes the lowest in April or May, which is the end of dry season, and becomes the highest in late rainy season in September to January. The average annual lowest and highest water levels are EL. 10.8m and EL. 12.4m, respectively. The average annual lowest water level is almost same as the mean sea level (MSL) of Manila Bay. It means that sea water intrusion to Laguna Lake occurs when high tide in the end of dry season.

For water level fluctuation during flood, hourly hydrograph in 2004 in which two floods were occurred by the tropical cyclone Wennie in August and the typhoon Yoyong in December is analyzed comparing the water levels among Rosario JS, Napindan JS and Laguna Lake. During flooding stage, water level of Rosario JS is more sensitive and always higher than Laguna Lake. It is expected that natural discharge to Laguna Lake through Manggahan Floodway always occurs during floods. On the other hand, clear correlation cannot be found between the water levels of Napindan JS and Laguna Lake. It is judged that natural diversion from Pasig River to Laguna Lake through Napindan Channel does not always occur.

(2) Water Level Fluctuation Model

Establishment of Analysis Model

The long-term one dimensional model correlating the water level at Angono, inflow discharge from tributaries, inflow from Rosario JS, inflow through Manggahan Floodway, inflow and outflow through Napindan Channel, and evaporation from Lake surface is established and calibrated with observed data in 2004 and 2009.

Validity of Including reverse flow (Napindan Waterway) of Laguna in Flood Measure Plan

Based on observed data in 2004 and analysis results in 2004 and 2009, water level of Rosario JS is always higher than Laguna Lake during floods. On the other hand, water level of Napindan JS is lower than Laguna Lake in many cases. Although it becomes higher than Laguna Lake occasionally depending of tidal level, its uncertainty is high to expect as flood control function and it is not recommended to include this phenomena as a flood control measure.

Influence of inflow from Pasig-Marikina River to Water Level Fluctuation of Laguna Lake

82 % of inflow to Languna Lake during Typhoon Ondoy is came from Laguna Lake Basin, while only 10 % comes through Manggahan Flood way and 8 % comes through Napindan Channel. Based on this simulation results, it is judged that influence of inflow from Pasig-Marikina River is very small to water level fluctuation of Laguna Lake.

Influence on Laguna Lake accompanying a Climate Change

Considering the climate change effect in 2040, 11.82 m of simulated high water level in 2004 becomes 11.93 m (+0.11 m) and 13.96 m of simulated high water level during Typhoon Ondoy invasion in 2009 becomes 14.25 m (+0.29 m).

(3) Examination Validity of Flood Management Measures

Based on the aforementioned examination, validity of the proposed flood management measures in this Study which discussed in Chapter 4 is confirmed in the aspect of effect to the water level of Laguna Lake.

Include reverse flow (Napindan Channel) to Laguna Lake in a flood measure plan.

In Napindan JS, the water level may become higher than Laguna Lake in some cases. However, the uncertainty of the flood regulation from a relation with a tide level is high, and it is not recommended to consider as a flood management measure.

Factor of a Laguna Lake water level rise

The factor of a water level rise of Laguna Lake can be judged from the comparison result of amount of flood discharge. It is that the rainfall to the inflow river and the surface of Laguna Lake occupies about 80%.

5 CLIMATE CHANGE EFFECT

(1) Change of Flood Safety Degree

Rainfall will increase about 10% in 2040 as a climate change impact, and rise of water level in Laguna Lake is expected to 29 cm as maximum. Besides, it is estimated based on the 4th IPCC report that tide level in Manila Bay rises about 22 cm. Peak discharges increase about 17 % for 1/30 years flood and about 10 % for 1/100 years flood. Therefore, safety degree of 1/30 years decline to 1/20 years and 1/100 years decline to 1/60 years.

(2) Change of Inundation by Climate Change after Phase IV Project Completion

Inundation areas increase about 1.26 times for 1/30 years flood and about 1.12 times for 1/100 years flood. On the other hand, inundation depths decrease about 15 cm for 1/30 years flood and about 9 cm for 1/100 years flood due to spread of inundation areas induced by increase of discharges.

(3) Adaptation Measures against Climate Change

The adaptation structural measures can be categorized into the measures upstream and downstream of MCGS.

The measures upstream of MCGS can be divided into the measures for flood control facilities upstream of Sto.Nino such as increase of capacities of retarding basins, improvement of flood control function of dam and additional dam and increase of diversion discharge to Laguna Lake such as increase of capacity of Manggahan Floodway by dredging or new floodway.

The measures downstream of MCGS is mainly the measures to reduce inflow discharge from San Juan River such as underground floodway, underground storage and runoff control facilities such as retarding storage, rainwater storage and infiltration facilities.

Non-structural measures shall be implemented according to change of inundation conditions induced by the climate change such as evacuation system improvement, hazard map and landuse regulation, and conservation of retarding function of basins.

6 CONCLUSION AND RECOMMENDATION

The works in this Study can be broadly categorized into the followings.

(a) Establishment of hydrological and hydrodynamic flood simulation model with appropriately selected dataset in consideration of the future climate change
(b) Reevaluation of technical validity of the proposed structural measures in Pasig-Marikina River Basin under the WB Study
(c) Examination of flood management measures against 1/30 and 1/100 years probable floods and proposal of direction of flood management measures

(1) Conclusion

The results and conclusions of above mentioned work categories are summarized as follows.

1) Establishment of Hydrological and Hydrodynamic Flood Simulation Model with Appropriately Selected Dataset in Consideration of Future Climate Change

Flood analysis model is established integrating runoff analysis model (WEB-DHM Model), river hydraulic model (one dimensional unsteady flow model) and inundation analysis model (two dimensional unsteady flow model). Since the detailed elevation data named LiDAR data, the latest river section survey, vegetation and landuse data, and timely and spatially varied hydrological data are utilized, accurate model against various types of flood including Typhoon Ondoy is established. Besides, H-Q equation is recalculated based on the detailed section data and discharges are estimated.

Flood Analysis Model

WEB-DHM Model is applied for runoff analysis since it can analyze hydrologic cycle among atmosphere, vegetation and soils with high accuracy reflecting the change of runoff pattern by changing of vegetation and landuse of a basin, and time and spatial variations of meteorology.

For river hydraulic model and inundation model, one-dimensional unsteady flow analysis model and two dimensional unsteady flow analysis model are applied, respectively, since effect of water level of Laguna Lake, effects of past and planned river improvement works, and effects of natural or artificial retarding basin can be properly reflected.

Verification of Model by Various Types of Floods

The river basin includes the center of Metro Manila in the downstream reach, and the river improvement works have been implemented to secure the safety against 1/30 years probable floods with assuming various types of floods. For examination of flood management measures against 1/100 years probable flood as the future target, various patterns of hyetographs such as high intensity with short period rainfall and long period rainfall including Typhoon Ondoy are utilized for calibration and verification of the model to improve the reproducibility of model.

Estimation of Discharge by New H-Q Equation

Observed water level and discharge date is required for calibration of model parameters. However, there is no recent observed discharge data. H-Q equations have been formulated by previous studies, however, accuracy of high water level is uncertain because there is no observed discharge data. Thus, H-Q equation is re-formulated by non-uniform flow calculation based on the river section data combining LiDAR data and latest survey data, and detailed parameters.

2) Reevaluation of Technical Validity of Proposed Structural Measures in Pasig-Marikina River Basin under the WB Study

Design discharges of PMRCIP based on the JICA Master Plan in 1990 and the WB Study are shown in Figure 7.1.

PMRCIP proposed diversion to Lower Marikina with 500m^3/s controlling by MCGS and shut down of NHCS during flood. On the other hand, the WB proposed that the diversion to Manggahan Floodway was controlled by Rosario Weir only without construction of MCGS, and natural diversion to Napindan Channel with NHCS open was expected.

Based on the analysis utilizing the established flood analysis model with referring the rainfall analysis results conducted by "the Study of Water Security Master Plan for Metro Manila and its Adjoining Areas" and the results of water level fluctuation analysis of Laguna Lake by this Study, technical validity of these proposals are reevaluated as follows.

Necessity of MCGS Diversion Function

The Study concludes that the proposed flood management measures by the Study including the MCGS function based on the JICA Master Plan is more effective than flood management measures without MCGS, in aspects of reliability, feasibility and step-wise improvement of flood safety. The features of flood management measures with MCGS are as follows.

<Reliability>

Various types of flood discharges can be securely diverted though Manggahan Flood way by the function of MCGS. As the results, Laguna Lake can be fully utilized as flood control facilities, and flood risk in lower reach can be reduced by controlling flood discharge to the downstream. This flood risk reduction in lower reach also works against excess floods or climate change impacts.

<Feasibility>

The flood management measures with MCGS function is more feasible since it does not reinvestment to the river sections where the river improvement works has been already implemented such as re-improvement of PMRCIP, reconstruction of existing bridges and re-improvement of Napindan Channel.

<Step-wise Improvement of Flood Safety>

With MCGS, the flood control works can be implemented separately by the upstream and downstream of MCGS since the discharge to downstream can be regulated by MCGS. Thus, improvement works can be implement in upstream sections with maintaining the safety against 1/30 years probable floods in the downstream of MCGS.

Besides, during the course of improvement of each section such as Lower Marikina and Upper-upper

Marikina, flood safety can be improved step-wise without temporary decrease of flood safety of the Basin.

Operation of NHCS

The water level fluctuation analysis in Laguna Lake reveals that the water level at the inlet of Manggahan Floodway (Rosario Weir) is always higher than Laguna Lake while there is no clear correlation between the water levels at the confluence of Napindan Channel and Pasig River (NHCS) and Laguna Lake. It is also founded that impact of inflow discharge from Pasig-Marikina River to water level fluctuation in Laguna Lake is small. Thus, it is concluded that NHCS shall be closed during floods to mitigate increase of flood risk in Pasig-Lower Marikina Basin by preventing discharge from Laguna Lake to Pasig River.

- By closing NHCS, discharge from Laguna Lake to Pasig River is blocked in case the water level of lake is higher than the river, resulting uncertainty of flood management is eliminated.
- In case of natural diversion from Pasig River to Laguna Lake is expected in the flood management plan by opening NHCS, uncertainty of the plan remains since diversion will not occur if the water level of lake is higher than the river. Besides, there are many issues in this option such as a possibility to increase of flood risk in Pasig-Lower Marikina Basin against excess floods, necessity of reinvestment in PMRCIP (Phase II) section, large scale dredging and re-improvement of Napindan Channel which requires large scale land acquisition.

Dredging of Pasig River

Under the alternative "Without MCGS and NHCS opening", design discharge in Pasig River becomes 1,800m^3/s which is about 1.5 times of the design discharge by PMRCIP of 1,200m^3/s. To flow this discharge large scale dredging is required to deepen the riverbed about 2 to 3 m below the design riverbed in the master plan. Tremendous amount of maintenance cost is also required to maintain the riverbed.

In this Study, design discharge with 1/100 years return period becomes 1,400m^3/s which is 200m^3/s increase than the previous plan. However, it is within the flow capacity of channel if the riverbed is dredged until the design riverbed level. And scale of dredging works is also small which can be treated as a river maintenance works.

3) Flood Management Measures for 1/30 and 1/100 Years Probable Floods

Review of hydrology with the latest data, 1/30 years probable flood discharge is estimated at 3,100m^3/s at Sto.Nino which is larger than the design discharge of PMRCIP at 2,900m^3/s. As alternatives for 1/30 years probable flood management, 2 alternatives are proposed as well as the PMRCIP plan (Alt-O: Phase IV only), one is enhancement of Manggahan Floodway (Alt-A: Phase IV + Manggahan Floodway) and the other is enhancement of retarding basin (Alt-B: Phase IV + Retarding Basin). And combining "dam" or "dam + retarding basin" options, 10 alternatives for 1/100 years probable flood management are also proposed with step-wise development scenarios from 1/30 probable flood management measures, consisting of 4 alternatives from Alt-A, 2 alternatives from Alt-O and 4 alternatives from Alt-B. (Refer to Figure 7.2) Economic feasibility is confirmed for all alternatives. By applying one of these alternatives, the flood management in Pasig-Marikina River can adapt to impacts of climate change with various options.

(2) Recommendations

Necessity of Further Studies

This Study is conducted using the various data and information from the previous studies. Thus, it is recommended to conduct further investigations, studies and designs such as follows.

- Optimal Location and Scale of Dam
- Scale and Capacity of Retarding Basin, Area of Natural Retarding Basin
- Design Flood Discharge in Phase IV Section and HWL
- Area of Channel Excavation of Manggahan Floodway

Restoration and Improvement of Manggahan Floodway

Manggahan Flood way was completed in 1988 with the design discharge of 2,400m^3/s. However, flow area has been reduced mainly due to houses in river course and sedimentation. To divert flood discharge to Manggahan Floodway by MCGS, restoration of its function is a precondition. Resettlement and dredging shall be implemented to restore the original capacity.

In case of the design discharge at Sto.Nino is 3,100m^3/s, flow capacity of Manggahan Floodway shall be increased to 2,600m^3/s with additional 200m^3/s. Considering excess floods and climate change impacts, capacity improvement of Manggahan Floodway is required. Enlargement of flow capacity of Manggahan Floodway by excavation is relatively easy since earth dyke is applied from Laguna Lake to 5km point.

Retention of Natural Retarding Function and Necessity of Detailed Investigation of Retarding Basin

The alternatives for 1/100 years probable flood management measures can be divided into “dam” options and “dam + retarding basin” options. Even if a “dam” option is selected, the current natural retarding function shall be maintained since the dam project needs long time. It is needed to fix the area of natural retarding basin and to regulate land use to maintain the natural retarding function.

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ABBREVIATION

Abbreviation	English
AOGCM	Atmosphere-Ocean General Circulation Model
AR4	Fourth Assessment Report
ARMM	Autonomous Region of Muslim Mindanao
AusAID	Australian Agency for International Development
B/C	Benefit/Cost Ratio
BOD	Bureau of Design
BRS	Bureau of Research and Standards
CAR	Cordillera Administrative Region
CPI	Consumer Price Index
CV	CIRUCULO VERDE
D/D	Detailed Design
DEM	Digital Elevation Model
DFL	Design Flood Level
DHWL	Datum High Water Level
DPWH	Department of Public Works and Highways
EFCOS	Effective Flood Control and Operation System
EIRR	Economic Internal Rate of Return
F/S	Feasibility Study
GBHM	Geomorphology-Based Hydrological Model
GCM	General Circulation Model
GNI	Gross National Income
H-Q	Water Level-Discharge
H-V	Water Level-Volume
HWL	Hight Water Level
IDW	Inverse Distance Weighted
IPCC	Intergovernmental Panel on Climate Change
JBIC	Japan Bank for International Cooperation
JICA	Japan International Cooperation Agency
L/A	Loan Agreement
LGU	Local Government Unit
LiDAR	Laser Imaging Detection and Ranging
LLDA	Laguna Lake Development Authority
LWL	Low Water Level

Abbreviation	English
MCGS	Marikina Control Gate Structure
MM	Man-month(s)
MMDA	Metro Manila Development Authority
MMHWL	Mean Monthly Highest Water Level
MP	Master Plan
MSL	Mean Sea Level
MTPDP	Medium Term Philippine Development Plan
MWSS	Metropolitan Manila Waterworks and Sewerage System
NAIA	Ninoy Aquino International Airport
NAMRIA	National Mapping and Resourece Information Authority
NCR	National Capital Region
NEDA	National Economic and Development Authority
NHCS	Napindan Hydraulic Contrpl Structure
NPC	National Power Corporation
NPV	Net Present Value
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
PD	Presidential Decree
PDFPFMM	Phisical Development Framework Plan for Metropolitan Manila
PDP	Philippine Development Plan
PMO-MFCP	Project Management Office - Major Flood Control Projects
PMRCIP	Pasig-Marikina River Channel Improvement Project
PPA	Philippine Ports Authority
PRBFFWC	Pampanga River Basin Flood Forecasting and Warning Center
RDC	Regional Development Council
RIDF	Rainfall Intensity-Duration Frequency
SAPROF	Special Assistance for Project Formation
SCS	Soil Conservation Service,United States
SiB2	Simple Biosphere Model 2
SPM	Summary for Policymarkers
SRES	Special Report on Emission Scenarios
SWL	Surcharge Water Level
UPLB	University of tha Philippines at Los Barios
WB	The World Bank
WEB-DHM	The Water And Energybudget-Based Distributed Hydrological Model
WL	Water Level

UNIT

(Length)
mm : millimeter(s)
cm : centimeter(s)
m : meter(s)
km : kilometer(s)

(Area)
mm2 : square millimeter(s)
cm2 : square centimeter(s)
m2 : square meter(s)
km2 : square kilometer(s)
ha : hectare(s)

(Weight)
g, gr : gram(s)
kg : kilogram(s)
ton : ton(s)

(Time)
s, sec : second(s)
min : minute(s)
h, hr : hour(s)
d, dy : day(s)
y, yr : year(s)

(Volume)
cm3 : cubic centimeter(s)
m3 : cubic meter(s)
l, ltr : liter(s)
mcm : million cubic meter(s)

(Speed/Velocity)
cm/s : centimeter per second
m/s : meter per second
km/h : kilometer per hour

LIST OF SOURCE

JICA 1990
The Study on flood control and drainage project in Metro Manila（1990）

JICA 2011
THE PREPARATORY STUDY FOR PASIG-MARIKINA RIVER CHANNEL IMPROVEMENT PROJECT (PHASE III) IN THE REPUBLIC OF THE PHILIPPINES (OCTOBER 2011)

JICA 2013
Study of Water Security Master Plan for Metro Manila and its Adjoining Areas（2013）

WB 2012
Master Plan for Flood Management in Metro Mani la and Surrounding Areas Final Draft Master Plan Report March 2012

CHAPTER 1 INTRODUCTION

1.1 Background and Objective of Study

1.1.1 Background

The Pasig-Marikina-San Juan River System, of which total catchment area is 621 km^2, runs through the center of Metro Manila and flows out to the Manila Bay. Its Main tributaries, the San Juan River and Napindan River, join the main stream at about 9.9 km and 19.9 km upstream from the Pasig River mouth, respectively. The three largest waterways contribute largely to the flooding in the metropolis brought about by the riverbank overflow of floodwaters. Metro Manila, which encompasses 16 cities and 1 municipality having a total projected population of over 11.5 million in 2010, is the economic, political and cultural center of the Philippines.

A Master Plan of flood control for the Pasig-Marikina River including the drainage in Metro Manila was prepared in 1954. In line with the flood control plan, the improvement works of the Pasig River, consisting mainly of river walls and revetments of the channel were constructed in the 1970's. The Manggahan Floodway having a design flow capacity of 2,400 m^3/s for diversion of flood from Marikina River to Laguna Lake was completed in 1988 to mitigate the flood damage due to the overflow of the lower Marikina River and Pasig River.

In addition to the Manggahan floodway, the necessity of river channel improvement of Pasig-Marikina River has been studied to cope with the existing flood problems in Metro Manila. The department of Public Works and Highways (DPWH) conducted an updated Master Plan (M/P) for flood control and drainage improvement in Metro Manila and a Feasibility Study (F/S) on the channel improvement of the Pasig-Marikina River from January 1988 to March 1990, under a technical assistance from the Japan International Cooperation Agency (JICA), called "The Study on Flood Control and Drainage Project in Metro Manila (JICA M/P Study)."

Based on the updating/review of the F/S for the river channel improvement project through the Special Assistance for Project Formulation (SAPROF) of Overseas Economic Cooperation Fund (OECF) in 1998, the "Pasig-Marikina River Channel Improvement Project (PMRCIP)" was proposed for the implementation in the following four phases under the financial assistance of Japanese ODA. The Preparatory Study for Pasig-Marikina River Channel Improvement Project (Phase II)" was also conducted in 2010-2011 under JICA technical cooperation, and the implementation of Phase II and III of PMRCIP is currently on-going funded by JICA.

On the other hand, the World Bank conducted the study "Master Plan for Flood Management in Metro Manila and Surrounding Areas" ("WB Study") under the objective to establish the vision, which will be the blue print or road map, for a sustainable and effective flood risk management in Metro Manila and surrounding areas until 2035. The specific objectives are as follows;

- To carry out a flood risk assessment study from Metro Manila and surrounding areas
- To prepare a comprehensive flood risk management plan; and
- To propose a set of priority structural and non-structural measures that will provide sustainable flood risk management up to a certain safety level

The WB Study has shown the results; 1) Review of current situation and arrangement of flood risk management, 2) Study on the mechanism of floods and flood damage, 3) Identification of constraints and barriers for flood risk management and directions for improvement, and 4) Formulation of the macro-framework for integrated flood risk management plan.

Based on the results of the WB Study and JICA M/P Study, JICA conducts "Data Collection Survey on Flood Management Plan in Metro Manila" to further examine with the detailed flood control measures in Pasig-Marikina River Basin.

JICA shall utilize effectively the related data and model established in the related studies such as:

- Cross-section data of the Pasig-Marikina River in the Detailed Design of the Pasig-Marikina River Channel Improvement Project (Phase III),
- Water and Energy Budge-based Distribution Hydrological Model (WEB-DHM) and results of

rainfall analysis obtained in “the Study of Water Security Master Plan for Metro Manila and its Adjoining Areas” (hereinafter referred to as the “JICA Water Security Study”)

1.1.2 Objective

The objective is to reexamine the technical validity of the proposed structural measures in Pasig-Marikina River Basin under the WB Study by utilizing the hydrological and hydrodynamic flood simulation model which is to be refined and updated with appropriately selected dataset in consideration of the future climate change; thereby bridging the concept planning and the actual implementation of projects.

1.2 Study Framework

1.2.1 Study Area

Study area is to Pasig-Marikina River Basin and Laguna Lake Basin in Metro Manila.

1.2.2 Summary of Study Purposes, Outputs and Activities

Project activities and purposes are summarized as follows.

<Overall Goal>

Basic data and information for practical flood management plan is prepared by reviewing previous study results such as design flood discharge prepared by WB considering future climate change.

<Project Purpose>

Technical validity of the proposed structural measures under WB Study is reexamined by utilizing the hydrological and hydrodynamic flood simulation model which is to be refined and updated with appropriately selected dataset in consideration of the future climate change.

<Outputs>

1. Climate change effect is analyzed.
2. Different rainfall patterns from Ondoy Typhoon are analyzed.
3. Discharge distribution plan is reviewed.
4. Future practical countermeasures are planned considering current level of river improvement in Pasig River.

Activities

1) Collection and Utilization of Previous Study Results
    - Runoff Characteristics of Pasig-Marikina River and Laguna Lake Basins
    - Hydrological Data, Data related River Course and Inundation

2) Establishment of Flood Analysis Model
    - Integration of Runoff Analysis Model, River Course Hydraulic Model and Inundation Model

3) Analysis of Design High-water Discharge
    - Examination of Previous Rainfall Analysis
    - Setting of Basic Flood Discharge
    - Examination of Planning Conditions and Parameters in Previous Studies

- Setting of Design Flood Discharge
- Examination of Validities of Flood Control Facilities (Cost & Benefit Analysis)

4) Analysis of Water Level Fluctuation in Laguna Lake during Flood in Pasig-Marikina River
   - Validity of Flood Management Measures considering Effect to Laguna Lake

5) Analysis of Climate Change Effects
   - Runoff Analysis considering Climate Change Effect
   - Examination of Climate Change Effect such as Change of Safety Degree
   - Proposal of Adaptation Measures against Climate Change

6) Information Sharing with Other Developing Partners

7) Assistance of Steering Committee

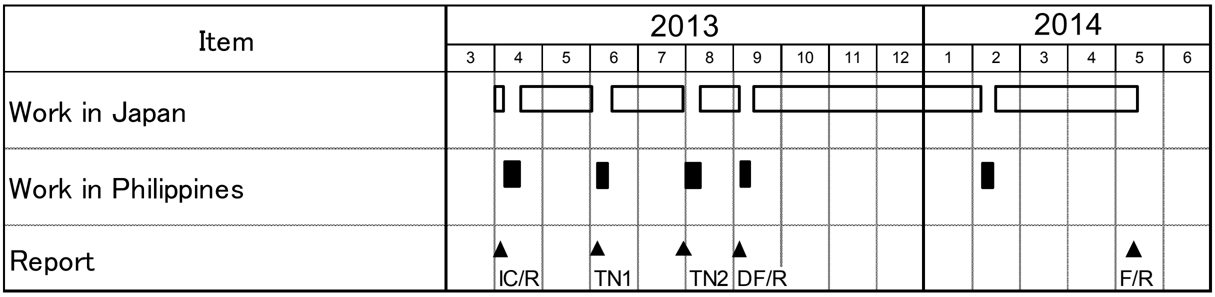
1.2.3 Counterpart Agency by Philippines Side

The counterpart agency is Department of Public Works and Highway (DPWH) of the Republic of Philippine.

1.3 Schedule of Study

The Study has been conducted from April 2013 to May 2014 as shown in Table 1.1.

Table 1.1 Schedule of Study



IC/R: Inception Report, TN1: Technical Note-1, TN2: Technical Note-2, DF/R: Draft Final Report, F/R: Final Report

Summary of the works of each work period are as follows.

[Preparatory Works in Japan (Beginning of April, 2013)]

- Analysis of Existing Reports and Documents, Study Planning, Preparation of Inception Report

[1st Work in Philippine (April 3 to 13, 2013)]

- Inception Report Meeting, Meeting with the WB
- Site Reconnaissance:
  Pasig-Marikina River, Manggahan Floodway, Napindan Channel, Laguna Lake, San Juan River
- Data and Information Collection

[1st Work in Japan (Middle of April to End of May, 2013)]

- Analysis of Collected Data and Information
- Establishment of Flood Analysis Model:
  - Preparation of River Cross Section Data and DEM
  - Analysis and Calculation of H-Q Equation

- Estimation of Peak Discharge of Typhoon Ondoy
- Selection of Past Floods
- Calibration of Parameters and Verification of Model

- Establishment of Water Level Fluctuation Model in Laguna Lake:
  - Verification of Data Availability
  - Analysis of Water Level Fluctuation Properties
  - Examination of Concepts of Model Establishment and Conditions
- Preparation of Technical Note-1

[2nd Work in Philippine (June 3 to 11, 2013)]

- Meeting on Technical Note-1:
  PMO, FCSEC, BOD, BRS, MMDA
- Site Reconnaissance:
  Upper-upper Marikina River, Expected Dam Sites, Manggahan Floodway
- Data and Information Collection

[2nd Work in Japan (Middle of June to End of July, 2013)]

- Analysis of Collected Data and Information
- Review of Rainfall Analysis and Setting of Design Rainfall
- Estimation of Basic Design Discharge
- Estimation of Design Flood Discharge and Proposal of Flood Management Measures:
  - Review of Preconditions (Current Flow Capacity, Plan of PMRCIP, Proposed Plan by the WB, Existing Structures)
  - Estimation of Design Flood Discharge (Evaluation of Design Flood Discharge of PMRCIP, Operation of NHCS, Necessity of MCGS)
  - Examination of Flood Management Measures against 1/30 and 1/100 Years Probable Floods
  - Preliminary Examination of Dam and Retarding Basin
  - Preparation of Technical Note-2
- Establishment of Water Level Fluctuation Model in Laguna Lake:
  - Establishment of Model and Analysis of Water Level Fluctuation
  - Flow Analysis in Napindan Channel during Flood
  - Analysis of Impact of Flood Management Measures to Water Level of Laguna Lake
  - Analysis of Impact of Climate Change to Water Level of Laguna Lake
- Preparation of Technical Note-2

[3rd Work in Philippine (July 31 to August 11, 2013)]

- Meeting on Technical Note-2:
  PMO, BOD, BRS, MMDA
- Meeting with the Secretary of DPWH
- Data and Information Collection

[3rd Work in Japan (Middle of August to Beginning of September, 2013)]

- Analysis of Collected Data and Information
- Establishment of Phased Development Scenarios
- Cost Estimate and Economic Evaluation
- Analysis of Water Level Fluctuation in Laguna Lake:
  - Examination Validity of Flood Management Measures
- Analysis of Impact of Climate Change to Flood Management of Pasig-Marikina River

- Preparation of Draft Final Report

[4th Work in Philippine (September 5 to 12, 2013)]

- Meeting on Draft Final Report
- Technical Working Group Meeting
- Meeting with the Secretary of DPWH
- Meeting with WB

[4th Work in Japan (Middle of September, 2013 to Beginning of February, 2014)]

- Preparation of Additional Explanation for Comments on Draft Final Report
- Preparation of Meeting Materials

[5th Work in Philippine (February 10 to 14, 2014)]

- Meeting on Results of Study and Direction of Improvement
- Technical Working Group Meeting
- Meeting with the Secretary of DPWH
- Meeting with WB

[5th Work in Japan (Middle of February to End of May, 2014)]

- Preparation of Final Report

CHAPTER 2 CONDITIONS OF BASIN

2.1 Natural Conditions of Basin

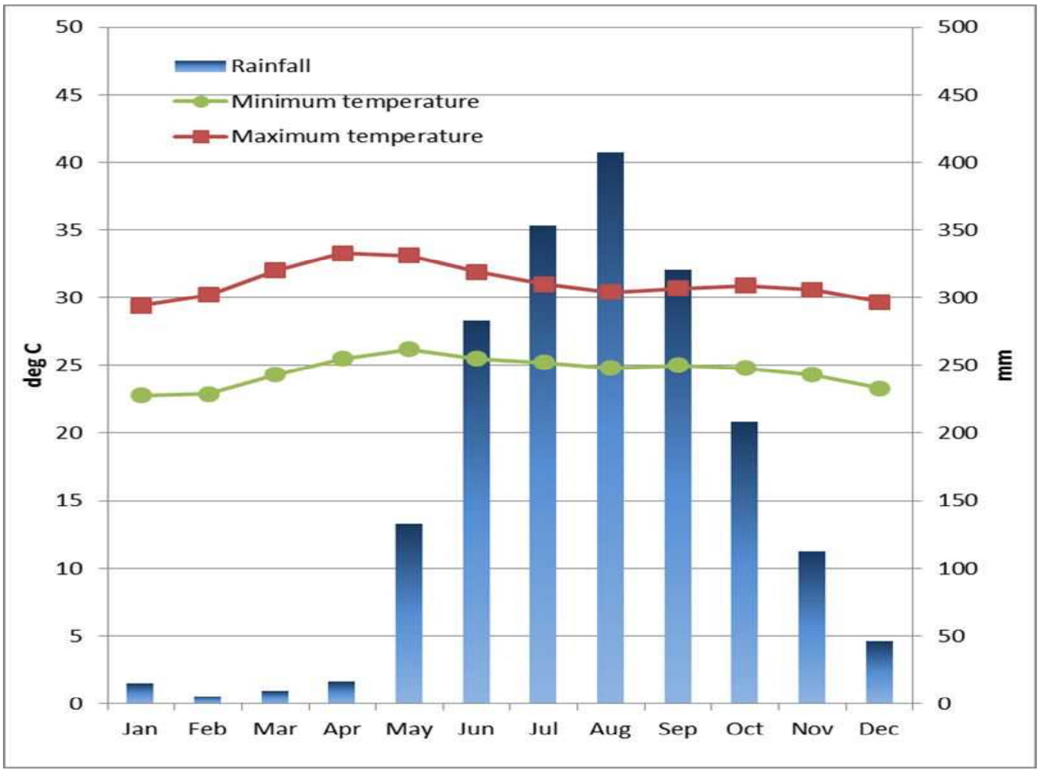
2.1.1 Topography and Geology

Luzon Island is topographically divided into three areas, namely North Luzon, Central Luzon and South East Luzon. Central Luzon including the Study area is structural geologically divided into Zambales Range in west, Central Valley in center and southern slope of Sierra Madre Mountains. Sierra Madre Mountains where upstream area of the basin is included consists of Cretaceous to Tertiary Periods soils such as limestone, tuff and several magmatic rocks.

Between Sierra Madre Mountains and Manila Delta is Marikina Valley consisting alluvial deposits such as sand gravel silt and clay. Depth of alluvial deposit varies randomly such as 120m at North Montalban, 15m at Marikina, and 40m at Pasig. Manila Delta is flat and consists of alluvial soil. Depth of alluvial deposits is more than 70m near the coast but relatively thin at Santa Messa, Makati and east Marikina areas.

2.1.2 Climate

Climate of Philippines are governed by monsoon, trade wind, tropical depression and their combinations. Typhoon has the most effect on flood. 20 to 30 typhoons pass on or near Philippines annually, and 20% of them pass on Central Luzon. Figure 2.1 shows average monthly rainfall and temperatures. Season is divided into two, rainy season from May to October and dry season from November to April.



Source: JICA Study Team

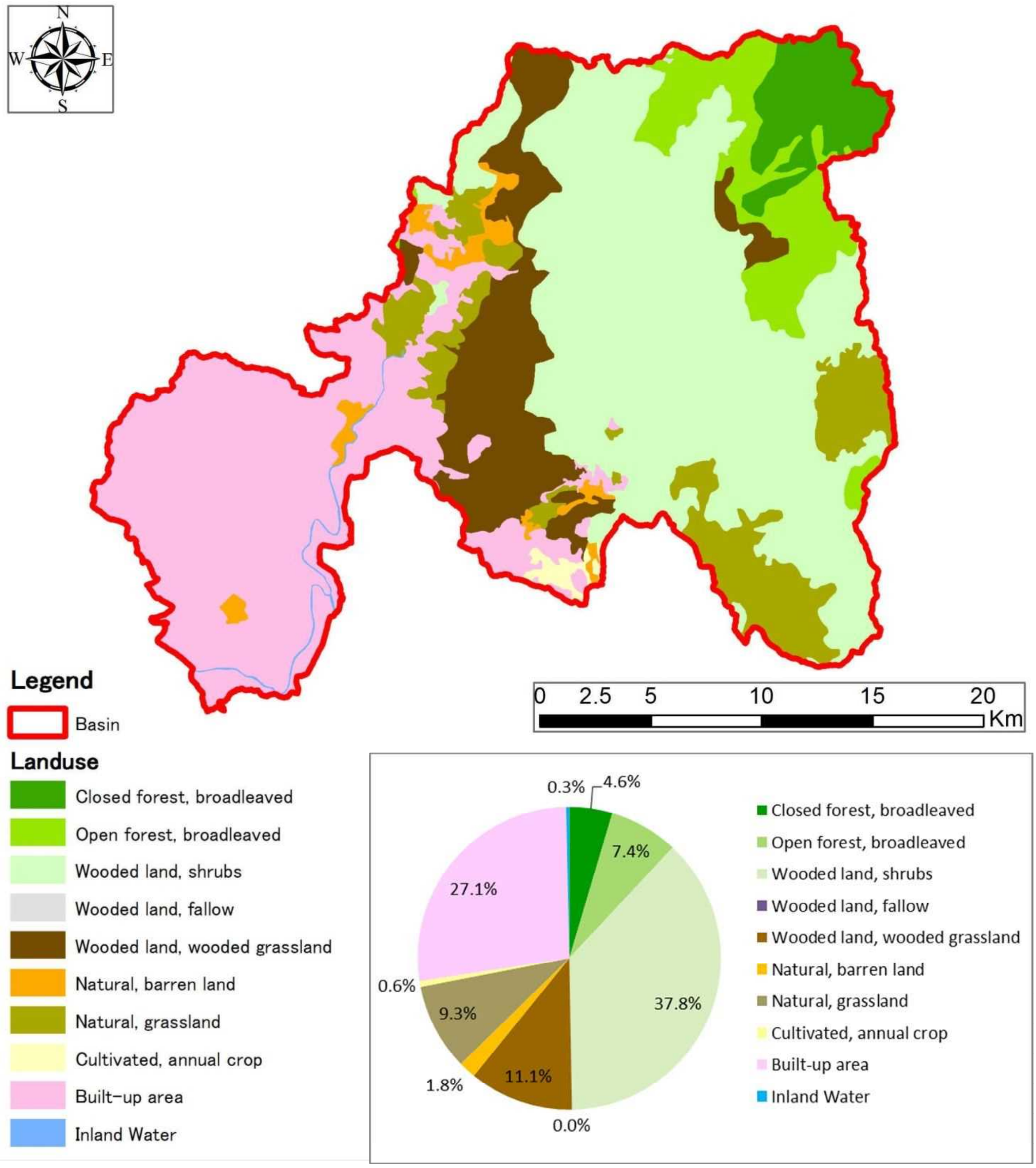
Figure 2.1 Average Monthly Rainfall, Average Minimum and Maximum Temperatures in Metro Manila

Rainfall is concentrated in rainy season from May to October when about 90% of annual rainfall comes down mainly induced by monsoon and typhoon.

Maximum temperature rises up to 33^{o}C in April-May when transition period from dry season to rainy season, and declines to less than 30^{o}C in December-January, however, seasonal variation is very small.

2.1.3 Land Use Conditions

Land use conditions is summarized based on the land use map by NAMRIA in 2005 as shown in Figure 2.3. Forest and woodland occupies about 61% which dominant in upstream basin while built-up area is 27% mainly in Metro Manila.



Source: JICA Study Team

Figure 2.2 Land Use of Pasig-Marikina River Basin (as of 2005)

2.1.4 Social Economy Conditions

(1) Outline of Relevant Governance Zones

Pasig-Marikina River is an urban river with a catchment area of 635 km^2, which runs from Rodriguez City in Rizal Province through the administrative and economical epicenter in National Capital Region (NCR) and finally flows into Manila Bay. The Pasig-Marikina River connects with Laguna Lake by way of the Napindan Channel and Mangahan Floodway.

The study area is the water area of 11 cities and municipalities in NCR and Rizal Province shown in Table 2.2. These cities and municipalities have made a rapid economic and population growth.

Table 2.1 Area of Relevant Governance Zones

Division	Governance Zone	Jurisdictional Area (km^2)
NCR	Makani City	21.57
	Mandaluyong City	9.29
	Manila City	24.98
	Marikina City	21.52
	Pasig City	48.46
	Quezon City	171.71
	San Juan City	5.95
	Pateros Municipality	10.40
	Taguig City	45.21
Rizal Province	Cainta Municipality	42.99
	Taytay Municipality	38.80
Total		440.88

Source：2010 Census of Population and Housing Report No.3 Population, Land Area, and Density

(2) Population and Population Density in Relevant Governance Zones

There is difference in zones like that the population in Manila City and San Fuan City have increased or decreased slightly, but that in the remaining cities/municipalities has increased steeply.

The study area has made a rapid population growth and this tendency seems to be continued in future. In 2010, Taguig City, Cainta City and Taytay City increased their population more than 100 percent compared with 1990.

From population density, that in Manila City is more than 66,000 people/km^2 and that in the others come within the range between 6,000 people/km2 and 35,000 people/km^2, even though these figures are equal to or higher than that in Tokyo with 6,000 people/km2 as of October 2013 in first place of Japan.

Table 2.2 Population of Relevant Governance Zones

Division	Governance Zone	Population (people) and Population Density (people/km^2)*		
		1990	2000	2010
NCR	Makani City	453,170 (21,009)	471,379 (21,853)	529,039 (24,527)
	Mandaluyong City	248,143 (26,711)	278,474 (29,976)	328,699 (35,382)
	Manila City	1,601,234 (64,101)	1,581,082 (63,294)	1,652,171 (66,140)
	Marikina City	310,227 (14,416)	391,170 (18,177)	424,150 (19,710)
	Pasig City	397,679 (8,206)	505,058 (10,422)	669,773 (13,821)
	Quezon City	1,669,776 (9,724)	2,173,831 (14,463)	2,761,720 (16,903)

	San Juan City	126,854 (21,320)	117,680 (19,778)	121,430 (20,408)
	Pateros Municipality	51,409 (4,943)	57,407 (5,520)	64,147 (6,168)
	Taguig City	266,637 (5,898)	467,375 (10,338)	644,473 (14,255)
Rizal Province	Cainta Municipality	126,839 (2,950)	242,511 (5,641)	311,845 (7,254)
	Taytay Municipality	112,403 (2,897)	198,183 (5,108)	288,956 (7,447)
Total		5,364,371	6,484,150	7,796,404

Note; The upper row : population, the lower row : population density
Source：2010 Census of Population and Housing Report No.3 Population, Land Area, and Density

(3) Economic-related Matters

The Philippine's economic growth rate was sluggish temporarily but it achieved 7 percent in 2012. And GNI per capita in 2012 reached US$ 4,380, this increased 20 % of that in 2008 as US$ 3,640. (refer to Table 2.4) However, Haiyan Typhoon killed thousands of people and destroyed a lot of residential houses and infrastructures of some islands in Central Visayas and Palawan Province on Nov. 8, 2013. Thus, the Philippines has frequently been damaged by natural disasters such as Typhoons.

NCR takes on the responsibility of acting the capital of Philippine centering on Manila City, and the Pasig-Marikina River runs through this zone as previously mentioned.

NCR came into being with 8 cities and 9 municipalities that were integrated from 4 cities (Manila City and Quezon City etc.) and 13 municipalities (Makati Municipality, Marikina Municipality and Muntinlupa Municipalty etc.) following Presidential Decree No. 824 in 1975.

As shown in Table 2.5, most of this zone was covered by agricultural and forest land in 1938, and residential, commercial and industrial area account for more than 70 percent of it in 1990 as a result of rapid urbanization in and after 1980.

Table 2.3 Basic Economic Indicator of Philippines

Item	2008	2009	2010	2011	2012
GNI per capita, PPP (US$)	3,640	3,650	3,920	4,070	4,380
Population (thousand person)	90,371	91,886	93,444	95,053	96,707
GDP (million US$)	173,603	168,334	199,589	224,095	250,182
GDP growth (annual %)	4	1	8	4	7

Source：The World Bank World Data Bank

Table 2.4 Changes in Urbanization of NCR (1938 – 1994)

Item	Proportion (%)			
	1938	1980	1990	1994
Residential	14.2	29.4	65.0	65.0
Commercial	-	3.0	3.4	8.0
Industrial	-	4.7	4.0	3.0
Institutional	-	4.5	5.2	10.6
Utilities	-	1.4	4.0	4.0
Agricultural	55.6	12.5	8.4	4.4
Open Space	5.1	24.3	8.0	4.0
Forest Land/Parks	25.1	20.2	2.0	1.0
Total	100.0	100.0	100.0	100.0

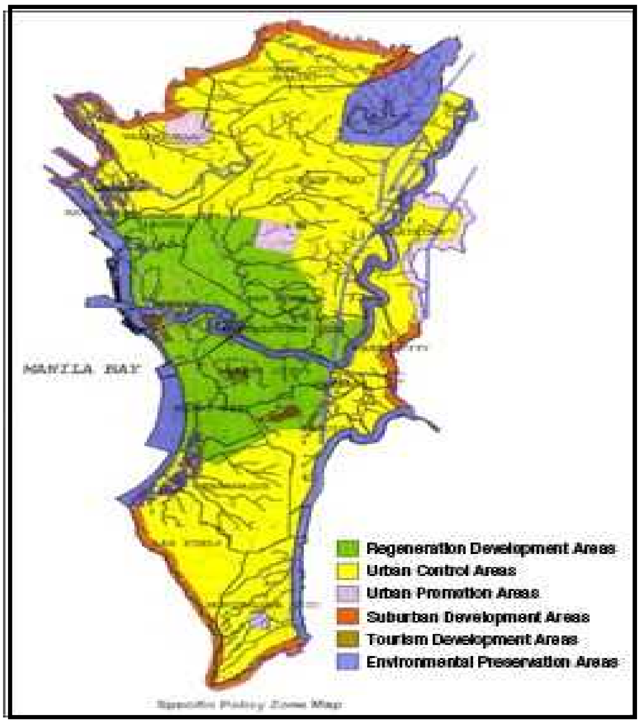
Source：Philippine Institute for Development Studies, DISCUSSION PAPER SERIES NO. 2000-20

1) Development Plan

A Medium-Term Philippine Development Plan (MTPDP) remains in force for six years, corresponding to the term of office of the country's president (however, the recent plan is a five-year plan, "Philippine Development Plan 2011 – 2016" (PDP), starting from the second year of the presidency). MTPDP is summarized as follows;

- MTPDP includes major policy initiatives, socioeconomic strategies, and major national programs.
- Meanwhile, regional development plans stipulate strategies, programs and projects that facilitate the goals of the national plans.
- The National Economic and Development Authority (NEDA), which charged with drafting the MTPDPs, coordinates with related agencies in formulating the plan. The final product is subject to the approval by a NEDA committee made up of government cabinet members (the "Cabinet Committee") and chaired by the president.
- Regional Development Council (RDC) organized in each region (except for NCR, Autonomous Region in Muslim Mindanao (ARMM)) is the counterparts of NEDA regional office established in each region that decides how plans should be implemented at the regional and municipal levels.
- Each RDC is made up of regional/municipal representatives, representatives from government departments in the region, and members of the private sector.

NCR is the only urban area in the country of which its geographical area and administrative power is legally defined (by 1995 Act for creating Metro Manila Development Authority). After Metropolitan Manila Authority (MMDA), the government agency, came into being in 1995, the first special planning document it issued was the "Physical Development Framework Plan for Metropolitan Manila, 1996 – 2016" (PDFPFMM). The plan was amended in 1999 and is maintained until now, but at the moment in February 2012, to replace it, formulation of a plan called "Metro Manila Green Print 2030" is under preparation. As a plan corresponding to Regional Development Plans of other regions, Regional Development Plan for the National Capital Region 2010 – 2016 (RDP – NCR) was established.



Source : Metro Manila Development Authority (1999) "A Physical Development Framework Plan for Metropolitan Manila, 1996 – 2016"

2) Industrial Cluster Strategy

The Philippine Development Plan 2011 – 2016 (PDP) sets out "Industrial Cluster Strategy" to promote creation of industrial clusters (geographical accumulation of specific industry) reflecting industrial activity and infrastructural character of respective domestic area which will contribute to the creation of regional wealth through export.

In this strategy, through developing industrial clusters, the government intends to promote fostering of inter-business cooperation between small and medium tiny companies to strengthen network toward collaboration, and this is based on the understanding that the past development policy had lead the country to "fall into the path of a trickle-down theory jobless growth" (Trickle-down theory is an economic thought that expresses vitalization of economic activities of large enterprises and wealthy class will make a stream of wealth pouring down onto low-income class that will finally bring benefit to the whole nation.)

The priority industrial cluster for NCR are Health and Wellness as shown in Table below.

Table 2.5 Priority Industrial Clusters (2011 – 2016)

Region	Area	Industrial Cluster
North Luzon	CAR (Cordillera Administrative Region)	Coffee
	R1 (Ilocos)	Milkfish
	R2 (Cagayan Valley)	Dairy and Dairy Products
	R3 (Central Luzon)	Bamboo and Logistics
South Luzon	R4A (Calabarzon)	ICT and IT-enabled Services and Logistics
	R4B (Mimaropa)	Eco-Tourism
	R5 (Bicol)	Wearable and Lifestyle
	NCR (National Capital Region)	***Health and Wellness***
Visayas	R6 (Western Visayas)	Gifts, Toys and Housewares, Health and Wellness, Food, ICT, Eco-Tourism
	R7 (Central Visayas)	Gifts, Toys and Housewares, Health and Wellness, Food, ICT, Eco-Tourism
	R8 (Eastern Visayas)	Gifts, Toys and Housewares, Food, Eco-Tourism
Mindanao	All	Banana, Mango, Seaweed, Wood, Coconut, Mining, Eco-Tourism, ICT

Source：National Economic Development Agency (2011) "Philippine Development Plan 2011 – 2016"

2.2 River Conditions

Pasig-Marikina River runs through Metro Manila into Manila Bay. Catchment area is about 635km^2 and 20% of it is within Metro Manila.

2.2.1 Pasig River

Pasig River has a length of 17.1km from river mouth to Napindan Hydraulic Control Structure (NHCS), with average riverbed slope of 1/10,000, river widths of 60m – 250m and depths of 6m – 12m. San Juan River is the major tributary which flows into Pasig River at 7.1km from the river mouth. Most of cross section is single section with revetment and parapet. From the river mouth to Delpan Bridge located at 700m from the river mouth, both river banks are utilized as wharf of Manila Bay operated by Philippine Port Authority (PPA).

Pasig River has an important role of regional economy as river transportation in whole section, especially in the section from Delpan Bridge to Jones Bridge there are many berths for factories at both sides. DPWH has conducted dredging work from the river mouth to Jones Bridge for river transportation.

2.2.2 Marikina River

Marikina River can be divided into three sections, namely lower Marikina from NHCS to the diversion to Manggahan Floodway with length of 7.2km, upper Marikina from Manggahan to Sto. Nino with length of 6.1km, and upper-upper Marikina from Sto. Nino to Montalban Bridge with length of 14.4km.

In the lower Marikina River, riverbed slope is less than 1/5,000, river widths are 90m – 100m, and depths are 4.2m – 9.5m. Cross section is single section with natural dyke, and foot paths are installed at middle section of the lower Marikina River. Bank protection works is merely conducted and the river area is covered by bush. There are many small houses and factories along the river.

In the upper Marikina River, riverbed slope is about 1/5,000 and river widths are 70m – 200m. Cross section is single section with natural dyke, and foot paths and parks are developed. As well as the lower Marikina River, bank protection works is merely conducted and the river area is covered by bush. There are many small houses along the river, but factory is few.

In the upper-upper Marikina River, riverbed slope becomes steeper about 1/1,450 and river widths are 70m – 350m. Cross section is composite section consisting of low flow channel and natural retarding basin. In the most section between Sto. Nino to the confluence of Nangka River, there are houses along river course while it is sparse between the upstream of confluence of Nangka River to Montalban Bridge.

2.3 Major Flood Disasters

Metro Manila suffers from flood disasters mainly during May to November due to typhoon and southwest monsoon. Major floods and their disasters in recent years are summarized in Table 2.1 and 2.2.

Table 2.6 Major Floods in Recent Years

Year	Month	Storm	Sto.Nino Peek WL (m)	Average-Rainfall over watershed (mm/1day)
2000	11	Seniang	18.01	149.0
2003	5	Chedeng	17.76	189.4
2004	11	Winnie	19.08	190.2
2009	9	Ondoy	22.16	290.8
2012	8	Kirogi	20.42	271.7

Source: JICA Study Team

Table 2.7 Major Flood Disasters in Recent Years

Year	Month	Storm	No. of Affected		Casualties			Total Damage (mil. Peso)
			Family	Persons	Dead	Injured	Missing	
2000	11	Seniang	14,818	77,899	3	N.A.	N.A.	N.A.
2003	5	Chedeng	2,227	11,144	0	0	0	N.A.
2004	11	Winnie	5,873	27,284	1	0	0	N.A.
2009	9	Ondoy	174,408	872,097	241	394	0	290
2012	8	Kirogi	90,121	419,555	41	4	2	410

N.A. : not available, Source: JICA Study Team

CHAPTER 3 ESTABLISHMENT OF FLOOD ANALYSIS MODEL

3.1 Establishment of Flood Analysis Model

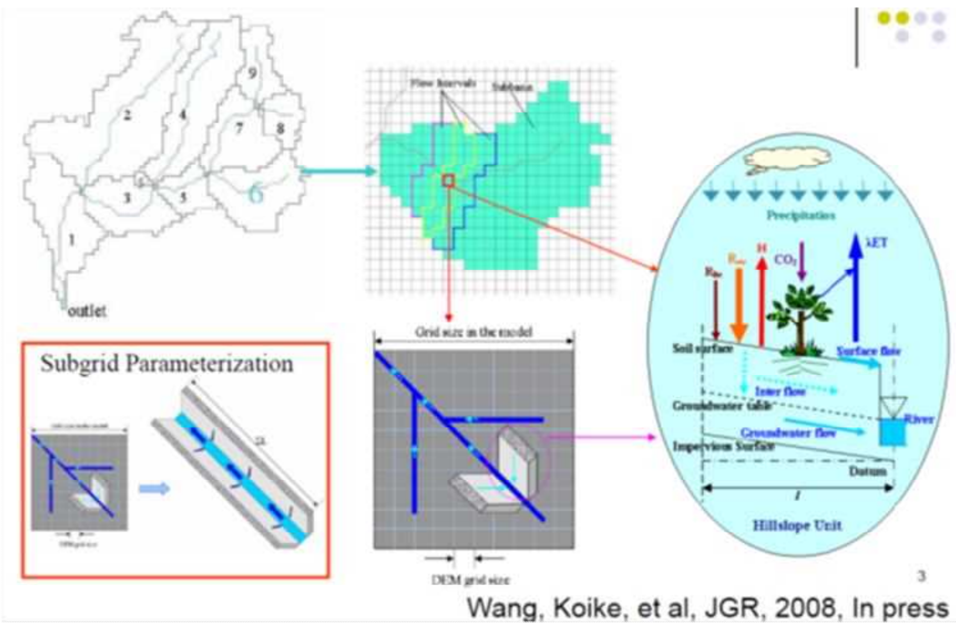
Flood analysis model was established integrating runoff analysis model (WEB-DHM Model), river hydraulic model (one dimensional unsteady flow model) and inundation analysis model (two dimensional unsteady flow model).

3.1.1 Runoff Analysis Model (WEB-DHM)

Runoff model was established based on data related to runoff characteristics such of area of basin, elevation, slope, landuse, vegetation, soil and so on. For establishing model, "Water and Energy Budget-based Distributed Hydrological Model" (WEB-DHM) which was established in in the Study of Water Security Master Plan for Metro Manila and its Adjoining Areas (hereinafter referred to as "JICA Water Security Study") was utilized.

Distributed type runoff analysis model can describe spatial variations of basin such as topography, dynamic behavior of rainwater, soil characteristics, spatial variation of rainfall and so on. WEB-DHM has been developed by fully coupling of a biosphere scheme (SiB2) with a distributed type runoff model named geomorphology-based hydrological model (GBHM). The SiB2 described the transfer of turbulent fluxes such as energy, water and carbon fluxes between the atmosphere and land surface for each model grid. The GBHM redistributes water moisture laterally trough simulation of both surface and subsurface runoff using grid-hill slope discretization and then flow routing in the river network.

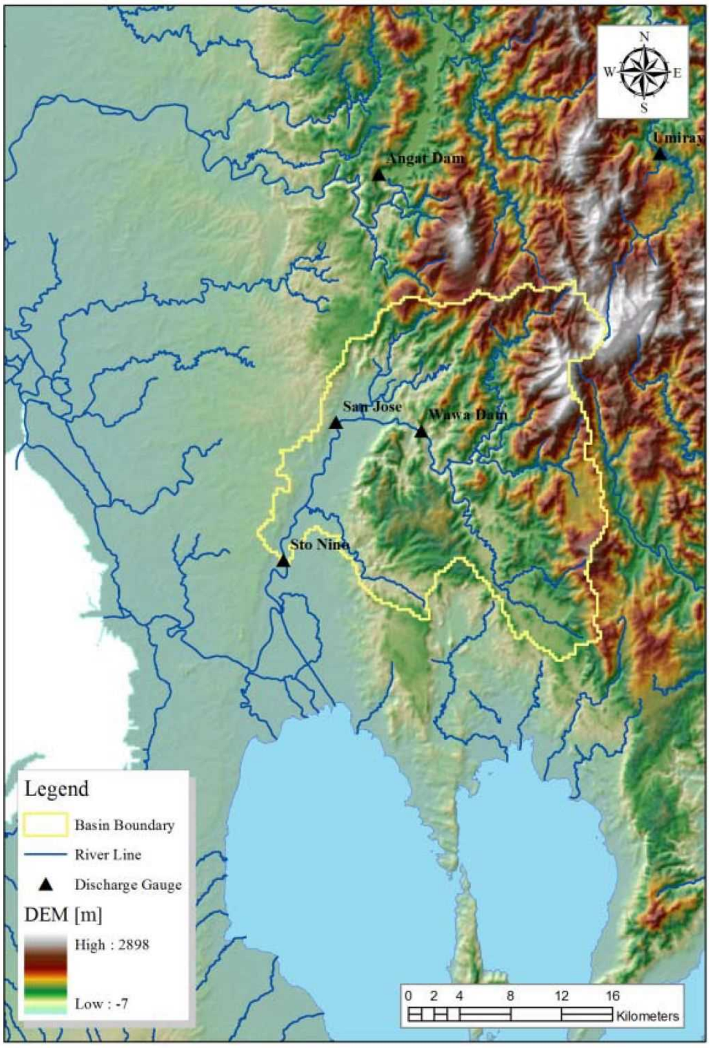
Outline of the model, area and basin segmentation for the modeling are shown in Figure 3.1 to 3.3.



Necessary Data
Soil Class
Vegetation
Leaf Area Index and Photosynthetically Active Radiation Absorption Factor
Relative Humidity
Insolation Time
Temperature
Wind Velocity
Air Pressure
Hourly Rainfall in Basin Division

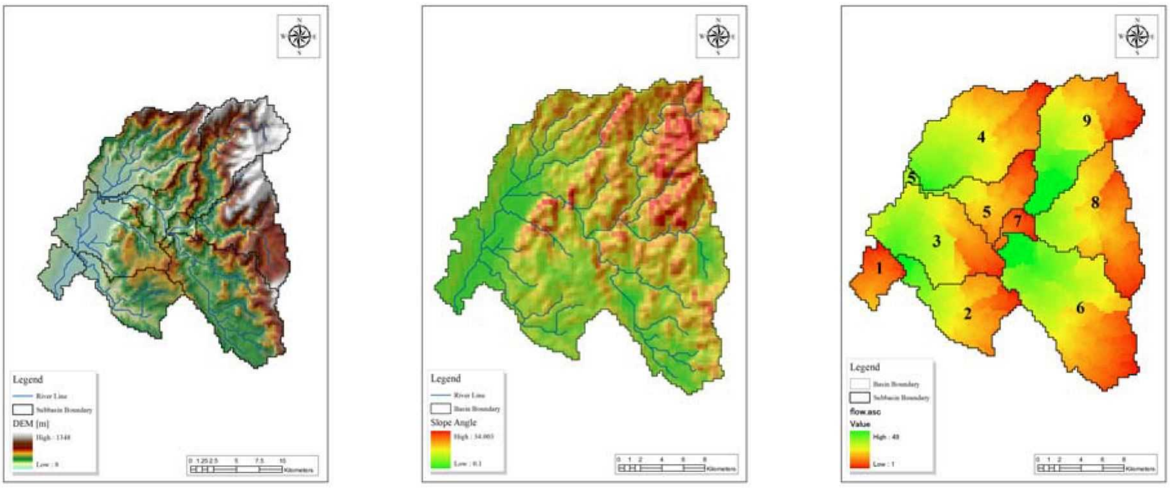
Source: WEB-DHM and IWRM, The 4th GEOSS AWCI ICG Meeting, Kyoto, 6-7 February 2009

Figure 3.1 Outline of WEB-DHM Model



Source: Study of Water Security Master Plan for Metro Manila and its Adjoining Areas

Figure 3.2 Area for Modeling



a. Digital Elevation Model b. Slope Angle c. Sub-Basins

Source: Study of Water Security Master Plan for Metro Manila and its Adjoining Areas

Figure 3.3 Basin Segmentation for Modeling

3.1.2 Inundation Model

(1) Model in Previous Study

The following items were examined for the river hydraulic model and inundation analysis model which established in the Preparatory Survey on Pasig-Marikina River Channel Improvement Project (Phase III).

- River Hydraulic Model (One-dimensional Non-uniform Flow Model):
  River Course Characteristic Data (River Networks, Cross Sections and Their Intervals, Hydraulic Constants, Downstream Boundary Conditions, Water Levels in Manila Bay and Laguna Lake)
- Inundation Analysis Model (Two-dimensional Unsteady Flow Analysis Model):
  Simulated Inundation Area, Landuse, Vegetation, Soil and so on.

Table 3.1 Provisions for Simulation in Previous Study

Item	Description
Method	River Course: One-dimensional Unsteady Flow Model River Basin: Two-dimensional Unsteady Flow Analysis Model
River Conditions	Current and After Improvement (Phase III)
Roughness Coefficient in Land	0.050 (Standard Value)
Mesh Size	100m×100m
Overflow Discharge when Dike Break	Overflow discharge is estimated by Honma' Formula
Boundary Conditions	Manila Bay: Mod; Curve (Max. MMHWL 11.4 E.L.m) Laguna Lake: 12.2E.L.m (Average W.L duirng Flood) (Refer to D/D Report in 2002)
Inflow Discharge	Estimated Hydrograph of Typhoon Ondoy

Source: Preparatory Survey on Pasig-Marikina River Channel Improvement Project (Phase III) (JICA)

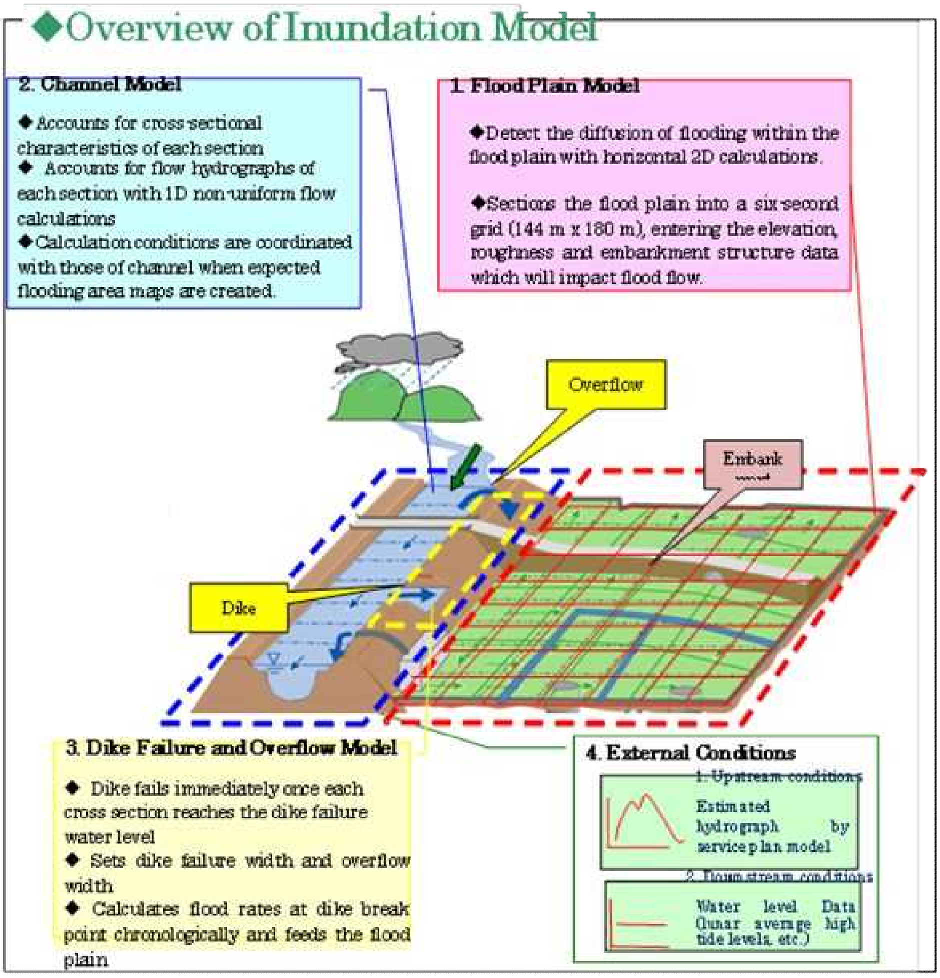
(2) Inundation Model

Flood analysis model is to combine above mentioned runoff model with river hydraulic model utilizing one-dimensional unsteady flow analysis model and inundation model utilizing two-dimensional unsteady flow analysis model.

Features of inundation model utilizing two-dimensional unsteady flow analysis model and image of model are shown in Figure 3.4.

＜Features of Model＞

- Compound Inundation Phenomena of Inland Water Inundation and Flood can be reproduced.
- In flood plains, runoff phenomena and inundation phenomena can be analyzed as phenomena happened simultaneously at same place.
- Chronological change of river water level can be reproduced considering change of water level at downstream boundary and runoff discharge from upstream, and effects of river crossing facilities such as bridge.
- Flow resistance due to landuse and density of building can be considered in the simulation of expanding of inundation areas and its velocities.
- Effects of channels, embankment and micro-topography can be reproduced in high accuracy.
- Effects of drainage by sluice way or pump with various conditions of inland and river water levels can be reproduced.
- Flood control function by storage facilities can be reproduced.

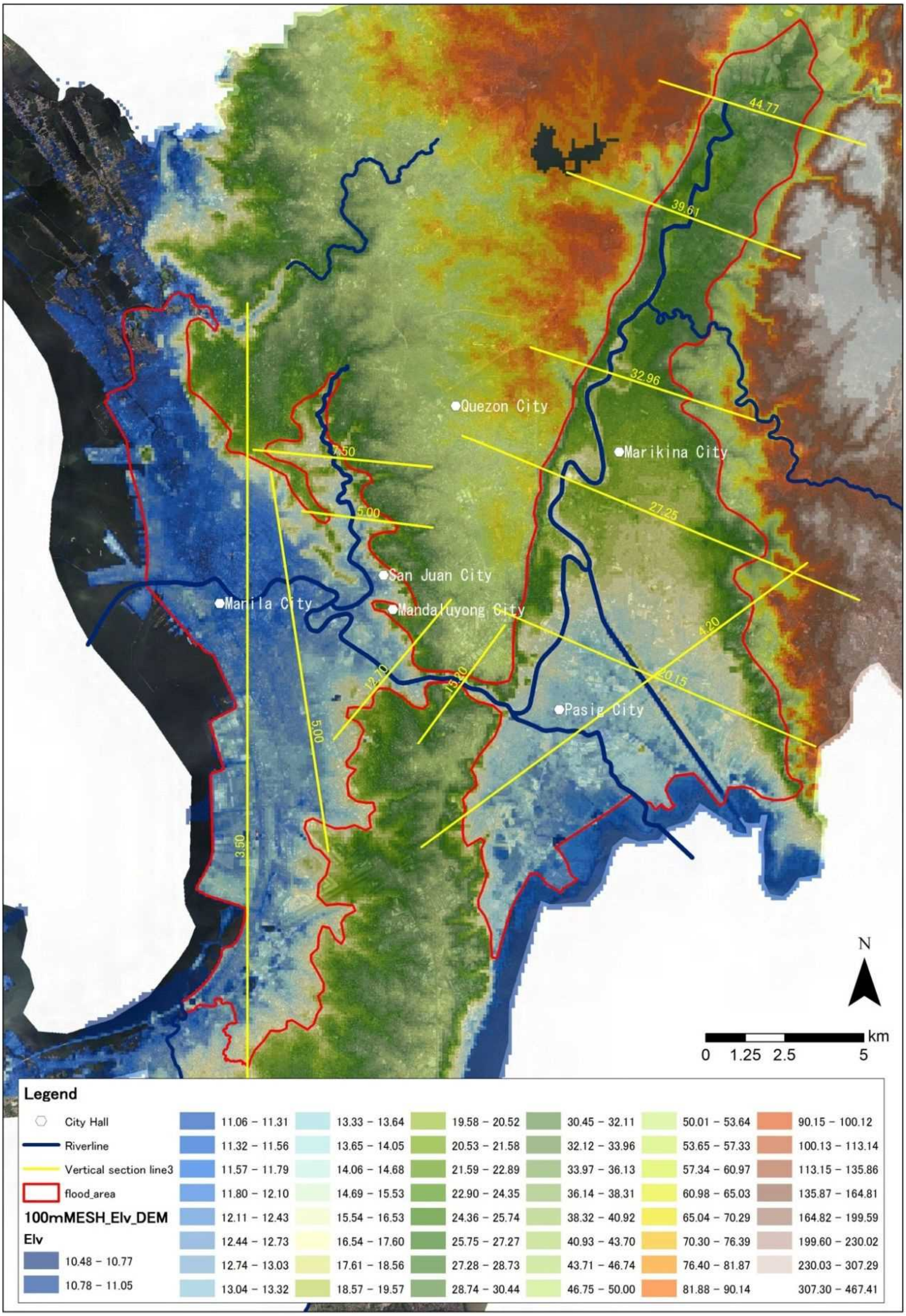


Source: JICA Study Team

Figure 3.4 Outline of River Hydraulic Model and Inundation Analysis Model

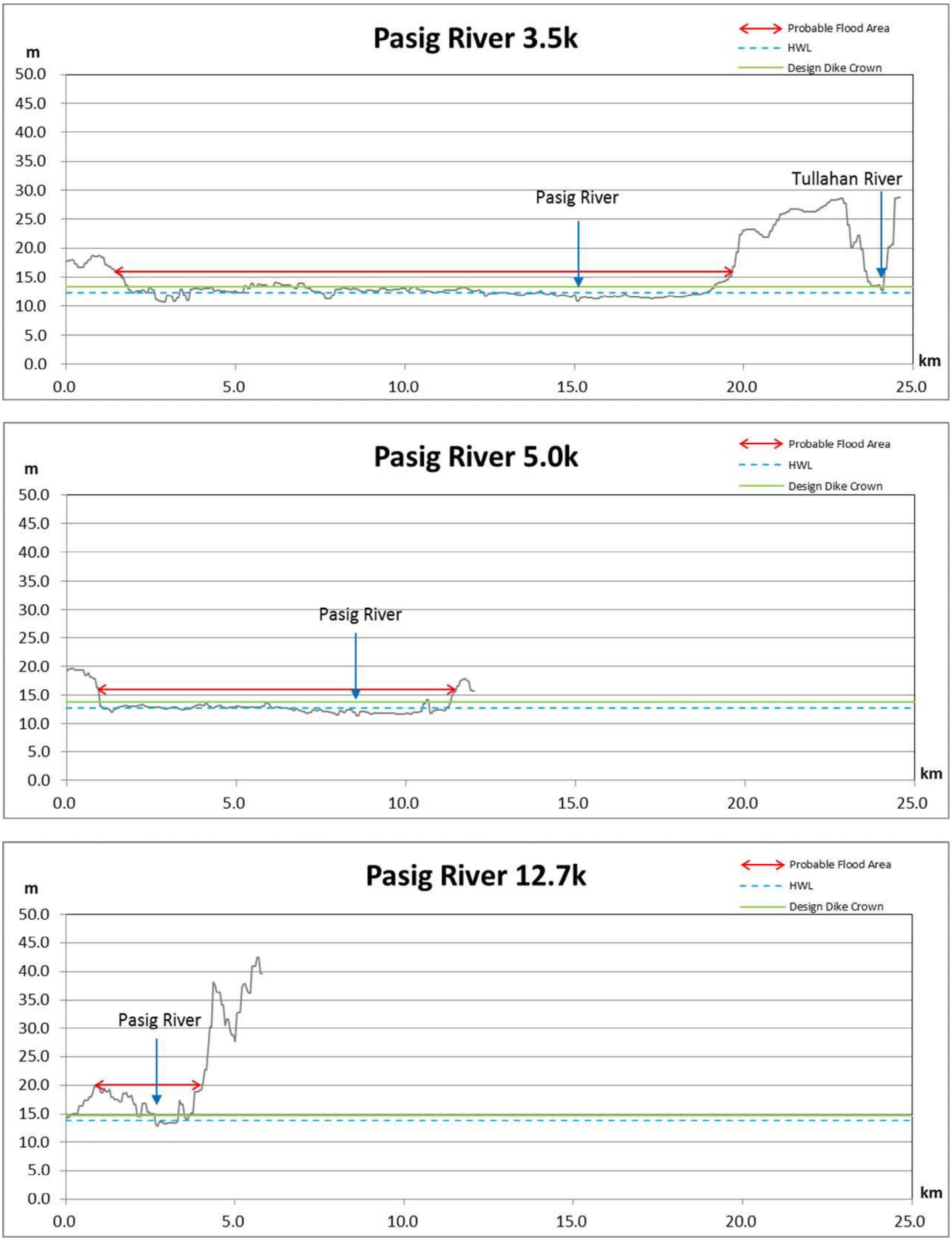
1) Target Area for Inundation Analysis

The target area for inundation analysis was set as shown in Figure 3.5. The boundary was determined by examining several cross sections as shown in Figure 3.6 to 3.9.



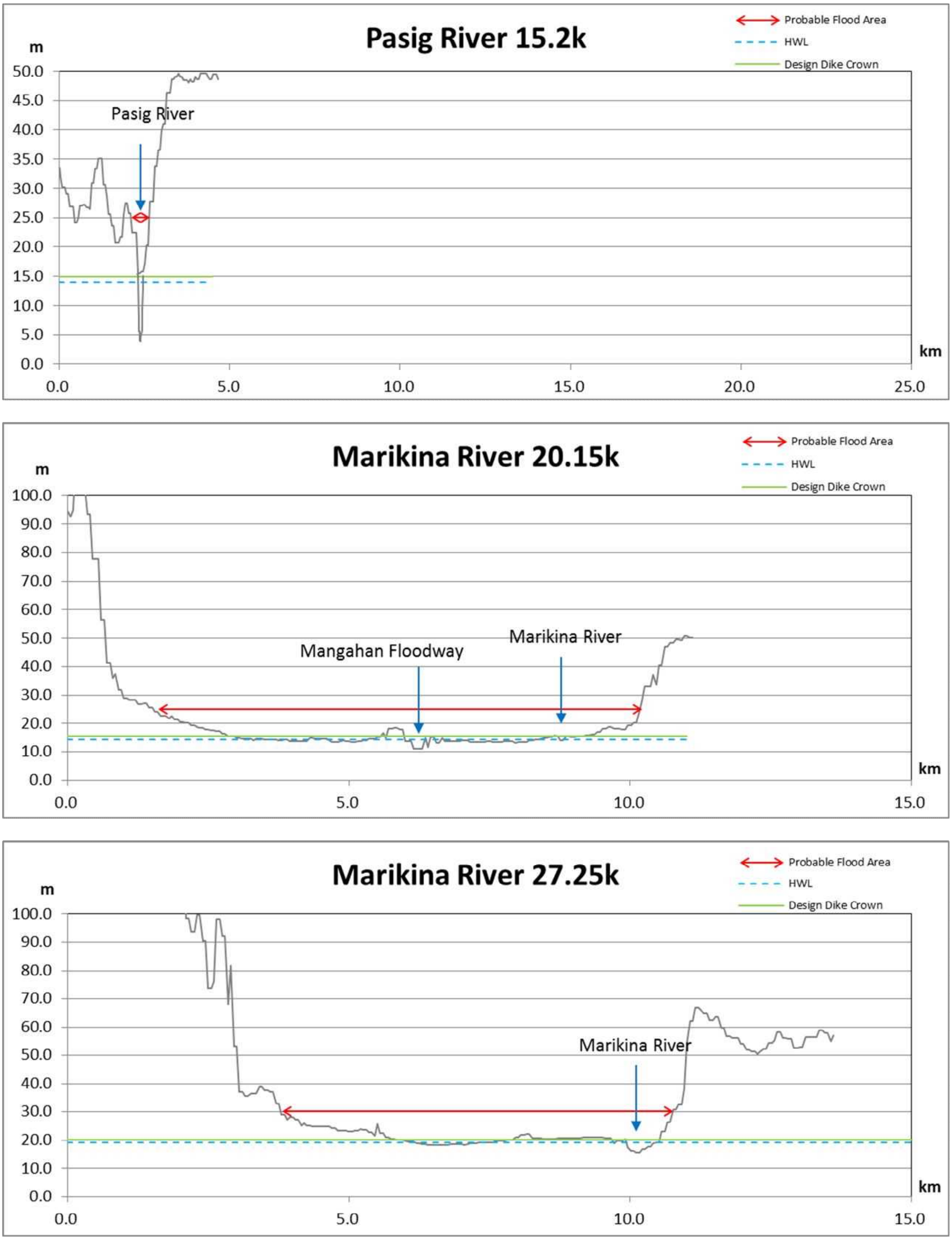
Source: JICA Study Team

Figure 3.5 Target Area for Inundation Analysis



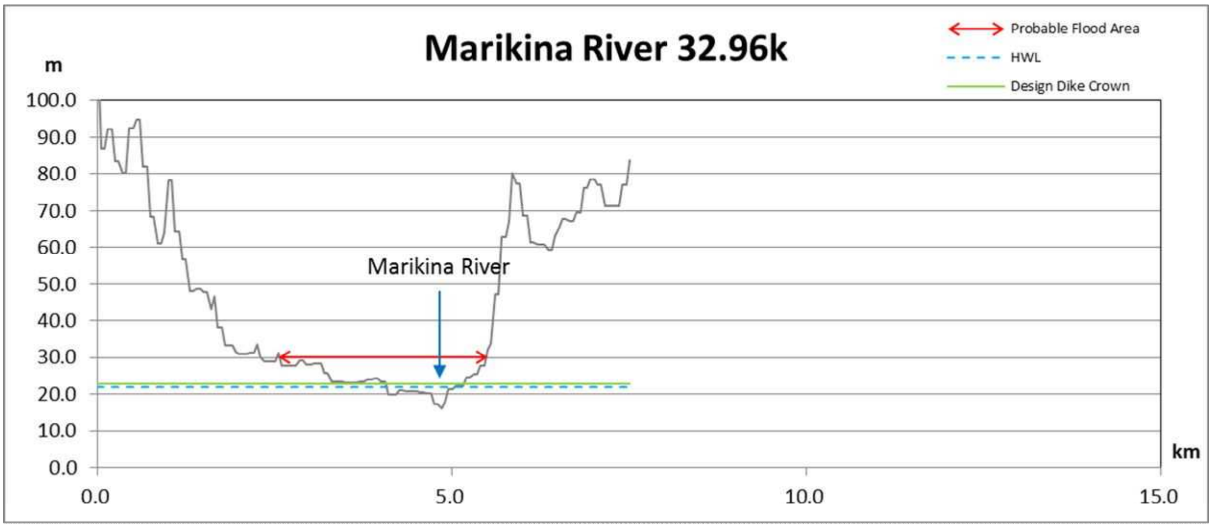
Source: JICA Study Team

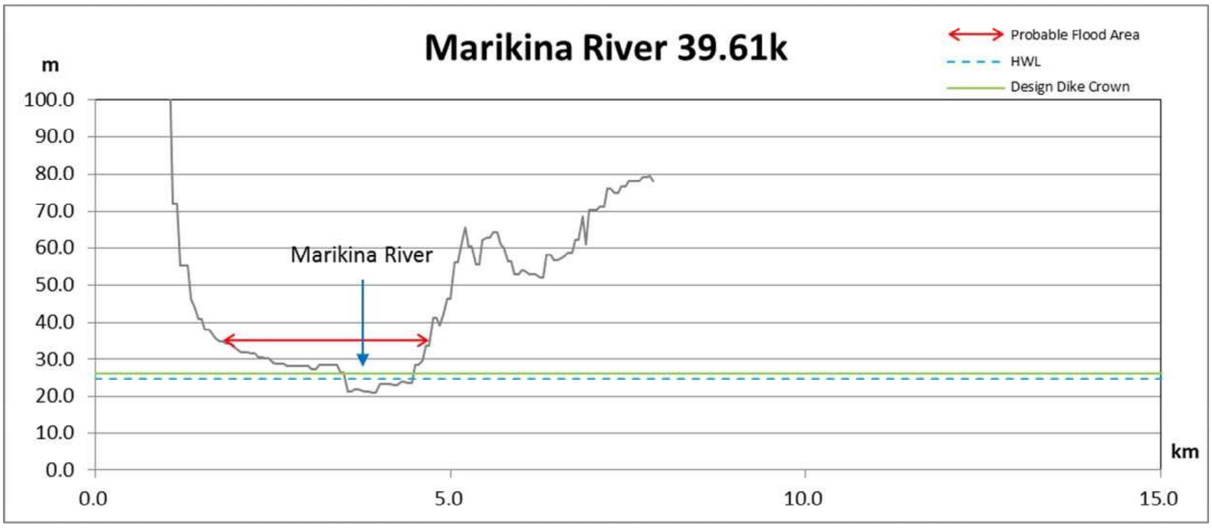
Figure 3.6 Cross Sections for Setup of Target Area (1/4)

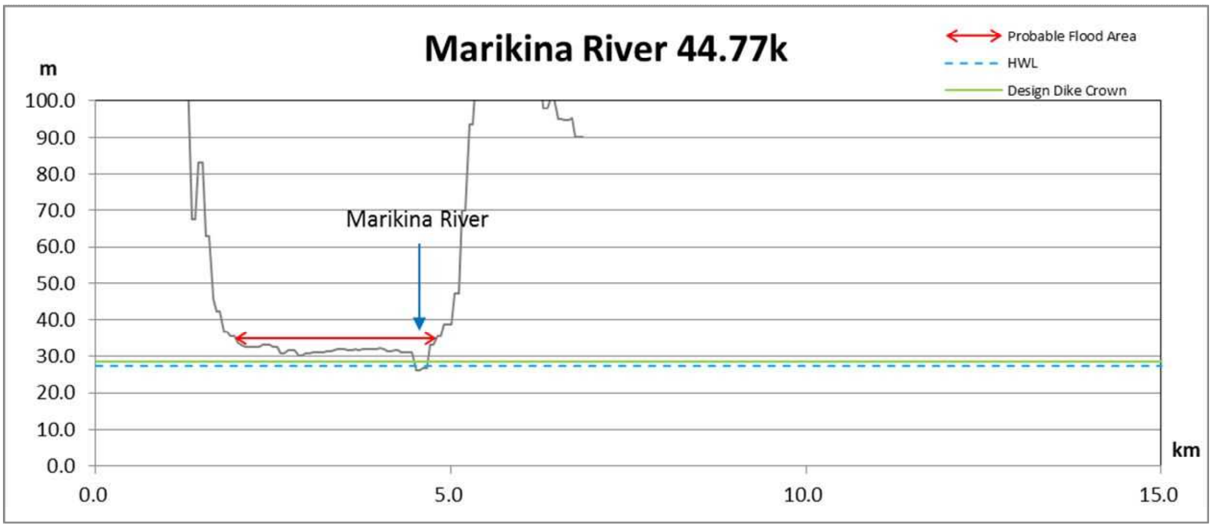


Source: JICA Study Team

Figure 3.7 Cross Sections for Setup of Target Area (2/4)

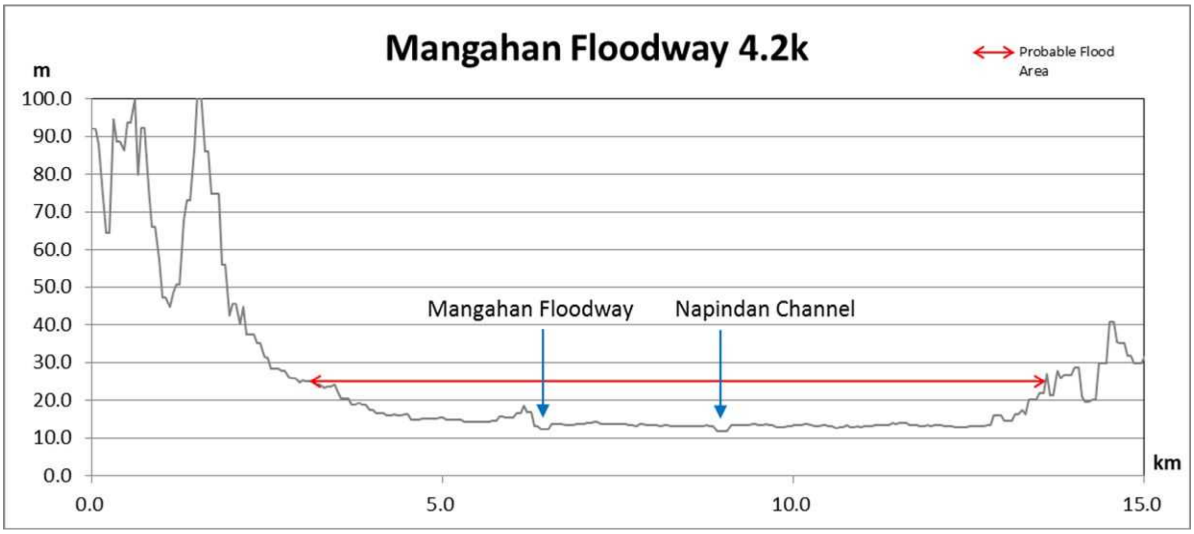


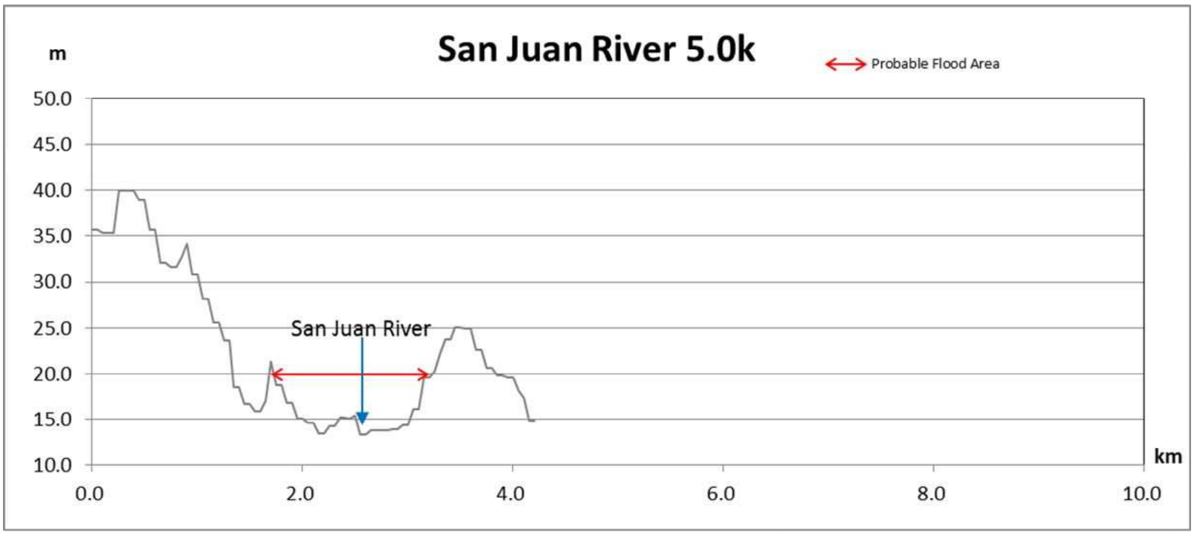


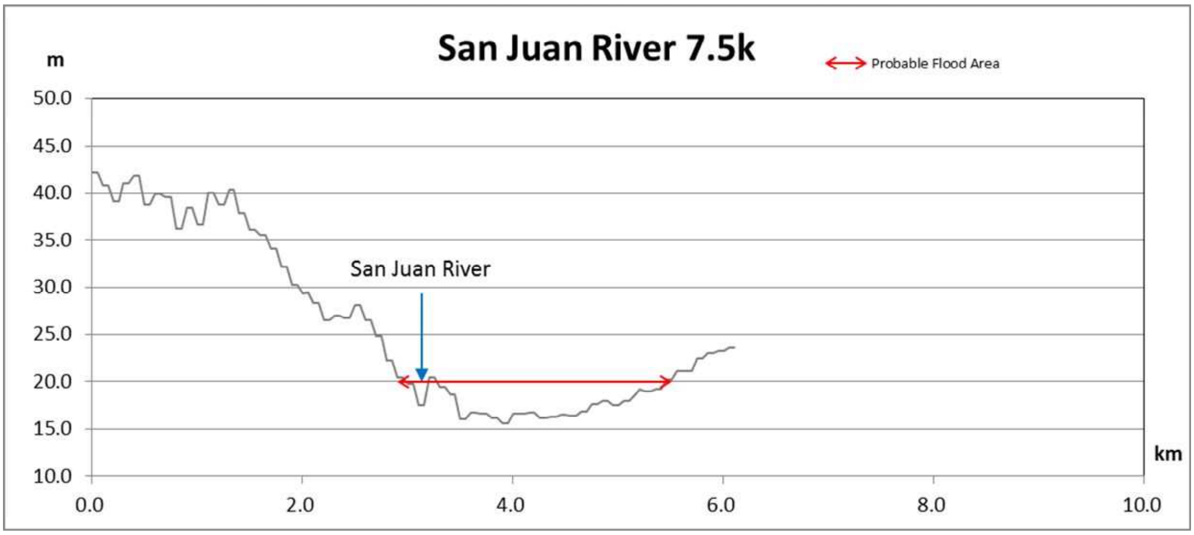


Source: JICA Study Team

Figure 3.8 Cross Sections for Setup of Target Area (3/4)







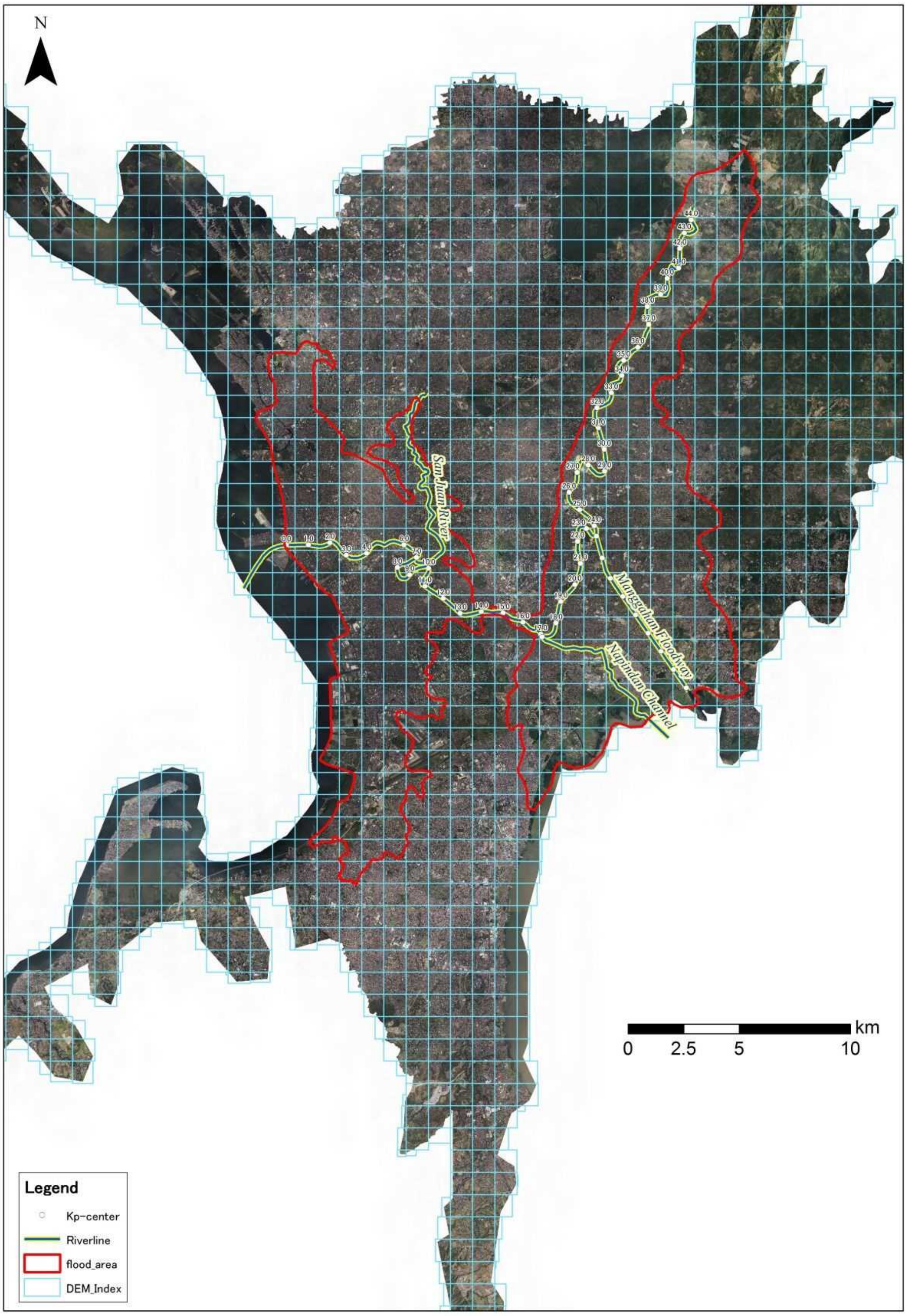
Source: JICA Study Team

Figure 3.9 Cross Sections for Setup of Target Area (4/4)

2) Preparation of Mesh Elevation Data

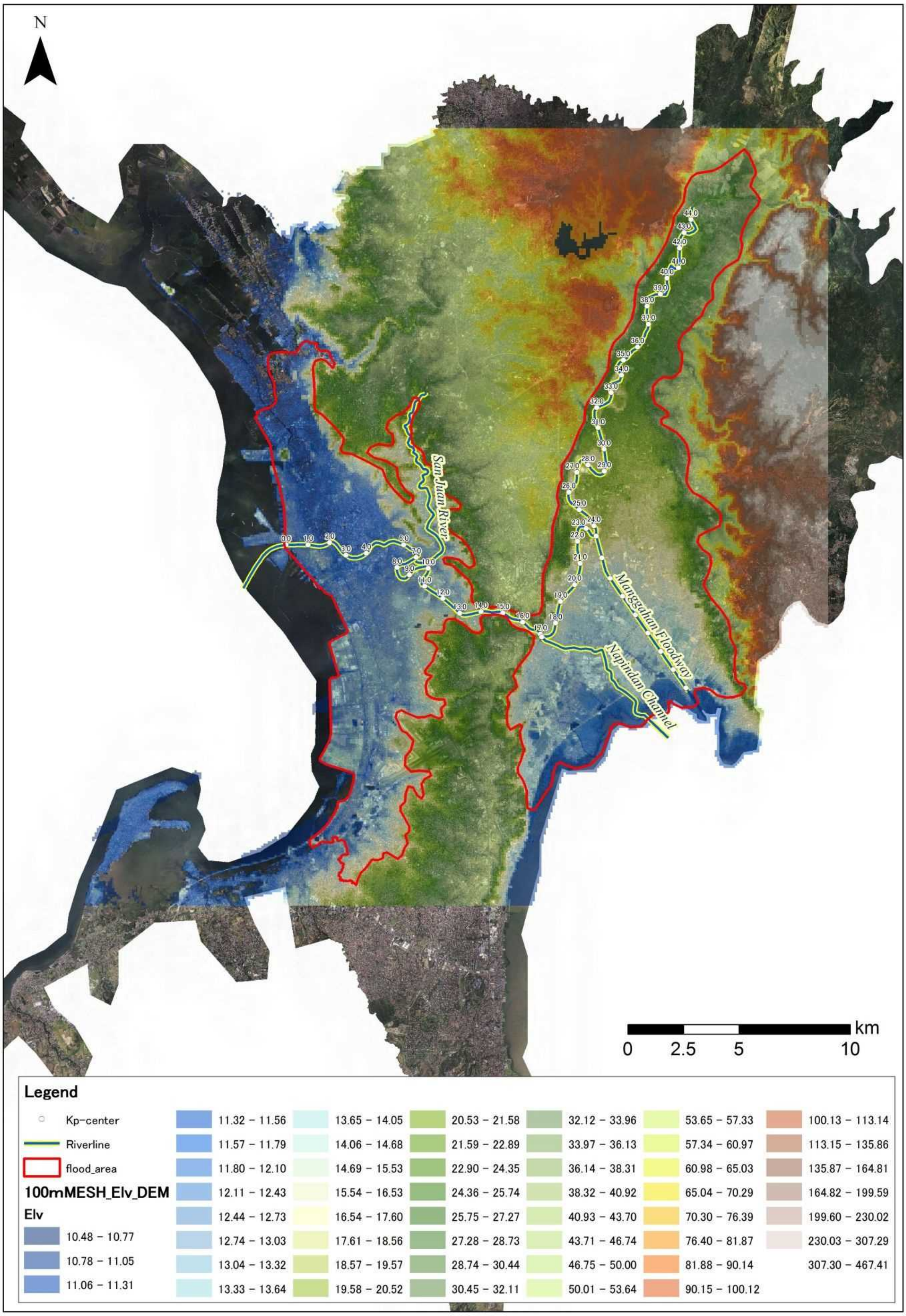
Based on the survey conducted from December, 2010 to January 2011, LiDAR data was created with 1m x 1m mesh. Based on this data, 100m x 100m mesh elevation data was created. DEM data frameworks and created 100m x 100m mesh elevation data are shown in Figure 3.10 and 3.11, respectively.

It is noted that the LiDAR data was formulated by Enhancing Risk Analysis Capacities for Flood, Tropical Cyclone Severe Wind and Earthquake for Greater Metro Manila Area – Component 5 of the Metro Manila Post – Ketsana Recovery and Reconstruction Program by AusAID.



Source: JICA Study Team

Figure 3.10 DEM Data Frameworks



Source: JICA Study Team

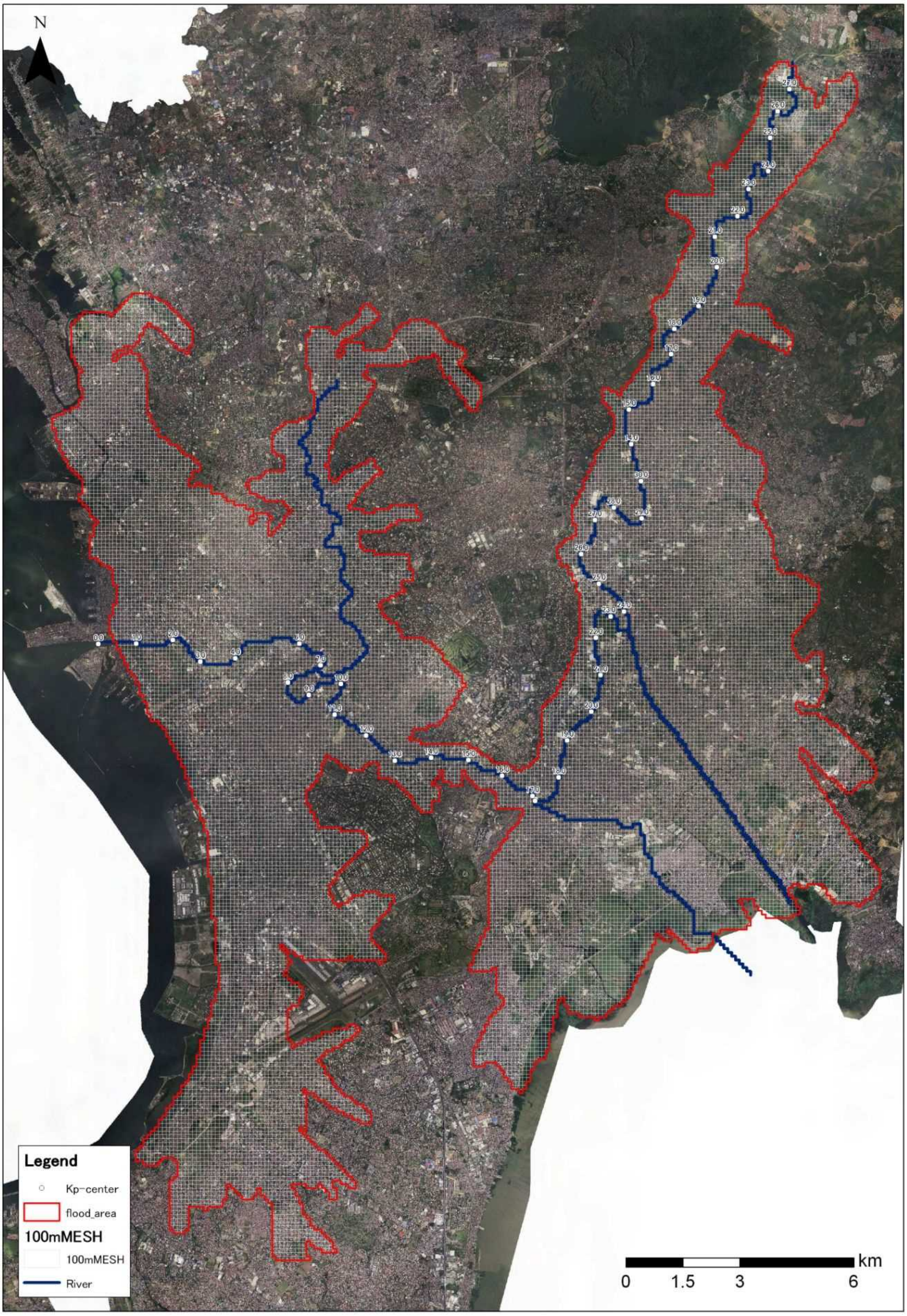
Figure 3.11 100m x 100m Mesh Elevation

3) Conditions for Flood Analysis

The following conditions shown in Table 3.2 were applied for flood analysis. Floodplain model is shown in Figure 3.12.

Table 3.2 Conditions for Flood Analysis

Item		Conditions
Method		River Course: One-dimensional Unsteady Flow Model River Basin: Two-dimensional Unsteady Flow Analysis Model
River Course Conditions	Area	Pasig-Marikina (-2.800k - 44.770k) San Juan (0.000k - 10.500k) Napindan Channel (0.000k - 8.176k) Manggahan Floodway (0.000k - 8.200k)
	Interval	About 100m - 200m
	Cross Section	Section in Year 2010
	Boundary Conditions	Manila Bay: Observed Hydrograph Laguna Lake: Observed Hydrograph
	Roughness Coefficient	Pasig-Marikina (-2.800k - 30.350k) : 0.028 Marikina (30.350k - 44.770k) : 0.030 San Juan (0.000k - 10.500k) : 0.030 Napindan Channel (0.000k - 8.176k) : 0.030 Manggahan Floodway (0.000k - 1.150k) : 0.021 Manggahan Floodway (1.200k - 8.200k) : Low Flow Channel 0.030 : Flood Channel 0.300
Floodplain Conditions	Inundation Type	Upstream of SanMateo: Flow along River Type Downstream of SanMateo: Dispersion Type
	Elevation	100m x 100m Mesh Elevation (based on LiDar Data)
	Roughness Coefficient	0.05
	Overflow Condition	Comparison of Dyke Elevation and Land Elevation



Source: JICA Study Team

Figure 3.12 Floodplain Model

3.2 Calibration of Model with Past Floods

Validity of established flood analysis model was calibrated comparing the observed discharge and water level data with simulation results such as discharge, river water level and inundation level.

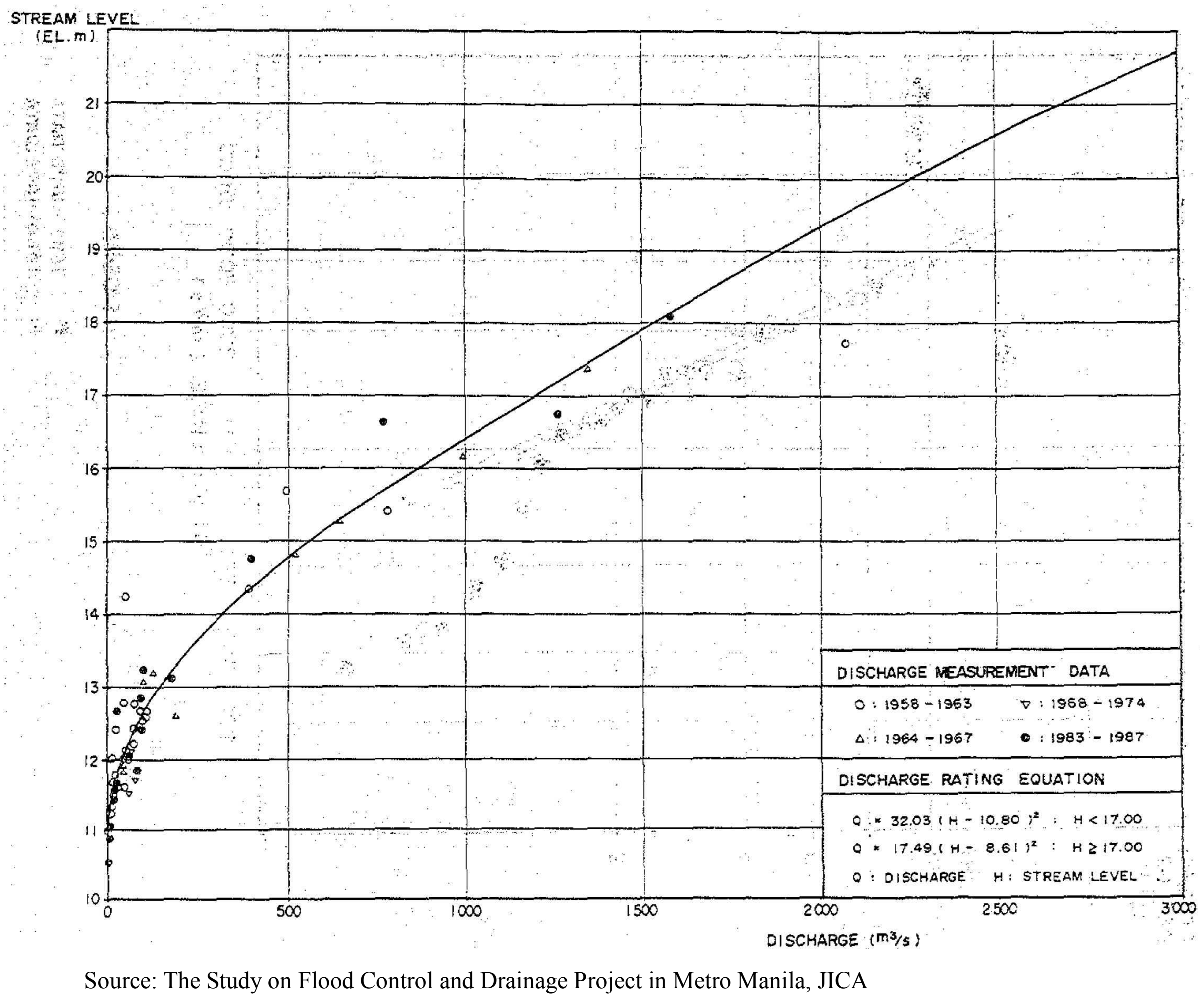
3.2.1 Verification of H-Q Equations

(1) H-Q Equations in Previous Studies

H-Q equations were established in Preparatory Survey on Pasig-Marikina River Channel Improvement Project (Phase III) (hereinafter referred to as the "JICA Study") and Master Plan for Flood Management in Metro Manila and Surrounding Areas (hereinafter referred to as the "WB Study"), respectively. These H-Q equations are quite different. By the H-Q equation in the JICA Study, the peak discharge of 2009 Flood is calculated at 3,211 m^3/sec. On the other hand, it becomes 3,950 m^3/sec by the H-Q equation in the WB Study, resulting more than 700 m^3/sec deviation. Each H-Q equation was formulated as follows.

1) JICA Study

In the JICA Study, same H-Q equation was utilized which was formulated by "The Study on Flood Control and Drainage Project in Metro Manila" (hereinafter referred to as the "JICA M/P Study") in 1990. This H-Q equation was calculated based on observed water level and discharge data from 1958 to 1987 as shown in Figure 3.13.

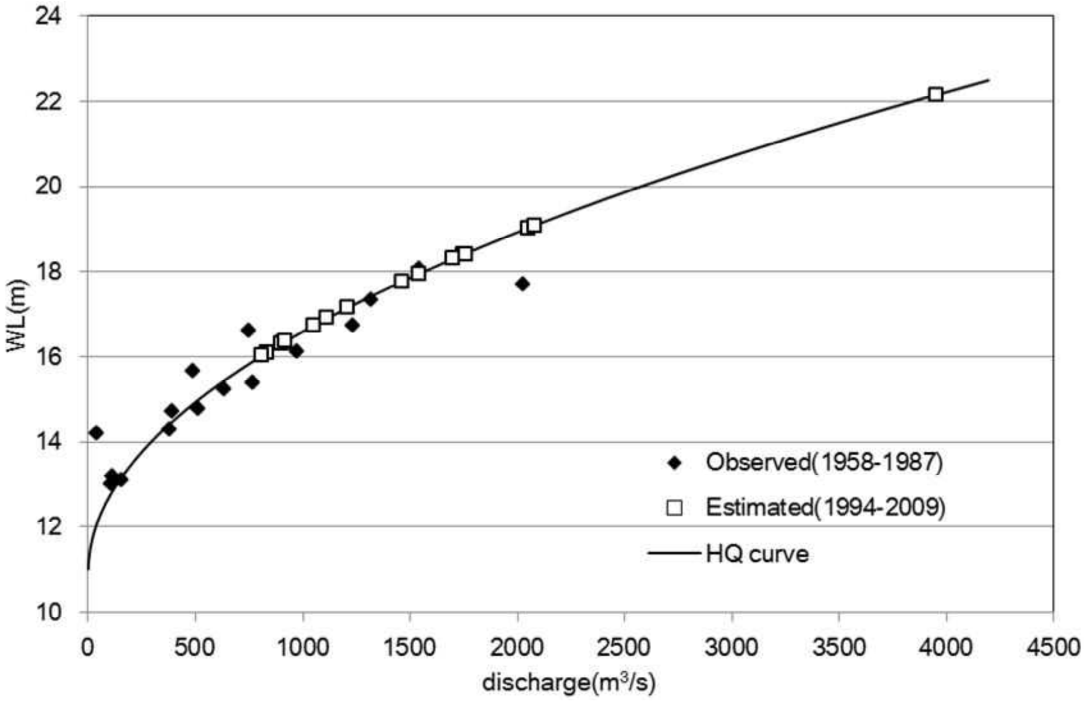


Source: The Study on Flood Control and Drainage Project in Metro Manila, JICA

Figure 3.13 H-Q Curve Formulated in JICA M/P Study

2) WB Study

Although it seemed that the utilized data was limited, the WB Study also utilized same observed data during 1958 – 1987 as the JICA M/P Study. Besides, estimated discharge using uniform flow equation based on observed water level data after 1994 were also utilized as shown in Figure 3.14. It is noted that roughness coefficient of n=0.033 and slope of 1/1,500 was applied for estimation of discharge.



Source: Master Plan for Flood Management in Metro Manila and Surrounding Areas, the World Bank

Figure 3.14 H-Q Curve Formulated in WB Study

(2) Recalculation of H-Q Equation

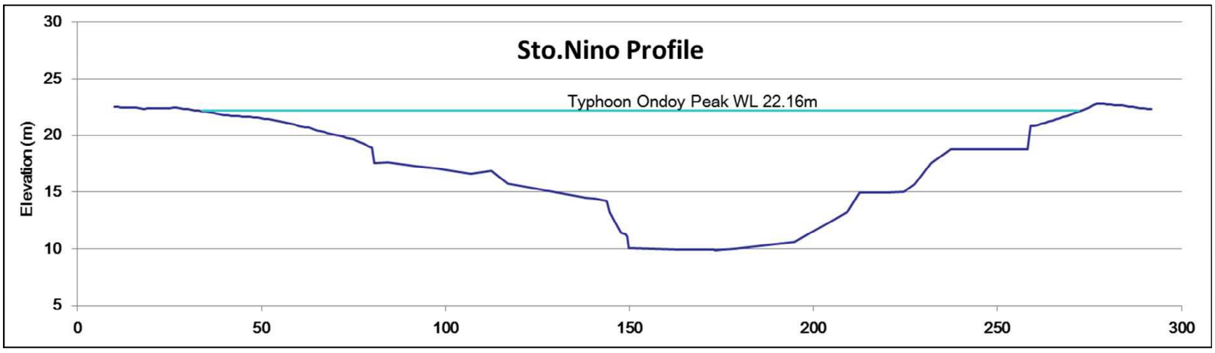
H-Q equation was recalculated in the Study in order to verify the previous H-Q equations. Since observation of discharge has not conducted since 1994, discharge was estimated using non-uniform flow calculation.

1) Conditions for Non-uniform Calculation

The following conditions were applied for non-uniform calculation.

- Utilized Water Level: Annual Maximum Water Level since 1994
- Section for Calculation: Rosario Weir to Sto.Nino Station
- Cross Section: Composite Data of Topographic Survey in 2010 and LiDAR Data
- Downstream Boundary: Water Level at Rosario Junction Side Station when Maximum Water Level at Sto.Nino Station
- Roughness Coefficients: the following coefficients were applied for riverbed, riverbank and flood channel referring to the "Hydraulic Formulas" in Japan.
  - Riverbed: 0.022 as standard value of natural straight uniform section channel
  - Riverbank: 0.030 considering vegetation on riverbank
  - Flood Channel: 0.050 as standard value of flood channel with trees

Composite roughness coefficient of river course and flood flow section including flood channel were about 0.024 and 0.028, respectively. It is noted that the composite roughness coefficient is same as the JICA Study. The cross section and site photos of Sto.Nino Station are shown in Figure 3.15 to Figure 3.17.



Source: JICA Study Team

Figure 3.15 Cross Section of Sto.Nino Station

Source: The preparatory study for sector loan on disaster risk managemnet in the Republic of Philippines, JICA 2010

Figure 3.16 Sto.Nino Bridge

Source: JICA Study Team

Figure 3.17 Upstream of Sto.Nino Bridge

Annual maximum flood discharges were estimated by trial calculation changing inflow discharges as shown in Table 2.3. As a result of calculation, energy gradients around Sto.Nino Station during 1994 flood were 1/2,500 to 1/3,000.

Table 3.3 Result of Annual Maximum Flood Discharge Estimation

Year	Water Level (m)	Estimate Discharge (m3/s)	Year	Water Level (m)	Estimate Discharge (m3/s)
1994	16.33	890	2004	19.08	1,940
1995	18.4	1,600	2005	16.03	760
1996	16.08	770	2006	16.37	890
1997	17.16	1,120	2007	16.9	1,040
1998	18.41	1,580	2008	16.74	1,020
1999	18.3	1,570	2009	22.16	3,480
2000	19.02	1,880	2010	NA	NA
2001	16.31	860	2011	19.13	1,920
2002	17.94	1,410	2012	20.42	2,570
2003	17.76	1,330			

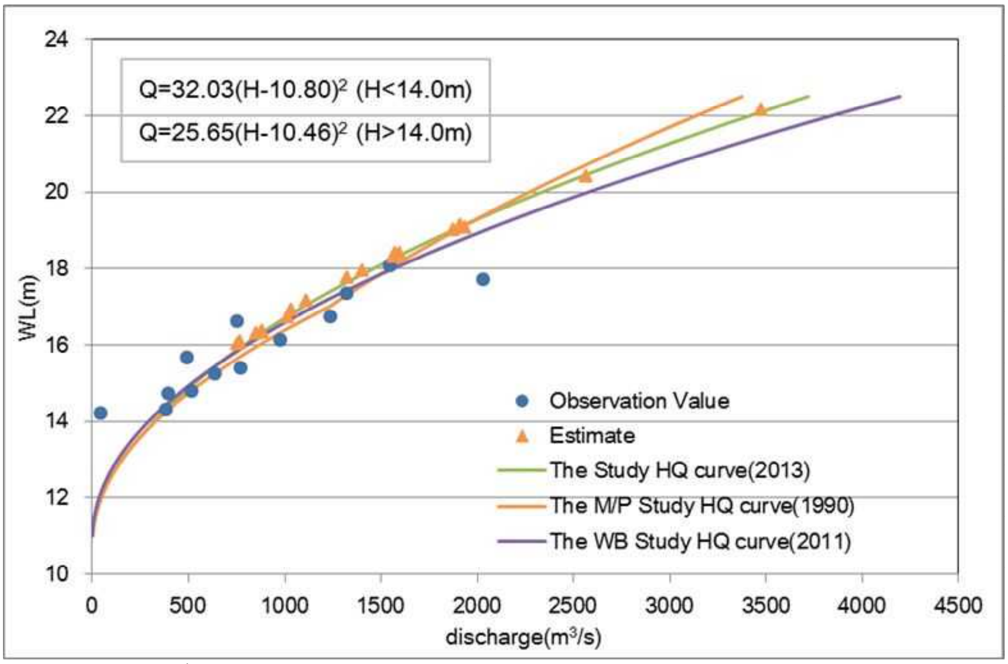
Source: JICA Study Team

2) Range of H-Q Recalculation

The number of observed water level and discharge data utilized for H-Q calculation in the JICA M/P is large in low flow discharge while the number of observed data more than 14m of water level is only 13 data. Thus, H-Q equation more than 14m was recalculated since H-Q equation by the JICA M/P Study less than 14m was expected to be high accuracy due to the number of observed data.

3) Result of Recalculation of H-Q Equation

H-Q equation more than 14m of water level was recalculated based on the observed data during 1958 – 1987 and the estimated data after 1994 as shown in Figure 3.18. The peak discharge of 2009 Flood of which water level is 22.16m is calculated at 3,500 m^3/sec.



Source: JICA Study Team

Figure 3.18 Recalculated H-Q Curve

(3) Validity of Previous H-Q Equations

The H-Q equations in previous studies are evaluated as follows.

<JICA Study>

H-Q equation was estimated based on observed data. However, number of data during flood is very few. Only 1 data was available for more than 2,000m^3/sec and reliability of this data was low comparing other observed data. Thus, it is judged that H-Q equation in low water has high accuracy but in high water more than 2,000m^3/sec discharge is not.

<WB Study>

H-Q equation was estimated using estimated discharge data as well as observed data including high water more than 2,000m^3/sec discharge. However, the followings can be pointed out regarding the accuracy of H-Q equation.

- In the WB Study, energy gradient of 1/1,500 was applied for uniform calculation. However, it is considered as too high because the energy gradients of annual maximum discharge were estimated as 1/2,500 to 1/3,000 by the non-uniform calculation conducted by the Study.
- In the WB Study, roughness coefficient of n=0.033 was applied for whole section, while 0.022 and 0.030 were applied for low flow channel and riverbank in the Study. As shown in Figure 2.13, the H-Q curve by the Study is quite similar to the H-Q curve by the JICA Study especially at the range of 14m to 16m water level. Since the H-Q curve by the JICA Study was based on observed data, it is expected that actual roughness coefficient of low flow channel is about 0.023, and the value applied in the WB Study, n=0.033, is considered as relatively high.
- Larger energy gradient causes more discharge while larger roughness coefficient causes smaller discharge. In this case, much difference of energy gradient effects to larger discharge.

As a conclusion, H-Q curve by the JICA of which water level up to 14m and the new H-Q curve for more than 14m water level which is recalculated by the Study are applied for further analysis in the Study.

3.2.2 Peak Water Level by Typhoon Ondoy at Sto.Nino Station

During the flood by Typhoon Ondoy, water level was not recorded at Sto.Nino Station after 18:00 on September 26 with the record of 22.16m, and the peak water level is uncertain. Thus, the peak time of Sto.Nino during the flood by Typhoon Ondoy is estimated comparing the hydrographs of past measure floods at Montalban and Rosario JS Stations. Hydrographs of floods in 2000, 2004, 2009 (Typhoon Ondoy), 2011 and 2012 and their peak time are summarized in Table 3.4 and Figure 3.19 to Figure 3.23.

Difference of peak times between Montalban and Sto.Nino varies from 1 to 3 hours. And the peak water level by Typhoon Ondoy might not be recorded at Montalba also. On the other hand, hydrographs at Rosario JS has same tendency with St. Nino, and difference of peak time is 1 or 2 hours. Out of examined 5 major floods, the floods in 2011 and 2012 were induced by monsoon and several peaks were observed. The floods in 2000 and 2004 were induced by Typhoon, which must have a same tendency in the hydrograph with Typhoon Ondoy. Difference of peak time between Rosario JS and Sto.Nino during 2000 and 2004 floods are 1 hour.

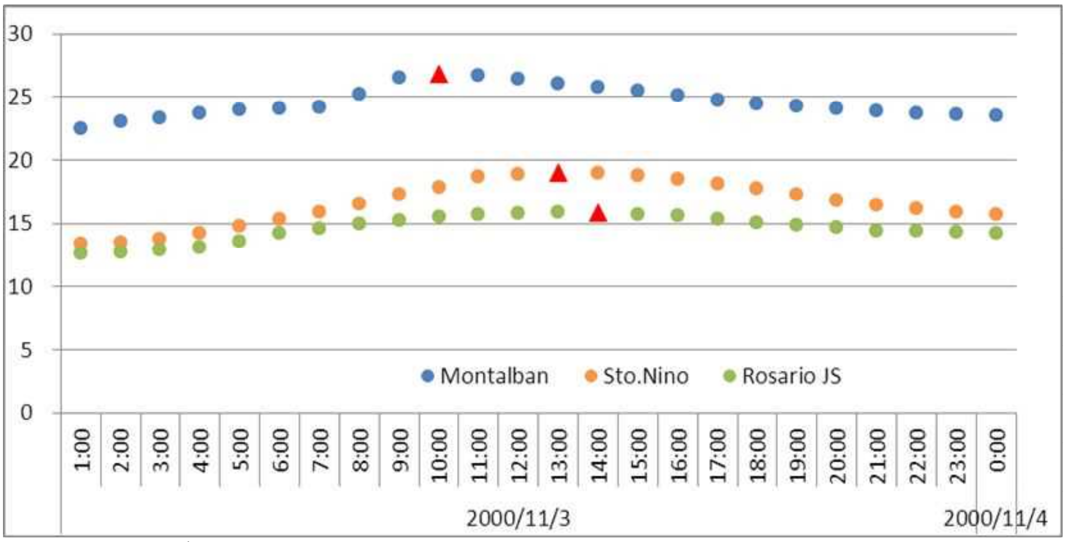
Based on the non-uniform flow calculation, average flow velocity between Sto.Nino and Rosario JS is estimated at 2.5m/sec. Applying this value, flood arrival time from Sto.Nino to Rosario JS is estimated as 6,550m / 2.5m/sec = 2,620 sec = about 44 minutes.

Based on above examinations, difference of peak time between Sto.Nino and Rosario JS is estimated at 1 hour and the peak time of Sto.Nino during the flood by Typhoon Ondoy was estimated at 17:00.

Table 3.4 Peak Time of Past Measure Floods

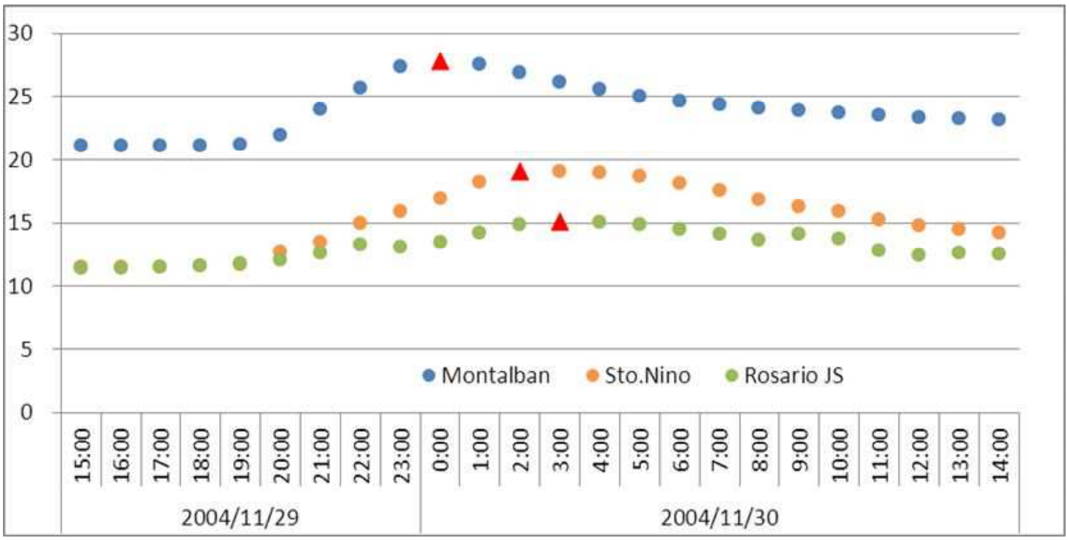
Occurrence date	Peak Time			Time lag of Sto.Nino and Rosario JS
	Montalban	Sto.Nino	Rosario JS	
2000.11.3	10:00	13:00	14:00	1:00
2004.11.30	0:00	2:00	3:00	1:00
2009.9.26	-	-	18:00	-
2011.9.27	15:00	18:00	19:00	1:00
2012.8.7	14:00	15:00	17:00	2:00

Source: JICA Study Team



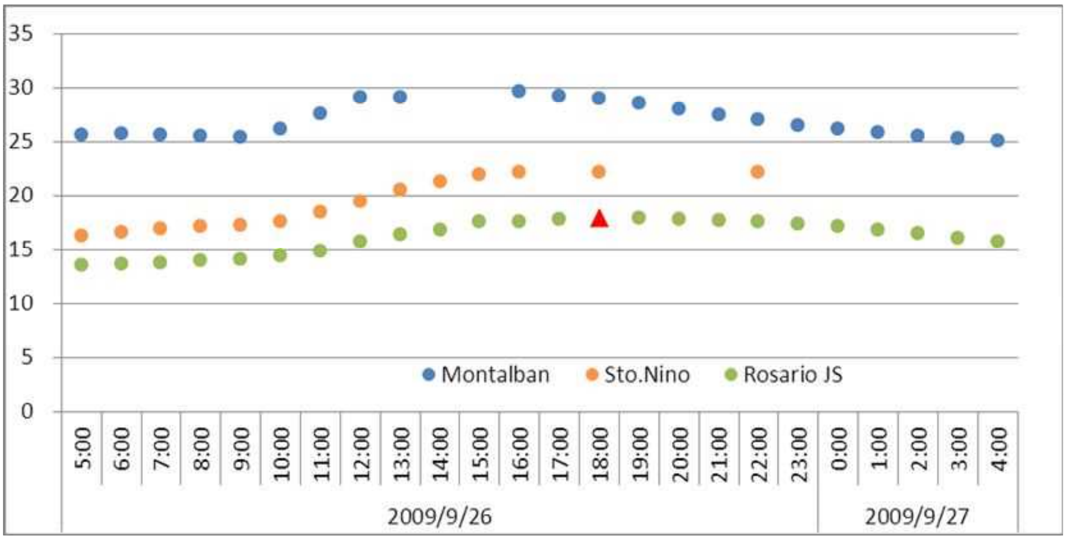
Source: JICA Study Team

Figure 3.19 Hydrograph of 2000 Flood



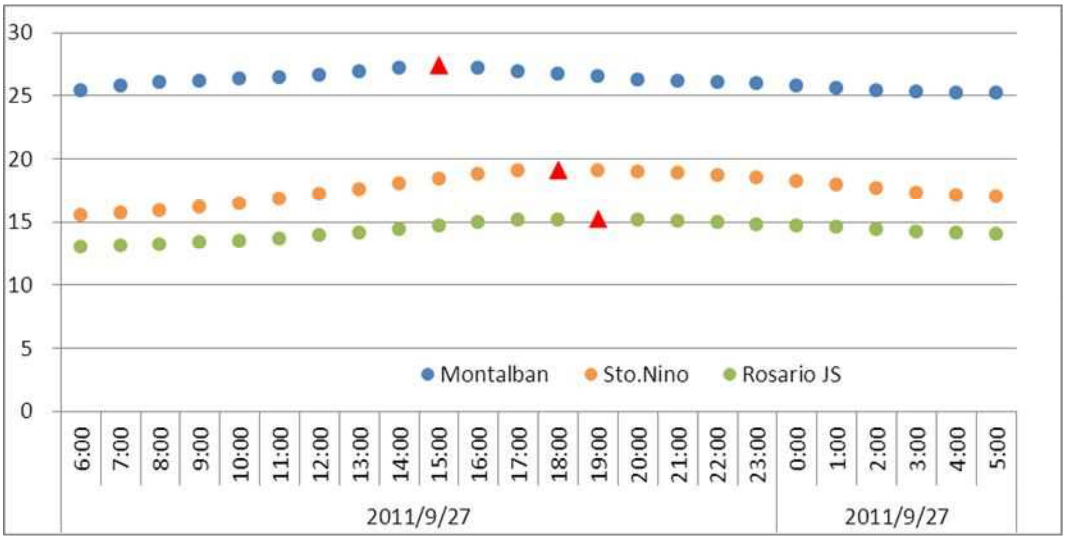
Source: JICA Study Team

Figure 3.20 Hydrograph of 2004 Flood



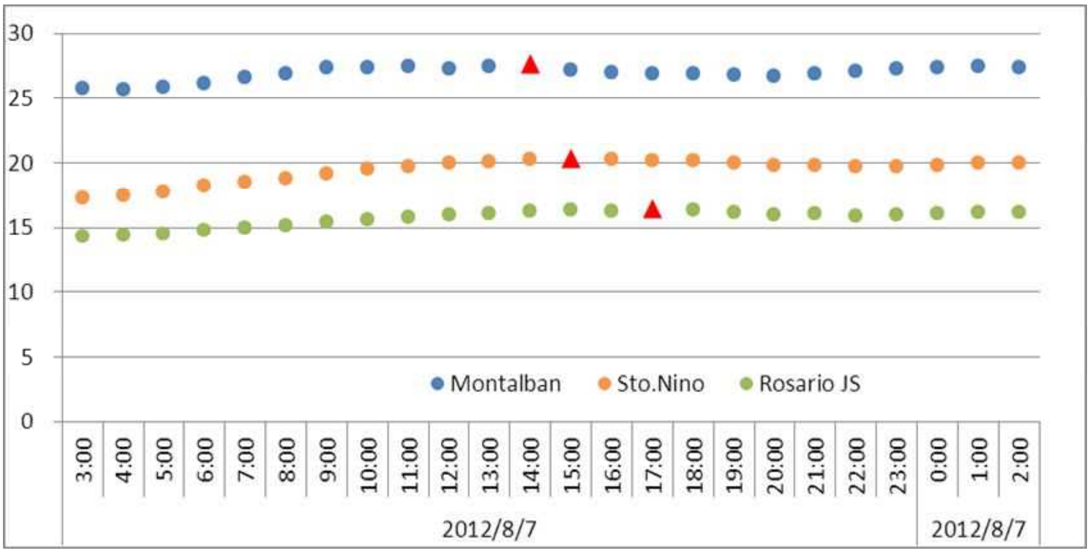
Source: JICA Study Team

Figure 3.21 Hydrograph of 2009 Flood



Source: JICA Study Team

Figure 3.22 Hydrograph of 2011 Flood



Source: JICA Study Team

Figure 3.23 Hydrograph of 2012 Flood

3.2.3 Selection of Past Floods for Model Calibration and Verification

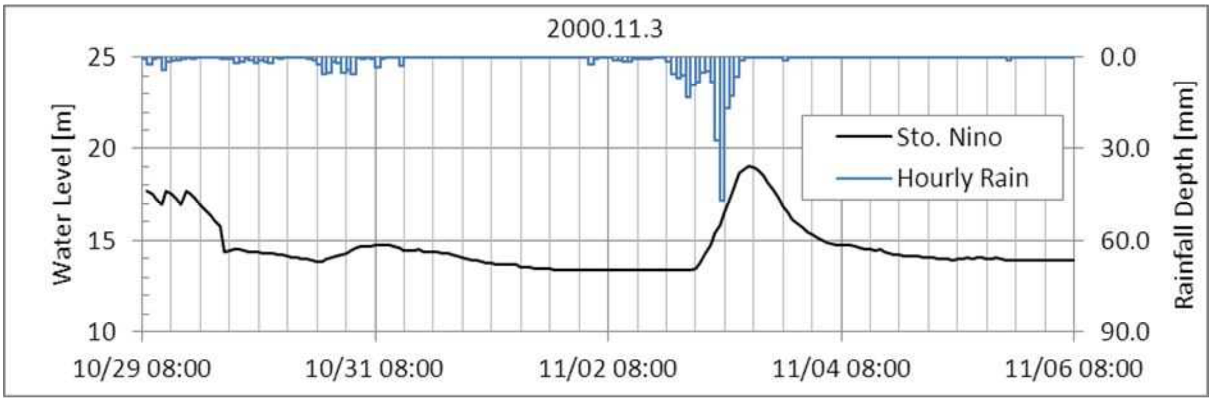
Out of 5 past floods for which hourly rainfall and water level data are available and the 5 highest water levels at Sto.Nino Station were recorded, the following 3 floods were selected for calibration and verification of the flood analysis model as the 3 largest basin daily rainfalls were recorded. Since the inundation area map is currently available only for Typhoon Ondoy as shown in Figure 3.25, data of Typhoon Ondoy was selected for calibration of model parameters.

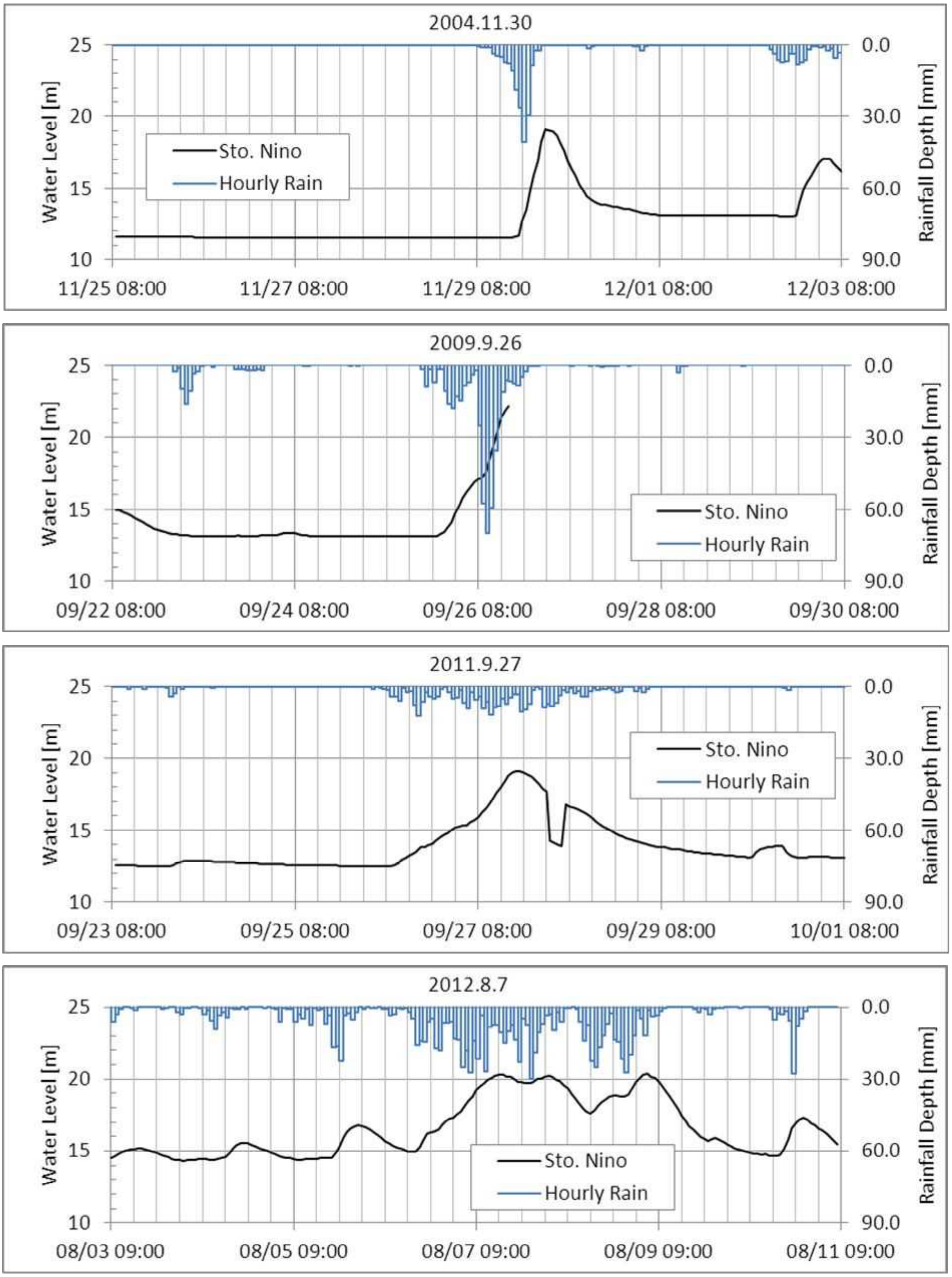
- For Calibration: Typhoon Ondoy in 2009 (Past Maximum)
- For Verification: Flood on November 29-30, 2004
  (Water level in Sto. Nino was the 4th highest after 1994)
- For Verification: Flood on August 7-9, 2012
  (Water level in Sto. Nino was the 2nd highest after 1994)

Table 3.5 Selection of Past Floods

Date	Cause	Peak WL at Sto.Nino (EL.m)	Basin Rainfall at Sto.Nino (mm/1day) (Probability)	Apply	Remarks
July 7, 2000	Typhoon	19.02	178.0 (1/10)	-	5th Highest WL at Sto.Nino after 1994
November 29, 2004	Typhoon	19.08	190.2 (1/10-1/20)	● Veri	4th Highest WL at Sto.Nino after 1994
September 26, 2009 Typhoon Ondoy	Typhoon	22.16	290.8 (1/110)	● Cali	Past Maximum
June 24, 2011	Monsoon	19.13	152.0 (1/5)	-	3rd Highest WL at Sto.Nino after 1994
August 7, 2012	Monsoon	20.42	271.7 (1/200)	● Veri	2nd Highest WL at Sto.Nino after 1994

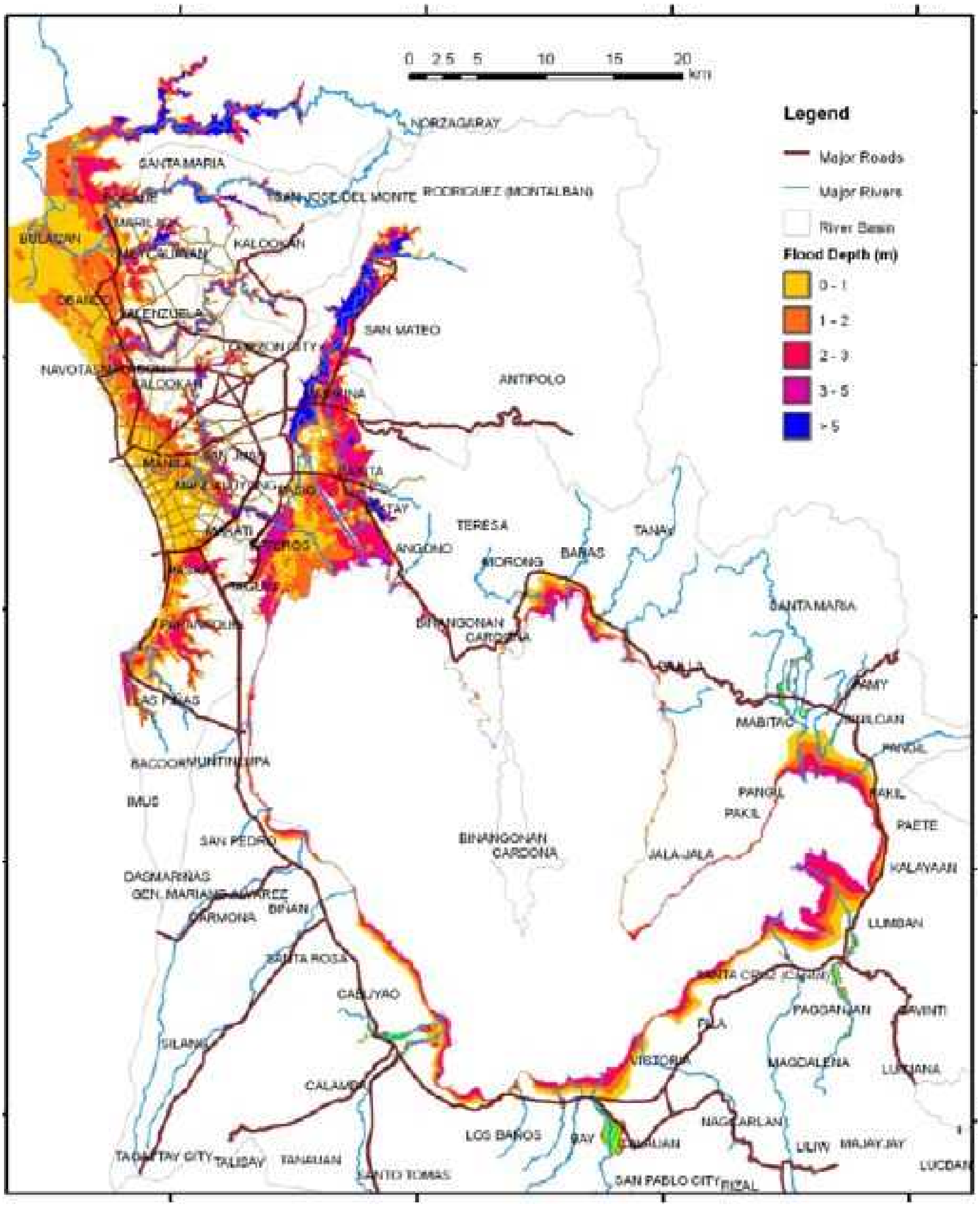
Remarks: Veri: for Verification, Cali: for Calibration
Note: Probability of rainfall is different for typhoon type and monsoon type rainfalls.
Source: JICA Study Team





Source: Study of Water Security Master Plan for Metro Manila and its Adjoining Areas, JICA

Figure 3.24   Hydrograph of Past Measure Floods



Source: Master Plan for Flood Management in Metro Manila and Surrounding Areas, the World Bank

Figure 3.25 Observed Inundation Map for 2009 Flood

3.2.4 Establishment of Flood Analysis Model

(1) Method of Model Calibration

Model calibration was conducted as the following procedure.

- Discharge to river course without inundation in upstream basin estimated by the runoff model (WEB-DHM) is given to the inundation model as a boundary condition.
- Water level in river course and inundation area is estimated by the inundation model
- Parameters are evaluated comparing estimated discharge, water level and inundation area to the observed ones.

The 2009 Flood (Typhoon Ondoy) was selected for calibration. As described below, the established model shows good reproductivity for relatively small peak flood such as the 2004 Flood and multi-peak flood such as 2012 Flood.

1) WEB-DHM Model

Based on the parameters set by the "Study of Water Security Master Plan for Metro Manila and its Adjoining Areas", surface soil parameters (ksat1, ksat2 and ksg) and roughness coefficient of river course were adjusted to reproduce short term runoff accurately.

2) Inundation Model

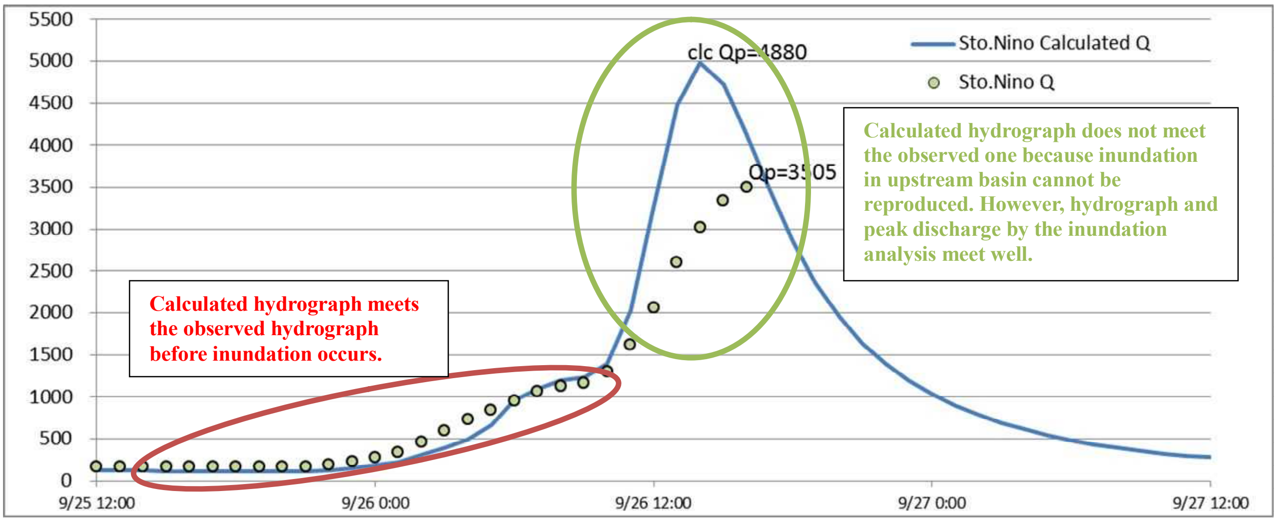
Since the discharge at Sto.Nino Station varies depending on inundation volume upstream, the roughness coefficient which was set by the JICA Study was adjusted.

(2) Result of Model Calibration and Verification

1) Calibration by Typhoon Ondoy in 2009

<WEB-DHM Model>

The surface soil parameters and roughness coefficient were calibrated comparing the estimated discharge using the recalculated H-Q equation based on observed water level (hereinafter referred to as the "observed discharge") and the calculated discharge. The output of WEB-DHM is discharge to river course without inundation upstream. Thus, the model was calibrated to meet hydrographs before inundation in upstream occurs, and inundation areas and hydrographs by the inundation model.

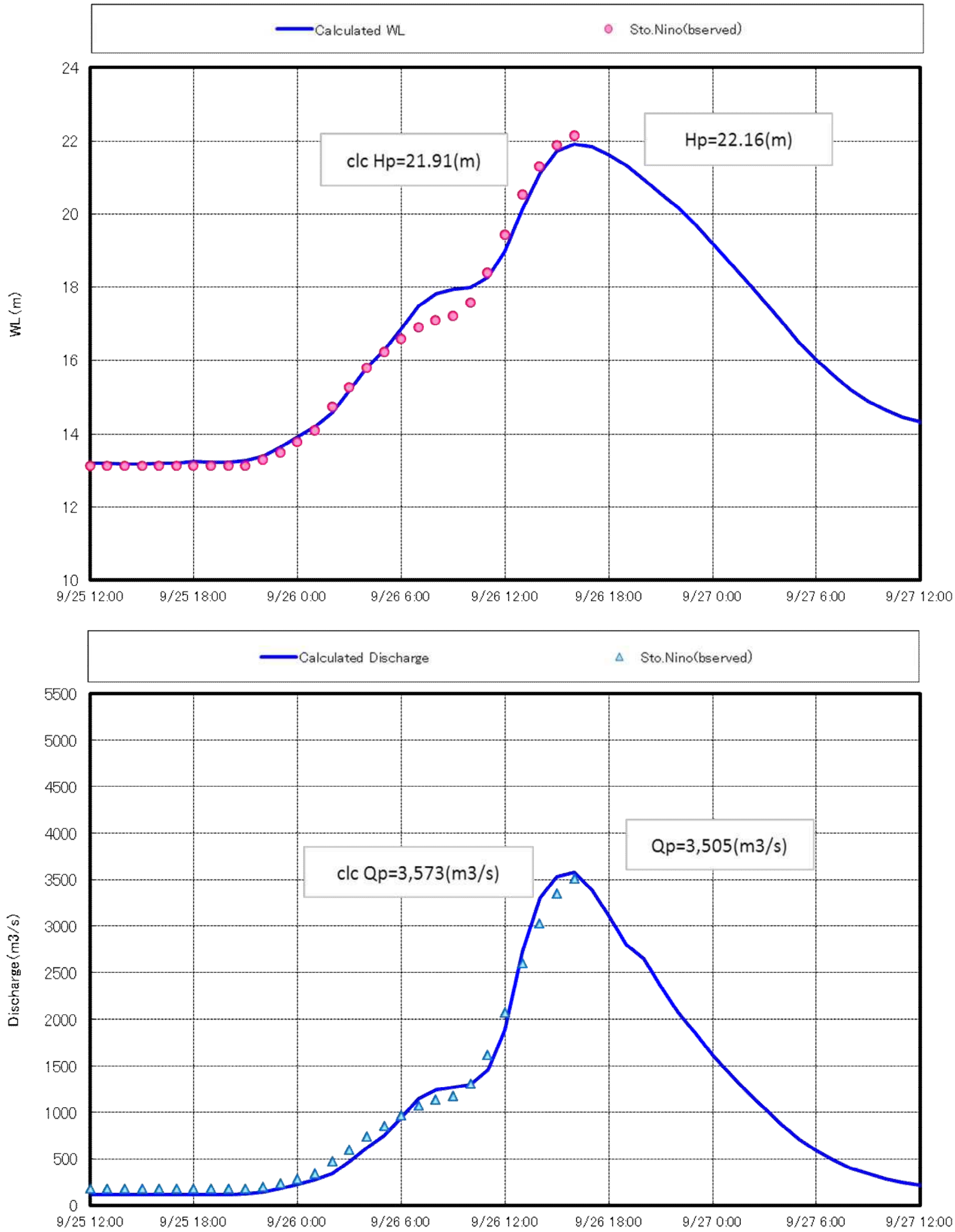


Source: JICA Study Team

Figure 3.26 Observed and Calculated Hydrographs by WEB-DHM Model (2009 Flood at Sto.Nino)

<Inundation Model>

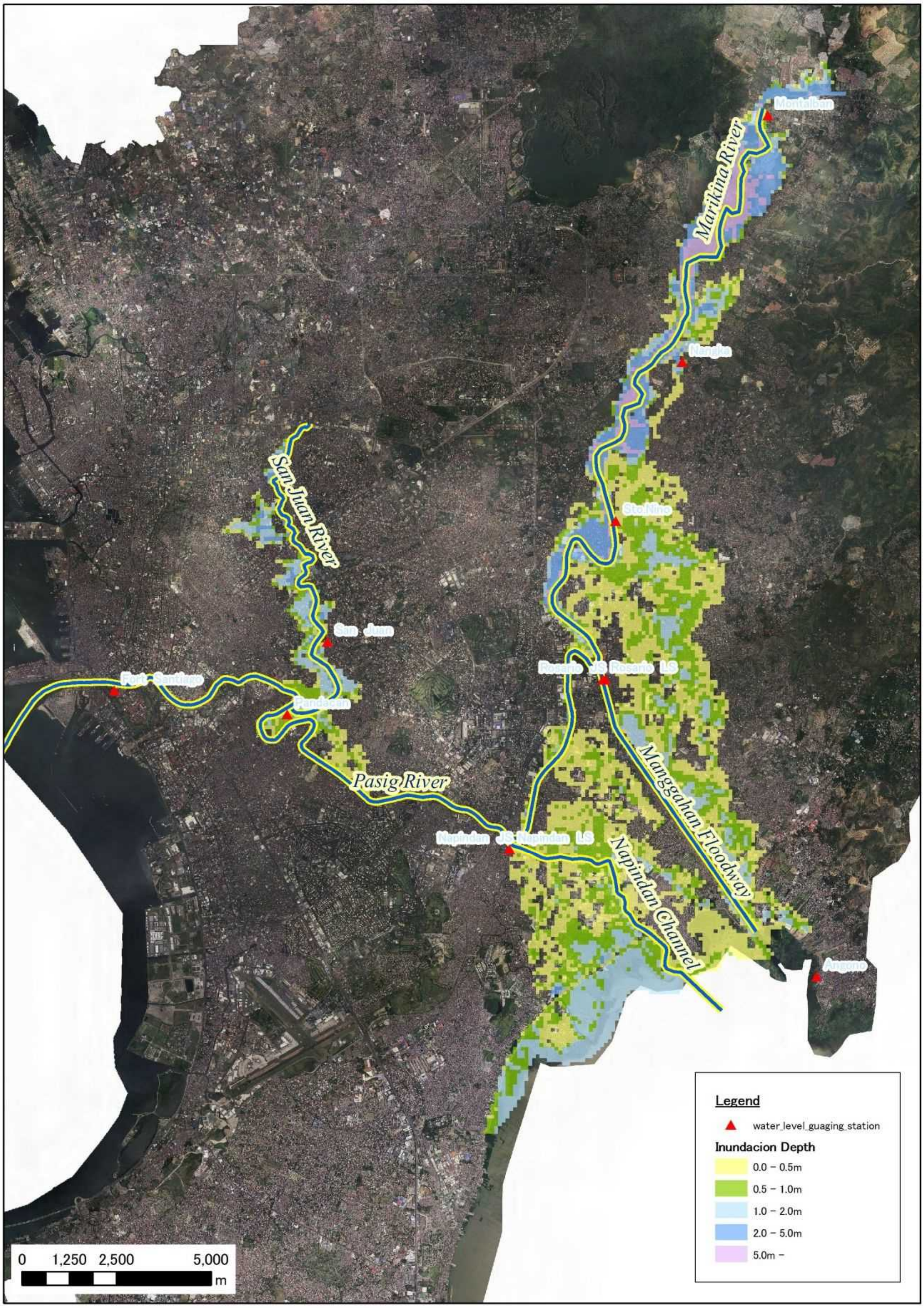
The roughness coefficient was calibrated comparing the observed discharge and water level, and the calculated discharge and water level so that the model can reproduce the peak discharge and rising phase of flood accurately. The comparison of the observed and calculated hydrographs is shown in Figure 3.27. The simulated inundation map is shown in Figure 3.28. Besides, estimated peak discharge is shown in Figure 3.29.



Source: JICA Study Team

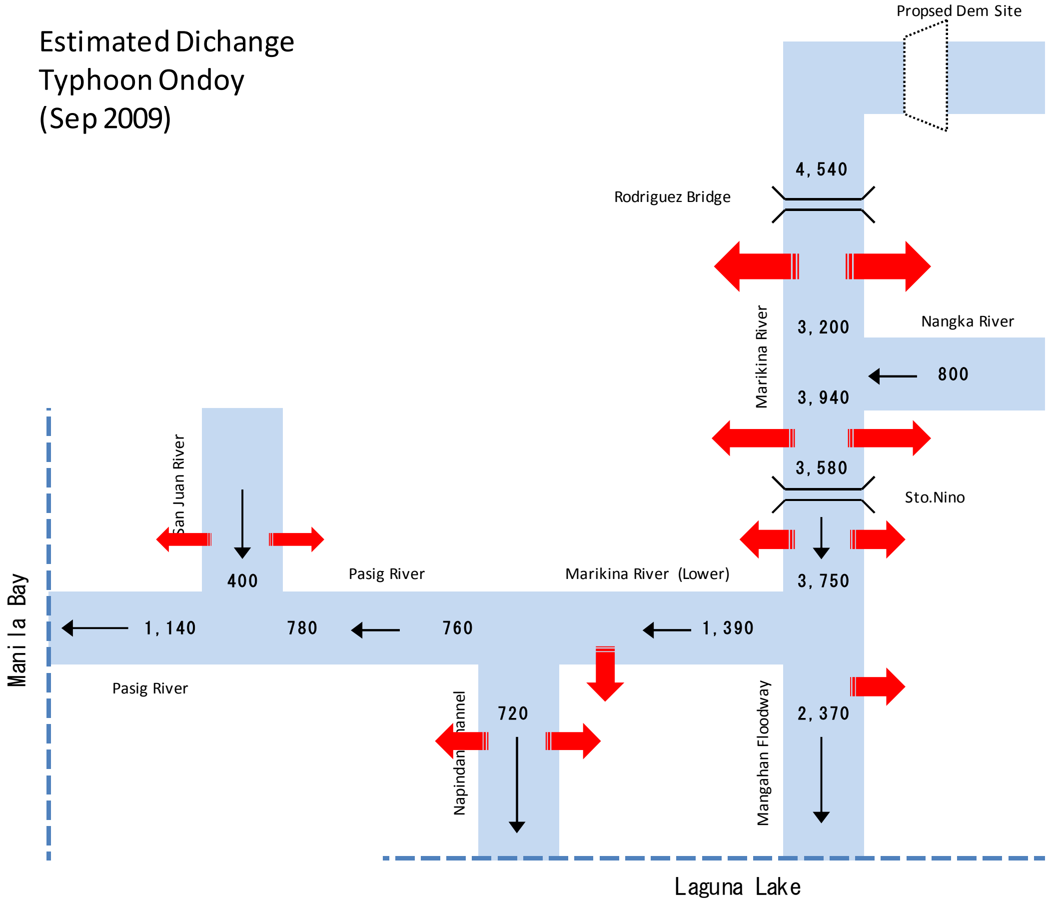
Figure 3.27 Observed and Calculated Hydrographs by Inundation Model (2009 Flood)

2009



Source: JICA Study Team

Figure 3.28 Observed and Calculated Hydrographs by Inundation Model (2009 Flood)



Source: JICA Study Team

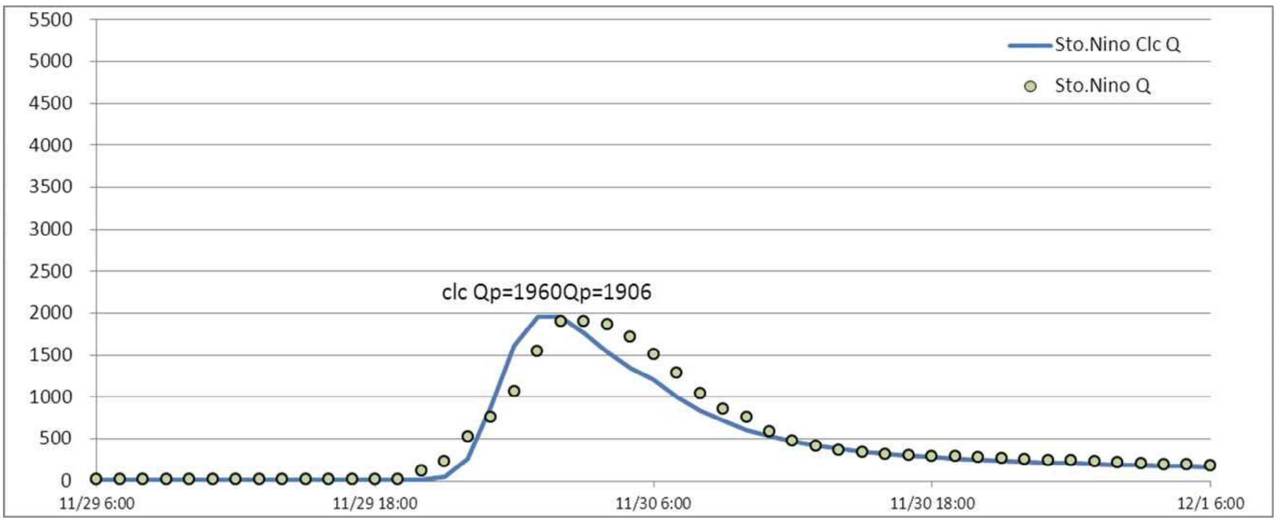
Figure 3.29 Simulated Peak Discharge of 2009 Flood

2) Verification by Flood on November 29-30, 2004

The simulation results of floods on November 29-30, 2004 using the parameters calibrated by the 2009 Flood as shown as below.

<WEB-DHM Model>

The comparison of the observed and calculated hydrographs is shown in Figure 3.30.

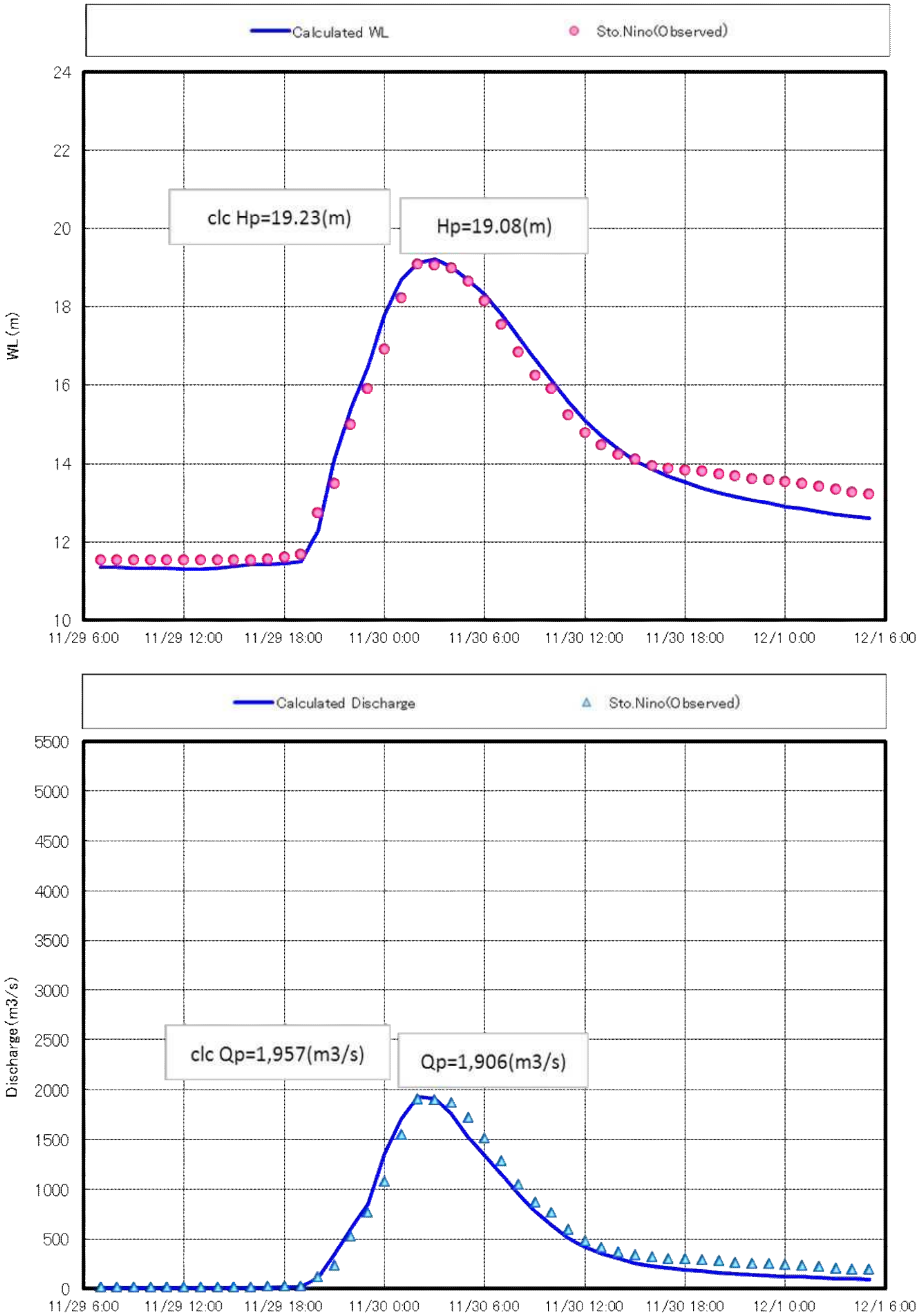


Source: JICA Study Team

Figure 3.30 Observed and Calculated Hydrographs by WEB-DHM Model (2004 Flood)

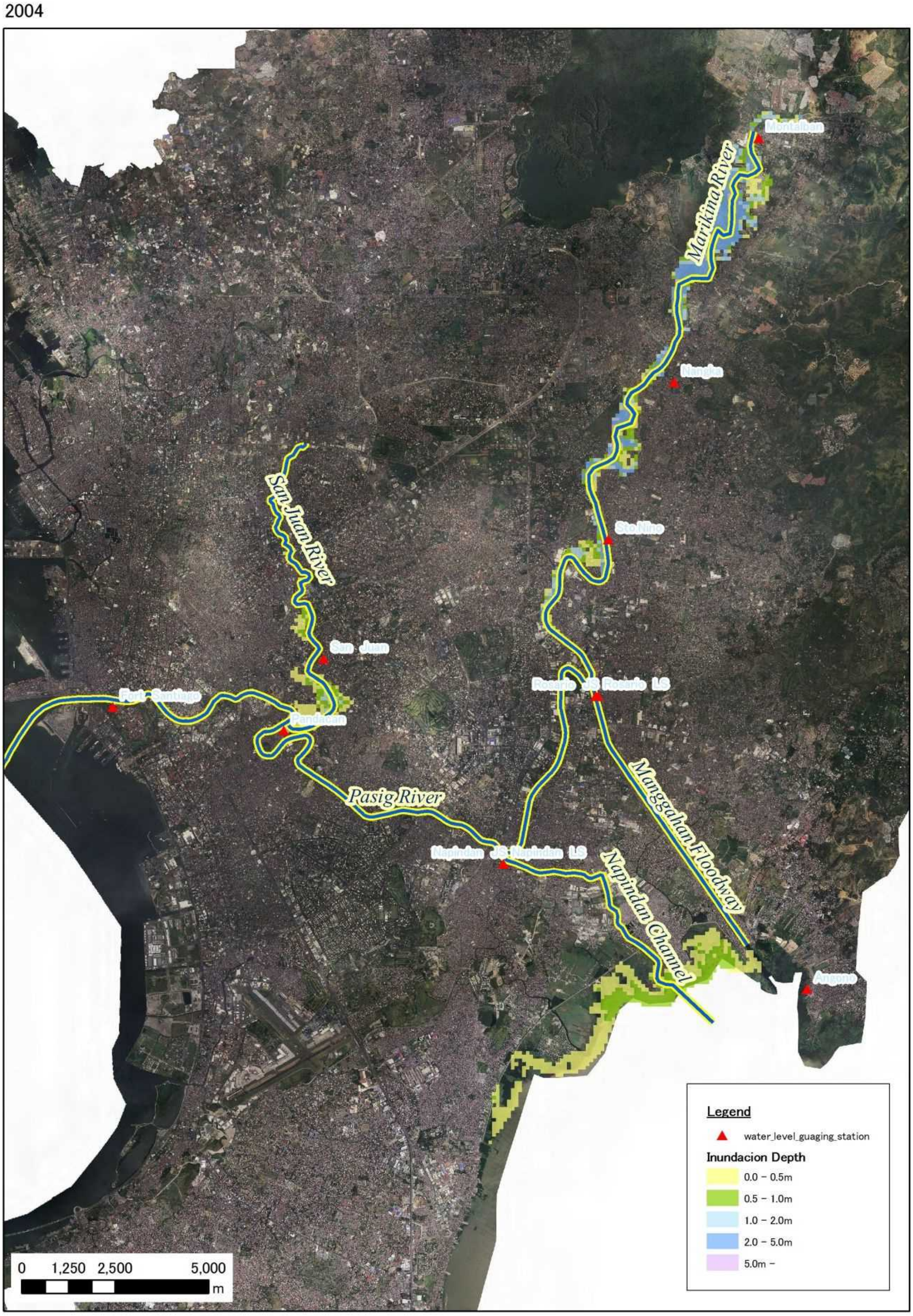
<Inundation Model>

The comparison of the observed and calculated hydrographs is shown in Figure 3.31. The simulated and inundation map is shown in Figure 3.32.



Source: JICA Study Team

Figure 3.31 Observed and Calculated Hydrographs by Inundation Model (2004 Flood)



Source: JICA Study Team

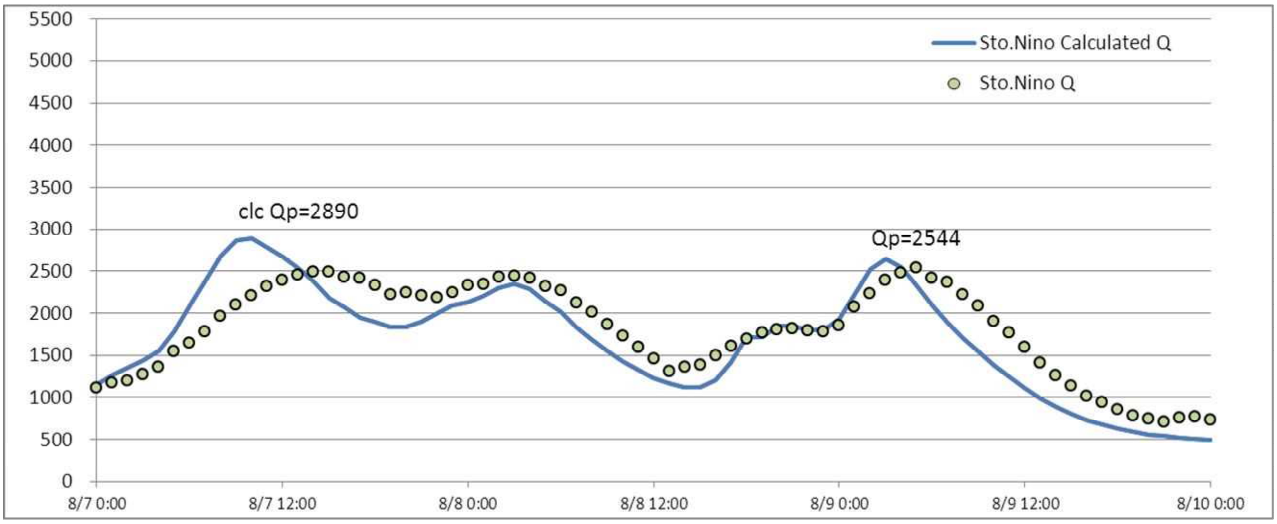
Figure 3.32 Observed and Calculated Hydrographs by Inundation Model (2004 Flood)

3) Verification by Flood on August 7-10, 2012

The simulation results of floods on August 7-10, 2012 using the parameters calibrated by the 2009 Flood as shown as below.

<WEB-DHM Model>

The comparison of the observed and calculated hydrographs is shown in Figure 3.33.

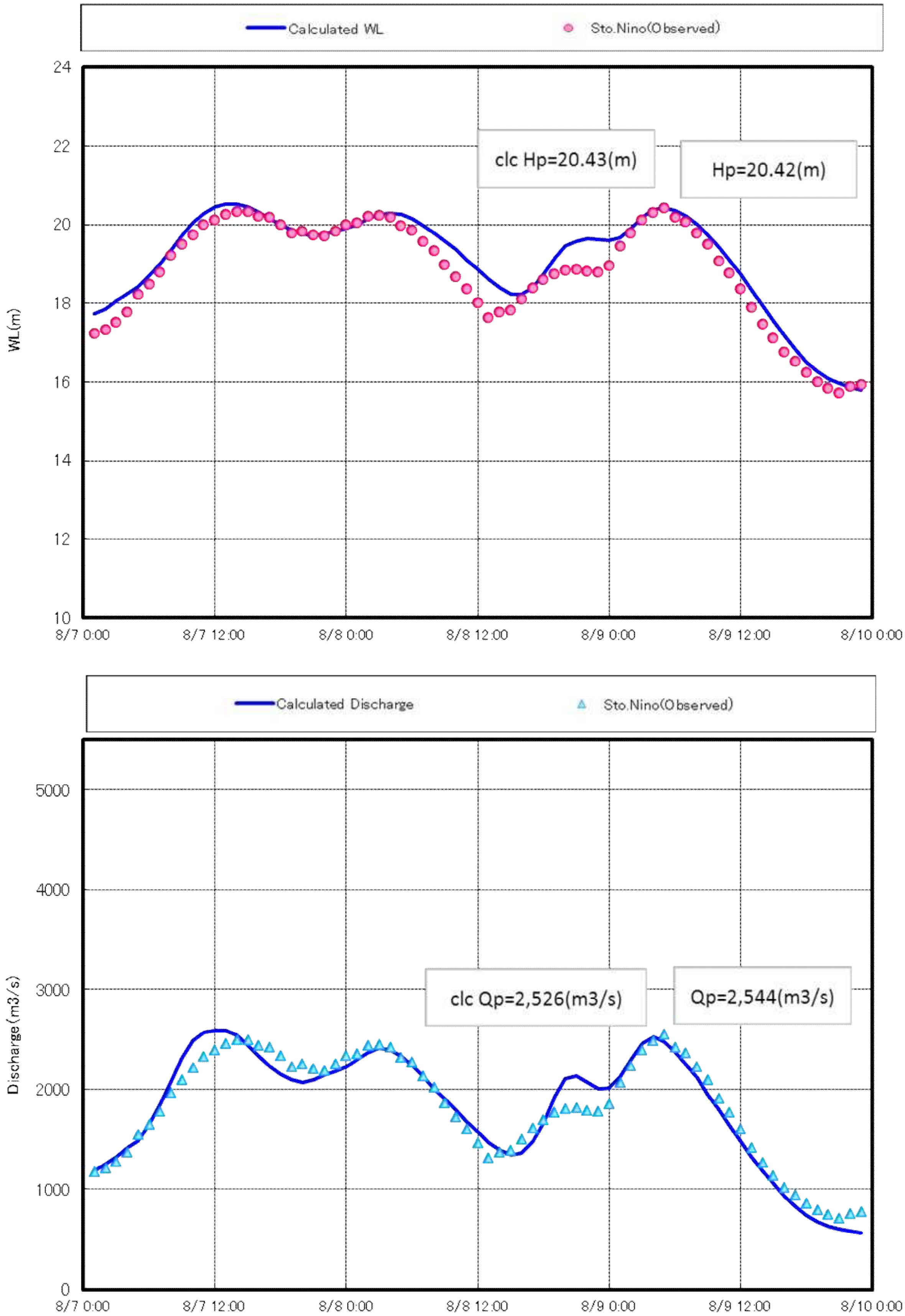


Source: JICA Study Team

Figure 3.33 Observed and Calculated Hydrographs by WEB-DHM Model (2012 Flood)

<Inundation Model>

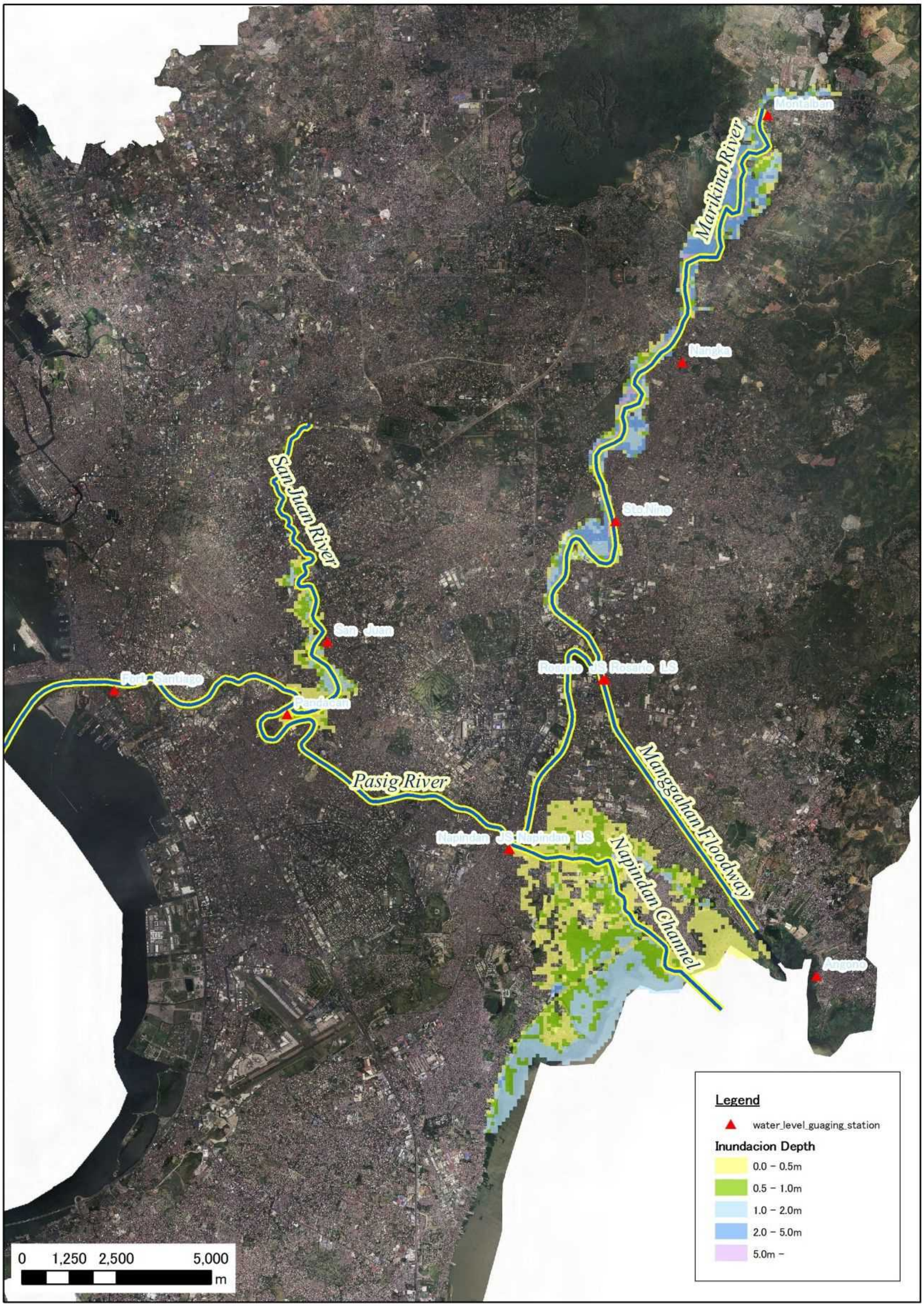
The comparison of the observed and calculated hydrographs is shown in Figure 3.34. The simulated and inundation map is shown in Figure 3.35.



Source: JICA Study Team

Figure 3.34 Observed and Calculated Hydrographs by Inundation Model (2012 Flood)

2012



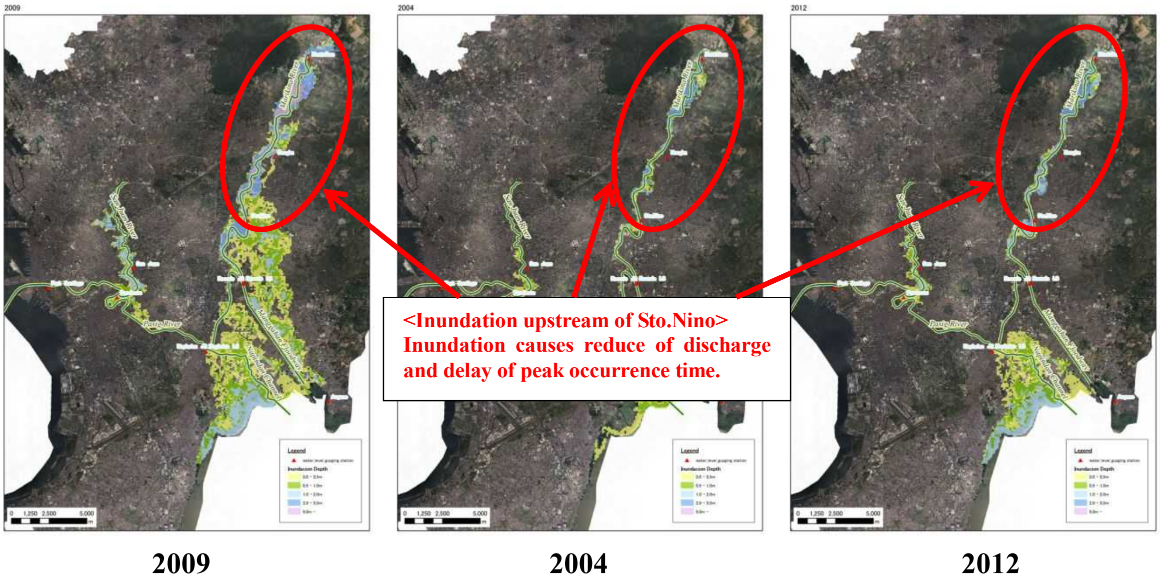
Source: JICA Study Team

Figure 3.35 Observed and Calculated Hydrographs by Inundation Model (2012 Flood)

(3) Evaluation of Analysis Results

By WEB-DHM which calculates discharge to river course as a boundary condition, calculated hydrograph does not meet the observed one. It is because WEB-DHM model calculates discharge before inundation occurs, and discharge inducing inundation as shown in Figure 3.36 cannot be reproduced since reduction of discharge by inundation is not calculated.

Since the calculated hydrographs by the WEB-DHM model meet the observed hydrographs before inundation occurs and hydrographs and peak discharges by the inundation analysis meet well, the runoff analysis results is evaluated as proper.



Source: JICA Study Team

Figure 3.36 Inundation Simulation Results

As described above, the established model integrating the WEB-DHM model and the inundation model shows good reproductivity for the maximum past flood in 2009, relatively small peak flood such as the 2004 Flood and multi-peak flood such as 2012 Flood. Since the model shows good reproductivity for various types of floods, the established flood analysis model is evaluated as proper and utilized to estimate the basic design discharge and the design flood discharge.

CHAPTER 4 ANALYSIS OF DESIGN FLOOD DISCHARGE

4.1 Preconditions for Analysis

As preconditions for analysis of design flood discharge, existing facilities, plans for the "Pasig-Marikina River Channel Improvement Project (Phase III)", design water level in previous studies, current flow capacity, and proposed measures by the "Study on Flood Control and Drainage Project in Metro Manila" (hereinafter referred to as the "JICA M/P Study") and "Master Plan for Flood Management in Metro Manila and Surrounding Areas" (hereinafter referred to as the "WB Study") are confirmed as follows.

4.1.1 Existing Facilities

(1) Manggahan Floodway

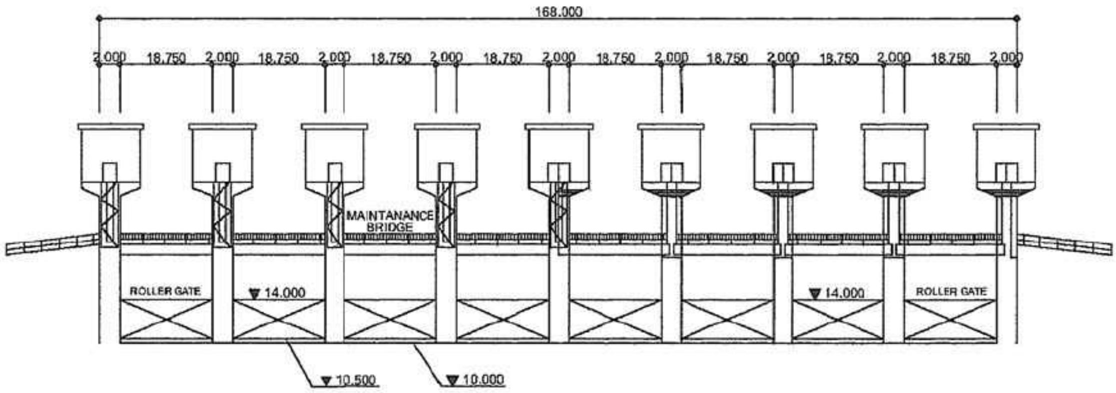
Manggahan Floodway was constructed in 1988 to protect the center of Metro Manila from 100 years probable flood with design discharge of 2,400m^3/s.

Currently, the original flow capacity has been reduced mainly due to informal settler families in the course of floodway and sedimentation.

There are three tributaries to Manggahan Floodway named Cainta, Buli and Maho rivers. However, they will be diverted to East Manggahan Floodway which in under planning.

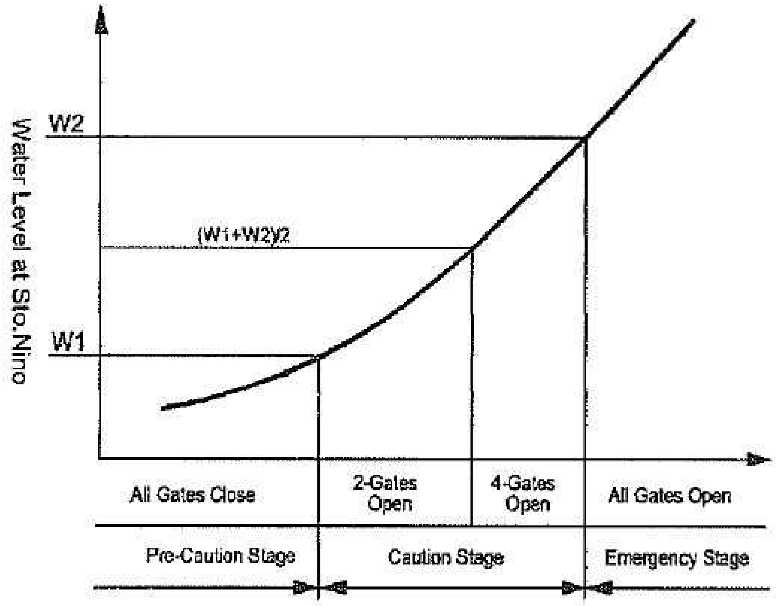
(2) Rosario Weir

Rosario Weir was constructed in 1986 to control diversion between Manggahan Floodway and Pasig-Marikina River. Gate control is conducted to divert a part of flood discharge to Laguna Lake. On the other hand, gate control is also conducted to reduce the water level of Laguna Lake when it is higher than that of Marikina River to protect lakeshore area. It is also has another function to divide Pasig-Marikina Basin and Laguna Lake Basin which is originally different river basins for environmental conservation purpose.



Source: EFCOS

Figure 4.1 Front View of Rosario Weir



Source: EFCOS

Figure 4.2 Operation Rule of Rosario Weir

4.1.2 Current Flow Capacity

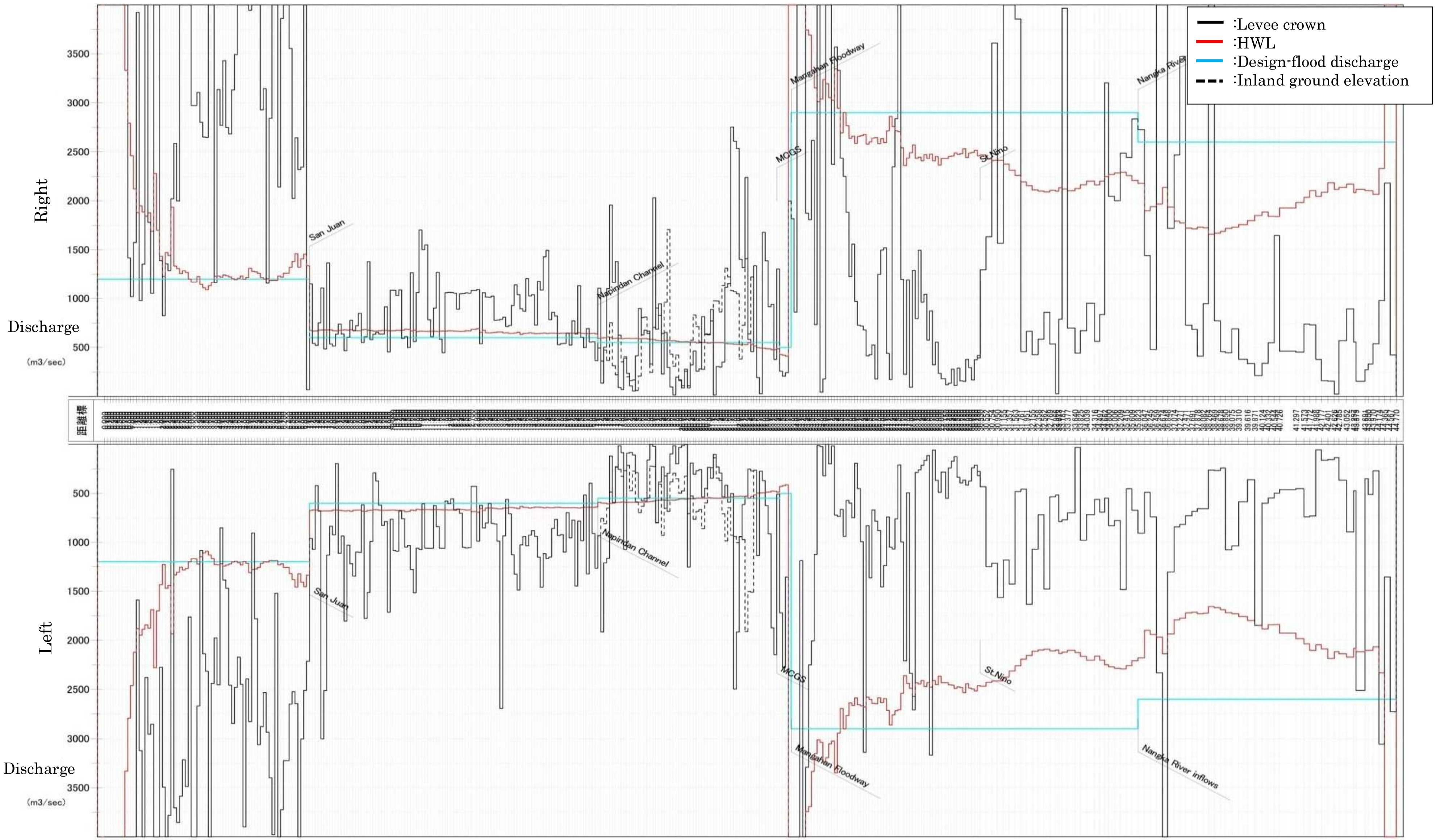
Current flow capacity of Pasig-Marikina is calculated with the conditions shown in Table 4.1. Result is shown in Table 4.2 and Figure 4.3. The average ratio of current flow capacities against design discharges are about 50% in Pasig, 80% in lower Marikina and 20% in upper and upper-upper Marikina. Flood control ratio is especially low in upper and upper-upper Marikina.

Table 4.1 Conditions for Flow Capacity Calculation

Item	Description
Calculation Method	Non-uniform Flow Calculation
River Section	Current Condition as of 2010 with 100 interval
Roughness Coefficient	Pasig (-2.800 k ～17.1k) :n=0.028 Lower Marikina (17.1k～23.700k) :n=0.028 Upper Marikina (23.700k～30.350k) :n=0.028 Upper Upper Marikina (30.350k～44.770k) :n=0.030
Lower End Start W.L.	High Water Level 11.4（-2.800k）
Calculation Case	0.1, 0.2, 0.4, 0.6, 0,8, 1.0, 1.2 and 1.4 times of 30 years probable flood
Evaluated Elevations	Dyke Crest, Land Elevation and HWL

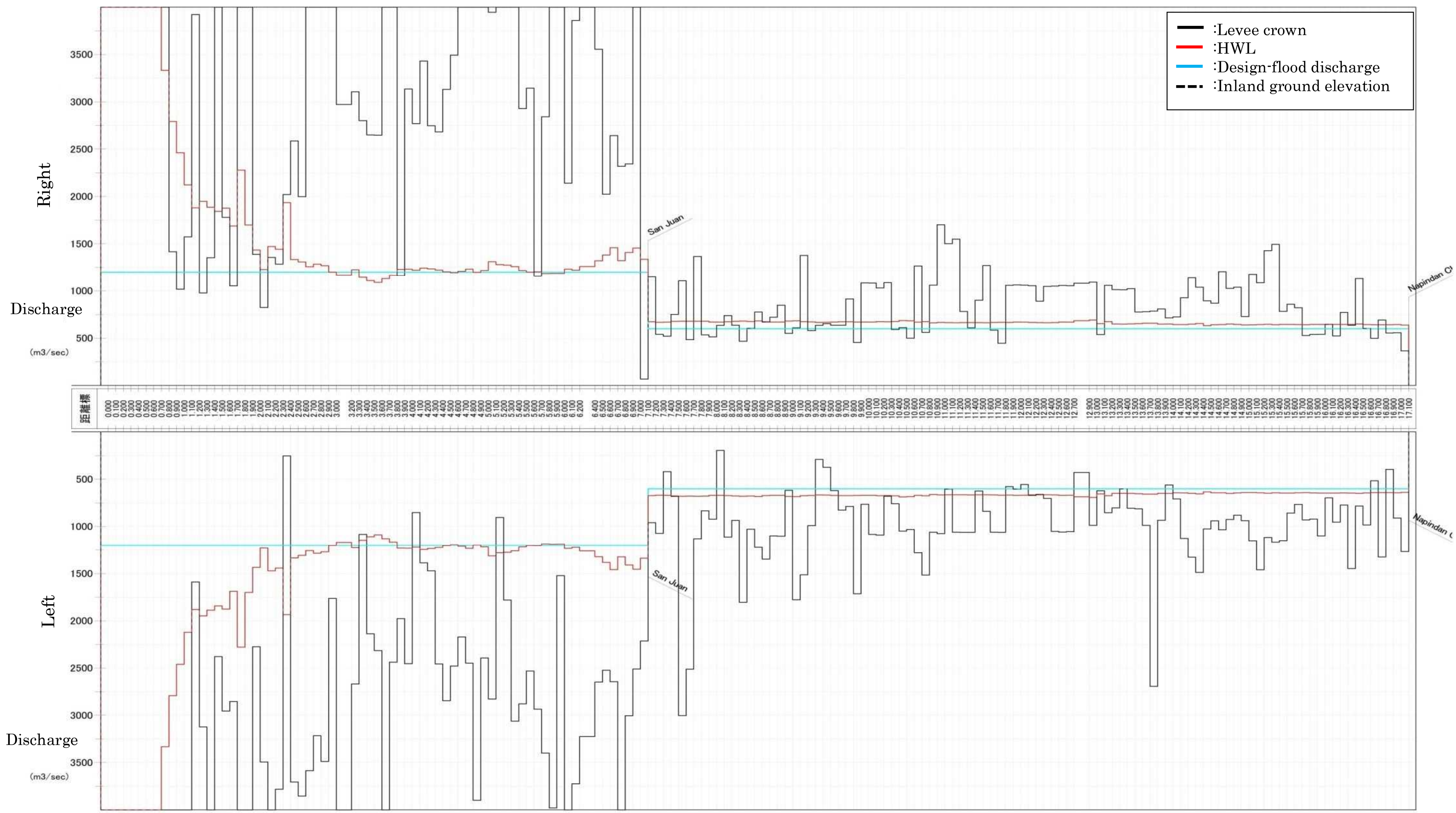
Table 4.2 Results of Flow Capacity Calculation

River Name	Stretch (Km)	Flow Capacity (m^3/s) Present Condition Average	Minimum	Maximum	Design Discharge for PMRCIP(m^3/s)
(1) Pasig River	0.0-1.0	1,200	900	1,500	1200
	1.0-4.0	600	200	1,200	
	4.0-7.0	1,000	600	1,500	
	7.0-17.1	500	200	1,000	600
(2) Lower Marikina	0.0-6.5	400	200	1,000	550
(3) Upper Marikina	6.6-13.2	400	100	2900 以上	2900
(4)Upper Upper Marikina	13.2-27.62	500	50	2900 以上	-



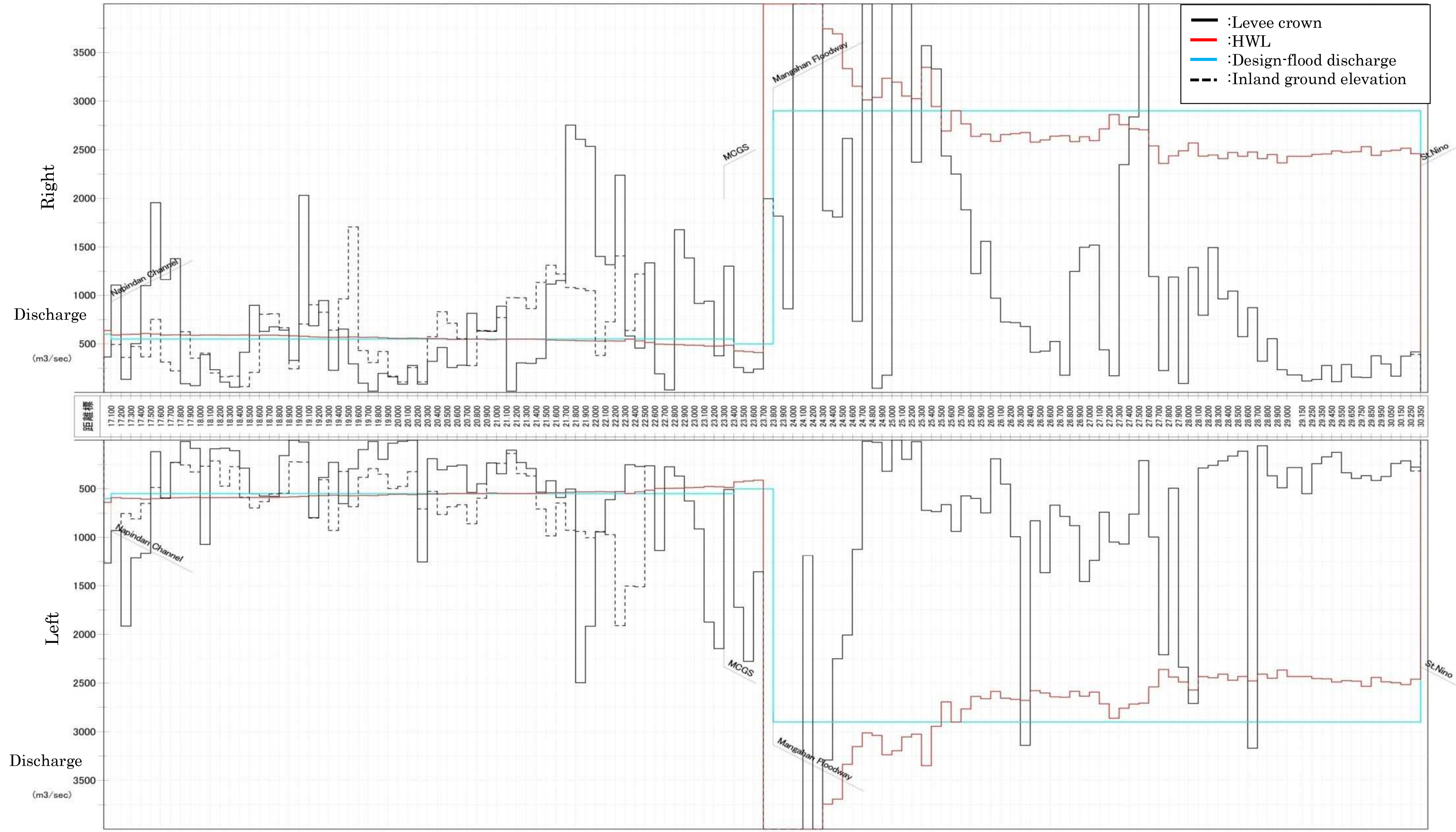
Source: JICA Study Team

Figure 4.3 Current Flow Capacity (Pasig-Marikina River)



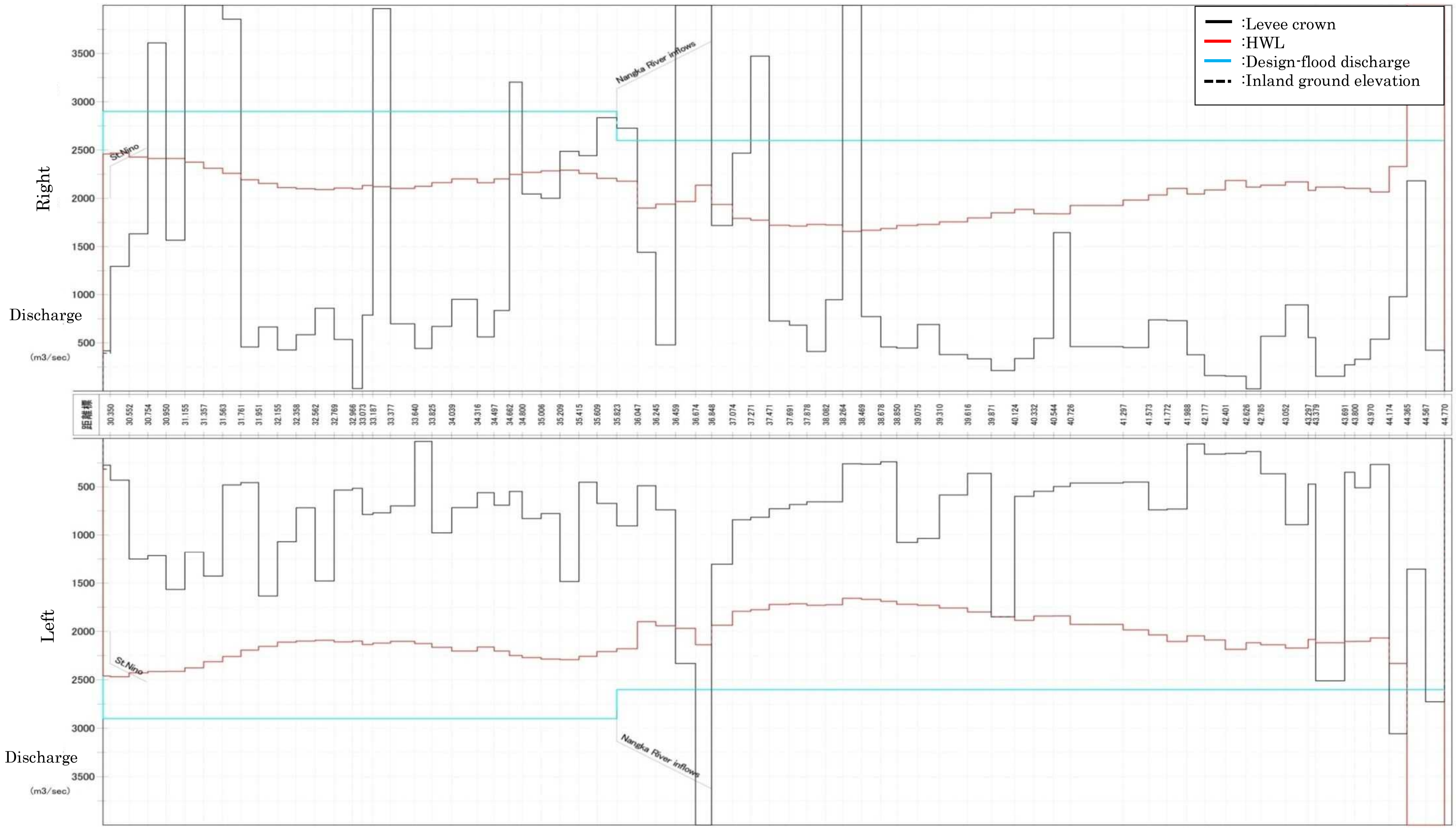
Source: JICA Study Team

Figure 4.4 Current Flow Capacity (Pasig River)



Source: JICA Study Team

Figure 4.5 Current Flow Capacity (Lower and Upper Marikina)



Source: JICA Study Team

Figure 4.6 Current Flow Capacity (Upper-Upper Marikina River)

4.1.3 Proposed Projects by Study on Flood Control and Drainage Project in Metro Manila

The proposed projects by the JICA M/P Study with the objective of 1/100 year probable flood are Markina Dam, MCGS and channel improvement works as summarized in Figure 4.7.

(1) Pasig-Marikina River

a. Channel Improvement

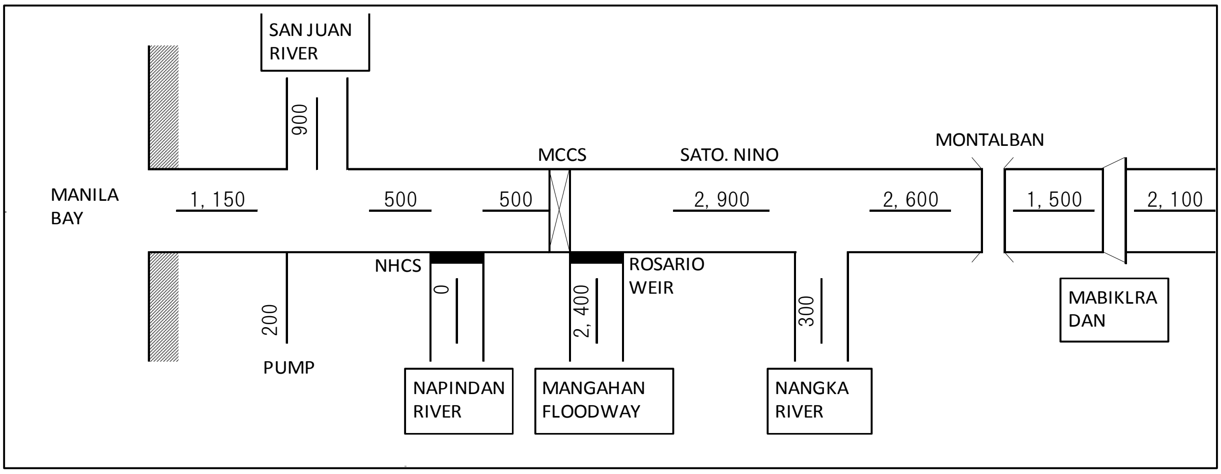
Section	Length (m)	Framework Plan (100 years)		Master Plan (100 years)	
		Design Discharge (m^3/s)	Work Item	Design Discharge	Work Item
Pasig	18,495	1,150	Dredging	Same as Framework Plan	
		500	Rehabilitation		
Lower Marikina	6,790	500	- ditto -	Same as Framework Plan	
Upper Marikina	20,565	2,900	Dredging Dyke	Same as Framework Plan	
San Juan	10,653	900	Dredging	Same as Framework Plan	

b. Strutcures

Strutcture	Framework Plan (100 years)	Master Plan (100 years)
Marikina Control Gate Strutcture (MCGS)	Roller Gate H 10.1m x W 17.5m x 2 units	Same as Framework Plan
Marikina Dam	Concrete Gravity Dam Dam Height 70m Orifice Type Spillway	Same as Framework Plan
Pandakan Bridge (Reconstrutcion)	Steel Plate Girder Span 137.6m x Width 5.4m	Same as Framework Plan

(5) Laguna Lake

Strutcture	Length (m)	Framework Plan	Master Plan
Improvement of Napindan Channel	5,242	Dredging Dyke (Design WL : 12.5m Crest Level : 13.3m)	Dredging Dyke (Design WL : 13.8m Crest Level : 14.6m)
Lakeshore Dyke	10,700	Dyke (Design WL : 12.5m Crest Level : 14.2 m)	Dyke (Design WL : 13.8m Crest Level : 15.5 m)
Panyarake Floodway	9,200	Dredging (Riveebed Width : 60 m)	



Source: The Study on Flood Control and Drainage Project in Metro Manila, JICA

Figure 4.7 Proposed Projects and Design Discharge Allocation by JICA M/P Study

4.1.4 Pasig-Marikina River Channel Improvement Project (Phase III)

Design flood discharge allocation was reviewed in the Preparatory Study for Pasig-Marikina Channel Improvement Project (Phase III) (hereinafter referred to as the JICA Study) in connection with occurrence of Typhoon Ondoy in 2009. The project plan is abstracted as follows.

(1) Objective of Project

1) Objectives of Overall PMRCIP Project

The objectives of the overall project are to mitigate the flood damage caused by channel overflow of the Pasig-Marikina River, to facilitate urban development, and to enhance the favorable environment along the river, as itemized below.

- To mitigate the frequent inundation or massive flooding caused by the overflowing of Pasig-Marikina River resulting in severe damages to lives, livestock, properties and infrastructure with the aim of alleviating the living and sanitary conditions in Metro Manila including parts of Rizal Province;
- To create a more dynamic economy by providing a flood-free urban center as an important strategy for furthering national development; and
- To rehabilitate and enhance the environment and aesthetic view along the riverside areas by providing with more ecologically stable condition which will arrest the progressive deterioration of environmental conditions, health and sanitation in Metro Manila.

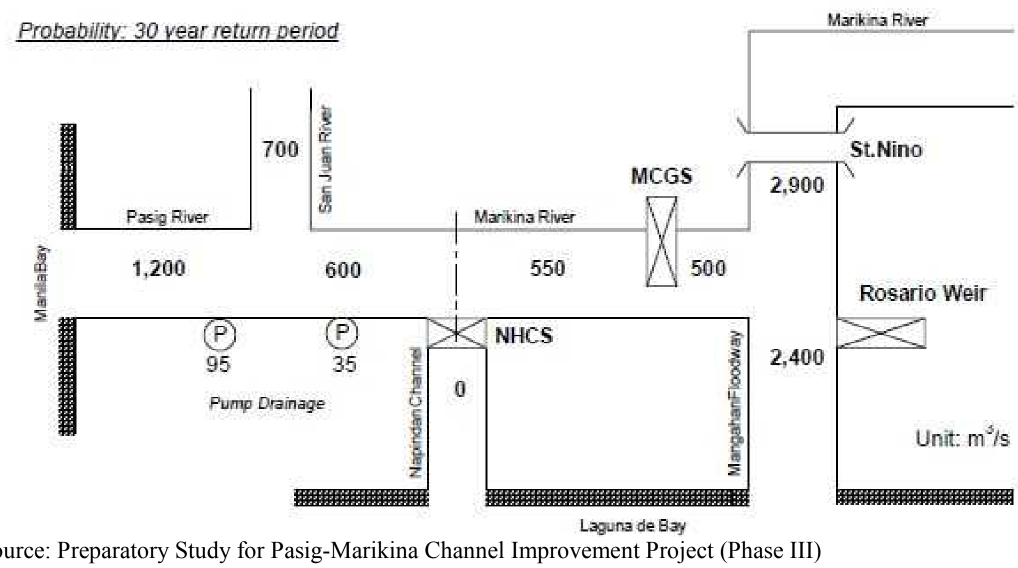
2) Objective of Phase III Project

In the context of the objectives of the overall project, objective of the Phase III Project is to implement the river channel improvement project for the stretch of Lower Marikina River and the remaining portions of Pasig River which are not covered by the ongoing Phase II Project.

(2) Design Flood Discharge

The target area of Phase III Project is the priority area out of potential area in Pasig River and Lower Marikina River. Implementation plan is reviewed considering site conditions based on the detailed design conducted by DPWH in 2002 and its review in 2008.

As urgent flood countermeasure, channel improvement plan was formulated to increase flow capacity to meet 1/30 years flood as shown in Figure 4.8. Based on the condition that MCGS would be constructed in future, design flood discharges are 550m^3/s in Lower Marikina River, 600m^3/s in Upper Pasig River and 1,200m^3/s in Lower Pasig River.



Source: Preparatory Study for Pasig-Marikina Channel Improvement Project (Phase III)

Figure 4.8 Design Flood Discharge Allocation for Phase III Project

(3) Channel Improvement Plan in Pasig and Lower Marikina Rivers

1) Design High Water Level (DHWL)

The applied design high water level for Pasig-Marikina River has been set through the detailed design stage (D/D) in 2002. Before the D/D, the structures provided in the Pasig-Marikina River Channel such as bridges, drainage facilities and navigation facilities were designed with reference to the ground height, recorded maximum flood level and so on around the site of each structure, leading to the provision of so many facilities and structures along the Pasig-Marikina River Channel.

In the detailed design stage, the Design High Water Level was set by mainly considering the following points:

- To minimize the effect to existing river related structures (bridges, drainage facilities, port facilities and navigation facilities).
- To minimize damage in case collapse of dike by minimizing the difference between the ground height and design high water level.
- To keep the design high water level within the recorded maximum flood water.
- To apply the average high spring tide at the design water level of river mouth, which is also the design height of port and coastal facilities.

2) Design Channel Alignment

Metro-Manila has been developed along the Pasig-Marikina river course since the ancient time where the area is fully utilized with houses, factories, commercial buildings and many infrastructures, so that the widening of river channel is almost impossible without drastically setting back the existing buildings or facilities. In this connection, the channel alignment follows the existing awkward river alignment, though it is desirable to modify the existing river alignment to smoothen the design alignment from the flooding point of view. Since this channel alignment set-up in the Detailed Design Stage seems to be the limit, it is assumed that this alignment will be maintained without any change in the future.

3) Design Longitudinal Profiles of Riverbed and DHWL

Pasig River, which is drains into Manila Bay, remarkably receives tidal influence and the flow capacity is not expected to increase so much by dredging and maintenance of the dredged river bed requires maintenance dredging time to time. From this consideration, the design longitudinal profile of riverbed for the Pasig River is based on the existing riverbed.

On the other hand, the riverbed of Lower Marikina River is required to be dredged for about 2m for navigation purpose and maintenance dredging also is required to assure the flow capacity of the Lower Marikina river channel.

4) Design Cross Sections

Since Pasig River runs through the urbanized area of Metro Manila, single section is applied to minimize land acquisition and resettlement. As the results, the lower reach Pasig River of confluence of San Juan River is 100 m as minimum river width except meandering section while the river width of Upper Pasig is 60 m and more. For Lower Marikina River, minimum river width is 90m.

5) Design Freeboard

Freeboard is applied to the design of flood control structures corresponding to the design discharge in accordance with the “Design Guidelines, Criteria and Standard” of DPWH, as shown in Table 4.3. Since design discharge is more than 500m^3/s in whole section, freeboard of 1.0m is applied.

Table 4.3 Design Freeboard

Design Discharge (m^3/s)	Freeboard (m)
Less than 200	0.6
200～500	0.8
500～2,000	1.0

6) Confirmation of Flow Capacity for Improved River Channel and Limit of River Channel Improvement

The flow capacity based on the design water level, dyke height, channel alignment, cross section and riverbed level which are set by above mentioned procedures was examined by non-uniform calculation and it was confirmed that the flow capacity corresponds to the design discharge distribution under a 30-year return period flood, if MCGS is constructed.

The design features for the river channel improvement expressed by the design high water level, alignment, longitudinal profile and cross-section is almost the limit for the Pasig-Marikina River and further improvement is difficult so that it will be difficult also to increase the flow capacity in a manner of river channel improvement. In this connection, it would be necessary to provide storage facilities in the upper river basin such as dam and retarding basin to store the excess discharge, and to further enhance the safety level as well as introduce nonstructural measures in the Pasig-Marikina River basin.

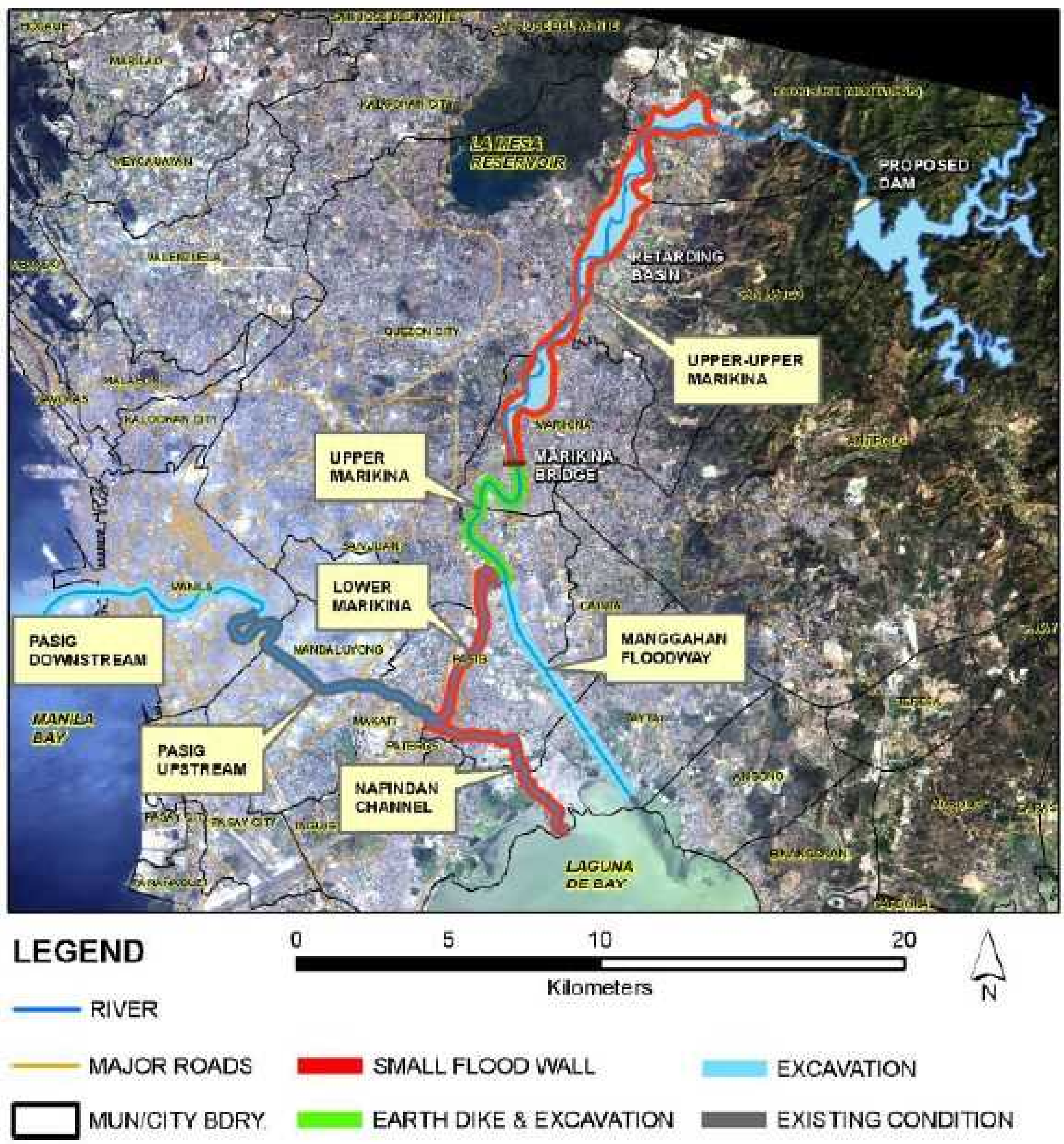
4.1.5 Proposed Projects by WB Study

The Proposed projects by the WB Study is as summarized in Table 4.4 and Figure 4.11 consisting the improvement of Upper and Upper-Upper Marikina River, Marikina Large Dam, re-improvement of Pasig River and Lower Marikina River and improvement of San Juan River and Napindan Channel with design flood discharge of 1/100 years return period. In the WP Plan, the current diversion system using both Manggahan Floodway and Napindan Channel is applied without construction of MCGS, which is against the concept of PMRCIP. This plan has several critical issues such as large scale dredging in lower Pasig resulting high maintenance cost required, re-improvement works are required such as heightening of dykes and bridges in Lower Marikina and uncertainty of natural diversion from Pasig to Laguna Lake through NHCS.

In the planning, 4 alternative plans shown in Table 4.5 and Figure 4.12 and 4.13 were compared and the Alternative-2 was selected.

Table 4.4 Proposed Projects by WB Study

Item	Description
Target Year	2035
Design Scale	1/100 years
Components	1) Improvements of the Upper and Upper Upper Marikina River (upstream from bifurcation of Manggahan Floodway to the existing Wawa Dam) 2) Construction of Marikina Large Dam 3) Re-improvement of the Pasig River and Lower Marikina River and improvement of the San Juan River and the Napindan Channel
Project Cost	198,435 Mil. Pesos



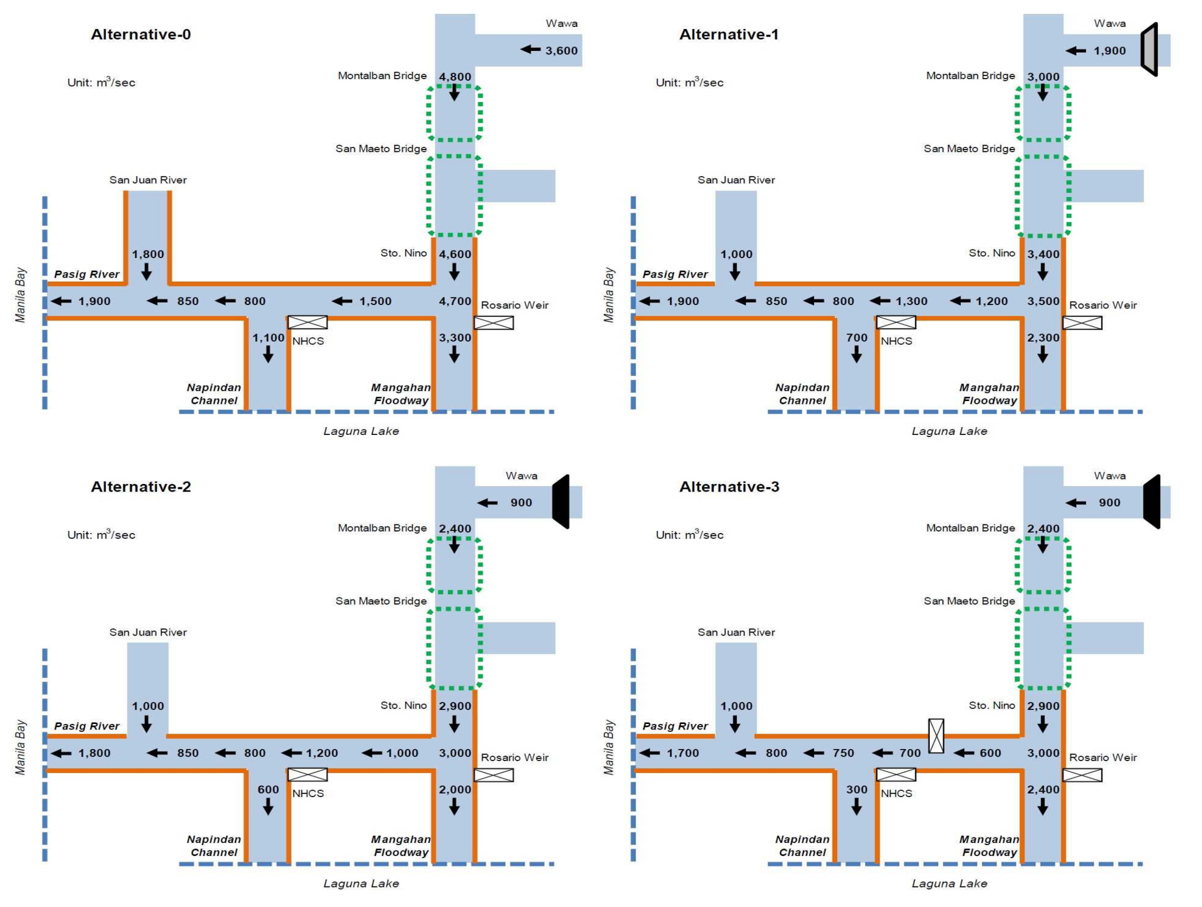
Source: Master Plan for Flood Management in Metro Manila and Surrounding Areas, the World Bank

Figure 4.9 Proposed Projects by WB Study

Table 4.5 Alternative Plans by WB Study

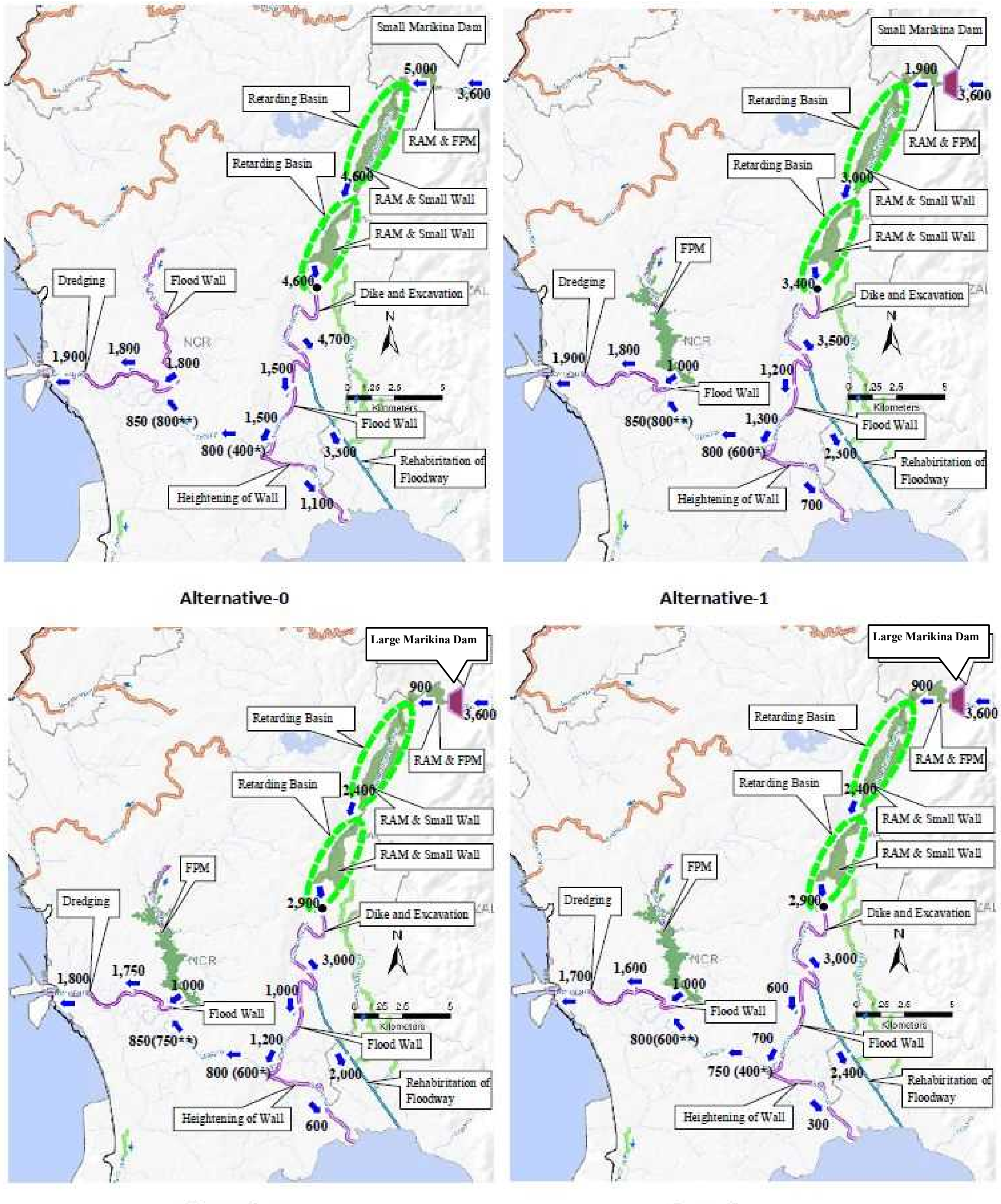
Alternatives	Item	Pasig Downstream*	Pasig Upstream**	Napindan Channel	Lower Marikina	Mangahan Floodway	Upper Marikina	Upper Upper Marikina	Project Cost (mil. Peso)
		River mouth to the Confluence of San Juan R.	The confluence of San Juan R. to Napindan Channel	Napindan Gate to the Laguna Lake	The confluence of Napindan Channel to the Rosario Weir	Rosario Weir to the Laguna Lake	Rosario Weir to Marikina Bridge	Upstream from Marikina Bridge	
Alt-0	RI & RTB	Exca.,River Widening(more than 130m in width), and Reconstruction of Dikes	Exca., River Widening (more than 130m in width), and Reconstruction of Dikes	Flood Wall Enhancement (Heightening: 1m to 30 cm)	River Widening (more than 120m) and Flood Wall (2m to 3m)	Exca. and Widening (more than 270m)	Exca., Flood Wall and Widening (more than 140m)	RTB and Excavation	444,041
Alt-1	RI,RTB, Small Dam	Exca. (Channel Width: 90m)	Existing Condition (Channel Width: 90m)	Flood Wall Enhancement (Heightening: 1m to 30 cm)	Flood Wall (0.8m to 2.4m)	Exca. (removal of sedimentation)	Dike and Exca. (Width: 90m)	RTB, Small Dam, Small Concrete Wall	202,094
Alt-2	RI, RTB, Large Dam	Exca. (Channel Width: 90m)	Existing Condition (Channel Width: 90m)	Flood Wall Enhancement (Heightening: 1m to 30 cm)	Flood Wall (0.8m to 2.0m)	Exca. (removal of sedimentation)	Dike and Exca. (Width: 90m)	RTB, Large Dam, Small Concrete Wall	198,435
Alt-3	RI, RTB, Large Dam and MCGS	Exca. (Channel Width: 90m)	Existing Condition (Channel Width: 90m)	Flood Wall Enhancement (Heightening: 1m to 30 cm)	MCGS	Exca. (removal of sedimentation)	Dike and Exca. (Width: 90m)	RTB, Large Dam, Small Concrete Wall	208,776

RI: River improvement, RTB: Retarding Basin, MCGS: Marikina Control Gate Structure, Exca: Excavation
*: River mouth to the Junction of San Juan and Pasig River, **: Upstream from the Junction,
Small Dam: 47 MCM Gross Storage Volume, Large Dam: 75 MCM Gross Storage Volume
Source: Master Plan for Flood Management in Metro Manila and Surrounding Areas, the World Bank



Source: Master Plan for Flood Management in Metro Manila and Surrounding Areas, the World Bank

Figure 4.10 Alternatives for Design Flood Discharge Allocation



Note: Values show peak discharge (m^3/s) for 100-year return period of floods by 2 days rainfall
*Discharge at the same timing of peak discharge of Lower Marikina River upstream of Jct. Napindan
**Discharge at the same timing of peak discharge of the San Juan River

Source: Master Plan for Flood Management in Metro Manila and Surrounding Areas, the World Bank

Figure 4.11 Alternative Plans by WB Study

4.1.6 Comparison of Previous Studies

Analysis methods and plans for the JICA Study and the WB Study were compared as shown in Table 4.6

Table 4.6 Comparison of Previous Studies

<table>
<tr><th></th><th>Preparatory Survey on Pasig-Marikina River Channel Improvement Project (Phase III) (JICA)</th><th>Master Plan for Flood Management in Metro Manila and Surrounding Areas（WB）</th></tr>
<tr><td>Design Hyetograph</td><td>Middle-peak Fictional Hyetograph
➢ Hyetograph based on probable rainfall intensities by rainfall durations of Port Area</td><td>Type 1: Typhoon Ondoy Type
➢ Observed Hyetograph
Type 2: Middle-peak Fictional Hyetograph
➢ Hyetograph based on probable rainfall intensities by rainfall durations of Port Area</td></tr>
<tr><td>Estimation of Basin Average Rainfall</td><td>Rainfall at Port Area x Rainfall Adjustment Coefficient
➢ Estimated as uniform rainfall in whole area</td><td>Type 1: Typhoon Ondoy Type
➢ Thiessen Method and Adjustment by IDW Method
➢ Estimated each 34 Thiessen Polygon
Type 2: Middle-peak Fictional Hyetograph
➢ IDW Method
➢ Estimated for 3 Sub-basins</td></tr>
<tr><td>Basin Average Probable Rainfall</td><td>Whole Basin (2 days)
・30 years 392.3mm
・100 years 445.8mm</td><td>Type 1: Typhoon Ondoy Type
➢ Observed 2 days rainfall x Enlargement Ratio
➢ Estimated each 34 Thiessen Polygon
➢ 3 Sub-basin Average Rainfall (Trial by WB Study)
<table>
<tr><th>Return Period</th><th>Probable 2 days Rainfall</th><th></th><th></th></tr>
<tr><td></td><td>SB-01</td><td>SB-02</td><td>SB-31</td></tr>
<tr><td>30</td><td>368</td><td>369</td><td>390</td></tr>
<tr><td>100</td><td>439</td><td>444</td><td>468</td></tr>
</table>
Type 2: Middle-peak Fictional Hyetograph
➢ Estimated for 3 Sub-basins
<table>
<tr><th>Return Period</th><th>Probable 2 days Rainfall</th><th></th><th></th></tr>
<tr><td></td><td>SB-01</td><td>SB-02</td><td>SB-31</td></tr>
<tr><td>30</td><td>368</td><td>366</td><td>382</td></tr>
<tr><td>100</td><td>438</td><td>441</td><td>458</td></tr>
</table></td></tr>
<tr><td>Probable Discharge at St.Nino</td><td>Annual highest water level in 1958-77, 1086 and 1994-2009 are converted by H-Q Equations.
H-Q Equations:
➢ $Q = 32.03 \times (H-10.80)2$ $H < 17.0$
➢ $Q = 17.49 \times (H-8.61)^2$ $H > 17.0$

Peack Discharge by Ondoy Typhoon (2009)
➢ 3,211m^3/sec

Probability Analysis of Annual Peak Discharge
➢ 30 Years: 2,750 m3/sec
➢ 100 Years: 3,390 m^3 /sec
Probable Discharge in Previous Study
➢ 30 Years: 2,900 m3/sec
➢ 100 Years: 3,500 m^3 /sec</td><td>Annual highest water level in 1958-77, 1086 and 1994-2009 are converted by H-Q Equations.
H-Q Equations:
➢ $Q = 31.44 \times (H-10.96)2$ $H > 13.0$

Peack Discharge by Ondoy Typhoon (2009)
➢ 3,950 m^3/sec

Probability Analysis of Annual Peak Discharge
➢ (None)</td></tr>
<tr><td>Runoff Anlysis</td><td>Rainfall-Runoff Model
➢ Storage Function Method: Mountanious Area
➢ Quasilinier Storage Type: Urbanized Area

Calibration and Verification of Model Parameters
➢ 2 fllods in 2004 was reproduced.
➢ Model parameters were calibrated to conform calculated hydrograph to observed discharge.
➢ Parameters for Storage Function Method (delay factors) were determined based on previous model.</td><td>Integrated Analysis Model of Basin, River and Flood Plains
➢ Basin: Rainfall-Runoff Model (SCS Unit Hydrograph Method)
➢ River: One-dimensional Unsteady Flow Model
➢ Flood Plain: Two-dimensional Unsteady Flow Model

Calibration and Verification of Model Parameters
➢ Flood by Ondoy Typhoon was reproduced.
➢ Model parameters were calibrated to conform calculated hydrograph to observed peak discharge and water level.
➢ Model was verified by reproducing 2004 flood and 1998 flood.</td></tr>
<tr><td>Inundation Analysis</td><td>Inundation Alaysis Model
➢ River: One-dimensional Unsteady Flow Model
➢ Flood Plain: Two-dimensional Unsteady Flow</td><td>Integrated Analysis Model of Basin, River and Flood Plains
➢ Flood by Ondoy Typhoon was reproduced.</td></tr>
</table>

<table>
<tr><th></th><th>Preparatory Survey on Pasig-Marikina River Channel Improvement Project (Phase III) (JICA)</th><th>Master Plan for Flood Management in Metro Manila and Surrounding Areas（WB）</th></tr>
<tr><td></td><td>Model
➢ Flood by Ondoy Typhoon was reproduced.
➢ Simulation results were well conformed with interview survey results.

Flood management effects of River Chasnnel Improvement Project Phases II & III and Manggahan Floodway was examined.</td><td>➢ Simulation results were well conformed with inundation map based on flood damage survey.</td></tr>
<tr><td>Runoff Calculation of Design Rainfalls</td><td>Probable Discharge at Sto.Nino
➢ 30 Years: 2,740 m^3/sec
➢ 100 Years: 3,210 m^3/sec
➢ No overflow from river course was assumed.</td><td>Probable Discharge at Sto.Nino
➢ 30 Years: 3,600 m^3/sec
➢ 100 Years: 4,100 m^3/sec
➢ Overflow from river course was assumed.
➢ In the section between confluence of Nangka River and Rosario Weir in Marikina River, large scale overflow and inundation due to dike break was assumed.</td></tr>
<tr><td>Design Discharge Allocation</td><td>➢ Discharge Allocation of 100 Years Return Period Discharge with Only River Channel Improvement Works (Without MCGS)

<table>
<tr><th>Section</th><th>Q(m^3/s)</th></tr>
<tr><td>Wawa</td><td>1,890</td></tr>
<tr><td>Rodoriges Bridge</td><td>2,500</td></tr>
<tr><td>Before Nangka River</td><td>2,850</td></tr>
<tr><td>St. Nino</td><td>3,210</td></tr>
<tr><td>Mangahan Floodway</td><td>2,100</td></tr>
<tr><td>Lower Marikina River</td><td>1,130</td></tr>
<tr><td>Napindan Channel</td><td>0</td></tr>
<tr><td>Pasig River</td><td>1,155</td></tr>
<tr><td>San Juan River</td><td>770</td></tr>
<tr><td>Pasig River – Manila Bay</td><td>1,400</td></tr>
</table>

➢ Based on flood runoff analysis, previous discharge allocation was applied for Phase III Project
➢ Measures against 30 Years Flood: River Channel Improvement & MSGS (Not to be implemented in Phase III Project)

➢ Discharge Allocation of 30 Years Return Period Discharge (Without MCGS)

<table>
<tr><th>Section</th><th>Q(m^3/s)</th></tr>
<tr><td>Wawa</td><td>1,590</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Rodoriges Bridge</td><td>2,110</td></tr>
<tr><td>Before Nangka River</td><td>2,420</td></tr>
<tr><td>St. Nino</td><td>2,740</td></tr>
<tr><td>Mangahan Floodway</td><td>1,820</td></tr>
<tr><td>Lower Marikina River</td><td>920</td></tr>
<tr><td>Napindan Channel</td><td>0</td></tr>
<tr><td>Pasig River</td><td>955</td></tr>
<tr><td>SanJuan River</td><td>690</td></tr>
<tr><td>Pasig River – Manila Bay</td><td>1,210</td></tr>
</table>
</td><td>➢ Discharge Allocation of 100 Years Return Period Discharge with Only River Channel Improvement Works (Alternative 0)

<table>
<tr><th>Section</th><th>Q(m^3/s)</th></tr>
<tr><td>Wawa</td><td>3,600</td></tr>
<tr><td>Montalban Bridge</td><td>4,800</td></tr>
<tr><td>(Retarding Basin)</td><td></td></tr>
<tr><td>St. Nino</td><td>4,600</td></tr>
<tr><td>Mangahan Floodway</td><td>3,300</td></tr>
<tr><td>Lower Marikina River</td><td>1,500</td></tr>
<tr><td>Napindan Channel</td><td>1,100</td></tr>
<tr><td>Pasig River</td><td>850</td></tr>
<tr><td>San Juan River</td><td>1,800</td></tr>
<tr><td>Pasig River – Manila Bay</td><td>1,900</td></tr>
</table>

➢ Alternative 2 consisting of the following measures against 100 years return period flood was recommended.
- River Channel Improvement
- Marikina Dam
- Retarding Basins
- Non-structural Measures

➢ Discharge Allocation of 100 Years Return Period Discharge (Alternative 2)

<table>
<tr><th>Section</th><th>Q(m^3/s)</th></tr>
<tr><td>Wawa</td><td>3,600</td></tr>
<tr><td>Marikina Dam</td><td>900</td></tr>
<tr><td>Montalban Bridge</td><td>2,400</td></tr>
<tr><td>(Retarding Basin)</td><td></td></tr>
<tr><td>St. Nino</td><td>2,900</td></tr>
<tr><td>Mangahan Floodway</td><td>2,000</td></tr>
<tr><td>Lower Marikina River</td><td>1,000</td></tr>
<tr><td>Napindan Channel</td><td>600</td></tr>
<tr><td>Pasig River</td><td>850</td></tr>
<tr><td>SanJuan River</td><td>1,000</td></tr>
<tr><td>Pasig River – Manila Bay</td><td>1,800</td></tr>
</table>
</td></tr>
</table>

Source: Study of Water Security Master Plan for Metro Manila and its Adjoining Areas

4.2 Review of Rainfall Analysis

4.2.1 Results of Rainfall Analysis

Conditions for calculation and its results as 30 years and 100 years return periods rainfall which obtained by the Study of Water Security Master Plan for Metro Manila and its Adjoining Areas (hereinafter referred to as the JICA Water Security Study) are summarized in Table 4.7, Table 4.9 to 4.11 and Figure 4.14 and 15 while the rainfall analysis results in the previous studies are shown in Table 4.8.

The JICA Water Security Study applied 1 day rainfall based on the analysis for correlation between rainfall duration and peak water level at Sto.Nino, while the previous studies applied 2 days rainfall.

Besides, the JICA Water Security Study applied several design hyetographs based on the observed hyetographs while the previous studies applied only milled-peak fictional hyetograph and the hyetograph of Typhoon Ondoy.

Table 4.7 Summary of Rainfall Analysis

Item	Description
Control Point	Sto. Nino
Duration of Design Rainfall	1 day (based on available data set and reasonableness of peak discharge occurrence)
Flood Concentration Time	11 hours (Method using Observation Data: 11 hours, Empirical Formula:7 hours)
Probable Rainfall	1/100: 285.5mm/1day (Typhoon type rainfall N=58, Gumbel Distribution) (1/30: 232.4mm/day) (Refer to Table 3.5)
Design Hyetographs	Enlarge of past actual hyetographs (7 hyetographs considering spatial variations) Fictional hyetograph (Middle-peak distribution without consideration of spatial variations) (Refer to Table 3.6, Table 3.7 and Figure 3.4)

Source: JICA Study Team based on Study of Water Security Master Plan for Metro Manila and its Adjoining Areas

Table 4.8 Comparison of Rainfall Analysis in Previous Studies

<table>
<tr><th></th><th>Preparatory Survey on Pasig-Marikina River Channel Improvement Project (Phase III) (JICA)</th><th>Master Plan for Flood Management in Metro Manila and Surrounding Areas（WB）</th></tr>
<tr><td>Design Hyetograph</td><td>Middle-peak Fictional Hyetograph
➢ Hyetograph based on probable rainfall intensities by rainfall durations of Port Area</td><td>Type 1: Typhoon Ondoy Type
➢ Observed Hyetograph
Type 2: Middle-peak Fictional Hyetograph
➢ Hyetograph based on probable rainfall intensities by rainfall durations of Port Area</td></tr>
<tr><td>Estimation of Basin Average Rainfall</td><td>Rainfall at Port Area x Rainfall Adjustment Coefficient
➢ Estimated as uniform rainfall in whole area</td><td>Type 1: Typhoon Ondoy Type
➢ Thiessen Method and Adjustment by IDW Method
➢ Estimated each 34 Thiessen Polygon
Type 2: Middle-peak Fictional Hyetograph
➢ IDW Method
➢ Estimated for 3 Sub-basins</td></tr>
<tr><td>Basin Average Probable Rainfall</td><td>Whole Basin (2 days)
・30 years 392.3mm
・100 years 445.8mm</td><td>Type 1: Typhoon Ondoy Type
➢ Observed 2 days rainfall x Enlargement Ratio
➢ Estimated each 34 Thiessen Polygon
➢ 3 Sub-basin Average Rainfall (Trial by WB Study)
<table>
<tr><td>Return Period</td><td colspan="3">Probable 2 days Rainfall</td></tr>
<tr><td></td><td>SB-01</td><td>SB-02</td><td>SB-31</td></tr>
<tr><td>30</td><td>368</td><td>369</td><td>390</td></tr>
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Type 2: Middle-peak Fictional Hyetograph
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</table>
</td></tr>
</table>

Table 4.9 Results of Probable Rainfall Analysis

Items	1 day Rainfall					2 days Rainfall		
	Case 1	Case 2	Case 3	JICA, 2011	WB, 2012	Case 4	JICA, 2011	WB, 2012
Meteor. Type	T	M	All	All	All	All	All	All
Model	Gumbel	Gumbel	Gumbel-Chow	Gumbel	Gumbel	Gumbel	Gumbel-Chow	Gumbel
Sample Number	58	61	63	94	35	63	87	35
1/30 Rainfall	232.4 m	203.3 m	251.2 m	255.0 m	268 mm	410.1mm	392.3mm	367 mm
(Estimate Error)	20.1mm	16.3mm	17.4mm	N/A	N/A	31.3mm	N/A	N/A
1/100 Rainfall	285.5mm	244.6mm	303.6mm	286.5mm	344mm	494.8mm	445.8mm	439 mm
(Estimate Error)	26.1mm	21.2mm	22.4mm	N/A	N/A	40.9mm	N/A	N/A
Selection	Selected	Not Selected	Not Selected	-	-	Not Selected	-	-

N/A: Not Available, T: Tropical Depression, M: Monsoon and Others
Source: Study of Water Security Master Plan for Metro Manila and its Adjoining Areas

Table 4.10 Cases of Design Hyetographs

	Enlarge of Actual Past Hyetograph	Fictional hyetograph
Time Variation	Actual Hourly Rainfalls is enlarged.	Middle-peak Distribution based on Hyetograph utilized in the Preparatory Survey on Pasig-Marikina River Channel Improvement Project (Phase III)
Spatial Variations	Spatial variations by Thiessen Distribution are applied.	None

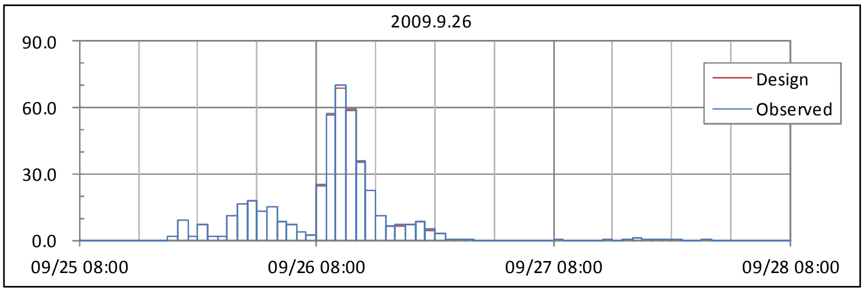
Source: Study of Water Security Master Plan for Metro Manila and its Adjoining Areas

Table 4.11 Design Hyetographs by Enlargement of Actual Past Hyetographs

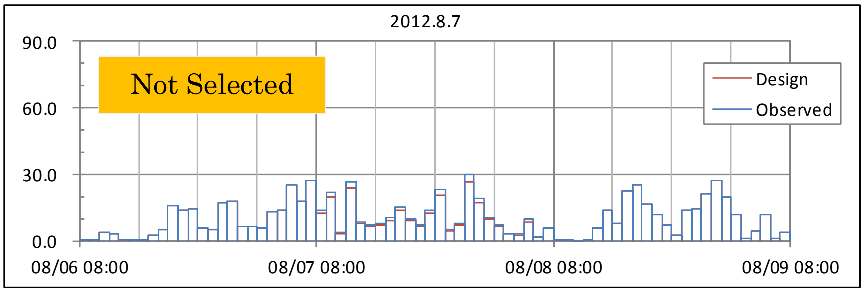
No.	Date	Event		Probability	Basin Mean Rainfall (1 Day)			Selection
		Type	Name		Observed (A)	1/100 Rain fall (B)	Ratio (B/A)	
1	2009/9/26	T	Ondoy	1/110	290.8mm	285.5mm	0.982	Selected
2	2012/8/7	M	-	1/200	271.7mm	244.6mm	0.900	Not Selected
3	1998/10/22	T	Loleng	1/30	234.0mm	285.5mm	1.220	Selected
4	2004/11/29	T	Winnie	1/10-1/20	190.2mm	285.5mm	1.501	Selected
5	2003/5/27	T	Chedeng	1/10-1/20	189.4mm	285.5mm	1.507	Selected
6	2000/7/7	T	Edeng	1/10	178.0mm	285.5mm	1.604	Selected
7	1997/8/18	M	-	1/10	170.0mm	244.6mm	1.439	Not Selected
8	2002/7/7	M	-	1/5-1/10	156.5mm	244.6mm	1.563	Not Selected
9	2011/6/24	T	Falcon	1/5	152.0mm	285.5mm	1.878	Selected
10	2000/11/2	T	Seniang	1/5	149.0mm	285.5mm	1.916	Selected

T:Tropical Depression, M:Monsoon and Others

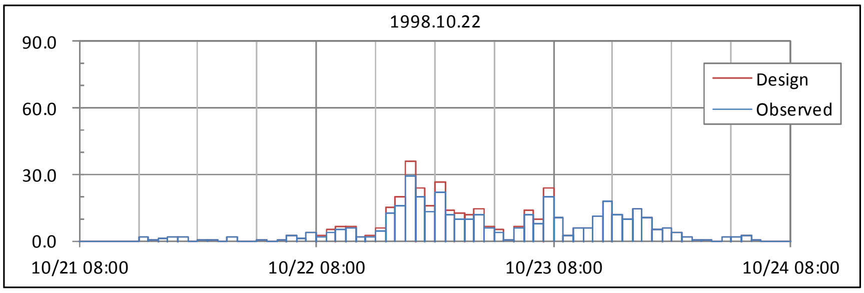
Remark: Typhoon type rainfall is applied considering conformity with probable rainfall.
Source: Study of Water Security Master Plan for Metro Manila and its Adjoining Areas



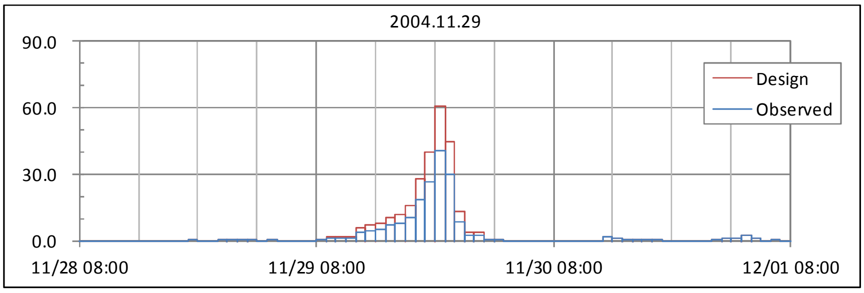
Station	Status
Science Garden	Out of Basin
Napindan	No Data
Mt.Campana	No Data
Aries	Fully Available
Nangka	Fully Available
BosoBoso	Fully Available
Mt.Oro	Fully Available



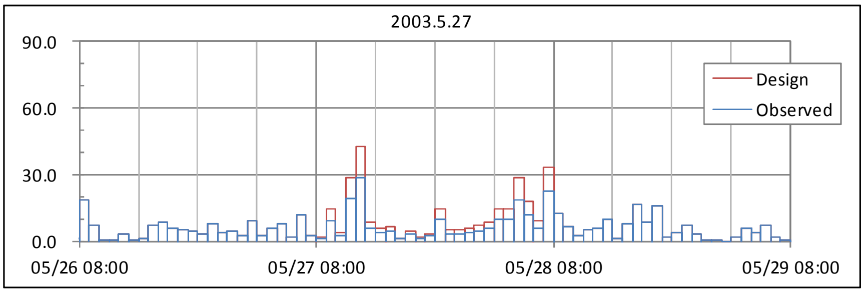
Station	Status
Science Garden	No Data
Napindan	No Data
Mt.Campana	No Data
Aries	Fully Available
Nangka	Partly Available
BosoBoso	Partly Available
Mt.Oro	Fully Available



Station	Status
Science Garden	No Data
Napindan	No Data
Mt.Campana	No Data
Aries	No Data
Nangka	No Data
BosoBoso	Fully Available
Mt.Oro	Fully Available



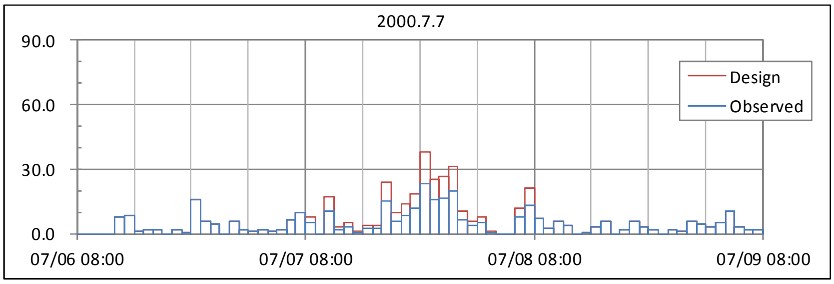
Station	Status
Science Garden	Out of Basin
Napindan	Out of Basin
Mt.Campana	Fully Available
Aries	Fully Available
Nangka	Fully Available
BosoBoso	Fully Available
Mt.Oro	Fully Available



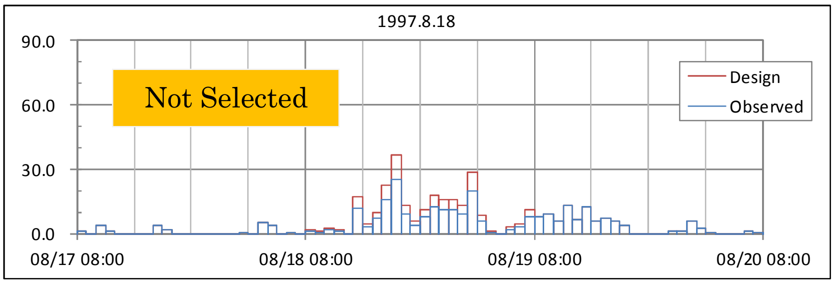
Station	Status
Science Garden	Out of Basin
Napindan	Out of Basin
Mt.Campana	Fully Available
Aries	Fully Available
Nangka	Fully Available
BosoBoso	Fully Available
Mt.Oro	Fully Available

Source: Study of Water Security Master Plan for Metro Manila and its Adjoining Areas

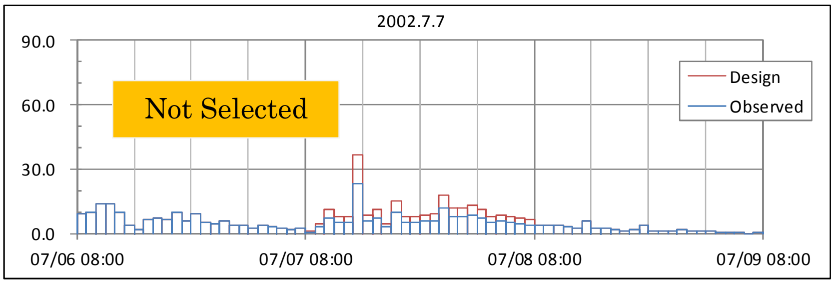
Figure 4.12 Design Hyetographs (1/100) (1/2)



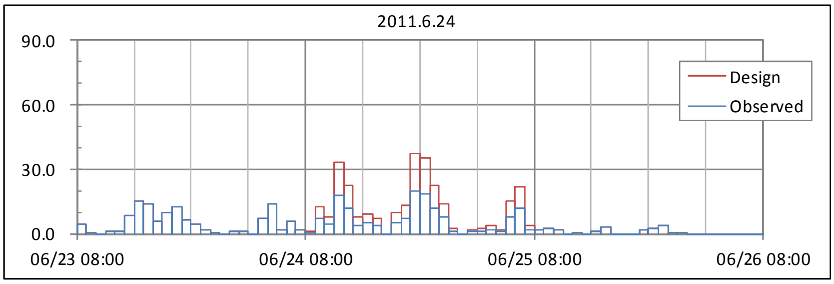
Station	Status
Science Garden	No Data
Napindan	No Data
Mt.Campana	No Data
Aries	No Data
Nangka	No Data
BosoBoso	Fully Available
Mt.Oro	Fully Available



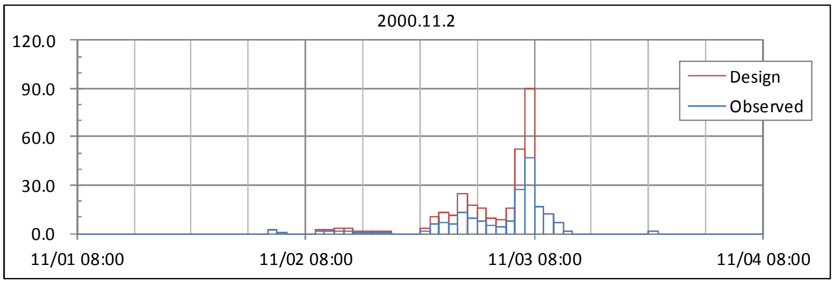
Station	Status
Science Garden	No Data
Napindan	No Data
Mt.Campana	No Data
Aries	No Data
Nangka	No Data
BosoBoso	Fully Available
Mt.Oro	Fully Available



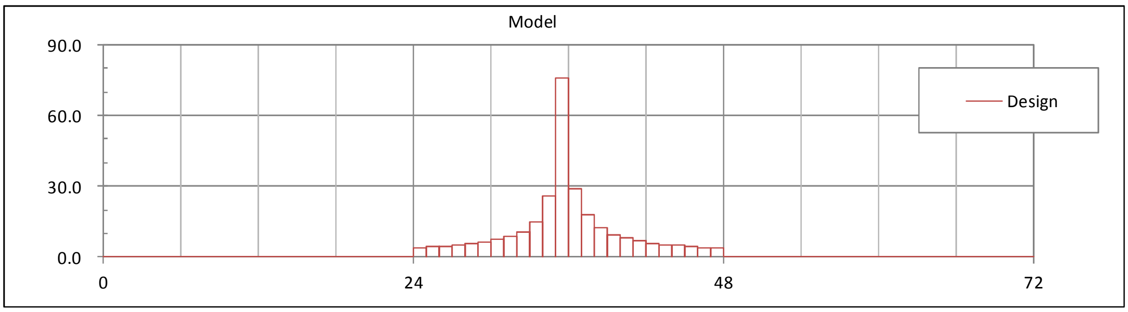
Station	Status
Science Garden	No Data
Napindan	No Data
Mt.Campana	No Data
Aries	No Data
Nangka	No Data
BosoBoso	Fully Available
Mt.Oro	Fully Available



Station	Status
Science Garden	No Data
Napindan	No Data
Mt.Campana	No Data
Aries	Fully Available
Nangka	Fully Available
BosoBoso	Fully Available
Mt.Oro	Fully Available



Station	Status
Science Garden	No Data
Napindan	No Data
Mt.Campana	No Data
Aries	No Data
Nangka	No Data
BosoBoso	Fully Available
Mt.Oro	Fully Available



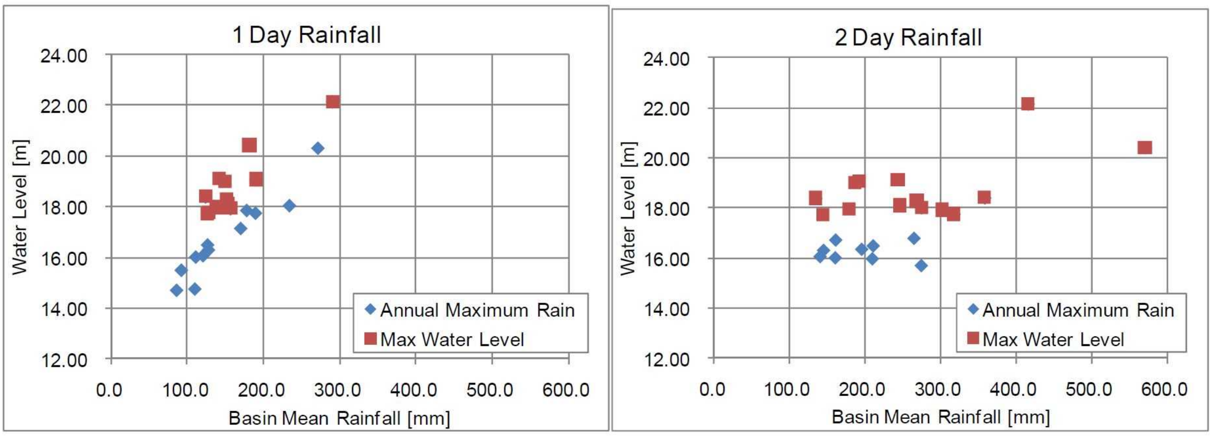
Source: Study of Water Security Master Plan for Metro Manila and its Adjoining Areas

Figure 4.13 Design Hyetographs (1/100) (2/2)

4.2.2 Design Rainfall Duration

The JICA Water Security Study reviewed the design rainfall duration in the previous studies and applied 1 day rainfall.

The previous studies applied 2 days rainfall to cover the observed rainfall durations of past floods. However, as shown in Figure 4.16, 1 day rainfall shows better correlation with peak water level comparing to the correlation between 2 days rainfall and peak discharge. Since the flood concentration time is estimated about 11 hours, it is not so effect to estimate flood discharge that the design rainfall duration does not cover the observed rainfall duration. Thus, the applied design rainfall duration by the JICA Water Security Study is considered as appropriate.



Source: Study of Water Security Master Plan for Metro Manila and its Adjoining Areas

Figure 4.14 Correlation between Basin Average Rainfalls and Peak Discharge (Left: 1 day, Right: 2 days)

4.2.3 Basin Average Rainfall

In the JICA Water Security Study, spatial variation of rainfall is estimated by Thiessen method and IDW method for the observed hyetographs while it is not estimated for middle-peak fictional hyetograph since the unified rainfall intensity is estimated. For estimation of probable rainfall, simple average method is applied since there is no significant difference between simple average method and Thiessen method.

The methods applied in the previous studies are as follows.

- JICA Study : Spatial variation is not considered since one middle-peak fictional hyetograph is based on the rainfall intensity of Port Area Station is applied.
- WB Study : Spatial variation of rainfall is estimated by Thiessen method and IDW method for the hyetographs of Typhoon Ondoy and IDW method for middle-peak fictional hyetograph

Since observed data increase since 1994 resulting that runoff analysis based on observed hyetograph is available, the method applied by the JICA Water Security Study which can describe spatial and time variations of rainfall is considered as appropriate.

4.2.4 Basin Average Probable Rainfall

According to the review of design rainfall duration, basin average probable rainfall is estimated in the JICA Water Security Study. Several probability distribution models are applied and the most suitable model is selected. And unbiased estimate value by Jackknife method is applied as probable hydrological value. It is considered that the method applied by the JICA Water Security Study which can describe spatial and time variations of rainfall is considered as appropriate.

4.3 Basic Design Discharge

Based on the established flood analysis model, basic design discharge is estimated using the hyetographs described in Section 4.2.1. It is noted that probability 1 day rainfall of the hyetograph of Typhoon Ondoy is evaluated as 1/110 years, however, it is not cut down to meet the 1/100 years rainfall since the both values are almost same.

The flood analysis was conducted with the following conditions.

- Water Level of Laguna Lake: 13.90 m (the highest water level after 1989)
- Sea Level of Manila Bay: High Water Level 11.40 m (same as the previous studies)
- Napindan Channel: 2 cases with open and closed
- Natural Retarding Function Upstream: 2 cases with and without natural retarding function upstream of Sto.Nino and upper San Juan River Basin
- Peak Discharge: The peak discharge at each point is applied as basic design discharge

4.3.1 Water Level of Laguna Lake

(1) Water Level of Laguna Lake in Previous Studies

As a boundary condition for non-uniform flow calculation and inundation analysis, water level of Laguna Lake was set in as shown in Table 4.12.

Table 4.12 Water Level of Laguna Lake in Previous Studies

Study	Water Level of Laguna Lake
JICA M/P Study (1990)	・For Non-uniform Flow Calculation: 12.5 m (Average Annual Maximum Water Level) ・Inundation Analysis: 13.8 m (Adjusted based on the Past Highest Water Level)
JICA Study (2011)	12.2m (Average of Past Flood Event)
WB Study (2012)	Observed Hydrograph of Typhoon Ondoy (12.78～13.85 m)

(2) Water Level of Laguna Lake in This Study

For setting the design water level of Laguna Lake, relation of water levels at Sto.Nino Station (Marikina River) and Anggono Station (Laguna Lake) using the hourly water level data after 1994 is analyzed.

It is confirmed that water level of Laguna Lake rise when flood occurs in Marikina River of which water level at Sto.Nino becomes more than 18 m and flooding occurs.

However, there is no significant relation about peak time of water levels between Marikina River and Laguna Lake such the case that peak water levels occur at almost same time, the peak water level of Laguna Lake is recorded prior to or behind.

It is due to spatial and time variations of rainfall and there is a possibility that peak time of water levels between Marikina River and Laguna Lake such the case that peak water levels occur at same time.

Based on this examination results, the water levels applied in the previous studies are not appropriate as described as follows.

- JICA Study:
  The average of past flood events of 12.2 m is applied which is less than the observed water level of Typhoon Ondoy. It is considered too low.
- WB Study:
  Observed hydrograph of Typhoon Ondoy was applied which is a considerable case as a boundary

condition of analysis. However, as the planning, higher water level shall be assumed due to the following reasons.

- ✓ There are cases that peak water level occurs in Laguna Lake prior to Pasig-Marikina River.
- ✓ Once water level rises in Laguna Lake, it takes time to start recession.
- ✓ Water level of Laguna Lake effects to diversion discharge of Manggahan Floodway.

Therefore, the highest water level after 1989 when Manggahan Floodway constructed is applied in this Study. Annual highest water level in Laguna Lake is shown in Table 4.13.

Table 4.13 Water Level of Laguna Lake in Previous Studies

year	WL_Max (m)	year	WL_Max (m)
1989	12.24	2001	12.69
1990	12.67	2002	12.55
1991	12.60	2003	11.72
1992	12.39	2004	11.85
1993	12.27	2005	12.15
1994	12.27	2006	12.30
1995	12.94	2007	12.49
1996	12.52	2008	12.14
1997	11.83	2009	13.85
1998	12.70	2010	12.09
1999	13.47	2011	12.61
2000	13.53	2012	13.90

Mean annual highest water level (1989-2012)
12.57m

Mean annual highest water level (Major flood)
13.54m

:Year of major flood occurrence

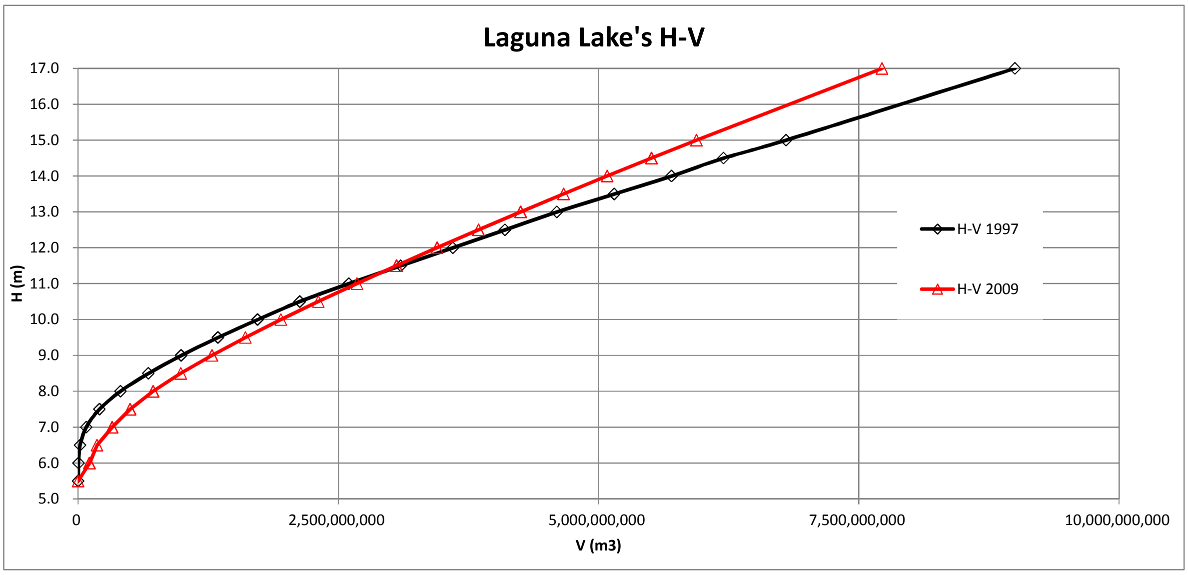
Source: JICA Study Team

(3) Water Level Rise in Laguna Lake due to Inflow from Pasig-Marikina River

Main factor of water level rise of Laguna Lake is confirmed by calculating relation of inflow volume from Pasig-Marikina River and water level rise of Laguna Lake in the case of Typhoon Ondoy.

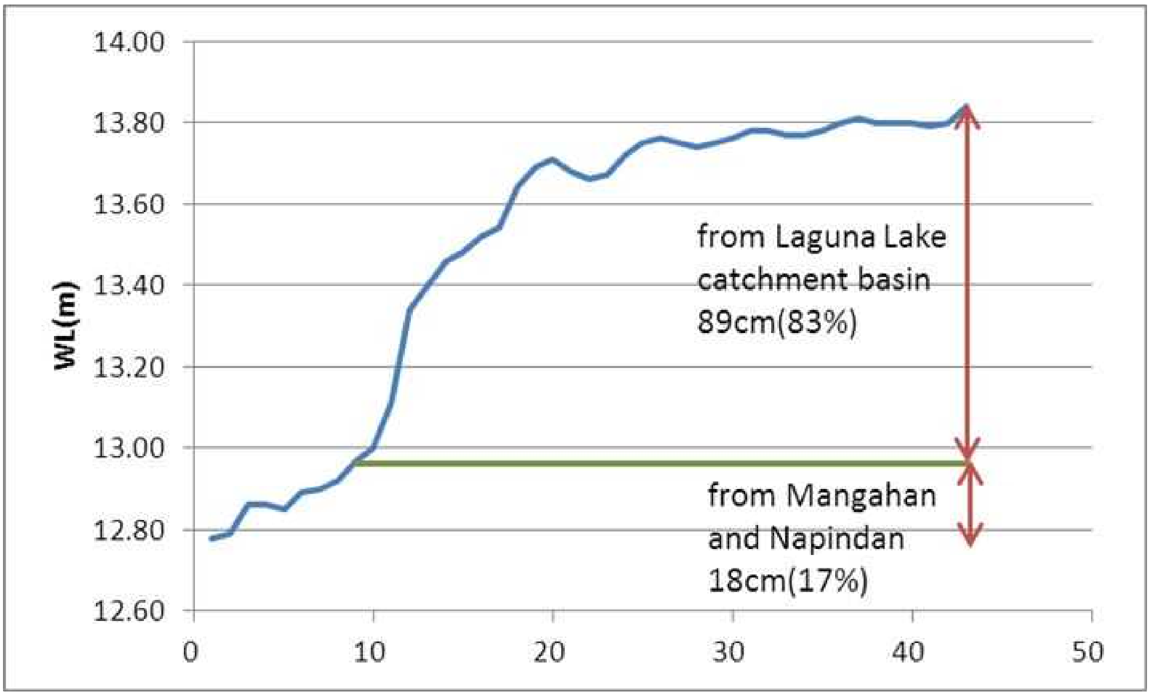
As a result of flood simulation, inflow volume from Pasig-Marikina River is estimated at 169 MCM consisting 115 MCM through Manggahan Floodway and 54 MCM through Napindan Channel. This inflow volume is equivalent to 0.18 m based on H-Q equation of Laguna Lake as shown in Figure 4.17, which is only 17% of total water level rise during the Typhoon Ondoy as shown in Figure 4.18.

Thus, it is judged that main factor of water level rise is rainfall in Laguna Basin and effect of diversion from Pasig-Marikina is very small.



Source: JICA Study Team

Figure 4.15 H-V Curve of Laguna Lake



Source: JICA Study Team

Figure 4.16 Factors of Water Level Rise in Laguna Lake during Typhoon Ondoy

4.3.2 Basic Design Discharge

The peak discharges of design hyetographs at Sto.Nino and their hydrographs are shown in Table 4.14 and Figure 4.21 to 28, respectively. The highest peak discharge is recorded at 2009/9/26 Flood (Typhoon Ondoy). Thus, basic design flood is determined applying 2009/9/26 hydrograph of which basic design discharge allocation is shown in Figure 4.19 and 4.20.

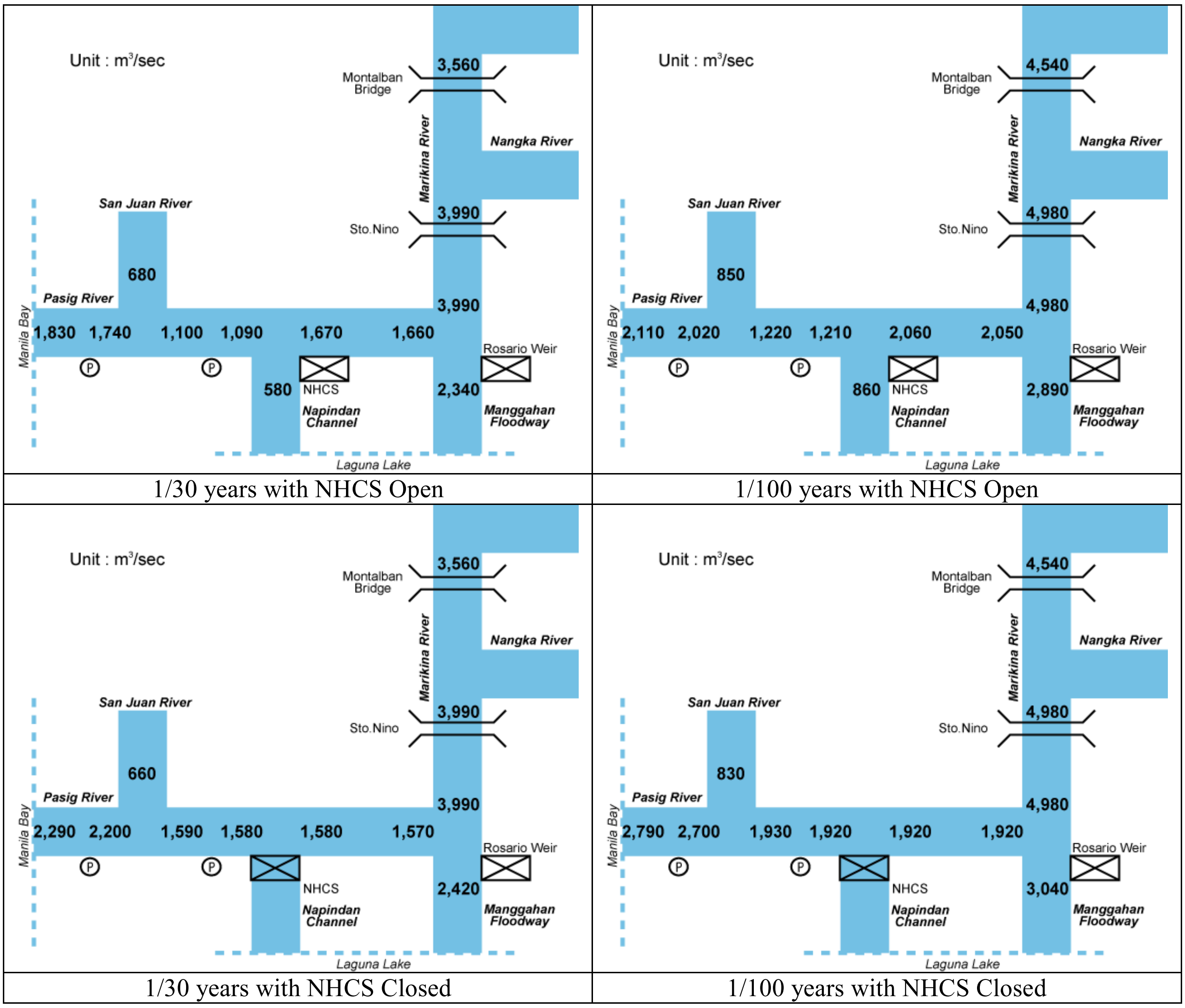
In case of “With Natural Retarding Function”, discharges are reduced comparing “Without Natural Retarding Function” with about 1,000 m^3/s for 1/30 years flood and about 1,400 m^3/s for 1/100 years flood.

Inundation upstream of Sto.Nino consists of inundation in natural retarding basin and inundation in upstream. This natural retarding basin is discussed in the flowing sections.

Table 4.14 Water Level of Laguna Lake in Previous Studies

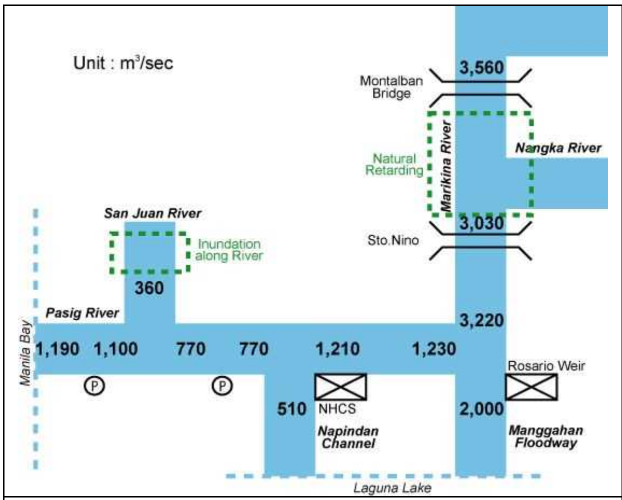
Type	Sto.Nino Qp	
	Without Retarding	With Retarding
2009/9/26	4,980	3,575
1998/10/22	2,173	2,150
2004/11/29	4,215	3,012
2003/5/27	2,269	2,149
2000/7/7	2,994	2,781
2011/6/24	2,030	1,813
2000/11/2	4,178	3,300
RIDF	2,825	2,530

Source: JICA Study Team

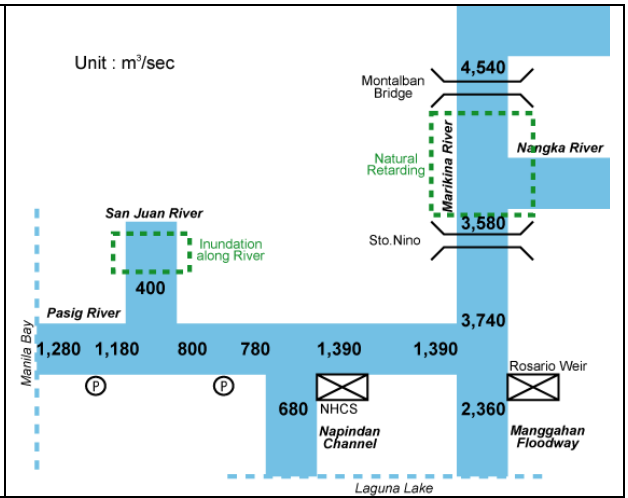


Source: JICA Study Team

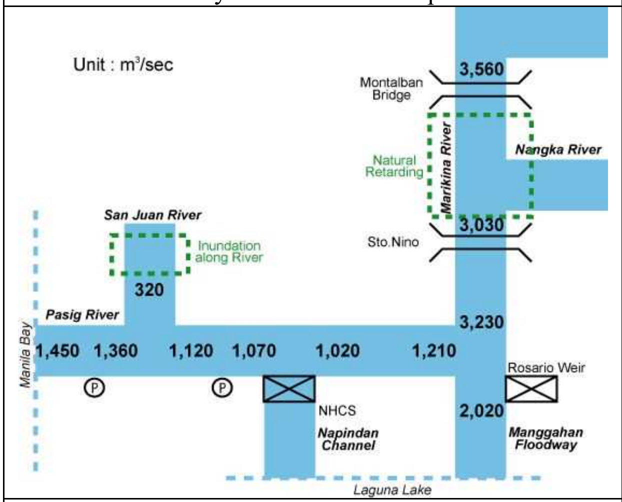
Figure 4.17 Basic Design Discharge Allocation (Without Natural Retarding Function)



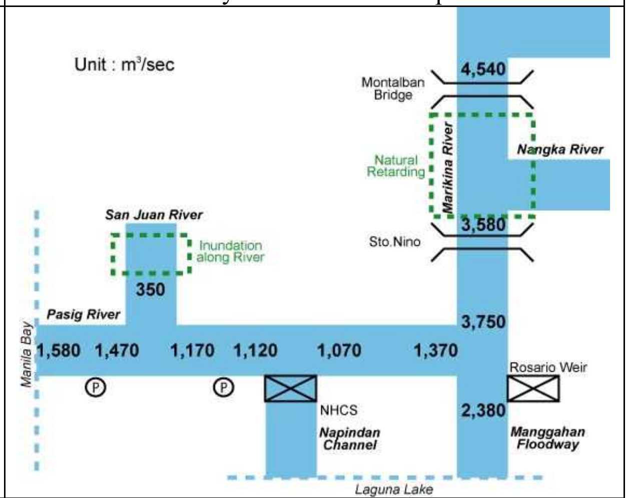
1/30 years with NHCS Open



1/100 years with NHCS Open



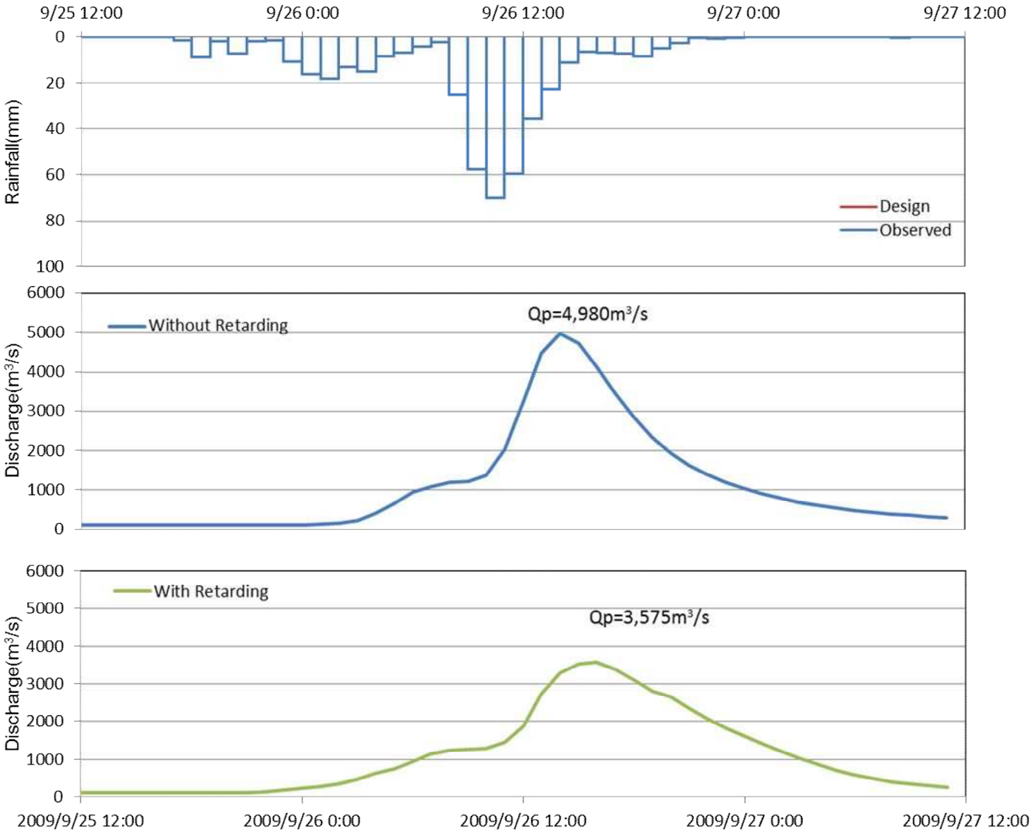
1/30 years with NHCS Closed



1/100 years with NHCS Closed

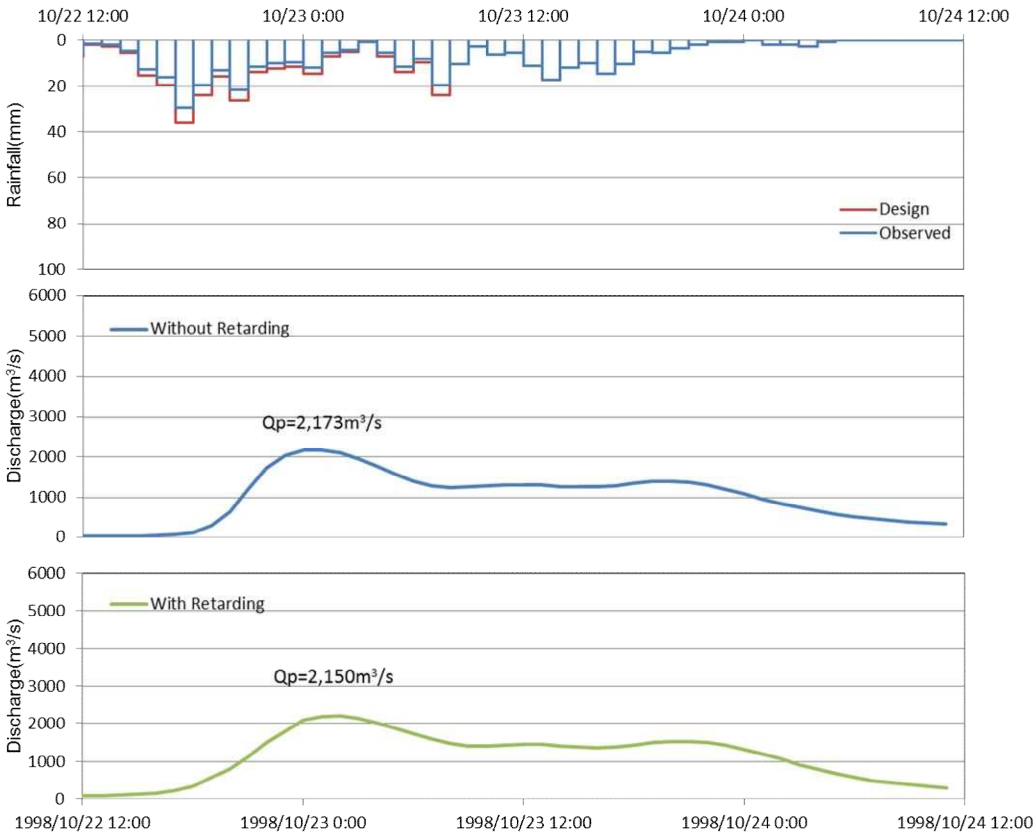
Source: JICA Study Team

Figure 4.18 Basic Design Discharge Allocation (With Natural Retarding Function)



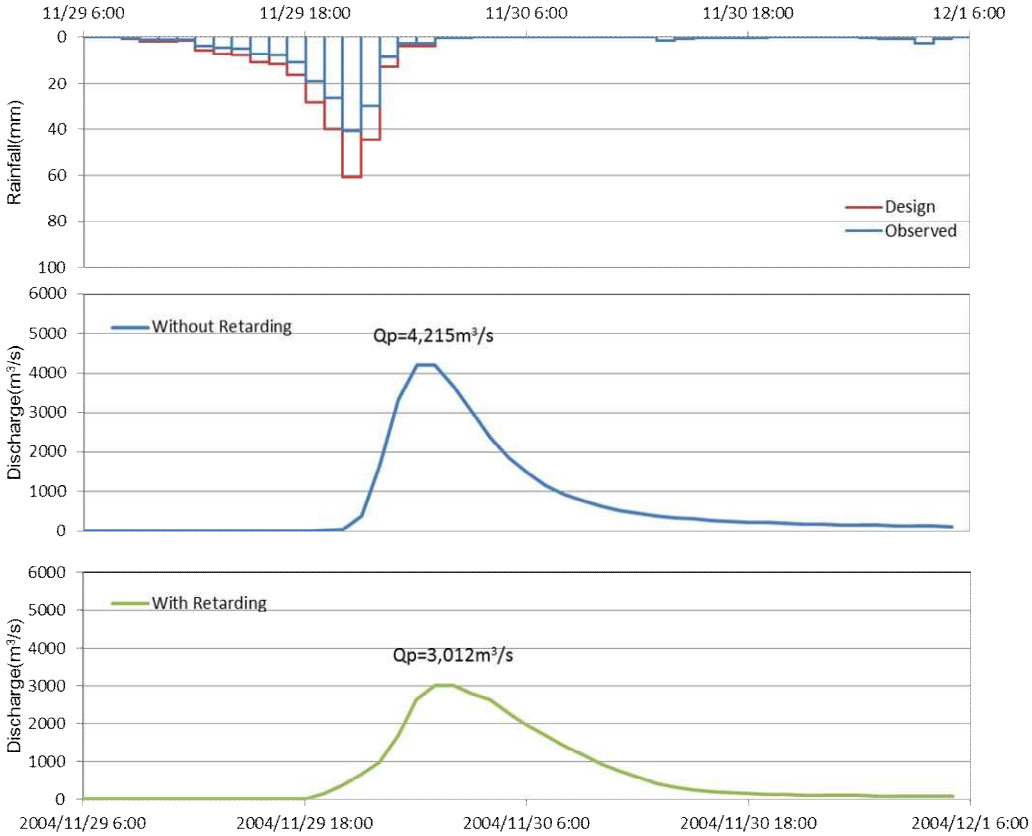
Source: JICA Study Team

Figure 4.19 Hyetograph and Hydrograph of 2009/9/26 Flood



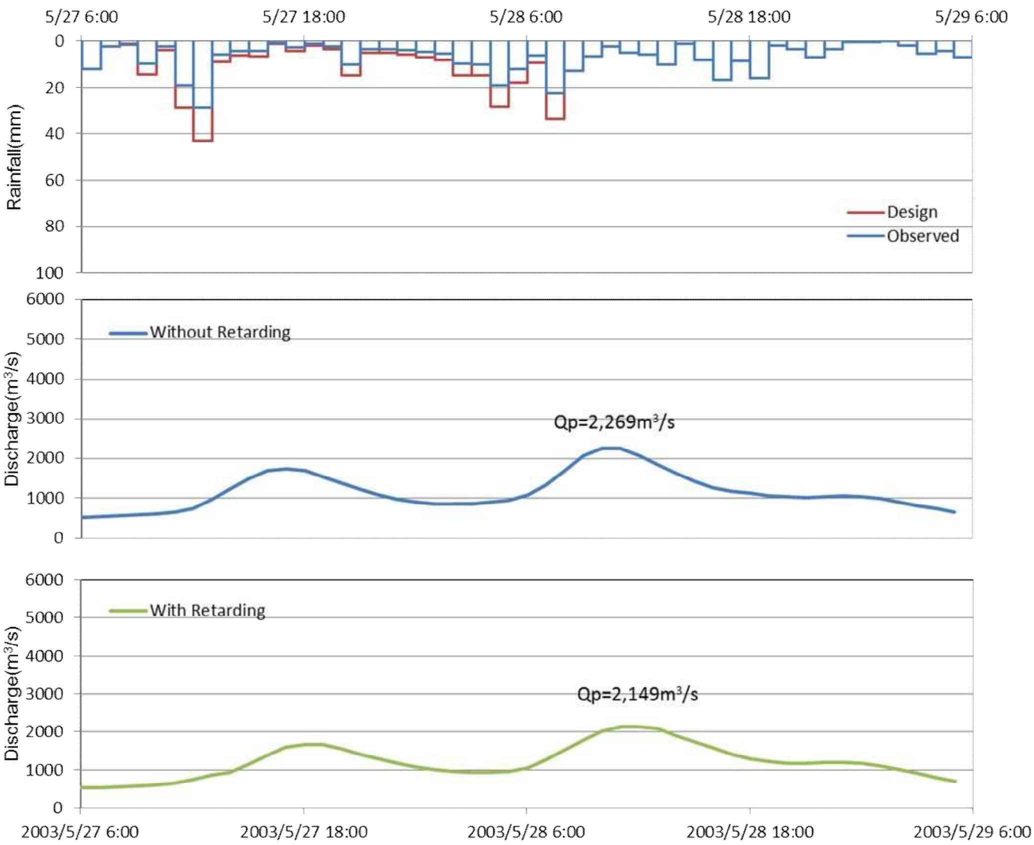
Source: JICA Study Team

Figure 4.20 Hyetograph and Hydrograph of 1998/10/22 Flood



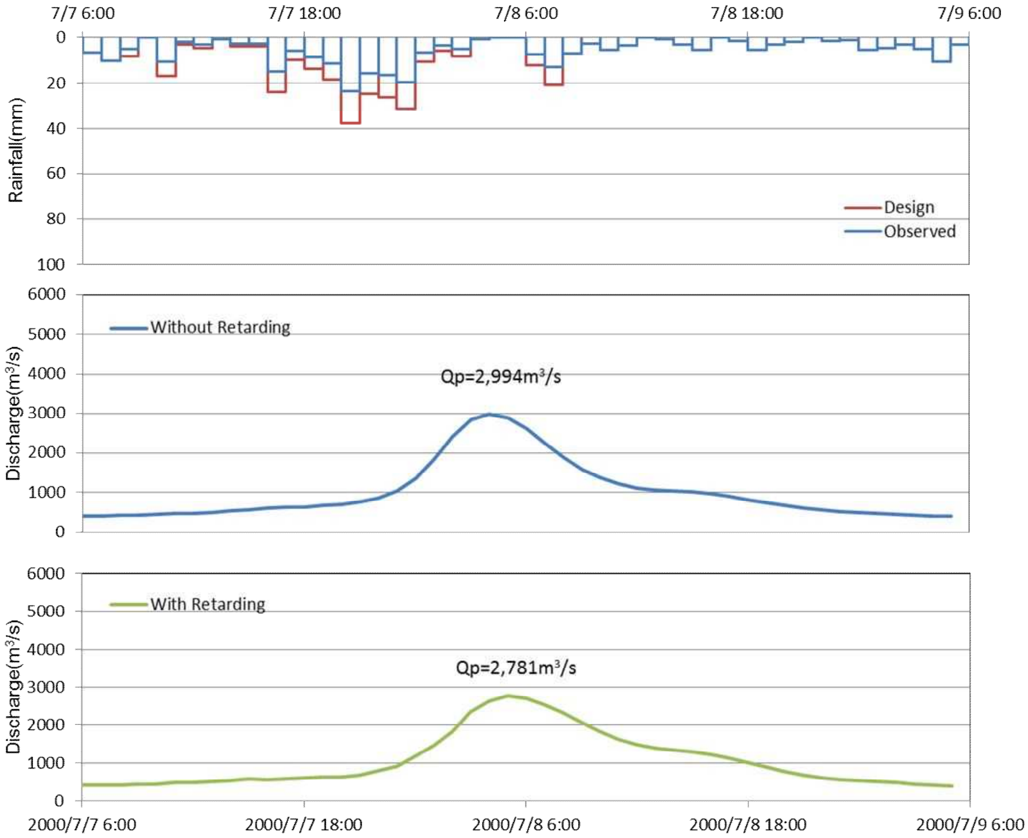
Source: JICA Study Team

Figure 4.21 Hyetograph and Hydrograph of 2004/11/29 Flood



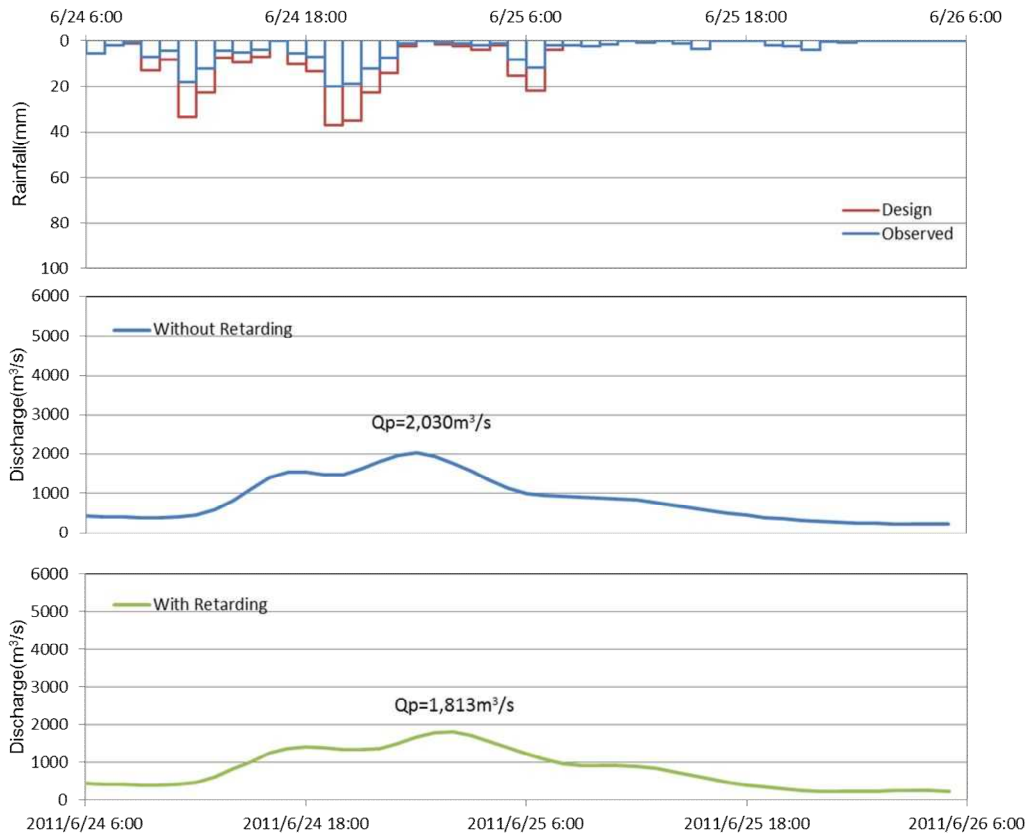
Source: JICA Study Team

Figure 4.22 Hyetograph and Hydrograph of 2003/5/27 Flood



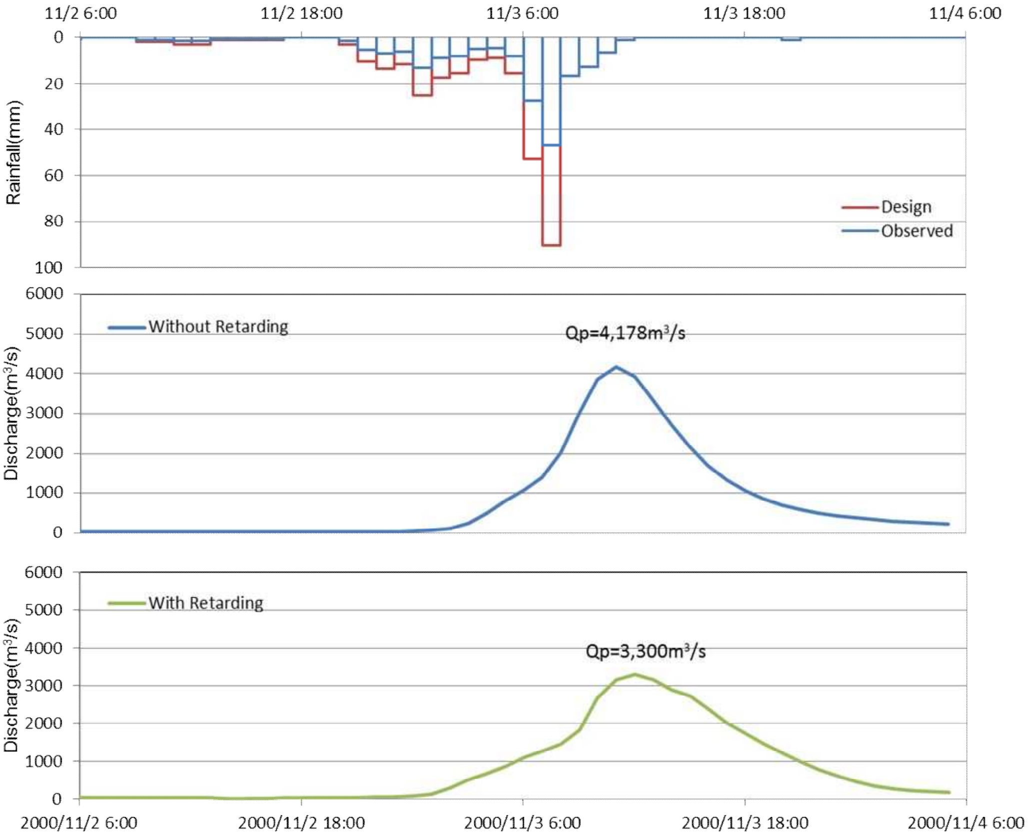
Source: JICA Study Team

Figure 4.23 Hyetograph and Hydrograph of 2000/7/7 Flood



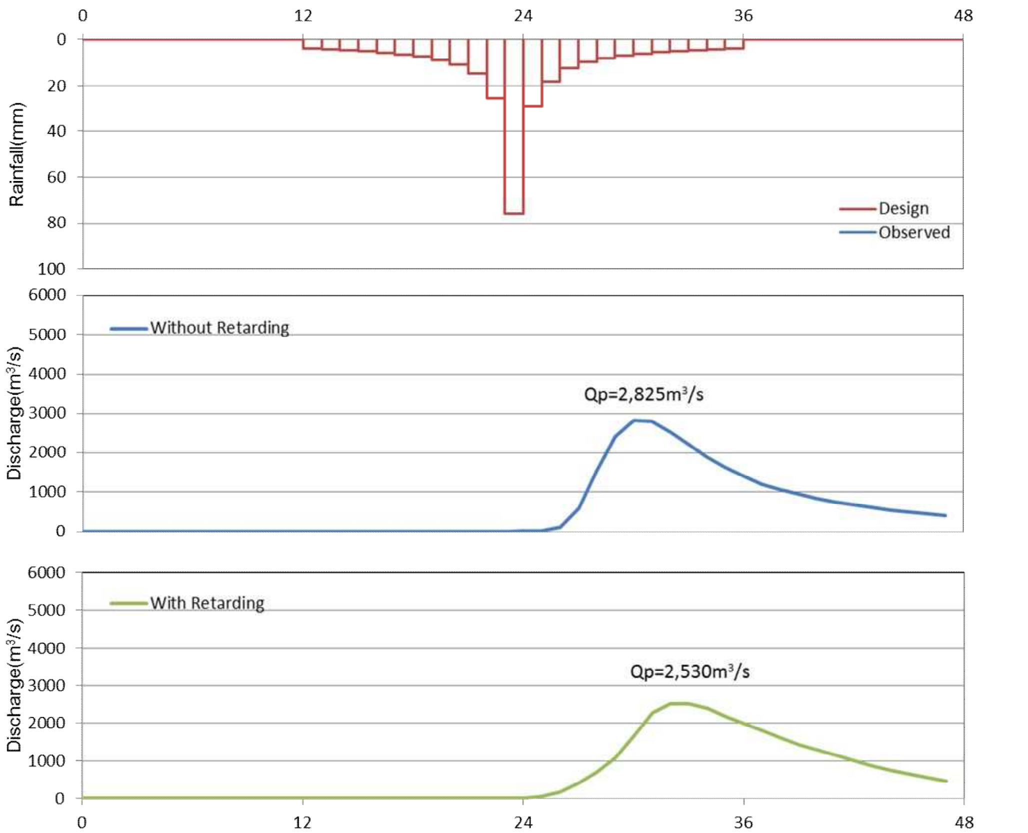
Source: JICA Study Team

Figure 4.24 Hyetograph and Hydrograph of 2011/6/24 Flood



Source: JICA Study Team

Figure 4.25 Hyetograph and Hydrograph of 2000/11/2 Flood



Source: JICA Study Team

Figure 4.26 Hyetograph and Hydrograph of Middle-peak Fictional Flood