Democratic Socialist Republic of Sri Lanka
Sri Lanka Land Development Corporation

THE PROJECT FOR STORM WATER DRAINAGE PLAN IN SELECTED AREAS IN COLOMBO METROPOLITAN REGION

FINAL REPORT

Volume 1 Main Report

February 2023

JAPAN INTERNATIONAL COOPERATION AGENCY

CTI ENGINEERING INTERNATIONAL CO., LTD.
NIPPON KOEI CO., LTD.
EARTH SYSTEM SCIENCE CO., LTD.

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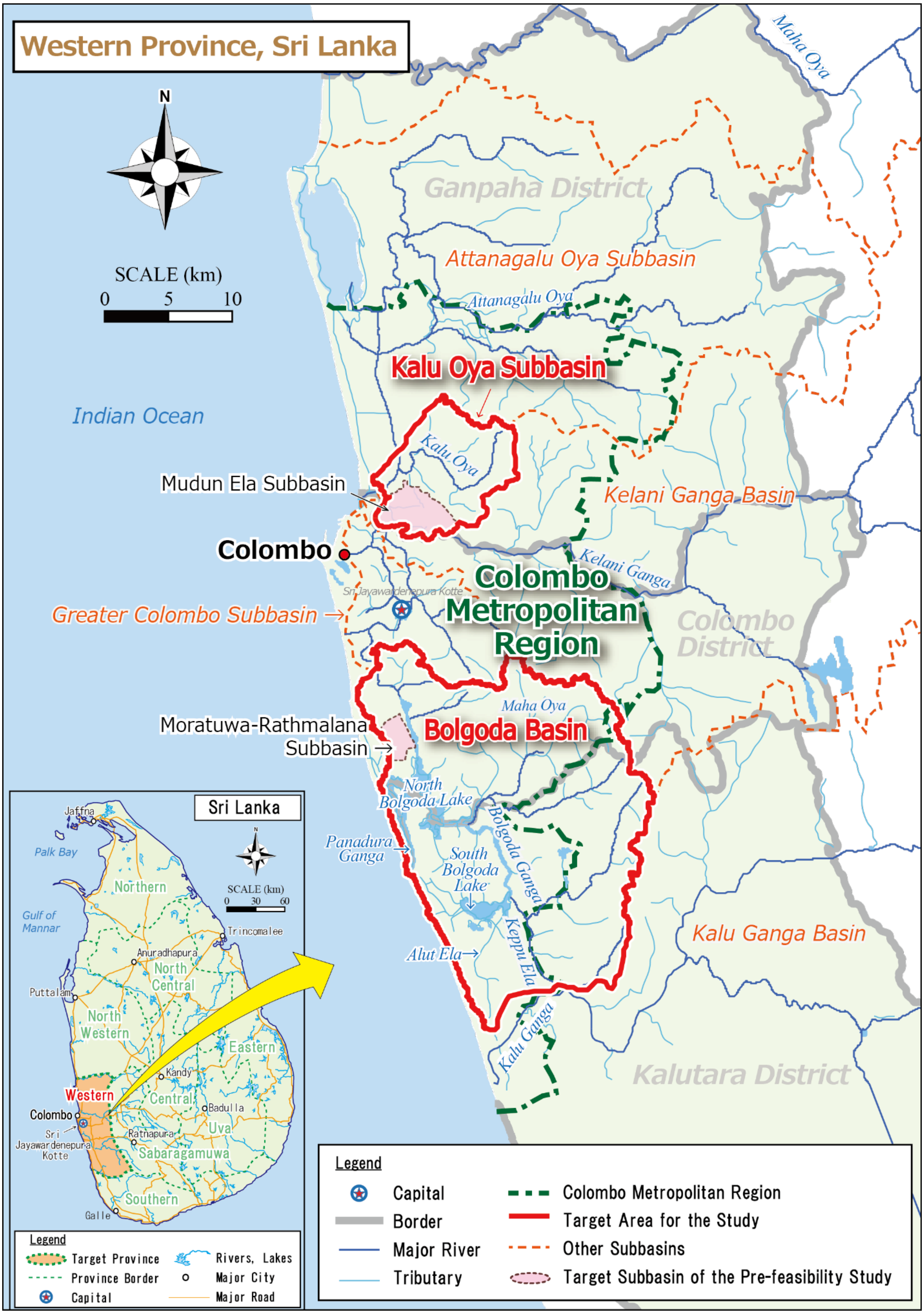


LOCATION MAP

ABBREVIATIONS AND ACRONYMS

AAGR	Annual Average Growth Rate
ADD	Agrarian Development Department
AGM	Assistant General Manager
AIIB	Asian Infrastructure Investment Bank
ARF	Area Reduction Factor
ASD	Agrarian Service Department
B/C	Cost-benefit Ratio
BOQ	Bill of Quantity
BS	Balance Sheet
CCaCDP	Colombo Capital City Development Plan
CCCDP	Colombo Commercial City Development Plan
CCD	Coast Conservation Department
CEA	Central Environment Authority
CEB	Ceylon Electricity Board
CMC	Colombo Municipal Council
COC	Certificate of Conformity
DCS	Department of Census and Statistics
DEM	Digital Elevation Model
DGM	Deputy General Manager
DMC	Disaster Management Center
DNP	Department of National Planning
DS	Divisional Secretariat
DWLC	Department of Wildlife Conservation
EIRR	Economic Internal Rate of Return
EPA	Environmental Protection Areas
F/S	Feasibility Study
FD	Forest Department
GDP	Gross Domestic Product
GIS	Geographical Information System
GM	General Manager
GOSL	Government of Sri Lanka
GZ	Gazette
ID	Irrigation Department
IRR	Internal Rate of Return
IUCN	International Union for Conservation of Nature
IWMI	International Water Management Institute
JCC	Joint Coordination Committee
JICA	Japan International Cooperation Agency

JICE	Japan Institute of Country-ology and Engineering
LCGD	Land Commissioner General's Department
LG	Local Government
LiDAR	Light Detection and Ranging
LKR	Sri Lanka Rupee
LRT	Light Rail Transit
LUPPD	Land Use Policy Planning Department
M/P	Master Plan
MC	Municipal Council
MCUDP	Metro Colombo Urban Development Project
MMWD	Ministry of Megapolis and Western Development
NAM	Nedbor Afstromnings Model
NWPS	National Wetland Policy and Strategy
PL	Profit and Loss Statement
Pre-F/S	Pre-Feasibility Study
PVC	Polyvinyl Chloride
RDA	Road Development Authority
SD	Survey Department
SEA	Strategic Environmental Assessment
SLCDMP	Sri Lanka Comprehensive Disaster Management Programme
SLLR&DC	Sri Lanka Land Reclamation and Development Corporation
SLLDC	Sri Lanka Land Development Corporation
SLSC	Standard Least Squares Criterion
UC	Urban Council
UDA	Urban Development Authority
WRMMP	THE MEGAPOLIS Western Region Master Plan

SUMMARY

1 INTRODUCTION

1.1 Background

Sri Lanka is vulnerable to natural disasters. Following the 2004 Indian ocean earthquake around Sumatra and the tsunami caused by the earthquake, the country has been strengthening its disaster prevention and risk prevention capabilities through the enactment of the disaster management act, the national disaster prevention committee, the Ministry of Disaster Management which is presently the Ministry of Public Administration and Disaster Management (hereinafter referred to as "MPADM"), and the establishment of a disaster management center.

According to records of the past 10 years up to October 2016, floods were the most frequently occurring disasters, accounting for about 37% of the total. In addition to the number of incidents, floods account for about 47% of house damage and about 57% of the number of people affected by the disaster. They are the most damaging type of disaster, and measures against floods are an urgent issue in Sri Lanka. In May 2016, flooding was caused by the backwater of the Kelani Ganga mainstream towards their tributaries resulting in inland inundation along the tributary basins in the Colombo Metropolitan Region. It caused economic damage amounting to 572 million U.S. dollars in total damages.

In addition to the fact that most of the Colombo Metropolitan Region is located in the low-lying areas, at 6 m or less above sea level, the area of wetlands which used to function as retarding basins has decreased for urbanization, and inland inundation has occurred frequently due to poor drainage capacity. This causes damage to assets and infrastructure facilities as well as deteriorating the sanitation of residents. Japanese Government had supported channel improvement, construction of a diversion channel and improvement of unused/used retarding basin areas by the Greater Colombo Flood Control and Environmental Improvement Project in phase 1 (Conclusion of the loan agreement (hereinafter referred to as "L/A") in 1992 and completion of the loan in 1999), and improvement of drainage pipes, drainage culverts, drainage open channel, and gutters by the same project in phase 2 (Conclusion of L/A in 1994 and completion of the loan in 2001) and phase 3 (Conclusion of L/A in 1996 and completion of the loan in 2005). In 2003, Japan International Cooperation Agency (hereinafter referred to as "JICA") conducted "the Study on Storm Water Drainage Plan for the Colombo Metropolitan Region" and proposed the master plan (hereinafter referred to as "M/P") for flood mitigation in the main four basins, of which are the Ja Ela basin, the Kalu Oya basin, the Greater Colombo basin and the Bolgoda basin. In response to the M/P, the Sri Lanka Land Reclamation and Development Corporation (hereinafter referred to as SLLR&DC, later, becomes Sri Lanka Land Development Corporation referred to as SLLDC) which has jurisdiction over urban drainage, has implemented some projects and conducted a detailed design, but the measures are insufficient yet and further investment in disaster prevention is required.

Due to progress in urbanization and development, the population of the Greater Colombo basin and the Bolgoda basin in 2015 became about 1.5 and 1.7 times as large as the ones in 2000, respectively. The concentration of population and assets increases the risk of flood damage and it is also difficult to secure candidate sites for diversion channels and retarding basins through development. With changes in rainfall-runoff mechanism due to urbanization, development conditions (concentration of assets and population), and land use conditions, the M/P needs to be revised in order to promote measures for urban drainage and against inland flooding.

Based on the above background, the SLLR&DC which studies urban drainage and the Ministry of Megapolis & Western Development (hereinafter referred to as "MMWD") which is in charge of supervising the SLLR&DC requested the project aiming to compile the development plan for the urban drainage and measures against inland flooding and to conduct the master plan and feasibility study at the priority areas in the Ja Ela-Attangalu basin, the Kalu Oya basin (including the Mudun Ela sub-basin), and the Greater Colombo basin (including the Kolonnawa and the Madiwela South diversion channel) and the Bolgoda basin (including the Moratuwa-Rathmalana sub-basin).

In December 2017, JICA conducted a detailed planning survey for the project, finding some areas which are not covered by the other donors including the Government of Sri Lanka (hereinafter referred to as GOSL) for the storm water drainage project, and agreed with the GOSL on the target areas and the project

1.2 Project Purpose

This project will contribute to mitigating the risk of storm water flooding in the selected areas in Colombo metropolitan region. After the completion of the project, the following outputs are expected.

Output 1: Storm water drainage plans for target areas in Colombo metropolitan region are elaborated,

Output 2: Pre-feasibility study for urgent projects is implemented, and

Output 3: Technology transfer on storm water drainage planning through the project activities is implemented.

1.3 Schedule

This study started in January 2019 and was completed in March 2023.

2 Master Plan Study

2.1 Overview of the Target Area

2.1.1 Topography of the Drainage Basin

Most of the target drainage basin is lowland along the coast. The Muthurajawela Wetlands extend to the north, with North Bolgoda Lake and South Bolgoda Lake located in the southern part. The topography of the survey area is generally classified into lowland swamps, lowlands around them, and hills.

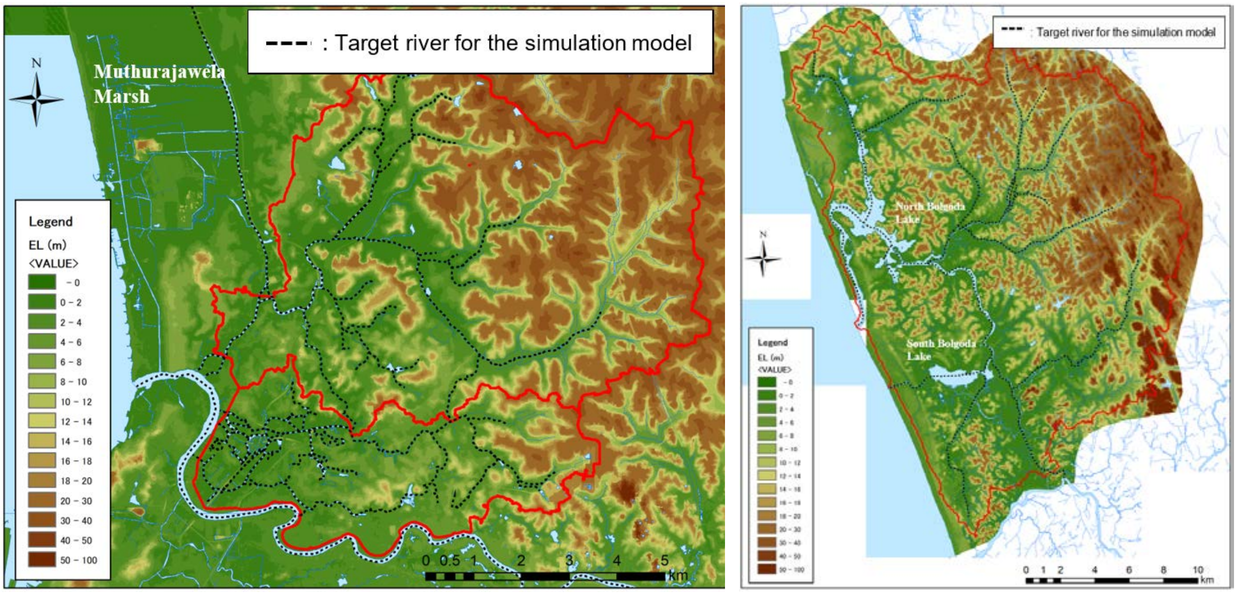


Figure 2.1 Distribution Map of Elevation

2.1.2 Land use of the Drainage Basin

The Mudun Ela sub-basin indicates the highest urbanized area. The target basins consist of built-up areas and artificial vacant areas by 6,078 ha (80% out of the total target basin). Breakdowns of the urbanized areas are calculated for the Kalu Oya basin (78 %, 4,336 ha) and the Mudun Ela sub-basin (84%, 1,672 ha). The Bolgoda basin has an area of 40,923 ha striding across Colombo District with 10 DS Divisions (42.6% of the Bolgoda basin) and Kalutara District with five DS Divisions (57.4 %). Among those 15 DS Divisions, the most highly urbanized DS Division is Sri Jayawardenepura Kotte (98.5% urbanization rate) including the capital municipality followed by Dehiwala (94.9%).

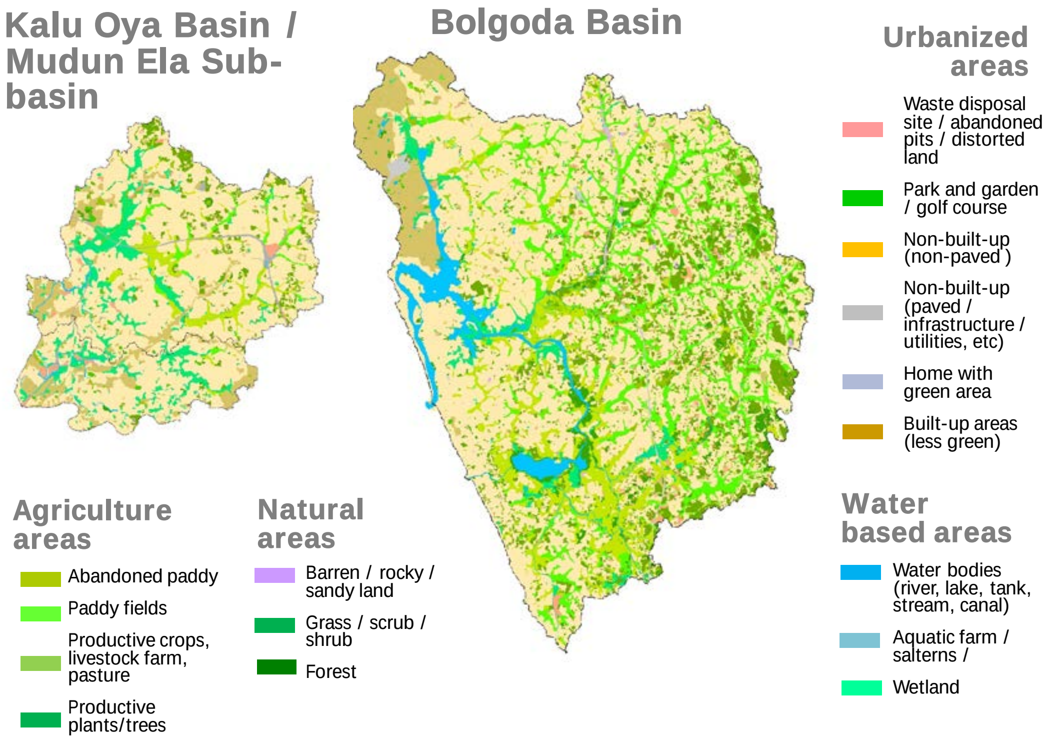


Figure 2.2 Existing Land Use Distribution

2.2 Historical Flood Damage

The most recent flood damages occurred in 2010, 2016, and 2017 in Colombo metropolitan area.

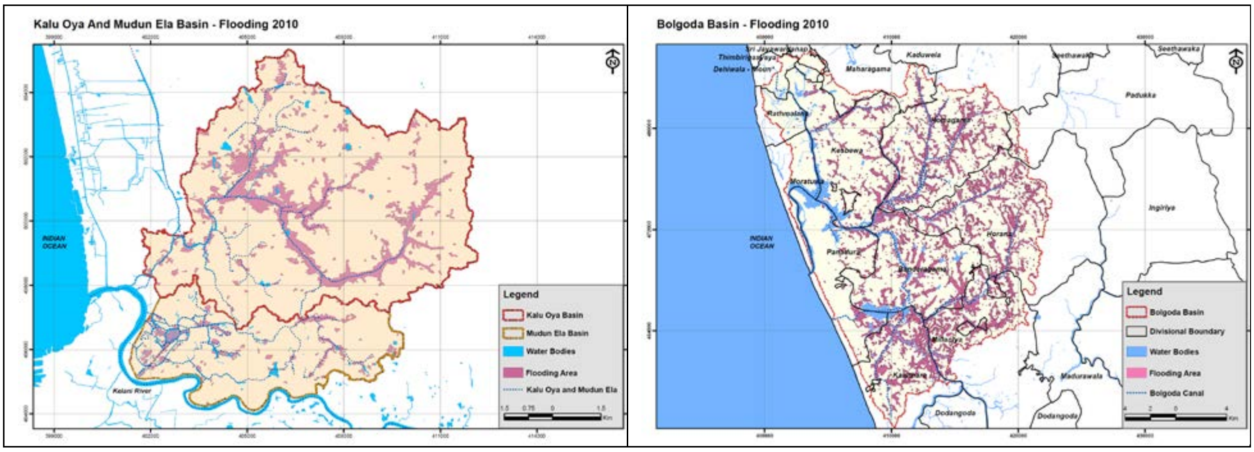


Figure 2.3 Historical Flood Area

2.3 Storm Water Drainage Plans Proposed in Previous Studies and Implemented Project Works

The first study formulating a drainage improvement master plan was “the Study on Storm Water Drainage Plan for the Colombo Metropolitan Region” in 2003 (hereinafter referred to as “JICA 2003 M/P”). Among them, the two basins, which are the Kalu Oya and the Bolgoda, are targeted in the current master plan study. In JICA 2003 M/P, the Weras Ganga basin whose catchment area is 56 km2 was selected as a priority project area and its feasibility study (hereinafter referred to as “F/S”) was conducted in the M/P (hereinafter referred to as “JICA 2003 F/S”). On the other hand, the Kalu Oya basin was studied under “Consultancy Services for Feasibility Study on Storm Water Drainage and Environment Improvement Project for Kalu Oya Basin” in 2018 conducted by Sri Lankan own budget (hereinafter referred to as “2018 F/S”).

Table 2.1 Target Basins and Relevant Previous Studies

Drainage Basin	Catchment Area (km2)	Previous Studies	Remarks
Kalu Oya Basin	58	JICA 2003 M/P & 2018F/S	
Mudun Ela Sub-basin	16	(not included)	Independent Basin from Kalu Oya
Bolgoda Basin	394	JICA 2003 M/P	
Weras Ganga Sub-basin	56	JICA 2003 F/S	Uppermost Basin of Bolgoda

2.4 Hydrological and Hydraulic Analysis Model

The analysis model uses the MIKE series (DHI). This model consists of three parts: runoff analysis model, river network model (flood routing model), and flood inundation analysis model. JICA 2003 M/P also uses the MIKE series in runoff analysis models and river network models.

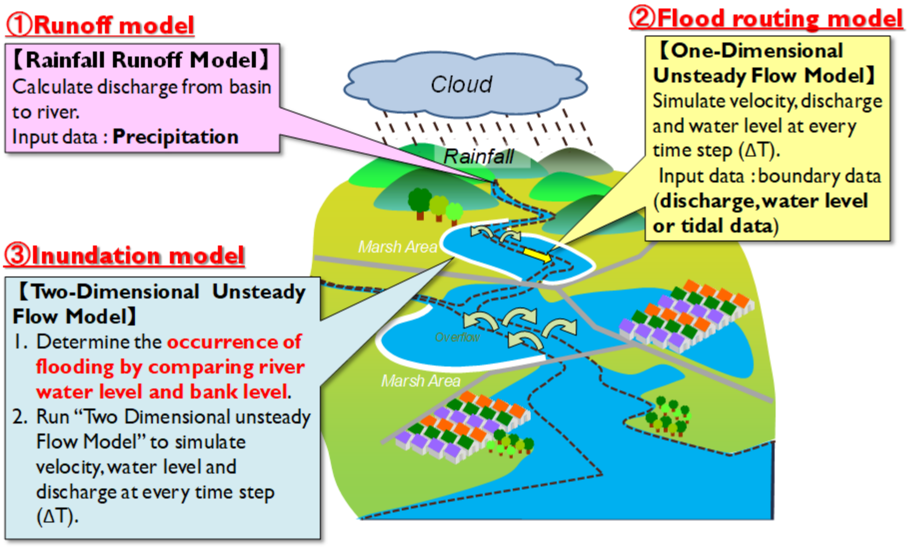


Figure 2.4 Basic Concept of Hydraulic/Hydraulic Analysis Model

2.5 Formulation of Storm Water Drainage Plan

2.5.1 Inundation Risk Mitigation Scenario

In the middle and upper streams of the target basin, wetlands including paddy fields spreading in the valley bottom plain exert a flood control effect (retention effect). However, the low flow capacity of the river channel in the downstream area increases the risk of inundation in the downstream lowlands, so it is first necessary to increase the flow capacity by structural measures. Furthermore, the establishment of a natural wetland park is proposed as a measure to preserve the retarding basin function of paddy fields and wetlands in the middle and upper reaches. This natural wetland park will prevent the invasion of houses, etc. into the wetland, and prevent and reduce the damage caused by flooding of residential areas along the outer edge of the valley bottom plain.

2.5.2 Planning Frame

The design scale of the long-term plan was set as follows. In Kalu Oya and Bolgoda, the 50-year return period is applied based on the balance between the main river and the tributary and the consistency with the existing plan. In Mudun Ela, a 25-year return period is applied based on the balance between the main river and tributaries, the size of the basin, and the design scale of other rivers in Sri Lanka. A 25-year return period is applied to the design scale of the med-term plan (2030).

2.5.3 Design Condition

(1) Design Rainfall

In this study, as in 2018 F/S, the concentrated hyetographs by probability scale were used as the design hyetograph using the rainfall intensity formulas at the Colombo and Rathmalana stations.

Kalu Oya Basin and Mudun Ela Sub-basin (Colombo station)	Bolgoda Basin (Rathmalana Station)

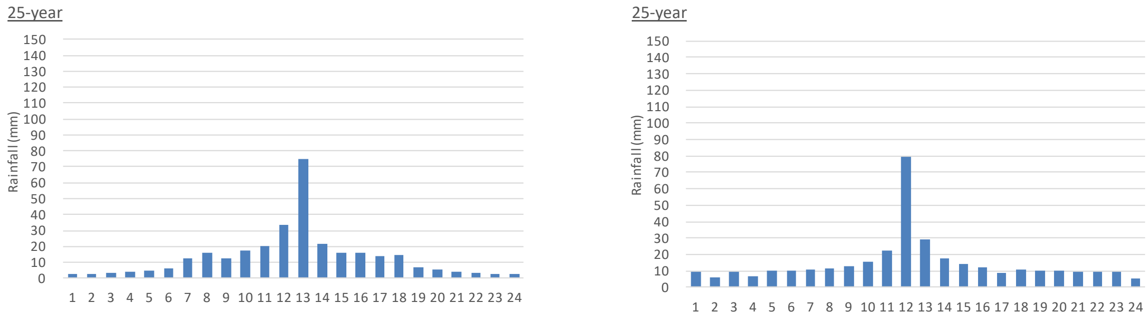


Figure 2.5 Design Hyetograph

(2) Design High Water Level and Freeboard

The design high water level is set according to the following policy.

- Basically, the excavated river channel will be used as a rule, and the design high water level will be set to about the ground level within the bank.
- Even if a dike is required, an excessive dike increases the risk of inundation when the dike breaks, so the relative height to the ground height within the dike is set to a freeboard height (0.5 m).
- If there are existing mitigation structures near the structure to be examined, set the design water level by following the existing plan for such structures.

(3) Design Tidal Level

The design tide level will be the mean high water spring tide level (MSL+ 0.6 m) calculated using the recent tide level data provided by SLLDC.

2.5.4 Inundation Analysis and Evaluation of Flood Risk

(1) Probable Rainfall

The 25-year probable discharge at the reference point in the Kalu Oya basin is about 304 m^3/s, and the discharge considering inundation is 72 m^3/s. The discharge is greatly reduced due to the flood storage effect upstream. Similarly, the 25-year probable discharge at the reference point in the Mudun Ela sub-basin is 78 m^3/s, the discharge considering flooding will be reduced to 17 m^3/s, the 25-year probable discharge at the reference point in Bolgoda is 1,009 m^3/s, and the discharge considering with inundation will be reduced to 464 m^3/s. It is extremely important to consider the flood storage effect of the basins when considering countermeasures for both basins.

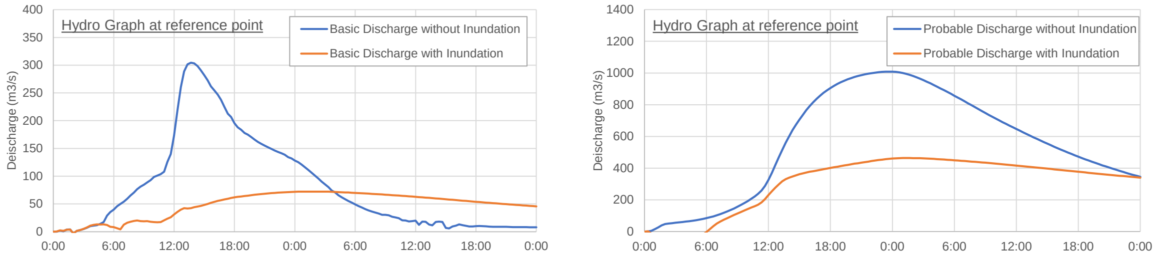


Figure 2.6 Hydrograph of 25-year Return Period

(2) Flood Risk

The inundation area for each land use was calculated by overlaying the assumed inundation area and the land use map. The proportion of residential areas to the total expected flooded area in the Bolgoda basin is 19.7% with a 25-year probability, but it is estimated to be 42.1% and 65.8% in the Kalu Oya basin and Mudun Ela sub-basin where assets are concentrated. The Mudun Ela sub-basin has the highest inundation risk, and urgent storm water drainage is required. On the other hand, in the Kalu Oya basin and the Bolgoda basin, areas with high inundation risk are locally distributed, and it is considered that targeted storm water drainage measures are necessary.

Table 2.2 Assumed Inundation Area and Percentage by Land Use

Kalu Oya

Land Use	2-year		5-year		10-year		25-year	
	Area(ha)	Ratio	Area(ha)	Ratio	Area(ha)	Ratio	Area(ha)	Ratio
Agricul Area	5.9	1.0%	7.0	0.9%	9.0	1.0%	13.2	1.1%
Lowland (Wetland)	407.9	66.7%	493.9	62.9%	548.4	59.8%	597.3	52.1%
Nature Area	2.0	0.3%	2.0	0.3%	2.0	0.2%	4.8	0.4%
Water Area	41.9	6.9%	46.1	5.9%	47.5	5.2%	49.4	4.3%
Settlement Area	153.9	25.2%	235.6	30.0%	310.1	33.8%	482.4	42.1%
Total	611.7	100.0%	784.7	100.0%	917.1	100.0%	1,147.1	100.0%

Mudun Ela

Land Use	2-year		5-year		10-year		25-year	
	Area(ha)	Ratio	Area(ha)	Ratio	Area(ha)	Ratio	Area(ha)	Ratio
Agricul Area	0.6	0.2%	1.4	0.3%	2.4	0.5%	4.3	0.6%
Lowland (Wetland)	135.6	34.8%	158.5	35.4%	172.2	33.0%	191.0	27.7%
Nature Area	1.3	0.3%	2.3	0.5%	2.5	0.5%	2.6	0.4%
Water Area	30.6	7.8%	32.3	7.2%	34.8	6.7%	37.8	5.5%
Settlement Area	221.7	56.9%	253.1	56.6%	310.1	59.4%	454.2	65.8%
Total	389.8	100.0%	447.6	100.0%	522.0	100.0%	689.9	100.0%

Bolgoda

Land Use	2-year		5-year		10-year		25-year	
	Area(ha)	Ratio	Area(ha)	Ratio	Area(ha)	Ratio	Area(ha)	Ratio
Agricul Area	316.3	10.0%	476.0	9.0%	544.4	8.4%	617.5	8.1%
Lowland (Wetland)	1,867.7	59.0%	3,213.7	60.7%	3,882.4	60.0%	4,435.8	58.3%
Nature Area	167.4	5.3%	279.6	5.3%	343.2	5.3%	404.0	5.3%
Water Area	427.4	13.5%	542.8	10.3%	606.0	9.4%	649.4	8.5%
Settlement Area	388.2	12.3%	782.1	14.8%	1,099.2	17.0%	1,499.2	19.7%
Total	3,167.0	100.0%	5,294.2	100.0%	6,475.2	100.0%	7,606.0	100.0%

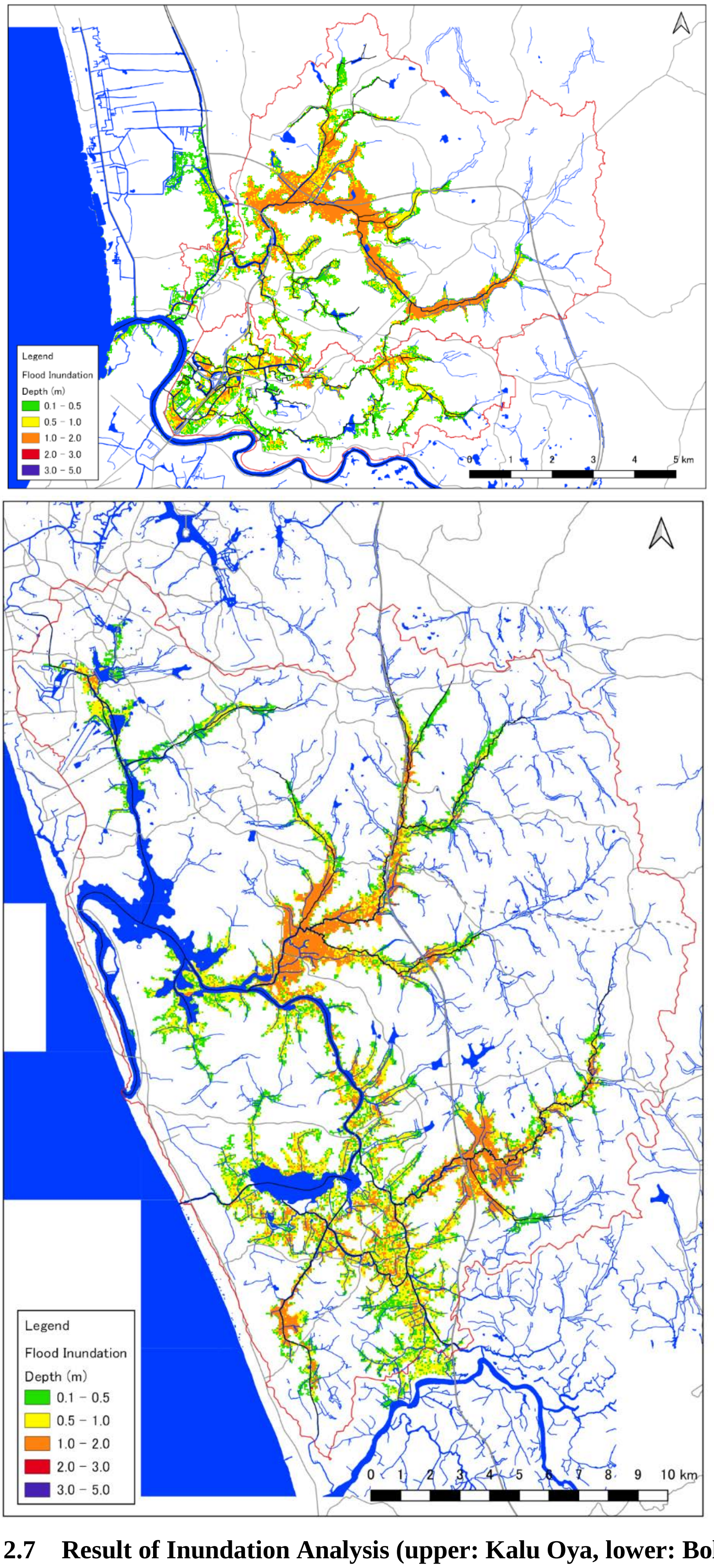


Figure 2.7 Result of Inundation Analysis (upper: Kalu Oya, lower: Bolgoda)

2.5.5 Storm Water drainage Plan (Structural Measures)

(1) Kalu Oya Improvement

The following is a list of countermeasures for the Kalu Oya basin to be examined in this study referring to the countermeasures proposed at JICA 2003 M/P and 2018 F/S.

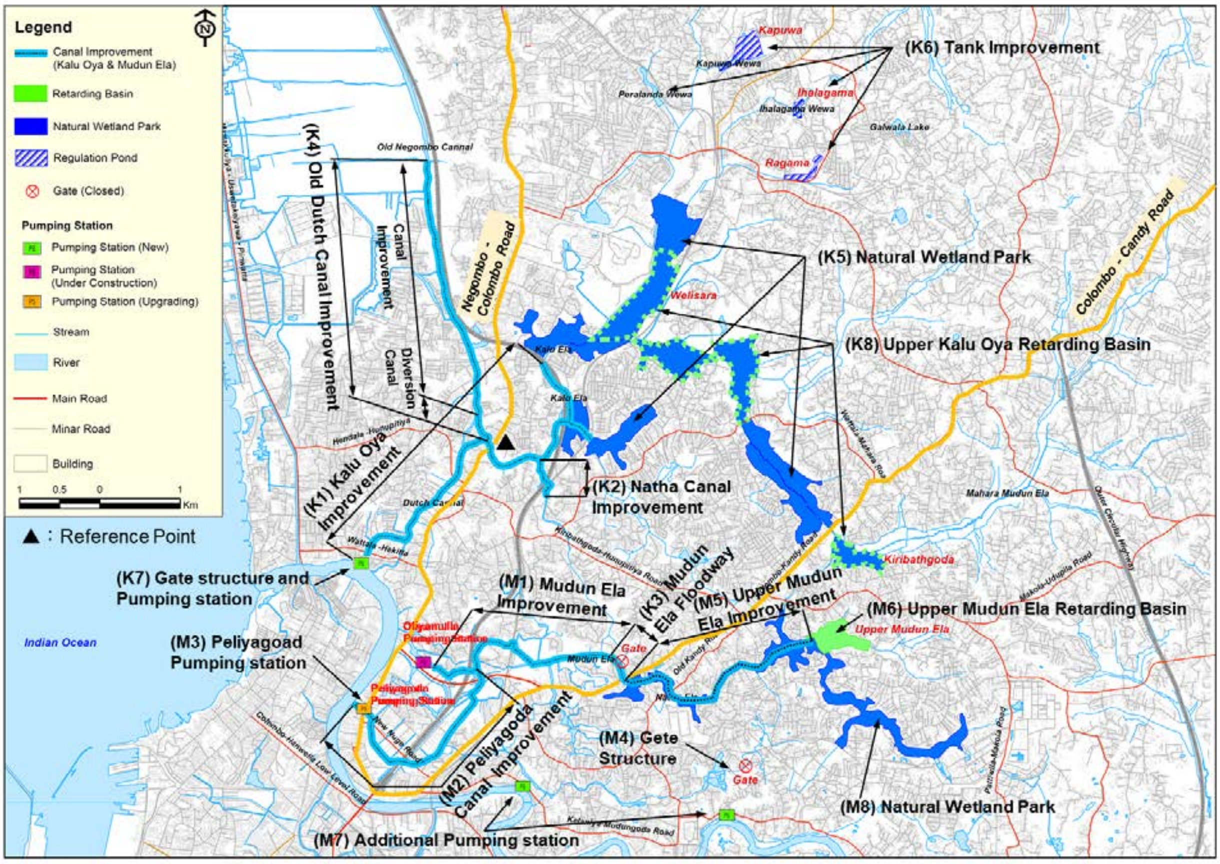


Figure 2.8 Storm Water Drainage Plan in the Kalu Oya Basin and the Mudun Ela Sub-basin

(2) Bolgoda Improvement

The land use assumed in 2030 and the inundation simulation result of the 25-year return period was overlaid, and the places where the residential land/urban area and the inundation area overlap were extracted. In addition, the priority area was set based on information such as the estimated flood area and distribution of the number of flooded houses by area, and the flood countermeasure plan was examined.

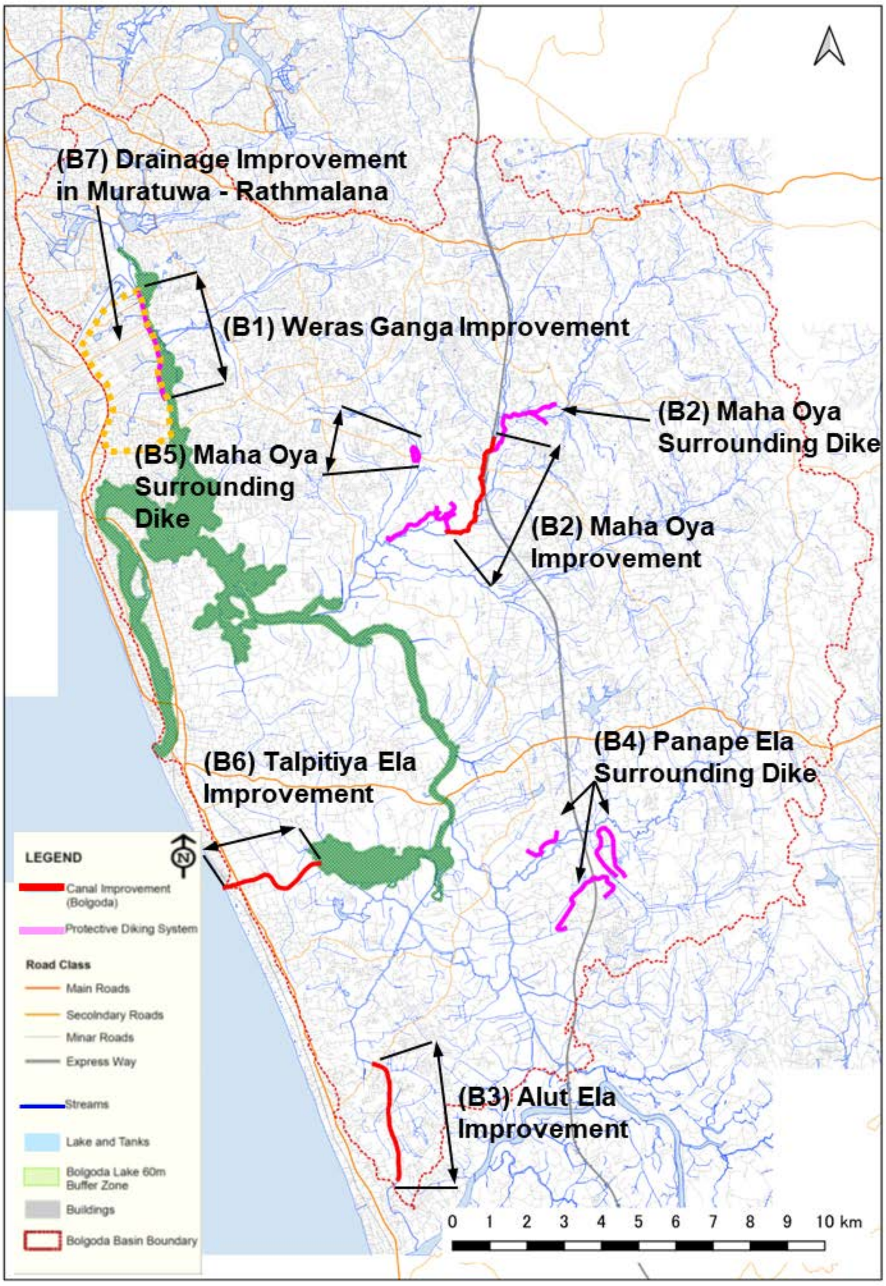


Figure 2.9 Storm Water Drainage Plan in the Bolgoda Basin

2.5.6 Storm Water Drainage Plan (Conservation of Natural Retention Water Function)

The conservation of the natural retention function of agricultural lands and wetlands is essential for stormwater drainage measures in the target area. It is proposed that the maintenance of the water retention function of wetlands and the preservation of the natural environment be defined as non-structural measures and that areas with water retention function be designated as "natural retention areas". Especially, “Natural Wetland Park” was proposed as a non-structural measure by conservation and enhancement of wetlands in the Kalu Oya basin and the Mudun Ela sub-basin.

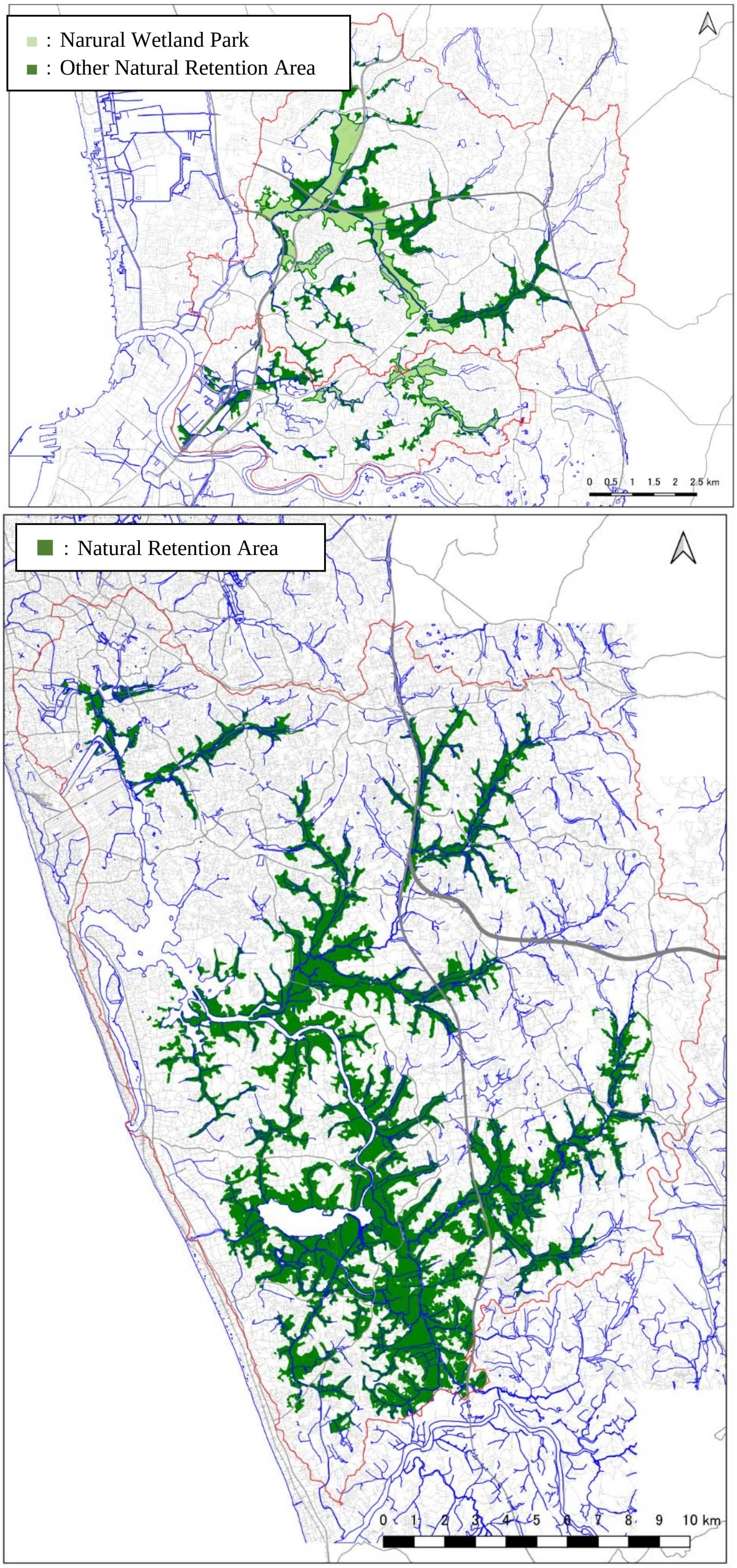


Figure 2.10 Natural Wetland Park and Natural Retention Area

2.5.7 Storm Water Drainage Plan (Master Plan)

The storm water drainage plan in this study is proposed as a long-term plan (overall plan) on the precondition that the flood control safety level of the entire basin is gradually improved to a 50-year return period. The combination of appropriate countermeasures to gradually improve the flood control safety level will be proposed considering the feasibility (construction cost and workable amount). The countermeasure menu to be implemented during the project period until 2030 will be selected as the mid-term plan for the storm water drainage plan. During the maintenance period until 2030, the flood control safety level of the Kalu Oya basin and the Bolgoda basin will improve to a 25-year return period.

Table 2.3 Storm Water Drainage Plan in Kalu Oya Basin

Safety Level	Priority	Summary of Countermeasure
10-year Return Period	1	Kalu Oya Improvement［K1］ ● Target: Kalu Oya Main Canal ● Measure: Canal improvement (Widening, Dredging, Embankment) Length: 5.1 km
	2	Natha Canal Improvement［K2］ ● Target: From Kalu Oya to Railway Bridge ● Measure: Canal improvement (Widening, Dredging, Embankment) Length: 0.5 km
	3	Mudun Ela Diversion［K3］ ● Target: Near the confluence of Upstream of Natha Canal and Mudun Ela ● Measure: Canal Improvement (Widening, Dredging, Embankment), Removal of the existing connecting gate, Installation of new deadline facility Length: 0.3 km
	4	Natural Wetland Park［K5］ ● Target: Wetlands located in the valley bottom plain in the middle and upper reaches of the main channel and tributaries ● Measure: Prevention of invasion of houses, etc. by converting existing wetlands into parks The total length of the small dike: 28.8 km
25-year Return Period	5	Old Dutch Canal Improvement and Flood diversion channel［K4］ ● Target: From Upstream of Negombo Wetland to the proposed new flood diversion channel ● Measure: Canal Improvement (Widening, Dredging, Embankment), Excavation of an existing channel (Widening, Dredging, Embankment) Length: Old Dutch Canal = 5.0 km, Flood diversion = 0.4 km
50-year Return Period	6	Installation of Gate structure and Pumping station［K7］ ● Target: The most downstream confluence of Kelani Ganga ● Measure: Gate structure and pumping stations for the Kelani Ganga embankment project at the confluence Drainage capacity: 35m^3/s, Gate Width: 30m
	7	Improvement of natural wetland park to retarding basin［K8］ ● Target: Natural wetland park along the Kalu Oya main river and primary tributaries ● Measure: Excavation in natural wetland park, Surrounding dike, Overflow dike Number of wetland parks: 4
-	Other	Improvement of Tank［K6］ ● Target: Upstream of Kalu Oya tributary, 3 location

Table 2.4 Storm Water Drainage Plan in Mudun Ela Sub-basin

Safety Level	Priority	Summary of Countermeasure
10-year Return Period	1	Mudun Ela Improvement［M1］ ● Target: Mudun Ela Main Canal (From Oliyamulla pumping station to Colombo-Kandy Road) ● Measure: Canal improvement (Widening, Dredging, Embankment) Length: 3.1 km
	2	Peliyagoda Improvement［M2］ ● Target: Peliyagoda canal connected to a pumping station ● Measure: Canal improvement (Dredging) Length: 2.8 km
	3	Improvement of Peliyagoda Pumping starion［M3］ ● Target: Peliyagoda Pumping station ● Measure: Enhancement of pump facilities (drainage capacity $0.5m^3/s$ to $1.0m^3/s$)
	4	Installation of Gate structure［M4］ ● Target: Peliyagoda canal ● Measure: Installation of Gate structure
	5	Natural Wetland Park［M8］ ● Target: Wetlands located in the valley bottom plain in the middle and upper reaches of the main and secondary channel ● Measure: Prevention of invasion of houses, etc. by converting existing wetlands into parks The total length of the small dike: 16.9 km
25-year Return Period	6	Upper Mudun Ela Improvement［M5］ ● Target: Upstream section from Colombo-Kandy road ● Measure: canal improvement (Dredging) Length: 3.0 km
	7	Construction of retarding basin of upper Mudun Ela［M6］ ● Target: Natural wetland park along Mudun Ela ● Measure: Excavation molding in natural wetland park, Surrounding dike, Overflow dike Number of wetland parks: 1
-	Other	Installation of two pumping stations and improvement of the connected canal［M7］ ● Target: Local flooding risk area around upper Nalanmini Oya ● Measure: Installation of two pumping facilities (Pethiyagoda Pumping Station: 15 m^3/s, Koholwila Pumping Station: 5 m^3/s) and improvement of the connected canal (Naranmini Oya/ Koholwila canal) Number: 2 location

Table 2.5 Storm Water Drainage Plan in Bolgoda Basin

Safety Level	Priority	Summary of Countermeasure
25-year Return Period	1	Weras Ganga Right Embankment [B1] ● Target: Moratuwa-Rathmalana Area (Weras Ganga Right side) ● Measure: Canal improvement (Embankment) Length: 3.0 km
	2	Local Flood Mitigation Measure in Panape Ela Basin [B4] ● Target: Flood inundation area along Panape Ela ● Measure: Surrounding diking system of three section Length: 6.7 km (total)
	3	Local Flood Mitigation Measure in Maha Oya Basin [B2] ● Target: Near the intersection of the Maha Oya and expressway and residential area ● Measure: Canal improvement (dredging, embankment), Replacement of 2 road bridges Length: 5.9 km
	4	Local Flood Mitigation Measure in Alut Ela Basin [B3] ● Target: Assumed flood inundation area along Alut Ela ● Measure: Canal improvement (dredging, embankment), Replacement of 4 road bridges Length: 3.4 km
	5	Local Flood Mitigation Measure in Maha Oya Tributary Basin [B5] ● Target: Near the intersection of the Maha Oya Tributary and expressway and residential area ● Measure: Surrounding diking system Length: 1.0 km
50-year Return Period	6	Weras Ganga Improvement [B1] ● Target: Moratuwa-Rathmalana Area (Weras Ganga) ● Measure: Canal improvement (Dredging) Length: 2.9 km
	7	Thalpitiya Ela Improvement [B6] Temporary ● Targe: Talptiya Ela and Coastal clogged point ● Measure: Canal improvement (Dredging, Excavation of clogged point) Length: 2.8 km
-	Others	Improvement of Drainage System of Moratuwa-Rathmalana Area［B7］ ● Target: Moratuwa-Rathmalan Area ● Measure: Installation of gate structures and pumping stations associated with Weras Ganga embankment, improvement of primary canals Length: 4.0km, Gate structure: 2 locations, Pumping station: 2 locations

2.5.8 Effect of Storm Water Drainage Plan

(1) Kalu Oya Basin and Mudun Ela Sub-basin

If flood control measures are implemented, the number of affected houses will decrease from about 3,500 to about 800 in the entire Kalu Oya basin with a 25-year probability. In the entire Mudun Ela sub-basin, 4,600 units will be reduced to 2,200 units.

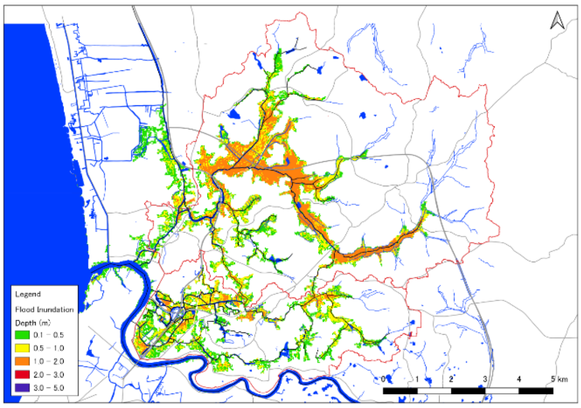
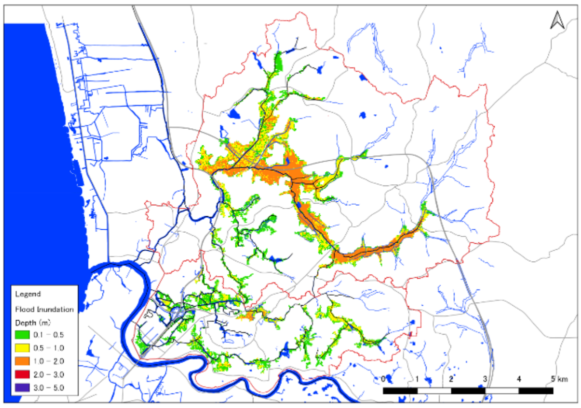
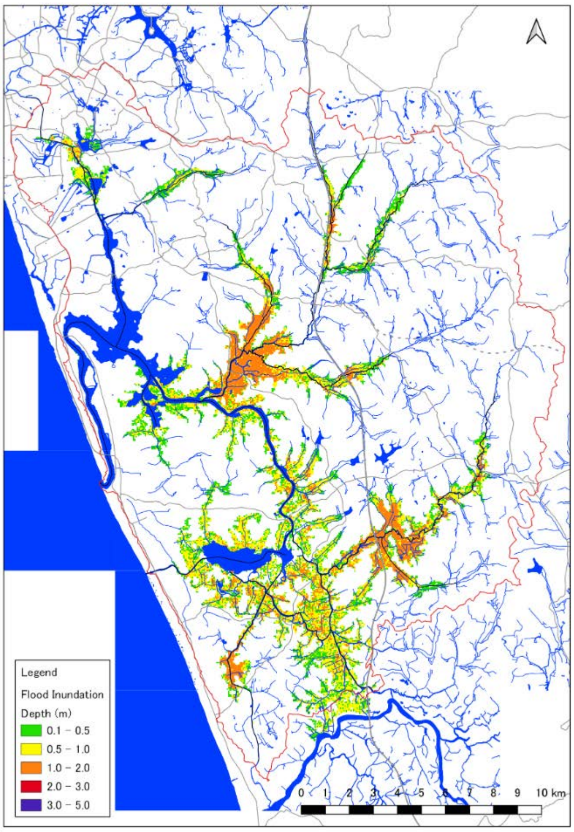



Figure 2.11 Assumed Inundation Area (Left: Without PJ, Right: with PJ)

(2) Bolgoda Basin

If flood control measures are implemented in the Bolgoda basin, the number of affected houses will be reduced from about 3,900 to about 2,600 in the entire Bolgoda basin.



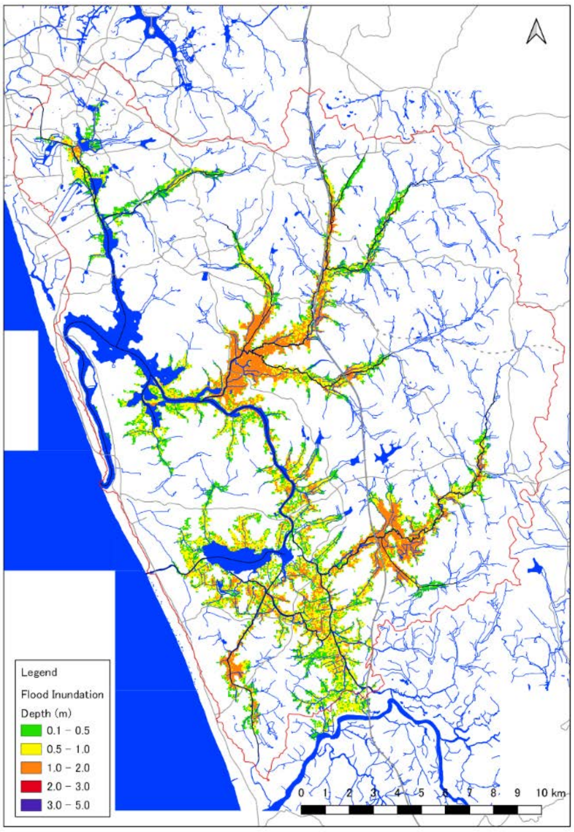


Figure 2.12 Assumed Inundation Area (Left: Without PJ, Right: with PJ)

2.5.9 Structure Design and Cost Estimation

(1) Design Guidelines, Manual, and Specification

In Sri Lanka, there is no design guideline, manual, or specification which shows the design methods or standard cross sections of structure measures. However, there are some specifications describing engineering works such as survey works and execution of construction works. The following design guideline, manuals, and specifications were referred to for the design.

Table 2.6 Design and Engineering Work Specification in Sri Lanka and Japan

Title of the reference in Sri Lanka	Title of the reference in Japan
・ Specifications for site investigation for building and civil engineering works (CIDA, January 2017) ・ Specifications for irrigation and land drainage works (CIDA, May 2013) ・ Specifications for water supply sewerage and storm water drainage works (CIDA, April 2002) ・ Specifications for bored and cast-in-situ reinforced concrete piles (CIDA, February 2016) ・ Standard specifications for construction and maintenance of roads and bridges (CIDA, June 2009) ・ Specifications for coastal and harbor engineering works (CIDA, June 2008)	・ Manual for Government Ordinance for Structural Standard for River Administration Facilities (Japan River Association, January 2000) ・ Technical Criteria for River Works and those practical guides-Survey, Planning, and Design (JRA, June 2012 (Survey) March 2019 (Planning), July 2019 (Design)) ・ Guideline for Structural Analysis on River Dike (Japan Institute of Construction Engineering (JICE), February 2012) ・ Manual for Mechanical Design of Revetment (JICE, November 2007) ・ Basic Guideline and Policy for Disaster Rehabilitation to maintain the beauty of mountains and rivers (Ministry of Land, Infrastructure and Transport, June 2018)

Source: JICA Study Team

(2) Design Criteria

Based on the following design conditions, cross sections and layout plans were proposed for the Kalu Oya basin, Mudun Ela Sub-basin, and Bolgoda basin. The cross sections are shown in the main part and appendix of the report.

Table 2.7 Design Specifications for the Master Plan design

Items	Kalu Oya basin, Mudun Ela sub-basin, Bolgoda basin	Weras Ganga Right Bank Dike
Freeboard (m)	0.5	0.5
Crown width (m)	4.0 (maintenance road: 3.0) 1.0 at narrow areas	3.0 (maintenance road: 2.0)
Slope	1 to 0.5 (Gabion wall) 1 to 2.0 (Slope with turf) Vertical (Steel sheet pile)	1 to 2.0 (Slope with turf)
Berm	3.0 for over 5.0m-high slopes	-

Source: JICA Study Team

(3) Rough Design

1) Embankment and Revetment

Considering the structural feature of deformation along with the uneven settlement, the constructability, experiences of contractors, construction cost, and ease of maintenance, the gabion wall is selected for the steep slope revetment.

At the vicinities of factories and buildings, a steel sheet pile wall is proposed to minimize the land acquisition and assurance of the stability of the land.

2) Surrounding Dike

The surrounding dike at the upstream area of Kalu Oya and in the Bolgoda basin are earth dikes. Its slope is at “1 to 2.0” and covered with turf. A berm is not required since it is not high.

3) Pumping Station

At the Peliyagoda Pumping Station, a new pump with a discharge capacity of 1.0 m^3/sec and its equipment will be installed at the empty lot. Although the existing pumping system with its discharge capacity of 0.5 m^3/sec will not be removed and be kept in operation, the total discharge is considered as 1.0 m^3/sec to be safe side.

Source: JICA Study Team

Figure 2.13 Existing Condition and Empty Lot at Peliyagoda Pumping Station

4) Closing Facility

As closing facilities, sluice gates are installed at Naranmini Oya and Natha Canal. The specification of the gates is shown in Table 2.8.

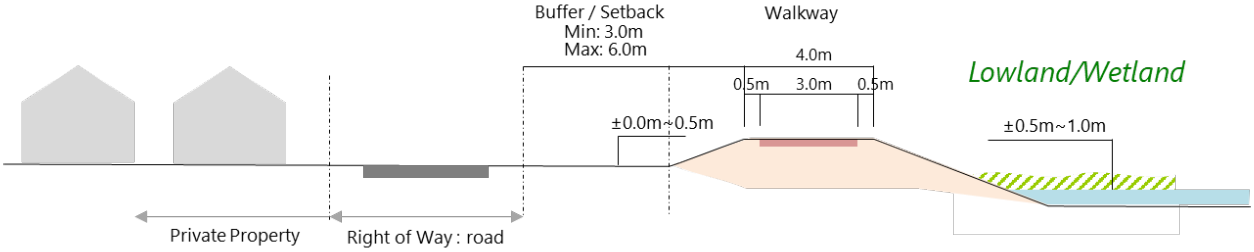
Table 2.8 Specification of Closing Facility

No.	Channel	Structure	Dimension
1	Naranmini Oya	Sluice gate	H = 1.5 m W = 2 m x 4 gates
2	Natha Canal	Sluice gate	H = 1.5m W = 2.5 m x 4 gates

Source: JICA Study Team

5) Natural Wetland Park

In order to maintain the current environment and retention effect of the natural wetland parks, core facilities such as sidewalks, small embankments and visitor centers are proposed. The small embankment will basically be an earth dike with a slope at "1 to 2.0" and covered with turf. The height of the embankment is approximately 0.5 m.



Source: JICA Study Team

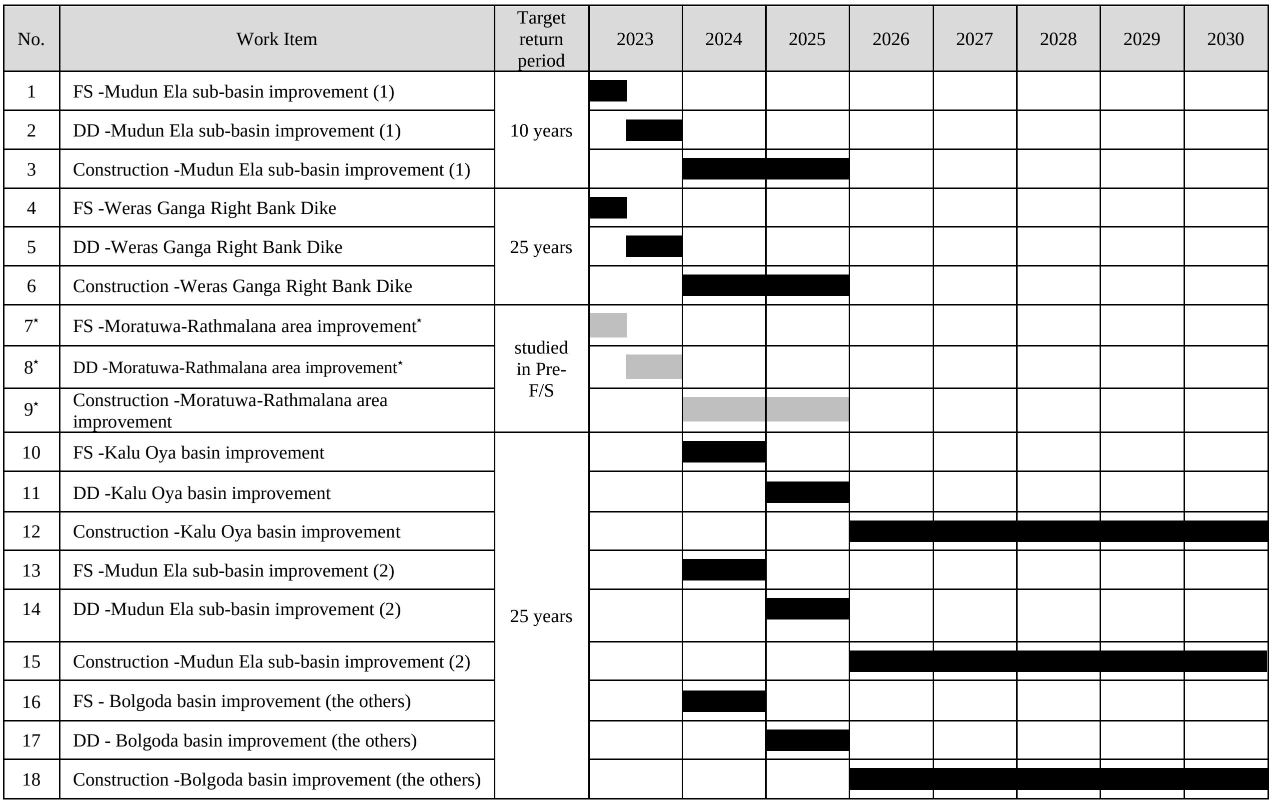
Figure 2.14 Concept Drawing of the Improvement of the Natural Wetland Park

6) Planned Retarding Basin

Dredging, sidewalks / small embankments, embankments along river channels, and overflow dikes will be constructed in the existing natural wetlands to be used as planned retarding basins. The small embankment will be basically an earth dike with a slope at "1 to 2.0" and covered with turf. The height of the embankment is varied from 0.5 m to 2.0 m.
In addition, a side-overflow dike is installed at the upstream end of each retarding basin, and a gate is installed at the downstream end. The margin of the reservoir capacity is set to approximately 15% referring to the Technical Criteria for River Works and those practical guides.

(4) Overall Project Schedule

Figure 2.15 shows the overall project schedule of this project.



Note: Improvement at the Moratuwa-Rathmalana area is shown here for comparison purposes although it is not included in the M/P.

Source: JICA Study Team

Figure 2.15 Overall Project Schedule

(5) Cost Estimation

1) Price Level

The cost estimate is at the price level as of December 2022. However, since price fluctuations caused by the recent economic crisis are considered to be temporary, fluctuations in exchange rates and price increases in recent years regarding the Sri Lankan Rupee are not taken into account. Specifically, the exchange rate was set based on the average value from November 11, 2019 to February 10, 2020, and price increases after this period were not considered.

2) Project Cost

The summaries of total project costs are shown in Table 2.9 and Table 2.10.

Table 2.9 Project Cost for Kalu Oya Basin and Mudun Ela Sub-basin

(million LKR)

Item	Kalu Oya Basin			Mudun Ela Sub-basin		
	F.C.	L.C.	Total	F.C.	L.C.	Total
Construction Cost	5,576	2,554	8,130	1,116	980	2,096
Engineering Service	335	153	488	67	41	108
Land Acquisition and Compensation	0	3,453	3,453	0	1,587	1,587
Administration cost	0	227	227	0	59	59
Physical Contingency	591	753	1,344	118	292	410
Price Contingency	0	1,372	1,372	0	312	312
VAT	0	1,700	1,700	0	439	439
Total	6,502	10,212	16,714	1,302	3,709	5,011

Source: JICA Study Team

Table 2.10 Project Cost for Bolgoda Basin and Total Area

(million LKR)

Item	Bolgoda Basin			Total Area		
	F.C.	L.C.	Total	F.C.	L.C.	Total
Construction Cost	2,010	4,185	6,195	8,703	7,718	16,421
Engineering Service	121	251	372	522	445	967
Land Acquisition and Compensation	0	2,628	2,628	0	7,668	7,668
Administration cost	0	237	237	0	523	523
Physical Contingency	213	832	1,045	922	1,877	2,799
Price Contingency	0	1,594	1,594	0	3,278	3,278
VAT	0	1,288	1,288	0	3,427	3,427
Total	2,344	11,015	13,359	10,147	24,936	35,083

Source: JICA Study Team

2.6 Socio-Economic and Financial Situations

The stakeholder meetings for the Strategic Environmental Assessment (hereinafter referred to as "SEA") were conducted four times to get feedback on the M/P contents and the SEA reports for the Kalu Oya basin including Mudun Ela sub-basin and the Bolgoda basin were compiled. The SEA concluded that the M/P will address many challenges associated with flooding and stormwater drainage. To minimize the environmental and social impacts associated with the implementation of the M/P and to maximize the positive impacts of the M/P, the SEA proposed the following recommendations.

Table 2.11 Recommendations of SEA to the Master Plan

	Area	Recommendation
1	Kalu Oya	When establishing wetland parks and retarding basins, adequate attention should be given to ensure that existing drainage patterns are not disturbed, as this would result in an accumulation of stormwater outside the wetland parks and retarding basins resulting in minor floods that would affect the surrounding communities.
2	Common	The vegetation that will be removed during canal improvements must be estimated before commencing these actions and a plan must be prepared as to how the estimated biomass will be managed.
3	Common	Since many of the plant species that will be removed during canal improvements are invasive alien species, the biomass management plan must have a separate set of guidelines on how to identify and process invasive alien species with the involvement of a specialist that has prior experience with managing invasive alien plant species.
4	Common	At each site where dredging will be undertaken, a sediment sample must be tested for the presence of heavy metals and other potentially toxic substances. If the sediment samples were found to have heavy metals or other toxic materials, their disposal should be carried out with special precautions to prevent leachate from such heavy metals or toxic material into the surrounding environment.
5	Common	The quantity of anticipated dredged material must be calculated before the commencement of the dredging operations. Temporary storage areas and permanent disposal sites should be identified according to the expected amount of material.
6	Common	The dredged material should be stored close to the dredging site to partially dry the material before it is transported to the permanent disposal site. Further, the route between the temporary storage site and the permanent disposal site should be preplanned to ensure that the transport of dredged material will not result in traffic congestion.
7	Bolgoda Basin	The dredged material can be used to restore the abandoned clay pits and therefore a detailed plan should be developed as to how the dredged material can be utilized within the basin for the restoration of abandoned lands.
8	Common	Ecological restoration of habitats should only use native species that are suitable for the basin, which should be identified with the help of a plant ecologist.
9	Common	The creation of access roads through wetlands should be minimized.
10	Bolgoda Basin	Boundaries of the Bolgoda EPA should be demarcated to prevent future encroachments.
11	Kalu Oya	Boundaries of the wetland parks and retarding basins should be demarcated to prevent future encroachments.

12	Bolgoda Basin	Restored areas should be used for recreation activities as this will create additional livelihoods, especially for marginalized communities.
13	Common	There would be some temporary inconvenience due to construction activities and care must be taken to implement the best construction management practices with the needs of the residents being given due consideration.
14	Common	All exposed areas in banks must be vegetated to prevent soil erosion. Turfing is not recommended as it would involve the use of exotic grasses. Alternatively, native ground cover can be used.
15	Common	Provide compensation if relocation/resettlement is taking place or for any physical and human damages.
16	Common	Conduct an awareness program for all the stakeholders, particularly project-affected local people, to get their support for the master plan

Source: JICA Study Team

2.7 Economic Evaluation

The Economic Internal Rate of Return (EIRR), B/C and Net Present Value (NPV) of the projects are calculated as shown in Table 2.12.

Table 2.12 EIRR and Other Indicators of Projects for River Basins

River Basin/Area	EIRR	B/C	NPV (million Rs.)
Kalu Oya	12.22%	1.02	134
Mudun Ela	53.79%	7.22	17,684
Bolgoda	20.72%	1.76	4,648

Source: Ministry of Finance, Central Bank of Sri Lanka, JICA Study Team

As SDR is set at 12%, all the projects for the river basins are evaluated as feasible. Though the EIRR of Mudun Ela seems very high, it is because this includes the effect of the construction of the pump station. If the construction cost of the pumping station is considered, EIRR becomes 30% level.

3 Pre-Feasibility Study

3.1 Introduction

As a preparation for the Pre-F/S, in addition to the ground elevation data used in the M/P study, data such as the cross section data of the drainage channels at the Moratuwa-Rathmalana area which were surveyed by the SLLDC in 2020 and 2021 were collected and compiled. The geotechnical investigation including boring, in-situ tests, and laboratory tests was subcontracted to understand the ground conditions.

3.2 Hydrological and Hydraulic Analysis

3.2.1 Mudun Ela Improvement

(1) The policy of Setting Canal Alignment and Cross section

The river channel plan was divided into five sections (S1-S5) considering (1) current channel width, (2) major structures such as highways, and (3) future land use. Based on the hydraulic calculations in the M/P study, the planned channel width was set at approximately 20 m for S1-S4 and 15 m for S5. After comparing the two route alternatives shown in Figure 3.1, the existing channel route was selected.

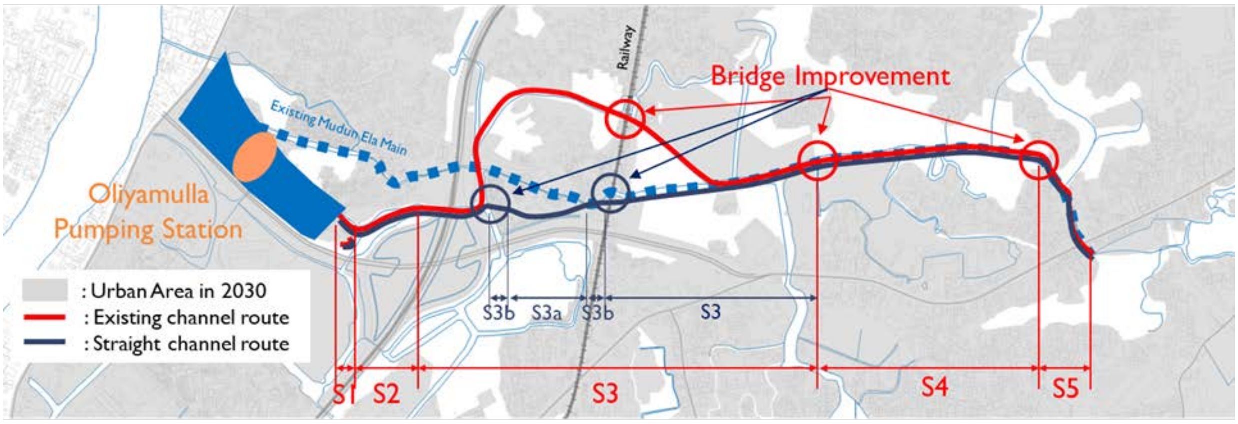


Figure 3.1 Planning Section (S1-S5) and Design Alignment

(2) Inundation Analysis

Using the inundation simulation model constructed in the M/P study, the inundation reduction effects of the Pre-F/S target projects (priority projects) were verified. The priority projects are targeted to secure the safety level of flood risk on the 10-year probability scale as immediate countermeasure projects. In particular, it was confirmed that the effect is particularly significant north of the Colombo-Candy Road, where future urban development is expected.

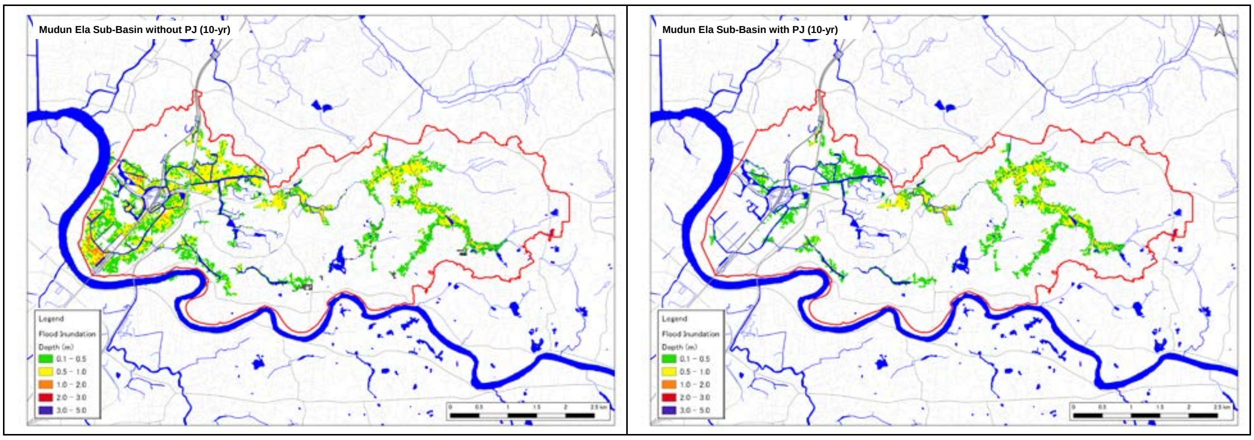
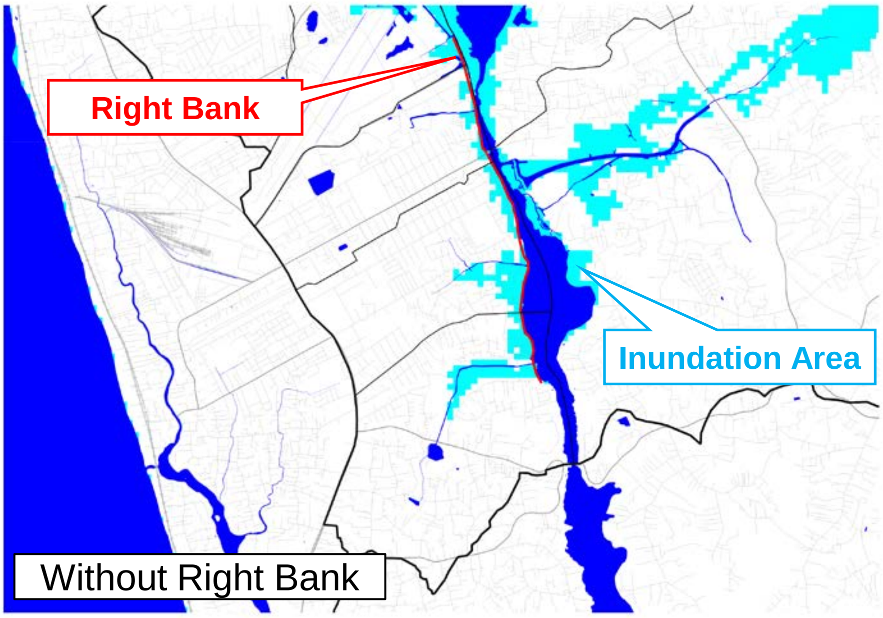


Figure 3.2 Estimated Inundation Area (Left: without PJ, Right: with PJ)

3.2.2 Bolgoda Improvement

The right bank of Weras Ganga is proposed as a measure to prevent inundation due to flooding from Weras Ganga in the Moratuwa-Rathmalana area. The 25-year probability flood inundation area in the Moratuwa-Rathmalana area was significantly reduced, indicating that the hydraulic effect of the right bank embankment is extremely large.



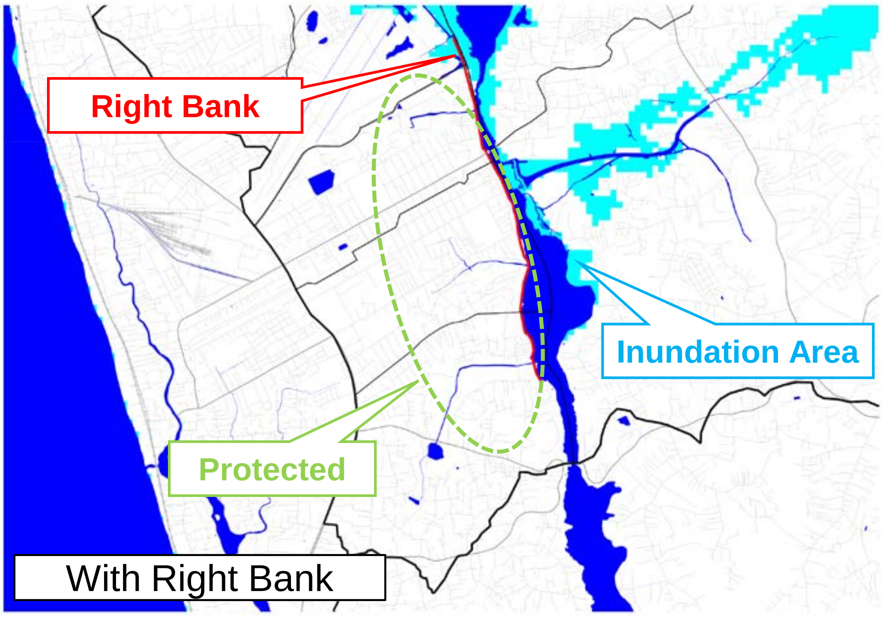


Figure 3.3 Estimated Inundation Area (Left: without PJ, Right: with PJ)

3.2.3 Moratuwa-Rathmalana Area

(1) Target Area

The Moratuwa-Rathmalana area is located on the right bank of the Weras Ganga, a tributary of the Bolgoda basin. There are three major canals in the area, and the catchments of these major drainage canals are referred to as Zone A, Zone B, and Zone C. The hydrological and hydraulic analysis model was constructed for each drainage area, and the design discharge and drainage channel specifications were examined.

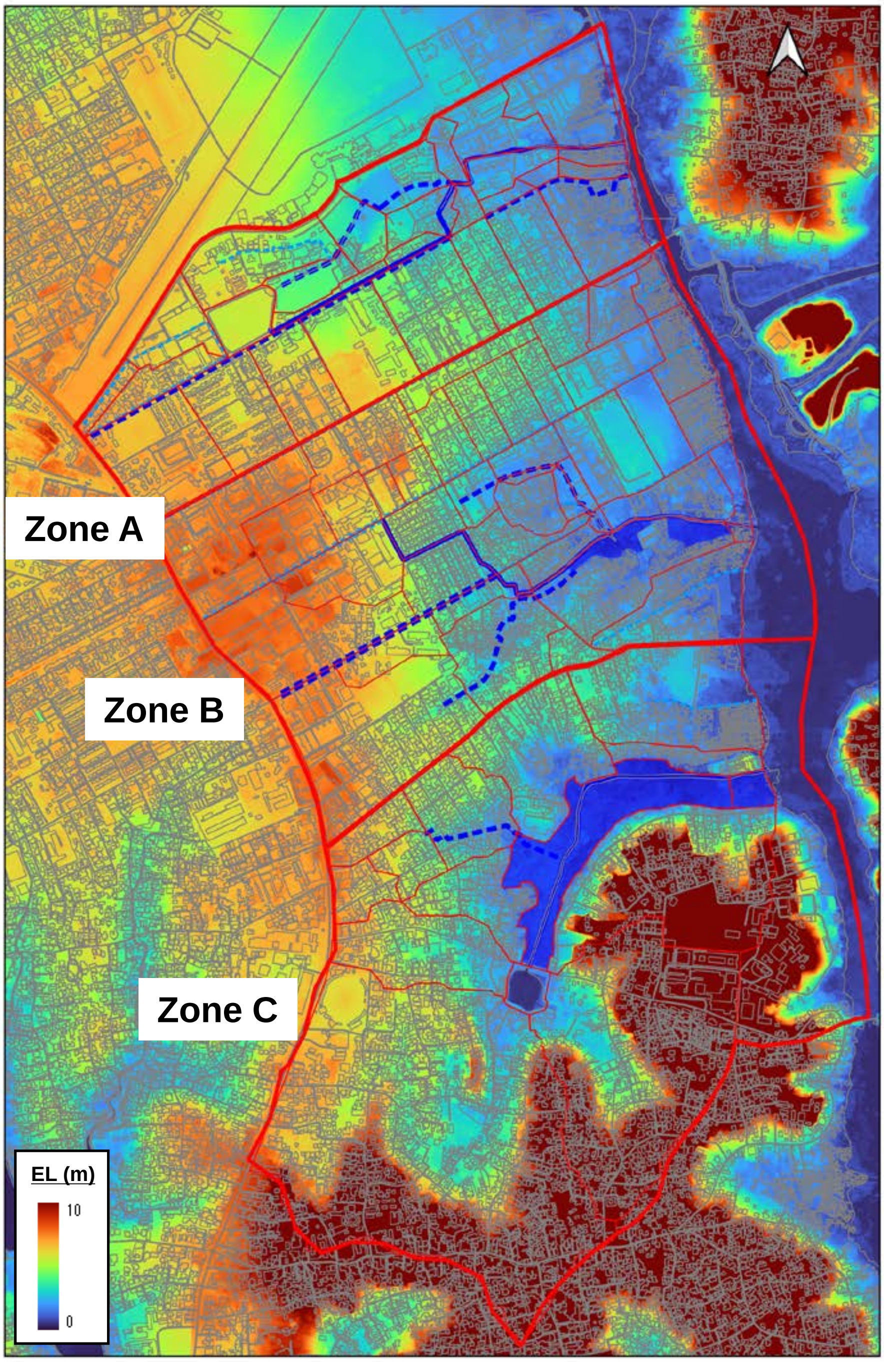


Figure 3.4 Sub-Catchment Area in Moratuwa-Rathmalana Drainage Area

(2) Design Scale

Referring to the design scale of neighborhood basins and the results of previous studies (JICA 2003M/P), it would be appropriate to set the design scale of the target area at a 2 to 10 years return period. Therefore, the design scale of the target area was determined by estimating the risk of inundation at several probability scales and the scale of facilities expected to reduce the inundation risk, as well as by considering the social impact of each of these factors. Ultimately, after discussion with SLLDC, it was decided to improve the main canal with a 10-year return period and the secondary canal with a 5-year return period.

(3) Inundation Analysis

Using the hydraulic analysis model, the flow discharge based on the design scale was calculated, the channel specifications were set by uniform flow calculation, and the inundation analysis was conducted. The effects of flood risk reduction by canal improvement are shown below.

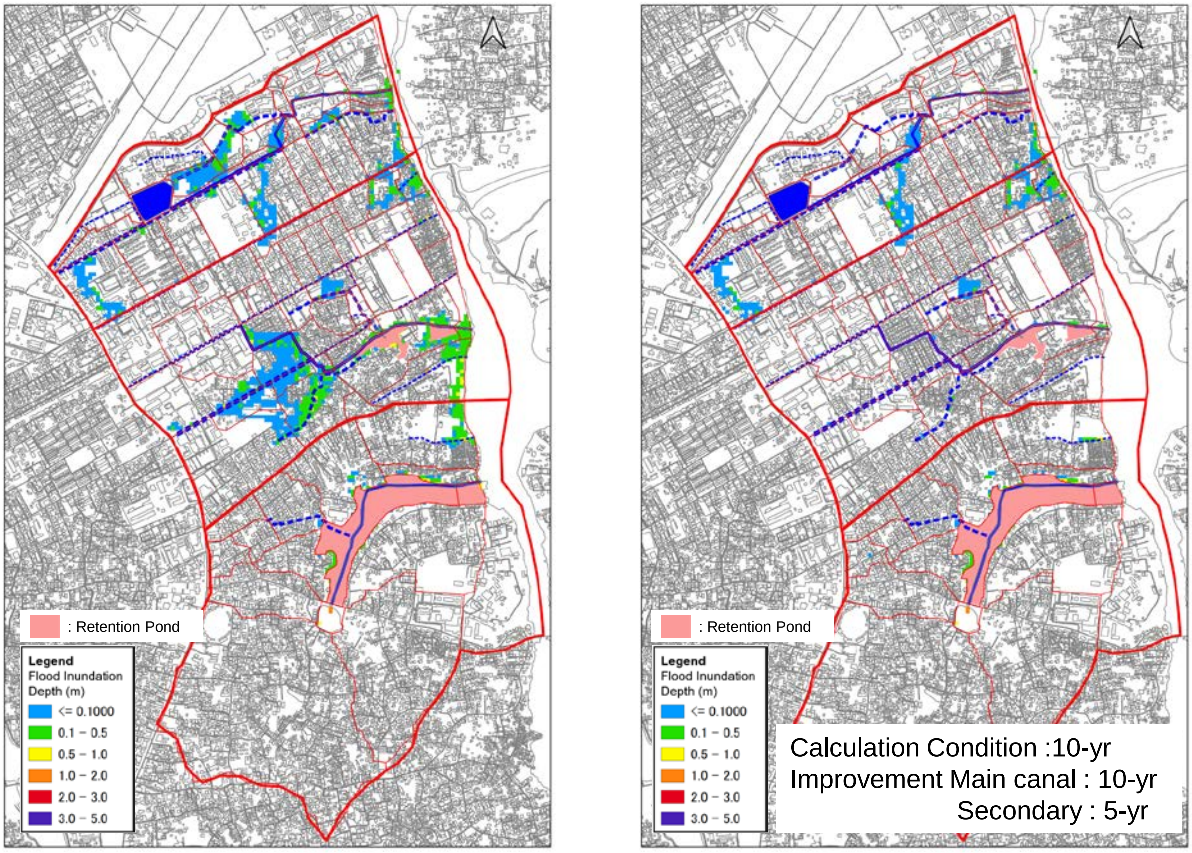


Figure 3.5 Reduction in flooding area due to drainage canal improvement (Left: without improvement, Right: with improvement)

3.3 Preliminary Design

3.3.1 Channel Improvement

Based on the following design conditions, cross sections and layout plans were proposed for the Mudun Ela improvement project, Weras Ganga Right Bank Dike and Moratuwa-Rathmalana area drainage improvement. The Cross sections are shown in the main part and appendix of the report.

Table 3.1 Design Specifications for the Preliminary Design

Items	Mudun Ela	Weras Ganga Right Bank Dike	Moratuwa- Rathmalana drainage
Freeboard (m)	0.5	0.5	0.0
Crown width (m)	4.0 (maintenance road: 3.0) 1.0 at narrow area	3.0 (maintenance road: 2.0)	3.0, 1.0 or 0.0
Slope	1 to 0.5 (Gabion wall) 1 to 2.0 (Slope with turf) Vertical (Steel sheet pile)	1 to 2.0 (Slope with turf)	1 to 0.5 (Gabion wall) 1 to 2.0 (Slope with turf) Vertical (Concrete, steel sheet pile)

Source: JICA Study Team

3.3.2 Pumping Station

At the Peliyagoda Pumping Station, a new pump with a discharge capacity of 1.0 m^3/sec and its equipment will be installed at the empty lot. Although the existing pumping system with its discharge capacity of 0.5 m^3/sec will not be removed and be kept in operation, the total discharge is considered as 1.0 m^3/sec to be safe side.

3.3.3 Closing Facility

As proposed in the M/P, closing facilities, a sluice gates are proposed at Naranmini Oya and Natha Canal. The specification of the gate is shown in Table 3.2.

Table 3.2 Specification of the Gate at Natha Canal and Naranmini Oya

No.	Channel	Gate type	Specification
1	Naranmini Oya	Slide gate	H = 1.1 m W = 1.7 m x 2 gates
2	Natha Canal	Slide gate	H = 1.5 m W = 2.5 m x 4 gates

Source: JICA Study Team

3.4 Procurement and Construction Plan

3.4.1 Condition for the Formulation of the Construction Plan

(1) Climate Condition

The average monthly precipitation in the Colombo and Rathmalana area is shown in Table 3.3.

Table 3.3 Average Monthly Precipitation (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
CMB	78	98	128	261	315	179	72	107	258	369	316	193	2,374
RTN	53	65	131	230	331	208	63	103	262	448	323	206	2,424

Note CMB: Colombo、RTN: Rathmalana
Source: Colombo Weather Station

(2) Workable Days

The number of workable days in a year as shown in Table 3.5 was calculated from the weather conditions based on rainfall records at the target sites during the period 2011-2018, and the total days of Sundays and holidays in Sri Lanka.

Table 3.4 Rainfall Days of 10mm/day or More

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2	3	4	7	8	6	2	3	7	9	9	5	65

Source: JICA Study Team

Table 3.5 Workable Days

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
23	19	23	19	20	22	24	24	21	20	20	22	21

Source: JICA Study Team

3.4.2 Construction Method

(1) Mudun Ela Sub-basin

The slope protection works for the drains in the Mudun Ela sub-basin have three types as shown in the following table. The construction method for each is shown below.

Steel Sheet Pile: Slope protection by steel sheet piles. Construction can be done by barge in the river, or from the riverbank side. If barges are not possible, half of the river should be reclaimed for construction.

Gabion: Protection of slopes by Gabions. The gabions are placed after a certain section is temporarily sealed with sandbags or steel sheet piles.

Embankment: The slope is 1:2.0 and the method is used in sections where construction sites are relatively available.

(2) Weras Ganga Right Bank

The Weras Ganga Right Bank Dike is a small-scale embankment structure and it will be constructed in a similar construction method to the embankment in the Mudun Ela sub-basin.

(3) Moratuwa-Rathmalana Area

In the Moratuwa-Rathmalana area, the drains will basically be U-shaped ditches and the construction will be applied for an open cut. For wider drains, slope protection will be applied as in the Mudun Ela sub-basin mentioned above. Where the construction spaces are very limited, precast U-shaped ditches will be installed with the support of steel sheet piles, or steel sheet pile revetments are used where sites are not available.

3.4.3 Construction Plan

(1) Daily Work Progress

The number of days required to work on each of the major work items associated with the construction of the drainage facility was assumed based on the production rate issued by the Ministry of Land, Infrastructure, Transport and Tourism, and JST has been estimated based on the hearing from SLLDC.

(2) Construction Period

Considering the construction volume of drainage facilities, as well as the daily work progress and workable days for construction described above, the construction periods in the Mudun Ela sub-basin, at the Weras Ganga Right Bank and in the Moratuwa-Rathmalana area were estimated (Refer to the main part of this report for details).

3.4.4 Procurement Plan

(1) Procurement of Construction Material and Equipment

SLLDC has a lot of experience in drainage improvement projects including bridge, gate, and pumping station construction. Labors and general natural construction materials can be procured in Sri Lanka and steel and oil-related materials can be imported from neighboring countries. Major equipment is owned by SLLDC and the local contractor.

(2) Procurement of the Contractor

The source of funds for the Project has not been determined yet and it may be considered at this moment to be implemented by the local government funds. Local contractors have enough experience to conduct the drainage improvement project in Sri Lanka. At the same time, they can also work as subcontractors to international contractors which have been procured through International Competitive Bidding.

(3) Consideration of Contract Packages

After consultation with the SLLDC, the two basins shall be divided into separate packages, and the following package demarcation was proposed based on the construction type rather than geographical divisions for sub-basins within each basin.

Table 3.6 Construction Packages

Basin	Packages
Mudun Ela Sub-basin	Package-1: Improvement of Drains
	Package-2: Construction of Gate and Pump
	Package-3: Replacement of Bridges
Weras Ganga Right Bank	Package-1: Construction of Right Bank
Morratuwa-Rathmalana area	Package-2: Improvement of Drains

Source: JICA Study Team

3.5 Preliminary Cost Estimation

3.5.1 Price Level

As the M/P, the cost estimate is at the price level as of December 2022.

3.5.2 Project Cost

The summaries of total project costs are shown in Table 3.7.

Table 3.7 Project Cost for the Priority Projects

(million LKR)

Cost	Mudun Ela channel improvement			Weras Ganga Right Bank Dike			Moratuwa-Rathmalana drainage canal improvement		
	F.C.	L.C.	計	F.C.	L.C.	計	F.C.	L.C.	計
Construction	595	495	1,091	70	86	156	362	364	726
Consulting	36	30	65	4	5	9	22	22	44
Land acquisition and compensation	0	870	870	0	978	978	0	549	549
Administration	0	47	47	0	26	26	0	30	30
Physical contingency	63	149	212	7	112	120	38	100	138
Price contingency	0	95	95	0	52	52	0	66	66
Tax	0	200	200	0	29	29	0	134	134
Total	694	1,886	2,580	82	1,288	1,371	422	1,265	1,687

Source: JICA Study Team

3.6 Implementation Schedule

The implementation schedule for the priority projects is shown in Table 3.8 and Table 3.9.

Table 3.8 Implementation Schedule (Mudun Ela Sub-basin)

Year	2023				2024												2025											
Month	1	4	7	10	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
F/S		■																										
D/D			■	■																								
Package 1 (Channel improvement)																												
Implementation (Section 1, L = 45m)					■	■	■	■	■	■	■	■	■	■														
Implementation (Section 2, L = 225m)								■	■	■	■	■	■	■	■													
Implementation (Section 3, L = 1,536m)						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
Implementation (Section 4, L = 711m)									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Implementation (Section 5, L = 272m)																					■	■	■	■	■	■	■	■
Implementation (Section 6, L = 120m)					■	■																						
Package 2 (Gate, Pumping station improvement)																												
Natha Canal, Naranmini Oya gate installation					■	■	■	■	■	■	■	■	■	■	■	■												
Peliyagoda pumping station improvement					■	■	■	■	■	■	■	■	■	■	■	■												
Package 3 (Bridge construction)																												
Bridge construction											■	■	■	■	■	■	■	■	■									

Source: JICA Study Team

Table 3.9 Implementation Schedule (Weras Ganga Right Bank Dike and Moratuwa-Rathmalana Area)

Year	2023				2024												2025											
Month	1	4	7	10	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
F/S		■																										
D/D			■	■																								
Weras Ganga Right Bank Dike																												
Right Bank Dike with U-ditch (L = 3,000 m)					■	■	■	■	■	■	■	■	■	■														
M-R area Drainage improvement																												
Main drainage channel (Zone A C5)					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
Main drainage channel (Zone A 2L-1)					■	■	■	■	■	■	■	■	■	■														
Secondary drainage channel (Zone A 2R)															■	■	■	■	■	■	■	■	■	■	■	■		
Secondary drainage channel (Zone A C)																				■	■	■	■	■	■			
Secondary drainage channel (Zone A C6)																				■	■	■	■	■	■	■	■	■
Main drainage channel (Zone B C4)					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
Secondary drainage channel (Zone B C2B2)																■	■	■	■	■	■	■	■					
Secondary drainage channel (Zone B C5)																						■	■	■	■	■	■	■
Secondary drainage channel (Zone B B1)																■	■	■	■	■	■	■	■					
Secondary drainage channel (Zone B B1T4)																							■	■	■	■	■	■
Secondary drainage channel (Zone B B1T5)																					■	■	■	■	■	■	■	■

Source: JICA Study Team

3.7 Operation and Maintenance Plan

3.7.1 Staffing Plan of Related Local Authorities

The staffing plans at Peliyagoda UC, Kelaniya PS, Dehiwala -Mount Lavinia MC and Moratuwa MC are shown in Table 3.10.

Table 3.10 Proposed Staffing Plan for Local Authorities Related to the Project

(Unit: No. of Person)

Staff	Peliyagoda UC and Kelaniya PS			Dehiwala -Mount Lavinia MC and Moratuwa MC		
	Existing	By the start of the Project	By the completion of the Project	Existing	By the start of the Project	By the completion of the Project
Manager / Engineer	0	0	1	0	1	1
Other Engineer	0	0	0	0	1	1
Technical Officer	0	1	1	0	1	2
Work Supervisor	0	0	2	0	2	3
Machine Operator	0	0	1	0	2	3
Clerical Staff	0	0	1	0	2	2
Labor	0	0	5	0	5	10

Source: JICA Study Team

3.7.2 Financial Arrangement for O&M

The preliminary annual O&M cost by SLLDC and each local authority in the Project area are summarized in Table 3.11.

Table 3.11 Preliminary Estimate of Annual O&M Cost for the Project

(Unit: 1,000 LKR)

Item	SLLDC	Peliyagoda UC	Kelaniya PS	Dehiwala - Mt. Lavinia MC	Moratuwa MC
(a) Routine Works					
Main canal	5,041	0	0	409	331
Secondary canal	720	0	0	354	365
Bank embankment	263	0	0	88	175
Inspection	98	12	42	22	22
(b) Reactive Works					
Repair	894	0	0	124	124
Emergencies	507	0	0	82	102
Total	7,523	12	42	1,079	1,119

Source: JICA Study Team

Not only procuring staff and the budget but staff training would also be required for the proper O&M.

3.8 Environmental and Social Consideration

3.8.1 Environmental Categorization

According to Central Environment Agency (hereinafter referred to as "CEA"), both projects require Initial Environmental Evaluation (hereinafter referred to as "IEE") study to obtain necessary permissions before implementation. However, considering the situation in Colombo around the time of this study and uncertainty regarding the timing of project implementation, an environmental assessment was conducted based on only existing data. Therefore, the IEE study should be conducted before implementing the projects.

3.8.2 Results of Impact Assessment and Proposed Measures

Based on the results of the impact assessment, the implementation of the project may have negative impacts on several items such as water quality, ecosystem/flora and fauna, and land acquisition. The following table summarizes expected impacts and some measures to be taken by the project proponent.

Table 3.12 Assessment Result and Proposed Measures of Key Environmental and Social Items

Items	Result of the Survey and proposed mitigation measures
Water Quality	The drainage function will be improved and the amount of wastewater discharged to downstream will increase during the operation phase. Considering the scale of the project, the impact is expected to be limited. Even so, conducting regular water quality monitoring and adequate water quality protection measures such as cleaning canals and waterways will be required.
Ecosystem/Flora and Fauna	Although the existence of important species was not confirmed through this study, it is desirable to conduct in depth survey during the IEE survey and monitor the effectiveness of conservation measures and take action from the perspective of ecosystem protection.
Land Acquisition and Resettlement	Land acquisition is necessary for project implementation, which will result in the involuntary resettlement of residents and business entities. As the livelihood of those who to be impacted may be negatively affected by project implementation, resettlement action plans shall be prepared in line with national legislation and international standards. In addition, the impact shall be mitigated by applying a livelihood restoration program and other required assistance.

Source: JICA Study Team

3.8.3 Land acquisition and Resettlement

The number of households and people to be affected by the project is calculated as follows.

Table 3.13 Number of Affected households and residents to be Resettled

Project	District	Nos of households (of which is located at the right bank embankment)	Number of residents relocated due to projects* (of which are located at the right bank embankment)	Average people per household
Mudun Ela	Kelaniya.	20	65	3.21
Moratuwa-Rathmalana (canal + right bank)	Moratuwa	20 (13)	79 (52)	3.93
	Rathmalana	13 (3)	55 (13)	4.20

*Note *) Number of households multiplied by the average number of people per household by district(socio-economic survey)*
Source: JICA Study Team

Compensation shall be made based on relevant national legislation such as Land Acquisition Act (1950) and international standards set by JICA and World Bank. Roughly estimated compensation costs for residents and business entities for both Mudun Ela and Moratuwa-Rathmalana projects are summarized in the following tables.

Table 3.14 Estimated Budget required for Resettlement (Mudun Ela Project)

Item	No.	Unit	Rs/unit	Total Rs
1. Compensation for Land				
Residential Land	2,815.8	m^2	79,073	222,654,489
Commercial Land	56.8	m^2	83,027	4,714,084
2. Compensation for structure				
Residential	1,407.9	m^2	83,582	117,675,098
Commercial	51.1	m^2	91,493	4,675,292
3. Other costs (for relocation and associated expenses)				
Expenses applicable to households	20	HHs	100,000	2,000,000
Expenses for business	1	Business	80,000	80,000
			Total	**351,798,964**

Source: JICA Study Team

Table 3.15 Estimated Budget required for Resettlement (Moratuwa-Rathmalana Project)

Item	No.	Unit	Rs/unit	Total Rs
1. Compensation for Land				
Residential Land	4,730.20	m^2	48,235	228,159,728
Commercial Land	280.0	m^2	50,646	14,180,999
2. Compensation for structure				
Residential	2,365.1	m^2	77,307	182,838,786
Commercial a	64.2	m^2	59,202	3,800,500
Commercial b	187.8	m^2	64,583	12,132,000
3. Other costs (for relocation and associated expenses)				
Expenses applicable to households	33	HHs	100,000	3,300,000
Expenses for business	2	Business	80,000	160,000
			Total	**444,572,012**

Source: JICA Study Team

For the implementation of proposed projects, SLLDC shall prepare the Resettlement Action Plan (RAP) based on the detailed design, conduct the activities planned in RAP, formulate a grievance redress mechanism, and monitor the progress of land acquisition as described in the main report.

3.9 Cost-Benefit Analysis and Financial Feasibility

The Economic Internal Rate of Return (EIRR), B/C and Net Present Value (NPV) of the projects are calculated as shown in Table 3.16.

Table 3.16 EIRR and Other Indicators of the Projects

River Basin/Area and Pre-F/S Target Project		EIRR	B/C	NPV (million Rs.)
Mudun Ela Project		96.8%	12.06	20,008
Muratuwa-Rathmalana	Drainage Improvement	8.32%	0.70	-341
	Weras Ganga Right Bank Dike	15.46%	1.34	337
	Both projects	11.44%	0.95	-105

Source: JICA Study Team

Mudun Ela improvement project and Weras Ganga Right Bank Dike are evaluated as feasible from the perspective of economic analysis since 12% is adopted as the shadow discount rate. However, although the EIRR of the drainage improvement did not reach the shadow discount rate of 12%, it was still 8.32%, which is not a low value for such an infrastructure project.

Part 1

Master Plan Study

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CHAPTER 1 INTRODUCTION

1.1 Background

Sri Lanka is vulnerable to natural disasters. Following the 2004 Indian ocean earthquake around Sumatra and tsunami caused by the earthquake, the country has been strengthening its disaster prevention and risk prevention capabilities through the enactment of the disaster management act, the national disaster prevention committee, the Ministry of Disaster Management which is presently the Ministry of Public Administration and Disaster Management (hereinafter referred to as “MPADM”), and the establishment of a disaster management center.

According to records of the past 10 years up to October 2016, floods were the most frequently occurring disasters, accounting for about 37% of the total. In addition to the number of incidents, floods account for about 47% of house damage and about 57% of the number of people affected by the disaster. They are the most damaging type of disaster, and measures against floods are an urgent issue in Sri Lanka. In May 2016, flooding was caused by the backwater of the Kelani Ganga mainstream towards their tributaries resulting in inland inundation along the tributary basins in the Colombo Metropolitan Region. It caused economic damage amounting to 572 million U.S. dollars in total damages.

In addition to the fact that most of the Colombo Metropolitan Region is located in the low-lying areas, at 6 m or less above sea level, the area of wetlands which used to function as retarding basins has decreased for urbanization, and inland inundation has occurred frequently due to poor drainage capacity. This causes damage to assets and infrastructure facilities as well as deteriorating the sanitation of residents. Japanese Government had supported channel improvement, construction of a diversion channel and improvement of unused/used retarding basin areas by the Greater Colombo Flood Control and Environmental Improvement Project in phase 1 (Conclusion of the loan agreement (hereinafter referred to as “L/A”) in 1992 and completion of the loan in 1999), and improvement of drainage pipes, drainage culverts, drainage open channel, and gutters by the same project in phase 2 (Conclusion of L/A in 1994 and completion of the loan in 2001) and phase 3 (Conclusion of L/A in 1996 and completion of the loan in 2005). In 2003, Japan International Cooperation Agency (hereinafter referred to as “JICA”) conducted "the Study on Storm Water Drainage Plan for the Colombo Metropolitan Region" and proposed the master plan (hereinafter referred to as “M/P”) for flood mitigation in the main four basins, of which are the Ja Ela basin, the Kalu Oya basin, the Greater Colombo basin and the Bolgoda basin. In response to the M/P, the Sri Lanka Land Reclamation and Development Corporation (hereinafter referred to as SLLR&DC, later, becomes Sri Lanka Land Development Corporation referred to as SLLDC) which has jurisdiction over urban drainage, has implemented some projects and conducted a detailed design, but the measures are insufficient yet and further investment in disaster prevention is required.

Due to progress in urbanization and development, the population of the Greater Colombo basin and the Bolgoda basin in 2015 became about 1.5 and 1.7 times as large as the ones in 2000, respectively. The concentration of population and assets increases the risk of flood damage and it is also difficult to secure candidate sites for diversion channels and retarding basins through development. With changes in rainfall-runoff mechanism due to urbanization, development conditions (concentration of assets and population), and land use conditions, the M/P needs to be revised in order to promote measures for urban drainage and against inland flooding.

Based on the above background, the SLLR&DC which studies urban drainage and the Ministry of Megapolis & Western Development (hereinafter referred to as “MMWD”) which is in charge of supervising the SLLR&DC requested the project aiming to compile the development plan for the urban drainage and measures against inland flooding and to conduct the master plan and feasibility study at the priority areas in the Ja Ela-Attangalu basin, the Kalu Oya basin (including the Mudun Ela sub-basin), and the Greater Colombo basin (including the Kolonnawa and the Madiwela South diversion channel) and the Bolgoda basin (including the Moratuwa-Rathmalana sub-basin).

In December 2017, JICA conducted a detailed planning survey for the project, finding some areas which are not covered by the other donors including the Government of Sri Lanka (hereinafter referred to as GOSL) for the storm water drainage project, and agreed with the GOSL on the target areas and the project components. The project target areas finally agreed upon are:

1. Target basins for storm water drainage plan
    - Kalu Oya basin
    - Bolgoda basin
2. Target urban areas for the pre-feasibility study
    - Mudun Ela sub-basin
    - Moratuwa-Rathmalana area

1.2 Objectives

This project will contribute to mitigating the risk of storm water flooding in the selected areas in Colombo metropolitan region. After the completion of the project, the following outputs are expected.

Output 1: Storm water drainage plans for target areas in Colombo metropolitan region is elaborated,

Output 2: Pre-feasibility study for urgent projects is implemented, and

Output 3: Technology transfer on storm water drainage planning through the project activities is implemented.

1.3 Schedule

This study started in January 2019 and was completed in March 2023.

CHAPTER 2 OVERVIEW OF THE TARGET AREA

2.1 Target Drainage Basin

As shown in the opening figure of this report, the survey area is located from the vicinity of Ragama on the north side to the vicinity of Kalutara on the south side. The range is 6 ° 36' to 7 ° 02' north latitude and 79 ° 50' to 80 ° 05' east longitude.

The target area is the two basins of Kalu Oya and Mudun Ela, which are tributaries of Kelani Ganga, and the Bolgoda basin located in the area between Kelani Ganga and Kalu Ganga. The outline is shown in the following table.

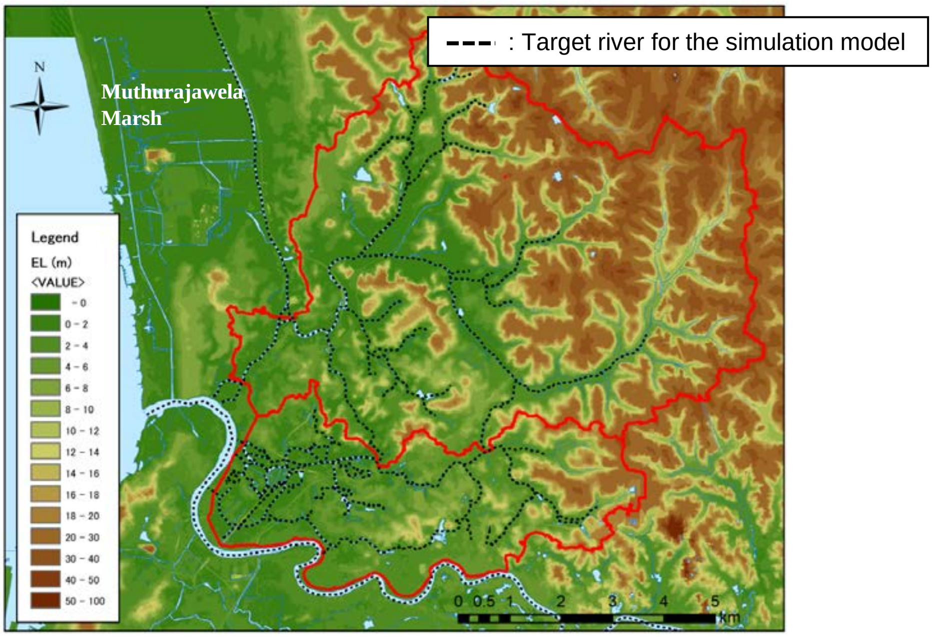
Table 2.1.1 Damaged Population in Major Flood

Drainage Basin	Catchment Area (km^2)	Mainstream Length (km)	Remarks
Kalu Oya Basin	58	13.5	
Mudun Ela sub-basin	16	9.1	Independent basin from Kalu Oya
Bolgoda Basin	394	32.3	From the river mouth up to Kappu Ela

Source: JICA study team

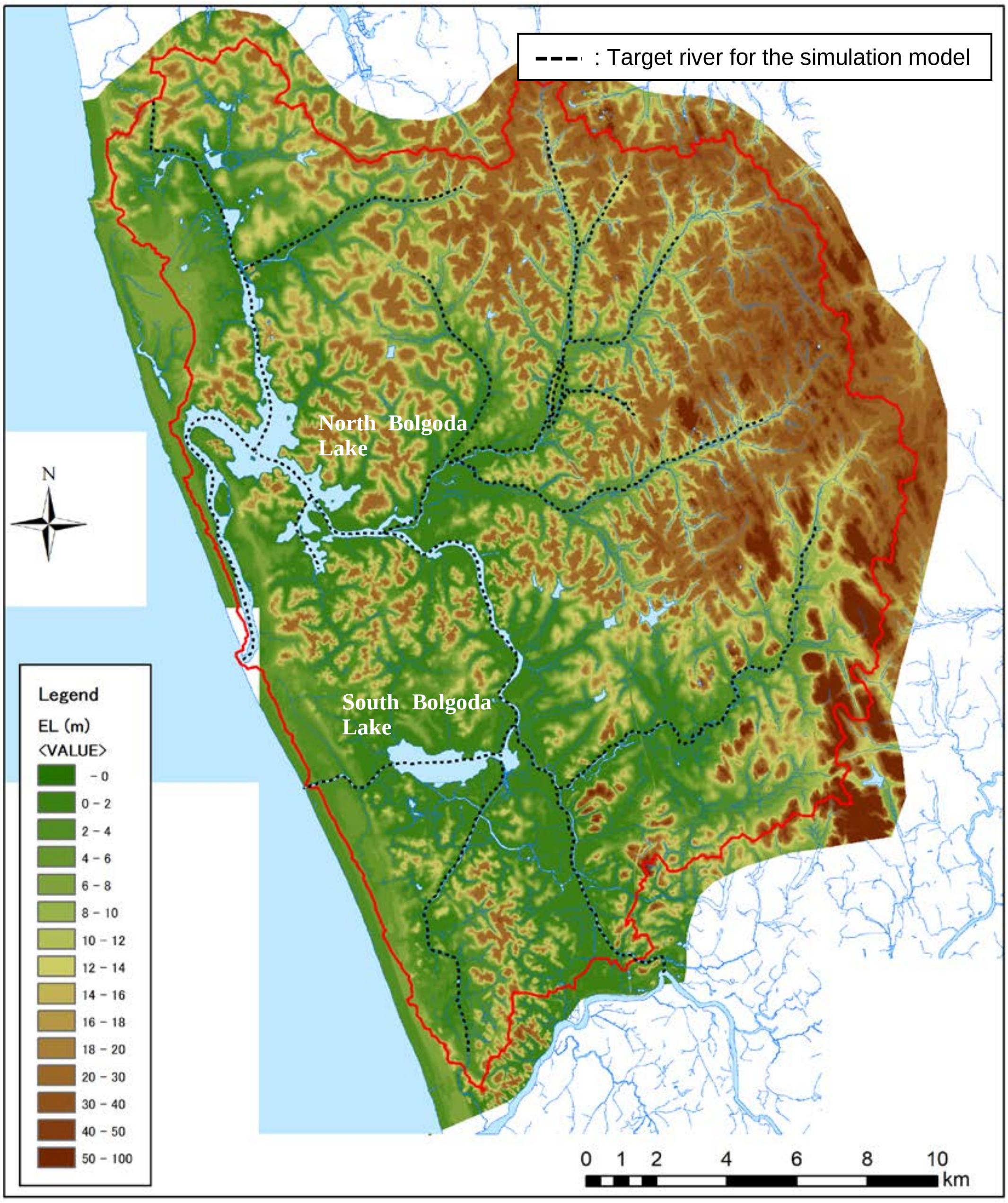
2.2 Topography and Geology of the Drainage Basin

Most of the target drainage basin is lowland along the coast. The Muthurajawela Wetlands extend to the north, with North Bolgoda Lake and South Bolgoda Lake located in the southern part. The topography of the survey area is generally classified into lowland swamps, lowlands around them, and hills. The lowland swamps extend along the coast in the lower reaches and their altitude is from about 0 m to 2 m. The altitude of the lowlands around the lowland swamp and along the rivers is from about 2 m to 5 m, and the altitude of the hills is 10 m or more. The soil quality of low-lying areas consists of sea sand, lake sediments (silt, clay), flying sand, and alluvial soil. The elevation distribution of each target drainage basin is shown in Figure 2.2.1 and Figure 2.2.2.



Source: Prepared by JICA study team using LiDAR data

Figure 2.2.1 Distribution map of Elevation (Kalu Oya and Mudun Ela Drainage Basin)



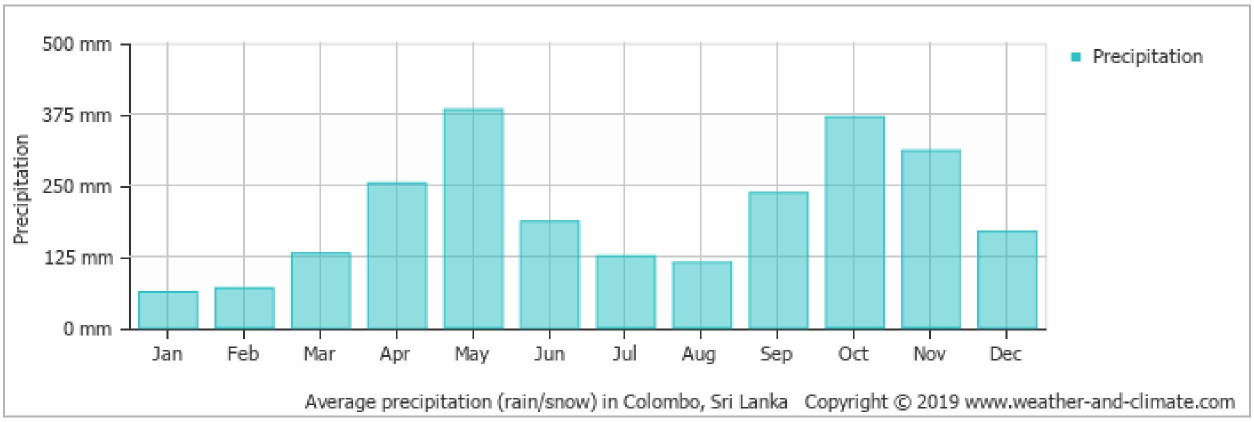
Source: Prepared by JICA study team using LiDAR data

Figure 2.2.2 Distribution map of Elevation (Bolgoda Drainage Basin)

2.3 Rainfall Characteristics of the Drainage Basin

The climate of the target basin is classified as a tropical rainforest climate in the Köppen climate classification. At the Colombo Meteorological Station (the location described in Chapter 5) located in the middle of the target basin, the average annual maximum temperature is 30°C and the average minimum temperature is 24°C.

Rainfall is highest in May, October, and November. In addition, the number of rainy days in May, June, October, and November is the highest. The dry season is due to the northeast monsoon from December to February, the rainy season is due to the southwest monsoon from March to May, and the rainy season is also from October to November (see the following figure).



Source: https://weather-and-climate.com/average-monthly-Rainfall-Temperature

Figure 2.3.1 Monthly Rainfall at Colombo Station

Under the Meteorological Department, the Colombo Meteorological Station observes short-term rainfall. According to the short-term rainfall intensity formula created based on this data, the probability rainfall intensity for one hour is as follows.

1) 2-year return period : 79.6 mm/hr
2) 5-year return period : 91.9 mm/hr
3) 10-year return period : 100.7 mm/hr
4) 25-year return period : 114.9 mm/hr
5) 50-year return period : 123.8 mm/hr
6) 100-year return period : 132.6 mm/hr

Although the above-mentioned rainfall intensity shows a considerably high intensity, those are general intensities as the rainfall intensity in the tropical monsoon region.

2.4 Land Use and Urban Development of the Drainage Basins

2.4.1 Existing Conditions of Kalu Oya Basin and Mudun Ela Sub-basin

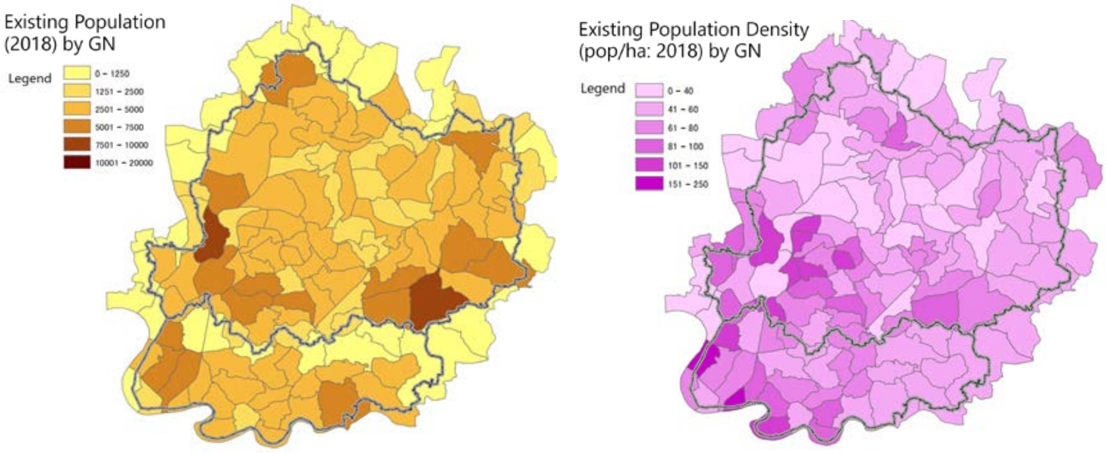
2.4.1.1 Existing Population by DS Division

The target basins of the Kalu Oya basin and the Mudun Ela sub-basin have 422,317 people (2018 estimation) consisting of the Kalu Oya basin (291,111 people) and the Mudun Ela sub-basin (around 131,236 people), which was estimated based on the population projection by WPF/OCHA at GN level. The Mudun Ela sub-basin is comparatively densely populated (65.6 people/ha on average) where green areas or open spaces are less than in the Kalu Oya basin area. The highest-populated DS Division is Wattala (110.4 people/ha) followed by Kelaniya (71.5 people/ha). As average household sizes by DS Division are shown in Table 2.4.1, the range of average family size is from 3.6 people to 4.0 people.

Table 2.4.1 Existing Population Distribution of the Kalu Oya Basin and the Mudun Ela Sub-basin by DS Division (2018*)

Project Area	DS Division	Target Area (ha)	Population (person)	Household (HH)	Average HH Size	Population Density (person/ha)
Kalu Oya basin	Biyagama	926	44,295	12,432	3.6	47.8
	Ja Ela	617	29,994	7,906	3.8	48.6
	Kelaniya	788	56,131	14,492	3.9	71.3
	Mahara	1,978	104,444	27,510	3.8	52.8
	Wattala	1,233	56,247	14,698	3.8	45.6
	sub-total	5,541	291,111	77,038	3.8	52.5
Mudun Ela sub-basin	Biyagama	682	34,431	9,591	3.6	50.5
	Kelaniya	1,259	90,141	23,874	3.8	71.6
	Wattala	60	6,633	1,658	4.0	110.4
	sub-total	2,001	131,206	35,122	3.7	65.6
Total Area	Biyagama	1,608	78,727	22,023	3.6	49.0
	Ja Ela	617	29,994	7,906	3.8	48.6
	Kelaniya	2,047	146,272	38,365	3.8	71.5
	Mahara	1,978	104,444	27,510	3.8	52.8
	Wattala	1,293	62,880	16,356	3.8	48.6
Total		7,542	422,317	112,160	3.8	56.0

Source: The population of the Basins in 2018 is estimated by the JICA Study Team based on the population projection (2018) of WPF/OCHA



Source: JICA Study Team

Figure 2.4.1 Existing Population and Population Density of the Kalu Oya and the Mudun Ela Sub-basin by DS Division

2.4.1.2 Existing Land Use

The Kalu Oya basin and the Mudun Ela sub-basin cover total land of 7,542 ha calculated by GIS mapping data[1](updated by the JICA Study Team), located with five DS Divisions of Ja Ela, Wattala, Kelaniya, Mahara, and Biyagama. The Mudun Ela sub-basin (2,001 ha) covers three DS Divisions of Wattala, Kelaniya, and Biyagama, while the total area of the Kalu Oya basin shares 73% (5,541 ha out of the total basins' area).

The Mudun Ela sub-basin indicates the highest urbanized area out of the target basins including the Bolgoda basin. As shown in Table 2.4.2 of the detailed existing land use compositions based on GIS measurements, the target basins consist of built-up areas and artificial vacant areas by 6,078 ha (80% out of a total target basin). Breakdown of the urbanized areas is calculated for the Kalu Oya basin (78 %, 4,336 ha) and the Mudun Ela sub-basin (84%, 1,672 ha).

Other land use categories in the Kalu Oya basin and the Mudun Ela sub-basin compose of the agriculture-based area including paddy fields (10.2%, 767 ha), natural area by natural vegetation including forest, shrub, barren and sandy areas (0.4%, 27 ha) and water-based area including river, stream, wetland, water bodies (10.3%, 777ha). And the land use category of U3 (non-built-up area such as paved, non-natural materials, infrastructure, utilities) by 827 ha occupies a large portion of land use in terms of considerable infiltration areas to be desirably covered by natural vegetation. The artificial green area as U5 (park, garden, and other recreational green areas) shares only 0.7% (54 ha) out of the total basins' area.

One of the characteristic land use categories not only in the basins but also in the Western Province is lowlands/wetlands, of which categories consist of A3/A4 (paddy field, abandoned paddy) and W1 (wetland/marsh/swamp). These land-use categories of lowlands/wetlands are counted by 1,079 ha sharing 14.3% of the total basin area.

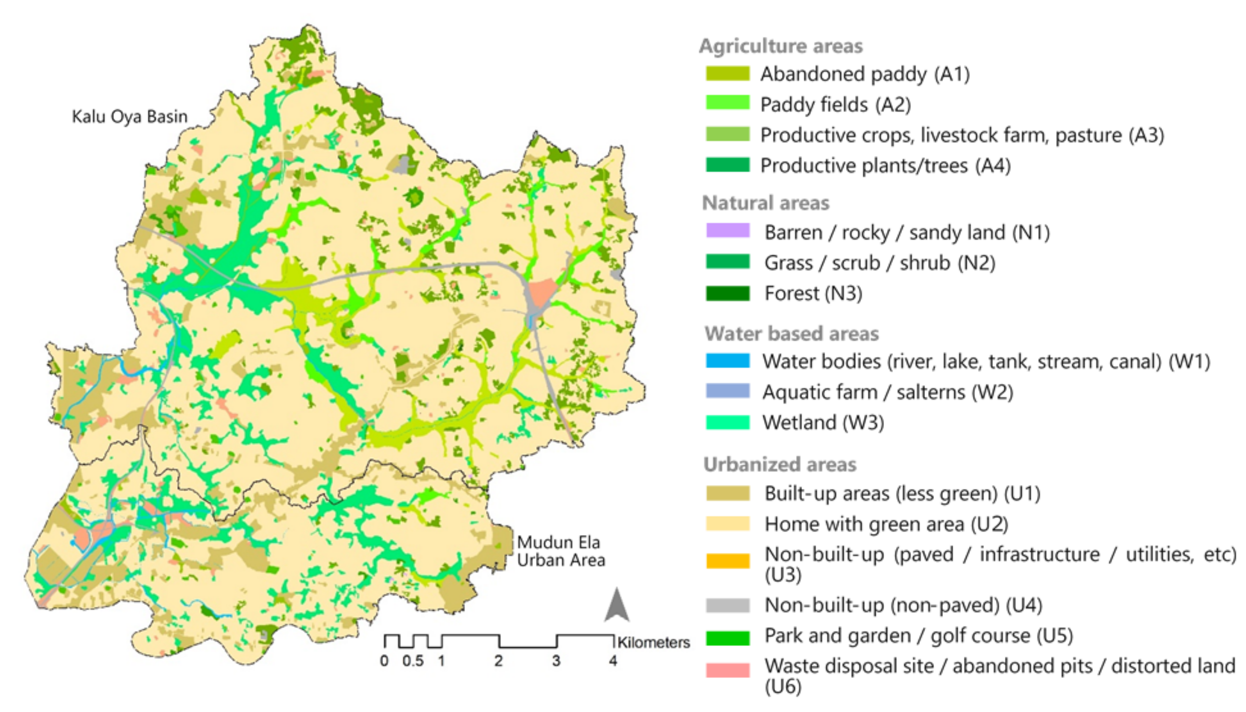
Table 2.4.2 Existing Land Use Composition of Kalu Oya Basin and Mudun Ela Sub-basin by DS Division (2018*)

Target Area	DS Division	Total Area (ha)	Agriculture-based Areas				Natural Areas			Water Bodies			Urbanized (artificial) Area					
			A1	A2	A3	A4	N1	N2	N3	W1	W2	W3	U1	U2	U3	U4	U5	U6
Kalu-Oya basin	Biyagama	926.2	72.9	0.1	5.5	110.8	0.8	0.5	0.5	19.4	0.6	3.6	25.9	651.3	26.4	3.9	2.7	1.3
	Ja Ela	616.8	82.8	0.5	0.0	9.4	0.0	1.2	0.0	63.7	15.6	0.0	33.9	386.2	1.3	14.2	8.1	0.0
	Kelaniya	787.7	4.2	0.0	0.0	25.0	0.0	1.0	0.0	87.5	0.1	4.3	92.2	532.3	25.2	8.6	7.5	0.0
	Mahara	1,977.5	140.3	0.8	60.8	89.2	0.0	8.7	0.0	106.7	7.5	7.4	59.5	1,429.3	35.6	23.2	7.8	0.7
	Wattala	1,233.2	20.8	0.0	24.8	72.3	0.0	6.8	0.0	146.4	16.2	15.6	191.7	679.5	21.8	22.3	14.7	0.1
	sub-total	5,541.5	320.9	1.3	91.2	306.8	0.8	18.3	0.6	423.6	40.0	30.9	403.2	3,678.6	110.2	72.1	40.8	2.2
Mudun Ela sub-basin	Biyagama	681.9	15.0	0.0	7.3	11.4	0.0	3.2	0.6	93.0	1.1	0.2	94.2	249.7	202.7	0.5	2.8	0.2
	Kelaniya	1,259.0	12.0	1.0	0.0	0.0	0.0	4.0	0.0	142.6	9.2	32.2	228.4	264.1	514.2	41.0	10.4	0.0
	Wattala	60.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	1.4	0.6	8.8	46.0	0.1	0.0	0.4	0.0
	sub-total	2,001.0	27.0	1.0	7.3	11.4	0.0	7.2	0.6	238.4	11.7	33.0	331.4	559.8	716.9	41.4	13.6	0.2
Total Area	Biyagama	1,608.1	87.9	0.1	12.8	122.3	0.8	3.7	1.2	112.4	1.7	3.8	120.1	901.0	229.0	4.3	5.6	1.5
	Ja Ela	616.8	82.8	0.5	0.0	9.4	0.0	1.2	0.0	63.7	15.6	0.0	33.9	386.2	1.3	14.2	8.1	0.0
	Kelaniya	2,046.8	16.1	1.0	0.0	25.0	0.0	5.0	0.0	230.1	9.2	36.5	320.6	796.3	539.4	49.6	17.8	0.0
	Mahara	1,977.5	140.3	0.8	60.8	89.2	0.0	8.7	0.0	106.7	7.5	7.4	59.5	1,429.3	35.6	23.2	7.8	0.7
	Wattala	1,293.3	20.8	0.0	24.8	72.3	0.0	6.8	0.0	149.1	17.6	16.2	200.5	725.5	21.8	22.3	15.1	0.1
	Total	7,542.4	347.9	2.3	98.5	318.2	0.8	25.5	1.2	662.0	51.7	63.9	734.7	4,238.4	827.1	113.6	54.4	2.4

Note : A1= productive plants/trees, A2=productive crops/livestock farm, pasture, A3 =paddy, A4 =abandoned agricultural area, N1=forest, N2=grass /scrub/shrublands, N3=barren / rocky/sandy lands, W1=wetland / marsh/swamp, W2=aquatic farm/salterns, W3=water bodies (river, stream, canal, lake, pond, tank, sea), U1=building area with paved area, U2=home with green area and open space, U3=nonbuilt-up area (paved, non-natural materials, mining pits, infrastructure, utilities), U4=non built-up area (non-paved, natural covered, quarries, mining pits), U5=park and garden/golf course, U6=waste disposal site, distorted land, abandoned pits

Source: Geodata updated by JICA Study Team based on the GIS data of LUPPD (2018), UDA, Survey Department (2016)JICA Study Team

[1] The geodata of the LUPPD (Land Use Policy Planning Department) 2018 was updated by JICA Study Team.



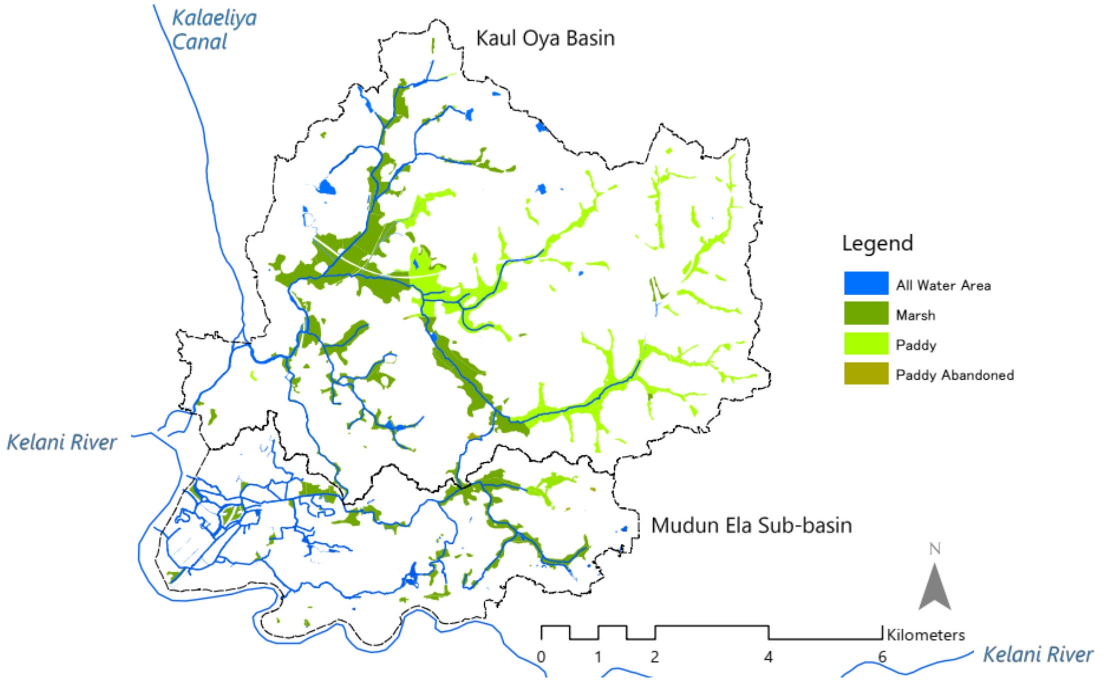
Source: Geodata updated by JICA Study Team based on the GIS data of LUPPD (2018), UDA, Survey Department (2016)

Figure 2.4.2 Existing Land Use Distribution of Kalu Oya Basin and Mudun Ela Sub-basin by DS Division (2018)

2.4.1.3 Lowlands/Wetlands Conditions

The existing conditions of lowlands/wetlands in the Kalu Oya basin and the Mudun Ela sub-basin were identified in detail in the report "the Wetland Management Strategy for the Kalu Oya and Mudun Ela sub-basins" in 2018 by SLLDC. The following are extracted from the study as the current status of the wetlands in the target basins, although the coverage area of the study area of the report is slightly smaller than the target basins.

- The wetlands in the upper areas of the two basins exist as active paddy lands, while the wetlands in the middle and lower areas managed as paddy lands in the past have now been abandoned and undergoing a process of natural succession as a mosaic of different habitat types.
- The wetlands in the Kalu Oya and the Mudun Ela sub-basin are categorized into three main habitat types, which are 1) open water, 2) herb-dominated, and 3) woodlands. Each of these main habitat types, in turn, is represented by a range of wetland types depending on the prevailing management regime, hydrodynamics, and vegetation types. The present wetland in the study area has been considered primarily as freshwater wetlands with the small effect of the low tide with minor intrusion near the outfall during the peak dry season.
- These wetlands support a rich floral and faunal assemblage. A total number of 168 plant species including seven (7) endemics, 11 nationally threatened (2 critically endangered, 1 endangered, and 8 vulnerable) and nine (9) nationally near threatened plant species were recorded. About 72% of the recorded plant species are native to Sri Lanka while 24% of the recorded plant species are exotic to the country.
- Several threats to the wetlands of the two basins were identified during the field studies. The most significant impact is the conversion and encroachment of wetlands by the heavy demand for land for urbanization by lot subdivisions. The next significant threats are unplanned and large-scale solid waste disposal.



Source: Geodata updated by JICA Study Team based on the GIS data of LUPPD (2018), UDA, Survey Department (2016)

Figure 2.4.3 Lowlands/Wetlands Distribution of Kalu Oya Basin and Mudun Ela Sub-basin (2018)

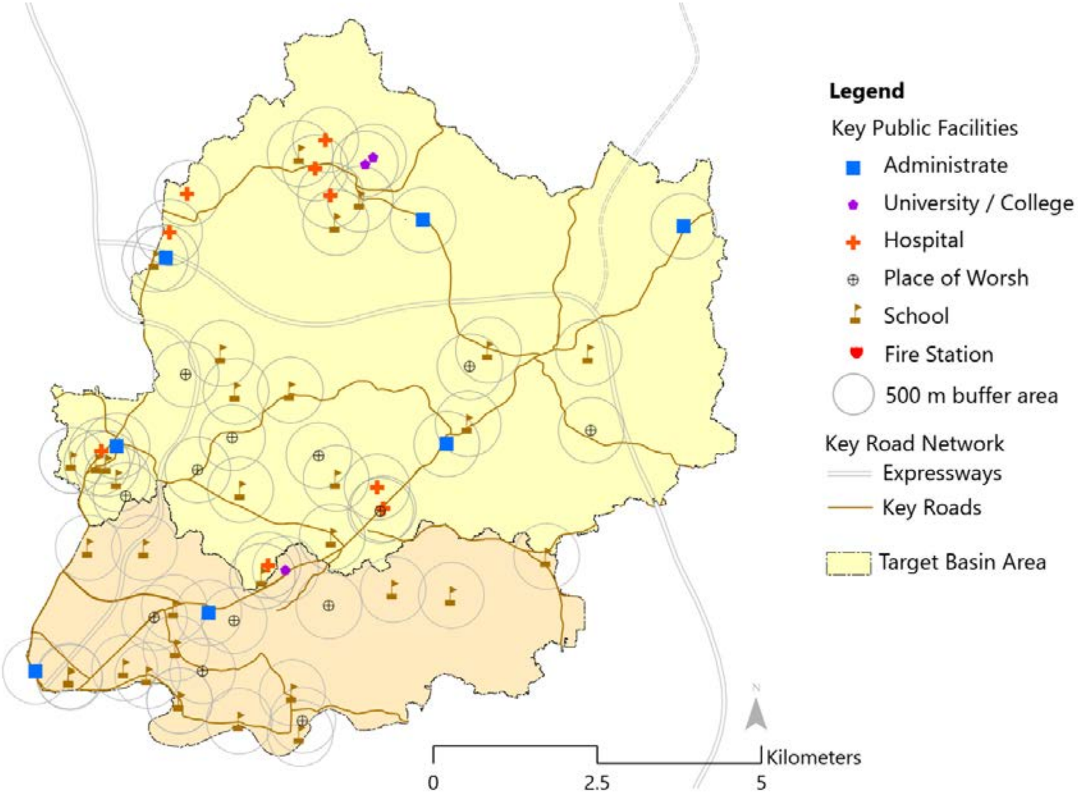
2.4.1.4 Key Public Facilities and Road, Transportation

Public facilities play essential roles in supporting daily life and socio-economic activities. On the other hand, they are expected also to play considerable roles in accommodating people as evacuation places or refuges and command places for disaster management, when a natural hazard event occurs in communities. The key public facilities for disaster response in the Kalu Oya basin and the Mudun Ela sub-basin are listed in the following table. The distribution of key public facilities in the target area is characterized by concentration into areas along the major road rather than places located in large population areas, and some densely populated areas such as GN divisions of Pamunuvila and Sapugaskanda are not covered by the catchment of public facilities sufficiently in the eastern part of Mudun Ela sub-basin.

Table 2.4.3 Key Public Facilities in Kalu Oya Basin and Mudun Ela Sub-basin by DS Division (2018)

Target Area	DS Division	Admin	School	Univ/Col	Hospital	Fire Station	Religious Facility	Total
Kalu Oya basin	Biyagama	0	2	0	0	0	1	3
	Ja Ela	0	2	2	3	0	0	7
	Kelaniya	1	4	0	3	0	3	11
	Mahara	2	4	0	0	0	3	9
	Wattala	2	6	0	3	0	2	13
	sub-total	**5**	**18**	**2**	**9**	**0**	**9**	**43**
Mudun Ela sub-basin	Biyagama	0	3	0	0	0	0	3
	Kelaniya	2	10	0	0	0	5	17
	Wattala	0	1	0	0	0	0	1
	sub-total	**2**	**14**	**0**	**0**	**0**	**5**	**21**
Total Area	Biyagama	0	5	0	0	0	1	6
	Ja Ela	0	2	2	3	0	0	7
	Kelaniya	3	14	0	3	0	8	28
	Mahara	2	4	0	0	0	3	9
	Wattala	2	7	0	3	0	2	14
	Total	**7**	**32**	**2**	**9**	**0**	**14**	**64**

Source: JICA Study Team based on the Open Source Map and Google Earth



Source: JICA Study Team based on the Open Source Map and Google Earth

Figure 2.4.4 Distribution of Key Public Facilities and Road Network in Kalu Oya Basin and Mudun Ela Sub-basin (2018)

The road network in the basins of Kalu Oya and Mudun Ela as urbanized areas comparatively has been developed densely by roads for inter-GNs and DS Divisions. Especially, two expressways are newly developed of which the Outer Circular Highway is currently open (2019) and the Central Expressway is under construction at present. The road alignment of two expressways utilizes mainly lowlands/wetlands in the Kalu Oya basin, therefore it will be one of the concerns to harmonize with the storm water drainage system in these areas.

2.4.2 Existing Conditions of Bolgoda Basin and Moratuwa-Rathmalana Sub-basin

2.4.2.1 Existing Population by DS Division

The population of the Bolgoda basin is approximately 1,215 thousand people (2018) consisting of 730 thousand people in the Colombo District and 485 thousand people in Kalutara District, which was estimated based on the population projection by WPF/OCHA at the GN level. The basin area belonging to Colombo District is comparatively densely populated (41.8 people/ha on average) whereas green areas or open spaces are less than the southern part of the basin in Kalutara District (20.7 people/ha on average). The most densely populated DS Division in the basins is Dehiwala (94.8 people/ha) followed by Sri Jayawardenepura Kotte (86.7 people/ha) and both DS divisions belong to Colombo District.

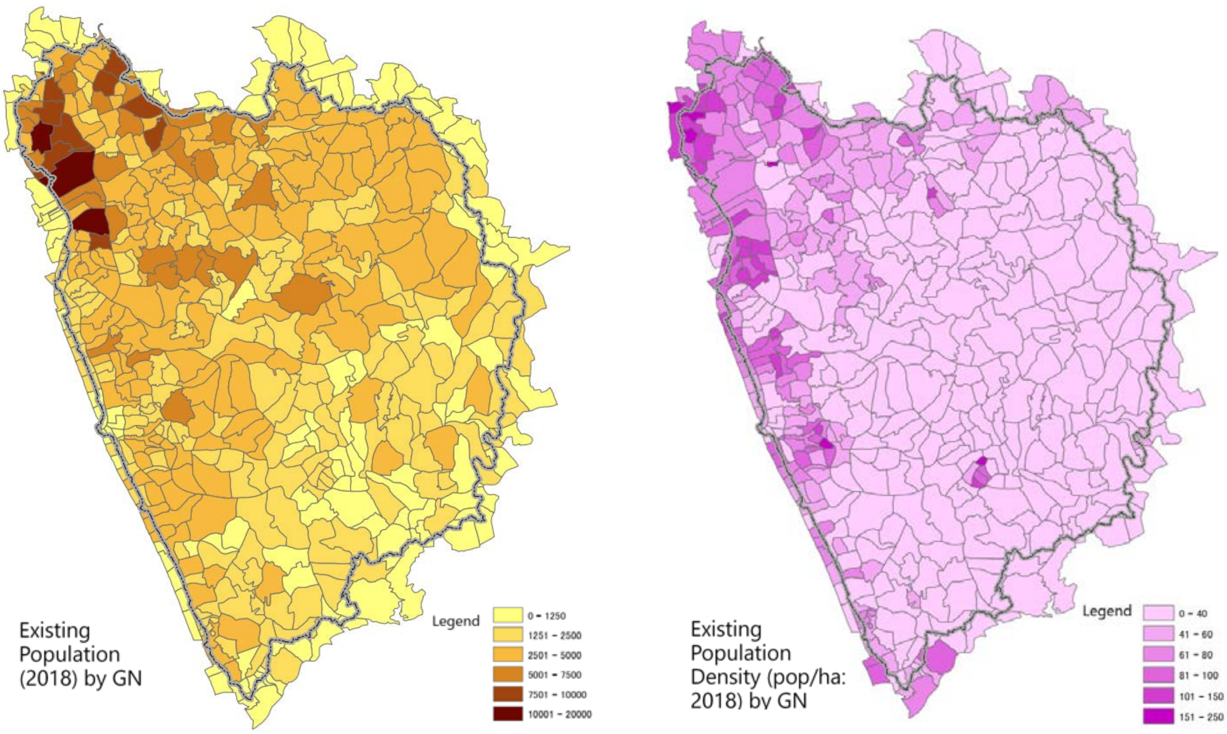
In the areas belonging to Kalutara District as less urbanized areas than Colombo District, Panadura, one of the coastal DS Divisions has the highest population density (45.1 people/ha) in the Bolgoda basins next to Moratuwa DS Division in Colombo District followed by Bandaragama (20.4 people/ha) also in the vicinity of Colombo District.

Average household sizes (estimated) by DS Division are shown in Table 2.4.4. The household sizes are from 3.5 people to 3.9 people and those are slightly less than the ones in the Kalu Oya basin and the Mudun Ela sub-basin.

Table 2.4.4 Existing Population Distribution of Bolgoda Basin and Moratuwa-Rathmalana Sub-basin by DS Division (2018)

District	DS Division	Target Area (ha)	Population (person)	Household (HH)	Average HH Size	Population Density (People/ha)
Colombo	Dehiwala	439	41,659	11,763	3.5	94.8
	Homagama	6,833	157,012	43,763	3.6	23.0
	Kaduwela	2	67	18	3.6	29.5
	Kesbewa	6,145	259,613	70,937	3.7	42.3
	Maharagama	1,436	80,431	21,395	3.8	56.0
	Moratuwa	1,179	95,774	24,846	3.9	81.2
	Padukka	345	3,379	926	3.6	9.8
	Rathmalana	872	72,723	19,754	3.7	83.4
	Sri Jayawardenepura Kotte	224	19,419	5,375	3.6	86.7
	Thimbirigasyaya	2	180	47	3.8	72.1
	sub-total	**17,477**	**730,257**	**198,825**	**3.7**	**41.8**
Kalutara	Bandaragama	5,741	117,312	30,127	3.9	20.4
	Horana	6,381	82,377	22,192	3.7	12.9
	Kalutara	3,624	63,385	16,511	3.8	17.5
	Millaniya	3,554	33,322	9,046	3.7	9.4
	Panadura	4,188	188,683	48,492	3.9	45.1
	sub-total	**23,488**	**485,079**	**126,368**	**3.8**	**20.7**
	Total	**40,965**	**1,215,335**	**325,193**	**3.7**	**29.7**

Source: The population of the Basins in 2018 is estimated by the JICA Study Team based on the population projection (2018) of WPF/OCHA



Source: JICA Study Team

Figure 2.4.5 Existing Population and Population Density of Bolgoda Basin and Moratuwa-Rathmalana Sub-basin by DS Division (2018)

2.4.2.2 Existing Land Use

The Bolgoda basin has an area of 40,923 ha striding across Colombo District with 10 DS Divisions (42.6% of the Bolgoda basin) and Kalutara District with five DS Divisions (57.4 %) as shown in Table 2.4.5. Among those 15 DS Divisions, the most highly urbanized DS Division is Sri Jayawardenepura Kotte (98.5% urbanization rate) including the capital municipality followed by Dehiwala (94.9%). The urbanization rate of the Colombo District including these two DS Divisions within the basin is 70.2%. On the other hand, looking into another part of the basin within Kalutara District (53.1% urbanization rate), the most highly urbanized DS Division is Panadura (65.8%) followed by Bandaragama (53.9%).

The majority of agricultural lands including paddy fields spread in some areas of Kalutara District sharing 21.1% of the total target basin. Horana DS Division holds the largest agricultural land (2,762 ha) followed by Badaragama (1,875 ha), while the biggest agricultural land in Colombo District within the basin belongs to Homagama (2,290 ha) in the northern part of the basin followed by Kesbuwa (1,068 ha). The abandoned paddy fields become unignorable amount (2,857 ha) in Kalutara District sharing 37% out of the total paddy fields (active and abandoned) in the Bolgoda basin.

Natural areas including forest, scrub, grass areas, and other natural lands are ranged in some DS Divisions of Kalutara District such as Horana with the largest area (268 ha) followed by Bandaragama (240 ha). Bolgoda Lakes (South and North) designated as EPA by CEA is one of the largest water bodies in the Western Province ranging from six DS Divisions of Rathmalana, Moratuwa, Kesbewa, Panadura, Bandaragama, and Kalutara. The total area of the water bodies is approximately 1,200 ha in the basin. 76% of the total water-based area is shared by Panadura, Bandaragama, and Kalutara in Kalutara District.

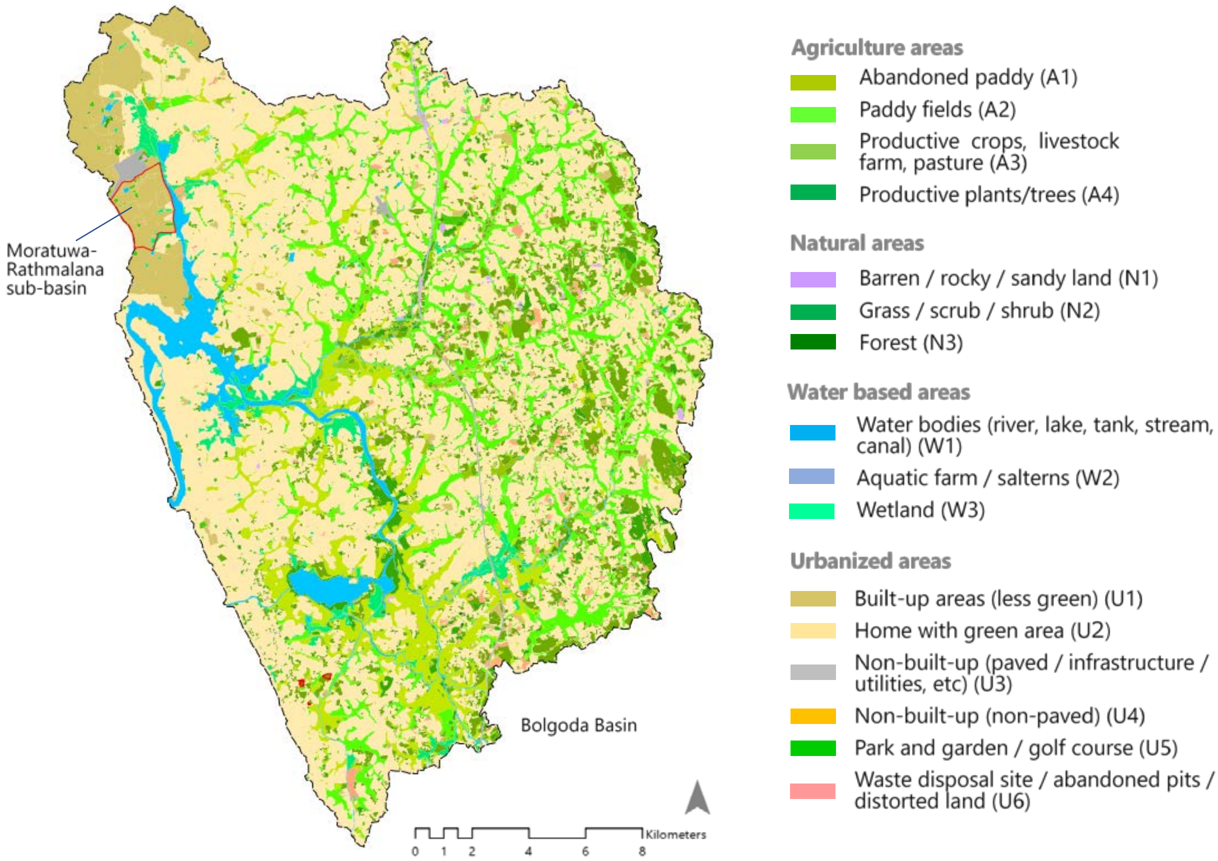
The artificial green area as U5 (park, garden, and other recreational green areas) shares only 0.3% (136 ha) out of the total basins' area. The lowlands/wetlands in the Bolgoda basin, of which categories consist of A3/A4 (paddy and abandoned paddy field) and W1 (wetland/marsh/swamp), are counted by 8,598 ha shared only 21% out of the total basin area.

Table 2.4.5 Existing Land Use Composition of Bolgoda Basin and Moratuwa-Rathmalana Sub-basin by DS Division (2018)

District	DS Division	Total Area (ha)	Agricultural Land				Natural Areas			Water Bodies			Urbanized / Man-made Area					
			A1	A2	A3	A4	N1	N2	N3	W1	W2	W3	U1	U2	U3	U4	U5	U6
Colombo	Dehiwala	439.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.7	3.4	7.3	346.0	66.0	0.6	0.3	3.9	0.0
	Homagama	6,832.8	850.2	72.2	1,137.8	230.8	0.9	157.1	58.0	29.6	29.8	15.7	71.7	3,976.5	60.9	97.4	36.0	8.2
	Kaduwela	2.3	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0
	Kesbewa	6,144.6	202.0	31.4	523.1	312.0	1.3	20.2	0.9	246.5	60.0	308.1	154.5	4,235.3	3.4	14.1	18.9	13.1
	Maharagama	1,398.9	46.4	14.3	92.9	68.0	0.0	5.3	20.2	14.2	18.7	0.0	0.0	1,088.0	15.9	9.8	5.2	0.1
	Moratuwa	1,173.6	2.7	0.2	0.1	0.0	0.1	0.0	0.0	22.5	2.6	240.7	608.9	275.8	2.1	4.9	12.9	0.0
	Padukka	344.8	132.0	1.9	47.1	1.3	0.0	3.9	0.8	0.0	0.1	0.0	0.8	151.6	0.1	3.3	0.0	2.0
	Rathmalana	872.3	2.6	3.1	0.0	0.0	0.0	16.4	2.7	76.7	12.1	26.3	542.2	81.6	89.9	1.8	16.9	0.0
	S.J. Kotte	223.9	0.0	0.0	1.9	0.0	0.0	0.3	0.0	0.9	0.3	0.0	212.1	7.8	0.0	0.5	0.1	0.0
	Thimbirigasyaya	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0
	Sub-total	17,435.1	1,236.6	123.0	1,802.9	612.0	2.3	203.2	82.6	402.1	127.0	598.2	1,938.7	9,884.2	173.1	131.9	94.0	23.4
Kalutara	Bandaragama	5,740.8	446.0	82.1	471.9	875.6	1.8	234.0	4.2	202.7	57.5	271.9	36.5	2,971.3	49.5	19.0	9.3	7.5
	Horana	6,380.6	1,405.6	116.3	1,111.0	129.5	1.6	232.1	34.6	4.6	17.3	6.3	37.1	3,144.6	19.6	26.9	9.5	84.1
	Kalutara	3,624.5	291.8	34.5	328.9	912.4	0.0	114.7	3.9	116.6	0.2	97.8	10.9	1,658.8	5.1	44.9	4.0	0.0
	Millaniya	3,554.2	736.0	20.3	468.3	513.2	6.5	176.8	0.0	25.4	1.3	39.9	32.3	1,337.9	30.9	83.4	5.8	76.1
	Panadura	4,188.2	196.2	13.5	49.2	426.4	0.0	93.1	9.5	145.7	0.3	496.8	33.4	2,701.4	5.2	3.5	14.1	0.0
	Sub-total	23,488.3	3,075.5	266.7	2,429.2	2,857.1	9.8	850.6	52.2	495.0	76.6	912.7	150.2	11,814.1	110.3	177.6	42.7	167.8
Total		40,923.4	4,312.1	389.7	4,232.2	3,469.1	12.2	1,053.8	134.8	897.1	203.7	1,510.8	2,088.8	21,698.3	283.4	309.5	136.7	191.1

Note: A1= productive plants/trees, A2=productive crops/livestock farm, pasture, A3 =paddy, A4 =abandoned agricultural area, N1=forest, N2=grass /scrub/shrublands, N3=barren / rocky/sandy lands, W1=wetland / marsh/swamp, W2=aquatic farm/salterns, W3=water bodies (river, stream, canal, lake, pond, tank, sea), U1=building area with paved area, U2=home with green area and open space, U3=non built-up area (paved, non-natural materials, mining pits, infrastructure, utilities), U4=non built-up area (non-paved, natural covered, quarries, mining pits), U5=park and garden/golf course, U6=waste disposal site, distorted land, abandoned pits

Source: Geodata updated by JICA Study Team based on the GIS data of LUPPD (2018), UDA, Survey Department (2016)



Source: Geodata updated by JICA Study Team based on the GIS data of LUPPD (2018), UDA, Survey Department (2016)

Figure 2.4.6 Existing Land Use Distribution of Bolgoda Basin and Moratuwa-Rathmalana Sub-basin by DS Division (2018)

2.4.2.3 Lowlands/Wetlands Conditions

As shown in the previous section for the land use pattern of the basin, the Bolgoda basin has kept a lot of green-water areas in combination with agricultural areas including paddy fields, natural vegetation areas, and water-based areas, especially in Kalutara District. As mentioned previously, abandoned paddy fields have become unignorable amount in the lowlands/wetlands of the basin.

This basin holds two types of environmental conservation areas[2] (Ballaniwa-Attidiya Sanctuary in the Weras Ganga and Bolgoda Environment Protection Area) involving wetlands described below, which have played a distinctive role in keeping an essential environmental feature of the Western Province.

(1) Ballaniwa-Attidiya Sanctuary

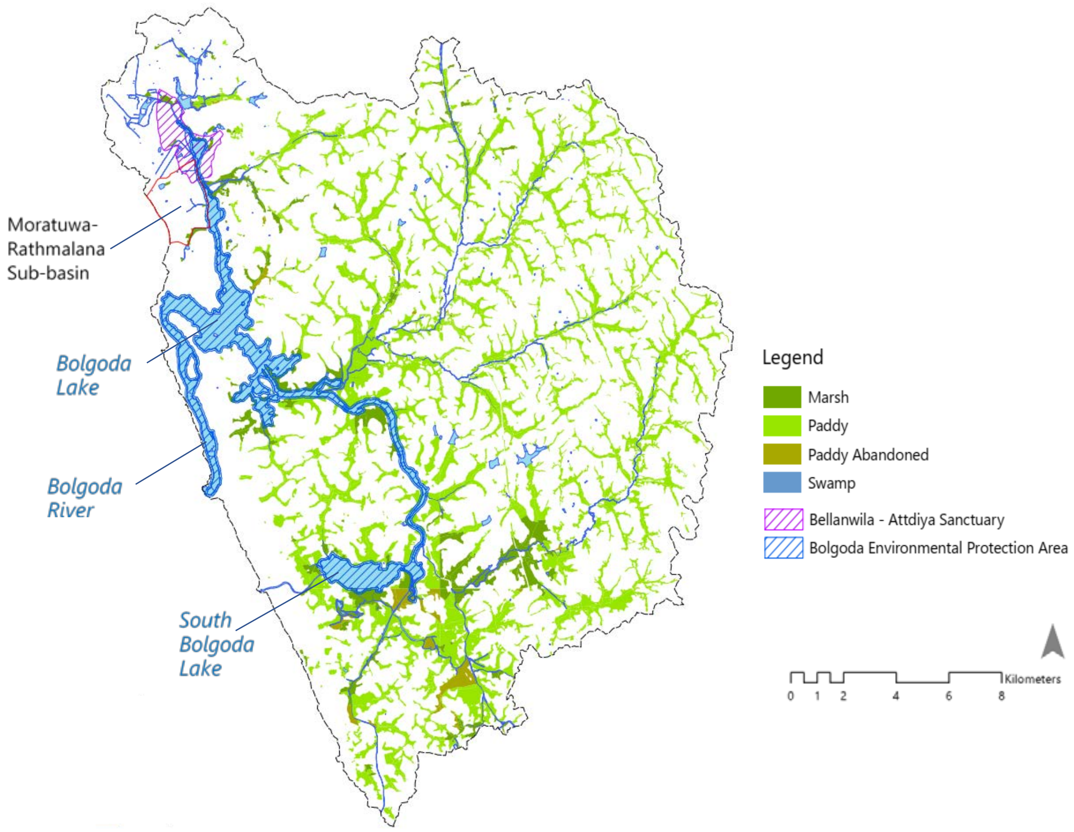
Bellanwila-Attidiya Sanctuary (372 ha) is one of the wetland areas located in the northern part of the Bolgoda basin, where paddy fields have existed until recently and were gradually abandoned. The sanctuary has maintained rich fauna of wetland birds especially. Besides, despite the declaration of Sanctuary by DWLC in 1990, threats such as encroachment, water pollution, and waste dumping have not been prevented effectively.

(2) Bolgoda Environment Protection Area (EPA)

The Bolgoda EPA (1,245 ha) is composed of two interconnected lakes of the North Lake and the South Lake. The North Lake is fed by Weras Ganga and Bolgoda Ganga and discharges to the sea through Pandura Estuary. South Lake is fed by Panape Ela. The two lakes are connected by the Bolgoda Ganga.

2 "Sanctuary" is the conservation system of Department of Wildlife Conservation (DWLC), "EPA (Environment Protection Area)" is based on the system by Central Environment Authority (CEA).

Bolgoda lake system has maintained a rich biodiversity repository and has been declared in 2009 as one of the EPAs in the Western Province.



Source: Geodata updated by the JICA Study Team based on the GIS data of LUPPD (2018), UDA, and Survey Department (2016), and the natural conservation areas are based on the geodata from CEA

Figure 2.4.7 Lowlands/Wetlands Distribution and Natural Conservation Areas in Bolgoda Basin and Moratuwa-Rathmalana Sub-basin (2018)

2.4.2.4 Key Public Facilities and Road, Transportation

The key public facilities in the Bolgoda basin are concentrated in higher urbanized areas such as the DS Divisions of Rathmalana, Moratuwa, and Panadura with Urban Councils. Other DS Divisions are in densely populated areas comparatively along major roads represented by Kalutara DS Division and Maharagama, Kesbewa, and Homagama. The number of key facilities in the basin such as hospitals and fire stations is larger than the number of facilities in the Kalu Oya basin and the Mudun Ela sub-basin despite its lower population in the basin. Locations of them are considered to allocate hilly areas avoiding flood or inundate-prone areas.

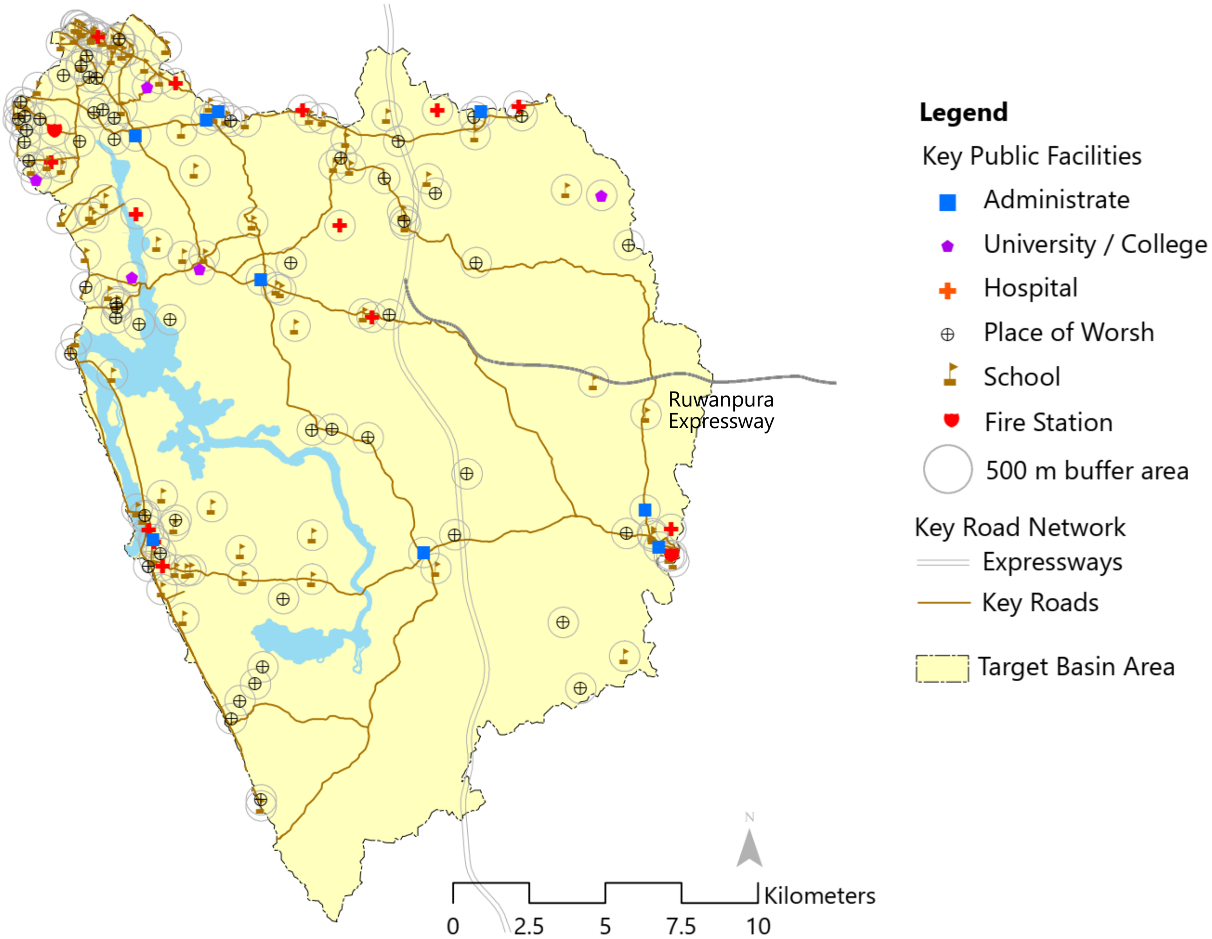
The road network in the Bolgoda basins has been developed differently according to urbanization patterns characterized by two areas 1) urbanized areas in Colombo District and 2) less urbanized areas in Kalutara District. The urbanized area in Colombo District has been developed densely by both major and collector roads for inter-GNs and DS Divisions. On the other hand, road development in the less urbanized areas in Kalutara District is a lower-density of road network.

To connect with the existing expressway (Southern Expressway) crossing the basin longitudinally, the Ruwanpura Expressway is currently under planning at present in the eastern part of the basin. As the road alignment of Ruwanpura Expressway is designed to utilize mainly lowlands/wetlands in the Bolgoda basin, therefore it will be one of the concerns to harmonize with the storm water drainage system in these areas.

Table 2.4.6 Key Public Facilities in the Bolgoda Basin and the Moratuwa-Rathmalana area by DS Division (2018)

District	DS Division	Admin	School	Univ/Col	Hospital	Fire Station	Religious Facilities	Total
Colombo	Dehiwala	0	13	0	1	0	3	17
	Homagama	1	7	1	3	0	8	20
	Kaduwela	0	0	0	0	0	0	0
	Kesbewa	2	13	0	1	0	10	26
	Maharagama	2	11	1	1	0	2	17
	Moratuwa	0	4	1	0	0	6	11
	Padukka	0	0	0	0	0	1	1
	Rathmalana	0	9	1	1	1	7	19
	S.J. Kotte	0	7	0	0	0	1	8
	Thimbirigasyaya	0	0	0	0	0	0	0
	Sub-total	**5**	**64**	**4**	**7**	**1**	**38**	**119**
Kalutara	Bandaragama	1	5	0	0	0	6	12
	Horana	2	6	0	1	1	1	11
	Kalutara	0	1	0	0	0	1	2
	Millaniya	0	1	0	0	0	2	3
	Panadura	1	12	0	3	0	8	24
	Sub-total	**4**	**25**	**0**	**4**	**1**	**18**	**52**
	Total	**9**	**89**	**4**	**11**	**2**	**56**	**171**

Source: JICA Study Team



Source: JICA Study Team

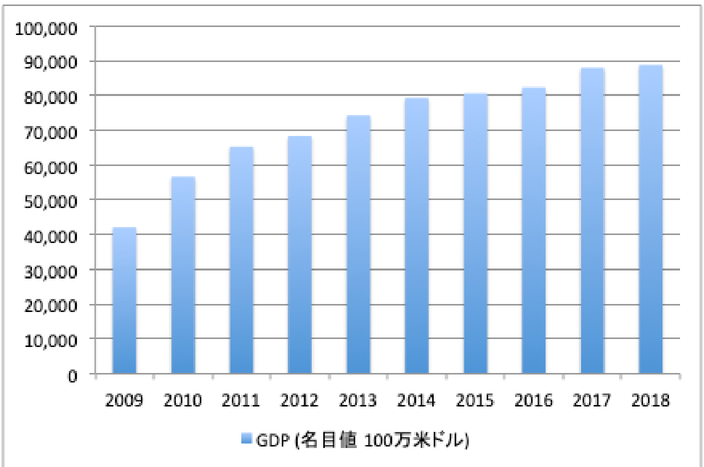
Figure 2.4.8 Distribution of Key Public Facilities and Road Network in Bolgoda Basin and Moratuwa-Rathmalana Sub-basin (2018)

2.5 Socio-Economic and Financial Situations

2.5.1 Socio-Economic Situation of Sri Lanka

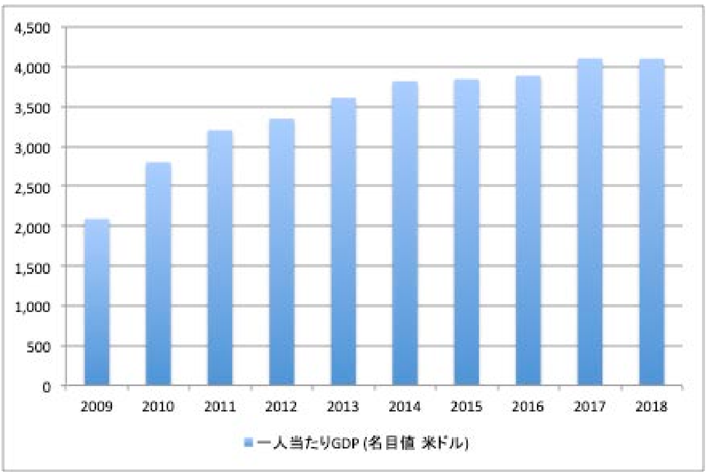
After the end of the conflict, Sri Lanka's economy achieved high growth with a real GDP growth rate of over 8% for the third consecutive year from 2010 to 2012 due to reconstruction demand and revitalization of economic activity. The growth rate fell after reaching a record high of 9.1% in 2012 but remained stable at a growth rate of around 4% for the three years from 2013 to 2015. GDP per capita in 2016 was 3,835 USD, with a growth rate of 4.4%. The breakdown of GDP in 2016 is 56.5% for the service industry, 26.8% for the industry, 7.1% for agriculture, and 9.6% for taxes (excluding subsidies).

In 2018, GDP was 88,901 million USD and the GDP per capita was 4,102 USD. Real GDP growth fluctuates sharply up and down. The following figure shows changes in GDP, per capita GDP, and real GDP growth rate as indicators of these economic growths.



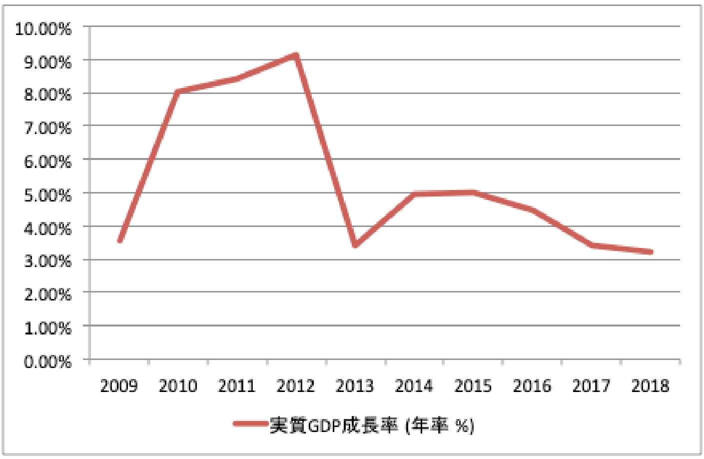
Source: Web site of World Bank (https://data.worldbank.org/country/)

Figure 2.5.1 GDP (100 million USD)



Source: Web site of World Bank (https://data.worldbank.org/country/)

Figure 2.5.2 GDP per capita (100 million USD)



Source: Web site of World Bank (https://data.worldbank.org/country/)

Figure 2.5.3 Real GDP growth rate (Annual rate %)

2.5.2 Socio-Economic Situation in the Target Drainage Basin

The western province, where the target basin is located, covers about 5.7% of the country's total area but accounts for about 42% of the country's GDP (2014). The breakdown is 60.9% for the service industry, 37.1% for industry, and 2.1% for agriculture. The economic growth rate of the province in 2014 was 5.9%.

2.6 Institutional Arrangement on River and Drainage Management

2.6.1 Current Status of Institutional Arrangement

2.6.1.1 Related Agencies

Many government agencies are involved in the planning, construction, operation, and maintenance of rivers and drainages. Particularly, "Sri Lanka Land Development Corporation (SLLDC)", "Irrigation Department (ID)", "Agrarian Development Department (ADD)", "Provincial Irrigation Department (PID)", and "Local Authorities" are playing main roles as major executing agencies.

In addition, "Urban Development Authority (UDA)" is responsible for land use and development regulations, "The Ministry of Land & Land Development" and UDA are responsible for land acquisition and resettlement, and "Central Environmental Authority (CEA)" is responsible for the regulation on environmental measures.

Ministries and government agencies involved in the planning, construction, management, operation, and maintenance of rivers and storm water drainage after the restructuring of ministries and government agencies in December 2019 are summarized in Table 2.6.1.

Table 2.6.1 Ministries and Agencies Relevant to the Project (as of Dec. 2019)

No.	Ministries and Agencies
1	**Ministry of Urban Development, Water Supply and Housing Facilities** • <u>Sri Lanka Land Development Corporation (SLLDC)</u> • <u>Urban Development Authority (UDA)</u> • National Water Supply and Drainage Board (NWSDB) • National Housing Development Authority (NHDA) • Urban Settlement Development Authority
2	**Ministry of Public Administration, Home Affairs, Provincial Councils & Local Government** • District Secretariats and Divisional Secretariats (DS, DSD and GND) • <u>Provincial Councils and Local Authorities (MC, UC and PS)</u> • Sri Lanka Institute of Local Government (SLILG)
3	**Ministry of Environment and Wildlife Resources** • <u>Central Environmental Authority (CEA)</u> • Department of Coast Conservation and Coastal Resource Management (DCC&CRM)
4	**Ministry of Mahaweli, Agriculture, Irrigation and Rural Development** • <u>Irrigation Department (ID)</u> • Agriculture Department • Agrarian Development Department (ADD) • Mahaweli Authority
5	**Ministry of Defence** • Department of Meteorology • Disaster Management Center (DMC) • National Building Research Organization (NBRO)
6	**Ministry of Lands & Land Development** • Survey Department
7	**Ministry of Roads and Highways** • Road Development Authority (RDA)
8	**Ministry of Transport Services Management** • Department of Sri Lanka Railways
9	**Ministry of Power & Energy** • Ceylon Electricity Board (CEB)
10	**Ministry of Information and Communication Technology** • Sri Lanka Telecom (SLTL)
11	**Ministry of Finance, Economic and Policy Development** • External Resources Department • National Planning Department (NPD)

Source: http://documents.gov.lk/files/egz/2019/12/2153-12_E.pdf

Regarding storm water drainage canals in the study area, in general, the "Major" canal (primary drainage canal) is managed by SLLDC and the "Minor" canal (secondary/tertiary drainage canal) is managed by local government. In fact, SLLDC is responsible for the planning and construction of storm water drainage improvement projects on as project basis in the Western Province, and continuously operates and maintains the storm water drainage facility only for designated canals and lakes (Major: 44 km, Minor: 54 km, etc.), especially in the Colombo District. On the other hand, Agricultural canals related to irrigation projects are developed, operated and maintained by Irrigation Department, Agrarian Development Department, and Provincial Irrigation Department, respectively, depending on the scale of the project.

As for the storm water drainage improvement project in the study area, basically, SLLDC is responsible for the designated canals and lakes, and the local government is responsible for the other small-scale drainage canals. In the case of a particularly important and large-scale storm water drainage improvement project, SLLDC will carry out the planning and construction, and then transfer the operation and maintenance together with the facility to the local government. However, local governments may not be able to respond it due to restrictions on human resources, equipment, and budget of local governments. In this case, considering the importance of the facility and the difficulty of operation and maintenance, the operation and maintenance will be continued after budgeting as a designated facility of SLLDC. Also note that the operation and maintenance of road drainage which is planned and constructed by the Road Development Authority will be transferred to local governments, except for drainage facilities connected to high-standard roads such as expressways.

(1) SLLDC

SLLDC is an organization under the "Ministry of Urban Development, Water Supply and Housing Facilities" (as of Dec. 2019) and is the main specialized executing organization responsible for storm water drainage management in urban areas. SLLR&DC Act No. 15 of 1968 (as Amended by SLLR&DC (Amendment) Act No.35 of 2006, Act No. 52 of 1982, and Act No. 27 of 1976) is the legal basis for the organization.

SLLDC was established in 1968 after splitting off from the drainage division of the Irrigation Department. The management of drainage canals managed by the former Irrigation Department in Western Province had been transferred to SLLDC.

An overview of SLLDC's annual budget for FY2018 (Sri Lanka's fiscal year is from January to December) is shown in Table 2.6.2. The annual budget for FY2018 is 4,273 million LKR, and 1,000 million LKR (23% of the annual budget) is due to Annual Programs. Out of that, 650 million LKR (15% of the annual budget) is allocated to the Maintenance of Canals, Lakes, and Walkways.

Table 2.6.2 Annual Budget of SLLDC for FY2018

Description		Budget for FY2018 (Million LKR)
1.0 Annual Programs		
	Maintenance of Canals, Lakes, and Walkways	**650.0**
	Flood Mitigation Activities	255.0
	Development of wetlands and lowlands	20.0
	Detailed designing, mapping, and feasibility studying	75.0
	Sub-total	1,000.0
2.0 Continuation Projects		
	Flood Mitigation activities	887.5
	Development of wetlands and lowlands	82.5
	Detailed designing, mapping, and feasibility studying	30.0
	Sub-total	1,000.0
3.0 Weras Ganga Project - Loan Repayments and Continuation of works		1,873.0
4.0 Pumping Station at Kalupalama, Kolonnawa		400.0
Total		**4,273.0**

Source: Detailed planning survey for the project for flood mitigation master plan for Colombo Metropolitan Region (JICA 2018)

The budget of SLLDC is mainly composed of the treasury budget (central government budget) and its own budget. Regarding the treasury budget, the budget can be executed after the annual treasury budget plan has been approved by the "Ministry of Finance, Economic and Policy Development". Drainage facility maintenance costs are allocated as the treasury budget every fiscal year.

(2) Local Authorities (LA)

Local Authorities are local government bodies below the Province under the "Ministry of Public Administration, Home Affairs, Provincial Councils & Local Government". The Local Authorities consist of Municipal Councils, Urban Councils, Pradeshiya Sabhas which are governed by three main laws of "The Municipal Councils Ordinance (1947)", "Urban Councils Ordinance (1939)" and "Pradeshiya Sabhas Act (1987)". The Local Authority carries out "Regulatory and administrative functions", "Promote public health and sanitation", "Environmental sanitation", "Public thoroughfares and public utility services", and so on.

The management of storm water drainage, as well as the management of local roads, is one of the important public services provided by Local Authorities. The budget for the management of storm water drainage is planned every fiscal year and the budget can be executed after the approval of the council. However, the budget allocated for the management of storm water drainage by local governments is very limited.

(3) Irrigation Department (ID)

Irrigation Department (ID) is an organization under the Ministry of Mahaweli, Agriculture, Irrigation, and Rural Development. The main objectives of the ID are the "Development of land and water resources for Irrigated agriculture, Hydropower, Flood control, Domestic use, Industrial use and Agriculture development", "Provision of Irrigation and drainage facilities for cultivable lands In irrigation and drainage projects", "Management of Water for Sustainable Agriculture", "Productivity enhancement of Land and Water in Major/ Medium Irrigation Schemes" and so on. The current legal basis for flood control and river management is "Flood Ordinance No. 22 of 1955".

The organizational structure of ID consists of six major departments, "Investigation, Planning & Designs", "Construction & Development", "System Management", "Riverine Management", "Administration" and "Finance". In addition, the "Drainage & Flood Systems / Disaster Management" section is set up under the "System Management" department.

ID is responsible for major irrigation schemes (over 1,000 acres) and medium schemes (200 to 1,000 acres), whilst the Provincial Irrigation Department or the Agrarian Development Department is responsible for minor schemes (less than 200 acres).

(4) Disaster Management Centre (DCM)

Disaster Management Centre (DMC) is the leading agency for disaster management under the Ministry of Defence. DMC was established in 2005 as per the provisions of the Sri Lanka Disaster Management Act, mandated with the responsibility of implementing and coordinating national and sub-national level programs for reducing the risk of disasters. The main activities of DMC are research and development, mitigation, planning preparedness, dissemination of early warning for the vulnerable population, emergency response, coordination of relief, and post-disaster activities in collaboration with other key agencies.

In order to facilitate the coordination and implement DMC activities, Disaster Management Committees were established at District, Divisional Secretary Division, Grama Niradari Division, across the country. District Disaster Management Coordination Units (DDMCU) were also established in all districts to carry out Disaster Risk Reduction (DRR) activities at the sub-national level.

(5) Urban Development Authority (UDA)

The Urban Development Authority (UDA) is an organization responsible for urban development under the Ministry of Urban Development, Water Supply, and Housing Facilities. UDA was established in 1978 to promote integrated planning and implementation for the economic, social, environmental, and physical development of the declared urban areas, with the "Urban Development Authority Act, No. 41 of 1978" as its legal basis. UDA's tasks include "formulation of urban development plans", "implementation of development projects" and "formation and implementation of urban land-use policies".

(6) Central Environmental Authority (CEA)

The Central Environment Authority (CEA) is an organization responsible for environmental consideration in the development process under the Ministry of Environment and Wildlife Resources. CEA was established on 12th August 1981, under the provision of the National Environmental Act No:47 of 1980. CEA was given wider regulatory powers under the National Environment (Amendment) Acts No:56 of 1988 and No:53 of 2000.

2.6.1.2 Local Administration System

Sri Lanka has two local administration systems in parallel as shown in Figure 2.6.1. One is the "National Administration Line" since independence and the other is the "Local Administration Line" introduced in 1987. Local Authority is a part of the "Local Administration Line". Local Authorities, which are responsible for the maintenance and management of storm water drainage as a part of public services, are situated in the lower administrative level of the Province on the “Local Administration Line”.

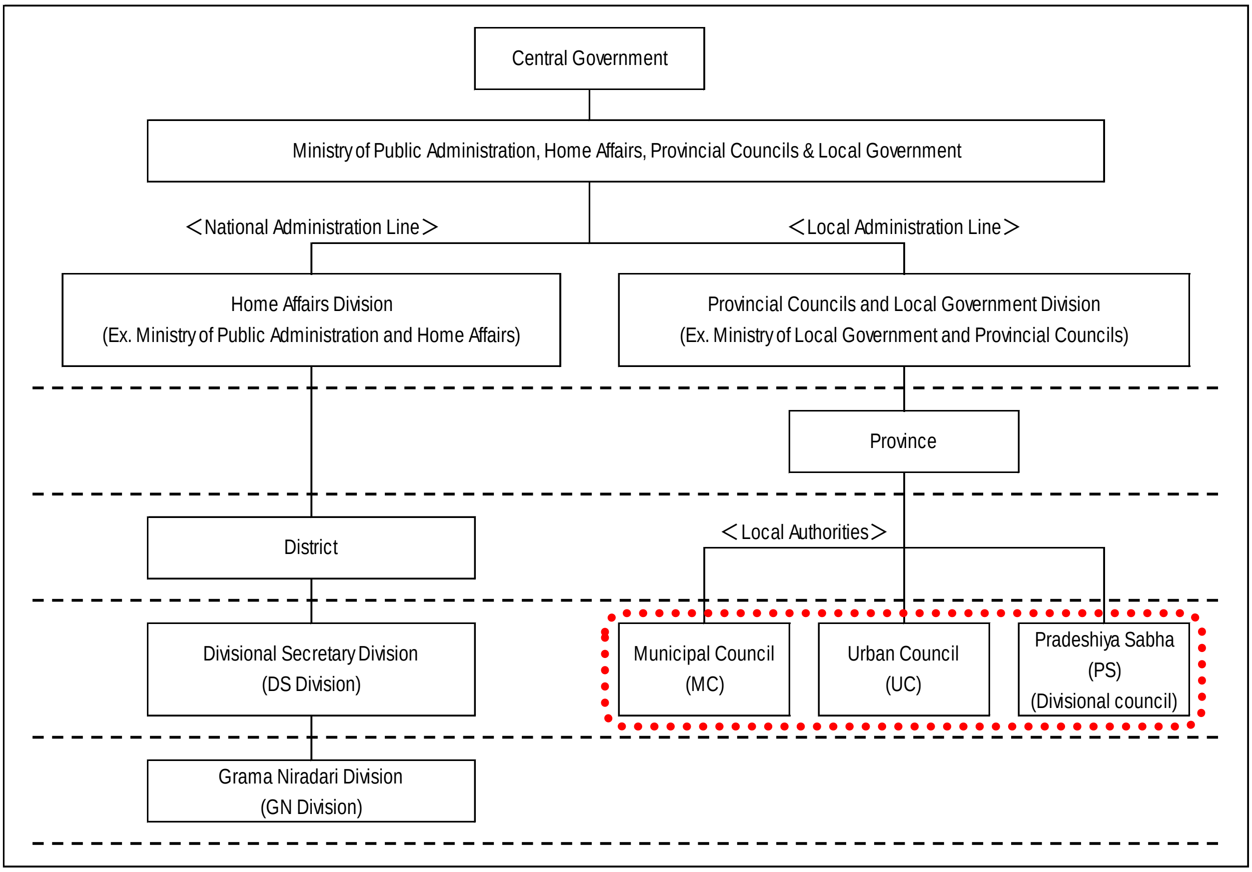
Local authorities are divided into three different groups: Municipal Councils (MC), Urban Councils (UC), and Pradeshiya Sabha (PS). On the other hand, The Divisional Secretary Division (DS Division), which is a subdivision of the District on the "National Administration Line", covers almost the same administrative boundary with Local authorities.

As an example where the DS Divisions boundary and Local Authorities boundary do not match; the area of the Colombo DS Division and the Thimbirigasyaya DS Division is equivalent to the area of the Colombo MC.

The district is administered under a District Secretary, who is appointed by the central government. The main tasks of the District Secretariat involve coordinating communications and activities of the central government and Divisional Secretariats. The District Secretariat is also responsible for implementing and monitoring development projects at the district level and assisting lower-level subdivisions in their activities, as well as revenue collection and coordination of elections in the district.

The storm water drainage in the study area is basically managed by SLLDC and Local Authorities. In some cases, due to the requests from the public such as improvement of poor drainage and water quality of canals, the District and DS Division take appropriate countermeasures with the central government budget.

The outline of the local administration system in Sri Lanka (as of Dec. 2019) is shown in Figure 2.6.1.



Source: Data Collection Survey on Disaster Risk Reduction Sector in Sri Lanka (JICA 2017), and modified by JICA Study Team

Figure 2.6.1 Local Administration System in Sri Lanka

The list of 21 local authorities related to the target basins (Kalu Oya, Mudun Ela, Bolgoda, and Moratuwa-Rathmalana) in this study is shown in Table 2.6.3, and the location map of related Local Authorities, Divisional Secretary Divisions, and target basins is shown in Figure 2.6.2 and Figure 2.6.3.

Table 2.6.3 List of Related Local Authorities in the Study Area

No.	Local Authority	Division	District	Province	Basin
1	Ja-Ela PS	Ja-Ela	Gampaha	Western	Kalu Oya
2	Mahara PS	Mahara	Gampaha	Western	Kalu Oya
3	Wattala PS	Wattala	Gampaha	Western	Kalu Oya
4	**Wattala Mabola UC**	**Wattala**	**Gampaha**	**Western**	**Kalu Oya, Mudun Ela**
5	**Kelaniya PS**	**Kelaniya**	**Gampaha**	**Western**	**Kalu Oya, Mudun Ela**
6	Peliyagoda **UC**	**Kelaniya**	**Gampaha**	**Western**	**Kalu Oya, Mudun Ela**
7	**Biyagama PS**	**Biyagama**	**Gampaha**	**Western**	**Kalu Oya, Mudun Ela**
8	Sri Jayawardanapura Kotte MC	Sri Jayawardanapura Kotte	Colombo	Western	Bolgoda
9	Maharagama UC	Maharagama	Colombo	Western	Bolgoda
10	**Dehiwala - Mount Lavinia MC**	**Dehiwala, Rathmalana**	**Colombo**	**Western**	**Bolgoda, Moratuwa-Rathmalana**
11	Boralesgamuwa UC	Kesbewa	Colombo	Western	Bolgoda
12	Homagama PS	Homagama, Padukka	Colombo	Western	Bolgoda
13	Kesbewa UC	Kesbewa	Colombo	Western	Bolgoda
14	**Moratuwa MC**	**Moratuwa**	**Colombo**	**Western**	**Bolgoda Moratuwa-Rathmalana**
15	Horana PS	Horana, Ingiriya	Kalutara	Western	Bolgoda

No.	Local Authority	Division	District	Province	Basin
16	Panadura PS	Panadura	Kalutara	Western	Bolgoda
17	Bandaragama PS	Bandaragama	Kalutara	Western	Bolgoda
18	Horana UC	Horana	Kalutara	Western	Bolgoda
19	Panadura UC	Panadura	Kalutara	Western	Bolgoda
20	Millaniya PS	Millaniya	Kalutara	Western	Bolgoda
21	Kalutara PS	Kalutara	Kalutara	Western	Bolgoda

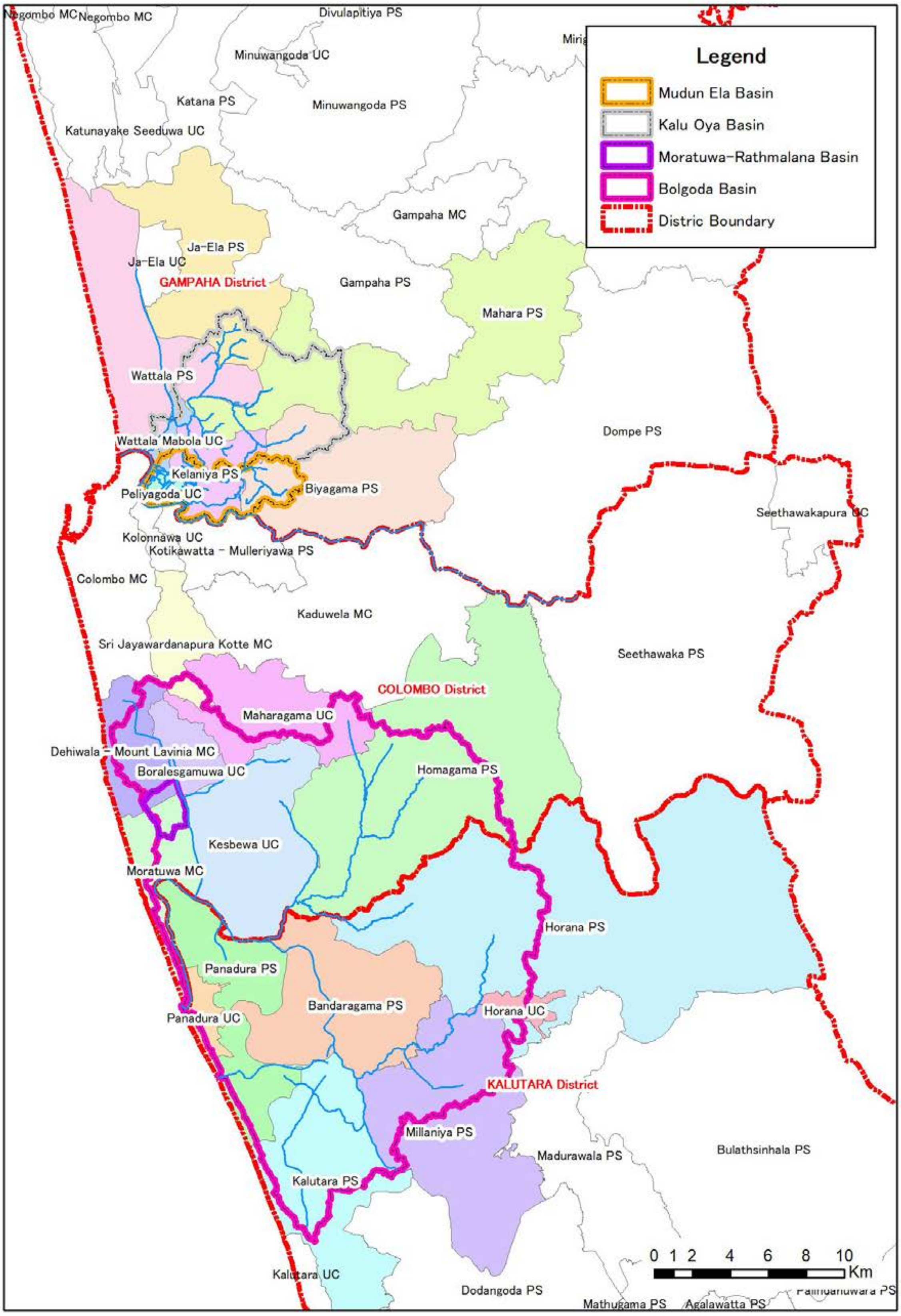
Source: JICA Study Team

In fact, except for large local authorities with sufficient budget and human resources such as Colombo MC, storm water management by local authorities is not easy due to budget and human resource limitations.

Although CMC is located outside the study area, it is the local government with the most budget and human resources for storm water management in the Western Province. As for the activities of CMC for storm water management, the Water Supply & Drainage Division of the CMC in the Technical Service Division manages storm water drainage along with water supply and sewage.

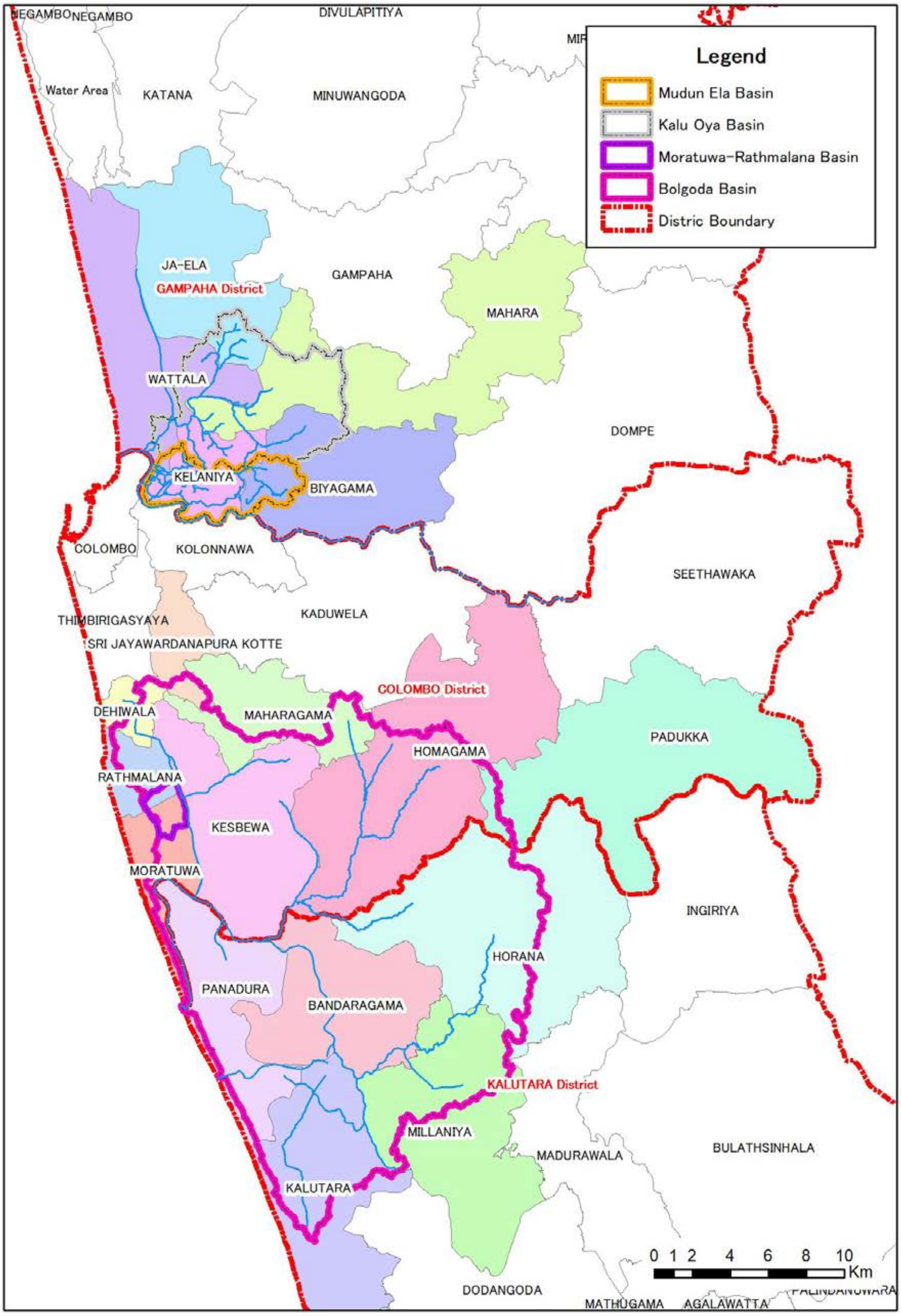
Meanwhile, the Peliyagoda drainage pumping station was operated and maintained by Peliyagoda UC until 2016 and then it was transferred from Peliyagoda UC to SLLDC in 2016. It is currently operated and maintained by the Colombo North Regional Office of SLLDC.

In addition, local authorities that can prepare a budget to improve and maintain drainage facilities may outsource to SLLDC on a project basis. However, this is a project-based individual response and not sustainable planned storm water drainage management.



Source: JICA Study Team

Figure 2.6.2 Related Local Authorities (MC, UC and PS) and Target Basins



Source: JICA Study Team

Figure 2.6.3 Related Divisional Secretary Divisions and Target Basins

2.6.2 Operation and Maintenance

SLLDC and local governments are responsible for the operation and maintenance of storm water drainage facilities, except for large rivers in the study area.

2.6.2.1 SLLDC

SLLDC is a government agency and is responsible for the operation and maintenance of storm water drainage facilities in designated areas, and the research and design division (hereinafter referred to as R&D Division) is responsible for the operation and maintenance of storm water drainage facilities in SLLDC. R&D Division has 7 Regional Offices and manages main canals: about 44 km and secondary canals: about 54 km. At least one Engineer is assigned in each Regional Office and manages the overall activity of maintenance of drainage canals and other related facilities. In addition, 500 workers are engaged in drainage canal cleaning.

Drainage facilities managed by R&D Division's Regional Office are mainly canals, lakes/wetlands and reservation areas along the canals and lakes/wetlands. Facilities that required operations, such as drainage pump stations and drainage control gates, are limited. Canal surface cleaning to ensure drainage capacity and improve water quality is an important daily work for drainage canal maintenance. In particular, in areas where the garbage collection system is not functioning well, illegal dumping of garbage into the drainage canal and how to deal with it has become a major issue.

The Peliyagoda drainage pumping station managed by the Colombo North Regional Office is one of the facilities that require daily operation work. Regarding the operation of the Peliyagoda drainage pumping station, there is an operation manual and it is in full operation for almost 24 hours during the monsoon season. The maintenance of pump equipment is managed by the Plan and Equipment Division of SLLDC.

As for the Oliyamulla drainage pumping station, which is currently under construction on a project basis, the management body after the completion of construction has not been decided, but the operation manual for the pump equipment is scheduled to be prepared by the manufacturer company. So far, there is no other information on facilities that require operation work for storm water drainage facilities that are operated and managed on a project basis.

According to the results of interview surveys at Colombo North, Colombo South and Muthurajawela Regional Office, there is no documented maintenance manual, and daily maintenance works are carried out under the direction of the work supervisor. As for dredging, the dredging plan is formulated based on the periodical survey of the bed sediment condition of drainage canals and lakes. Normally, canal dredging is carried out about once every three years, and lake dredging is carried out about once every ten years. Dredging heavy equipment is managed and maintained by the Plant and Equipment Division of SLLDC.

(1) Budget for Operation and Maintenance

The annual budget of the R&D Division (responsible for the operation and maintenance of storm water drainage facilities in SLLDC) for FY2019 is 561 million LKR. Out of it, 496 million LKR (88% of the annual budget) is allocated to the "Maintenance of canals, lakes and walkways", and 65 million LKR (12% of the annual budget) is allocated to "Flood Mitigation Activities".

In addition to the above budget, SLLDC also maintains and manages storm water drainage canals based on contracts with local governments. As a contract with Colombo MC in 2018, SLLDC carried out annual maintenance work (from August 2018 to August 2019) on drainage canals in 10 districts with a contract amount of Rs. 31,000,000. Contracts with Gampaha District Secretariat were also made for canal cleaning and dredging with approximately a contract amount of 26.2 million LKR in 2017 and 32.4 million LKR in 2015. The Gampaha District Secretariat is not responsible for storm water management under its current mandate, but the District Disaster Management Coordinating Unit of the Gampaha District Secretariat arranged the contract budget as part of disaster management measures.

(2) Current Issues of Operation and Maintenance

The main issues related to the operation and maintenance of storm water drainage facilities based on interviews with the R&D Division are summarized below.

- Decrease of drainage capacity due to illegal dumping of garbage into drainage canals (There are also problems with the local garbage collection system)
- Deterioration of water quality in drainage canals
- Illegal landfill in drainage canal (Decrease of drainage capacity)
- Illegal constructions and structures in the drainage canal
- Responding to local inundation problems due to disturbance of drainage capacity (by garbage, etc.) in secondary and tertiary drainage canals (the management body is unclear)
- Responding to illegal construction, illegal occupation, illegal residence, and illegal structure in the reservation areas
- Difficult to access reservation areas of Wetland for maintenance
- Difficult to secure working space for maintenance dredging

2.6.2.2 Local Authority

Storm water drainage management is one of the important services of Local Authorities. The Local Authorities (Municipal Council: MC, Urban Council: UC, Pradeshiya Sabha: PS) are responsible for the operation and maintenance of storm water drainage facilities within their respective administrative territories, except for the designated canals and lakes of SLLDC. However, the main operation and maintenance work of local governments is only the cleaning of canals and limited repair works, due to human resources, equipment and budget constraints.

The organizational structure of Local Authorities is basically the same for MC, UC, and PS, but the organizational structure of the department differs depending on the scale of the Local Authority. In MC and UC, there are several council departments under the mayor or secretary, and the responsibility for the operation and maintenance of storm water drainage facilities is mainly in the engineering department. On the other hand, the organizational structure of PS does not have many departments, there are several divisions under the secretary. Generally, the Health Service Division implements canal cleaning along with road cleaning, garbage collection and other related tasks.

2.6.2.3 Others

Depending on the scale of the project, the "Irrigation Department", "Agrarian Development Department" and "Provincial Irrigation Department" are the main management bodies for the operation and maintenance of agricultural canals (irrigation canals and drainage canals) within irrigation projects. Specifically, the Irrigation Department is in charge of projects with irrigation areas of 200 acres or more, and the Agrarian Development Department or Provincial Irrigation Department is in charge of the operation and maintenance of related canals for projects below 200 acres.

However, due to changes in land use with urbanization, drainage canals from urban areas are connected to these agricultural canals, and at present, these agricultural canals also function as important urban drainage canals. Especially in the study area, conversion from farmland to residential land is progressing in order to meet the land use demand due to urbanization. Therefore, due to the scale reduction of the irrigation project, it is not properly operated and maintained by the irrigation project-related organizations, but in reality, many agricultural canals function as urban drainage canals in the study area. These are issues to be solved in the operation and maintenance of the drainage canals.

2.7 Support from Other Aid Agencies

Sri Lanka's 30-year civil war ended in 2009, which led to a return to political stability in the country, and the economy began to grow at an average annual rate of 6.7% (2010-2014). In order to support this recovery, the priority was to rebuild the metropolitan area and urban growth. Against this background, two projects related to the relevant areas and the target watersheds have been implemented with the support of the World Bank, as follows. These projects are summarized below.

(1) Metro Colombo Urban Development Project (MCUDP)

(2) Climate Resilience Improvement Project (CRIP)

(3) Climate Resilience Multi-Phase Programmatic Approach (CResMPA)

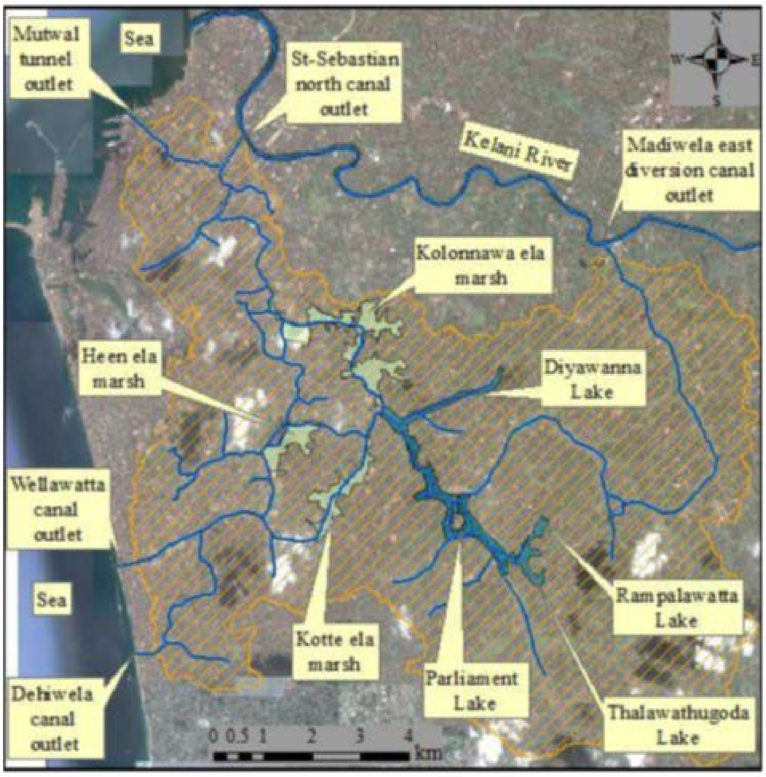
2.7.1 MCUDP

(1) Purpose

It aims to support the government's urban reconstruction program by reducing the physical and socio-economic risks of flood inundation in the Colombo metropolitan area and improving local infrastructure facilities and public services.

(2) Target area

The target area is the Greater Colombo Basin (the watershed area is 105 km^2), shown in the following figure, and includes the main area of the capital city of Colombo and the lake where the presidential palace is located, called Parliament Lake.



Source: Flood Inundation Analysis for Metro Colombo Area, Sri Lanka, Mohamed Moufer, SLLDC, 2014

Figure 2.7.1 Canal system in Metro Colombo

(3) Implementation period, implementing agency, project cost, etc.

The project was approved by the World Bank in March 2012 and is partially completed in December 2021. The total project cost is 320.60 million USD and the residual incomplete portion will be implemented with the GOSL fund. The project is divided into three components, and the executing agency is also divided accordingly.

Component 1: Development of main canals and canal networks required for flood drainage management, including the construction of an integrated flood management system, which is being implemented mainly by SLLDC.

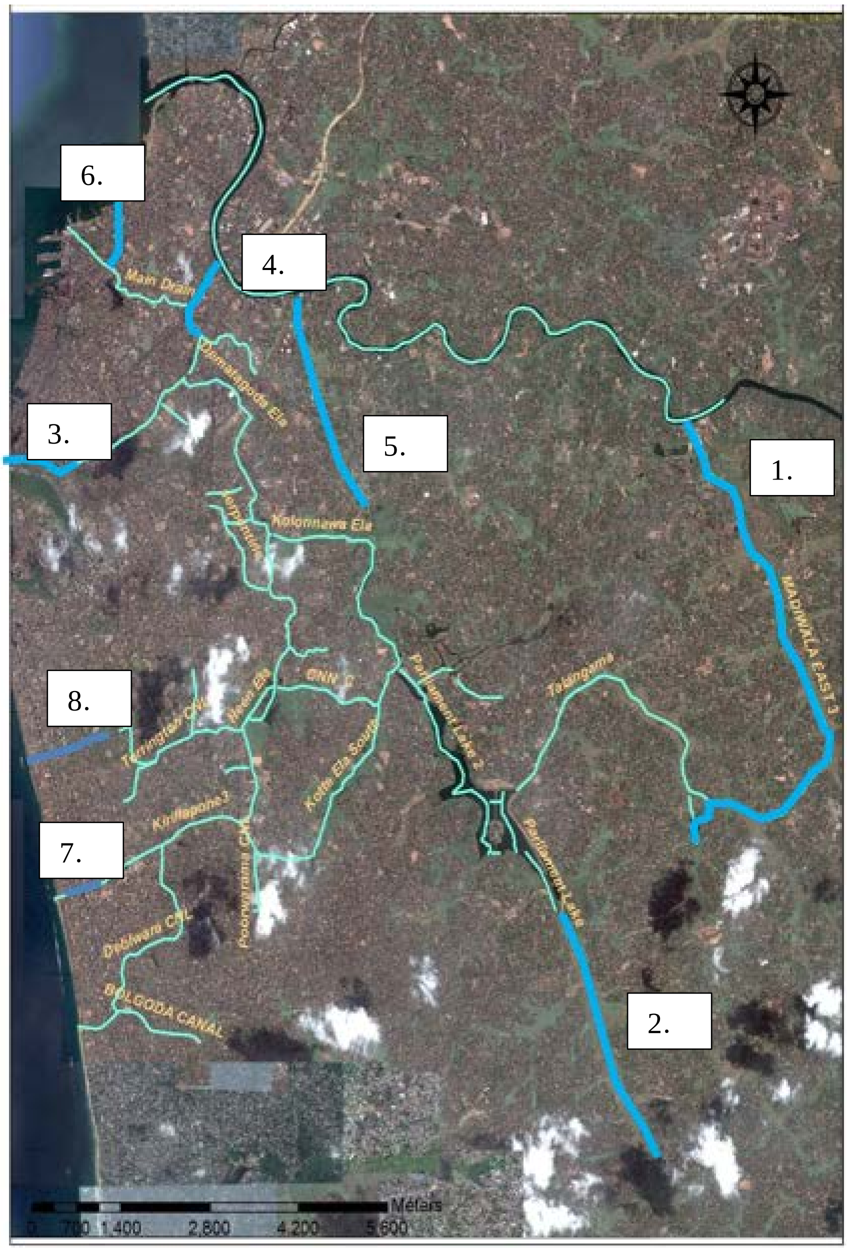
Component 2: Rehabilitation of related infrastructure in the city and capacity building of related local governments in the Colombo metropolitan area, with related local governments as the implementing body.

Component 3: Support for efficient and effective project implementation.

(4) Major countermeasure projects and progress

In the wake of the great flood that occurred in 2010 and caused enormous damage to the Colombo metropolitan area, consideration was given to the review of rainfall based on the review of the 2003 JICA Master Plan.

A plan was drafted centered on the renovation of the main canals, including many canals (see the next figure). Initially, MCUDP was planned to be completed in 2017 and extended to December 2021. However, as of August 2019, 21 of the 35 subprojects of Component 1 have been completed and 14 are in progress. Among these, it is judged that the construction of three pump facilities, one tunnel canal and one canal cannot be completed within the construction period. A review of the implementation plan is being discussed by the World Bank and the GOSL. This MCUDP does not include the Madiwela South Diversion project. This Diversion is planned to flow out of the basin through Maha Ela, a tributary of the Weras Ganga basin, which is upstream of the Bolgoda basin.



1. Improvements to Madiwela East Diversion Scheme
2. Madiwela South Diversion Scheme
3. St. Sebastian South Diversion
4. St. Sebastian North Lock widening & Pumping Station
5. Kolonnawa Canal diversion
6. New Mutwal Tunnel
7. Provide guide walls at Wellawatta Bridge
8. Torrington Tunnel

Source: Flood Mitigation in Metro Colombo & Kolonnawa Basins, SLLDC

Figure 2.7.2 Major Canal Improvement Project in Metro Colombo Drainage Basin

2.7.2 CRIP and CResMPA（CRIP2 [F/S-D/D]）

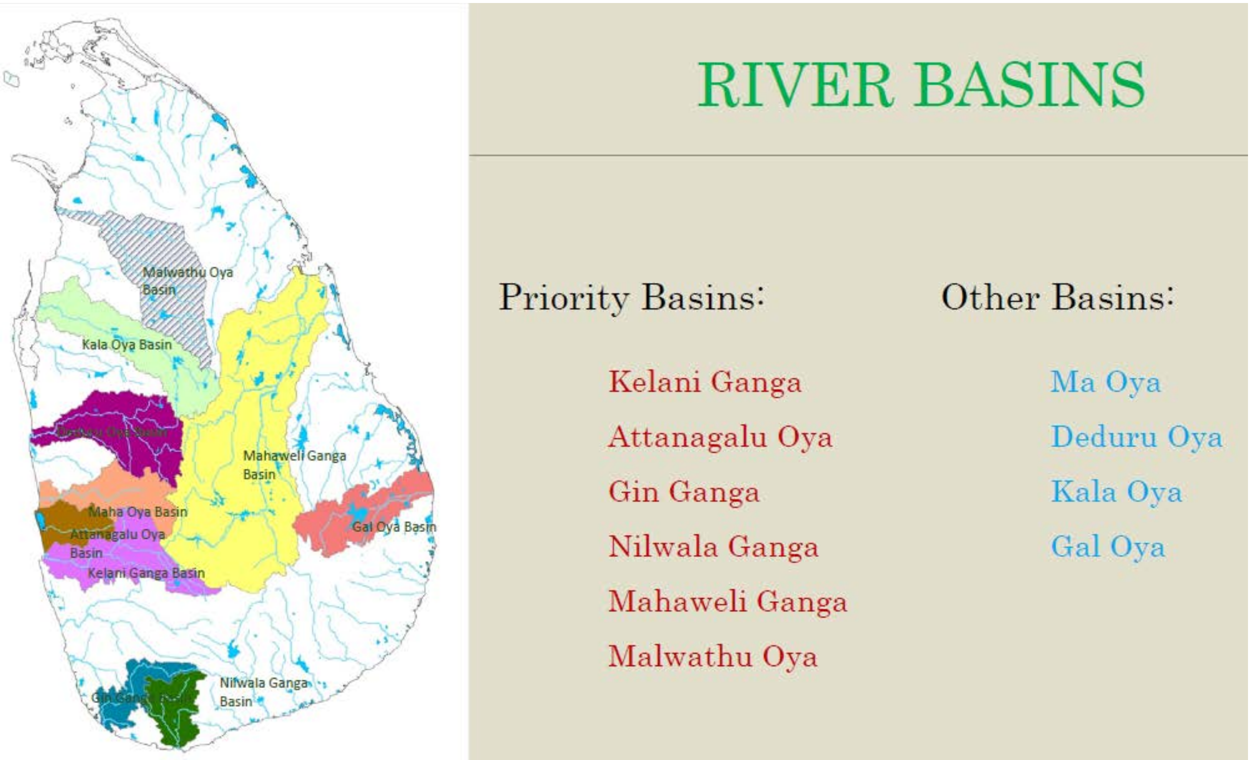
(1) Purpose

The aim is to reduce the vulnerability of people and assets to risks associated with meteorological hydrology such as floods, droughts and landslides, and to improve the government's ability to respond to disasters effectively.

(2) Target area

1) CRIP

The target area is the 10 major river basins in Sri Lanka.



Source: CRIP Explanation Material, Irrigation Department, 2017

Figure 2.7.3 Target River Basin of CRIP

A basin investment plan for these 10 basins was formulated, and Kelani Ganga, which corresponds to the main river of Kalu Oya and Mudun Ela, which are the target basins of this study, was selected as the highest priority basin.

This is because basin investment plans were formulated for each of the 10 basins, and Pre-F/S was implemented for about 3 to 4 projects in each basin.

Based on these results, in the Kelani Ganga basin, a downstream embankment aiming at 1/50 flood control safety was proposed as a short-term measure, and the construction of a multi-purpose dam group to secure 1/100 flood control safety as a long-term measure was proposed. Planned.

This is the "Climate Resilience Multi-Phase Programmatic Approach (CResMPA)" of the next stage of the project.

2) CResMPA (CRIP2 [F/S-D/D])

The "Climate Resilience Multi-Phase Programmatic Approach (CResMPA)" is an F/S and D/D project aimed at examining the construction of downstream embankments and upstream multipurpose dams in the Kelani Ganga basin, which was selected as the highest priority basin by CRIP.

(3) Implementation period, implementing agency, project cost, etc.

1) CRIP

Initially, the implementation period was five years from August 2014 to May 2019. A watershed investment plan was formulated (13 million USD), emergency measures to improve the climate resilience of infrastructure facilities (90 million USD) were implemented, and the remaining budget was used for project management (5 million USD) and emergency response reserve funds (2 million USD).

The executing agency is mainly the Irrigation Department, and the Mahaweli Authority of Sri Lanka, National Building Research Organization (NBRO), and Road Development Authority (RDA) are the main agencies in charge.

After that, additional measures were needed to respond to the floods that occurred in 2014, and a budget of 42 million USD was added in 2016.

2) CResMPA (CRIP2 [F/S-D/D])

In addition, CResMPA was approved in June 2019, and a five-year construction project with a completion target of September 2024 was started. The project cost is 310 million USD.

(4) Major projects and progress

1) CRIP

In the first half of the CRIP, investment plans for major river basins in Sri Lanka were examined, priorities were set for each basin, and Pre-F/S for each priority project was implemented. Based on this, CResMPA targeting the Kelani Ganga basin, which has been regarded as a top priority, has proposed a program divided into the following three phases.

2) CResMPA (CRIP2 [F/S-D/D])

The CResMPA (CRIP2 [F/S-D/D]) currently underway proposes a program divided into the following three phases: construction of a flood warning system, embankment in the downstream area, and detailed design of 2 dams in the upstream area and implementation.

<u>Phase-I: Kelani Ganga Flood Forecast Warning and Downstream Flood Control</u>

Implementation of the following 5 component projects using the project cost of 310 million USD

1) Flood warning system
This component includes support for the installation of hydrological meteorological observation equipment on DMC, ID, NBRO, and MD, construction of an integrated management system, formulation of disaster prevention plans for embankment riverside areas, and improvement of residents' flood response capabilities. The project is carried out by each responsible organization.

2) Hydraulic control measures downstream of Kelani Ganga
This component includes a 15km downstream embankment, 13 pumping stations, the replacement of tide weirs and a detailed design of two dams.

3) Land use regulation, resident relocation support, safety measures
4) Project management
5) Emergency response reserve

<u>Phase-II: Implementation of flood control measures in the lower reaches of Kelani Ganga</u>

Phase-III: Dam construction project in the upper reaches of Kelani Ganga

Source for this sub-section
1) *https://projects.worldbank.org/en/projects-operations/project-detail/P122735*
2) *Flood Inundation Analysis for Metro Colombo Area, Sri Lanka, Mohamed Moufer, SLLDC, 2014*
3) *Flood Mitigation in Metro Colombo & Kolonnawa Basins, SLLDC*
4) *Implementation Status & Results Report, World Bank, 2019*
5) *CRIP Explanation Material, Irrigation Department, 2017*
6) *Combined Project Information Documents/Integrated Safeguards Datasheet Additional Financing, World Bank, Jan. 2016*
7) *Climate Resilience Multi-Phased Programmatic Approach, World Bank, Feb. 2019*

(5) Summary of the Kelani Ganga Improvement in CRIP

In CRIP, the investment plan and the Pre-F/S were proposed. This study proposed several cases with the safety level of a 25-year return period, 50-year return period, and 100-year return period at the Kelani Ganga lower area (35 km from the river mouth). Finally, it concluded the combination of a 50-year return period at the river improvement, and a 50-year return period with two upstream dams, which resulted in a 100-year return period in total. The followings are the specification summaries.

1) River Channel Improvement: Dike (35km from the river mouth)

- Three alternatives of the dike (with its freeboard of 0.5 m) alignment, which were 1) along the existing riverbank, 2) setting back by 15 m from the existing riverbank and 3) based on the existing riverbank and the conditions of the surrounding areas such as ground elevations and land use were proposed. Finally, case “3)” was selected.
- Approximately 3,000 people are resettled, and 71 hectares of land are acquired.
- Construction cost: 194 million U.S. dollars, Land acquisition and resettlement: 80 million U.S. dollars, Total cost: 274 million U.S. dollars.

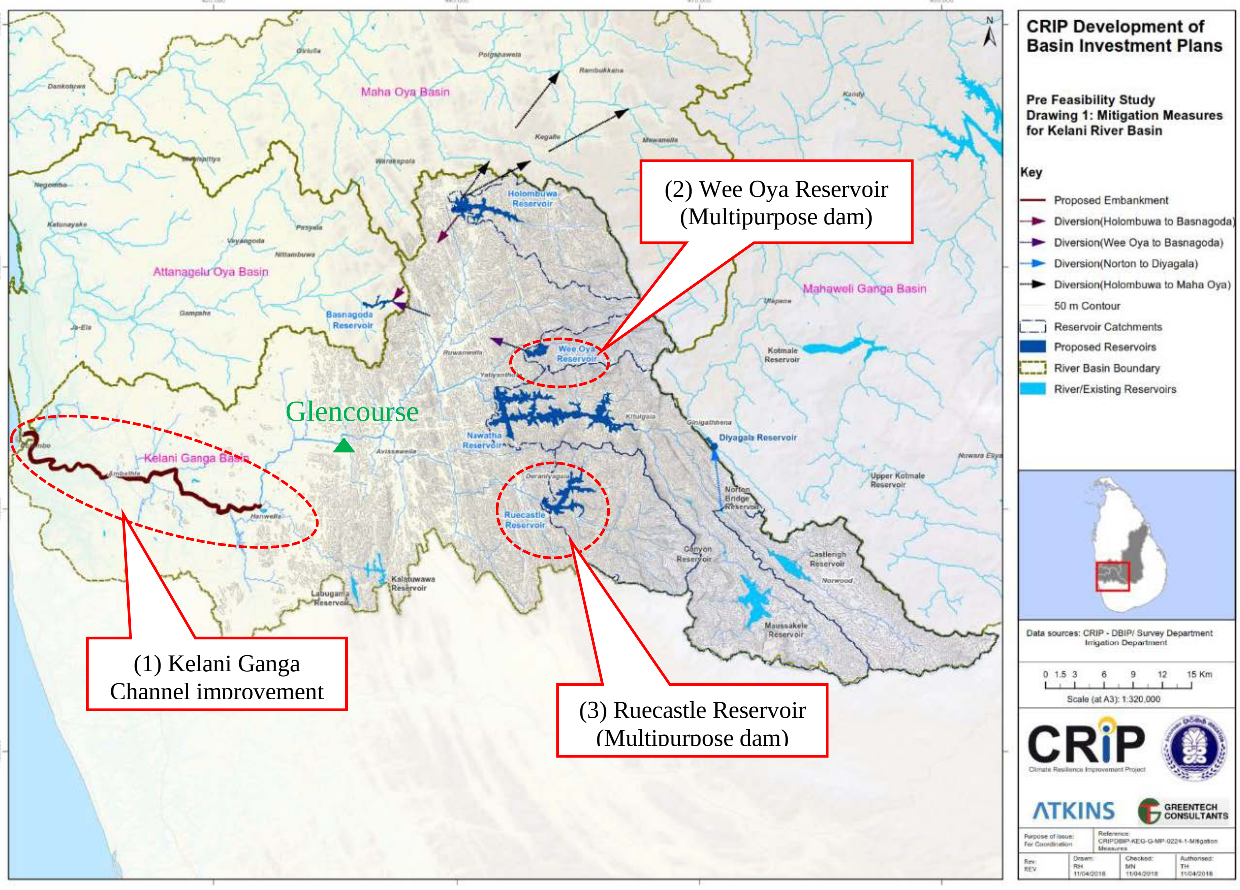
2) Wee Oya Reservoir (Multipurpose dam)

- Dam top length: 190 m, Dam height: 63 m, Catchment area: 53 km^2, Storage capacity: 48 MCM
- Approximately 300 people are resettled, and 440 hectares of land are acquired.
- The purpose of the dam is power generation, water supply and flood mitigation
- Construction cost: 82.5 million U.S. dollars, Land acquisition and resettlement: 6.1 million U.S. dollars, Total cost: 88.6 million U.S. dollars.

3) Ruecastle Reservoir (Multipurpose dam)

- Dam top length: 440 m, Dam height: 39 m, Catchment area: 184 km^2, Storage capacity: 215 MCM
- Approximately 1,460 people are resettled, and 330 hectares of lands are acquired.
- The purpose of the dam is power generation, water supply and flood mitigation
- Construction cost: 115 million U.S. dollars, Land acquisition and resettlement: 20.9 million U.S. dollars, Total cost: 136 million U.S. dollars.

The Kelani Ganga channel improvement is prioritized and the construction of Wee Oya reservoir and Ruecastle reservoir are secondarily and thirdly prioritized, respectively. The location map is shown in Figure 2.7.4. The concrete construction plan was not explained in the CRIP report and is expected to be described in CResMPA (CRIP2 [F/S-D/D]). Although some pumping stations were proposed at the river confluences connected to Kelani Ganga, details are not described, either.



Source: CRIP

Figure 2.7.4 Location of the Priority Projects along Kelani Ganga Proposed in CRIP

2.8 Climate Change

Regarding future climate change, sea-level rise and changes in rainfall are shown below as phenomena related to stormwater drainage plans. Changes in inundation risk due to climate change are described in detail in Chapter 6. For climate change scenarios, information has been updated from the RCP scenarios in the Fifth IPCC Report, and the following five scenarios are defined in the Sixth IPCC Report. This section summarizes information on two scenarios, SSP2-4.5 and SSP5-8.5, which correspond to RCP4.5 (medium greenhouse gas emissions scenario) and RCP8.5 (high greenhouse gas emissions scenario) defined in the Fifth IPCC Assessment Report.

Table 2.8.1 IPCC Sixth Assessment SSP Scenario and RCP Scenario

Scenario	Type of Scenario	RCP Scenario
SSP1-1.9	Scenario for keeping temperature rise below 1.5°C under sustainable development	not applicable
SSP1-2.6	Scenarios that limit the temperature increase to less than 2.0°C under sustainable development	RCP2.6
SSP2-4.5	Scenarios for adopting climate policies under intermediate development	RCP4.5
SSP3-7.0	Scenarios without climate policy under regionally conflicting development リオ	RCP6.0 と 8.5 の間
SSP5-8.5	Maximum emissions scenario without climate policy under fossil fuel-dependent development	RCP8.5

Source: Arranged by JICA Study Team using IPCC Sixth Report

2.8.1 Sea Level Rising

The following figure shows the predicted results of global sea-level rise. This is a prediction based on the model used in the 6th IPCC. According to this figure, the 2030 target is expected to be 0.093 m in the case of SSP2-4.5 (RCP4.5) and 0.101 m in the case of SSP5-8.5 (RCP8.5).

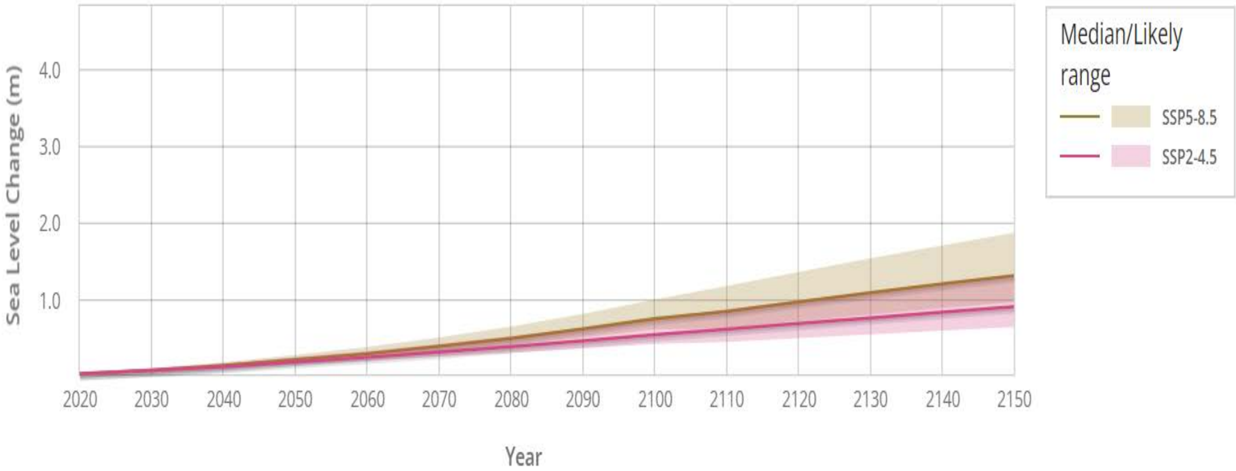


Figure 2.8.1 Global Mean Sea Level Rise (SSP2-4.5 and SSP5-8.5)

2.8.2 Precipitation Change

Similar to sea level rise, the World Bank's findings show future increases and decreases in rainfall in Sri Lanka for SSP2-4.5 (RCP4.5) and SSP5-8.5 (RCP8.5) cases, as shown in the table below.

This is the forecast result for the period of 2020-2039 and shows the change in the maximum daily rainfall with a 25-year return period.

There is a large variation in the predicted values using the global model of nearly 30 cases, and as a result, it is inferred that the median ensemble average was reversed between RCP4.5 and RCP8.5.

Considering the Kalu Oya basin, an increase of about 2.4 % to 4.1 % is expected for the design rainfall of 358.7 mm. The changes in runoff discharge will be examined in Chapter 6.

Table 2.8.2 Projected Increase or Decrease of the 25-year Probability Annual Maximum Daily Rainfall (2020-2039)

Scenario	Ensemble Median	10-90% Range
SSP-4.5（RCP4.5）	14.65 mm	-2.44 to 17.22 mm
SSP5-8.5（RCP8.5）	8.72 mm	-12.50 to 14.80 mm

CHAPTER 3 HISTORICAL FLOOD DAMAGE

3.1 Historical Inundation Area

As a result of interviews with the Disaster Management Center (hereinafter referred to as "DMC"), the most recent flood damages occurred in 2010, 2016 and 2017 in Colombo Metropolitan Area. Among them, historical inundation data was collected for 2010 and 2016.

In addition, the disaster database managed by DMC was used to organize the affected population in Gampaha, Colombo and Kalutara districts related to the target basin.

This historical flood damage data also revealed that the affected population in 2010 and 2016 was extremely large. Therefore, in the analysis model construction of this study, the May 2016 flood was targeted for model identification, and the May 2010 flood was targeted for model verification.

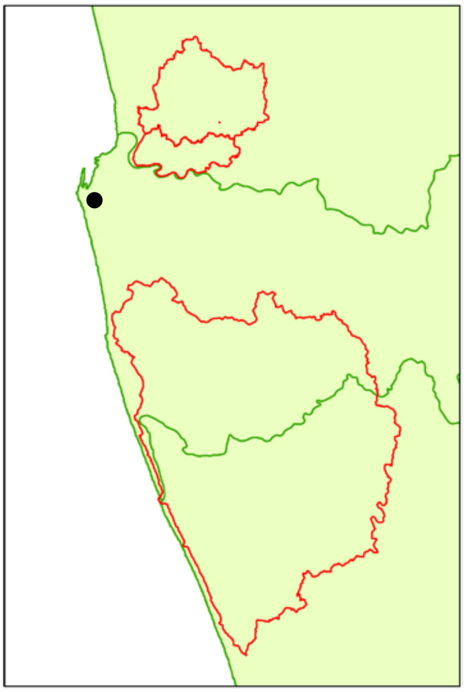
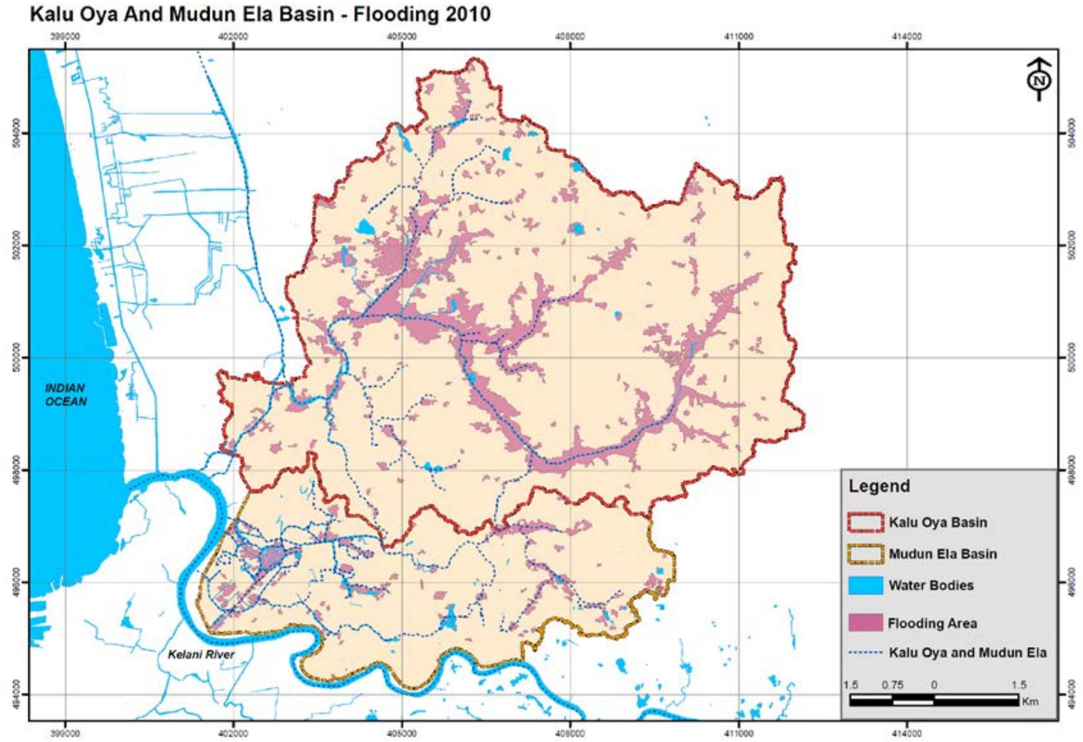


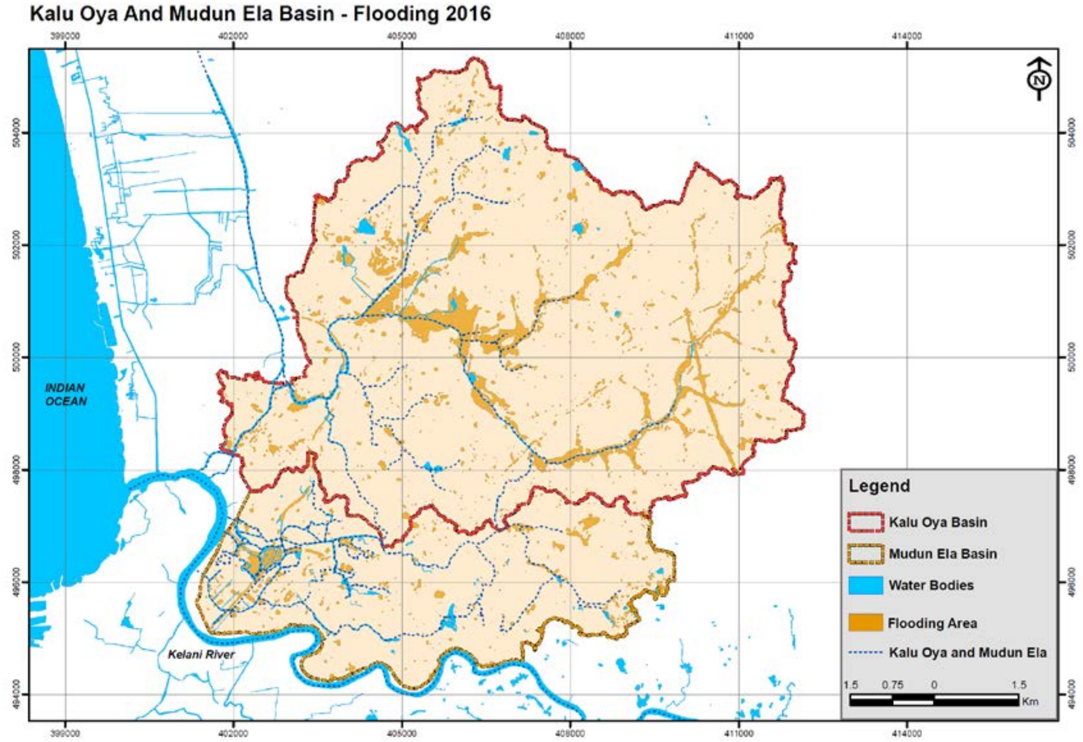
Figure 3.1.1 Location Map of Target River Basins

Table 3.1.1 Damaged Population in Major Flood

Gampaha district				Colombo district				Kalutara district			
Rank	Date	Affected people	Target	Rank	Date	Affected people	Target	Rank	Date	Affected people	Target
1	2010/5/16	99,927	✓	1	2010/5/13	28,897	✓	1	2010/5/14	67,984	✓
2	2006/11/17	58,775		2	2010/11/10	15,885		2	2003/5/17	33,165	
3	2016/5/15	57,101	✓	3	2010/11/12	10,611		3	2010/11/10	29,598	
4	2008/6/2	53,222		4	2010/5/14	8,938	✓	4	2017/5/26	24,910	
5	2013/5/4	48,289		5	1999/10/12	8,750		5	2008/6/1	16,247	
6	2018/5/21	41,183		5	1994/10/1	8,750		6	1994/5/28	15,994	
7	2016/5/16	35,860		7	2016/5/15	7,542	✓	7	2008/6/2	14,454	
8	2005/11/22	32,946		8	2017/5/26	5,445		8	2014/6/2	10,714	
9	2017/5/26	32,133		9	2018/10/6	5,351		9	1999/4/19	10,281	
10	2007/5/4	29,098		10	2005/11/21	4,177		10	2006/10/26	10,132	
11	2006/10/24	26,595		11	2004/12/3	3,160		11	2018/10/6	8,848	
12	1999/10/12	25,310		11	2004/11/9	3,160		12	1993/5/26	7,958	
13	2008/10/25	23,852		13	1991/6/2	2,500		13	2005/5/15	7,683	
14	2008/4/28	23,827		14	2005/11/22	2,282		14	2005/11/22	7,437	
15	2010/10/23	23,713		15	2007/5/5	2,090		15	1998/7/15	7,140	
16	2008/10/21	20,591		16	2008/6/1	1,827		16	2016/5/15	5,728	
17	2006/10/26	19,883		17	2011/5/27	1,681		17	2007/5/4	4,100	
18	2014/6/2	19,701		18	1995/5/6	1,500		18	2006/10/27	3,855	
19	2010/5/14	17,113		19	2018/5/21	1,126		19	2005/11/25	2,845	
20	2010/10/10	16,266		20	2006/10/20	1,000		20	2009/11/17	2,736	

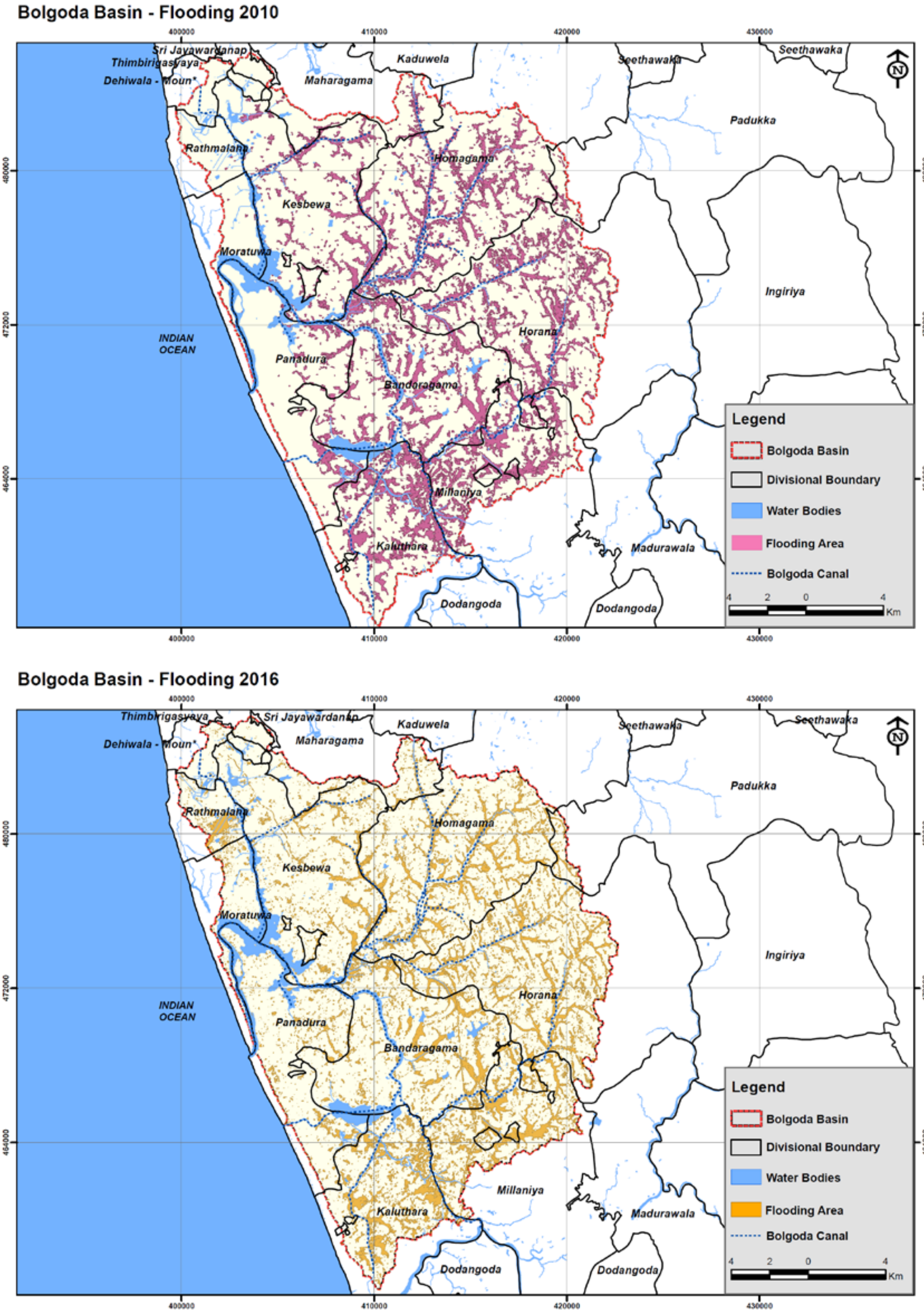
Source : JICA Study Team





Source: Prepared by JICA Study Team based on the data obtained from DMC and Sentinel Asia

Figure 3.1.2 Historical Flood Aria in the Kalu Oya Basin and Mudun Ela Sub-basin



Source: Prepared by JICA Study Team based on the data obtained from DMC and Sentinel Asia

Figure 3.1.3 Historical Flood Aria in Bolgoda Basin

3.2 Interview Survey

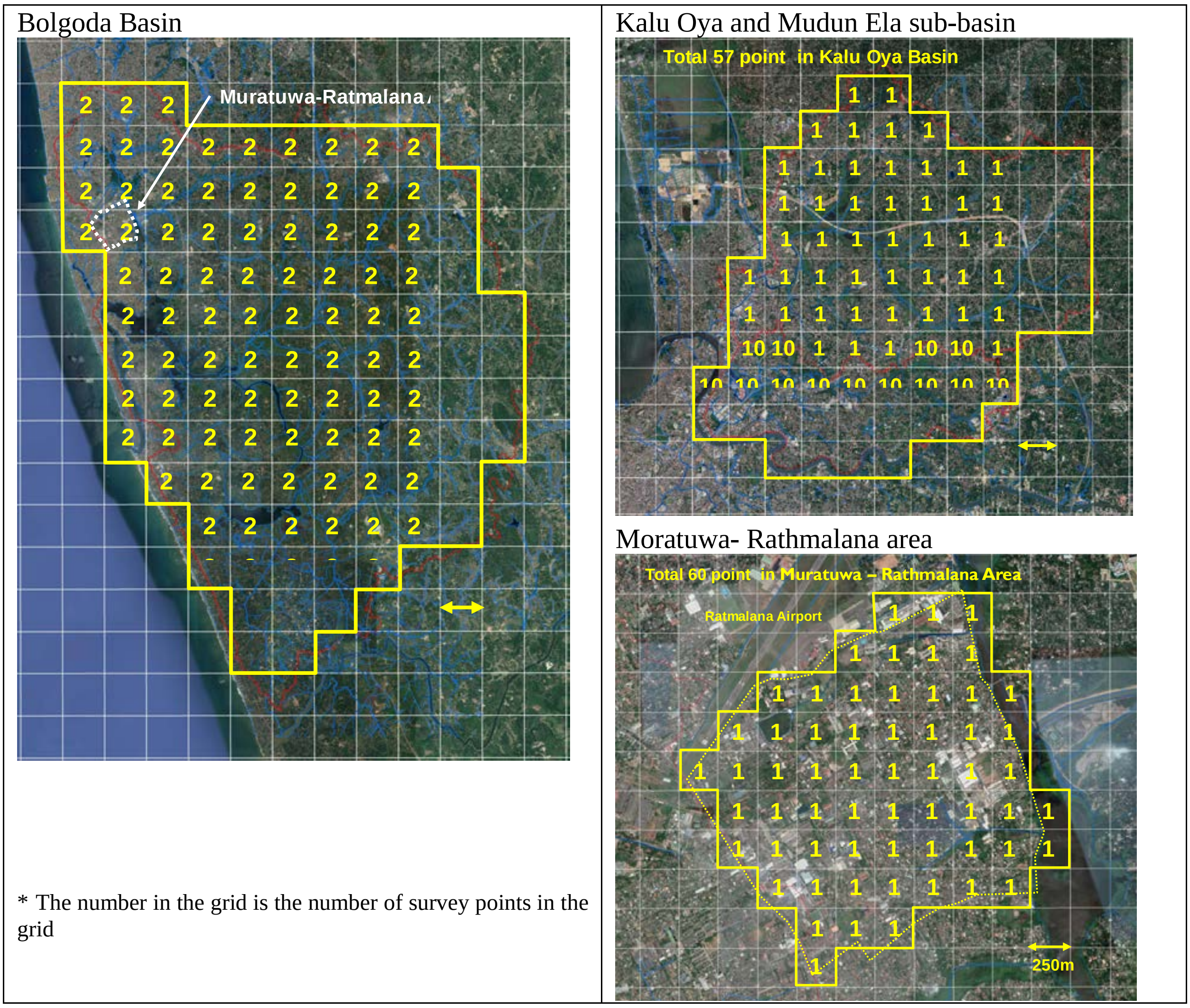
3.2.1 Implementation Outline

As mentioned above, inundation depth or flood frequency cannot be obtained from the historical inundation area of 2010 and 2016 provided by DMC and Sentinel Asia. Therefore, a flood damage survey was conducted. The outline of the implementation is shown below.

Table 3.2.1 Outline of Flood Damage Survey

Item	Contents
Target Area	As the following figure
Number of targets	Bolgoda basin = 212, Kalu Oya basin = 57, Mudun Ela sub-basin = 230, Moratuwa - Rathmalana sub-basin = 60
Survey Period	Middle of April to the end of July
implementing agency	Moratuwa University
Purpose	• Special attention is given to "inundation frequency" and is used to consider the return period of drainage • Using for calibration of inundation analysis • In addition, survey items on the social environment were added

Source: JICA Study Team



Source: JICA Study Team

Figure 3.2.1 Scope and Quantity of Flood Damage Survey

Table 3.2.2 Survey Contents of Flood Damage Survey

No.	Contents
1. Basic information	
1	Date of survey
2	Name of Interviewer
3	Basin name of Interview point
4	Interview Point by GPS Receiver
2. Respondent detail	
1	Name of Respondent
2	Age of household head
3	Sex of household head
4	Ethnicity of household head
5	The religious belief of the household head
6	Final Education of household head Literacy of household head
3. House of detail	
1	Type of house/ building (select in 4 types)
2	Status of house ownership
3	Number of years living in the current house
4	Height of the floor from the ground
5	Maximum inundation depth from the ground
6	When the maximum inundation depth and damage occurred?
4. Frequency of Flood inundation	
1	Frequency of flood inundation
2	Experience of flood inundation
5. Impact of the 2017 flood	
1	The affected extent in 2017
2	Inundation Depth from the ground in 2017
3	Inundation Duration in 2017
4	Flood Water came from?
5	The financial cost of repairing the damage to your house/building?
6	The financial cost of repairing the damage to your household articles?
7	Inundation depth from the ground in 2017
6. Impact of the 2016 flood	
1	The affected extent in 2016
2	Inundation Depth from the ground in 2016
3	Inundation Duration in 2016
4	Flood Water came from?
5	The financial cost of repairing the damage to your house/building?
6	The financial cost of repairing the damage to your household articles?
7	Inundation depth from the ground in 2016
7. Impact of the 2010 flood	
1	The affected extent in 2010
2	Inundation Depth from the ground in 2010
3	Inundation Duration in 2010 flood
4	Flood Water came from?
5	The financial cost of repairing the damage to your house/building?
6	The financial cost of repairing the damage to your household articles?
7	Inundation depth from the ground in 2010
8. Socio-economic status	
1	Household size (number of people in the household)
2	Number of elderly (60 and over) in the household
3	Number of dependent (not working) members in the household
4	Household income (Household total)
5	Sources of main income (multiple selections of several sectors)
6	Whether the household receives any government support program
7	Commuting time to the main workplace of the household head
8	Commuting transportation to the main workplace of the household head
9	Commuting time to school (if there are school-age children in the household)
10	Commuting transportation to school (if there are school-age children in the household)
Others	
1	Site photos

Source: JICA Study Team

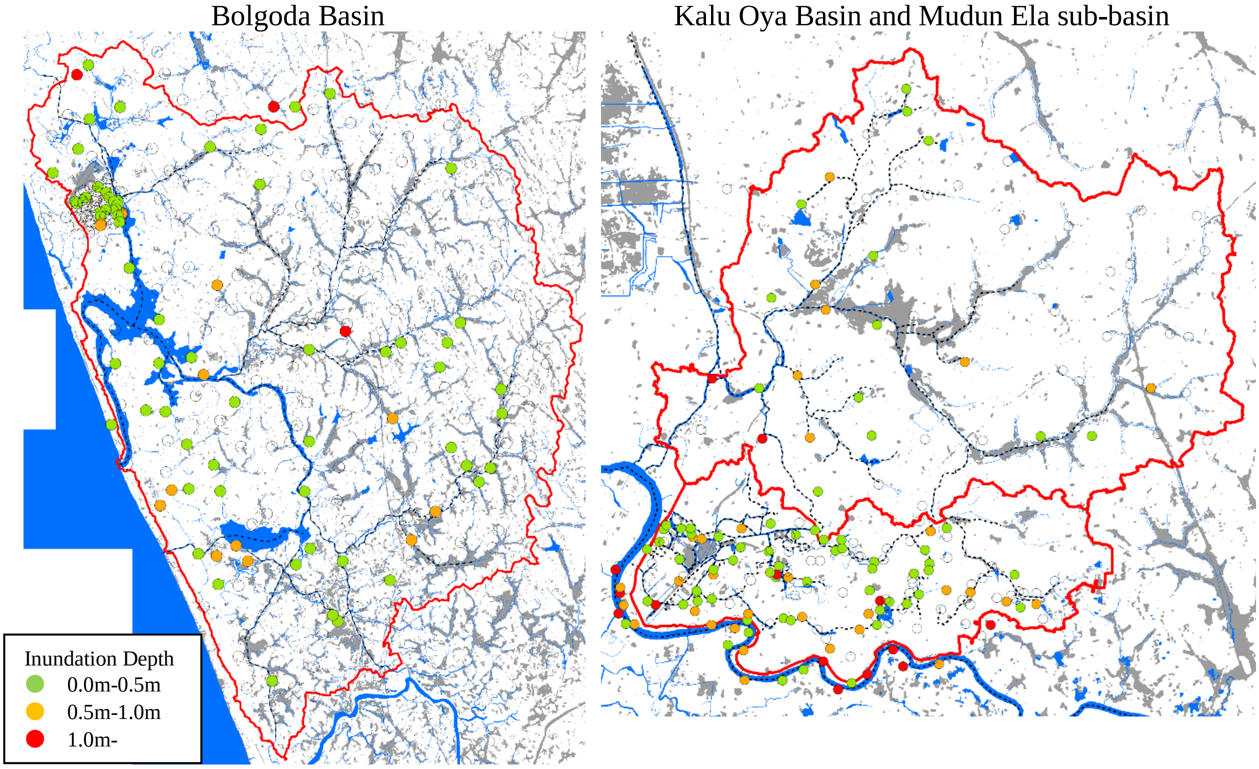
3.2.2 Summary of Results of Flood Damage Survey

The maximum inundation depth in May 2016 was shown below as a sample of the result of the flood damage survey.

Both Bolgoda and Kalu Oya basins have a wide distribution of inundation depths of 0.0 m to 0.5 m (green color) and 0.5 m to 1.0 m inundation depth (yellow color) along the Mudun Ela sub-basin and main rivers.

The low flood plains and high inundation potential along the Mudun Ela sub-basin and the main rivers show that the results of the survey are in line with actual conditions.

The flood analysis model was identified using these flood damage survey results.



Source: JICA Study Team

Figure 3.2.2 Example of Results of Flood Damage Survey

CHAPTER 4 STORM WATER DRAINAGE PLANS PROPOSED IN PREVIOUS STUDIES AND PROJECT WORKS IMPLEMENTED

4.1 Storm Water Drainage Plans Previously Proposed in the Target Two Drainage Basins

4.1.1 Study and Research History

The first study formulating a drainage improvement master plan was “the Study on Storm Water Drainage Plan for the Colombo Metropolitan Region” in 2003 (hereinafter referred to as “JICA 2003 M/P”). The plan covers four drainage basins, namely: the Ja Ela, the Kalu Oya, the Greater Colombo and the Bolgoda including Weras Ganga. Among them, the two basins, which are the Kalu Oya and the Bolgoda, are targeted ones in the current master plan study, In JICA 2003 M/P, the Weras Ganga basin whose catchment area is 56 km^2 was selected as a priority project area and its feasibility study (hereinafter referred to as “F/S”) was conducted in the M/P (hereinafter referred to as “JICA 2003 F/S”). On the other hand, the Kalu Oya basin was studied under “Consultancy Services for Feasibility Study on Storm Water Drainage and Environment Improvement Project for Kalu Oya Basin” in 2018 conducted by Sri Lankan own budget (hereinafter referred to as “2018 F/S”). The following table summarizes the target two drainage basins and previous related studies.

Table 4.1.1 Target Basins and Relevant Previous Studies

Drainage Basin		Catchment Area (km^2)	Previous Studies	Remarks
Kalu Oya Basin		58	JICA 2003 M/P & 2018 F/S	
	Mudun Ela Sub-basin	16	(not included)	Independent Basin from Kalu Oya
Bolgoda Basin		394	JICA 2003 M/P	
	Weras Ganga Sub-basin	56	JICA 2003 F/S	Uppermost Basin of Bolgoda

Source: JICA Study Team
Note: 2018 F/S was carried out by SMEC International in association with Deltares and Ocyana Consultants.

Drainage improvement works in both target drainage basins, the Kalu Oya and the Bolgoda, were proposed in the M/P or F/S as mentioned in Table 4.1.1. In both basins, the proposed drainage improvement plan components are summarized in the following clause.

4.2 Kalu Oya Drainage Basin

JICA 2003 M/P secured a 50-year flood recurrence as a safety level and selected optimum components among the conceivable alternatives as enumerated below, while 2018 F/S proposed similar components except for Muthurajawela Diversion to secure a 10-year flood. The proposed mitigation components in both plans are summarized in Table 4.2.1. Referring to flood peak discharges computed in JICA 2003 M/P and 2018 F/S, those could not be simply compared due to differences in simulation methodology and flooding process. The proposed flood mitigation components are more or less similar in both studies; the major components for flood control are channel improvement of Kalu Oya and Old Negombo canal, and conservation of wetlands as flood retarding areas.

Regarding the Muthurajawela diversion proposed in 2018 F/S, this alternative was examined in JICA 2003 M/P as well. The alternative combinations including the Muthurajawela diversion indicated a higher B/C and EIRR than the others without the diversion. The diversion channel, however, required an additional crossing of both Negombo road and Colombo-Katunayake Expressway, which would cause rather difficult technical and social problems. As a result, the above diversion alternative component was rejected for the optimum plan. At present construction of Muthurajawela Diversion becomes much more difficult compared to the situation during JICA 2003 M/P, due to the progress of urbanization.

Table 4.2.1 Flood Mitigation Components Proposed in Kalu Oya Basin by JICA 2003 M/P and 2018 F/S

Safety Level/Design Discharge and Mitigation Components	2003 JICA M/P	2018 F/S
Safety Level (24-hour Design Rainfall)	50-year (300mm)	10-year (231mm)
Design Discharge at Negombo Road Crossing	Basic Flood: 185 m^3/s Design Flood: 35 m^3/s	Basic Flood: 105 m^3/s Design Flood: 62 m^3/s
A. Channel Improvement of Kalu Oya	• 0 to 3.8 km: 50 m wide in trapezoidal cross-section • 3.8 to 5.0 km: 25 m wide in rectangular cross-section	0.0 to 5.0 km: 40 m wide in rectangular cross-section
B. Channel Improvement of Dutch Canal	0.0 to 4.5 km: 40 m wide in trapezoidal cross-section	0.0 to 5.0 km: 30 m wide in rectangular cross-section
Muthurajawela Diversion		Tunnel part: 150 m long x 20 m wide x 2.7m high reinforced concrete tunnel
Conservation of Natural Retarding Area	• Lower reaches: 360 ha • Upper reaches: 89 ha	• The total area of 684 ha: 453 ha of marsh, 96 ha of paddy, 135 ha of abandoned paddy, but 305 ha of settlement inundated • Providing footpaths along the selected wetland boundaries
Others		• Kalu Oya minor outfall improvement • Mudun Ela Diversion • Improvement of tributary convergence points (Natha and Nahena canals) • Rehabilitation of existing reservoirs (Kapua & Paralanda reservoirs)

Source: JICA 2003 M/P、2018 F/S
Notes; A and B in Mitigation Components are referring symbols for the project locations indicated in Figure 4.2.1 and Figure 4.2.2

4.2.1 Storm Water Drainage Plan Proposed in JICA 2003 M/P

The following figure shows the rehabilitation plan proposed by JICA2003M/P. The improvement proposed by JICA 2003 M/P is the rehabilitation of the channel of Kalu Oya and Old Dutch Canal, and the conservation of wetlands to maintain the retarding basin function, neither of which has been implemented.

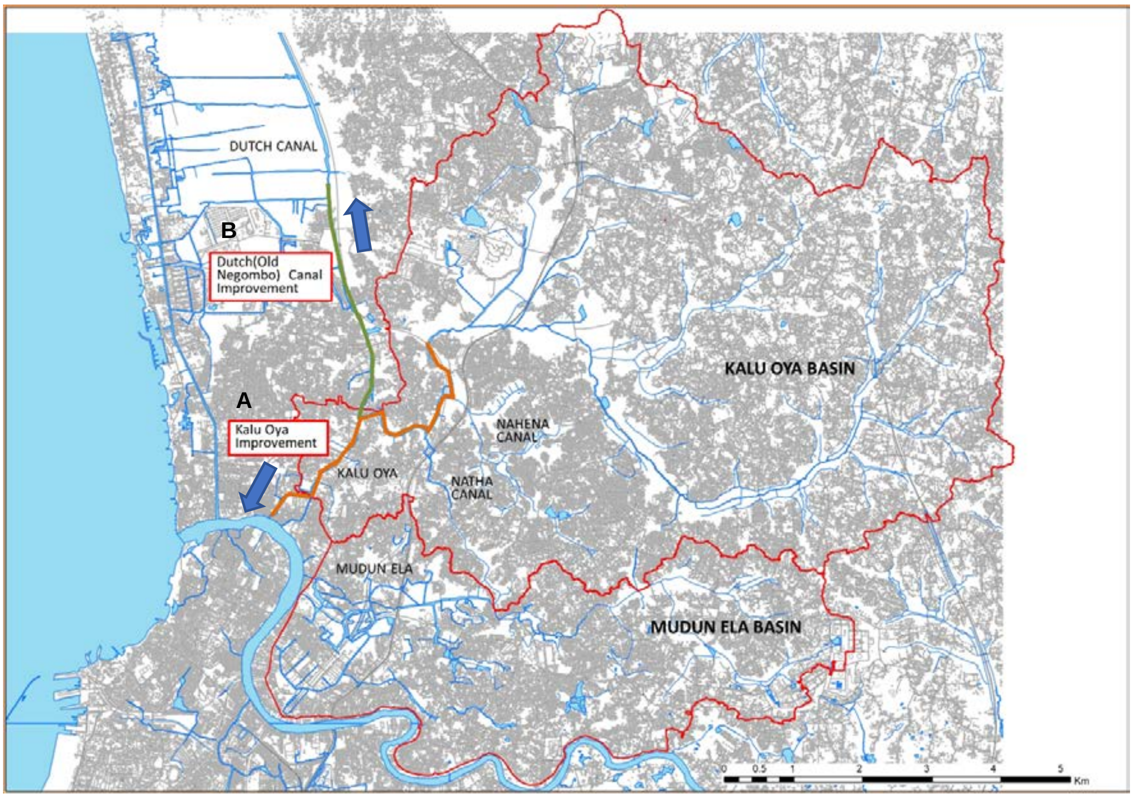


Figure 4.2.1 Flood Mitigation Components Proposed in Kalu Oya Basin by JICA 2003 M/P

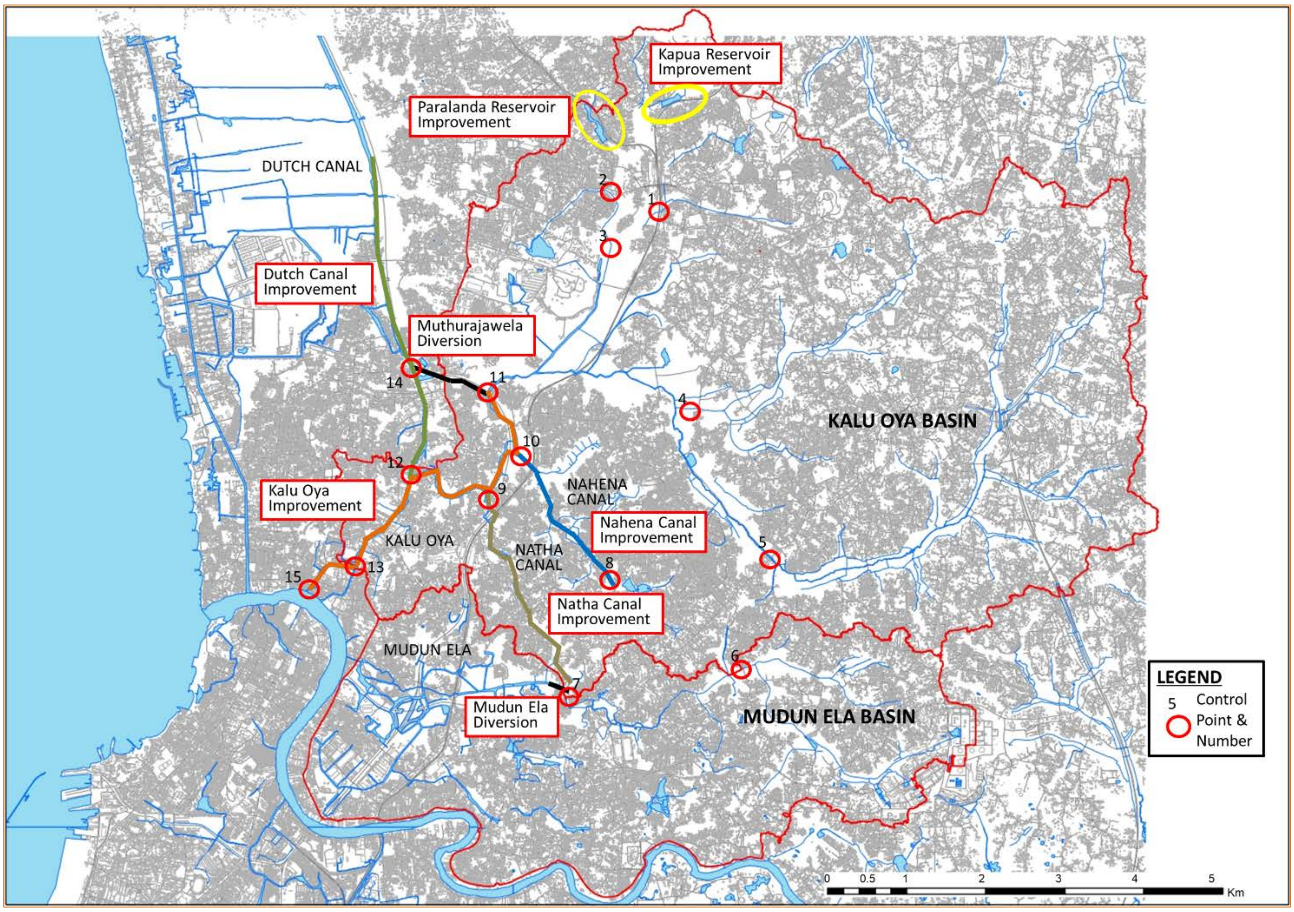
4.2.2 Evaluation of Storm Water Drainage Plan in the Kalu Oya Basin Proposed 2018 F/S

As mentioned in the previous section, in the studies of JICA2003M/P and 2018F/S, similar measures were proposed in the Kalu Oya basin as enumerated below, but none have been implemented.

- Channel improvement: Kalu Oya, Datch (Old Negombo) Canal and related tributaries (Natha Canal and Nahena Canal),
- Diversion: Muthurajawela and Mudun Ela diversions,
- Rivermouth improvement: backwater gate, drainage pump, and
- Local improvement: Channel constriction improvement of bridges and culverts, and utilization of abandoned irrigation ponds for storm water drainage.

The countermeasure works proposed in 2018F/S are shown in Figure 4.2.2. Figure 4.2.2 shows the location map and water level evaluation points of the measures proposed in 2018 F/S.

In this F/S, the improvement plan of the 25-year probability flood level was initially considered. However, it was found that the land acquisition and project costs would be excessive for the assumed conditions, and it was judged that the proposed countermeasures could not be realized. As a result, the improvement plan for 10-year probability is proposed in the final report.



Source: JICA Study Team, based on the report below
Storm Water Drainage and Environment Improvement Project for Kalu Oya Basin-Feasibility Study, SMEC, 2018

Figure 4.2.2 Drainage Improvement Components Proposed by 2018 F/S

In addition, the Mudun Ela sub-basin which is located southern side of the Kalu Oya basin is newly included in the study area and its pre-feasibility study (hereinafter referred to as "Pre-F/S") will be conducted in the study. The upper part of its basin was regarded as a part of the Kalu Oya basin in both previous studies, but such part shall be included in the Mudun Ela sub-basin because of the natural hydraulic tendency of flow directions.

Significant river improvement works in both basins have never been conducted/progressed since the formulation of JICA 2003 M/P except for the Oliyamulla pumping station at the outfall of Mudun Ela. It is under construction with 30 -35 m^3/s of pump capacity.

4.3 Bolgoda Drainage Basin

In the upper part of the Bolgoda basin, Weras Ganga sub-basin, the feasibility study was conducted in JICA 2003 M/P as a priority project. Those proposed mitigation components are summarized in Table 4.3.1.

In Weras Ganga basin, the proposed storm water drainage components have been mostly constructed following JICA 2003 F/S as presented in Table 4.3.2 and Figure 4.3.1, except for the entire Moratuwa-Ratmalana scheme and right bank flood protection of Weras Ganga scheme. They, however, become a new target scheme for the Pre-F/S in this study.

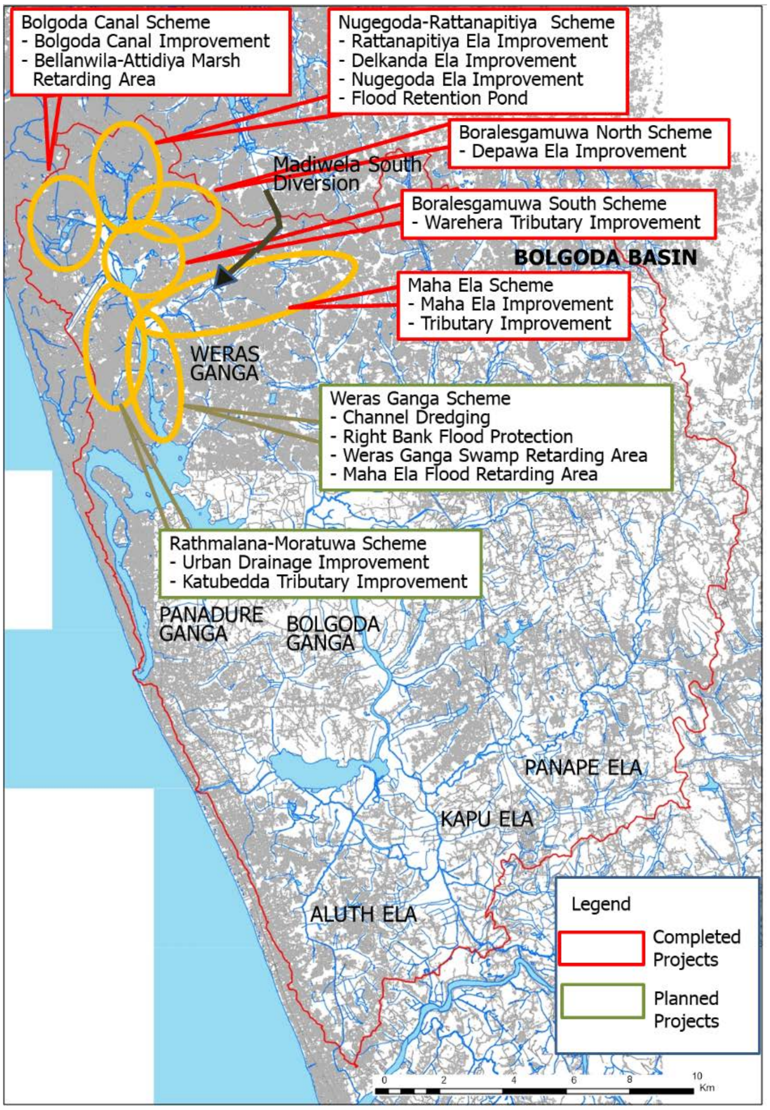
Regarding the Madiwela South Diversion Project delineated in Figure 4.3.1, it has the following shortcomings pointed out in the "Annual Report & Accounts for the Year 2017", June 2018.

1. High construction cost and difficulty in a suitable construction methodology for the diversion through the basin ridge at Pannipitiya,
2. Possible adverse hydrological impacts to Maha Ela of Weras Ganga basin, and
3. Adverse social and environmental issues.

Table 4.3.1 Target Sub-basins for Storm Water Drainage Plan of the Weras Ganga Basin and their Planning Scales Proposed by JICA 2003 M/P

Mitigation Scheme	Target river	Safety Level (24-hour Design Rainfall)	Basic Discharge	Design Discharge
Nugegoda-Rattanapitiya Scheme	Rattanapitiya Ela	10-year (201 mm)	71 m^3/s	52 m^3/s
	Delkanda Ela	10-year (201 mm)	37 m^3/s	29 m^3/s
	Nugegoda Ela	10-year (201 mm)	34 m^3/s	24 m^3/s
Bolgoda Canal Scheme	Bolgoda Canal	10-year (201 mm)	106 m^3/s	51 m^3/s
Boralesgamuwa North Scheme	Depawa Ela	2-year (137 mm)	-	-
Boralesgamuwa South Scheme	Werahera Tributary	2-year (137 mm)	-	-
Rathmalana-Moratuwa Scheme	Urban Drainage	2-year (137 mm)	-	-
Maha Ela Scheme	Maha Ela	10-year (201 mm)	185 m^3/s	185 m^3/s
Weras Ganga Scheme	Weras Ganga	50-year (258 mm)	312 m^3/s	164 m^3/s

Source : JICA 2003 M/P



Source: JICA Study Team

Figure 4.3.1 Storm Water Drainage Components Proposed in Weras Ganga Basin by JICA 2003 M/P and their Progress

Table 4.3.2 Storm Water Drainage Schemes of the Weras Ganga Basin Proposed by JICA 2003 M/P

Mitigation Scheme	Proposed Works
Nugegoda-Rattanapitiya Scheme	• Rattanapitiya Ela Improvement: Channel dredging and widening (L=2,130 m) • Delkanda Ela Improvement: Channel dredging and widening (L=1,760 m) • Nugegoda Ela Improvement: Channel dredging and widening (L=1,580 m) • Flood Retention Pond (A=36 ha)
Bolgoda Canal Scheme	• Bolgoda Canal Improvement: Channel dredging and widening (L=2,400 m) • Bellanwila-Attidiya Marsh Retarding Area (A=108 ha)
Boralesgamuwa North Scheme	• Depawa Ela Improvement: Channel dredging and widening (L=3,090 m)
Boralesgamuwa South Scheme	• Werahera Tributary Improvement: Channel dredging and widening (L=980 m)
Rathmalana-Moratuwa Scheme	• Urban Drainage Improvement: Revetment (L=11,120 m) and retention ponds (A=13 ha) • Katubedda Tributary Improvement: Channel dredging and widening (L=1,250 m)
Maha Ela Scheme	• Maha Ela Improvement: Channel dredging and widening (L=2,700 m) • Tributary Improvement: Channel dredging and widening (L=1,760 m)
Weras Ganga Scheme	• Dredging: (L=5,500 m) • Right Bank Flood Protection: (L=2,300m) • Weras Ganga Swamp Retarding Area: 65 ha • Maha Ela Flood Retarding Area: 106 ha

Source: JICA 2003 M/P

4.3.1 Implementation Issues on Storm Water Drainage Plan Proposed by JICA 2003 M/P

As mentioned in Chapter 1 (see Figure 1.1.1), JICA 2003 M/P study formulated the storm water drainage master plan for the four basins of Ja Ela, Kalu Oya, Greater Colombo and Bolgoda in the Colombo metropolitan area, from north to south. Among these four basins, the F/S was conducted for the Weras Ganga basin, which is the most urbanized area of the Bolgoda basin. Following the F/S results, D/D was carried out with the support of China. After its completion, the drainage improvement project was commenced in 2013 with the own funds of the GOSL, and the project is still in progress. The total project cost of Weras Ganga was estimated at 14.2 billion LKR. For example, out of SLLDC's annual budget of 4.3 billion LKR in 2018, 1.9 billion LKR was allocated to the Weras Ganga project.

Of the four basins, in the Greater Colombo basin located in the central part of the metropolitan area, as described in 2.7.1, MCUDP was started in 2012 with the support of the World Bank, and the project is scheduled to be completed in 2020. So far the basins under unimplemented drainage projects were Ja Ela, Kalu Oya and Bolgoda other than the Weras Ganga. These basins are located slightly away from the center of the metropolitan area. However, the Ja Ela Basin is currently being incorporated into the World Bank-supported CRIP to implement F/S.

In order to implement storm water drainage measures, there is an approach of taking financial measures and slowly proceeding with the project within the annual budget of SLLDC, but as shown in the improvement projects of Weras Ganga, the investment amount to be allocated is limited. Alternatively, it may be most practical to seek a solution for F/S, D/D and the project implementation with the support of MDB (World Bank, ADB, etc.) or a donor country.

CHAPTER 5 HYDROLOGICAL AND HYDRAULIC ANALYSIS

5.1 Basic Policy of Rainfall Analysis

The design rainfall duration, design rainfall and design hyetograph which were the design condition for drainage measures, was examined.

In this study, daily rainfall data at 36 points in the target basin (of which 2 points include short-term rainfall at the Colombo and Rathmalana stations) and rainfall intensity formulas at the Colombo and Rathmalana stations were collected.

When short-term rainfall is widely observed in the target basin, it is appropriate to use short-term rainfall for all studies of rainfall analysis, but short-term rainfall data is available only at Colombo and Rathmalana stations (refer to Appendix).

In addition, as a result of discussions with C/P, it was found that the observed daily rainfall varied in accuracy and was unreliable depending on the location. As a result, the design rainfall duration, design rainfall, and design hyetograph were determined according to the policy shown in Table 5.1.1. Note that the study results related to rainfall analysis using daily rainfall are treated as reference values.

Table 5.1.1 Summary of Discussion on Rainfall Analysis

Item	Contents of discussion with C/P (proposal from the study team)	Conclusion (discussion results)
Design Rainfall Duration	- As the representative station, Colombo station was selected. - Selected major hydrograph based on historical flood damage data. - Confirmed the rainfall time distribution and duration from the actual hyetograph	- Design rainfall duration was determined to be one (1) day.
Design Rainfall	- Comparison between 24-hour accumulated rainfall of hourly rainfall data and daily rainfall. - There is no big difference between 24-hour accumulated rainfall and daily rainfall, and most series of rainfall fall within the observation period of daily rainfall. - Daily rainfall is used to calculate design rainfall (probable rainfall)	- Some observation values in the target basin have low observation accuracy and low reliability (C/P recognition). Therefore, it is not appropriate to use daily rainfall data
	- It is not appropriate to apply the actual rainfall waveform of Colombo Observatory because the rainfall characteristics of Colombo Station and each target basin (Karuoya Basin and Borgoda Basin) are different. - To consider the regional distribution of rainfall, calculate the basin mean rainfall using the Thiessen method and use it to estimate the probable rainfall.	- The missing period of daily rainfall is relatively long in the target basin, and it cannot be judged that the estimated values represent the basin. - -Some observation values in the target basin have low observation accuracy and low reliability (C/P recognition). Therefore, it is not appropriate to use daily rainfall data
	- Design rainfall was set using the rainfall intensity formula at Colombo station and Rathmalana station. At that time, multiply by an appropriate area reduction factor. - Refer to the setting method of the area reduction coefficient used in previous studies of MCUDP etc.	- Set design rainfall using rainfall intensity formulas at Colombo and Ratumalaana stations
Design Hyetograph	- Extraction of major hydrograph from short-term rainfall data at Colombo Station and selection of model hyetograph with appropriate time distribution from runoff calculation - Creating a concentrated hyetograph using rainfall intensity formulas at Colombo and Rathmalana stations.	- The design hyetograph is a concentrated hyetograph using rainfall intensity formulas at Colombo and Rathmalana stations.

Source: JICA Study Team

5.2 The Setting of Design Rainfall

5.2.1 Design Rainfall Duration

Using the hourly rainfall at the Colombo station, 33 major rainfall events of recent years (1990-2018) were extracted. The extraction rules are shown below. In addition, the top 10 rainfalls of the extracted cumulative rainfall of 33 rainfalls will be used for the examination of the design hydrograph described later. The top 10 hyetographs are shown in Figure 5.2.1 and Figure 5.2.2.

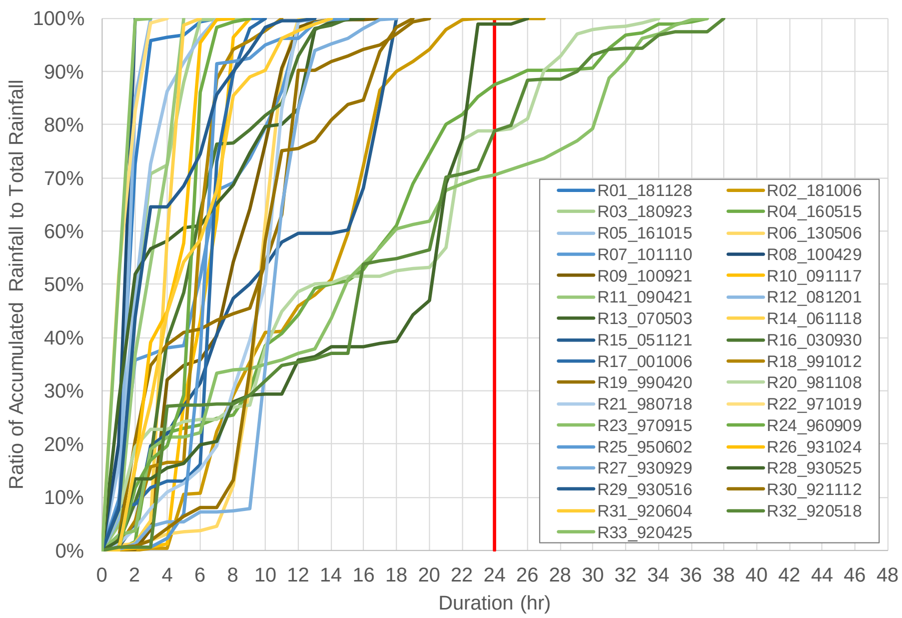
- It is defined as a series of floods of up to no rain for two consecutive hours. Extraction of rainfall events in which cumulative rainfall of a series of floods exceeds 100 mm.

The mass curve of extracted 33 rainfalls is shown in Figure 5.2.1. Except for the 4 rainfalls, the design rainfall duration was set to 24 hours (1 day) because a series of rainfalls converged within 24 hours.

Table 5.2.1 Major Rainfall Events (Colombo Station)

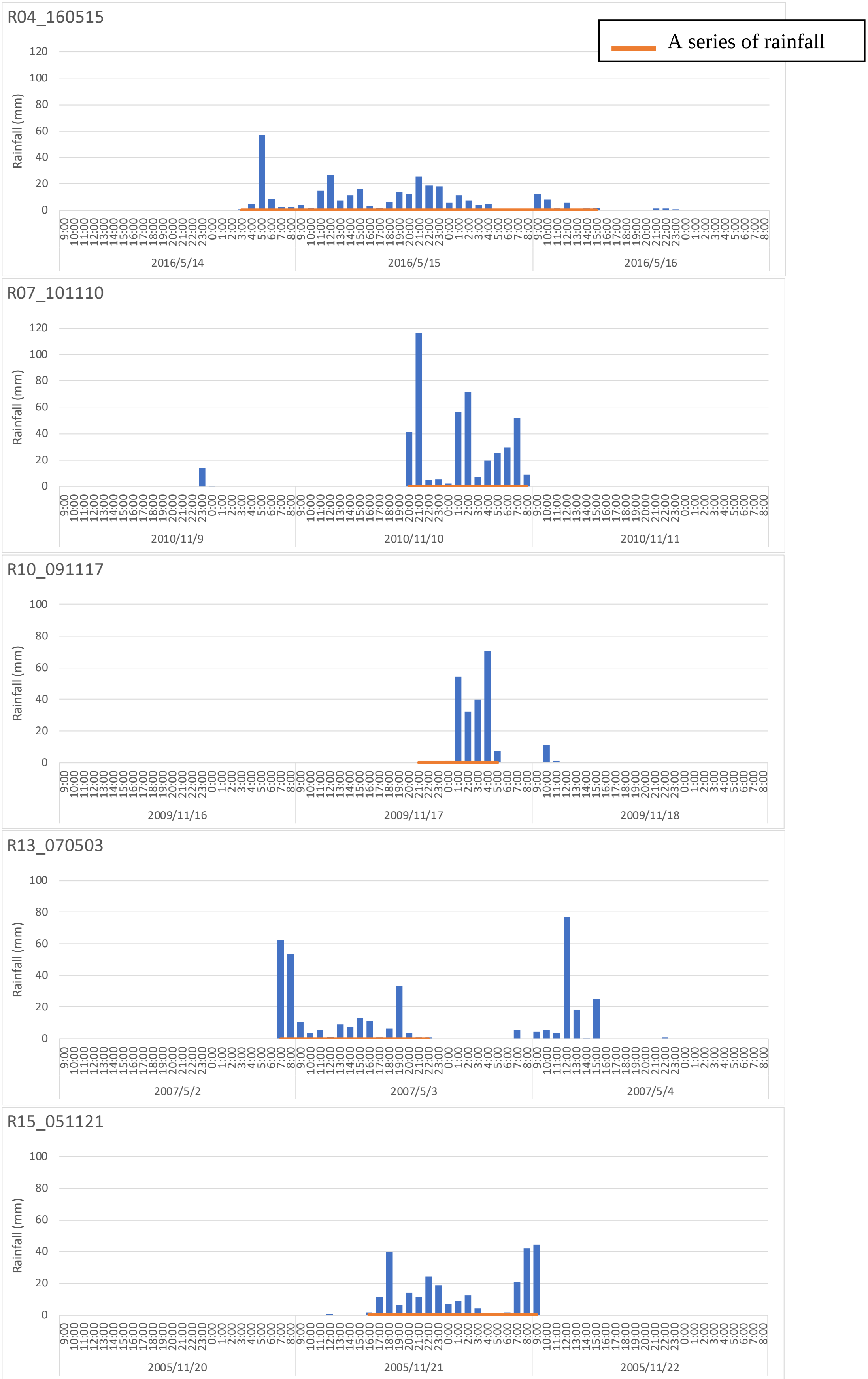
No.	Date	Rainfall duration	Accumulated rainfall	Rank
R01	2018/11/28	10	117.0	27
R02	2018/10/6	28	130.1	18
R03	2018/9/23	9	109.2	32
R04	**2016/5/15**	**38**	**322.8**	**3**
R05	2016/10/15	8	124.7	19
R06	2013/5/6	14	134.3	16
R07	**2010/11/10**	**13**	**440.2**	**2**
R08	2010/4/29	2	117.1	26
R09	2010/9/21	17	124.6	20
R10	**2009/11/17**	**9**	**207.0**	**7**
R11	2009/4/21	5	137.4	15
R12	2008/12/1	3	100.9	33
R13	**2007/5/3**	**16**	**224.0**	**6**
R14	2006/11/18	6	118.8	24
R15	**2005/11/21**	**18**	**269.8**	**5**
R16	2003/9/30	15	110.5	31
R17	2000/10/6	10	163.0	11
R18	1999/10/12	12	114.9	30
R19	**1999/4/20**	**20**	**279.9**	**4**
R20	1998/11/8	34	139.1	14
R21	1998/7/18	13	131.8	17
R22	1997/10/19	4	117.2	25
R23	**1997/9/15**	**37**	**186.1**	**9**
R24	1996/9/9	9	122.3	23
R25	1995/6/2	15	115.0	29
R26	1993/10/24	8	158.4	12
R27	**1993/9/29**	**18**	**177.3**	**10**
R28	1993/5/25	26	156.3	13
R29	1993/5/16	13	115.4	28
R30	1992/11/12	19	122.9	22
R31	**1992/6/4**	**14**	**483.9**	**1**
R32	**1992/5/18**	**38**	**193.8**	**8**
R33	1992/4/25	3	123.7	21

Source: JICA Study Team



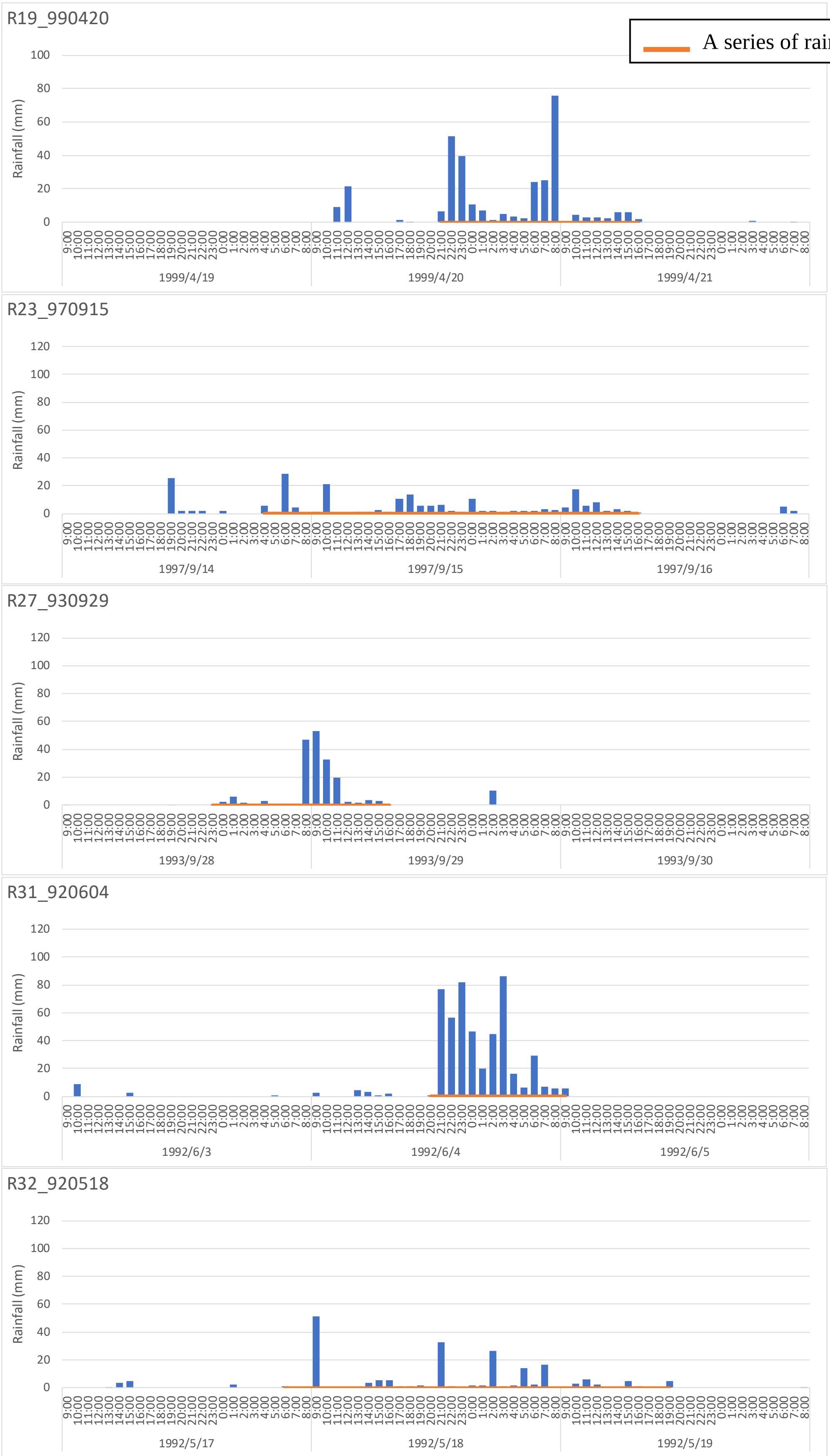
Source: JICA Study Team

Figure 5.2.1 Mass Curve



Source: JICA Study Team

Figure 5.2.2 Hourly Rainfall at Major Rainfall Events (Colombo Station, 1/2)



Source: JICA Study Team

Figure 5.2.3 Hourly Rainfall at Major Rainfall Events (Colombo Station, 2/2)

5.2.2 Design Rainfall

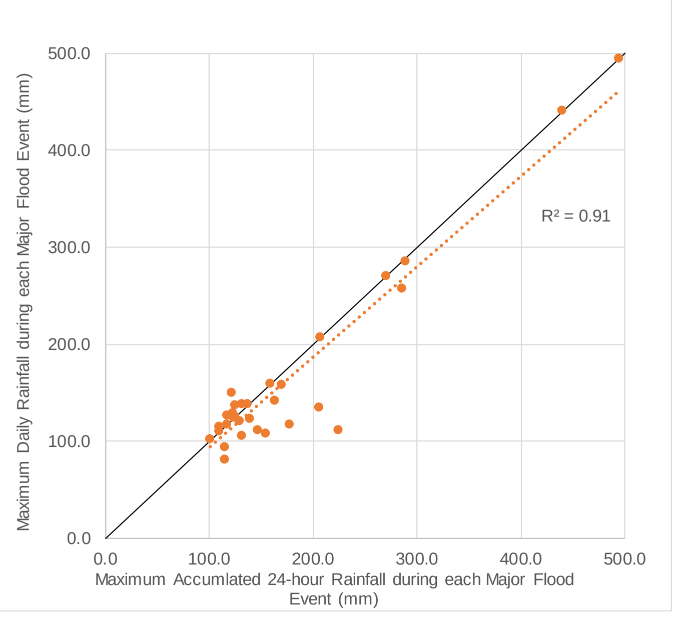
5.2.2.1 Policy Setting for Design Rainfall

(1) Application of Daily Rainfall Data to Study Design Rainfall

Figure 5.2.4 shows the correlation diagram between maximum rainfall for 24-hour rainfall and daily rainfall for the 33 rainfall events (Table 5.2.1) extracted in the study of design rainfall duration.

As shown in Figure 5.2.4, there is a certain correlation between the maximum 24-hour rainfall calculated from hourly data and the daily rainfall on that day.

Therefore, it was proposed that the daily rainfall be used for the study of design rainfall in the target basin, and the initial study was conducted.



Source: JICA Study Team

Figure 5.2.4 Correlation Diagram Between Maximum Rainfall for 24-hour Rainfall and Daily Rainfall

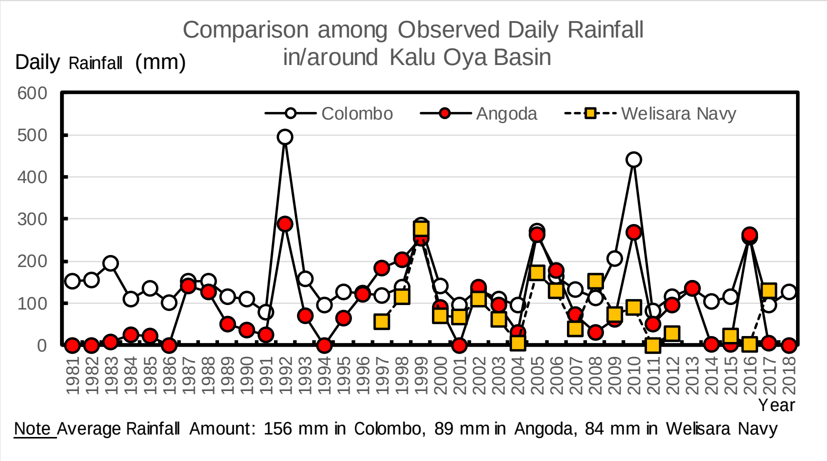
(2) Applicability of Calculation of Basin Mean Rainfall and its Application to Design Rainfall by Thiessen Method

In this study, the design rainfall in each basin will be examined by statistical analysis using basin mean rainfall calculated by the Thiessen method.

On the other hand, at 2018 F/S, the Colombo station was used as the representative observatory, and probable rainfall using the rainfall intensity formula was multiplied by an Area Reduction Factor (ARF) to obtain the design rainfall in the Kalu Oya basin.

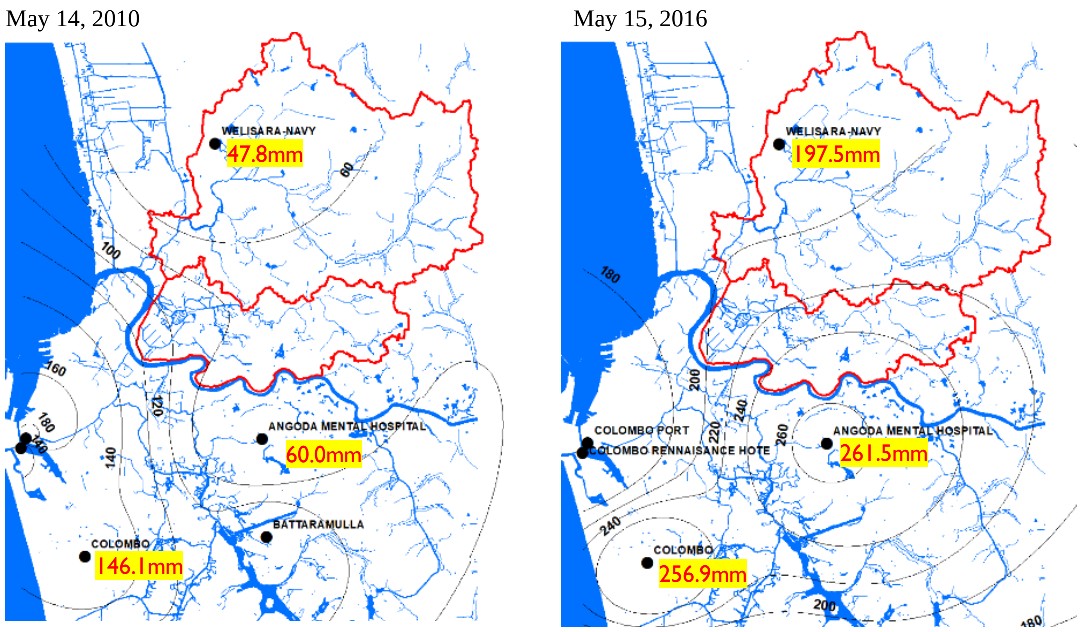
Although it is expected that the same method will be used in this study, it was judged that the Colombo station could not represent the Kalu Oya basin and the Mudun Ela sub-basin for the following reasons, and statistical analysis using the basin mean rainfall was proposed to calculate the design rainfall.

- As shown in Figure 5.2.5, the annual maximum daily rainfall around the Kalu Oya basin varies greatly, and the rainfall at the Colombo station near the coast tends to be relatively large.
- As shown in Figure 5.2.6, the regional distribution of daily rainfall on major flood days (May 14, 2010, May 15, 2016) shows that the rainfall on the coast or south of the Kalu Oya basin tends to be large.



Source: JICA Study Team

Figure 5.2.5 Comparison of Annual Maximum Daily Rainfall at Kalu Oya Basin



Source: JICA Study Team

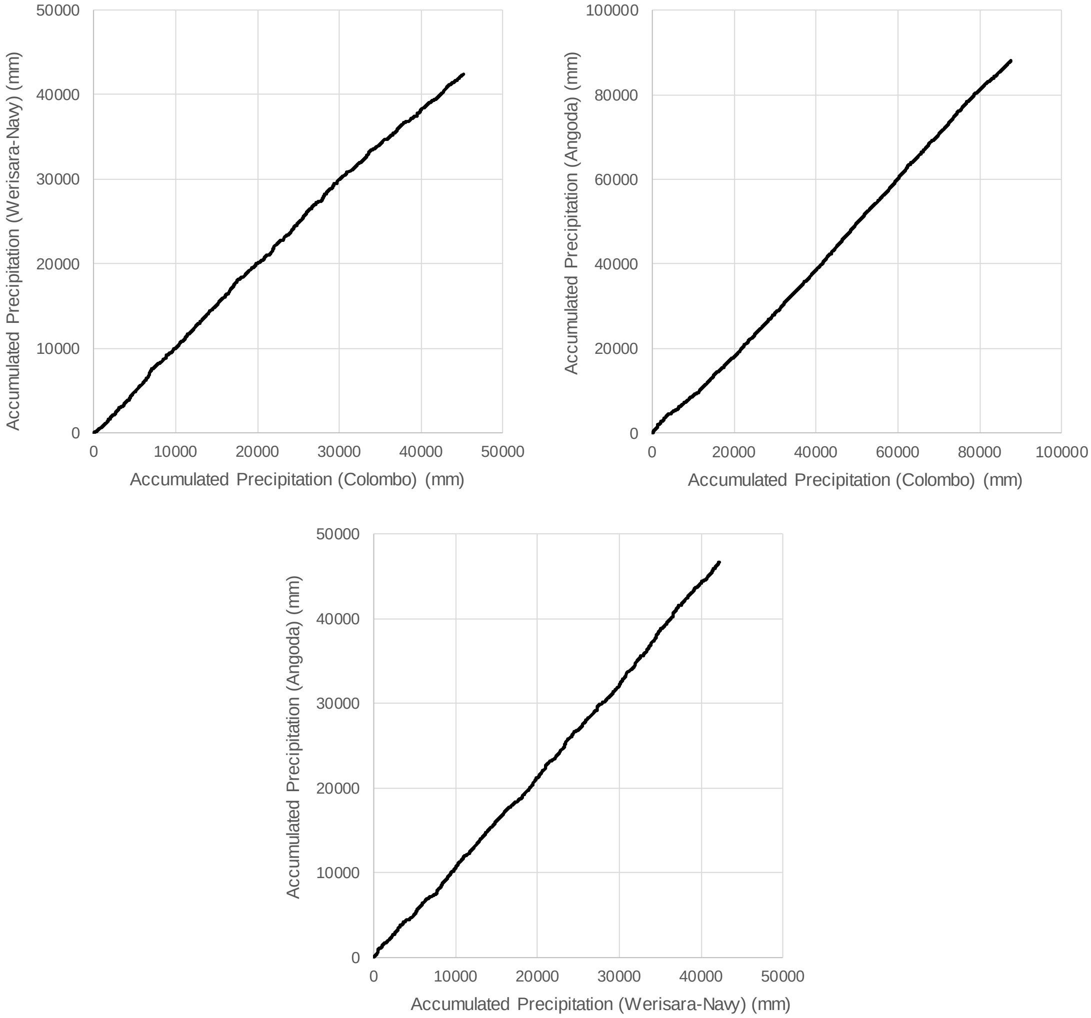
Figure 5.2.6 Regional Distribution of Daily Rainfall During Major Floods

(3) Observation Accuracy of Daily Rainfall

The rainfall stations used to calculate basin mean rainfall are managed by the Meteorological Department, and it is expected that a certain level of observation accuracy will be secured.

As a reference for accuracy verification, the daily rainfall double mass curve is shown in Figure 5.2.7 using daily rainfall data from Colombo, Angoda and Werisara stations from 1981 to 2018.

The relationship between each observatory is extremely good, and it is assumed that the observation accuracy is secured without any change in the observing status over time or errors in the observed values.



Source: JICA Study Team

Figure 5.2.7 Double Mass Curve

(4) Background to the Decision to Design Rainfall Study

Based on the above (1) to (3), as a method generally implemented in Japan, we proposed a method for studying design rainfall using basin mean rainfall based on daily rainfall and presented the results of this study.

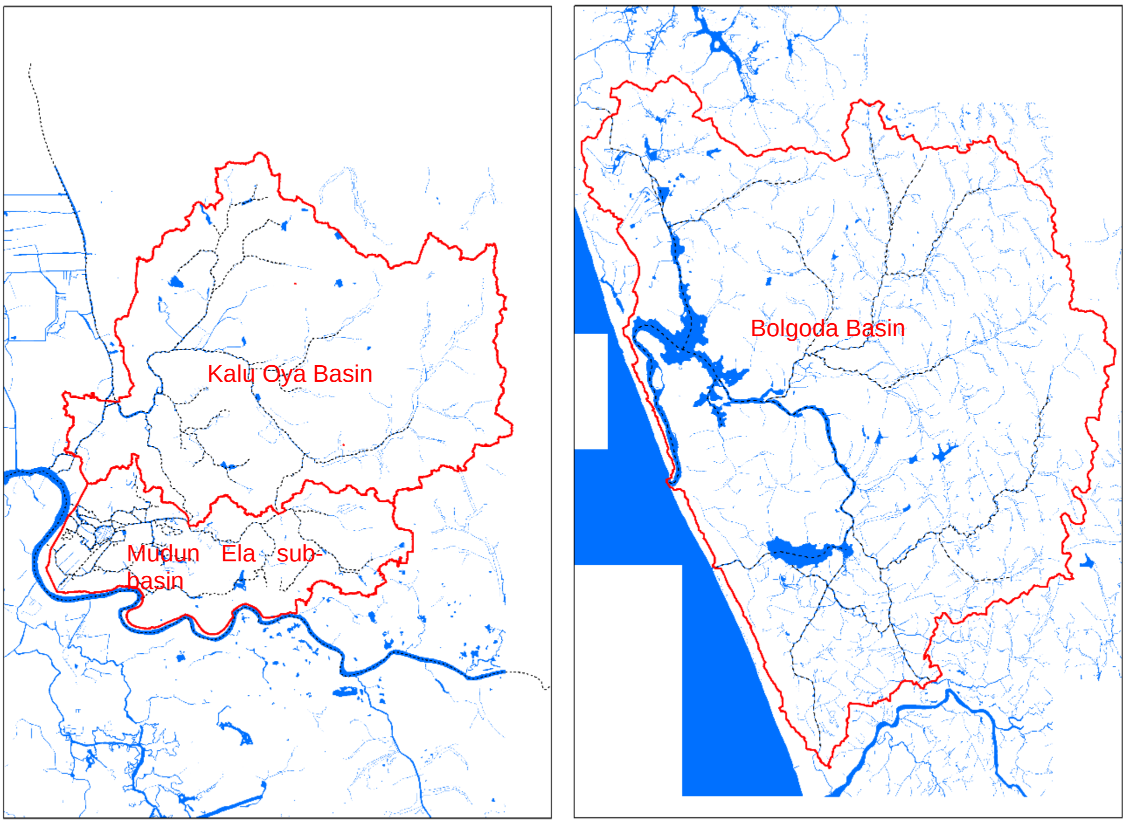
However, as a result of discussions with the C/P, the design rainfall was calculated based on the rainfall intensity formula of the Colombo station for the Kalu Oya basin and Mudun Ela sub-basin and based on the rainfall intensity formula of the Rathmalana station for the Bolgoda basin.

- The stations for daily rainfall managed by the Meteorological Department are manual observations, the management system in normal times is not good, and the observation accuracy is low (common recognition of C/P)
- Since the period during which rainfall is considered during the study period (1981-2016) is also relatively long, the basin mean rainfall is calculated in only two or three points in many years. The accuracy of calculating basin mean rainfall is not high.

5.2.2.2 Basin Boundary Data

Regarding the basin boundary data used to calculate the basin mean rainfall (reference Value) and runoff calculation, the Kalu Oya basin and Mudun Ela sub-basin obtained the boundary data set by SLLDC using the latest LiDAR data.

The Bolgoda basin was modified in this study using LiDAR data based on the boundary data set by JICA 2003 M/P.



Source: JICA Study Team

Figure 5.2.8 Basin Boundary Data

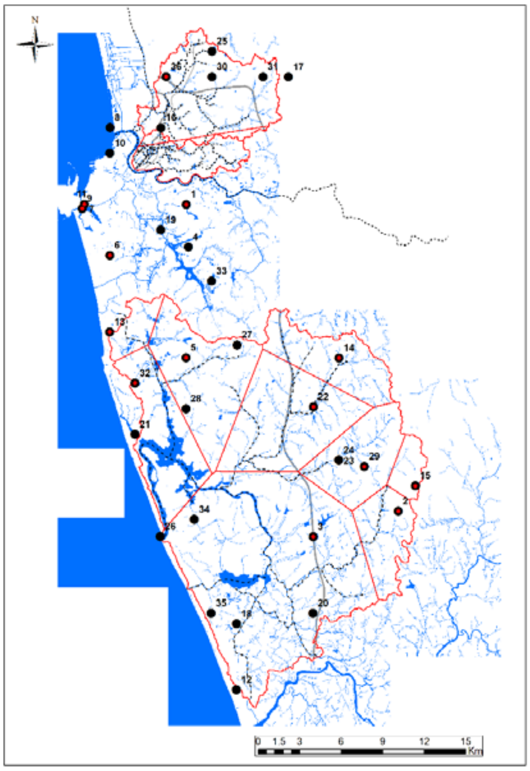
5.2.2.3 Basin Mean Rainfall (Reference Value)

The basin mean rainfall in the Kalu Oya and Bolgoda basins was calculated by the Thiessen method. Among the rainfall data of 36 stations within the target range, 19 stations (refer to Appendix) with good data existence were used.

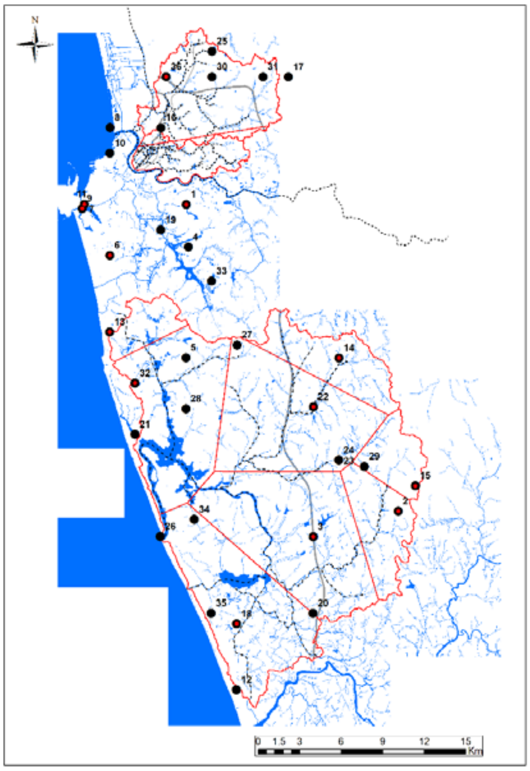
In addition, in each year from 1981 to 2018 (38 years), the Thiessen coefficient of one pattern each year was calculated according to the existence of data to calculate basin mean rainfall.

Figure 5.2.9 shows the Thiessen division diagram for 2004 and 2016 as an example.

Figure 5.2.10 shows the secular change of the calculated daily average rainfall in the basin and Table 5.2.2 shows the annual maximum daily rainfall in the basin.



2004



2016

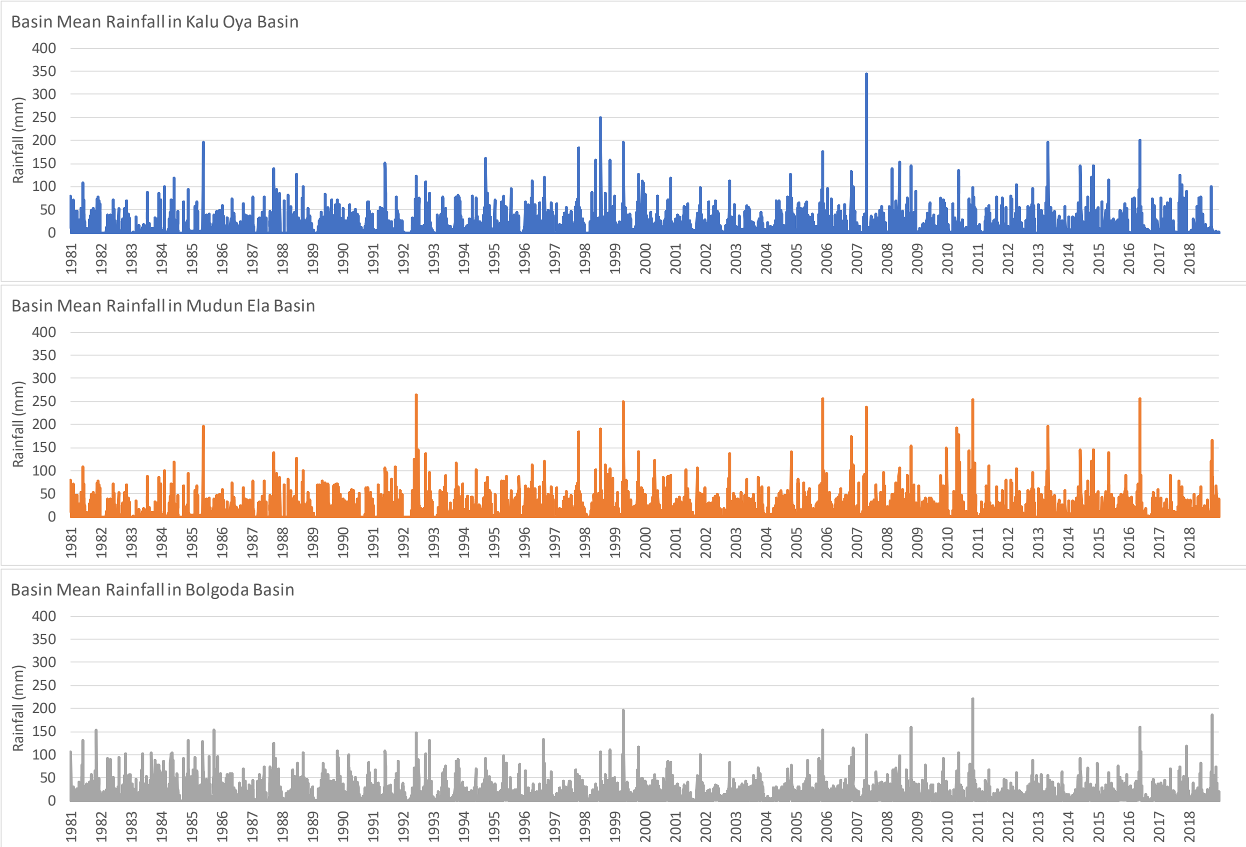
Source: JICA Study Team

Figure 5.2.9 Thiessen Split Diagram (2004 and 2016)

Table 5.2.2 Maximum Annual Basin Mean Rainfall (mm/day)

No	Kalu Oya basin		Mudun Ela sub-basin		Bolgoda basin	
	Date	Rainfall (mm)	Date	Rainfall (mm)	Date	Rainfall (mm)
1	1981/5/28	107.4	1981/5/28	107.4	1981/11/9	153.4
2	1982/5/29	70.9	1982/5/29	70.9	1982/10/26	101.2
3	1983/7/19	87.6	1983/7/19	87.6	1983/9/6	104.7
4	1984/5/30	117.4	1984/5/30	117.4	1984/11/19	129.6
5	1985/5/19	195.6	1985/5/19	195.6	1985/9/24	154.1
6	1986/5/1	73.2	1986/5/1	73.2	1986/9/14	68.2
7	1987/9/23	139.7	1987/9/23	139.7	1987/9/23	123.9
8	1988/6/25	127.0	1988/6/25	127.0	1988/9/12	104.5
9	1989/6/3	82.6	1989/4/26	77.9	1989/10/28	108.7
10	1990/11/6	67.9	1990/11/1	63.5	1990/3/10	99.6
11	1991/5/31	152.0	1991/9/29	108.8	1991/5/31	108.8
12	1992/6/5	121.4	1992/6/4	263.8	1992/6/4	146.7
13	1993/10/20	80.7	1993/9/29	115.2	1993/10/24	89.4
14	1994/9/29	161.1	1994/5/27	101.9	1994/9/28	91.3
15	1995/7/25	95.7	1995/6/2	88.2	1995/5/5	98.0
16	1996/9/9	120.5	1996/9/9	120.5	1996/8/22	133.5
17	1997/10/19	184.0	1997/10/19	184.0	1997/9/15	66.9
18	1998/7/19	250.0	1998/7/18	189.1	1998/11/8	110.5
19	1999/4/20	196.3	1999/4/20	248.6	1999/4/20	195.4
20	2000/11/7	118.7	2000/5/3	123.3	2000/10/6	86.0
21	2001/10/26	97.0	2001/9/21	106.5	2001/10/26	99.8
22	2002/10/19	111.3	2002/10/19	135.9	2002/10/16	82.7
23	2003/5/11	58.4	2003/9/30	86.1	2003/9/30	72.0
24	2004/10/26	126.5	2004/11/1	140.4	2004/11/1	77.9
25	2005/11/21	176.1	2005/11/21	255.2	2005/11/21	154.0
26	2006/10/27	132.1	2006/10/27	173.1	2006/11/18	114.7
27	2007/5/3	344.4	2007/5/3	237.3	2007/5/3	143.2
28	2008/6/1	153.1	2008/10/21	153.3	2008/10/20	160.2
29	2009/10/18	75.2	2009/12/26	148.0	2009/11/17	91.8
30	2010/5/15	134.8	2010/11/10	253.4	2010/11/10	221.2
31	2011/8/23	77.3	2011/5/24	109.2	2011/5/25	67.3
32	2012/4/14	104.2	2012/4/14	104.2	2012/10/31	88.1
33	2013/5/7	195.3	2013/5/7	195.3	2013/10/16	63.8
34	2014/10/31	145.9	2014/10/31	145.9	2014/6/1	92.3
35	2015/5/10	114.9	2015/5/9	137.9	2015/9/3	75.1
36	2016/5/15	200.4	2016/5/15	256.6	2016/5/15	160.1
37	2017/9/13	123.8	2017/5/25	90.5	2017/11/29	119.2
38	2018/9/24	99.9	2018/10/7	166.3	2018/10/6	185.4
Maximum	2007/5/3	344.4	1992/6/4	263.8	2010/11/10	221.2
Minimum	2003/5/11	58.4	1990/11/1	63.5	2013/10/16	63.8
Average	-	132.1	-	144.7	-	114.3

Source: JICA Study Team



Source: JICA Study Team

Figure 5.2.10 Annual Change of Basin Mean Rainfall

5.2.2.4 Probable Rainfall (Reference Value)

Probable rainfall was calculated by statistical analysis using the calculated basin mean rainfall and the point rainfalls at Colombo and Rathmalana stations.

As the probability distribution model, a model with a high degree of conformity was applied according to the following policy using the 13 typical probability distribution models shown in Table 5.2.4

< Probability rainfall calculation policy >

- Probable rainfall was calculated using the 13 probability distribution models shown in Table 5.2.5, and the stability of the Jackknife method was evaluated.
- Priority is given to Gumbel (Gumbel Distribution), SqrtEt (Square-root Exponential Type Maximum Distribution), and Gev (Extreme Value Distribution) based on the extreme value theory, which is generally said to have a good fit, and SLSC is 0.04 or less. And the smallest one was selected.
- If the above does not apply, select the probability distribution with SLSC of 0.04 or less from other probability distributions and select the one with the smallest estimation error due to the stability evaluation of the Jackknife method.

Table 5.2.3 Calculation Condition of Probable Rainfall

Item	Contents
Sample	1981 ~ 2018 (total of 38 years)
Site	- Kalu Oya, Mudun Ela, Bolgoda Basin - Colombo and Rathmalana rainfall gauging station
Rainfall Duration	1-Day
Software	JICE Model, Japan (*Suimon Toukei Utility*, Ver. 1.5)

Source: JICA Study Team

Table 5.2.4 List of Probability Distribution Model

NO.	Probability Distribution Model	
1.	Exp	Exponential Distribution
2.	Gumbel	Gumbel Distribution
3.	SqrtEt	Square-root Exponential Type Maximum Distribution
4.	Gev	Extreme Value Distribution
5.	LP3Rs	Peason Type III Distribution (Real Space)
6.	LogP3	Peason Type III Distribution (Logarithmic Space)
7.	Iwai	Iwai Method
8.	IshiTaka	Ishihara・Tahase Method
9.	LN3Q	Log-normal Distribution (Quantile Method)
10.	LN3PM	Log-normal Distribution 3 (Slade II)
11.	LN2LM	Log-normal Distribution 2 (Slade I, L-moment method)
12.	LN2PM	Log-normal Distribution 2 (Slade I, Product moment method)
13	LN4PM	Log-normal Distribution 4 (Slade IV, Product moment method)

Source: JICE (Japan Institute of Country-ology and Engineering)

Table 5.2.5 Result of Probable Rainfall

Return Period	Basin Mean Rainfall			Point Rainfall	
	Kalu Oya	Mudun Ela	Bolgoda	Colombo	Ratmalana
2	119.3	135.5	107.8	126.5	136.3
3	141.6	160.8	124.3	148.4	160.9
5	168.3	188.3	142.6	179.9	191.6
10	204.5	221.6	165.7	233.6	235.8
20	241.7	252.1	187.8	304.7	284.4
25	253.9	261.5	194.8	332.3	301.2
30	264.1	269.0	200.5	356.9	315.3
50	293.1	289.6	216.4	436.8	357.1
100	333.6	316.4	237.9	576.7	419.2
SLSC*1	0.025	0.037	0.023	0.034	0.027
Adopted Probability Distribution models	Gev	LN4PM	Gumbel	Gev	Gev

**1 : SLSC = Standard Least Squares Criterion*
Source: JICA Study Team

5.2.2.5 Comparison of Probable Rainfall with Past Studies (Reference)

The calculated probable rainfall was compared with the past study results (Table 5.2.6).

Since the calculation method is the same for this study and JICA 2003 M/P, the probable rainfalls are almost the same. On the other hand, it is far from 2018 F/S.

Table 5.2.6 Comparison of Probable Rainfall with the Past Studies

Return Period	Kalu Oya				Bolgoda	
	2003 JICA M/P	2018 F/S		This Study	2003 JICA M/P	This Study
		Without ARF	With ARF			
2	130.0	155.3	139.7	119.3	103.0	107.8
5	184.0	225.2	202.6	168.3	137.0	142.6
10	220.0	256.4	**230.7**	204.5	160.0	165.7
25	266.0	368.7	331.8	**253.9**	188.0	194.8
50	300.0	483.9	**435.4**	**293.1**	210.0	**216.4**
100	-	634.7	571.3	333.6	-	237.9

Source: JICA Study Team

Table 5.2.7 Result of Probable Rainfall (Basin Mean Rainfall)

Basin Mean Rainfall of Kalu Oya Basin

Item	Return Priod	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM	LN4PM
Probable Rainfall	2	113.9	123.1	118.9	119.3	－	118.8	－	－	118.4	－	－	－	－
	3	138.0	146.1	141.0	141.6	－	141.4	－	－	141.4	－	－	－	－
	5	168.4	171.7	167.4	168.3	－	168.4	－	－	168.8	－	－	－	－
	10	209.6	203.9	203.5	204.5	－	204.7	－	－	205.2	－	－	－	－
	20	250.8	234.8	241.0	241.7	－	241.9	－	－	241.9	－	－	－	－
	25	264.1	244.6	253.5	253.9	－	254.1	－	－	253.8	－	－	－	－
	30	274.9	252.6	263.9	264.1	－	264.2	－	－	263.6	－	－	－	－
	50	305.3	274.8	293.8	293.1	－	293.1	－	－	291.4	－	－	－	－
	100	346.5	304.7	336.4	333.6	－	333.6	－	－	329.9	－	－	－	－
Estimated Error of Jack Knife Method	2	7.2	8.1	7.6	8.1	－	8.2	－	－	6.8	－	－	－	－
	3	10.0	11.1	9.9	9.9	－	10.1	－	－	8.8	－	－	－	－
	5	14.6	15.1	13.1	13.0	－	13.4	－	－	13.5	－	－	－	－
	10	21.4	20.4	17.9	20.1	－	20.9	－	－	23.2	－	－	－	－
	20	28.4	25.7	23.3	31.2	－	32.1	－	－	36.4	－	－	－	－
	25	30.7	27.4	25.1	35.7	－	36.5	－	－	41.3	－	－	－	－
	30	32.6	28.7	26.6	39.7	－	40.4	－	－	45.5	－	－	－	－
	50	37.9	32.6	31.2	52.6	－	52.6	－	－	58.5	－	－	－	－
	100	45.1	37.8	37.8	74.3	－	72.8	－	－	78.8	－	－	－	－
SLSC		0.035	0.043	0.026	0.025	－	0.022	－	－	0.023	－	－	－	－

Basin Mean Rainfall of Mudun Ela Sub-Basin

Item	Return Priod	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM	LN4PM
Probable Rainfall	2	124.6	134.7	130.3	133.1	136.7	－	136.8	－	135.2	－	133.8	133.8	135.5
	3	151.2	160.1	155.1	158.3	163.2	－	161.4	－	159.7	－	159.2	158.7	160.8
	5	184.7	188.4	185.1	187.0	191.3	－	187.7	－	186.4	－	188.0	186.7	188.3
	10	230.2	224.0	225.9	224.3	224.6	－	219.1	－	218.2	－	224.5	222.2	221.6
	20	275.7	258.0	268.5	261.0	254.3	－	247.5	－	246.8	－	259.9	256.4	252.1
	25	290.4	268.9	282.8	272.8	263.2	－	256.3	－	255.4	－	271.2	267.3	261.5
	30	302.4	277.7	294.5	282.5	270.4	－	263.3	－	262.4	－	280.5	276.3	269.0
	50	335.9	302.2	328.6	309.8	289.7	－	282.4	－	281.0	－	306.4	301.3	289.6
	100	381.4	335.3	377.1	347.1	314.2	－	307.2	－	304.6	－	341.9	335.4	316.4
Estimated Error of Jack Knife Method	2	8.1	8.7	8.6	10.8	11.0	－	10.3	－	15.3	－	8.6	8.6	8.8
	3	10.0	10.8	11.1	13.4	13.5	－	12.4	－	16.6	－	10.9	10.7	10.9
	5	13.1	13.5	14.7	15.6	15.2	－	14.4	－	15.9	－	14.3	13.8	13.7
	10	17.8	17.1	20.1	17.4	15.9	－	16.3	－	14.8	－	19.5	18.4	17.4
	20	22.7	20.8	26.0	18.7	15.4	－	18.1	－	19.5	－	25.2	23.5	21.1
	25	24.3	21.9	28.0	19.1	15.0	－	18.7	－	22.5	－	27.2	25.3	22.3
	30	25.6	22.9	29.8	19.6	14.8	－	19.2	－	25.5	－	28.8	26.7	23.2
	50	29.4	25.6	34.8	21.7	14.0	－	20.8	－	35.6	－	33.6	31.0	25.8
	100	34.5	29.3	42.1	26.9	13.8	－	23.5	－	52.7	－	40.5	37.1	29.2
SLSC		0.061	0.045	0.045	0.045	0.042	－	0.033	－	0.035	－	0.033	0.034	0.037

Basin Mean Rainfall of Bolgoda Basin

Item	Return Priod	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM	LN4PM
Probable Rainfall	2	101.2	107.8	105.4	106.6	108.3	106.8	108.5	108.1	104.7	108.5	108.5	108.5	－
	3	118.5	124.3	121.3	122.9	125.0	122.9	124.7	124.8	121.2	125.3	124.8	124.5	－
	5	140.2	142.6	140.3	141.7	143.2	141.4	142.2	143.1	141.1	143.6	142.7	142.0	－
	10	169.8	165.7	165.8	166.0	165.6	165.2	163.6	165.5	167.7	165.7	164.7	163.5	－
	20	199.3	187.8	192.1	190.1	186.5	188.6	183.5	186.5	194.8	186.2	185.3	183.6	－
	25	208.8	194.8	200.9	197.9	193.0	196.1	189.7	193.1	203.7	192.6	191.8	189.9	－
	30	216.5	200.5	208.1	204.2	198.3	202.3	194.7	198.4	211.1	197.7	197.0	195.0	－
	50	238.3	216.4	228.8	222.1	212.9	219.8	208.6	213.1	232.1	211.9	211.6	209.2	－
	100	267.8	237.9	258.2	246.5	232.3	243.9	226.9	232.7	261.8	230.6	231.1	228.2	－
Estimated Error of Jack Knife Method	2	5.2	5.7	5.6	6.6	6.6	6.4	6.8	6.8	5.1	6.8	5.6	5.6	－
	3	6.6	7.1	7.2	8.1	8.0	7.7	8.1	8.2	6.5	8.2	7.1	7.0	－
	5	8.8	9.1	9.3	9.6	9.6	9.3	9.4	9.6	9.1	9.6	9.3	9.0	－
	10	12.3	11.8	12.5	11.9	11.7	11.8	11.4	11.6	14.0	11.6	12.3	11.8	－
	20	15.9	14.5	16.0	15.2	14.1	15.2	14.1	14.3	20.2	14.2	15.6	14.8	－
	25	17.1	15.3	17.2	16.7	15.0	16.5	15.2	15.3	22.5	15.2	16.7	15.8	－
	30	18.1	16.1	18.2	18.0	15.9	17.7	16.1	16.2	24.5	16.1	17.6	16.6	－
	50	20.8	18.0	21.2	22.5	18.4	21.5	19.0	19.0	30.5	18.9	20.2	19.0	－
	100	24.6	20.8	25.4	30.7	22.5	27.9	23.6	23.6	39.7	23.5	23.9	22.3	－
SLSC		0.039	0.023	0.026	0.024	0.033	0.025	0.030	0.028	0.026	0.028	0.029	0.030	－

Source: JICA Study Team

Table 5.2.8 Result of Probable Rainfall (Point Rainfall)

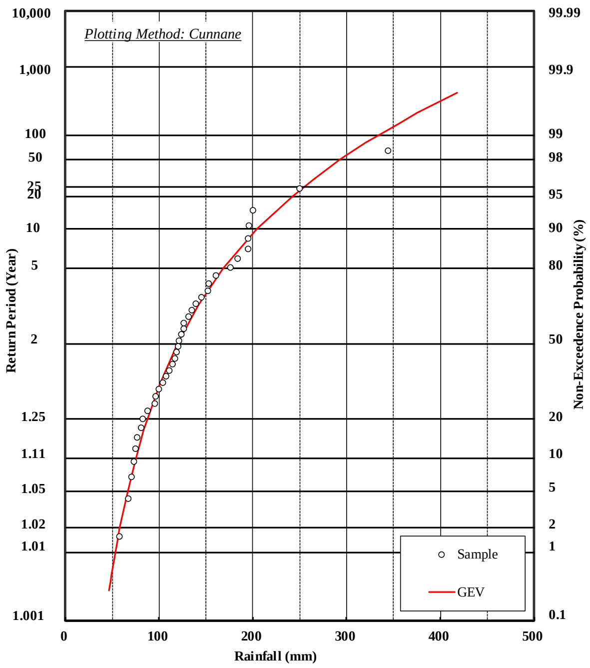
Point Rainfall at Colombo Station

Item	Return Priod	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM	LN4PM
Probable Rainfall	2	131.4	143.6	134.9	126.5	－	－	129.0	－	131.5	－	－	－	－
	3	163.4	174.1	157.3	148.4	－	－	155.0	－	157.0	－	－	－	－
	5	203.7	208.2	184.0	179.9	－	－	190.3	－	189.9	－	－	－	－
	10	258.4	250.9	220.0	233.6	－	－	244.1	－	237.6	－	－	－	－
	20	313.2	291.9	257.4	304.7	－	－	305.8	－	289.8	－	－	－	－
	25	330.8	304.9	269.7	332.3	－	－	327.5	－	307.7	－	－	－	－
	30	345.2	315.5	280.0	356.9	－	－	346.0	－	322.7	－	－	－	－
	50	385.5	345.0	309.5	436.8	－	－	401.0	－	366.5	－	－	－	－
	100	440.2	384.7	351.5	576.7	－	－	484.4	－	430.8	－	－	－	－
Estimated Error of Jack Knife Method	2	8.6	11.4	8.7	7.3	－	－	8.4	－	9.1	－	－	－	－
	3	16.4	19.1	13.0	11.3	－	－	12.8	－	13.2	－	－	－	－
	5	26.8	28.0	18.7	17.9	－	－	20.3	－	19.8	－	－	－	－
	10	41.2	39.2	26.8	30.9	－	－	33.9	－	31.8	－	－	－	－
	20	55.7	50.1	35.6	51.1	－	－	52.0	－	48.0	－	－	－	－
	25	60.4	53.5	38.6	59.8	－	－	58.9	－	54.3	－	－	－	－
	30	64.2	56.3	41.1	67.8	－	－	64.9	－	59.7	－	－	－	－
	50	75.0	64.2	48.3	96.0	－	－	83.8	－	77.1	－	－	－	－
	100	89.5	74.7	58.9	151.7	－	－	114.5	－	105.5	－	－	－	－
SLSC		0.076	0.108	0.113	0.034	－	－	0.040	－	0.040	－	－	－	－

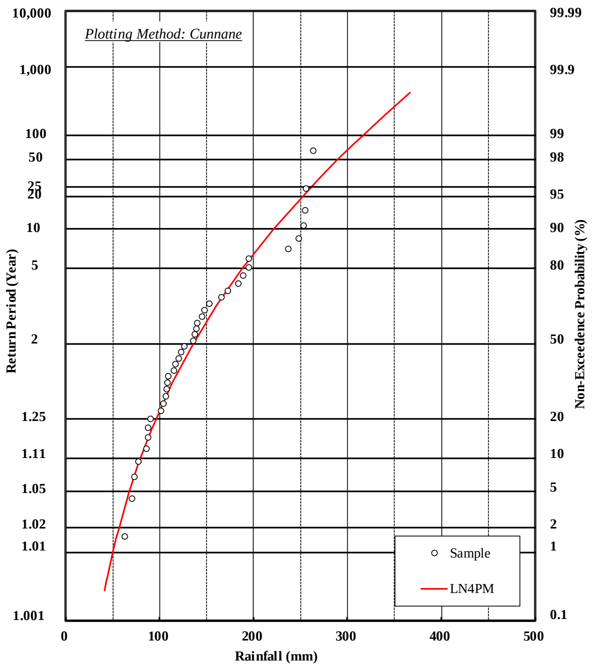
Point Rainfall at Ratmalana Station

Item	Return Priod	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM	LN4PM
Probable Rainfall	2	132.9	143.6	138.3	136.3	－	136.2	－	－	135.9	－	－	－	－
	3	160.8	170.2	162.3	160.9	－	161.3	－	－	161.7	－	－	－	－
	5	196.0	199.9	190.9	191.6	－	192.7	－	－	193.8	－	－	－	－
	10	243.8	237.2	229.9	235.8	－	237.0	－	－	238.7	－	－	－	－
	20	291.5	272.9	270.2	284.4	－	284.7	－	－	286.2	－	－	－	－
	25	306.9	284.3	283.6	301.2	－	300.9	－	－	302.2	－	－	－	－
	30	319.4	293.5	294.8	315.3	－	314.5	－	－	315.5	－	－	－	－
	50	354.6	319.2	326.8	357.1	－	354.4	－	－	354.1	－	－	－	－
	100	402.4	353.9	372.4	419.2	－	412.8	－	－	409.7	－	－	－	－
Estimated Error of Jack Knife Method	2	8.0	9.4	8.5	8.2	－	8.6	－	－	9.8	－	－	－	－
	3	12.2	13.8	11.3	10.6	－	11.4	－	－	12.3	－	－	－	－
	5	18.4	19.2	15.2	14.9	－	16.0	－	－	16.1	－	－	－	－
	10	27.5	26.2	21.0	24.2	－	25.6	－	－	23.0	－	－	－	－
	20	36.8	33.1	27.3	38.6	－	39.6	－	－	32.5	－	－	－	－
	25	39.8	35.3	29.4	44.5	－	45.1	－	－	36.1	－	－	－	－
	30	42.2	37.1	31.2	49.8	－	50.1	－	－	39.2	－	－	－	－
	50	49.1	42.2	36.5	67.4	－	66.2	－	－	49.1	－	－	－	－
	100	58.5	49.0	44.2	98.3	－	93.7	－	－	65.1	－	－	－	－
SLSC		0.041	0.059	0.043	0.027	－	0.025	－	－	0.025	－	－	－	－

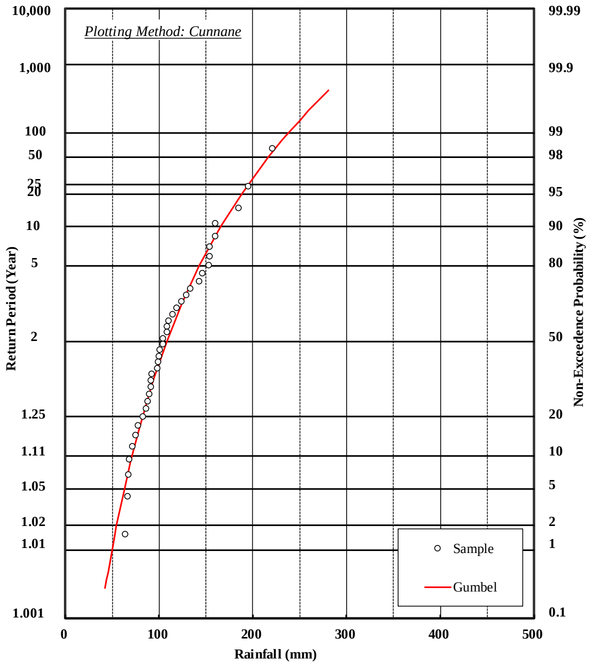
Source: JICA Study Team



Kalu Oya Basin



Mudun Ela Sub-Basin



Bolgoda Basin

Source: JICA Study Team

Figure 5.2.11 Probability Distribution Map

5.2.2.6 Relationship Between Basin Mean Rainfall and Point Rainfall (Reference)

For reference, the probable rainfall of Kalu Oya basin and the probable rainfall of Colombo station was compered.

The reduction factor is 0.67 for rainfall with a 50-year probability, which is the design scale proposed by JICA 2003 M/P.

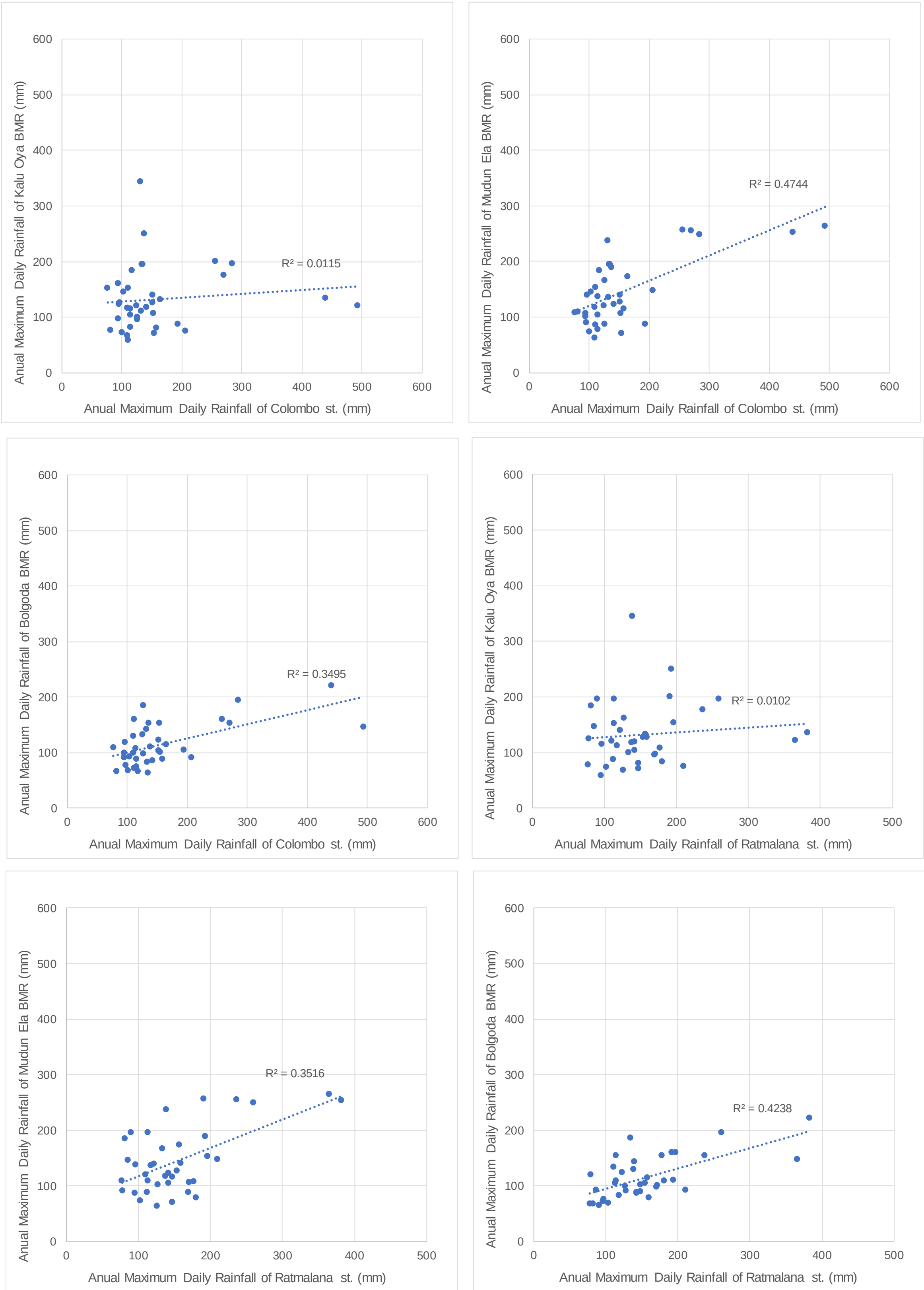
Table 5.2.9 Comparison of Basin Mean Rainfall and Point Rainfall

Return Period	Point rainfall Colombo (A)	Basin Mean Rainfall (B)	Reduction factor (B/A)
2	126.5	118.8	0.94
3	148.4	141.4	0.95
5	179.9	168.4	0.94
10	233.6	204.7	0.88
20	304.7	241.9	0.79
25	332.3	254.1	0.76
30	356.9	264.2	0.74
50	**436.8**	**293.1**	**0.67**
100	576.7	333.6	0.58

Source: JICA Study Team

Figure 5.2.12 shows the correlation diagram between the annual maximum rainfall in the three target basins and the maximum rainfall in Colombo and Rathmalana stations.

The average of each basin and the point rainfall have low correlations, and the tendency is remarkable, especially in the Kalu Oya basin and each point rainfall.



Source: JICA Study Team

Figure 5.2.12 Correlation Diagram of Annual Maximum Basin Mean Rainfall and Maximum Annual Point Rainfall in the three target basins

5.2.3 Design Hyetograph

5.2.3.1 Summary

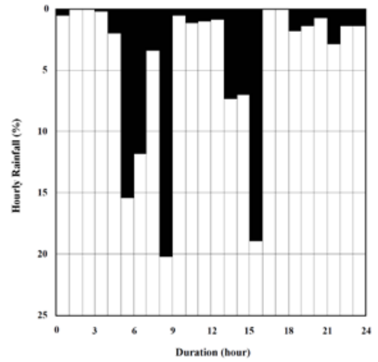
In JICA 2003 M/P, the June 1992 rainfall was selected as a model hyetograph from multiple actual rainfall patterns, and it was extended to the rainfall equivalent to the probability scale using basin mean rainfall as the design hyetograph (Figure 5.2.13). (See left figure).

On the other hand, at 2018 F/S, a concentrated hyetograph by probability scale was created using the rainfall intensity formula of the Colombo station, which was considered in the Metro Colombo Urban Development Project (MCUDP). The graph is multiplied by the area reduction factor and applied to the Kalu Oya basin.

In this study, as in the MCUDP and 2018 F/S surveys, the rainfall intensity equations at the Colombo and Rathmalana stations were used as design hyetograph, with concentrated hyetograph classified by probability scale.

However, it was judged that the calculated values of the Colombo and Rathmalana stations could not be directly applied to each basin because of the secular change in the annual maximum rainfall up to the above, the regional distribution of rainfall, and the relationship between the basin mean rainfall and the point rainfall. The area reduction factor was set with reference to the method used in MCUDP.

Design hyetograph in JICA 2003 M/P



Duration (hr)	Rainfall (%)	Duration (hr)	Rainfall (%)
1	0.54	13	0.89
2	0.00	14	7.33
3	0.00	15	6.98
4	0.18	16	18.96
5	1.97	17	0.00
6	15.38	18	0.00
7	11.81	19	1.79
8	3.40	20	1.43
9	20.21	21	0.72
10	0.54	22	2.86
11	1.16	23	1.43
12	0.98	24	1.43

The Study on Storm Water Drainage Plan for the Colombo Metropolitan Region in the Democratic Socialist Republic of Sri Lanka
JAPAN INTERNATIONAL COOPERATION AGENCY
Figure 3.3.3
Design Storm Rainfall Pattern

Design hyetograph in 2018 F/S

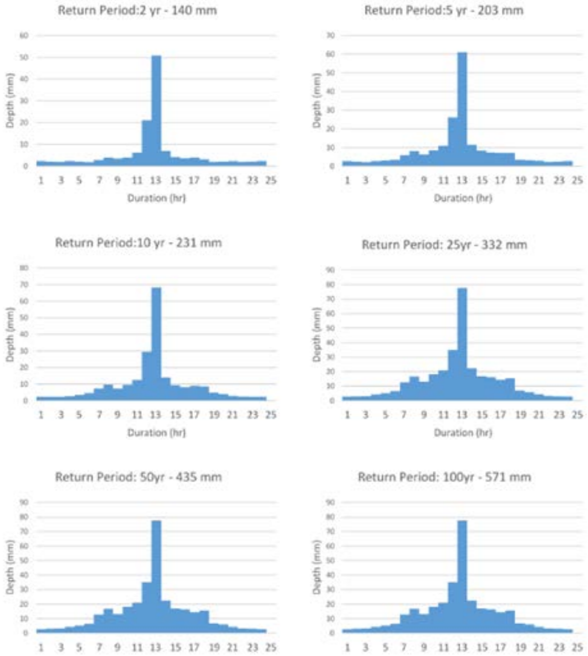


Figure 4-34: Hyetographs for Design Rainfalls

Source: JICA 2003 M/P and 2018 F/S

Figure 5.2.13 Example of Design Hydrograph in Past Studies

5.2.3.2 Area Reduction Factor

The rainfall intensity formula provided in this study was corrected by referring to the area reduction factor used in MCUDP. The outline is shown below.

MCUDP uses an area reduction factor (ARF=0.9) to convert point rainfall intensity into planar rainfall intensity. Furthermore, it has been proposed that the correction should be increased as short-term rainfall, and the following correction coefficient is multiplied according to the duration of rainfall.

Duration (hrs):	1	2	3	4	5	6	7	8	9	10	24
Reduction:	0.80	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	1.00

Source: 'CONSULTANCY SERVICES FOR CONDUCTING A DETAILED FLOOD RISK ASSESSMENT FOR COLOMBO METROPOLITAN REGION January 2017 (Deltales)'

In order to apply point rainfall to the entire basin, the area reduction factor (ARF=0.9) is multiplied by the correction factor based on the rainfall duration.

In this study, this method was adopted, and the rainfall intensity at Colombo and Rathmalana stations was corrected by multiplying the coefficients shown in Table 5.2.10.

Table 5.2.10 Correction Factor

Rainfall Duration (hr)	Time correction factor (1)	Area reduction factor (2)	(3)=(1)*(2)
1	0.80	0.90	0.72
2	0.82	0.90	0.74
3	0.83	0.90	0.75
4	0.84	0.90	0.76
5	0.85	0.90	0.77
6	0.86	0.90	0.77
7	0.87	0.90	0.78
8	0.88	0.90	0.79
9	0.89	0.90	0.80
10	0.89	0.90	0.80
11	0.90	0.90	0.81
12	0.91	0.90	0.82

Rainfall Duration (hr)	Time correction factor (1)	Area reduction factor (2)	(3)=(1)*(2)
13	0.92	0.90	0.83
14	0.93	0.90	0.84
15	0.94	0.90	0.85
16	0.95	0.90	0.86
17	0.95	0.90	0.86
18	0.96	0.90	0.86
19	0.97	0.90	0.87
20	0.98	0.90	0.88
21	0.98	0.90	0.88
22	0.99	0.90	0.89
23	1.00	0.90	0.90
24	1.00	0.90	0.90

Table 5.2.11 Rainfall Intensity Formula (without Correction Factor)

Colombo Station

$R = a\ (T - b)^c$

	2-year	5-year	10-year	25-year	50-year	100-year
a	6844.65	4383.95	2832.77	1579.57	1124.45	831.49
b	-31.22	-22.87	-15.39	-5.82	-0.83	3.49
c	-0.99	-0.88	-0.77	-0.63	-0.54	-0.46

Rainfall Intensity (mm/hr)

T (hr)	2-year	5-year	10-year	25-year	50-year	100-year
1.0	79.6	91.9	100.7	114.9	123.8	132.6
2.0	48.3	57.1	64.1	76.6	85.7	95.4
3.0	34.7	42.0	48.3	60.0	69.0	79.0
4.0	27.1	33.5	39.3	50.4	59.2	69.1
5.0	22.3	28.0	33.4	43.9	52.5	62.4
6.0	18.9	24.1	29.2	39.3	47.6	57.4
7.0	16.4	21.2	26.0	35.7	43.8	53.4
8.0	14.5	19.0	23.5	32.9	40.8	50.3
9.0	13.0	17.2	21.5	30.6	38.3	47.6
10.0	11.8	15.7	19.9	28.6	36.2	45.4
11.0	10.8	14.5	18.5	27.0	34.4	43.5
12.0	9.9	13.5	17.3	25.6	32.8	41.8
13.0	9.2	12.6	16.3	24.3	31.5	40.3
14.0	8.6	11.8	15.4	23.2	30.2	38.9
15.0	8.0	11.2	14.7	22.3	29.1	37.7
16.0	7.6	10.6	13.9	21.4	28.1	36.6
17.0	7.1	10.0	13.3	20.6	27.2	35.6
18.0	6.7	9.5	12.8	19.9	26.4	34.7
19.0	6.4	9.1	12.2	19.2	25.7	33.9
20.0	6.1	8.7	11.8	18.6	25.0	33.1
21.0	5.8	8.4	11.3	18.0	24.3	32.3
22.0	5.6	8.0	10.9	17.5	23.7	31.7
23.0	5.3	7.7	10.6	17.1	23.2	31.0
24.0	5.1	7.5	10.2	16.6	22.6	30.4

Colombo Station

Rathmalana Station

$R = a\ (T - b)^c$

	2-year	5-year	10-year	25-year	50-year	100-year
a		1513.00	1522.00	1557.00	1596.00	1647.00
b		8.00	8.10	8.30	8.50	8.60
c		-0.6795	-0.6535	-0.6270	-0.6115	-0.5994

Rainfall Intensity (mm/hr)

T (hr)	2-year	5-year	10-year	25-year	50-year	100-year
1.0	72.5	86.0	96.5	110.2	120.4	130.6
2.0	45.7	56.0	63.8	74.2	81.9	89.6
3.0	34.5	43.1	49.7	58.3	64.8	71.2
4.0	28.2	35.7	41.5	49.0	54.7	60.4
5.0	24.0	30.8	36.0	42.8	48.0	53.0
6.0	21.1	27.3	32.0	38.3	43.0	47.7
7.0	18.9	24.6	29.0	34.8	39.2	43.6
8.0	17.1	22.5	26.6	32.1	36.2	40.3
9.0	15.7	20.8	24.7	29.8	33.7	37.6
10.0	14.5	19.4	23.1	28.0	31.7	35.3
11.0	13.6	18.2	21.7	26.4	29.9	33.4
12.0	12.7	17.2	20.5	25.0	28.4	31.7
13.0	12.0	16.3	19.5	23.8	27.0	30.2
14.0	11.4	15.5	18.6	22.7	25.8	28.9
15.0	10.8	14.8	17.8	21.8	24.8	27.8
16.0	10.3	14.2	17.0	20.9	23.8	26.7
17.0	9.8	13.6	16.4	20.1	23.0	25.8
18.0	9.4	13.1	15.8	19.4	22.2	24.9
19.0	9.1	12.6	15.2	18.8	21.5	24.1
20.0	8.7	12.2	14.7	18.2	20.8	23.4
21.0	8.4	11.8	14.3	17.6	20.2	22.7
22.0	8.1	11.4	13.8	17.1	19.6	22.1
23.0	7.9	11.1	13.5	16.7	19.1	21.5
24.0	7.6	10.8	13.1	16.2	18.6	21.0

Rathmalana Station

Table 5.2.12 Rainfall Intensity Formula (with Correction Factor)

Rainfall Intensity (mm/hr)

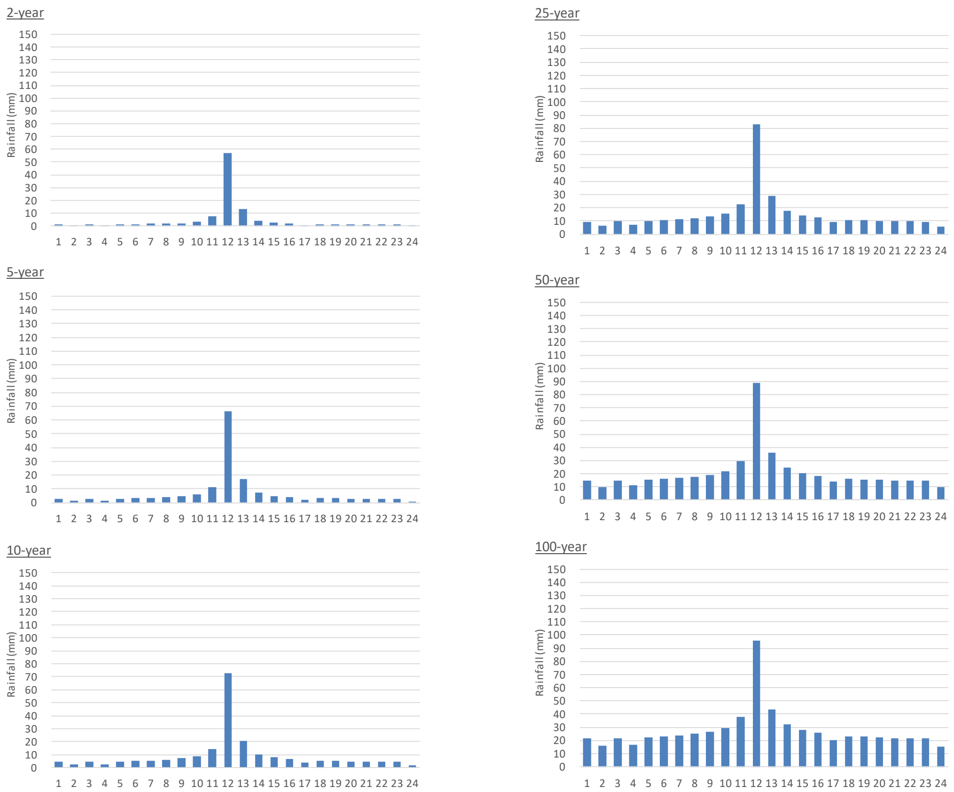
T (hr)	2-year	5-year	10-year	25-year	50-year	100-year
1.0	57.3	66.2	72.5	82.7	89.2	95.5
2.0	35.7	42.1	47.3	56.5	63.2	70.4
3.0	26.0	31.4	36.1	44.8	51.5	59.0
4.0	20.5	25.3	29.7	38.1	44.7	52.3
5.0	17.0	21.4	25.5	33.6	40.2	47.7
6.0	14.6	18.6	22.6	30.4	36.8	44.4
7.0	12.9	16.6	20.4	28.0	34.3	41.8
8.0	11.5	15.0	18.6	26.0	32.3	39.8
9.0	10.4	13.8	17.3	24.5	30.7	38.2
10.0	9.4	12.6	15.9	22.9	29.0	36.4
11.0	8.7	11.8	15.0	21.9	27.9	35.2
12.0	8.1	11.0	14.2	20.9	26.9	34.2
13.0	7.6	10.4	13.5	20.1	26.0	33.3
14.0	7.2	9.9	12.9	19.4	25.3	32.6
15.0	6.8	9.4	12.4	18.8	24.6	31.9
16.0	6.5	9.0	11.9	18.3	24.1	31.3
17.0	6.1	8.6	11.4	17.6	23.3	30.4
18.0	5.8	8.2	11.0	17.2	22.8	30.0
19.0	5.6	8.0	10.7	16.8	22.4	29.6
20.0	5.4	7.7	10.4	16.4	22.0	29.2
21.0	5.1	7.4	10.0	15.9	21.4	28.5
22.0	5.0	7.2	9.8	15.6	21.1	28.2
23.0	4.8	7.0	9.5	15.3	20.8	27.9
24.0	4.6	6.7	9.2	14.9	20.4	27.4

Colombo Station

Rainfall Intensity (mm/hr)

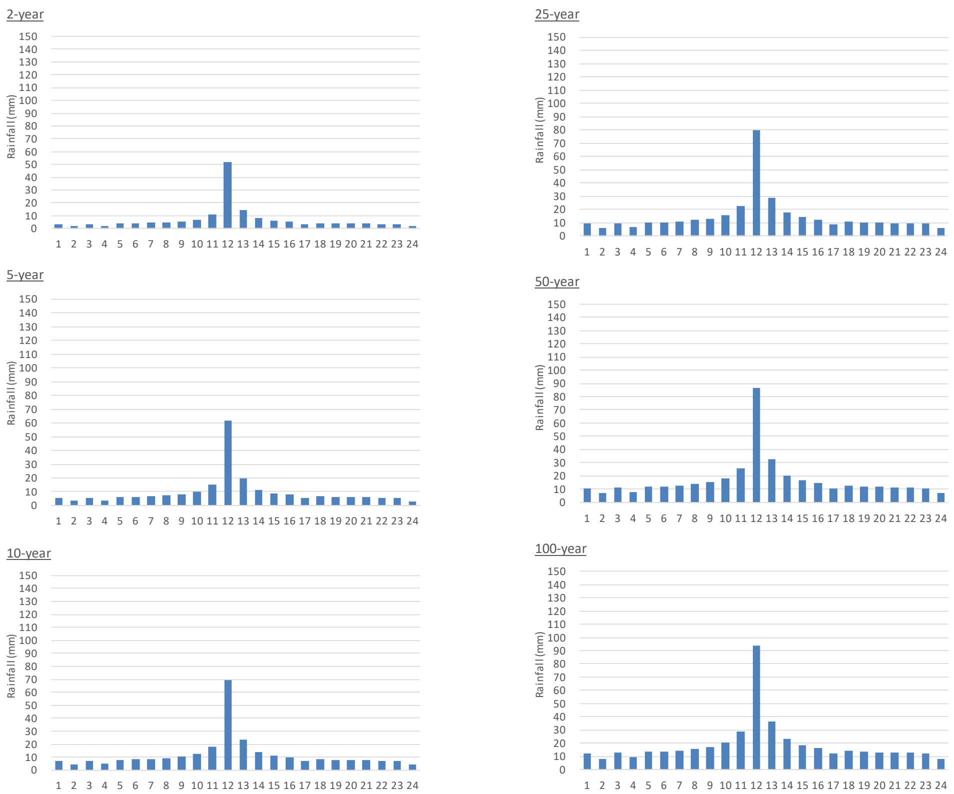
T (hr)	2-year	5-year	10-year	25-year	50-year	100-year
1.0	52.19	61.94	69.47	79.33	86.66	94.04
2.0	33.76	41.31	47.12	54.76	60.46	66.14
3.0	25.80	32.20	37.10	43.58	48.42	53.22
4.0	21.31	27.00	31.34	37.08	41.38	45.64
5.0	18.39	23.58	27.52	32.76	36.69	40.57
6.0	16.32	21.14	24.79	29.65	33.30	36.90
7.0	14.77	19.30	22.72	27.29	30.72	34.10
8.0	13.56	17.86	21.10	25.42	28.68	31.89
9.0	12.58	16.69	19.78	23.91	27.02	30.09
10.0	11.65	15.55	18.48	22.40	25.36	28.27
11.0	10.99	14.75	17.57	21.36	24.21	27.03
12.0	10.42	14.07	16.80	20.46	23.22	25.95
13.0	9.93	13.48	16.13	19.68	22.37	25.02
14.0	9.51	12.96	15.54	19.00	21.62	24.21
15.0	9.13	12.51	15.02	18.40	20.96	23.49
16.0	8.80	12.10	14.56	17.87	20.37	22.84
17.0	8.41	11.62	14.00	17.21	19.64	22.04
18.0	8.15	11.30	13.63	16.78	19.17	21.52
19.0	7.91	11.01	13.30	16.39	18.74	21.06
20.0	7.69	10.74	12.99	16.04	18.35	20.64
21.0	7.42	10.39	12.59	15.56	17.82	20.05
22.0	7.24	10.17	12.34	15.27	17.50	19.70
23.0	7.07	9.97	12.11	15.00	17.20	19.38
24.0	6.85	9.69	11.78	14.61	16.76	18.89

Rathmalana Station



Source: JICA Study Team

Figure 5.2.14 Design Hyetograph (Colombo Station)



Source: JICA Study Team

Figure 5.2.15 Design Hyetograph (Rathmalana Station)

5.3 Formation of Hydrological/Hydraulic Analysis Model

5.3.1 Basic Policy

5.3.1.1 Analysis Model

In order to understand the flood characteristics of the target basin and draft effective drainage countermeasures, a hydro-hydraulic analysis model will be constructed and studied.

The analysis model uses the MIKE series (DHI). This model consists of three parts: runoff analysis model, river network model (flood routing model), and flood inundation analysis model.

JICA 2003 M/P also uses the MIKE series in runoff analysis models and river network models. After that, SLLDC improved the analysis model provided in the same survey and used it independently for drainage planning.

In this study, the latest data such as cross-section survey, land use and elevation distribution were updated based on the analytical model constructed in 2003 and the analytical model improved by SLLDC.

Figure 5.3.1 shows the procedure for the formation of the analysis model.

1. Runoff Model (NAM Module)

- Set up sub-catchment area based on the river/canal network
- Set up design rainfall
- Runoff analysis (runoff from each sub-catchment)

↓

2. River Network Model (MIKE11)

- Preparation of latest river cross section data
- Set up initial roughness coefficient
- Modeling major river control facilities
- Set up of boundary condition

↓

3. Inundation Model (MIKE 21)

- Building floodplain model with latest ground elevation data
- Set up of roughness coefficient of floodplain considering the latest land use condition
- Modeling continuous structures (i.e. embankment of highway)

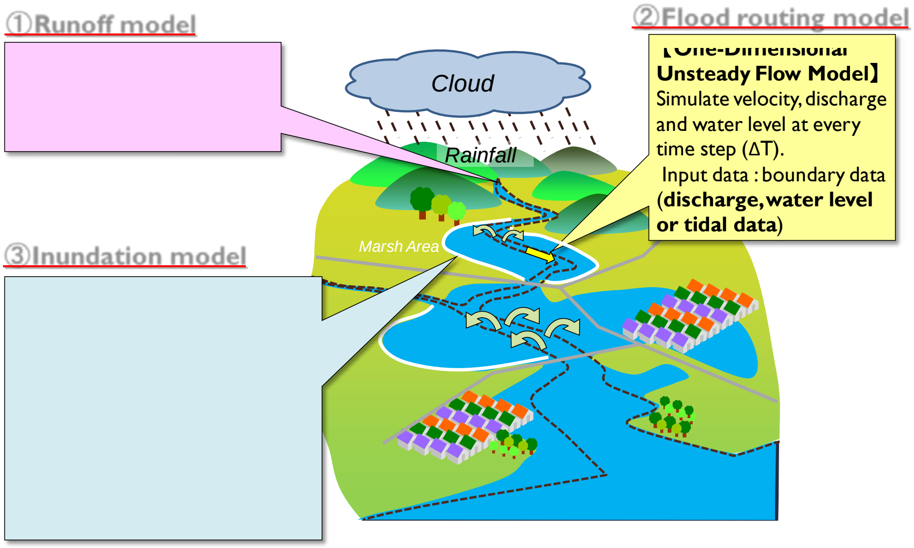
↓

4. Flood Analysis (MIKE-FLOOD)

- Building of flood analysis model
- Selection of target floods
- Collection of observed water level and inundation area/depth for model calibration.
- Execution of flood analysis and parameter fitting (roughness coefficient etc.)

Source: JICA Study Team

Figure 5.3.1 Procedure for Formation of the Analysis Model.



Source: JICA Study Team

Figure 5.3.2 Basic Concept of Hydraulic/Hydraulic Analysis Model

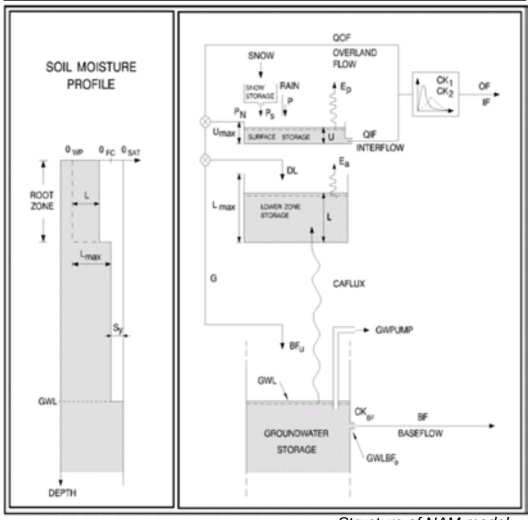
5.3.2 Run-off Analysis

The runoff from each small basin is analyzed by NAM (Nedbor-Afstromnings-Model) module which is used for long-term as well as short-term runoff.

NAM, a rainfall-runoff analysis model, is a tank-type centralized runoff model developed by the Technical University of Denmark. The runoff phenomenon is expressed by four tanks including surface flow, intermediate flow and groundwater flow, and short-term and long-term runoff phenomena can be analyzed. NAM performs rainfall-runoff analysis by continuously calculating the water content of four different tanks that are interrelated.

Run-off Analysis

NAM*: A lumped, conceptual rainfall-runoff model, simulating the overland-, inter-flow, and base-flow components as a function of the moisture contents in four storages.*



Structure of NAM model

Run-off parameters

Surface and root zone parameters	
U_{max}	Maximum water content in surface storage
L_{max}	Maximum water content in root zone storage
CQOF	Overland flow runoff coefficient
CKIF	Time constant for interflow
CK_{12}	Time constant for routing interflow and overland flow
TOF	Root zone threshold value for overland flow
TIF	Root zone threshold value for interflow
Groundwater parameters	
CK_{BF}	Baseflow time constant
TG	Root zone threshold value for groundwater recharge
CQ_{LOW}	Recharge to lower groundwater storage
CK_{LOW}	Time constant for routing lower baseflow
C_{area}	Ratio of groundwater catchment to topographical catchment area
GWL_{BF0}	Maximum groundwater depth causing baseflow
S_y	Specific yield
GWL_{FL1}	Groundwater depth for unit capillary flux

Source: JICA Study Team

Figure 5.3.3 Outline of NAM (Runoff Analysis) and Parameters

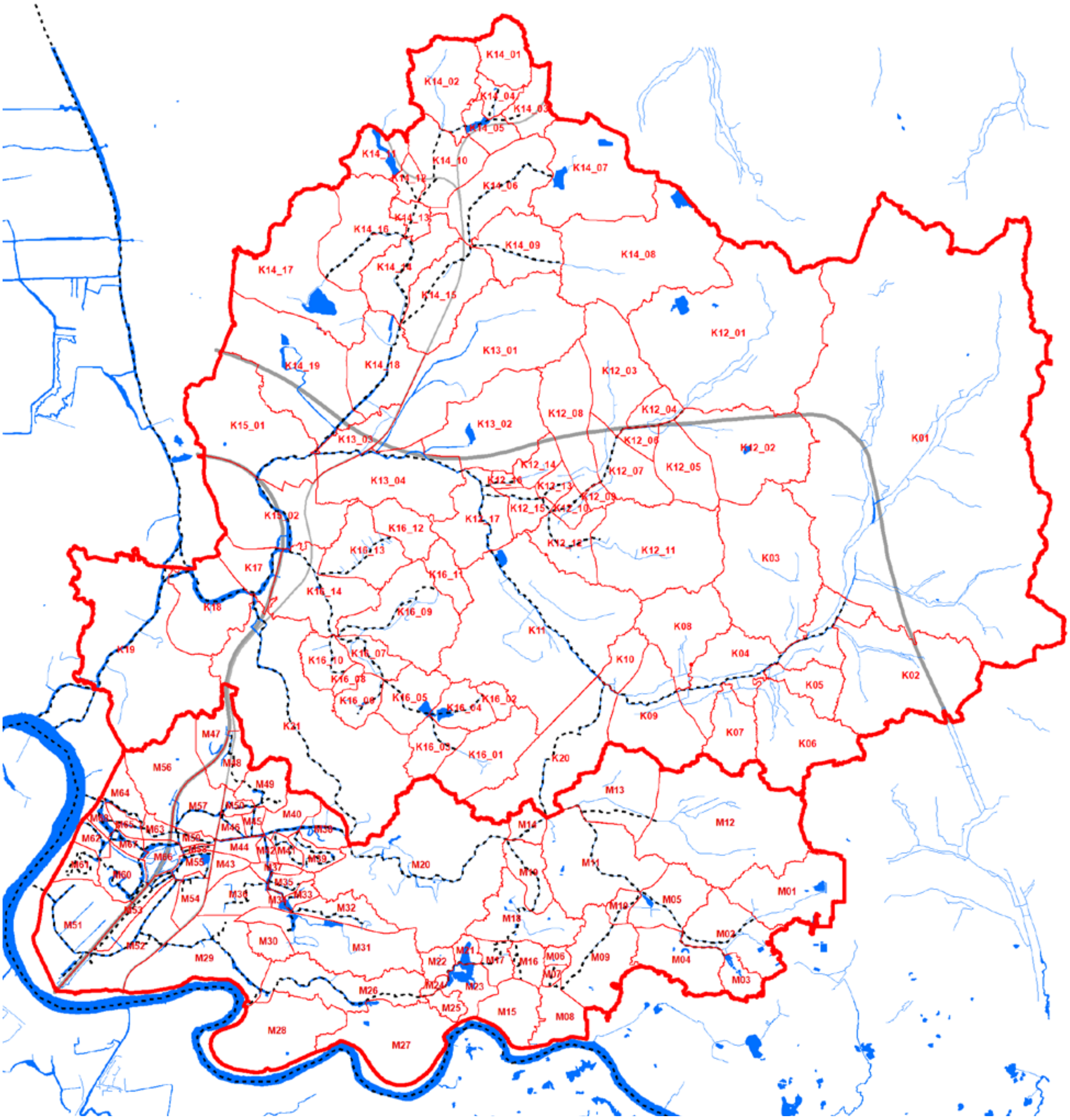
5.3.2.1 Sub Basins

In the target basin, the topography and land use situation has changed significantly due to recent urban development and the construction of expressways.

In particular, the Kalu Oya and Mudun Ela sub-basins have undergone significant changes, and the SLLDC has reconstructed the necessary sub-basin divisions and has independently considered drainage plans.

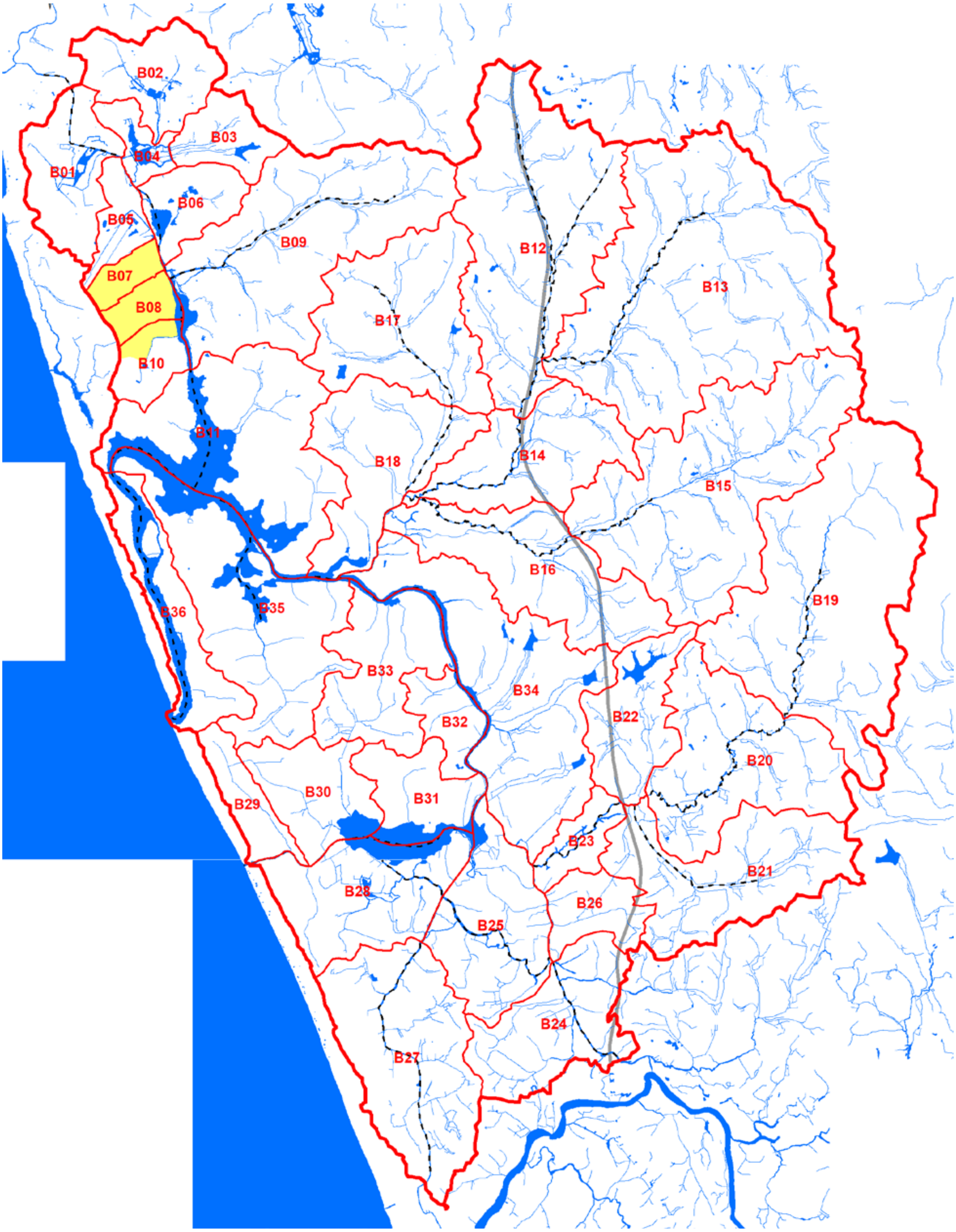
Therefore, in the Kalu Oya and Mudun Ela sub-basins, SLLDC obtained the sub-basin split being reconstructed and modified the sub-basin split using the LiDAR data and the results of the field survey.

For the Bolgoda basin, information of the sub-basins constructed by JICA 2003 M/P was reconstructed by reference to LiDAR data and field survey. Figure 5.3.4 and Figure 5.3.5 show the map of each sub-basin.



Source: JICA Study Team

Figure 5.3.4 Sub-Basin Division in Kalu Oya Bain and Mudun Ela sub-basin

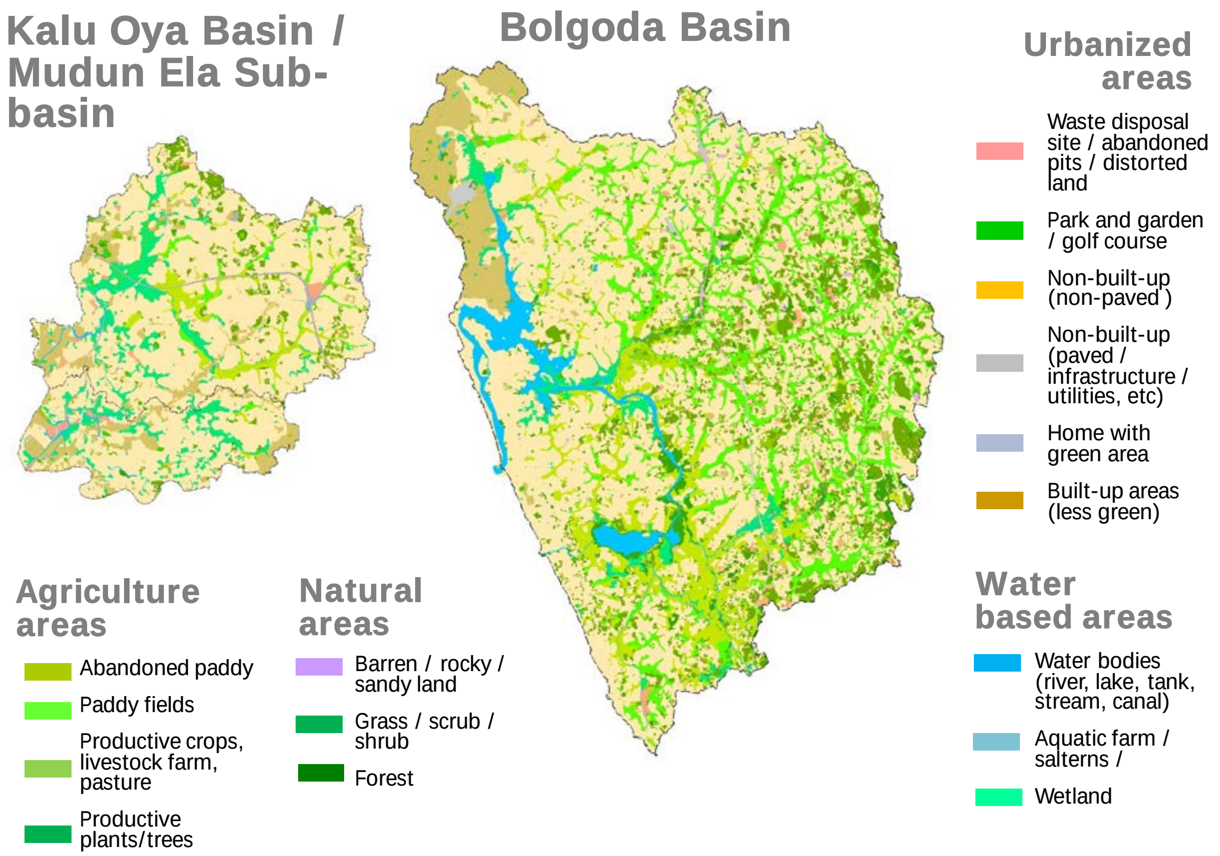


Source: JICA Study Team

Figure 5.3.5 Sub-Basin Division in Bolgoda Basin

5.3.2.2 Land Use

Land use distribution data is needed as reference information for determining runoff parameters of the NAM model, and the present and future land use data were updated in this study. Items related to land use are detailed in Chapter 4.



Source: JICA Study Team

Figure 5.3.6 Existing Land Use Map

5.3.2.3 Initial Setting of Parameter

Initial values of runoff parameters in the NAM model will be set by referring to the setting method of JICA 2003 M/P and will be changed by calibration of the analysis model.

JICA 2003 M/P classifies the land-use situation into four categories, Type-1 to Type-4, shown in Table 5.3.1, and applies the NAM parameters shown in Table 5.3.2.

The land use distribution categories shown in Table 5.3.3 were classified into Type-1 to Type-4, the land-use area ratio of each small basin was calculated, and NAM parameters were set by area-weighted average.

Table 5.3.1 Classification of Land Use Type Used for Parameter Setting

Types	Type-1	Type-2	Type-3	Type-4
Land Use Category	Urbanized area	Semi-Urbanized area	Rural area	Marsh, Water

Source: JICA Study Team

Table 5.3.2 NAM Parameters by Land Use Type

	Land Use Type			
	Type-1	Type-2	Type-3	Type-4
Umax	5.00	7.00	9.00	1.00
Lmax	16.00	68.00	85.00	6.70
CQOF	0.80	0.65	0.50	0.90
CKIF	500	500	500	500
CK12	3.50	6.00	9.00	0.50
TOF	0.20	0.20	0.20	0.20
TIF	0	0	0	0

Source: JICA Study Team

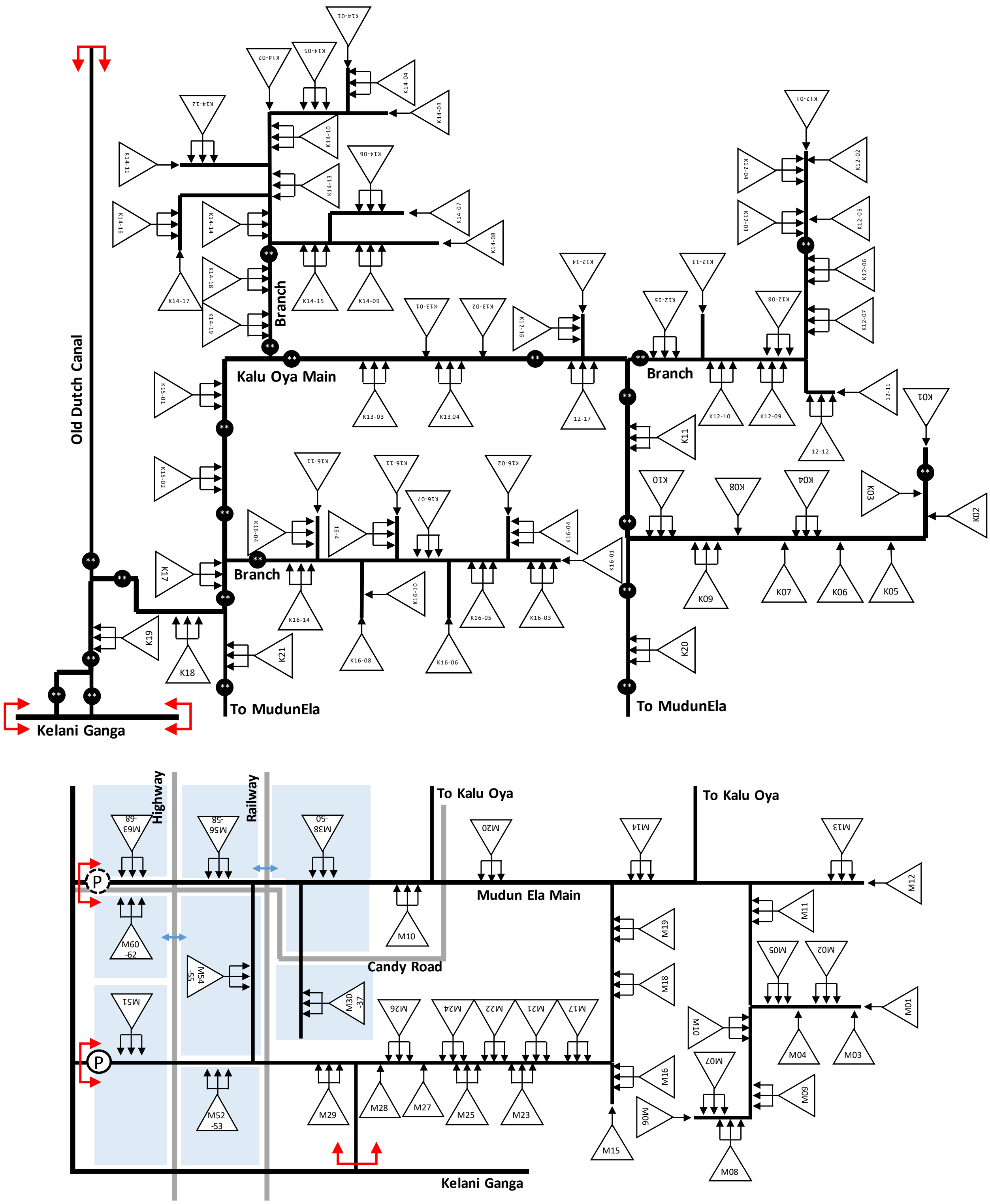
Table 5.3.3 Correspondence Table of Existing Land Use Categories and Land Use Types Used for Parameter Setting

Class		Type
AG1	Productive plants/trees	3
AG2	Productive crops, livestock farm, pasture	3
AG3	Paddy	3
AG4	Abandoned agriculture areas	3
N1	Forest	3
N2	Grass Lands/scrub/shrub	3
N3	Barren/rocky land / sandy land	3
W1	Wetland/marsh / swamp	4
W2	Aquatic farm / abandoned / Salterns / Tanks / Canal	4
W3	Water Surface (river, pond, lake, stream, tanks, canal, sea)	4
U1	Building Areas (building 60~80% covered)	1
U2	Home with the green area covered by 30~60%	2
U3	Non-built-up (paved, non-natural materials, infra, utilities)	2
U4	Non-built-up (non-paved, quarries, mining pits, naturally covered)	2
U5	Park and Garden, golf course	3
U6	Waste disposal land, abandoned pits, Distorted land	2

Source: JICA Study Team

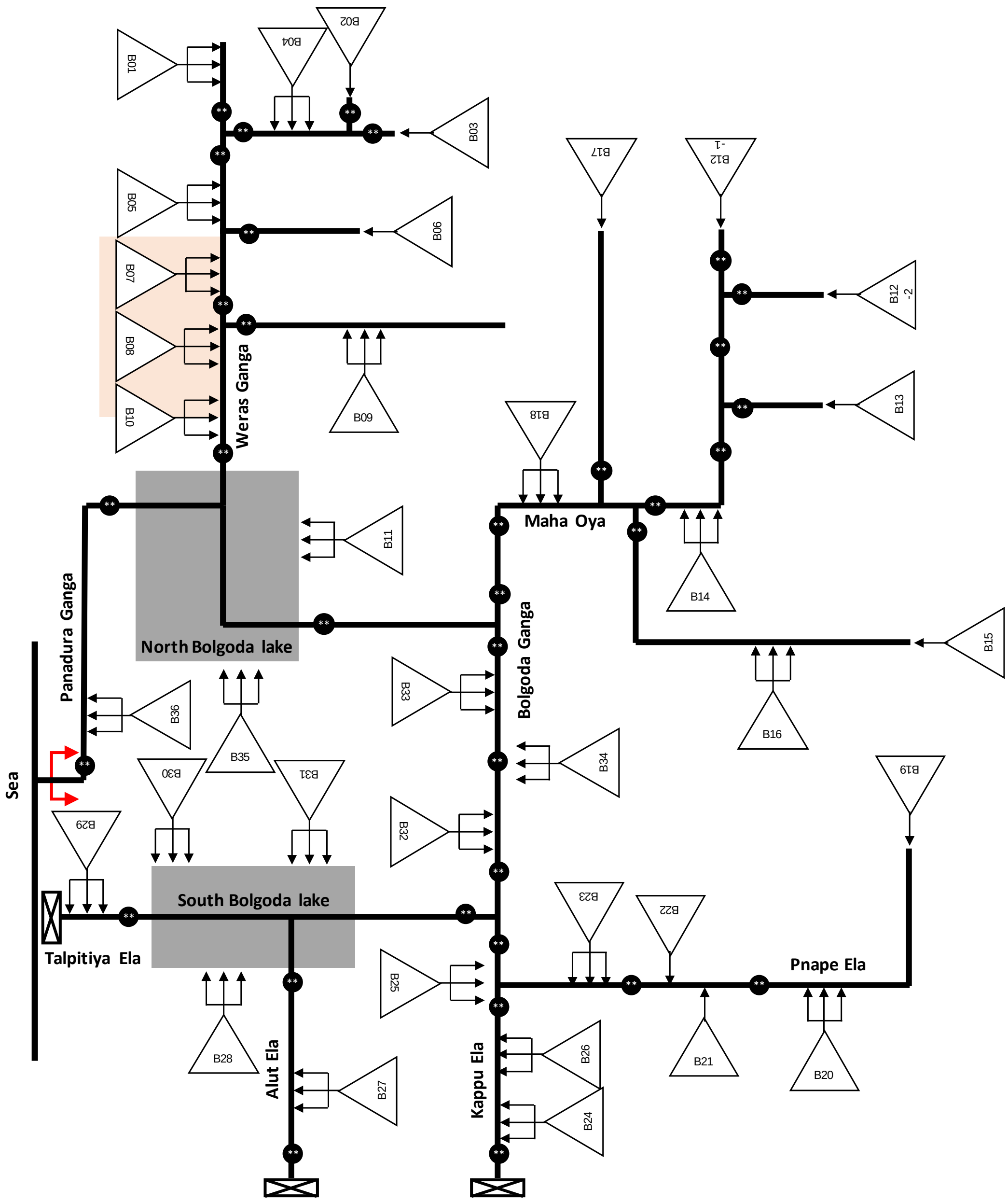
5.3.3 River Network Model

Figure 5.3.7 and Figure 5.3.8 show schematic diagrams of river networks and inflow points in each basin. Each river discharge was calculated using MIKE-11 which combines the runoff model and the river network model.



Source: JICA Study Team

Figure 5.3.7 River Network and inflow schematic (Kalu Oya Basin・Mudun Ela sub-basin)



Source: JICA Study Team

Figure 5.3.8 River Network and inflow schematic (Bolgoda Basin)

5.3.3.1 Other Condition in River Network Model（MIKE-11）

The main calculation conditions in the river network model are as follows.

Table 5.3.4 Conditions in River Network Model

Items	Kalu Oya and Mudun Ela sub-basin	Bolgoda Basin
Roughness Coefficient	0.030	Same as the left
River Network	The main river and major 1st and 2nd tributaries	The main river and major 1st and 2nd tributaries
Cross Section	2017 and 2018 survey results	2019 survey result and As build drawings of Weras Ganga Project
Structures	Major bridges, weirs, culverts, and pumping stations	Same as the left
Boundary Condition	Upstream The output of the runoff analysis Downstream Observed water level（Kelani river and tide）	Upstream The output of the runoff analysis Downstream Observed water level (tide)

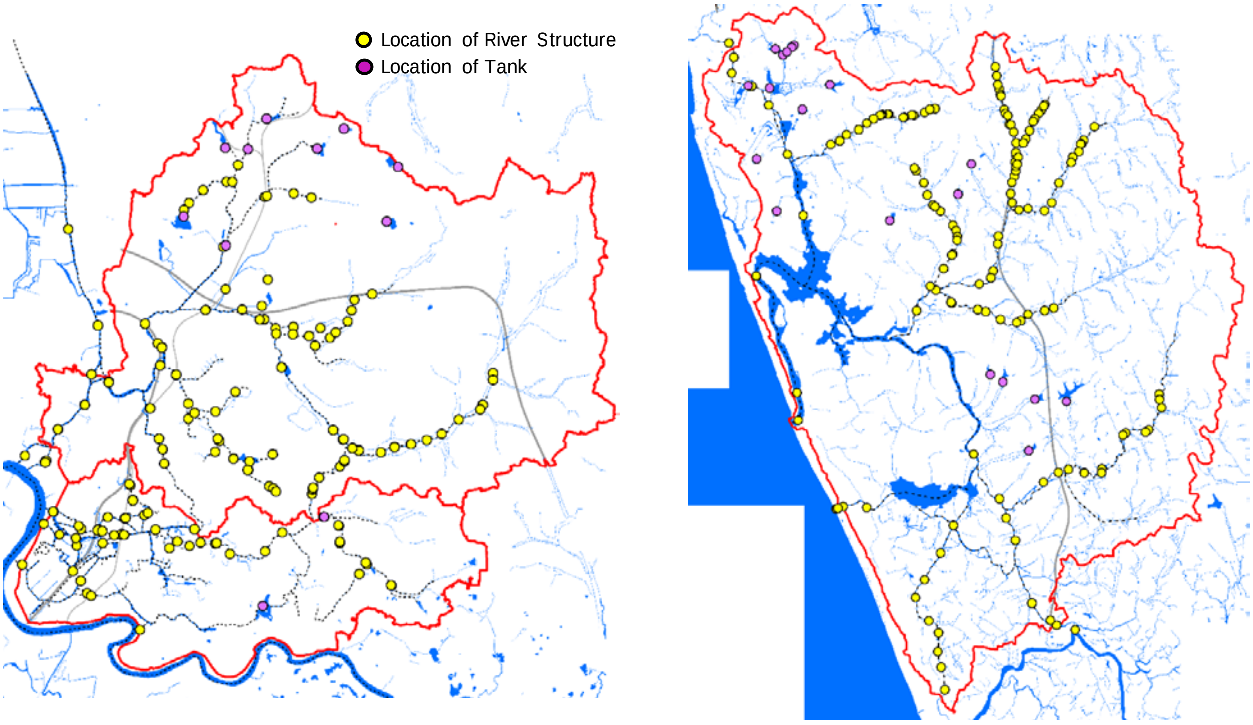
Source: JICA Study Team

(1) Modeling river structures

River structures that affect flood flow (bridges, weirs, culverts) are extremely important in analyzing runoff and inundation phenomena.

In addition, the flood control effect of the reservoirs located upstream of the target basin also affects the runoff volume, so it is necessary to consider it in the analysis model.

As for the data of these river structures, structural specification data were obtained from 2018 F/S and JICA 2003 M/P. The on-site confirmation of the acquired data was carried out in this study and then reflected in the analysis model.

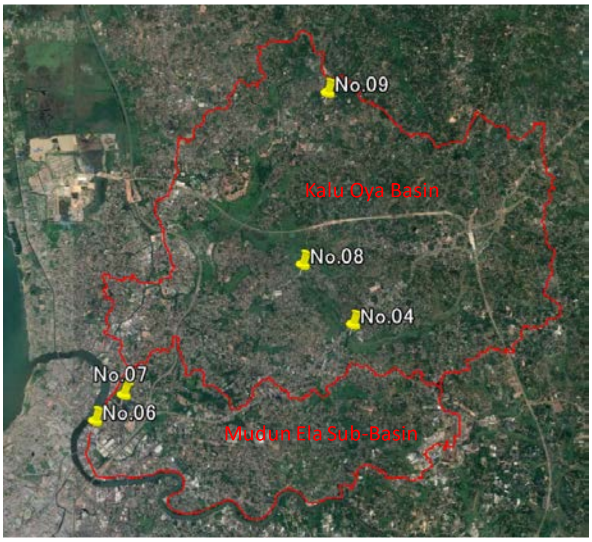


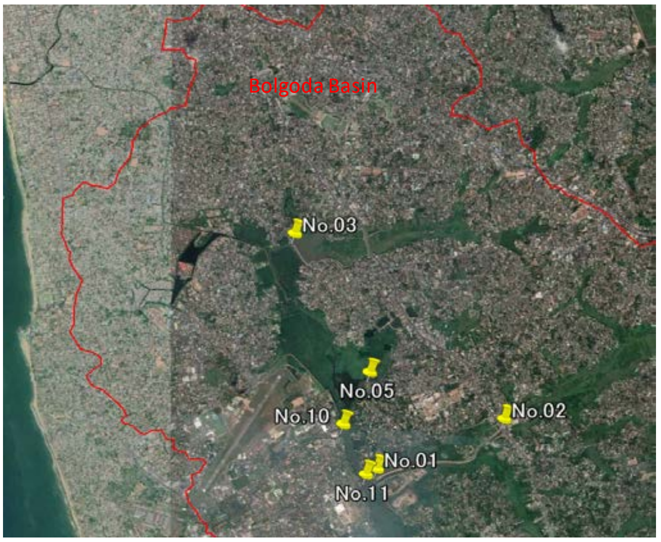
Source: JICA Study Team

Figure 5.3.9 Location Map of Modeled River Structures

(2) Field survey for Formation of Analysis model

In constructing a hydrological/hydraulic analysis model, a field survey was conducted to understand the general condition of the target basin. Only the points that should be noted in the model construction are shown below.





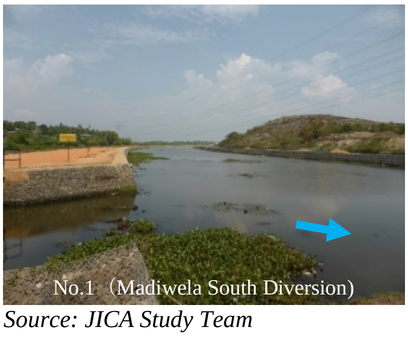
Source: JICA Study Team

Figure 5.3.10 Location Map of Field Survey Point (only representative points)

1) Weras Ganga Storm Water Drainage and Environment Improvement Project

The rehabilitation plan at Weras Ganga in the Bolgoda basin, which is one of the priority projects proposed by JICA 2003 M/P, is expected to be mostly completed by implementing SLLDC.

The main countermeasures for this project are river improvement and flood control pond construction. In this study, an analysis model was constructed with the completion of this project as the current condition.



Source: JICA Study Team

Photo 5.3.1 Condition of Weras Ganga Project

2) Wetland Area

One of the most important menus in the flood countermeasure plan examined in the M/P study is to maintain the flood control function by conserving the wetland area.

In the Kalu Oya basin and the Mudun Ela sub-basin, it is expected that the conservation of these wetland areas will become an issue with the progress of urbanization in recent years. The flood control function of these wetland areas was reproduced by an analytical model in consideration of future land use.

Source: JICA Study Team

Photo 5.3.2 Condition of Wetland Area

3) Pumping Station

There is only one pumping station in the Mudun Ela sub-basin, but as of September 2019, SLLDC will install a new pumping station (pumping capacity 30 m^3/s) in the basin. The construction has just started. These flood control facilities were also considered in the analysis model like other river structures.

Source: JICA Study Team

Photo 5.3.3 Pumping Station
(left: Existing Pumping Station, right: Construction Site of Oliyamulla Pumping Station)

5.3.4 Flood Inundation Analysis

The main calculation conditions in the flood inundation model are shown in Table 5.3.5.

Table 5.3.5 Conditions in Flood Inundation Analysis Model

Items	Kalu Oya and Mudun Ela sub-basin	Bolgoda Basin
Grid Size	25m	50m
DEM (Digital Elevation Model)	Averaged elevation for each grid will be arranged using LiDAR data.	Same as left
Roughness Coefficient of the flood plain.	0.080	0.010

Source: JICA Study Team

5.3.5 Result of Reproduction Calculation

A flood inundation analysis model was constructed based on the above conditions, and a reproduction calculation was performed for the October 2016 flood.

Since there is no hourly data such as water level used for identification, model identification was performed by comparison with the interview survey results (inundation location/inundation depth).

The calculation results of the inundation location and inundation depth in the Kalu Oya basin and the Bolgoda basin are almost in agreement with the results of the interview survey.

However, it is assumed that inundation is reported at locations that are clearly different from the calculated values due to local drainage failure.

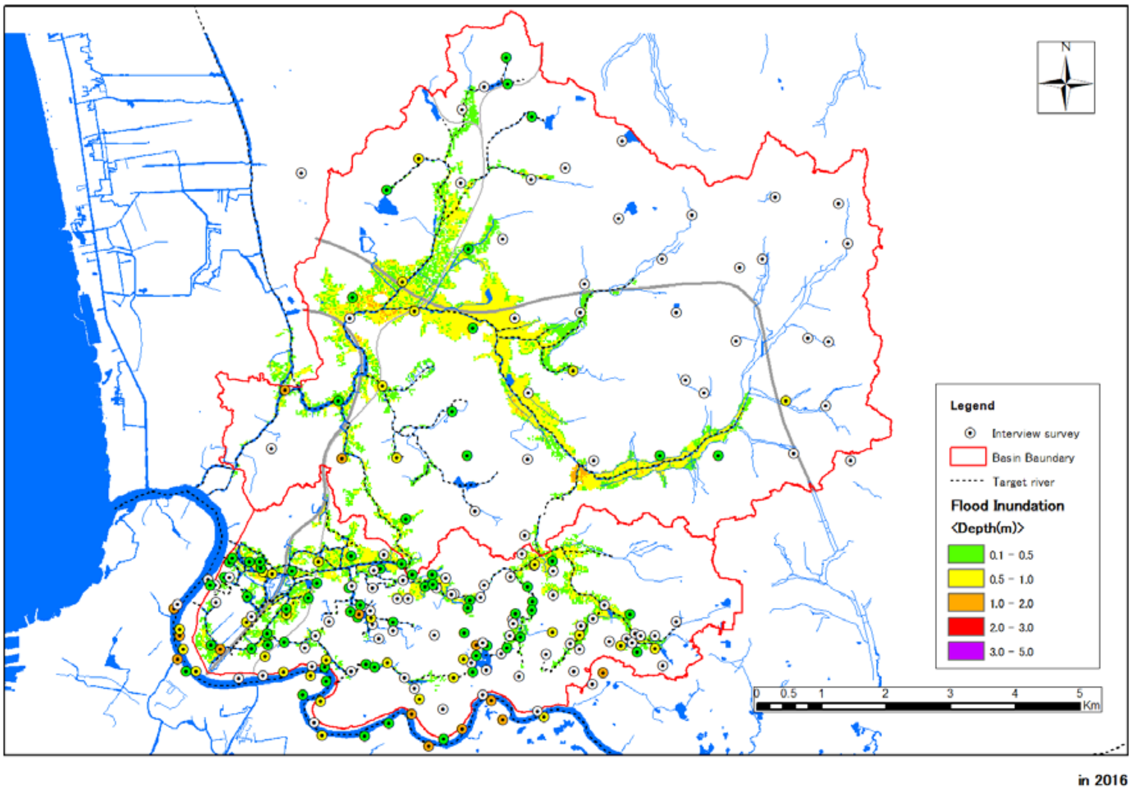


Figure 5.3.11 Result of Reproduction Analysis (October 2016 Flood: Kalu Oya Basin)

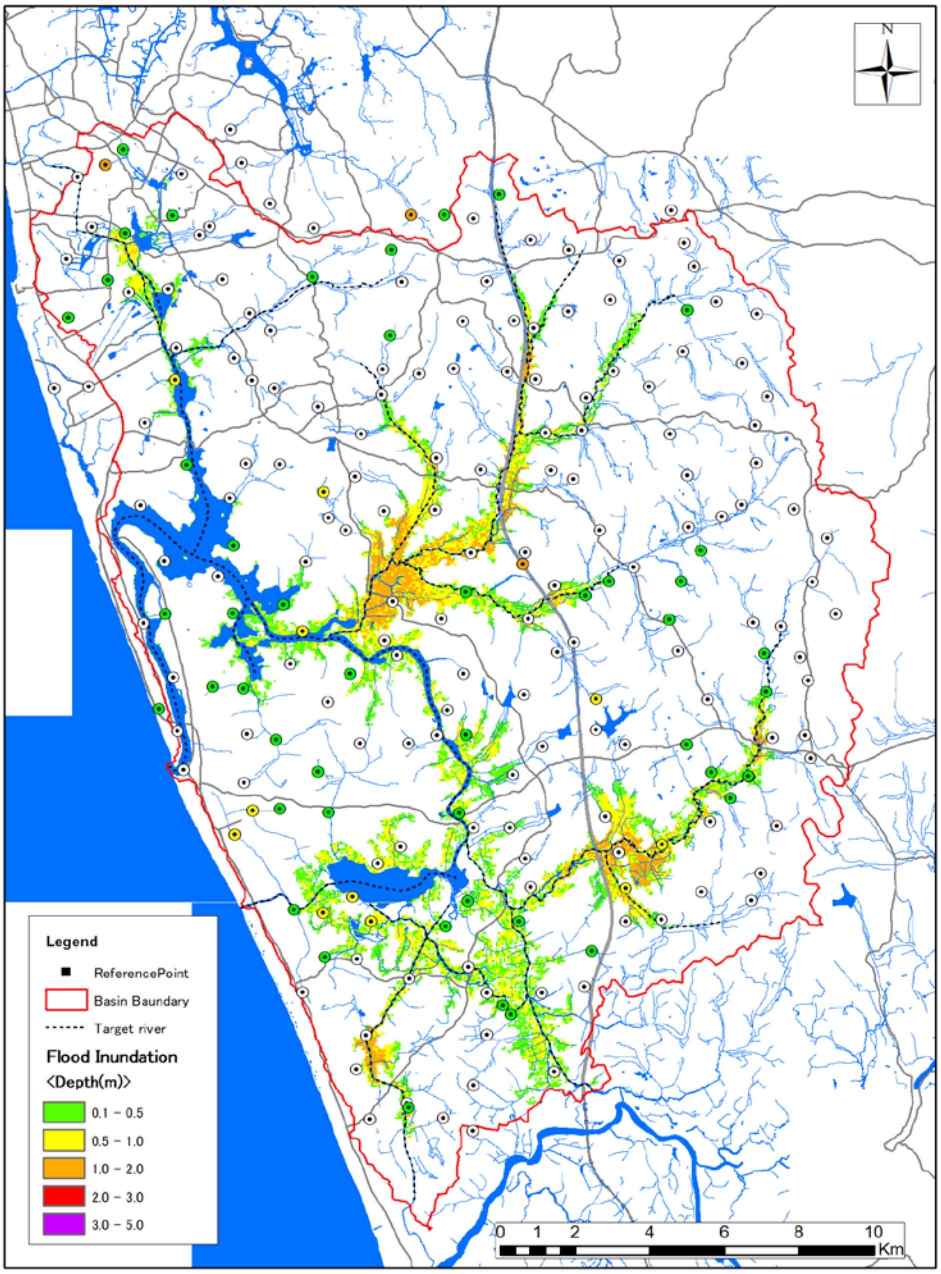


Figure 5.3.12 Result of Reproduction Analysis (October 2016 Flood: Bolgoda Basin)

CHAPTER 6 FORMULATION OF STORM WATER DRAINAGE PLAN

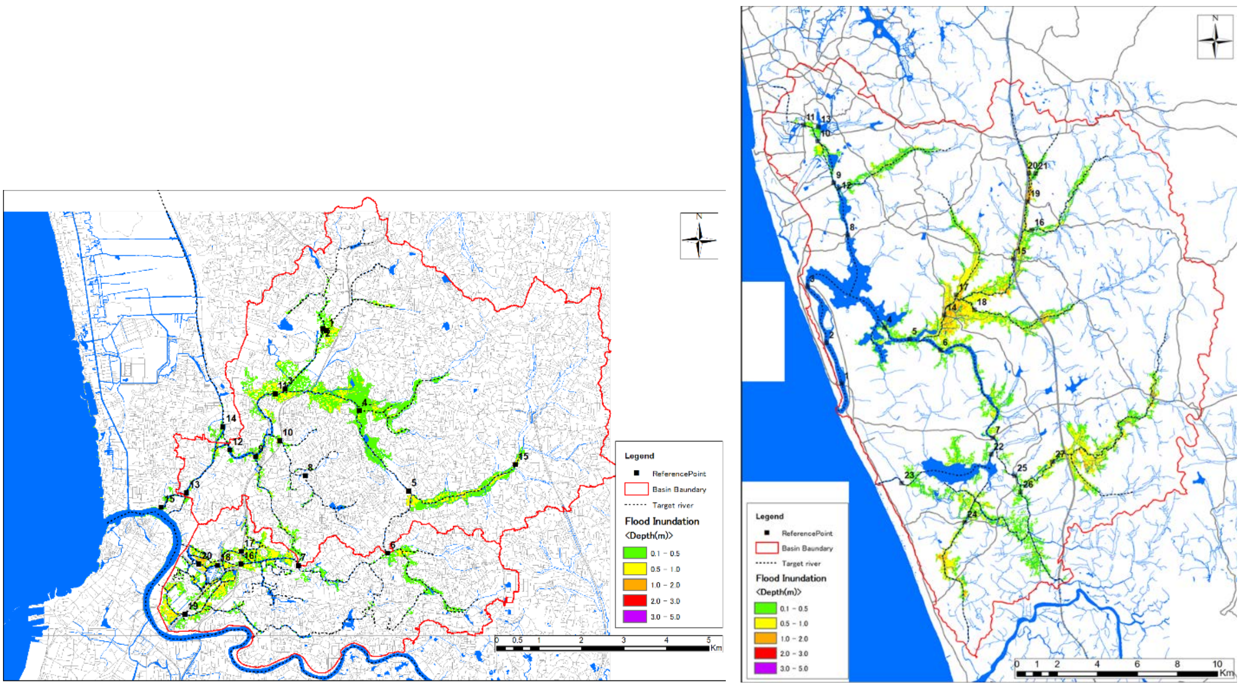
6.1 Present Status and Issues on Storm Water Drainage

6.1.1 Urbanization of Drainage Basin and Flood Carrying Capacity of Drainage System

Both Kalu Oya and Mudun Ela sub-basins have large urban areas along the lower stretches, where the socio-economic assets accumulate. It is the flood retarding functions of wetlands and paddy fields along the river in the mid-and upstream areas that reduce flood damage in these downstream areas.

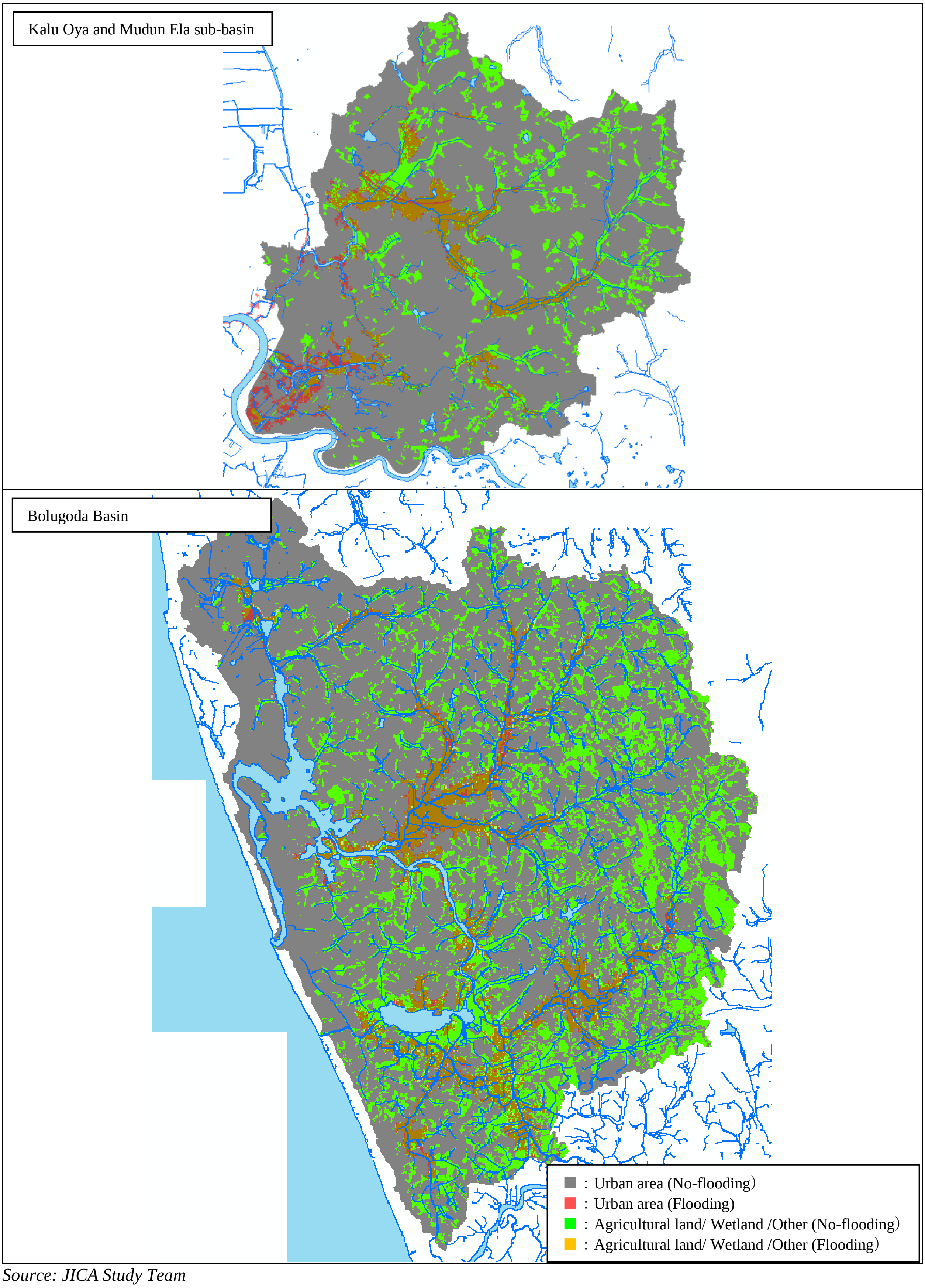
On the other hand, in the Bolgoda basin, two Bolgoda lakes in the north and south are extending downstream, and it is expected that there will be a function of flood retarding functions along the river channel, and flood mitigation functions can be expected. Large-scale development plans such as Science and Tech City and Industrial City Horana have been made upstream in the Bolgoda basin, but detailed land use plans have not yet been revealed. For the future, it is considered that the upstream area of the Bolgoda basin will be further urbanized on the extension of the adjacent Colombo District.

Based on the difference in the layout of the urban areas in the basin, flood simulation was conducted using probable floods, and the safety levels of each drainage system were examined. The results are shown in the following figures. In the Kalu Oya basin, upstream inundation areas are limited to wetlands and paddy fields, and it can be judged that the downstream river channel secures a safety level of a 2-year return period. In the Mudun Ela sub-basin, the reduction of inundation in the downstream area depends on the construction of pumping facilities. On the other hand, in the Bolgoda basin, the safety of the downstream river channel is ensured by the flood retarding functions in the mid-upstream area, but this flooded area also partially includes urban areas such as residential areas. From these conditions, the degree of safety of the target basin depends on the flood retarding functions in the upstream wetlands, but the land use and necessary measures in each flooded area are different so that the conservation of the flood retarding functions in wetlands and flood control of residential areas are extremely important to maintain and improve storm water drainage safety.



Source: JICA Study Team

Figure 6.1.1 Simulated Inundation Area in 2-Year Probable Flood (Left: Kalu Oya and Mudun Ela, Right: Bolgoda)



Source: JICA Study Team

Figure 6.1.2 Overlaying Simulated Inundation Area in 2-Year Probable Flood and Urban Areas

Thus, the canal system secures the flood control safety level of 2-year return period as a whole. In addition to the low safety level, the following issues have been pointed out by the relevant local governments.

- Lowlands along the upstream river are cultivated as paddy fields, but due to urbanization resulting in deteriorated water quality and dumping of municipal solid waste in the surrounding areas, farmers' motivation for cultivating paddy fields has been unstrung. There are many areas where abandoned paddy field is seen due to environmental deterioration. This situation promotes the intrusion of urban facilities into the lowlands along the rivers and increases the risk of inundation not only in the area but also downstream.
- Road networks and railway networks are being developed in response to the urbanization of the basin, but due to a lack of sufficient consultation at the time of highway planning, the inflow capacity was insufficient due to insufficient overflow capacity in the overpass section of the highway. The existing railroad bridges are aging and the existing railway bridges are aging, and due to the lack of cross-section, they have very low flow capacity. Similarly, many road bridges and culverts also need to be replaced and replaced.

6.1.2 Disaster Risk Mitigation in Flooding Damages

In the event of a serious inundation disaster in an area where there is chronic inundation in poor drainage areas or topographical depressions in the urban area, the Disaster Management Center (DMC) will act as a coordinator and cooperate with related ministries and departments, among which carry out disaster mitigation and relief activities. The military (army/navy), National Disaster Relief Service Center (NDRSC), etc. participate in this. In addition, disaster prevention-related departments: DMC, NDRSC, National Building Research Organization (NBRO), and Department of Meteorology (DoM), etc. were all gathered under the Ministry of Defense following the reorganization of ministries and agencies in December 2019.

However, regarding the mitigation of flooding especially during heavy rainfall, SLLDC has expertise with mobile drainage facilities (two amphibious pump vehicles and two mobile pump vehicles) and is also indispensable for such disaster mitigation activities. In particular, local inundation areas scattered in urban areas bring inconvenience to citizens, so that originally, due to the construction of drainage channels, such inundation habitual areas scattered in urban areas are completely controlled. It is difficult to do so even in terms of budget. Therefore, it is indispensable to maintain a sufficient number of mobile pump vehicles in order to promptly eliminate flooding even if it occurs.

6.1.3 Operation and Maintenance and Responsible Institutions for Drainage Facilities

6.1.3.1 Unclear Responsibility among Governmental Agencies on Management of Drainage Facilities

In the study area, there are several responsible agencies in charge of waterway development and operation and maintenance, such as SLLDC, Irrigation Department (ID), Agrarian Development Department (ADD), Provincial Irrigation Department (PID), and Local Authority (LA). Among them, rivers and irrigation canals are developed, operated, and maintained by ID, ADD, or PID. However, due to land-use changes through urbanization, drainage canals from urban areas are connected to these irrigation canals, and at present, these irrigation canals also function as important urban drainage canals. Especially in the study area, conversion from farmland to residential land is progressing in order to meet the demand for land due to urbanization. For this reason, due to the reduction in the scale of irrigation projects, irrigation facilities such as waterways and gates are not properly operated and maintained by the above-mentioned organizations, so that many of them actually function as storm water drainage canals in the study area.

It is generally accepted that the primary (Major) drainage canal is managed by SLLDC and the secondary/tertiary (Minor) drainage canal is managed by local governments. SLLDC is designing, constructing, operating, and maintaining storm water drainage measures to the designated canals and lakes (Major: 44 km, Minor: 54 km). As for other drainage channels, design, construction, operation, and maintenance works are basically under the responsibility of the local governments. However, because the management range of SLLDC is not well-known to local governments and many local governments do not have sufficient budget and human resources to devote to storm water drainage measures, many canals exist without operation/management agencies.

As mentioned above, in the study area, appropriate management, maintenance and repair works are carried out due to the unclear management body of storm water drainage measures in many drainage canal sections and insufficient budget and human resources. This situation results in flood damage presently.

6.1.3.2 Shortage of Resources for Storm Water Drainage Management

In the study area, SLLDC and local governments are the main organizations that implement storm water drainage management. The issues of each organization are shown below.

(1) SLLDC

In recent years, SLLDC has expanded its staff for management specialists, technical engineers, and workers, as well as equipment for construction and maintenance, through the implementation of large-scale storm water drainage projects such as MCUDP. From this, it can be said that SLLDC has enough knowledge and experience necessary for storm water drainage projects, and equipment for managing facilities, as well as human resources for their planning, implementation, and operation and maintenance.

However, there are increasing issues year by year in responding to environmental improvements peculiar to urban drainage canals, such as the illegal dumping of garbage into drainage canals and the deterioration of water quality due to the inflow of domestic wastewater into storm water drainage canals. There are also insufficient staff and equipment to properly operate and maintain the drainage system over a wide area. Also, if the designated area of SLLDC is expanded in the future, it will be necessary to respond to facilities such as drainage canals transferred from other organizations, and take over operation and maintenance work on a contract basis from requests of local governments. And it is also necessary to provide training such as technical guidance to local government staff. To meet these future needs, it is necessary to further develop human resources and enhance maintenance equipment.

(2) Colombo Municipal Council (CMC)

The Colombo Municipal Council (CMC) is located outside the study area. However, it is the local government with the most budget and human resources for storm water drainage management in the western provinces. The following is a summary of CMC's efforts to manage storm water drainage as reference information.

As for the activities of CMC for management of storm water drainage, the Water Supply & Drainage Division of the CMC Technical Service Department manages storm water drainage along with clean water and sewage. The Division Head Office is set up separately from the city hall, and the Regional Office, which divides the CMC area into 6 areas, is located, and dedicated technical staff is stationed at each office. Regarding storm water drainage management, the office is in charge of designing, constructing, and maintaining small-scale drainage canals in the CMC area. The annual budget of 336 million LKR is allocated for storm water drainage in FY2020. The main work is maintenance and cleaning of drainage canals in CMC, and repair of drainage canals. However, the total drainage canal length in the CMC is very long (about 350 km), and about 33 km out of this is positioned as an important section to be managed, but most of the other drainage canals are not sufficiently maintained.

Due to the shortage of human resources and maintenance equipment, CMC has a contract amount of Rs. 31 million to SLLDC for annual maintenance of the drainage canals in 10 districts in 2018 (August 2018-August 2019). In 2019, a similar outsourced contract to SLLDC continues, but the budget application was rejected by the Congress.

These situations mean a shortage of construction and maintenance equipment (tractors, backhoes, submersible pumps, generators, etc.) as well as a shortage of technical staff and operation and maintenance workers. The budget allocated for storm water drainage management is not sufficient compared to the extension of drainage canals that should be maintained.

(3) Other Local Governments (MC, UC, PS)

In other municipalities, except for large-budget municipalities such as CMC, storm water drainage-related activities are mostly limited to cleaning and repairing small drainage canals, including road gutters. Most local governments do not have full-time technical staff. Technical staff at the supervisor level working not only for storm water drainage but also for other public facilities is limited in many local governments. In addition, most local governments usually have only a backhoe and tractors, and this equipment is not dedicated to the maintenance of storm water drainage canals.

Considering the annual budget of these local governments, it is not easy for the local governments to increase the human resources and equipment to maintain the storm water drainage canal system. However, as the urbanization of existing urban areas expands to the suburbs and the number of storm water drainage facilities, public services will increase so that the need for proper operation and maintenance of storm water drainage canals by local governments will increase year by year. It is necessary to consider the expansion of human resources and equipment.

6.1.4 Environmental Issues in Drainage Canal System

As environmental problems in storm water drainage, environmental degradation is caused by deterioration of water quality due to discharge of sewage due to urbanization of surrounding areas and illegal dumping of solid waste. The current status and issues of water quality problems and waste treatment are summarized here.

(1) Environmental Improvement in Water Quality

Deterioration of surface water quality causes the following problems in storm water drainage.

- Paddy fields are still cultivated in the upper Kalu Oya and the middle and lower Bolgoda basins, and the irrigation water depends on the surface water flowing down these canals and rivers. However, the quality of surface water deteriorates mainly due to the inflow of domestic sewage due to urbanization in the surrounding area, which may lead to a decline in motivation for farming and may also affect the storm water drainage plan, which is expected to have a flood retarding function.
- The sewage system in the Colombo Metropolitan Area is dumped into the sea area at two points, north and south, by the sewage pipe system constructed in 1902. However, this treatment area is only in the old town of Colombo, and the Kalu Oya and the Bolgoda basins are located at the outer edge depending on on-site treatment such as septic tanks. In order to maintain this treatment function, it is necessary for each household to regularly remove their sludge, and water quality deterioration is inevitable due to insufficient maintenance.
- Such deterioration of water quality and increase of nutrient concentration adversely affect the above-mentioned irrigation water and promote the outbreak of water hyacinth in the downstream area, which also becomes a factor of impeding the flow of water. This situation is particularly noticeable in Mudun Ela, Old Dutch Canal, and Weras Ganga in Bolgoda.

(2) Environmental Improvement in Solid Waste

Regarding the current status of waste treatment, in the Western Province, which controls the three districts of Gampaha, Colombo, and Kalutara where the target basin is located. Waste Management Authority was established to formulate a 5-year action plan (2015-2020) for waste treatment to promote waste management. In this project, under the following goals, the improvement works have progressed.

- Increase solid waste collection rate from 61% to 72%,
- Increase the separation rate based on the amount generated from 17% to 38%.
- Increase resource recovery rate by composting and incineration from 13% to 71%.

As a result of these efforts, especially in the urban areas of Gampaha and Colombo, it can be expected that the environment will be improved in terms of solid waste treatment, and the amount of floating and sunken waste in the canal system is expected to reduce.

6.2 The Purpose and Strategy for Storm Water Drainage Improvement

6.2.1 The Purpose of Storm Water Drainage Improvement

In the Kalu Oya basin, the Mudun Ela sub-basin, and the Bolgoda basin, the flooding safety level of existing urban areas is only about a 2-year return period, and inundation damage occurs frequently. In addition, there is concern that the risk of flood damage will increase in the future due to the progress of urbanization. Therefore, the purpose of this study is to formulate a storm water drainage improvement plan based on the development status of existing facilities in each basin and future land use and to prevent and reduce inundation damage in each basin.

6.2.2 The Strategy for Storm Water Drainage Improvement

The current flood safety level of river channels is only about 2 years, considering the retarding function of the upper and middle stream, and a large project cost is required to significantly improve the flood safety level.

For this reason, measures that combine the improvement of river channels with storage facilities such as retarding basins will be considered, taking into consideration the effects of hydraulic control, social impacts such as house relocation, ease of operation and maintenance, and costs. Furthermore, the priority of rivers and waterways is set based on the balance between upstream and downstream, and the balance between main river and tributary, and a stepwise development plan is formulated. From the current 2-year return period scale to the 10-year return period scale and then to the 25-year return period scale, the hydraulic safety level will gradually improve.

In addition, due to urbanization, there is concern that assets will be concentrated in areas with high inundation risk and inundation damage will increase, so river channel countermeasures and storage facility development will be prioritized. Furthermore, as a measure against the residual risk during and after the facility development proposed in the rainwater drainage plan, land use regulation and guidance measures will be examined from the viewpoint of urban development management, and inundation damage will be further reduced.

From the above, inundation damage can be prevented and reduced concerning the target flood scale.

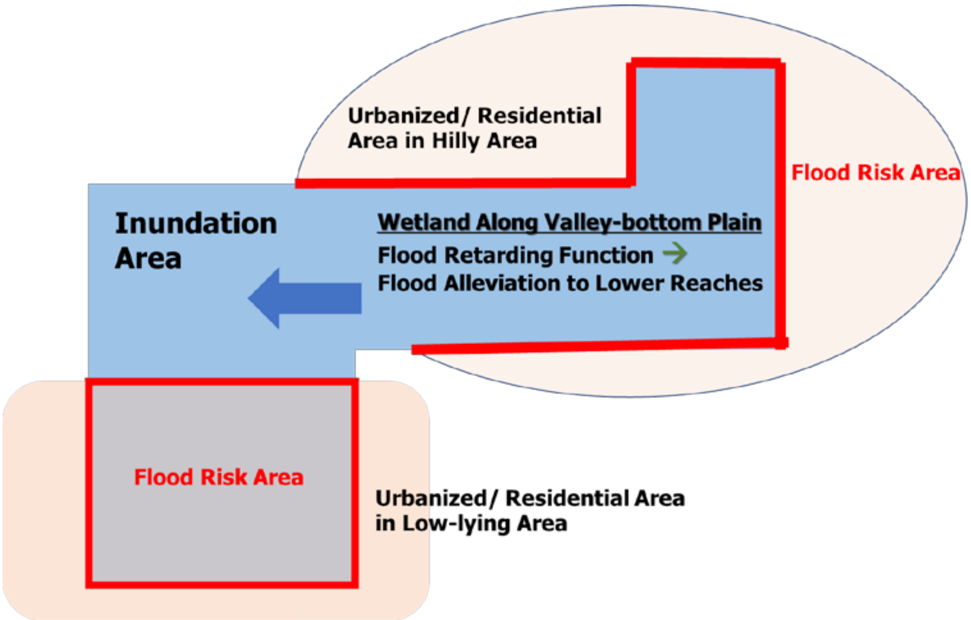
6.2.2.1 Current Inundation Risk Analysis and Project Implementation Policy

In considering measures to reduce the risk of inundation, it is first necessary to understand the following items.

- Clarification of areas with a high risk of inundation in the basin
- Clarification of structural characteristics of the basin that cause inundation risk
- Measures to minimize inundation risk for the entire basin

Based on the above items, the confirmation results of the Kalu Oya basin and the Bolgoda basin in the survey area are as follows.

- As a structural characteristic of the basin, the risk of inundation in the basin can be topographically limited to floodplains such as valley bottom plains and alluvial lowlands, except for small-scale local floods due to lack of flow capacity of drainage such as secondary and tertiary drainage canals.
- In order to minimize the risk of inundation in the entire basin, it is necessary to conserve this floodplain as much as possible and develop the basin while preserving the inherent retarding function.
- Paddy fields and wetlands remain in the valley bottom plains in the middle and upper stream of the study area. It is the policy of the project to conserve and utilize these retarding functions and reduce the risk of inundation in the downstream urban areas and the residential areas on the outer edge of the valley bottom plain.



Source: JICA Study Team

Figure 6.2.1 Relationship Between Inundation Risk and Required Conservation of Retarding Basin Function

6.2.2.2 Inundation Risk Mitigation Scenario

In the middle and upper streams of the target basin, wetlands including paddy fields spreading in the valley bottom plain exert a flood control effect (retention effect). However, the low flow capacity of the river channel in the downstream area increases the risk of inundation in the downstream lowlands, so it is first necessary to increase the flow capacity by structural measures.

Furthermore, the establishment of a natural wetland park is proposed as a measure to preserve the retarding basin function of paddy fields and wetlands in the middle and upper reaches. This natural wetland park will prevent the invasion of houses, etc. into the wetland, and prevent and reduce the damage caused by flooding of residential areas along the outer edge of the valley bottom plain.

In this way, the concept of the countermeasures proposed in this study is to reduce the risk of inundation by structural measures such as the improvement of drainage channels and non-structural measures such as wetland conservation.

The scenarios for reducing the inundation risk in the Kalu Oya basin, Mudun Ela sub-basin, and Bolgoda basin are as follows.

Based on the current safety level of flood control, the accumulation of assets such as residential areas along the river, the balance between upstream and downstream, and the balance between main channel and branch, the safety level of flood control will be gradually improved by structural measures toward the target level. The following table and the following figure show this scenario. The details will be given in Section 6.6.

Table 6.2.1 Flood Carrying by Storm Water Drainage Function in The Kalu Oya Basin (River Improvement, Natural Retarding Basin Function Including Natural Wetland Park, Planned Retarding Basin)

Storm Water Drainage Function	Flood Carrying and Retarding Capacity in Flood Safety Level							
	2- yr	(Share)	10- yr	(Share)	25- yr	(Share)	50- yr	(Share)
River / Water Channel	24.5	18.4%	63.6	31.0%	107.0	35.1%	151.8	36.8%
Planned Retarding Basin	0.0	0.0%	0.0	0.0%	0.0	0.0%	5.5	1.3%
Natural Wetland Park	45.9	34.5%	63.2	30.8%	80.7	26.5%	87.2	21.1%
Other Inundation	62.7	47.1%	78.6	38.3%	117.0	38.4%	168.1	40.7%
Total	133.1	100.0%	205.4	100.0%	304.7	100.0%	412.6	100.0%

Unit: m3/sec, Source: JICA team

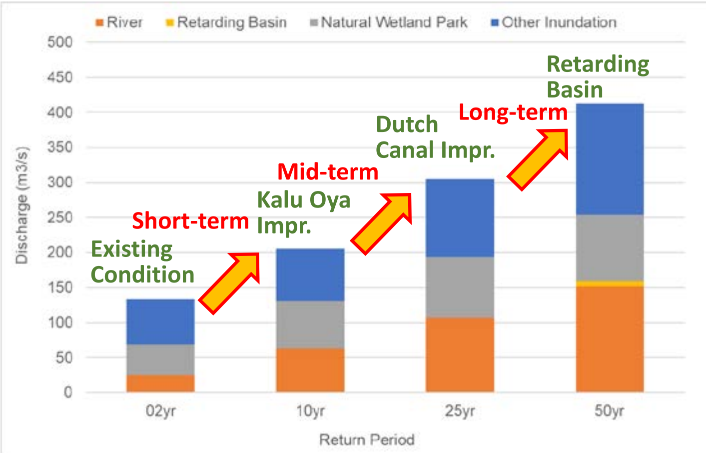


Figure 6.2.2 Stepwise Scenario of Flood Risk Mitigation (Kalu Oya Basin)

Table 6.2.2 Flood Carrying By Storm Water Drainage Function in The Mudun Ela Sub-Basin (River Improvement, Natural Retarding Basin Function Including Natural Wetland Park, Planned Retarding Basin)

Storm Water Drainage Function	Flood Carrying and Retarding Capacity in Flood Safety Level					
	2- yr	(Share)	10- yr	(Share)	25- yr	(Share)
River / Water Channel	8.2	34.3%	17.9	32.8%	24.1	30.8%
Planned Retarding Basin	0.0	0.0%	0.0	0.0%	6.8	8.7%
Natural Wetland	3.2	13.5%	14.4	26.4%	9.6	12.3%
Other Inundation	12.5	52.1%	22.2	40.7%	37.7	48.3%
Total	24.0	100.0%	54.5	100.0%	78.1	100.0%

Unit: m3/sec, Source: JICA team

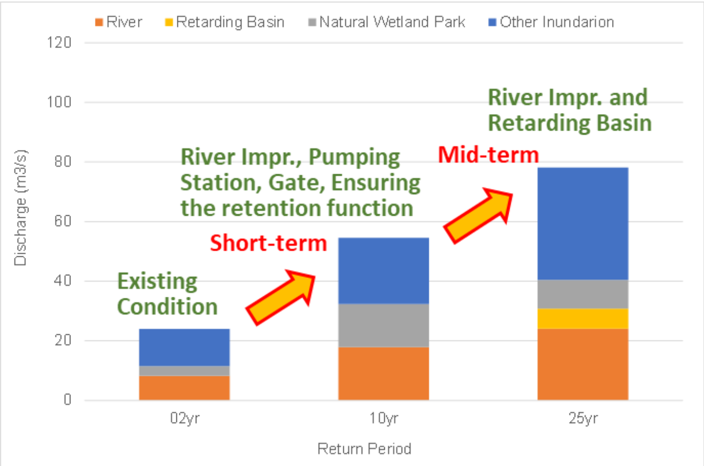


Figure 6.2.3 Stepwise Scenario of Flood Risk Mitigation (Mudun Ela Sub-Basin)

Table 6.2.3 Flood Carrying by Storm Water Drainage Function in The Bolgoda Basin (River Improvement, Natural Retarding Basin Function)

Storm Water Drainage Function	Flood Carrying and Retarding Capacity in Flood Safety Level					
	2- Yr	(Share)	25- Yr	(Share)	50- Yr	(Share)
River / Water Channel	236.9	54%	535.1	53%	605.7	52%
Natural Wetland	119.4	27%	282.9	28%	329.1	28%
Other Inundation	83.0	19%	198.2	20%	241.0	20%
Total	439.3	100%	1016.2	100%	1175.8	100%

Unit: m3/sec, Source: JICA team

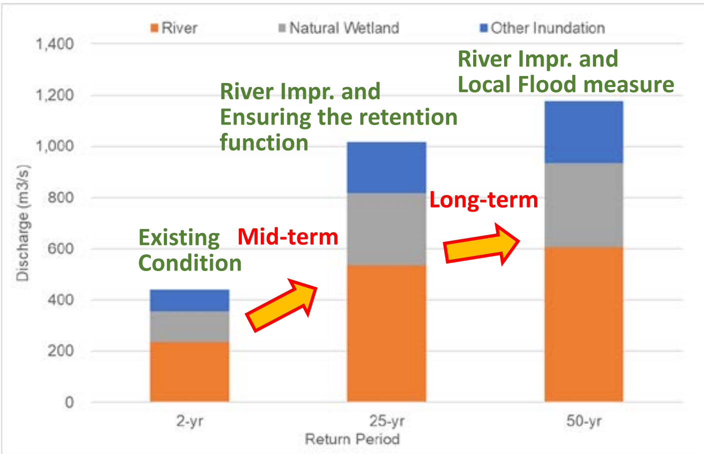


Figure 6.2.4 Stepwise Scenario of Flood Risk Mitigation (Bolgoda Basin)

6.3 Planning Frame

Based on the flood risk mitigation scenario in Section 6.2.2.2, the storm water drainage plan was divided into a "long-term plan" and a "medium-term plan". Each target year and the target safety level are shown below as the planning frame.

6.3.1 Target Year

Currently, it has been agreed with UDA to consider the frame of urban development based on the Western Region Megapolis Master Plan 2030, and the target year of the plan has been set to 2030. However, at present, there are only about 10 years by the target year, but since there is no alternative plan, the plan up to 2030 will be the "medium-term plan". In addition, since it is necessary to formulate the next plan after the completion of the "medium-term plan" and to proceed with the development in stages, the target year of the "long-term plan" has not been set. For example, it is assumed that it will be consistent with the target year of Kelani Ganga, which is the main river of Kalu Oya, but the specific improvement schedule of Kelani Ganga is not clear. It is appropriate that the target year of the "long-term plan" is at least at the same time as the completion of the Kelani Ganga improvement or later. It will be decided through consultation between SLLDC and related organizations after clarification of the improvement schedule.

6.3.2 Target Flood Safety Level

6.3.2.1 Design Scale of the Long-Term Plan

(1) Design Scale of Kalu Oya Basin and Mudun Ela Sub-basin

The design scale of the river improvement plan should be set by comprehensively considering the importance of the river, the actual damage, and the economic effect. These conditions are almost same because urbanization is similar in the adjacent basins of the Kalu Oya and Mudun Ela sub-basins. Therefore, the design scale was decided in consultation with SLLDC based on the consistency of the design scale of the main river and the tributary, the consistency with the existing improvement plan, the size of the basin area, etc.

1) Consistency of design scale between the main river and tributary

Kalu Oya and Mudun Ela are tributaries of the Kalani Ganga, where the World Bank is currently implementing CRIP. According to CRIP, the embankment of a 50-year return period is planned for the downstream of Kalani Ganga. It is appropriate that the long-term target safety level of Kalu Oya and Mudun Ela should be 50 years or less in consideration of the balance between the main river and the tributary.

2) Consistency of existing improvement plan

In the existing plan, the design scale of the Kalu Oya basin is set to a 50-year return period in JICA 2003 M/P. On the other hand, the Mudun Ela sub-basin has been never set to a target safety level.

3) Basin area

Comparing the size of the basin, the Kalu Oya basin is 55.3 km^2 and the Mudun Ela sub-basin is 20.0 km^2. For example, in Japan, the design scale of small and medium-sized rivers is a 30-year return period for basin areas of 50 km^2 or less, and a 50-year return period for basin areas of 50 km^2 to 100 km^2.

4) The scale of the largest flood in the past

The maximum history of floods (rainfall) is the Colombo Observatory rainfall station, with a daily rainfall of 494 mm occurring in June 1992, which is about a 50-year return period.

Based on the above, the design scale of the long-term plan was set as follows. In Kalu Oya, the 50-year return period is applied based on the balance between the main river and the tributary and the consistency with the existing plan. In Mudun Ela, a 25-year return period is applied based on the balance between the main river and tributaries, the size of the basin, and the design scale of other rivers in Sri Lanka.

(2) Design scale of Bolgoda basin

1) Consistency between the main river

The plan for the Bolgoda basin includes the main tributary. There is a past storm water drainage plan only in the Weras Ganga basin, which is included in the Bolgoda basin, and the design scale is a 50-year return period. There are no previous storm water drainage plans for other tributaries.

2) Consistency of existing plan

As mentioned above, the storm water drainage plan exists only in the Weras Ganga basin included in the Bolgoda basin, and the design scale is a 50-year return period in JICA2003M/P.

3) Basin area

The basin area is 394 km^2. For example, in Japan, the design scale of small and medium-sized rivers is a 50-year return period for basin areas of 50 km^2 to 100 km^2.

4) Design scale of other rivers in Sri Lanka

In the adjacent Metro Colombo Urban Development Project, a 50-year return period is applied to the design scale.

5) The maximum historical flood level

The maximum historical flood (rainfall) is observed at the Rathmalana Observatory rainfall station, with a daily rainfall of 383 mm recorded in November 2010, which is about a 50-year return period.

Based on the above, the design scale of the long-term plan is applied 50-year return period based on the consistency with the existing plan and the design scale of other rivers in Sri Lanka.

6.3.2.2 Design Scale of Mid-Term Plan (2030)

(1) Design scale of Kalu Oya basin and Mudun Ela sub-basin

Considering the following points, a 25-year return period is applied to the design scale of the med-term plan (2030).

- Even if both basins have a retarding basin function in the upstream area, the current safety level of flood control is at most 2 years.
- Conclusion of 2018 F/S that proposed the safety level of a 10-year return period.
- Restrictions on the project period, project funds, and workable amount until 2030, which is the target year for the mid-term plan.

(2) Design scale of Bolgoda basin

Since the Bolgoda basin has the same tendency as the Kalu Oya basin and the Mudun Ela sub-basin, the design scale of the medium-term plan (2030) is set to a 25-year return period.

Table 6.3.1 Reference Information For Setting The Design Scale For Flood Control

Reference information	Target basin (area)		
	Kalu Oya (55.3 km^2)	Mudun Ela (20.0 km^2)	Bolgoda (394 km^2)
1. Existing plan (JICA2003M/P) ・ The general target of safety level: 1/50 ・ Tributary in Weras Ganga basin (Area= 3-20 km^2): 1/10	1/50	-	1/50
2. Existing plan (2018F/S)	Initial:1/25 Final:1/10	-	-
3. Existing plan in the adjacent target basin (MCUDP): 1/50 （Area =105 km^2）	-	-	1/50
4. Design scale of small and medium-sized rivers in Japan 50 km^2:1/30、50-100 km^2:1/50	1/50	1/30	
5. The maximum historical flood scale	About 1/50	About 1/50	About 1/50
Design scale of a long-term plan in this project The number shown in parentheses is the design scale of the mid-term plan	1/50 (1/25)	1/25	1/50 (1/25)

Source: JICA team

6.4 Planning Condition

6.4.1 Design Scale

In this project, the design scale is set to a 25-year return period for the Kalu Oya basin, the Mudun Ela sub-basin and the Bolgoda basin. As a long-term plan, a 50-year return period will be gradually achieved in the next stage after the completion of this plan.

6.4.2 Design Hyetograph

In this study, as in 2018 F/S study, the concentrated hyetographs by probability scale were used as the design hyetograph using the rainfall intensity formulas at the Colombo and Rathmalana stations.

However, it was judged that the calculated values at the Colombo and Rathmalana stations could not be directly applied to each basin because of the secular change in the annual maximum rainfall up to the above, the regional distribution of rainfall, and the relationship between the basin average rainfall and the point rainfall. The area reduction factor was set with reference to the method used in MCUDP.

Kalu Oya Basin and Mudun Ela sub-basin (Colombo station)	Bolgoda Basin (Rathmalana station)

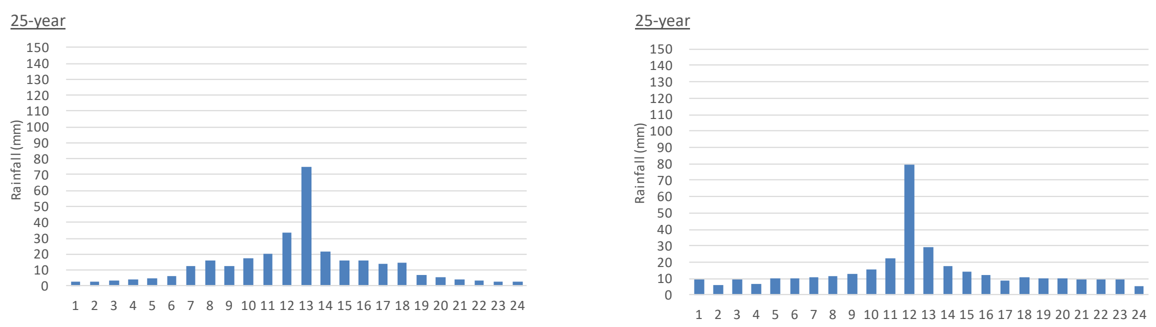


Figure 6.4.1 Design Hyetograph

6.4.3 Design High Water Level and Freeboard

6.4.3.1 Basic Policy for Design High Water Level

The design high water level is one of the criteria for river management, and it is a standard that enables the design high water flow to be safely discharged below this water level.

Generally, necessary items are taken into consideration depending on the situation of the target river from the land use and ground height of the hinterland, historical flood, and the history of river improvement up to that point. In the target watershed, no consistent and unified planning standard is established for the water system, and the design high water level is not clearly defined.

In some basins, for example, the Weras Ganga Left Bank Inflow Canal (see Figure 6.4.2), the river improvement has been implemented by SLLDC with the design dike height is 2.0m, HWL is 1.5m, and freeboard is 0.5m.

Based on these, the design high water level is set according to the following policy. It should be noted that the above-mentioned freeboard is a value that has been set empirically in the target basin, and in order to ensure consistency with existing structures, this freeboard will also be followed in this study.

- Basically, the excavated river channel will be used as a rule, and the design high water level will be set to about the ground level within the bank.
- Even if a dike is required, an excessive dike increases the risk of inundation when the dike breaks, so the relative height to the ground height within the dike is set to a freeboard height (0.5 m).
- If there are existing mitigation structures near the structure to be examined, set the design water level by following the existing plan for such structures.

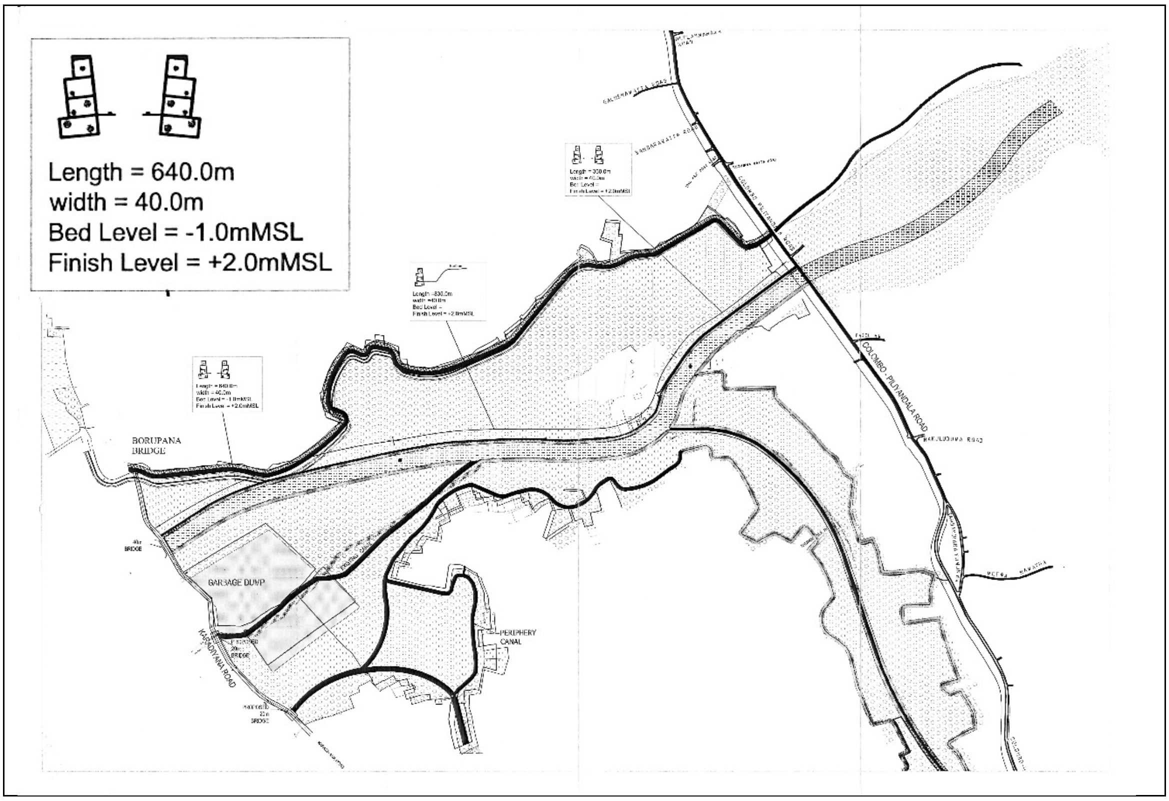


Figure 6.4.2 Plan of Existing Canal on the Left Bank of Weras Ganga Basin (Madiwera South Diversion Channel)

6.4.3.2 Design High Water Level

(1) Impact of backwater and policy for setting boundary conditions at the river mouth of Kalu Oya

It is extremely important to set the boundary conditions at the river mouth because the riverbed gradient is gentle in the downstream section of Kalu Oya and the backwater of the main river will affect upstream reach.

If there is an influence of the backwater of the main river and the runoff discharge and water level can be calculated at the same time as the main river, it is appropriate to set the maximum water level considering the peak time difference of the runoff. However, there is currently no model that simultaneously calculates Kelani Ganga and Kalu Oya, including runoff calculations.

Comparing the design hydrographs of Kelani Ganga in the CRIP report, the flood duration is 5 days for Kelani Ganga and 1 day for Kalu Oya, and the peak time difference of the flood is extremely large.

In this study, since no data can clearly judge the confluence time difference, two alternatives, which are a backwater dike and a normal dike with the pumping station, were considered as the improvement of the downstream section referring to the main river improvement plan. As a result, it was decided to be applied a normal dike with the pumping station. The results of this comparative study are shown below.

(2) Boundary condition in case of backwater dike

At the confluence, Kelani Ganga, a CRIP has been drafted with the support of the World Bank, and a Pre-F/S study is being conducted. In this Pre-F/S study, a 50-year return period embankment plan was drafted in the downstream section, and this embankment plan is the highest priority menu in the overall project. However, the specific project schedule such as the project implementation period and completion time is unknown. According to the Kelani Ganga embankment plan, the maximum difference between the embankment height and the current ground height is 3m (freeboard 0.5m), and the Pre-F/S study report does not show the design high water level. Only the longitudinal profile and water level values of some reference points are shown.

Table 6.4.1 Reference Discharge and Water Level of Kelani Ganga

Return Period	Discharge at upstream end	Embankment	Water Level at Kelani Ganga		
	Glencouse		River mouth 0.0 km	Confluence of Kalu Oya 1.0 km	N' street 4.0 km
1/50	2,450	With dike	0.6 m*	1.780	3.138

**Boundary condition of river mouth: In the hydraulic calculation in CRIP, 0.124 m of water level rise due to climate change is added to the actual water level in 2016. (Approximately the maximum water level is 0.6m)*
Source: JICA team

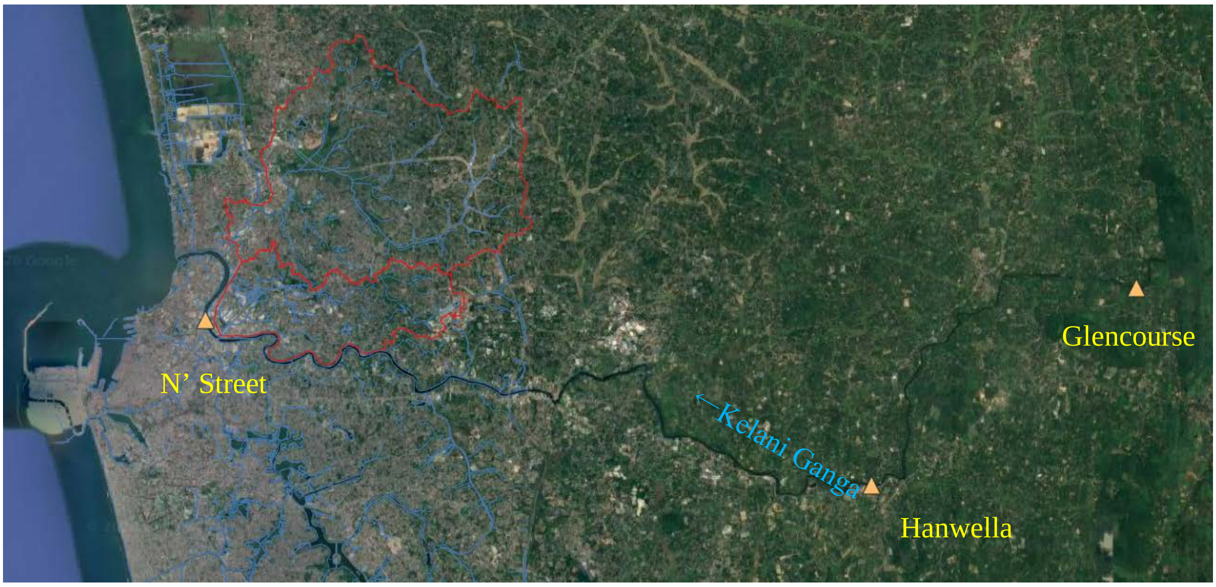


Figure 6.4.3 Location Map of the Reference Point Of Kelani Ganga

(3) Boundary condition in case of a normal dike with a pumping station

The Pre-F/S study of CRIP notes that a detailed consideration of measures at the confluence of major tributaries is needed. It is presumed that the consideration of countermeasures for this confluence of major tributaries is included in the detailed design phase of the next CRIP2. At least, the Pre-F/S study proposes the installation of gates and pumping stations as part of the confluence of multiple tributaries included in the Kelani Ganga embankment project. The Pre-F/S report states that Kalu Oya is also included, but the details are undecided.

(4) Comparison of design high water level based on the type of dike

If the boundary condition of the river mouth of Kalu Oya is set to 1.780 m for the main river shown in (2) and the design high water level and design dike level of Kalu Oya are set on the premise of the construction of the backwater dike, the backwater dike needs to be considerably extended. This is expected to affect the flooding level in the area set as the natural retarding function section. The influence of the backwater dike is extremely large.

Therefore, the design high water level is proposed to be set to the ground level inside the embankment on the premise of the construction of a normal dike with a gate and pumping station at the river mouth in this study. The proposed design high water level is shown in the figure below. Details of this study are also given in Section 6.6.2.

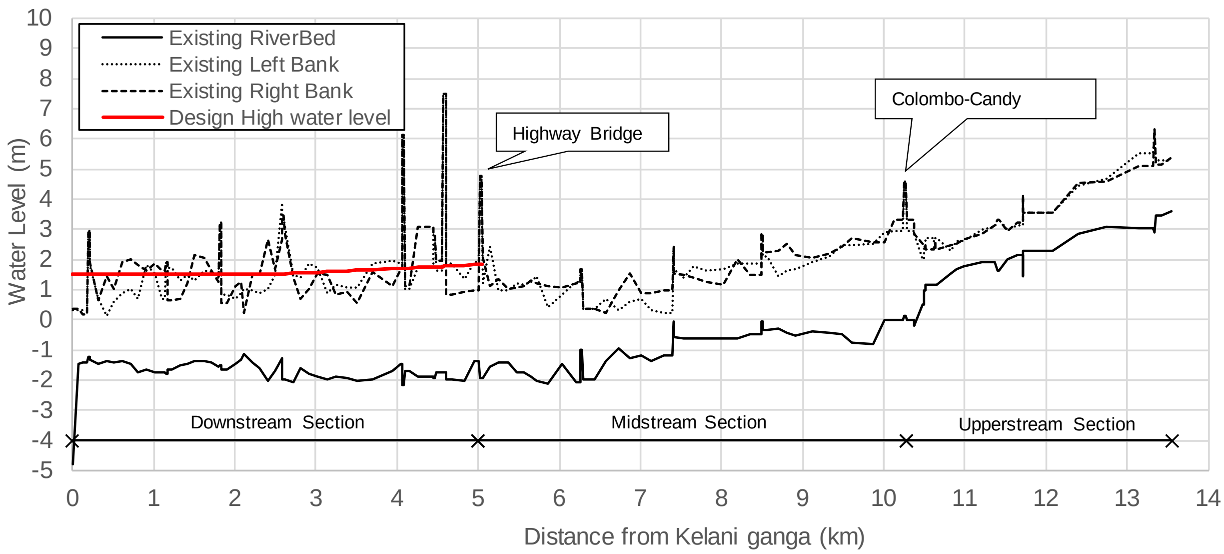


Figure 6.4.4 Proposed Design High Water Level of Kalu Oya

(5) Consideration of the project schedule of CRIP

The project schedule for the CRIP embankment project is undecided at this time, and details will be clarified in the next detailed design phase. It is expected to take a long time to determine the countermeasure policy for the confluence by CRIP. Even if the embankment project is actually started, it is unlikely that the embankment will be completed in a few years (at least by 2030). Therefore, it is not realistic to include gate and pump plans in the mid-term plan (2030) in this study. After the embankment height and planned high water level of Kelani Ganga have been determined, it is reasonable to be considered the details of the gate and pumping station specifications at the Kalu Oya confluence by CRIP. In this regard, SLLDC should continue discussions with CRIP and Kelani Ganga administrators to share information.

6.4.3.3 Design High Water Level of Mudun Ela

(1) Existing plan (Oliyamulla pumping station)

The downstream end of each channel in the Mudun Ela sub-basin connects to the Kelani Ganga and has been drained by gates and pumping facilities. In addition, SLLDC is constructing a new pumping station in the Oliyamulla area downstream of Mudun Ela, and the end of the Mudun Ela main channel, which is proposed to be improved in this study, will be connected to the Oliyamulla pumping station.

The height of the top of the bank around the regulating pond of the Oliyamulla pumping station is MSL+4.0 m (see the figure below), and the low water level during pump operation is MSL+0.0 m and the high water level is MSL+3.0 m.

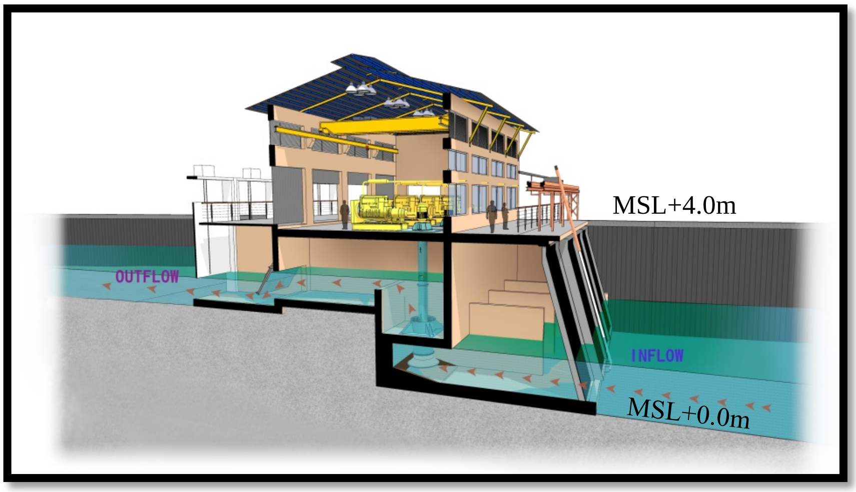


Figure 6.4.5 Oliyamulla Pumping Station

(2) Boundary condition of water level and design high water level of Mudun Ela

There is no embankment in the lower reaches of Mudun Ela, and as shown in Figure 6.4.6, the ground height is MSL + 1.0 to 2.0 m up to around 3.0 km. The riverbed gradient is extremely gentle, and the influence of backwater at the downstream end water level is large. It can be considered that the design high water level will be applied MSL+3.0 m, which is the high water level of the pump facility, as a boundary condition, but it is not realistic because it greatly exceeds the ground height.

Therefore, the design high water level is set by the following procedure. Regarding the detailed plan near the pumping station, the final plan will be reconfirmed, and the specifications of the river improvement of Mudun Ela will be proposed in the Pre-F/S survey.

i. Implementation of hydraulic calculations considering pump operation (35m^3/s)

ii. Trial calculation of widening width and excavation depth

iii. Set the envelope curve of the water level in a hydraulic calculation to the design high water level

iv. Set the design high water level (downstream end) to MSL+1.5m, which is about the ground height.

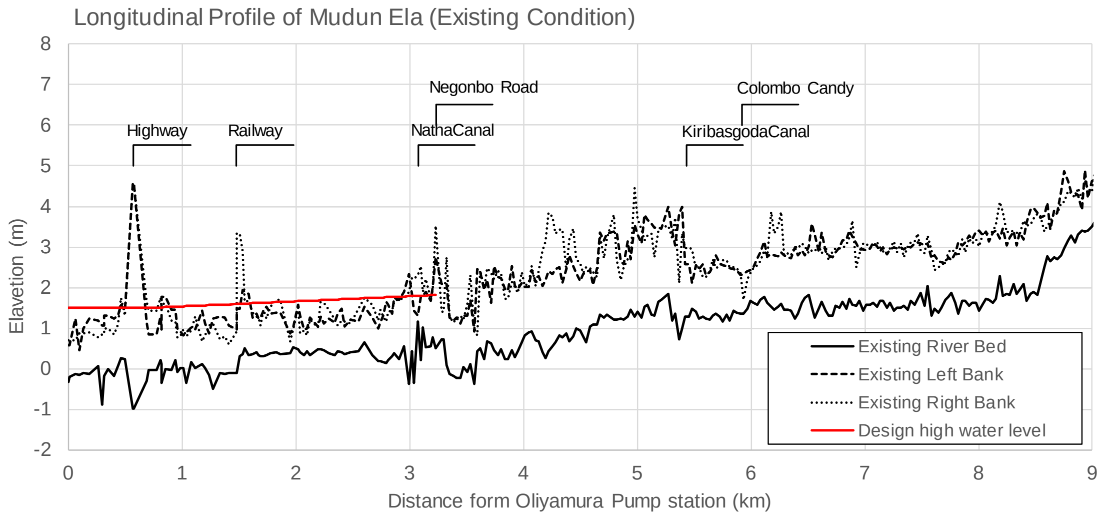


Figure 6.4.6 Proposed Design High Water Level of Mudun Ela

6.4.3.4 Design high Water Level of Bolgoda

(1) Boundary condition of water level and design high water level

Since the end of the river in the Bolgoda basin is the sea, the boundary condition is set to the mean high water spring tide level of 0.6 m. Unlike the Kalu Oya basin and the Mudun Ela sub-basin, river improvement is being completed or underway in the Weras Ganga basin, the most upstream part of the north. Therefore, the design high water level is set by the trial of hydraulic calculation (repair width, excavation depth) so as not to be inconsistent with the improvement conditions of the Weras Ganga basin.

6.4.4 Design Tidal Level

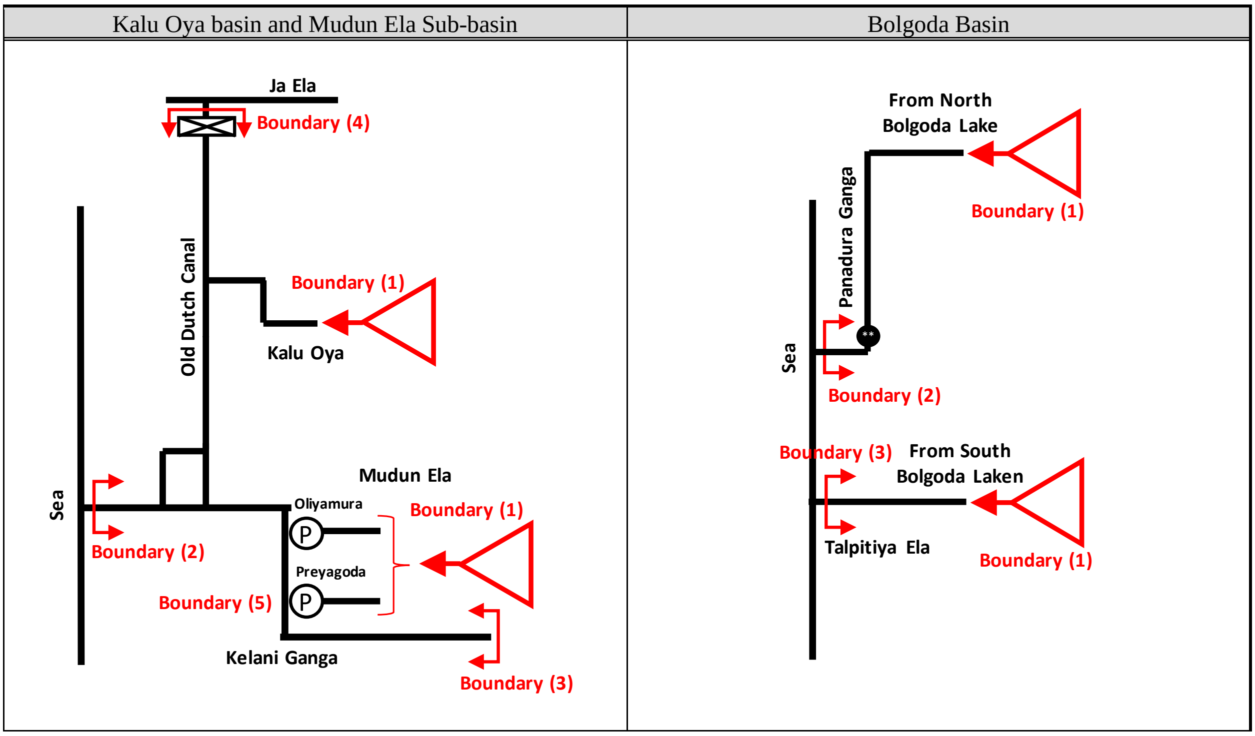
The design tide level will be the mean high water spring tide level (MSL+ 0.6 m) calculated using the recent tide level data provided by SLLDC.

6.4.5 Boundary Condition

The boundary conditions used in the planning are shown below. In addition, in order to understand the flood storage effect, it is assumed that there is flooding from each target river.

Table 6.4.2 List of Boundary Conditions

No	Condition	No	Condition
(1)	Upstream of target river： ⇒Discharge of Rainfall-Runoff analysis based on design hyetograph	(1)	Upstream of target river： ⇒Discharge of Rainfall-Runoff analysis based on design hyetograph
(2)	Kelani Ganga river mouth： ⇒Design Tide（MSL+0.6m）	(2)	Panadura Ganga river mouth ⇒Design Tide（MSL+0.6m）
(3)	Kelani Ganga Upstream： ⇒Probable discharge was calculated by observed river discharge of Kelani Ganga (Constant value).	(3)	Thalpitiya Ela river mouth： ⇒Maintaining the current status of estuary blockage due to sedimentation *There is no assumption of improvement such as excavation
(4)	Old Dutch Upstream： ⇒closing flood gate at Ja Ela confluence		
(5)	MudunEla downstream pumping station： ⇒Drain a specified discharge with the pump drain model		

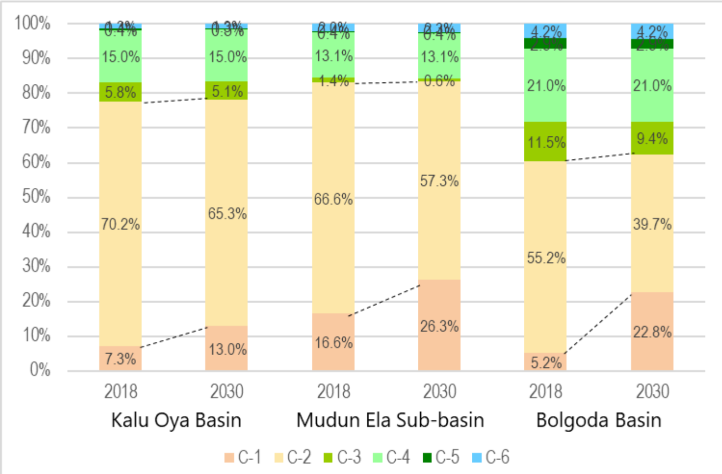


Note: No in the figure corresponds to Table 6.4.2

Figure 6.4.7 Setting Diagram of Boundary Conditions

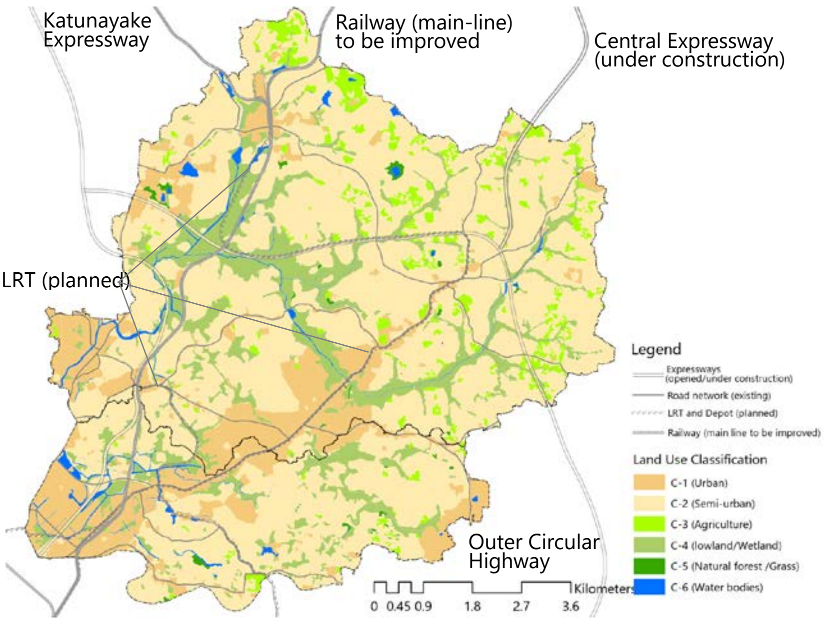
6.4.6 Future Land Use

The future land use framework for the storm water drainage plan is formulated based on the future population framework and the proposed urban structure of the WRMMP, while several proposed zones (under approval process) in development plans for DS Divisions are referred to. The changes in land use composition by share are indicated in Figure 6.4.4, and their land uses as spatial distribution patterns of the Kalu Oya basin with the Mudun Ela sub-basin and the Bolgoda basin are depicted in Figure 6.4.5 and Figure 6.4.6.



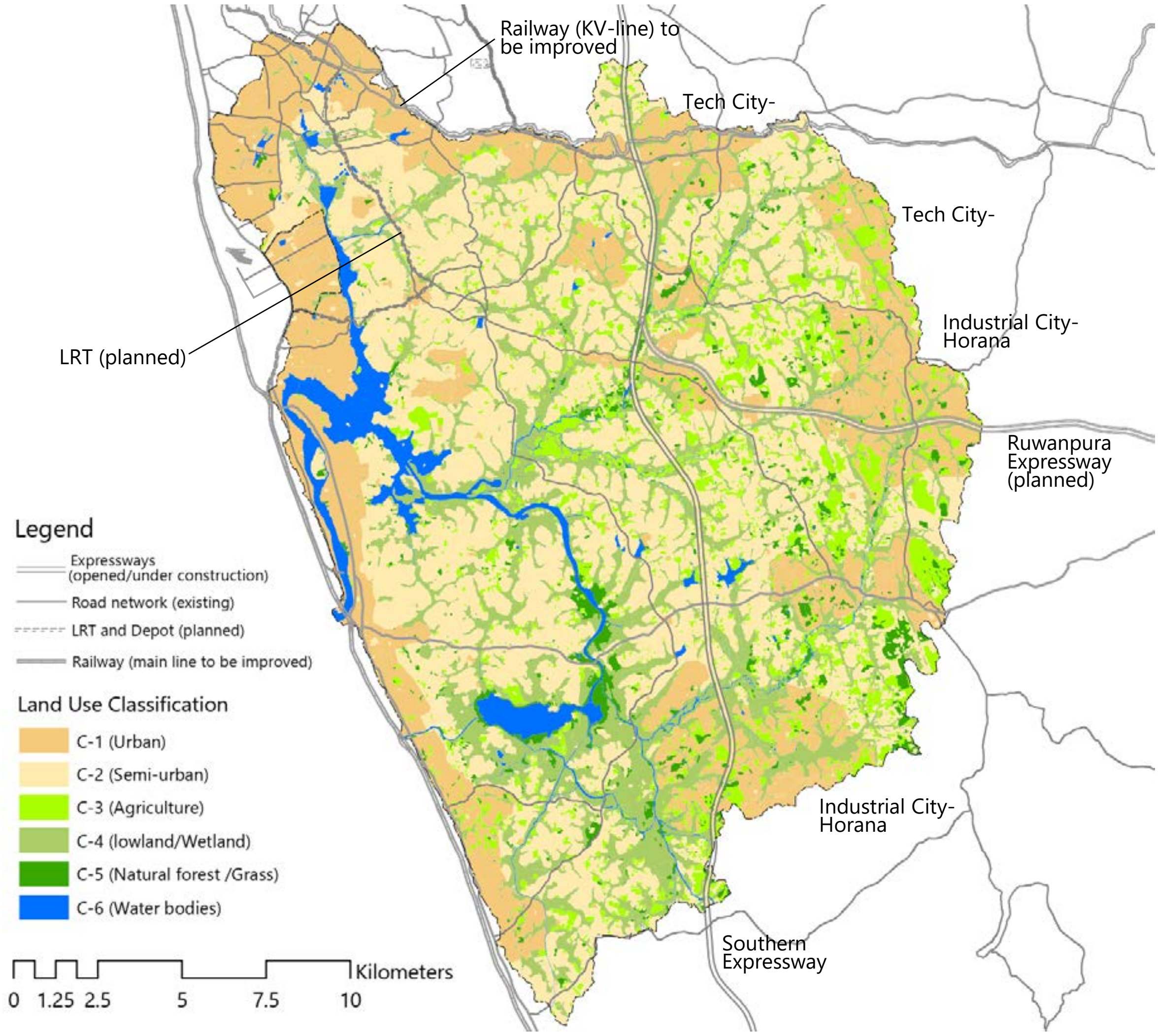
Note: C-1(urban) as a medium-high dense settlement with less green and paved surface, C-2 (semi-urban) as a low-medium settlement with green and open spaces, C-3 (agriculture) vegetable and orchards on the higher ground level, C-4 (lowland green) includes marshy area, a scrub area in lowland/wetland and paddy fields, abandoned paddy fields, C-5 (natural green) as natural forest green and grassland on hilly grounds, C-6 (water bodies) includes a river, stream, pond, lake, and tank Source: JICA Study Team

Figure 6.4.8 Future Land Use Compositions 2030 of the Kalu Oya Basin, the Mudun Ela Sub-basin and the Bologoda Basin



Source: JICA Study Team

Figure 6.4.9 Future Land Use Pattern 2030 of the Kalu Oya Basin and the Mudun Ela Sub-basin



Source: JICA Study Team

Figure 6.4.10 Future Land Use Pattern 2030 of the Bolgoda Basin

6.5 Inundation Analysis and Flood Risk Evaluation

6.5.1 Probable Discharge

Runoff analysis (with and without flooding) of the target basin was conducted using the above-mentioned design hyetograph (25-year probability).

Figure 6.5.5 and Figure 6.5.5 show the flow distribution graph. The 25-year probable discharge at the reference point in the Kalu Oya basin is about 304 m^3/s, and the discharge considering inundation is 72 m^3/s. The discharge is greatly reduced due to the flood storage effect upstream.

Similarly, the 25-year probable discharge at the reference point in Mudun Ela sub-basin is 78 m^3/s, the discharge considering flooding inundation will be reduced to 17 m^3/s, the 25-year probable discharge at the reference point in Bolgoda is 1,009 m^3/s, and the discharge considering with inundation will be reduced to 464 m^3/s. It is extremely important to consider the flood storage effect of the basins when considering countermeasures for both basins. The flow distribution map for each probable scale is shown in the appendix.

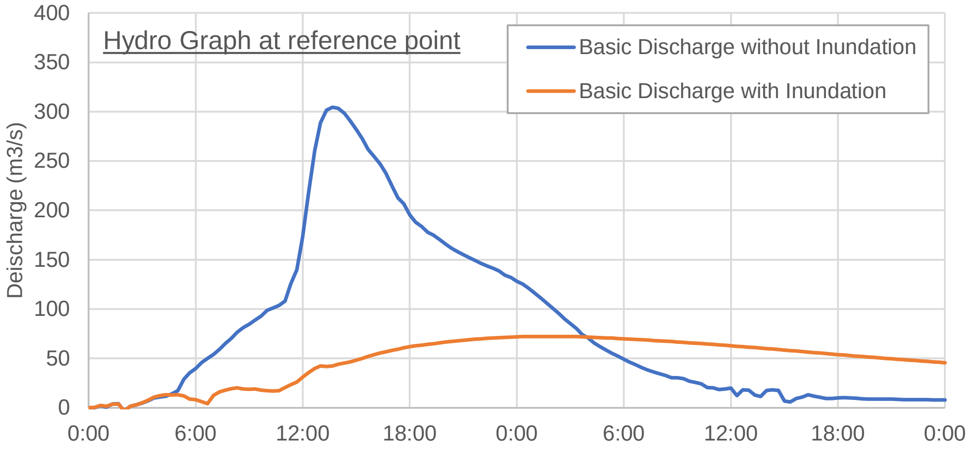


Figure 6.5.1 Hydrograph of 25-year Return Period (Kalu Oya) [Existing River Condition]

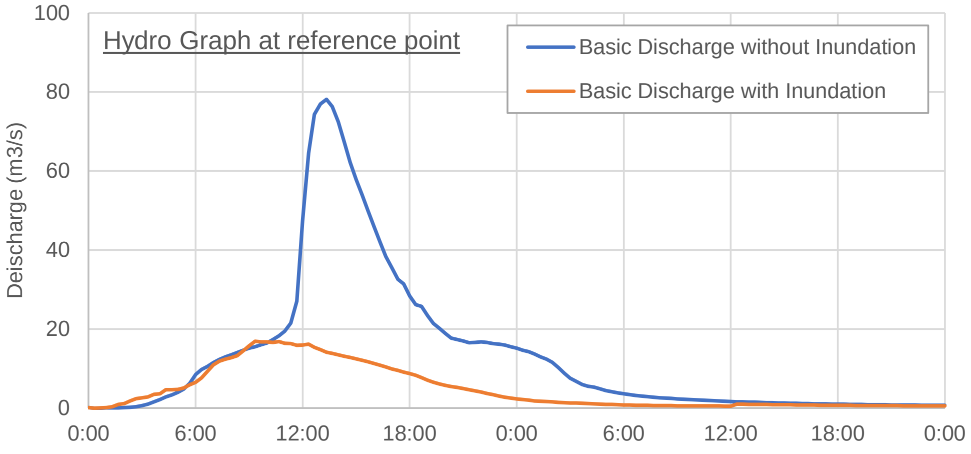


Figure 6.5.2 Hydrograph of 25-year Return Period (Mudun Ela) [Existing River Condition]

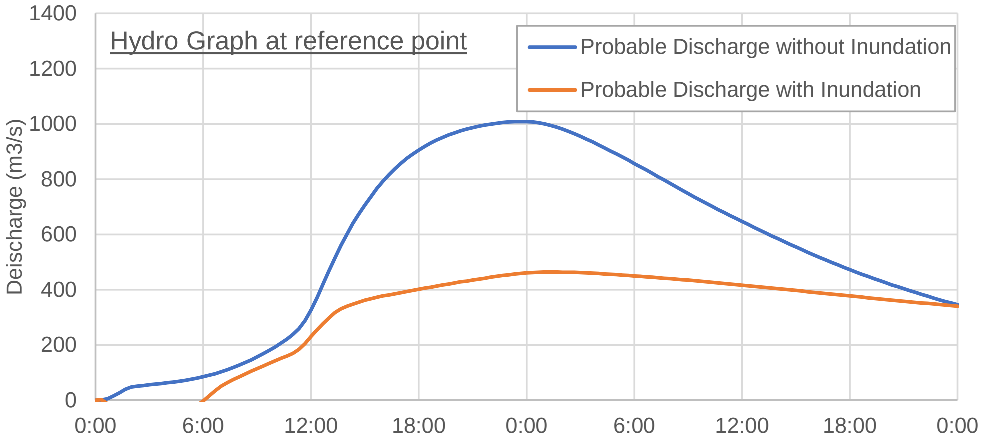


Figure 6.5.3 Hydrograph of 25-year Return Period (Bolgoda) [Existing River Condition]

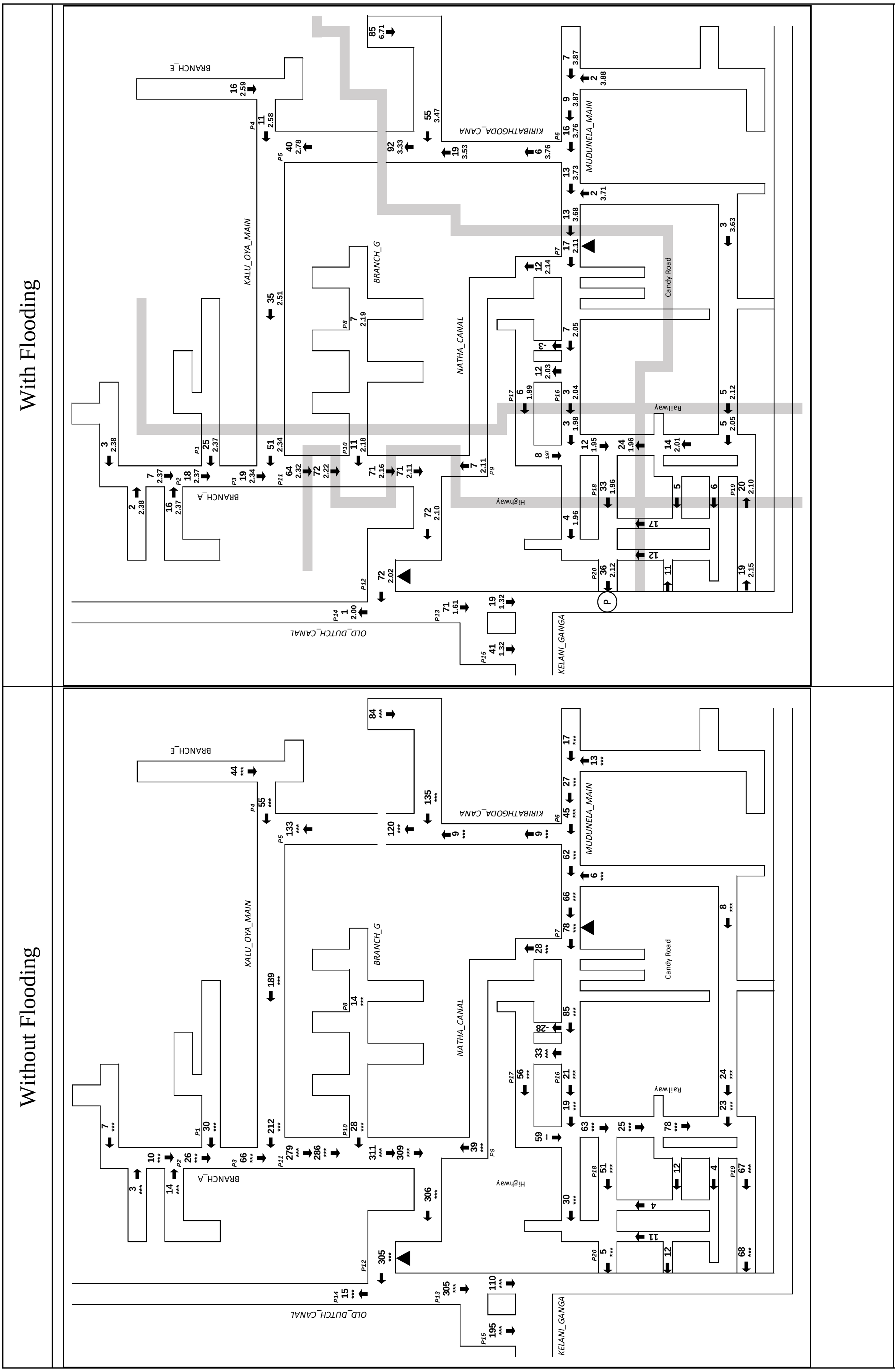


Figure 6.5.4 Flow Distribution of 25-year Return Period (Kalu Oya and Mudun Ela)【Existing River Condition】

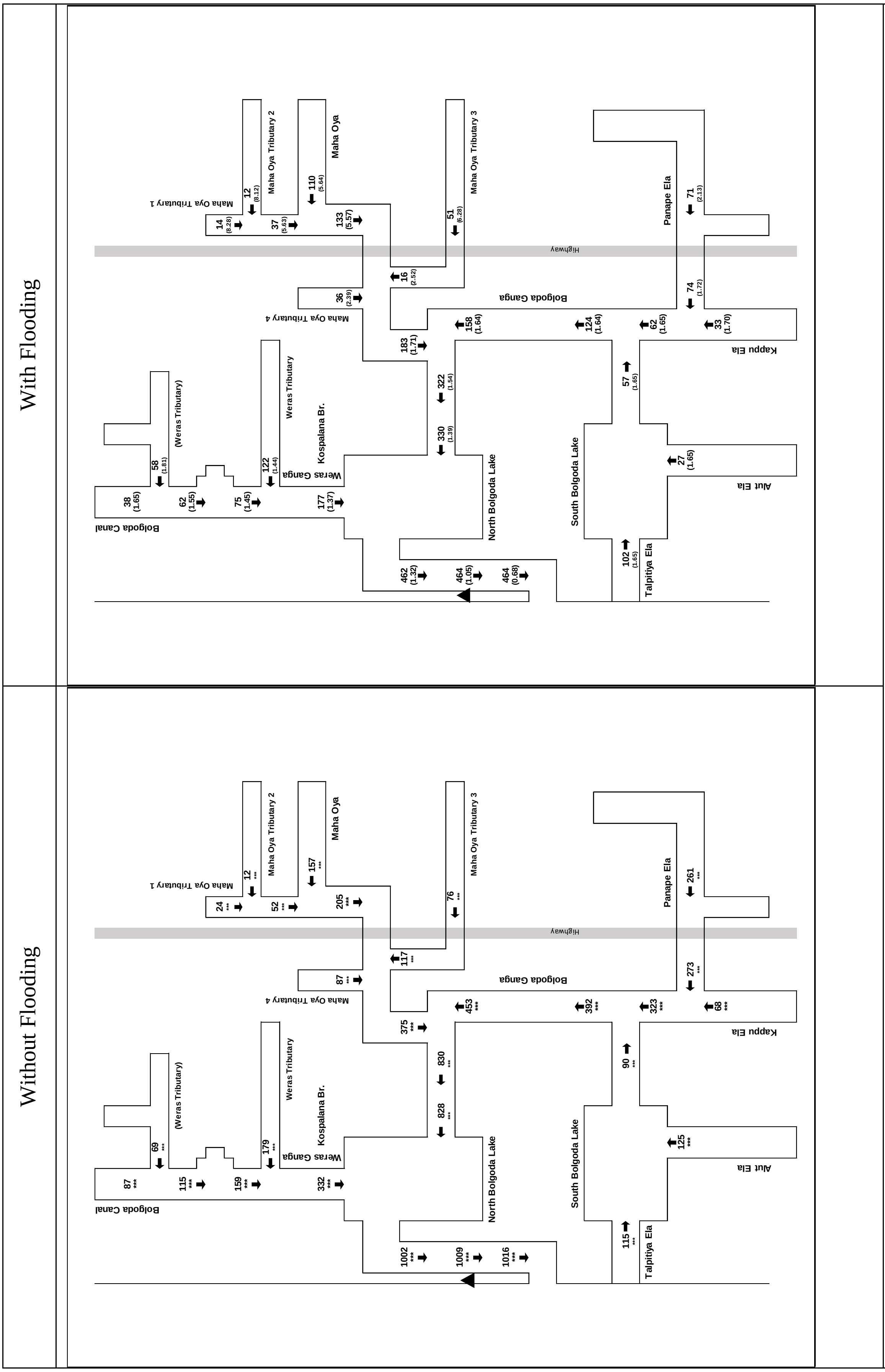


Figure 6.5.5 Flow Distribution of 25-year Return Period (Bolgoda Basin)【Existing River Condition】

6.5.2 Inundation Area of Each Probable Scale

Using the constructed flood inundation analysis model, inundation analysis was performed by probability scale. Figure 6.5.6 to Figure 6.5.11 show the calculation results of each.

6.5.3 Expected Inundation Area and Number of Houses

The inundation area for each land use was calculated by overlaying the assumed inundation area and the land use map (Table 6.5.1).

The proportion of residential areas to the total expected flooded area in the Bolgoda basin is 21.9% with a 25-year probability, but it is estimated to be 41.6% and 64.2% in the Kalu Oya basin and Mudun Ela sub-basin where assets are concentrated. Especially in the Mudun Ela sub-basin, the estimated number of inundated houses with a 25-year probability is estimated to be about 4,000 households (see Table 6.5.2(1)), which is approximately 11% of the total.

The Mudun Ela sub-basin has the highest inundation risk, and urgent storm water drainage is required. On the other hand, in the Kalu Oya basin and the Bolgoda basin, areas with high inundation risk are locally distributed, and it is considered that targeted storm water drainage measures are necessary.

Table 6.5.1 Assumed Inundation Area and Percentage by Land Use (Existing River Condition)

Kalu Oya

Land Use	2-year		5-year		10-year		25-year	
	Area(ha)	Ratio	Area(ha)	Ratio	Area(ha)	Ratio	Area(ha)	Ratio
Agricul Area	5.9	1.0%	7.0	0.9%	9.0	1.0%	13.2	1.1%
Lowland (Wetland)	407.9	66.7%	493.9	62.9%	548.4	59.8%	597.3	52.1%
Nature Area	2.0	0.3%	2.0	0.3%	2.0	0.2%	4.8	0.4%
Water Area	41.9	6.9%	46.1	5.9%	47.5	5.2%	49.4	4.3%
Settlement Area	153.9	25.2%	235.6	30.0%	310.1	33.8%	482.4	42.1%
Total	611.7	100.0%	784.7	100.0%	917.1	100.0%	1,147.1	100.0%

Mudun Ela

Land Use	2-year		5-year		10-year		25-year	
	Area(ha)	Ratio	Area(ha)	Ratio	Area(ha)	Ratio	Area(ha)	Ratio
Agricul Area	0.6	0.2%	1.4	0.3%	2.4	0.5%	4.3	0.6%
Lowland (Wetland)	135.6	34.8%	158.5	35.4%	172.2	33.0%	191.0	27.7%
Nature Area	1.3	0.3%	2.3	0.5%	2.5	0.5%	2.6	0.4%
Water Area	30.6	7.8%	32.3	7.2%	34.8	6.7%	37.8	5.5%
Settlement Area	221.7	56.9%	253.1	56.6%	310.1	59.4%	454.2	65.8%
Total	389.8	100.0%	447.6	100.0%	522.0	100.0%	689.9	100.0%

Bolgoda

Land Use	2-year		5-year		10-year		25-year	
	Area(ha)	Ratio	Area(ha)	Ratio	Area(ha)	Ratio	Area(ha)	Ratio
Agricul Area	316.3	10.0%	476.0	9.0%	544.4	8.4%	617.5	8.1%
Lowland (Wetland)	1,867.7	59.0%	3,213.7	60.7%	3,882.4	60.0%	4,435.8	58.3%
Nature Area	167.4	5.3%	279.6	5.3%	343.2	5.3%	404.0	5.3%
Water Area	427.4	13.5%	542.8	10.3%	606.0	9.4%	649.4	8.5%
Settlement Area	388.2	12.3%	782.1	14.8%	1,099.2	17.0%	1,499.2	19.7%
Total	3,167.0	100.0%	5,294.2	100.0%	6,475.2	100.0%	7,606.0	100.0%

Table 6.5.2 (1) Estimated Number of Damaged Houses and Proportion by Inundation Depth (Existing River Condition)

Kalu Oya

Flood Depth (m)	2-year		5-year		10-year		25-year	
	Number of Houses	Ratio	Number of Houses	Ratio	Number of Houses	Ratio	Number of Houses	Ratio
0.0-0.1	236	35.6%	455	38.3%	554	31.3%	871	24.7%
0.1-0.5	393	59.2%	628	52.8%	924	52.3%	1,762	50.0%
0.5-1.0	35	5.3%	106	8.9%	290	16.4%	688	19.5%
1.0-1.5	0	0.0%	0	0.0%	0	0.0%	203	5.8%
1.5-2.0	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2.0-	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total	664	100.0%	1,189	100.0%	1,768	100.0%	3,525	100.0%

Mudun Ela

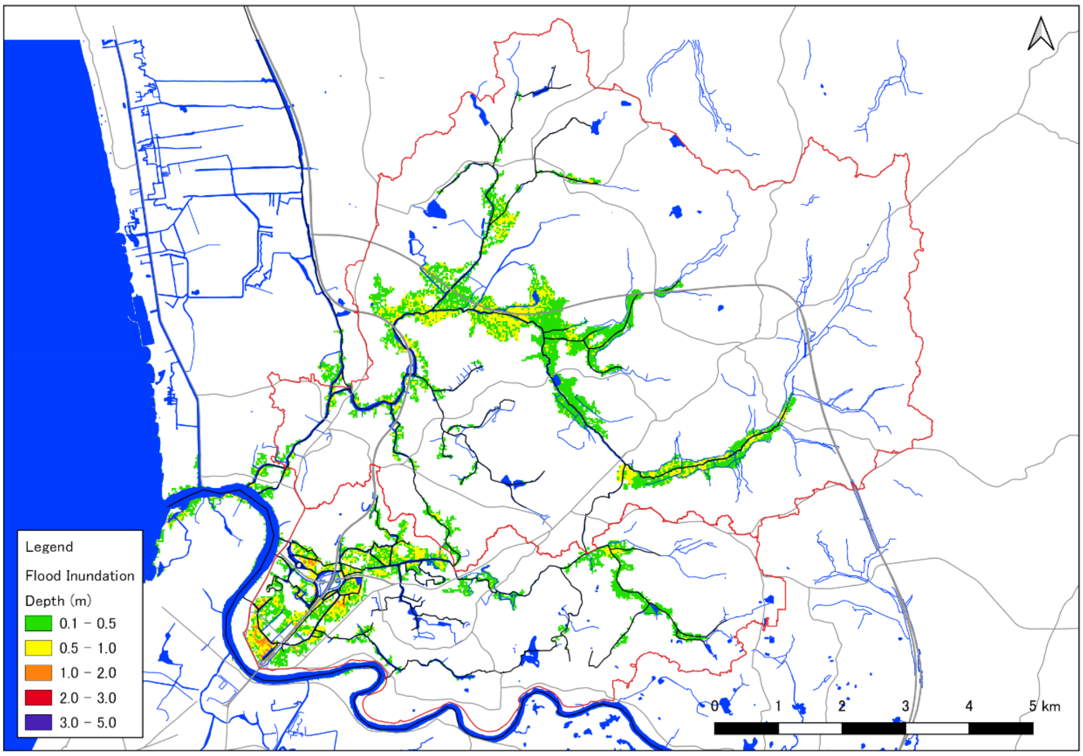
Flood Depth (m)	2-year		5-year		10-year		25-year	
	Number of Houses	Ratio	Number of Houses	Ratio	Number of Houses	Ratio	Number of Houses	Ratio
0.0-0.1	480	38.6%	589.4	28.5%	795	24.5%	1,170	17.7%
0.1-0.5	1,037	58.5%	1,110.0	58.4%	1,297	54.0%	2,304	48.6%
0.5-1.0	197	3.0%	216.6	13.0%	259	20.7%	519	25.4%
1.0-1.5	0	0.0%	0	0.1%	0	0.8%	0	8.2%
1.5-2.0	0	0.0%	0	0.0%	0	0.0%	0	0.1%
2.0-	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total	1,714	100.0%	1,916	100.0%	2,351	100.0%	3,993	100.0%

Bolgoda

Flood Depth (m)	2-year		5-year		10-year		25-year	
	Number of Houses	Ratio	Number of Houses	Ratio	Number of Houses	Ratio	Number of Houses	Ratio
0.0-0.1	40	11.0%	70	7.2%	55	2.7%	158	4.1%
0.1-0.5	252	70.0%	515	53.0%	1,052	52.1%	1,909	49.0%
0.5-1.0	32	8.9%	173	17.9%	373	18.4%	665	17.1%
1.0-1.5	36	10.0%	171	17.6%	487	24.1%	1,018	26.1%
1.5-2.0	1	0.2%	42	4.3%	44	2.2%	129	3.3%
2.0-	0	0.0%	0	0.0%	10	0.5%	17	0.4%
Total	360	100.0%	971	100.0%	2,021	100.0%	3,897	100.0%

Table 6.5.2 (2) Estimated Number of Damaged Houses and Proportion in the Basin (Existing River Condition)

Target Basin	2-year		5-year		10-year		25-year		Number of Houses in Target Basin (5)
	Number of Houses (1)	Ratio (1)/(5)	Number of Houses (2)	Ratio (2)/(5)	Number of Houses (3)	Ratio (3)/(5)	Number of Houses (4)	Ratio (4)/(5)	
Kalu Oya	664	1.0%	1,189	1.7%	1,768	2.5%	3,525	5.1%	69,360
Mudun Ela	1,714	4.8%	1,916	5.4%	2,351	6.6%	3,993	11.2%	35,710
Bolgoda	360	0.1%	971	0.3%	2,021	0.7%	3,897	1.3%	304,315



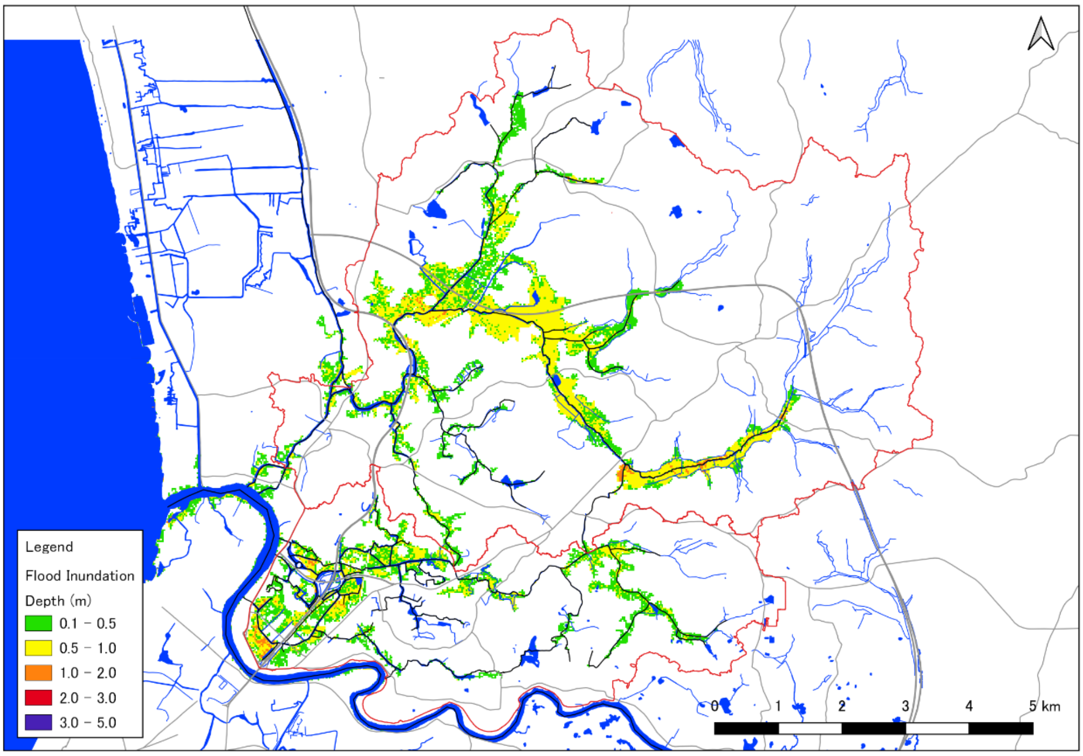
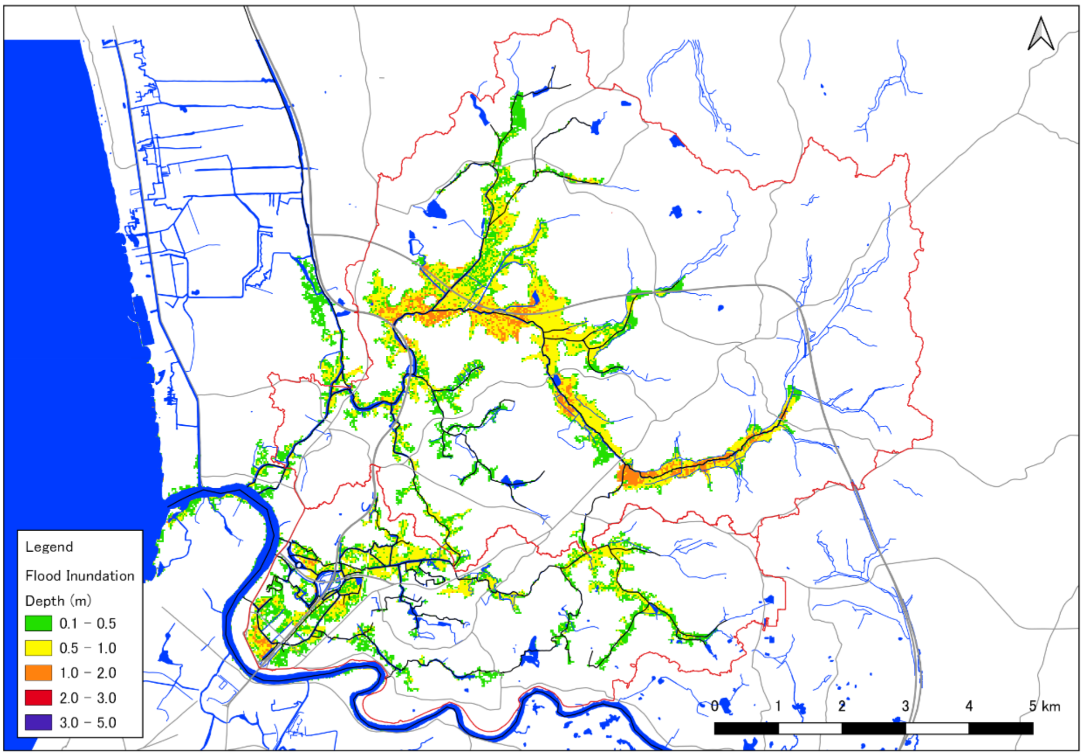


Figure 6.5.6 Result of Inundation Analysis in the Kalu Oya Basin
(upper: 2-year return period, lower: 5-year return period) (Existing river condition)



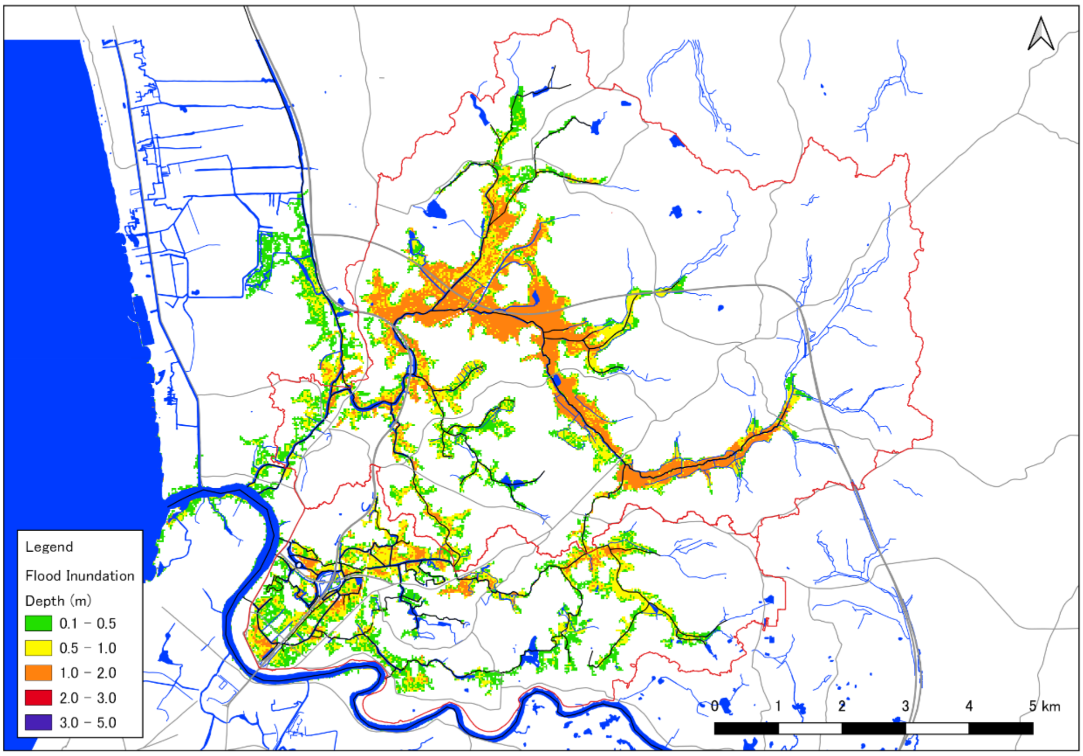


Figure 6.5.7 Result of Inundation Analysis in the Kalu Oya Basin (upper: 10-year return period, lower: 25-year return period) (Existing river condition)

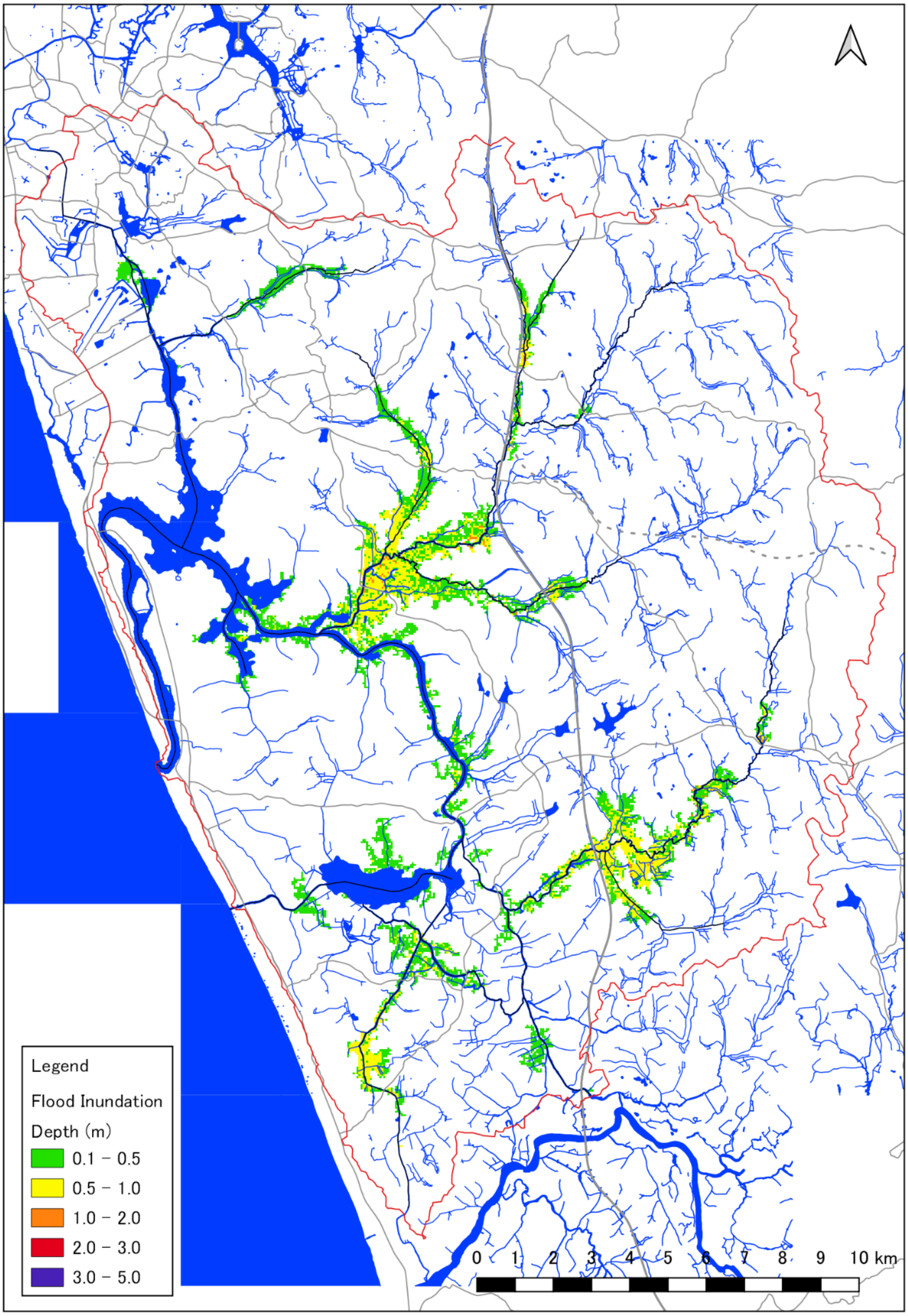


Figure 6.5.8 Result of Inundation Analysis in the Bolgoda Basin (2-year return period) (Existing river condition)

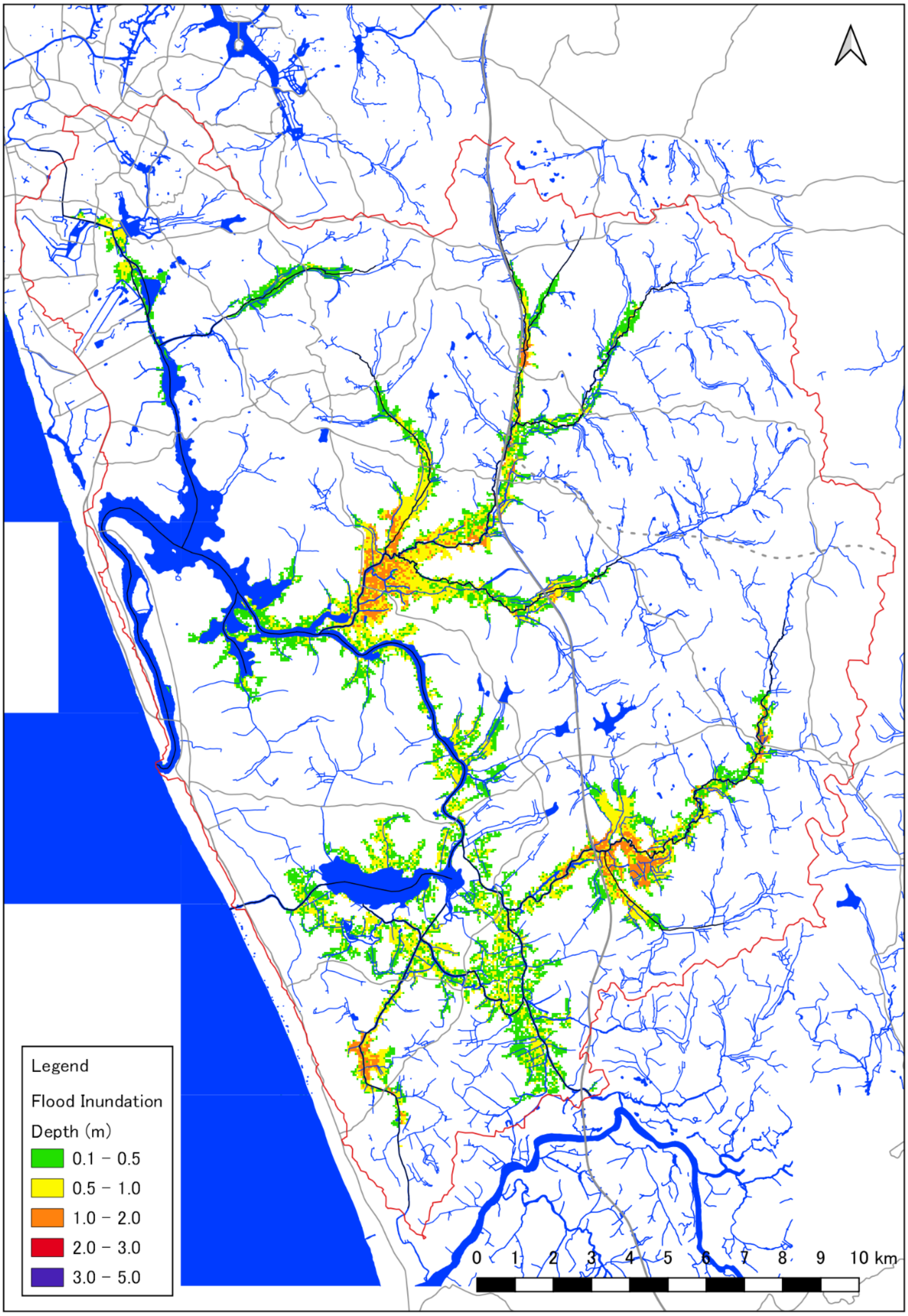


Figure 6.5.9 Result of Inundation Analysis in the Bolgoda Basin (5-year return period) (Existing river condition)

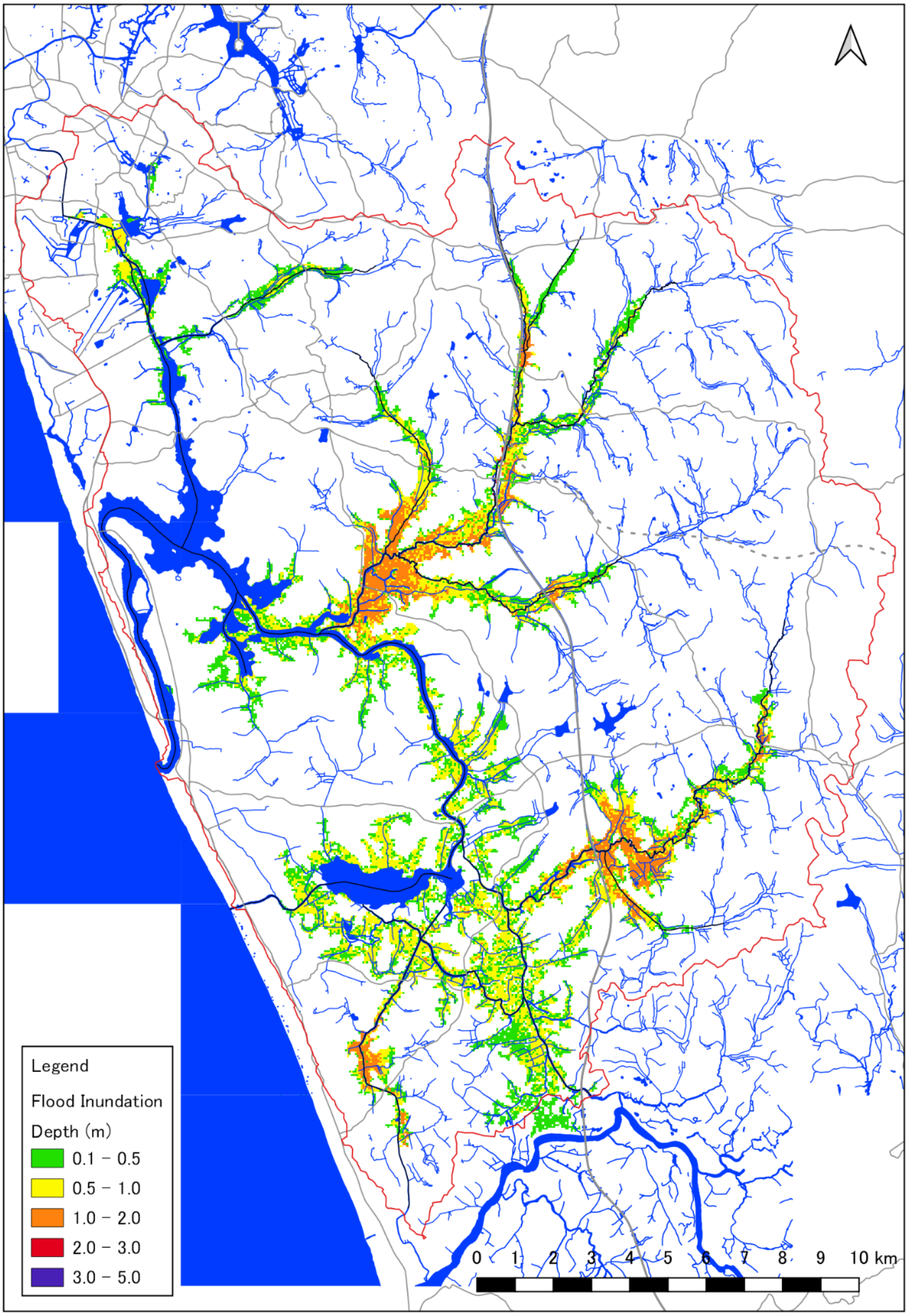


Figure 6.5.10 Result of Inundation Analysis in the Bolgoda Basin (10-year return period) (Existing river condition)

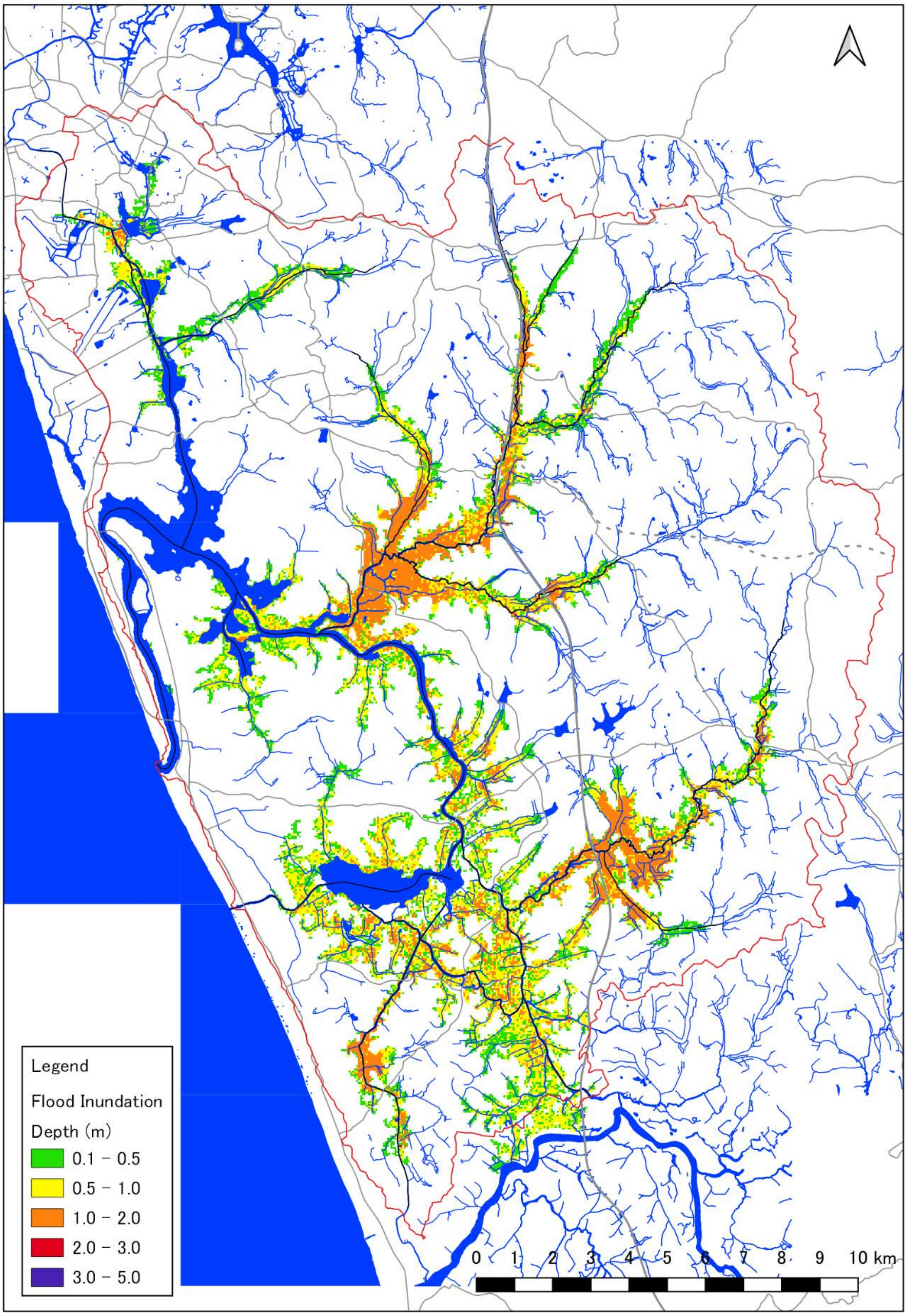


Figure 6.5.11 Result of Inundation Analysis in the Bolgoda Basin (25-year return period) (Existing river condition)

6.5.4 Calculated Water Level by Probability Scale

The location of the major canal is shown below and the water level profile of the major canal is shown in Figure 6.5.13.

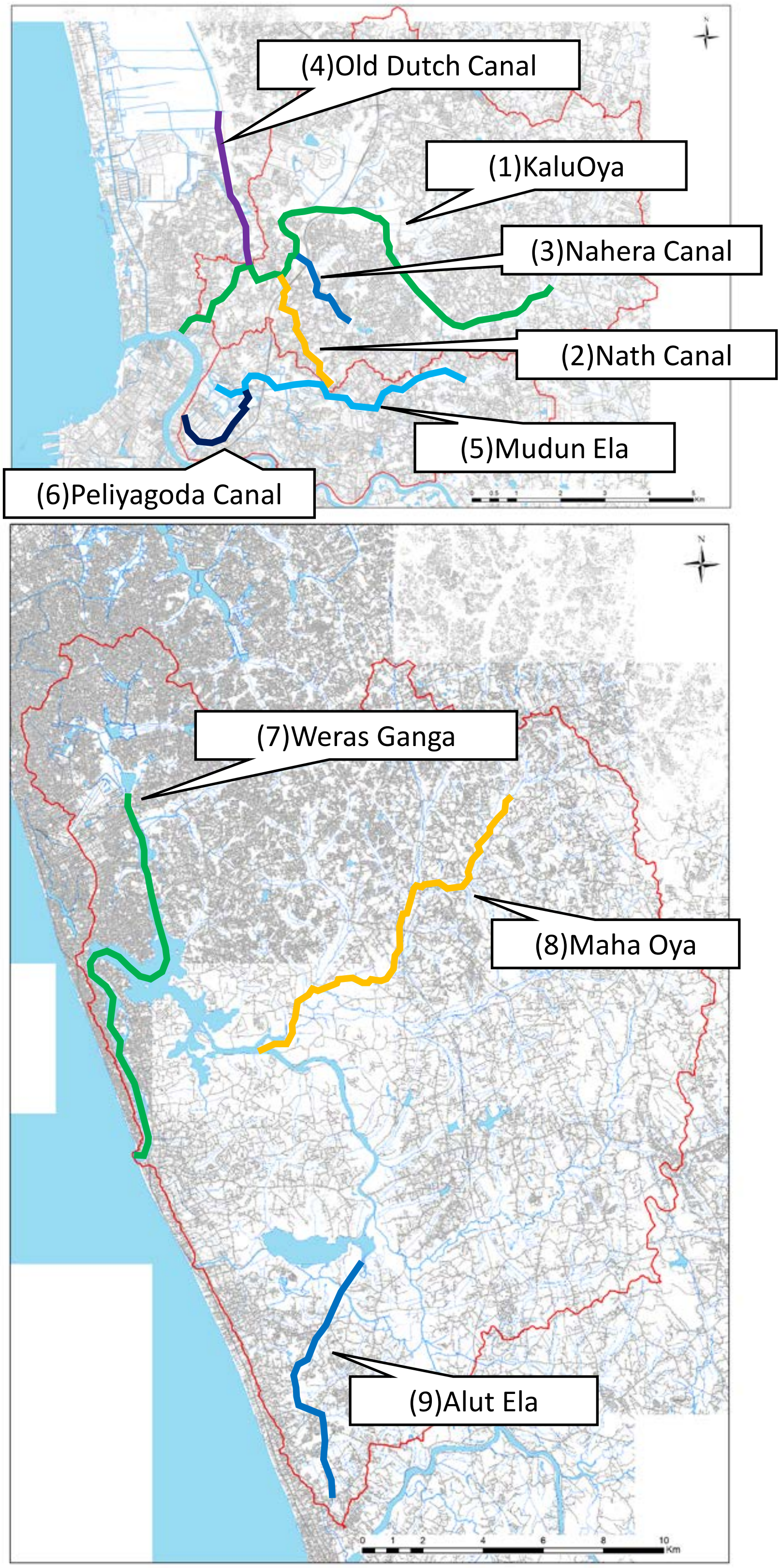
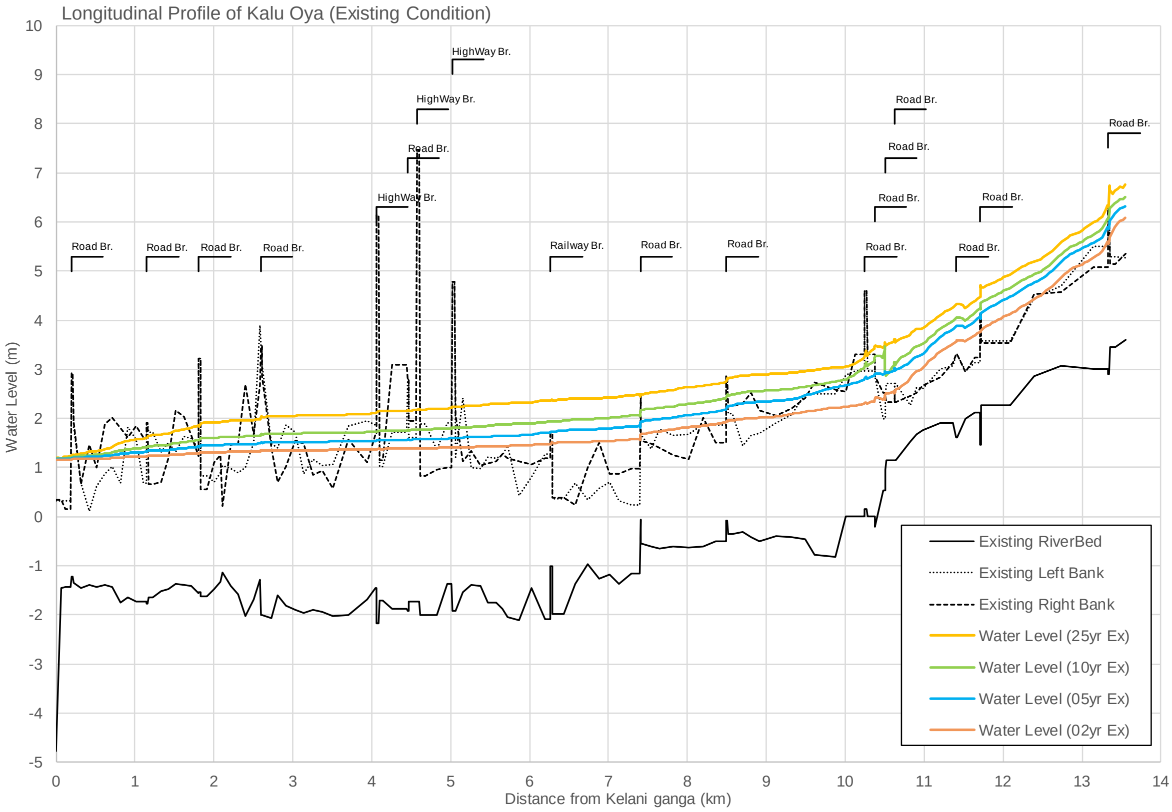


Figure 6.5.12 Location of Major Canal in the Kalu Oya Basin and the Bolgoda Basin



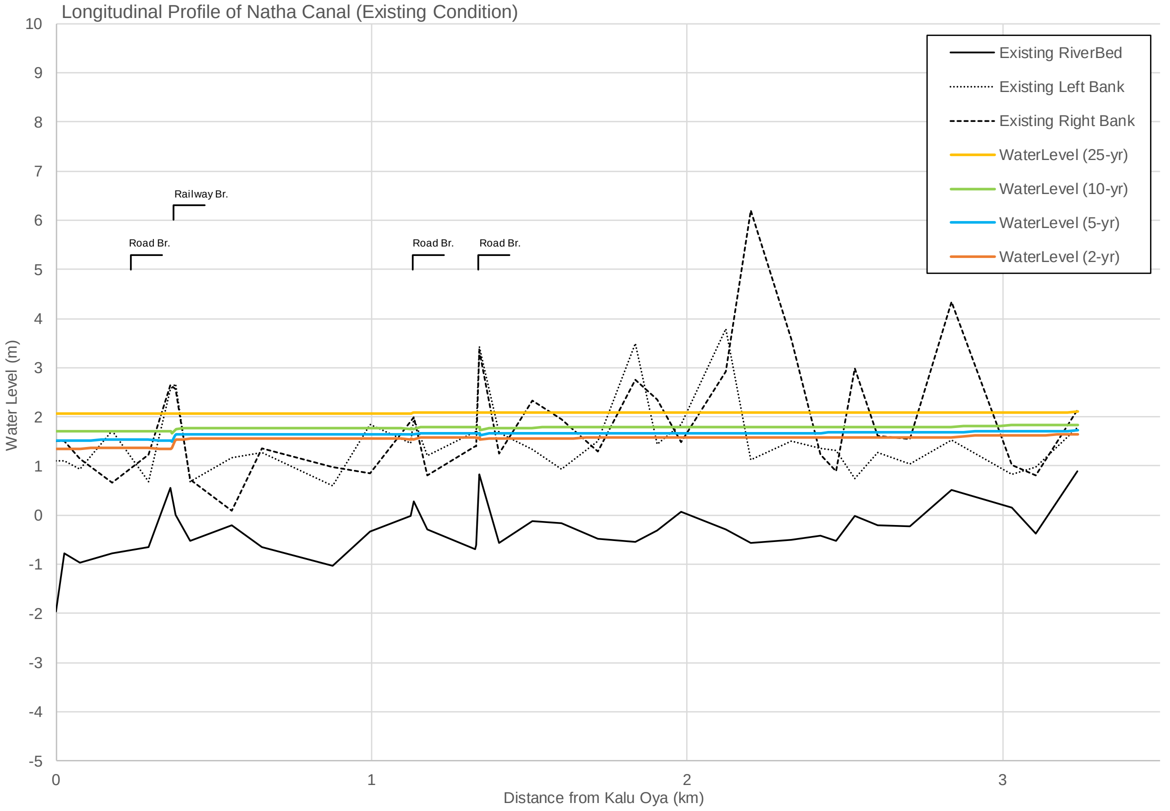
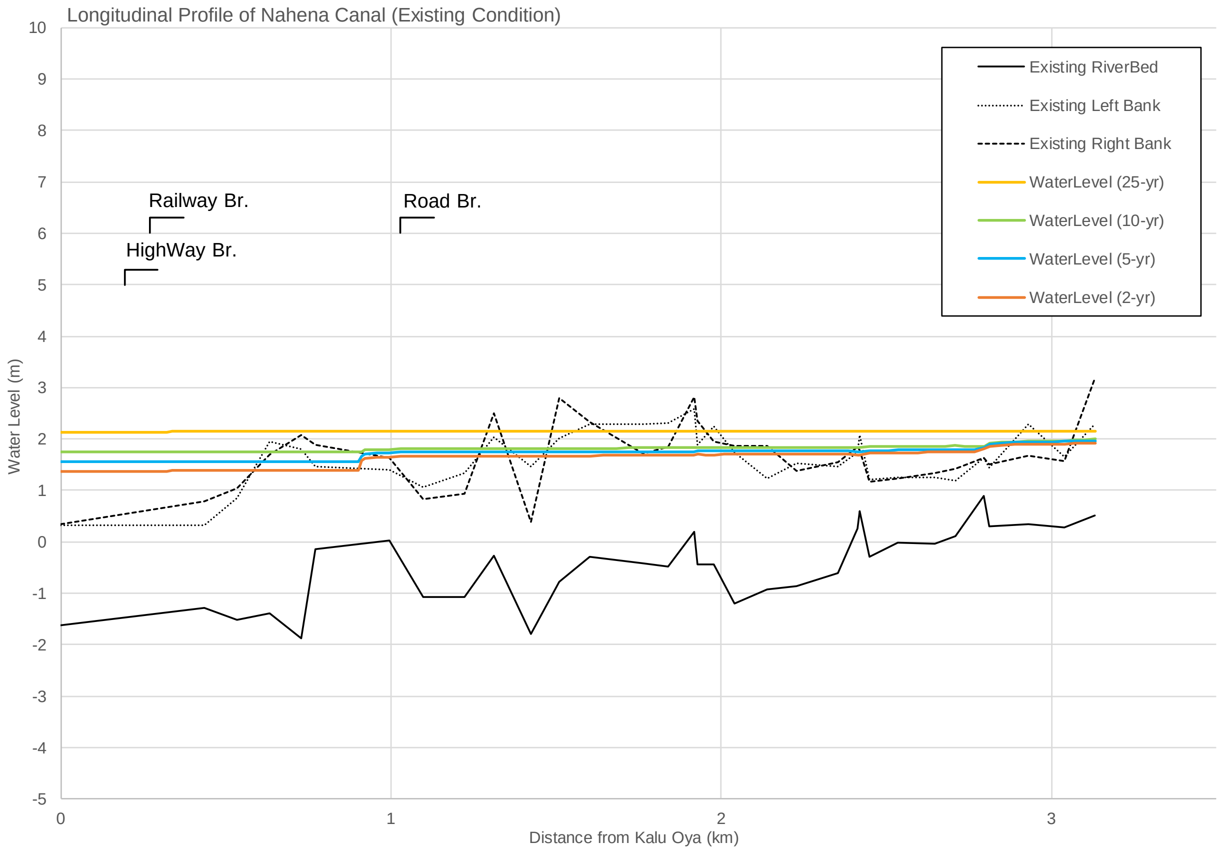


Figure 6.5.13 (1) Water Level Profile by Probability Scale (upper: Kalu Oya, lower: Natha Canal) Existing Condition



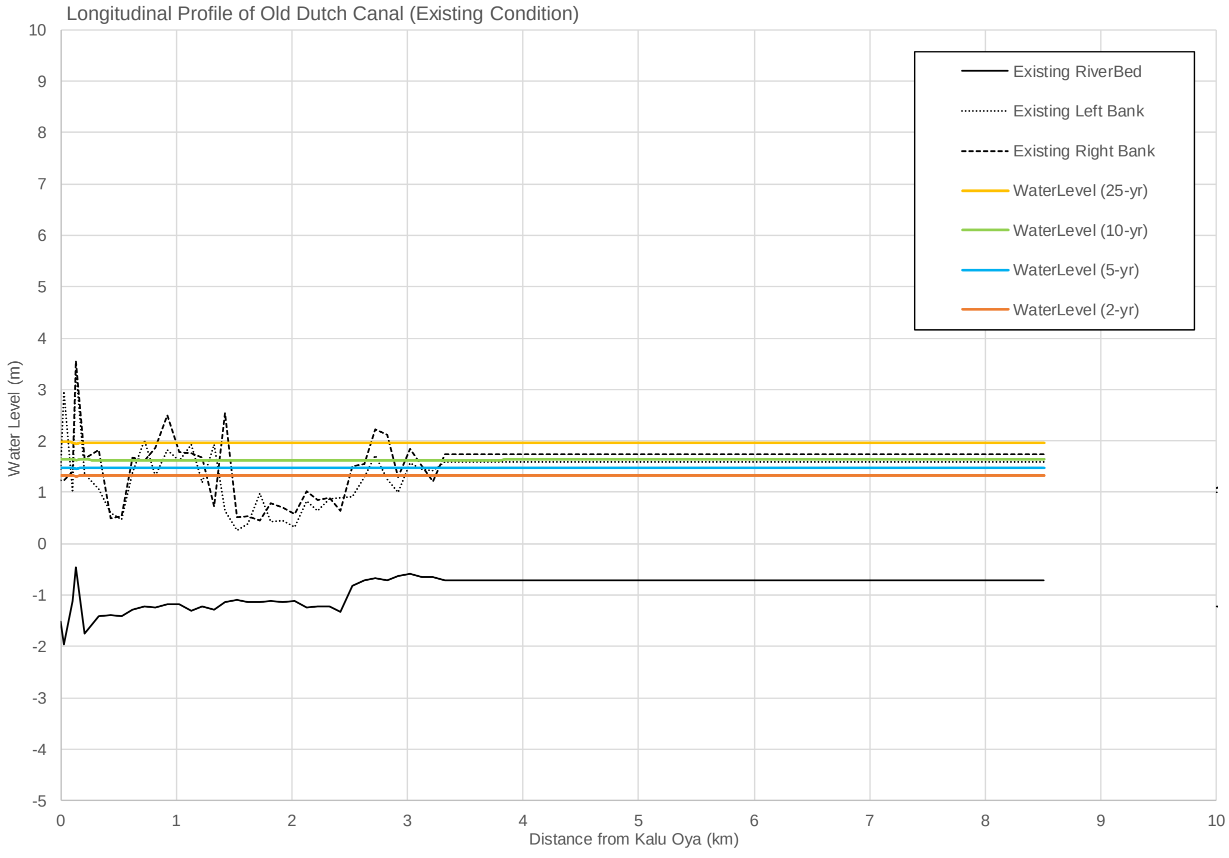
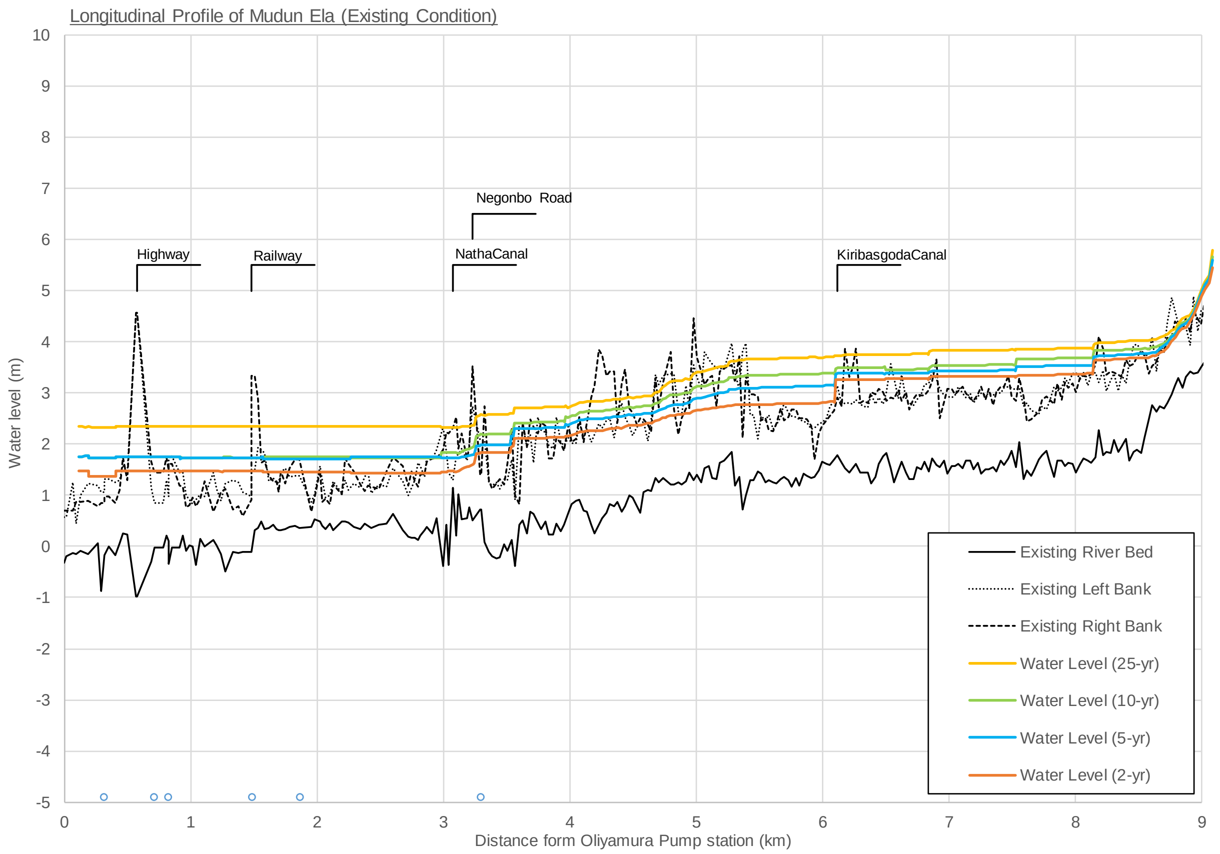


Figure 6.5.13(2) Water Level Profile by Probability Scale
(upper: Nahena Canal, lower: Old Dutch Canal) Existing Condition



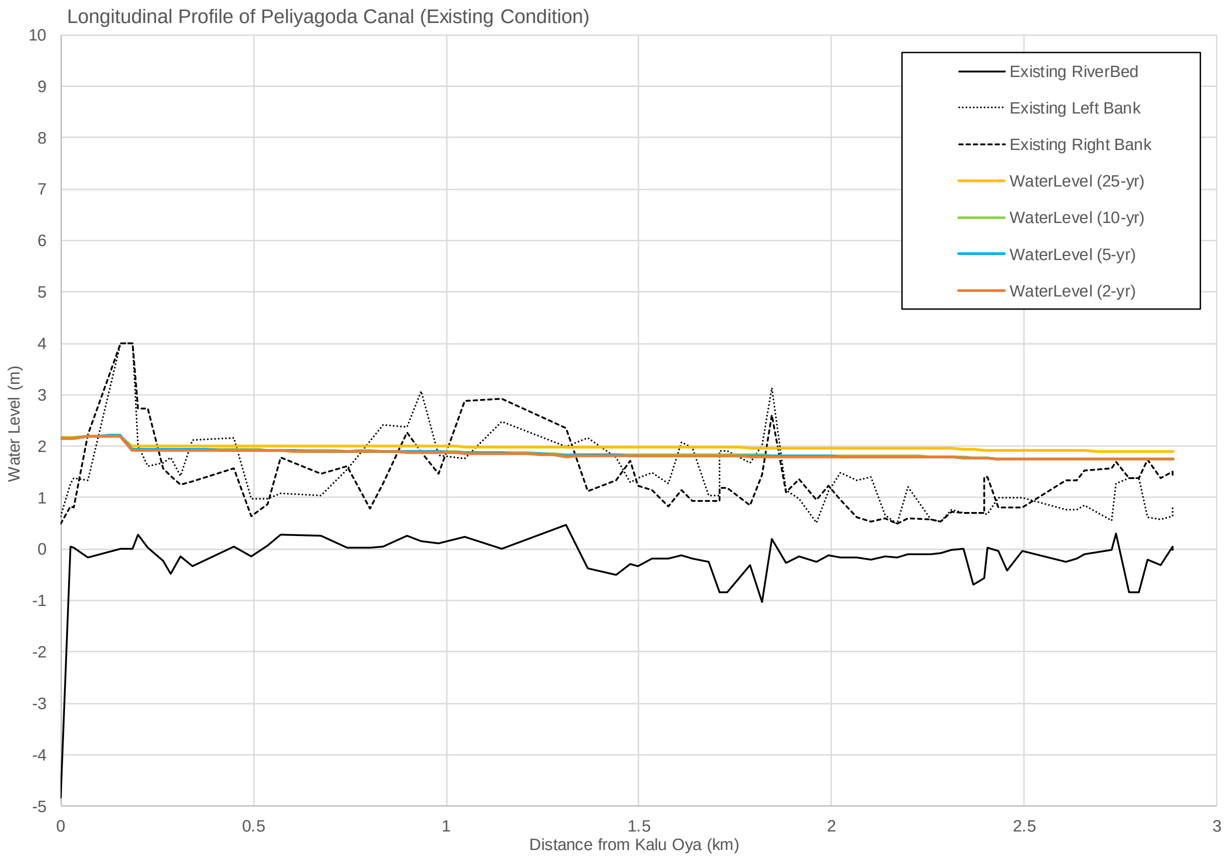
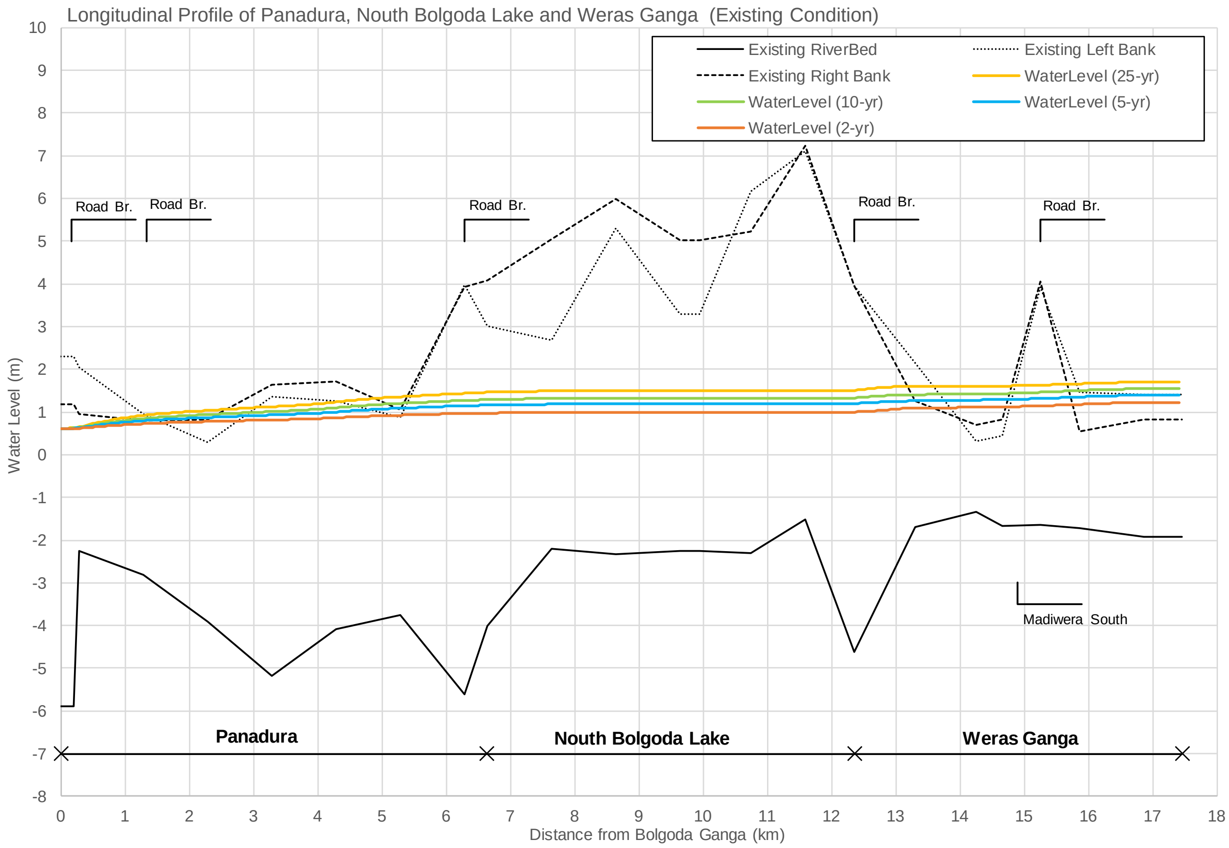


Figure 6.5.13 (3) Water Level Profile by Probability Scale
(upper: Mudun Ela, lower: Peliyagoda **Canal) Existing Condition**



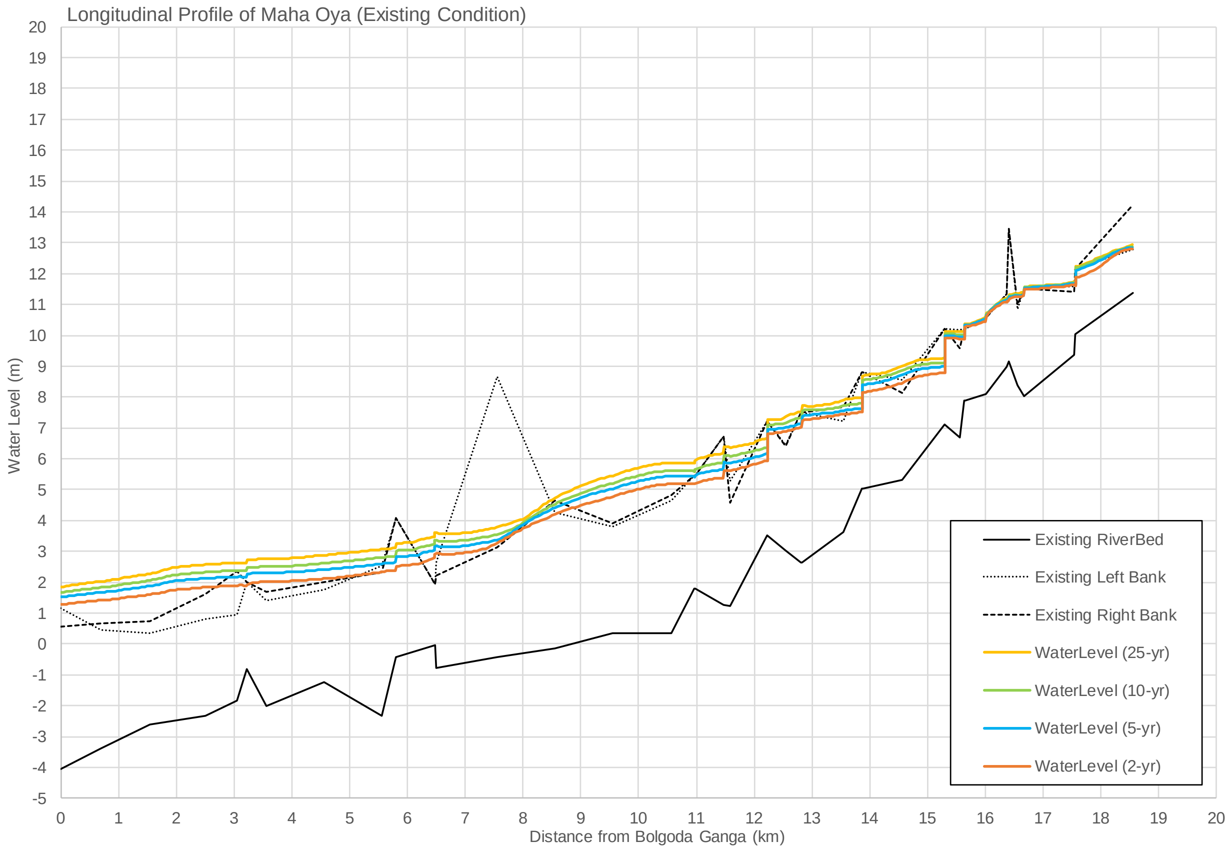


Figure 6.5.13 (4) Water Level Profile by Probability Scale
(upper: Weras Ganga, lower: Maha Oya) Existing Condition

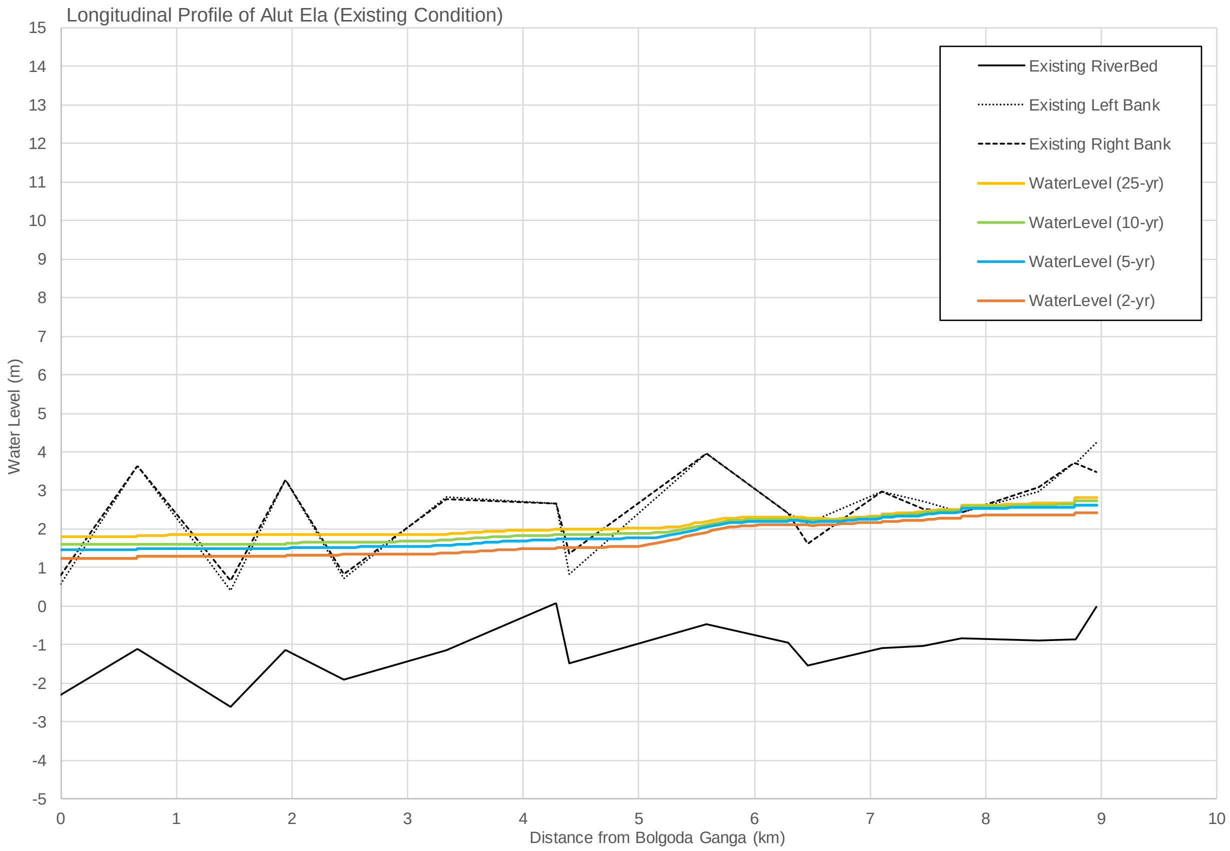


Figure 6.5.13 (5) Water Level Profile by Probability Scale (Alut Ela) Existing Condition

6.5.5 Climate Change Assessment for Floof Risk

6.5.5.1 Caluculation Condition

The impact of climate change on inundation risk was evaluated using the inundation analysis model concerning two scenarios, SSP2-4.5 and SSP5-8.5, which fall under RCP4.5 (medium greenhouse gas emissions scenario) and RCP8.5 (high greenhouse gas emissions scenario), as shown in Section 2.8. Verification was conducted for two scenarios, SSP2-4.5 and SSP5-8.5. The increased rainfall conditions and downstream water level conditions due to sea level rise are shown in Table 6.5.3.

Table 6.5.3 Rainfall and water level conditions taking into climate change impacts

Scenario	Daily rainfall	Water Level at the downstream end
Existing	358.70 mm	+0.000 m
SSP2-4.5	373.33 mm (+4.1%)	+0.093 m
SSP5-8.5	367.41 mm (+2.4%)	+0.101 m

6.5.5.2 Calculation Result

Referring to the climate change scenarios from the 6th IPCC report, a change of 2.4-4.1% in daily rainfall and a change of about 0.1 m in sea level rise (downstream edge water level) were applied to the inundation analysis model. Figure 6.5.14 shows a longitudinal water level cross section of the Kalu Oya main river and Figure 6.5.15 shows the assumed inundation area map. The river level is affected up to more than 10 km upstream due to the increase in flow with increased rainfall and the rise in water level at the end Similarly, the inundation area was found to change slightly.

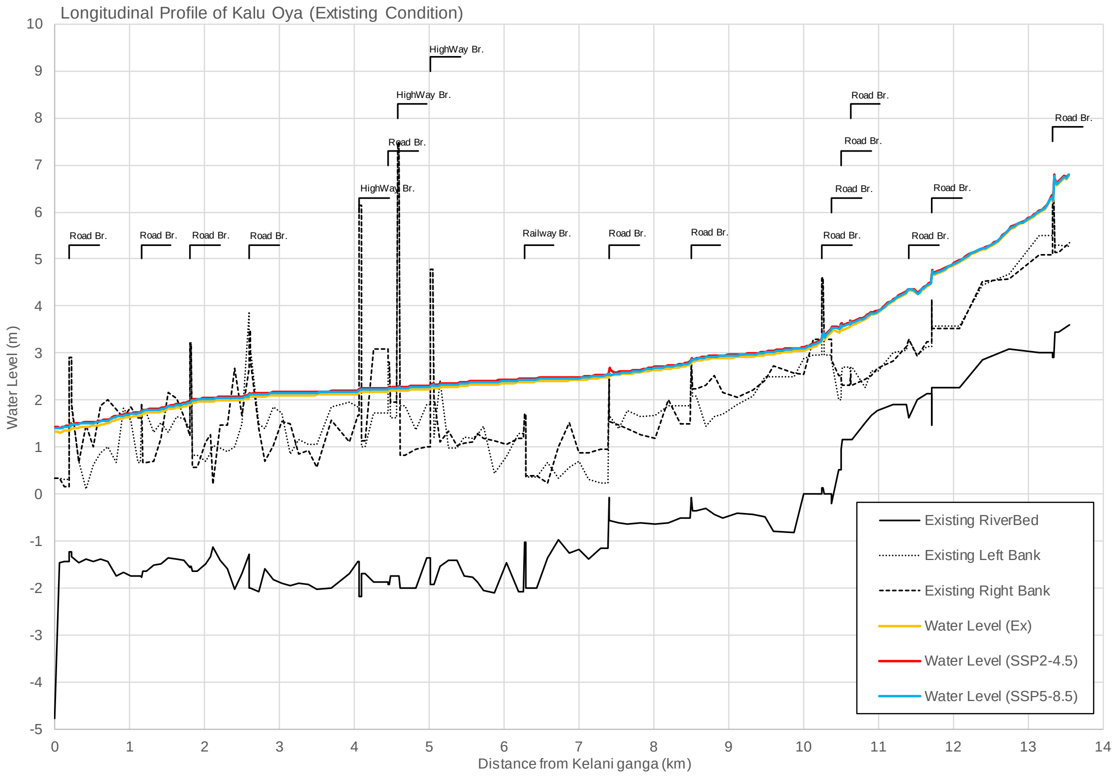
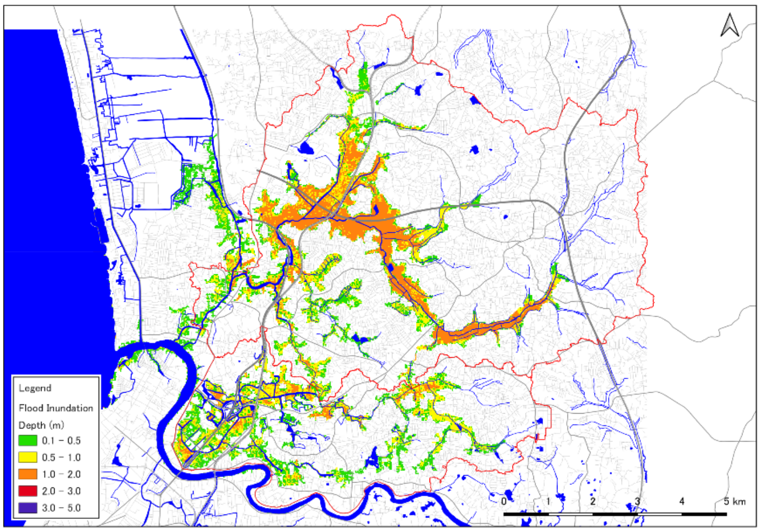
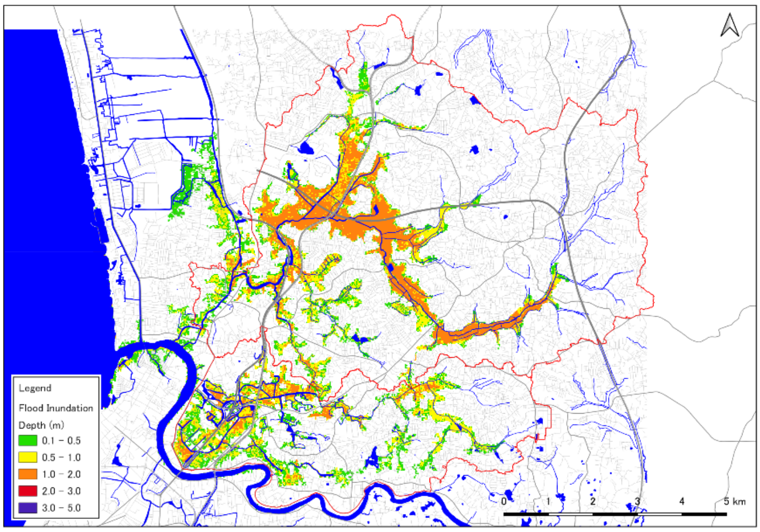


Figure 6.5.14 Longitudinal Water Level of Kalu Oya Main River

Existing Condition



SSP2-4.5 Scenario



SSP5-8.5 Scenario

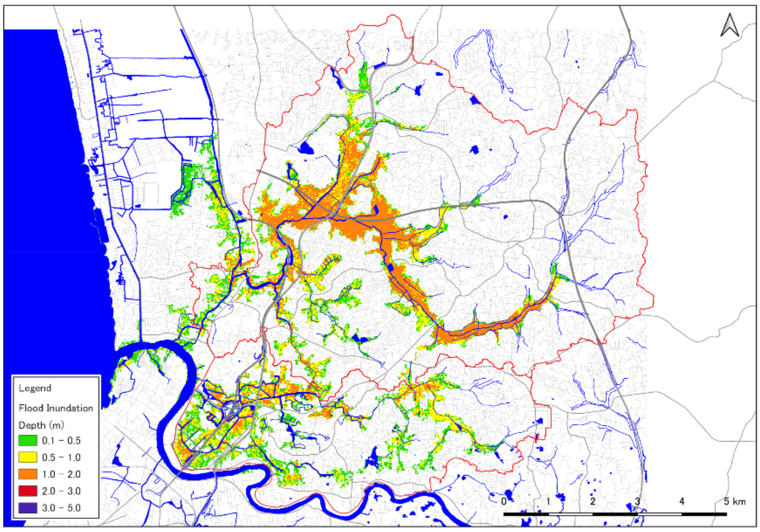


Figure 6.5.15 Assumued Inundation Map Affected Climate Change Impact

6.6 Study on Countermeasure for Storm Water Drainage

6.6.1 Basic Concept of Storm Water Drainage Plan

6.6.1.1 Basic Concept of the Kalu Oya Basin

(1) Policy for reviewing countermeasures in the previous study

A big difference could be recognized in effect among the single measure. Among the countermeasures proposed in 2018 F/S, the following selection criteria were considered in order to identify effective countermeasures in this study.

- The wide extent of effects
- Construction is relatively easy and there are few social and environmental problems.

The following is an evaluation of individual measures in due consideration of these selection criteria.

The evaluation results of each countermeasure in the past study as shown in Table 6.6.1 and Table 6.6.2. Each countermeasure will be examined and evaluated, and a comparative study of alternatives that can eliminate these drawbacks will be carried out in Chapter 6 to propose the optimum plan of storm water drainage plan.

1) Widening of Channel Constriction (12 bridges and culverts)

It is an essential item for improvement works, but as shown in Table 6.6.1, wide-extent effects cannot be expected. It can be said that it is a suitable measure against local flooding issues upstream of the structure. In particular, railway bridges should be recommended the necessary improvement specifications for railway electrification work that will begin shortly. In addition, many culverts have formed abruptly constricted sections from the field survey, and their expansion is indispensable.

2) Upstream Tank Improvement (Kapua and Paralanda reservoirs)

This improvement is effective for local flooding in the immediate downstream areas. However, it is important to fully consider the strength of the existing earth dam, the protection of the surrounding dike against over-banking flooding, and the design of the proper outlet works considering the reservoir storage.

3) Kalu Oya Improvement, Natha Canal Improvement, Nahena Canal Improvement

Improvement of Kalu Oya and improvement of Natha Canal and Nahena Canal, which are tributaries of Kalu Oya, are extremely effective as countermeasures for the Kalu Oya basin. JICA 2003 M/P also proposes the improvement of Kalu Oya as a countermeasure menu. In this study, the target channel that needs to be improved, the improved sections, and the improvement specifications will be reviewed referring to 2018 F/S.

4) Dutch Canal Improvement

The Old Dutch Canal will be improved as a connection to the Muthurajawela Flood diversion. However, this flood diversion plan was rejected at JICA 2003 M/P due to technical and social problems, and the route was revised at 2018F/S. However, the technical and social issues remained. Therefore, in this study, a new connection and diversion route to the Old Dutch Canal will be examined and the Old Duch Canal improvement will be reviewed.

5) Muthurajawela Diversion

As mentioned above, the Muthurajawela diversion was considered by JICA2003M/P, but the flood diverting route passes through the intersection of Colombo Katunayake Expressway and Negombo-Colombo Road, which has social impacts and technical/engineering issues. It was rejected due to general difficulty.

However, it was taken up again in 2018 F/S, but due to the difficulty of moving houses along the

Expressway and underpass of Negombo-Colombo Road, this plan is not expected to be realistic. However, since it is expected that the discharge reduction by the diversion channel is an effective countermeasure, the new connection and diversion route will be examined in this study.

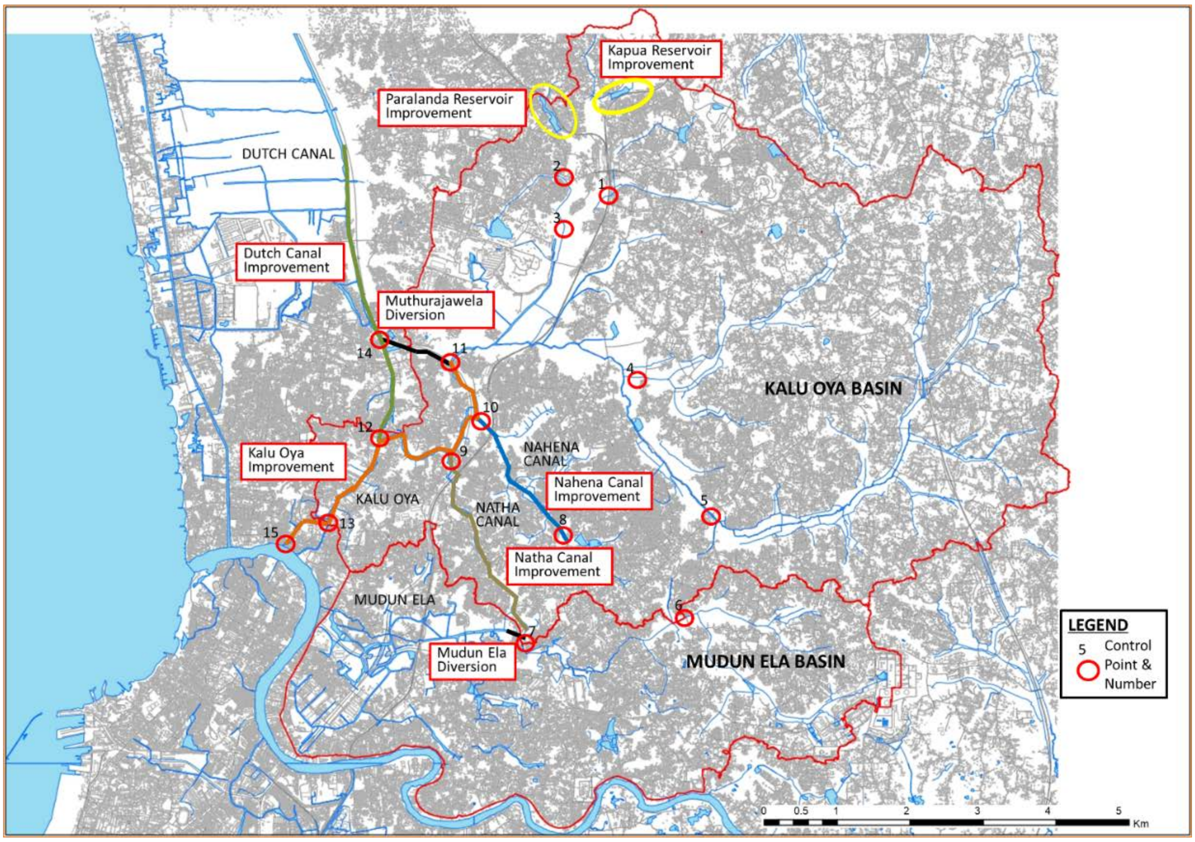
6) Mudun Ela Diversion

In 2018F/S, as shown in Table 6.6.1, the water level reduction effect was obtained at three representative points in the basin, and the basin change due to the improvement of the connecting waterway has a hydraulic effect. Although not considered in JICA 2003 M/P, in this study, the specifications of the renovation of the connecting waterway and the specifications of the gate for dividing the basin will be examined referring to the results of 2018 F/S.

7) Hekitta Pumping Station

It was necessary to consider the backwater effect of Kelani Ganga, which is the main river of Kalu Oya, and a pump drainage plan was considered for both JICA 2003 M/P and 2018 F/S. However, although land for a regulation pond is required for the effective operation of the pump drainage, it was difficult to obtain sufficient land in the downstream area. Since this regulation pond could not be created, it was necessary to set the pump scale to about 100 m^3/s. Due to these social and economic factors, this pump drainage plan has been rejected for both JICA2003M/P and 2018F/S.

However, at the time of this survey, the CLIP (WB) was studying the flood control plan of Kelani Ganga at the confluence. Hence, the design high water level of Kalu Oya will be reviewed based on the water level conditions of Kelani Ganga. Therefore, the measures for the confluence including the pump drainage plan will be reviewed and examined in this study.



Source: *JICA Study Team, based on "Storm Water Drainage and Environment Improvement Project for Kalu Oya Basin-Feasibility Study, SMEC, 2018"*

Figure 6.6.1 Drainage Improvement Components Proposed in 2018 F/S

Table 6.6.1 Water Level Lowering Effects by Drainage Improvement Alternative Measures

Countermeasures		No Action (25-yr)	Widening of channel constriction (bridges and culverts)	Upstream tank improvement (Kapua & Paralanda)	Kalu Oya improvement (B=45 m, L=5km)	Dutch Canal improvement (B=30 m, L=5km)	Natha Canal Improvement (B=15 m, L=3.2 km)	Nahena Canal Improvement (B=15 m, L=3.0 km)	Diversion to Muthurajawela (to Dutch Canal)	Diversion to Mudun Ela (Decreasing catchment of Natha Canal)	Pumping at Hekitta (Rivermouth)
Control Point Number	Ground Elevation (m MSL)										
1	3	3.17	2.85 (-0.32)	3.18(0.01)	3.16(-0.01)	3.16(-0.01)	3.17(0)	3.17(0)	3.16(-0.01)	3.17(0)	3.17(0)
2	3.5	2.86	2.86(0)	2.85(-0.01)	2.68(-0.18)	2.84(-0.02)	2.88(0.02)	2.90(0.04)	2.74(-0.12)	2.85(-0.01)	2.85(-0.01)
3	2	2.85	2.85(0)	2.85(0)	2.67(-0.18)	2.84(-0.01)	2.87(0.02)	2.90(0.05)	2.74(-0.11)	2.85(0)	2.85(0)
4	2	2.90	2.90(0)	2.90(0)	2.85(-0.05)	2.89(-0.01)	2.91(0.01)	2.94(0.04)	2.86(-0.04)	2.88(-0.02)	2.89(-0.01)
5	2.5	3.46	3.46(0)	3.46(0)	3.46(0)	3.46(0)	3.46(0)	3.46(0)	3.46(0)	3.46(0)	3.46(0)
6	4	3.71	3.71(0)	3.68(-0.03)	3.71(0)	3.71(0)	3.71(0)	3.71(0)	3.71(0)	3.68(-0.03)	3.71(0)
7	1.5	2.42	1.94(-0.48)	2.30(-0.12)	2.22(-0.20)	2.26(-0.16)	2.07(-0.35)	2.32(-0.10)	2.32(-0.10)	1.63(-0.79)	2.30(-0.12)
8	2	2.58	2.58(0)	2.59(0.01)	2.52(-0.06)	2.57(-0.01)	2.59(0.01)	2.44(-0.14)	2.57(-0.01)	1.99(-0.59)	2.58(0)
9	1.5	2.35	2.18(-0.17)	2.27(-0.08)	1.94(-0.41)	2.15(-0.20)	2.13(-0.22)	2.28(-0.07)	2.28(-0.07)	2.27(-0.08)	2.26(-0.09)
10	2	2.45	2.38(-0.07)	2.43(-0.02)	2.10(-0.35)	2.36(-0.09)	2.37(-0.07)	2.44(-0.01)	2.35(-0.10)	2.42(-0.03)	2.42(-0.03)
11	2.5	2.84	2.83(-0.01)	2.83(-0.01)	2.63(-0.21)	2.82(-0.02)	2.86(0.02)	2.88(0.04)	2.71(-0.13)	2.83(-0.01)	2.83(-0.01)
12	2	2.17	2.00(-0.17)	2.09(-0.08)	1.75(-0.42)	1.86(-0.31)	1.96(-0.21)	2.09(-0.08)	2.22(0.05)	2.09(-0.08)	2.06(-0.11)
13	1.5	1.88	1.73(-0.15)	1.82(-0.06)	1.59(-0.29)	1.60(-0.28)	1.73(-0.15)	1.83(-0.05)	1.90(0.02)	1.83(-0.05)	1.72(-0.16)
14	1.3	1.97	1.76(-0.21)	1.84(-0.13)	1.54(-0.43)	1.62(-0.35)	1.73(-0.23)	1.84(-0.13)	2.34(0.37)	1.84(-0.13)	1.81(-0.16)
15	0.55	1.59	1.50(-0.09)	1.54(-0.05)	1.45(-0.14)	1.45(-0.14)	1.50(-0.09)	1.56(-0.03)	1.60(0.01)	1.56(-0.03)	1.39(0.20)

Source：Storm Water Drainage and Environment Improvement Project for Kalu Oya Basin-Feasibility Study, SMEC, 2018

Number in parentheses is a difference of water level from the one in no action case.

(shaded) Most effective alternatives showing the lowest water level at each key location

Table 6.6.2 Water Level Lowering Effects by Drainage Improvement Alternatives

Countermeasures Evaluation Parameters	Widening of channel constriction	Upstream tank improvement (Kapua and Paralanda)	Kalu Oya improvement (B=45 m, L=5km)	Dutch Canal improvement (B=30 m, L=5km)	Natha Canal Improvement (B=15 m, L=3.2 km)	Nahena Canal Improvement (B=15 m, L=3.0 km)	Diversion to Muthurajawela (to Dutch Canal)	Diversion to Mudun Ela (Decreasing catchment of Natha Canal)	Pumping at Hekitta (Rivermouth)
Major Construction Item	Widening of openings of 12bridges and culverts	2 reservoirs: dredging & outlet structural improvement	Channeling including slope protection works and dredging	Channeling including slope protection works and dredging	Channeling including slope protection works and dredging	Channeling including slope protection works and dredging	Channeling and diversion tunnel	Connection channel widening	Closing gate and pumping station
Effects of Measures	Limitation of extent in effect	Suitable measures for local flooding	Widely extensive effects	Effects depending on diverting location	Insignificant effects due to backwater of Kalu Oya	Insignificant effects due to backwater of Kalu Oya	Insignificant effects due to hydraulic limitation	Significant effects along Natha canal	Significant effects limited around the river mouth
Measure’s Cost	High	Low	High	High	High	High	High and technically difficult	Low	High and high OM cost
Adverse Impacts	Minimal	Minimal	Some houses to be resettled	Some houses to be resettled	Some houses to be resettled	Some houses to be resettled	Many houses to be resettled	Minimal	Many houses to be resettled
Construction Period	Medium	Short	Long	Long	Long	Long	Medium	Short	Medium
Measures Selected in Optimum Plan	Selected	Selected	Selected	Selected	Selected	Selected	Selected	Selected	Excluded
Candidates of Measures for this M/P	Basic candidates	Much more effective reservoir to be selected	Basic candidates	Basic candidates	Basic candidates	Basic candidates	An alternative route to examine through hydraulic simulation	Basic candidates	Gate alternative to be examined

Source：JICA Study Team enumerated based on Storm Water Drainage and Environment Improvement Project for Kalu Oya Basin-Feasibility Study, SMEC, 2018

(2) Countermeasure in the Kalu Oya Basin

The following is a list of countermeasures for the Kalu Oya basin to be examined in this study referring to the countermeasures proposed at JICA 2003 M/P and 2018 F/S.

Appropriate combinations of these measures and project implementation procedures were examined, and the mid-term plan of the 25-year return period and the long-term plan for the 50-year return period were formulated.

Table 6.6.3 Countermeasure of Kalu Oya Basin

No	Measure	Specification
(K1)	Kalu Oya Improvement	Channel widening and dredging (L=5.1 km W=30-40 m)
(K2)	Natha Canal Improvement	Channel widening and dredging (L=0.5 km W=15-20 m)
(K3)	Mudun Ela Floodway	Channel widening and dredging (L=0.3 km W=15 m) New Gate Structure
(K4)	Old Dutch Canal Improvement	Channel widening and dredging (L=5.0 km W=30-40 m) Flood diversion channel (L=0.4 km W=30m)
(K5)	Natural Wetland park	6 locations (A=245.1 ha, L=28.8 km (outer perimeter))
(K6)	Tank Improvement	4 locations (A=8.4 ha, V=126,900 m3)
(K7)	Kalu Oya Gate Structure and Pumping station	1 unit (Capacity 35.0m3/s)
(K8)	Upper Kalu Oya Retarding Basin	Retarding Basin Dredging A=13.6 ha Depth=2.0m

1) Kalu Oya Improvement (K1)

River improvement in the approximately 5km section was a major measure in JICA 2003 M/P and 2018 F/S. In this study, the hydraulic functions of the natural flow method and the pump drainage method were compared as the treatment method at the Kalani Ganga confluence. The pump drainage plan was rejected by JICA 2003 M / P due to its low cost-benefit, and similarly, it was rejected by 2018 F / S due to its excessive facility scale. However, in order to upgrade to a 50-year return period in the future, it will be essential to install a gate and plan a pumping station to mitigate the effects of backwater from Kelani Ganga. It is appropriate that gates and pumping stations be constructed after the 50-year return period of the Kelani Ganga main river. In addition, the extension of Kalu Oya repair is relatively long, about 5 km, and it takes time to complete. Therefore, the procedure for implementing countermeasures, such as implementing the Old Dutch Canal repair in 4) as the next step after the Kalu Oya improvement.

2) Natha Canal Improvement (K2)

It is a countermeasure work proposed at 2018 F/S. The improvement of the approximately 0.5km section from the confluence of Kalu Oya to the railway intersection is proposed.

3) Mudun Ela Flood way (K3)

The Kalu Oya basin and the Mudun Ela sub-basin are connected through a connecting channel in the Natha Canal, and part of the flow in the middle and upper reaches of the Natha Canal flows into the Mudun Ela sub-basin. Backflow (inflow from Mudun Ela sub-basin to Kalu Oya basin) is also occurring due to the difference in water level. It is a countermeasure work proposed in 2018 F / S, but there is no specific information. It was proposed to remove the existing irrigation junction gate (which is dilapidated and non-functional), to improve the river from the gate to the intersection with the Colombo-Kandy road, and to install a gate at the junction to the Natha channel. The above measures have the following advantages.

- Currently, the Oliyamulla pumping station, which has a drainage capacity of 35 m3 / s, is under construction at the most downstream of Mudun Ela. The Mudun Ela Flood Bypass has the capacity to drain the Kalu Oya flood to a new pumping facility.

・ Even in the Kalu Oya basin, changing the basin from the middle and upper stream of Natha Canal to the Mudun Ela sub-basin is effective in reducing the flood risk.

Figure 6.6.2 Outline of Mudun Ela Diversion

4) Old Dutch Canal Improvement (K4)

The Old Dutch Canal will be refurbished as a discharge destination for the Muthurajawela drainage channel shown in Figure 6.6.3. However, technical and social issues were pointed out in JICA 2003 M/P, and although the route was revised in 2018F/S, technical and social issues were pointed out. It is necessary to consider a new connection (water discharge) route to the Old Dutch Canal. After the Kalu Oya refurbishment is complete, the Old Dutch Canal will need to be refurbished.

In this study, the diversion route shown in the following figure was proposed. A small channel already exists on this route, but its flow capacity is extremely small. The channel will be widened over a length of 400 m, increasing the diversion discharge and connecting to the Old Dutch Canal. Flood discharges flow into the Muthurajawela Wetlands through the Old Dutch canal. Since the calculation of the hydraulic natural diversion volume is extremely important, the validity is examined by hydraulic simulation.

If this effect is verified, it will be proposed as an alternative route to the Muthurajawera diversion, which has been proposed in JICA 2003 M/P and 2018F/S. The type of drainage channel is an open channel system by widening the existing channel, and the widening section is about 400 m. This also has an advantage in workability.

If diversion is hydraulically possible, this plan is extremely effective as a flood control measure, and it is expected that superiority or inferiority will be judged only by hydraulic examination. In Old Dutch Canal, it is proposed to improve the existing canal connected to the Muthurajawera Wetland in order to expand the flood diversion function.

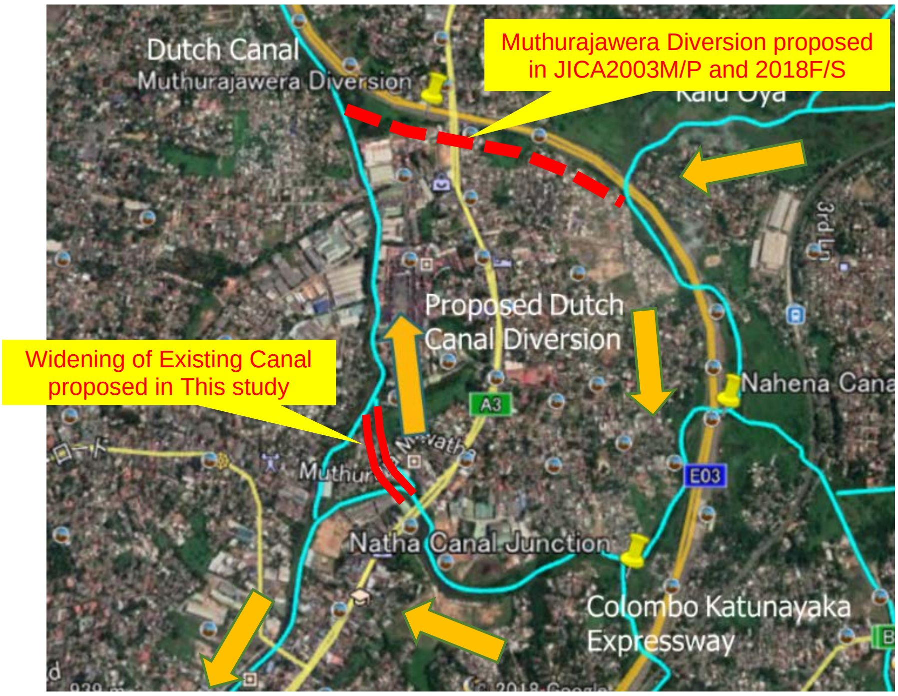


Figure 6.6.3 Proposed New Route for Dutch Canal Diversion

Proposed new route for Dutch Canal Diversion

The following figure shows the hydraulic effects of the combination of these proposed measures, including channel improvement and flood diversion construction, based on the simulation results described in 2018 F/S. The figure is followed by findings.

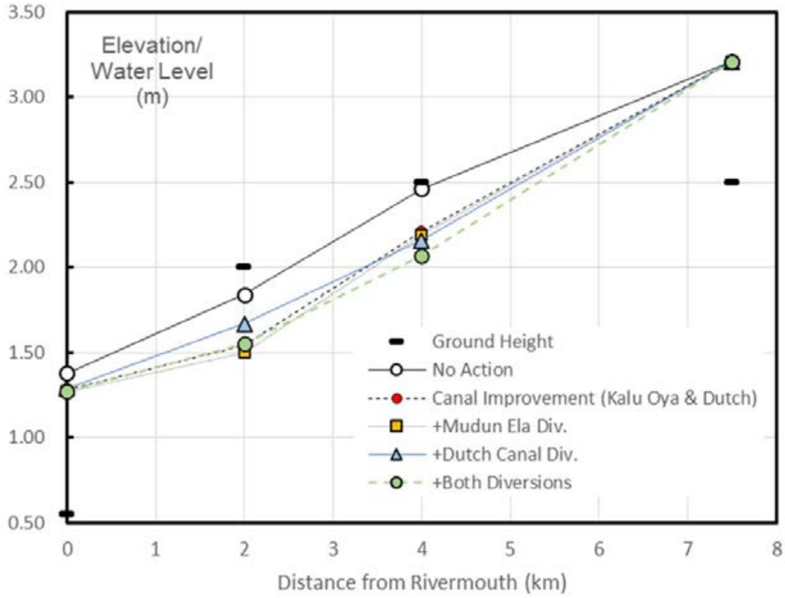


Figure 6.6.4 Hydraulic Effects of The Combination Of Channel Improvement and Flood Diversion (For 10-Year Return Period)

- This figure plots the elevation of the inland areas. In each case, the upstream natural retarding function has already been taken into the consideration. However, in the case of only the upstream wetland natural retarding function (Case “No. Action”), the flood level compared to the ground elevation is not safe. In other words, river channel improvement is deemed necessary.
- In the Kalu Oya basin, the stretch of the main river improvement is approximately 5 km from the river mouth. Therefore, to lower the flood water level in this section, it is necessary to construct the flood diversion connecting to the Old Dutch Canal in addition to the channel improvement.

5) Natural Wetland park (K5)

Ensuring the retarding function by conserving wetlands is a countermeasure proposed in JICA 2003 M/P and 2018 F/S. The priority is river improvement, but since it takes time and project costs to realize, as a measure to ensure the existing retarding function in the future, It is proposed to install a natural wetland park to conserve the current wetlands.

The effects of these structural and non-structural measures are quantitatively summarized from the flood simulation results as follows. If the reference point of Kalu Oya is set at the intersection with the Negombo road, the 2-year probability flood in the current river channel is expressed as follows.

- Total runoff volume (without inundation) :120 m^3/s
- Runoff volume shared by river channels :25 m^3/s (21%)
- Reduction by paddy fields in the upstream area :40 m^3/s (33%)
- Reduction by wetlands in the middle stream area :55 m^3/s (46%)

As a result of the simulation, 79% of runoff discharge of the current river channel depends on the retarding basin function of the upstream paddy field and the middle stream wetland, and the flow capacity of the channel is only 21%. The safety level of flood control of downstream rivers depends on the retarding basin function of the middle and upper reaches, and if this system is broken, the safety level will drop at once, and the flood risk may increase. Based on this, considering the difficulty of widening the river channel in the downstream urban area, there is a limit to the improvement of safety level by structural measures. It is important to formulate a comprehensive storm water drainage plan while considering conservation measures for lowlands in the upper and middle streams.

Ensuring the retarding basin function by conserving such wetlands is a measure proposed in JICA 2003M/P and 2018F/S. The priority is to improve the safety level of flood control through channel improvement, but it takes time and project costs to realize channel improvement. Therefore, as a measure to ensure this retarding basin function in the future, it is proposed to develop a natural wetland park to conserve the current wetland. In other words, the purpose of this measure is not to "enhance" the retarding basin function but to "ensure" it, and it is basically implemented in parallel with other structural measures.

- Construction of a small bank on the periphery of the wetland area (height: 0.5 m, width 3 m). In normal times, it provides park function as a jogging or walking path for residents.
- Based on hydraulic simulations, flood inundation from a 2-year to 10-year return period can be stored inside a small dike area while mitigating the floods. For an even greater flood, the small dike will be submerged, but the retarding basin function will be ensured.
- In the event of about a 2-year to 10-year return period flooding, it is expected to function as a regional disaster prevention embankment to protect surrounding residential areas and buildings from inundation.

6) Tank Improvement (K6)

An irrigation pond is installed in the upper reaches of the Kalu Oya basin. SLLDC has drafted an improvement plan for the addition of hydraulic control functions to these ponds.

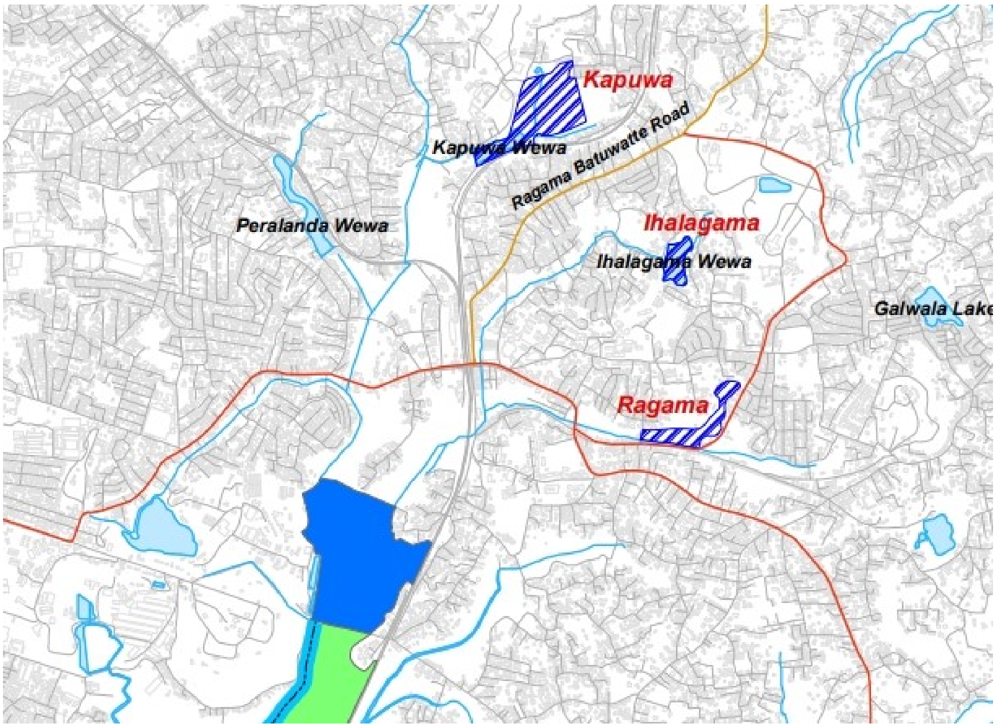


Figure 6.6.5 Agricultural Pond for Irrigation of the Upper Stream of the Kalu Oya Tributary

Table 6.6.4 Agricultural Pond for Irrigation of the Upper Stream of the Kalu Oya Tributary

Name	Area of pond (ha)	Volume (1,000m^3)	Remarks
Ihalagama	1.8	27.6	Effective for flood mitigation
Kapua	1.7	25.2	Effective for flood mitigation
Paralanda	2.5	38.1	a little effective for flood mitigation
Ragama	2,4	36.0	Effective for flood mitigation

Of the four ponds, 1) Kapuwa, 2) Iharagama, and 3) Ragama have relatively large catchment areas and can be expanded by excavation. Flood control rehabilitation is effective as a local inundation mitigation measure, although the flood control effect is limited locally. The following points should be noted in the tank improvement.

- Expand the current tank water storage surface as much as possible. Further excavation to secure storage.
- Spillway design based on hydrological analysis
- Planning preventive measures assuming an emergency dike breach due to the levee body being an earth dike.

6.6.1.2 Mudun Ela Sub-Basin

(1) Countermeasure of Mudn Ela sub-basin

The Mudun Ela sub-basin is not included in JICA 2003 M/P or 2018 F/S. Mudun Ela sub-basin is a former irrigation canal network with drainage channels distributed in a network. The main drainage canal and secondary drainage canal to be constructed were identified, and countermeasures with a 25-year return period were examined. The measures for the Mudun Ela sub-basin are as follows.

Table 6.6.5 Countermeasure of Mudun Ela sub-basin

No	Measure	Specification
(M1)	Mudun Ela Improvement	Channel widening and dredging (L=3.1 km W=20 m)
(M2)	Peliyadoga Canal Improvement	Channel widening and dredging (L=2.8 km W=15-20 m)
(M3)	Peliyadoga Pumping Station	1 unit (Capacity 1.0m3/s)
(M4)	New Gate Structure	1 location
(M5)	Upper Mudun Ela Improvement	Channel dredging (L=3.0km)
(M6)	Upper Mudun Ela Retarding Basin	Retarding Basin Dredging A=17.0ha Depth=2.0m
(M7)	Additional New Pumping Station	2 locations (1 unit)
(M8)	Natural Wetland Park	2 locations (A=71.3 ha, L=16.9 km (outer perimeter))

1) Mudun Ela Improvement (M1)

Improvement of the 3.1 km section from the Oliyamulla pumping station currently under construction to the intersection of the Colombo-Kandy road. The purpose is to fully demonstrate the functions of the 35 m^3/s pump after construction.

2) Peliyadoga Canal Improvement (M2)

Dredging of a secondary drainage channel connecting to the existing Peliyagoda pumping station.

3) Peliyadoga Pumping Station (M3)

Improved drainage capacity of the existing Peliyagoda pumping station. The purpose is to increase the pumping capacity from 0.5 m^3/s to 1.0 m3/s.

4) New Gate Structure (M4)

Installation of gate facilities to divide the basin and determine the flow direction.

- A gate to be closed will be installed at the point connecting the Mudun Ela Flood diversion to the Natha Canal as shown in the explanation of countermeasures for the Kalu Oya basin.
- A gate to be closed will be installed at the slope change point of the Naranmini Oya upstream of the secondary drainage channel leading to the Peliyagoda pumping station to reduce the inflow to the Peliyagoda canal.

5) Upper Mudun Ela Improvement (M5)

Simple excavation from the Colombo-Kandy road intersection to the planned retarding basin site upstream. Enhancement of natural flow capacity from the planned retarding basin.

6) Upper Mudun Ela Retarding Basin (M6)

Construction of a retarding basin upstream of Mudun Ela. This Mudun Ela upstream retarding basin will be a model project for the area including the Kalu Oya basin.

7) Additional New Pumping Station (M7)

The low-lying areas of the Pethiyagoda and Shiharamulla districts along the Kelani Ganga are areas where local inundation occurs frequently. Since this area is a densely populated urban area, there is a limit to drastic channel improvement, so SLLDC proposed the installation of a pumping station in this area, which will be also listed as one of the measures for this study.

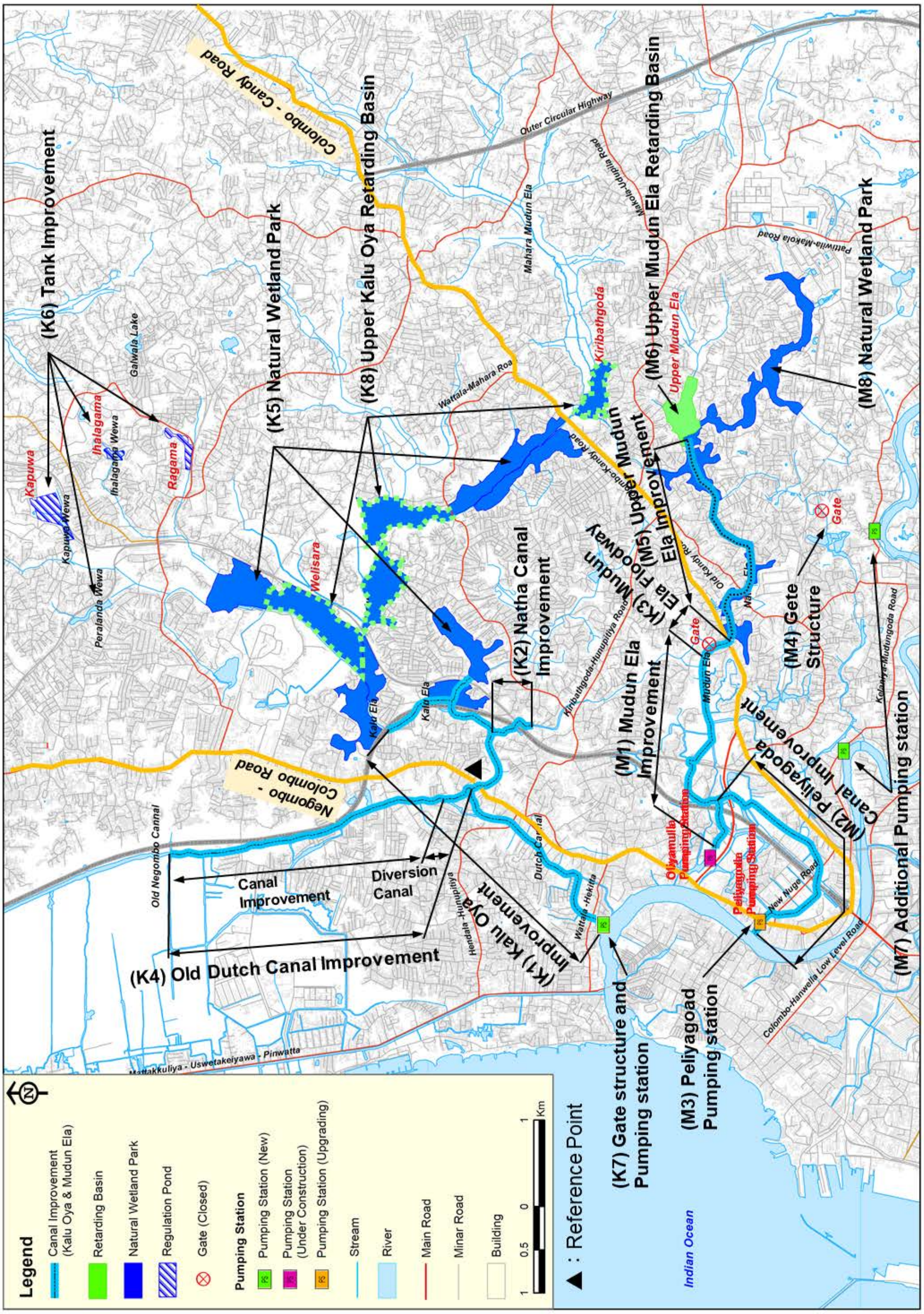


Figure 6.6.6 Storm Water Drainage Plan in the Kalu Oya Basin and the Mudun Ela Sub-basin

(2) Other Countermeasure in the Mudun Ela Sub-basin

1) Urban Development Plan in the Mudun Ela Sub-basin

The westernmost area of the Mudun Ela Sub-basin, where the highway entrances and junctions are located, is extremely attractive to public and private developers and has already been set apart as a large development zone. Wetlands and other areas that have been effective in reducing flood risk are obviously also included in the development zone, and SLLDC is in the process of studying its own storm water drainage plan based on the current status of the development plan shown by the urban development department in Figure 6.6.7.

SLLDC has proposed "tertiary channel rehabilitation" and "two new pumping facilities" and other measures to reduce flooding damage in the area (so-called local flooding) as well as to provide efficient drainage, regardless of whether it is a main canal or a secondary canal. These proposed measures are also clearly listed as future projects to be implemented by SLLDC, and it is necessary to align the JICA study team's proposals with SLLDC's project policies.

In addition to the measures proposed by the JICA team, it is also essential to actively implement the SLLDC's proposed projects in order to cope with the increased discharge rate due to rapid urban development.

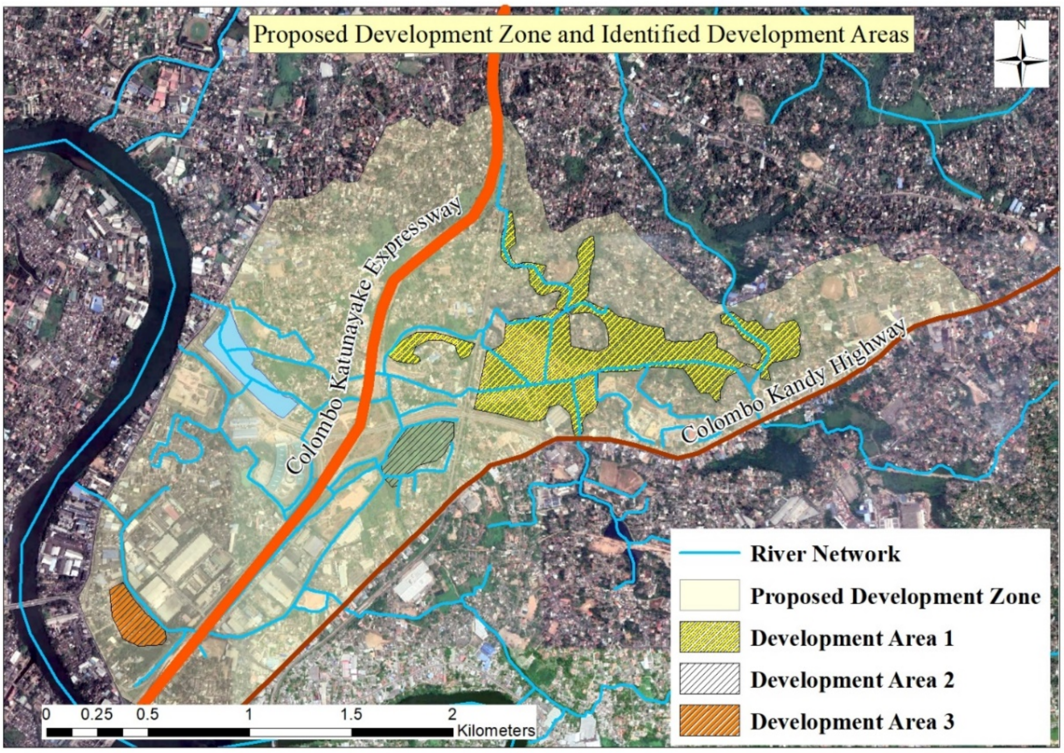


Figure 6.6.7 Urban Development Area in the Mudun Ela Sub-basin

2) Proposed Countermeasures by SLLDC

A list of proposed measures and location maps for the Mudun Ela watershed proposed by SLLDC are shown in Table 6.6.6 and Figure 6.6.8 The JICA study team has proposed measures for trunk and secondary channels in the Mudun Ela watershed. On the other hand, SLLDC has proposed countermeasures including tertiary channels, especially the rehabilitation of Naranmini Oya near the Kelani Ganga watershed in the south and two pumping facilities for drainage of the surrounding area.

Table 6.6.6 Proposed Countermeasure by SLLDC

Proposed Countermeasure by SLLDC	Relationship with Proposed Countermeasure by JICA team	Remarks
(1) Mudun Ela Improvement	Mudun Ela Improvement［M1］ Mudun Ela Floodway［K3］	
(2) Peliyagoda Improvement	Peliyadoga Canal Improvement［M2］	
(3) Naranmini Oya Improvement	-	
(4) Koholwila Improvement	-	
(5) Pethiyagoda Pumping Station	-	Pump Capacity: 15 m^3/s
(6) Koholwila Pumping Station	-	Pump Capacity: 5 m^3/s
(7) Peliyagoda Pumping Station	Peliyadoga Pumping Station［M3］	Pump Capacity: 1 m^3/s
(8) Gate Structure	New Gate Structure［M4］	

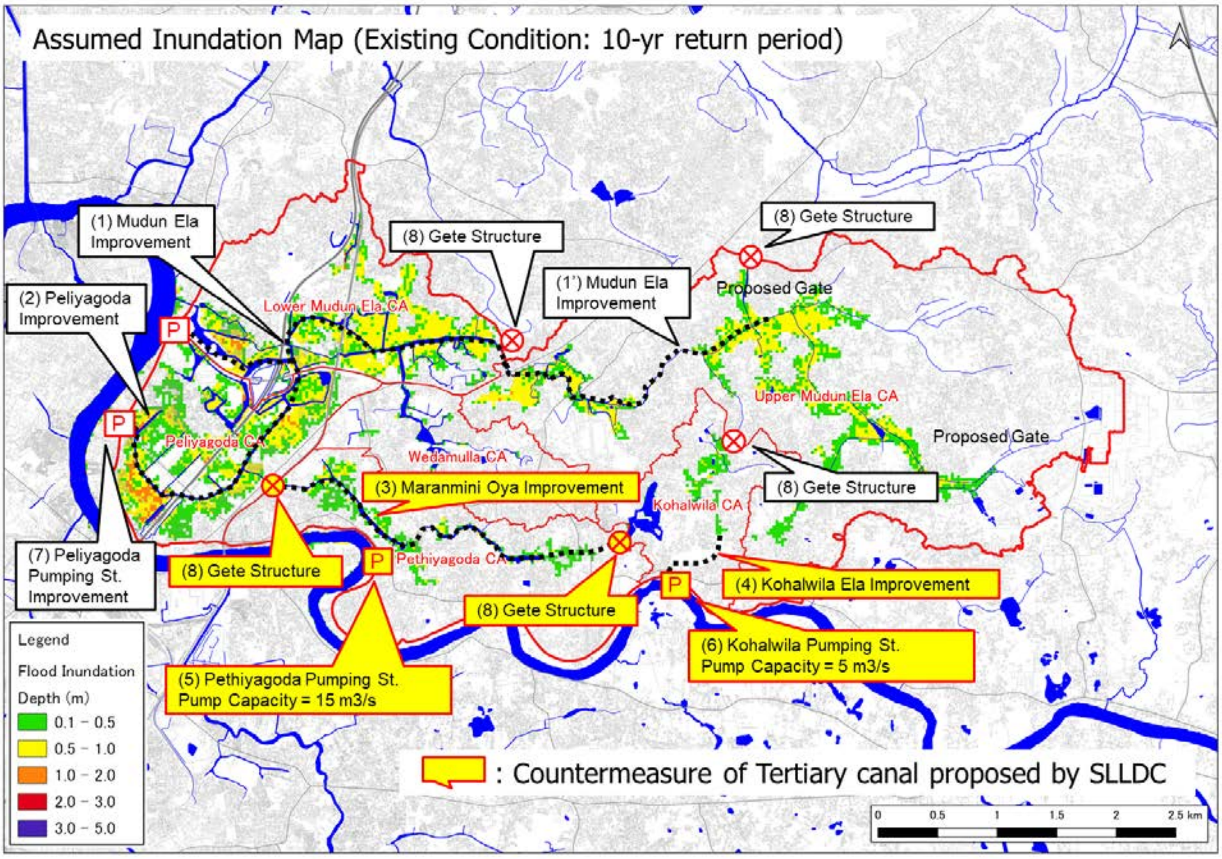


Figure 6.6.8 Countermeasure proposed by SLLDC in the Mudun Ela Sub-basin

6.6.1.3 Bolgoda Basin

(1) Policy for Considering Measures

The Weras Ganga, the most upstream area in the northern part of the Bolgoda basin, is located in the capital city Colombo District, so it is taken up as an F/S target for JICA2003MP, and then a rehabilitation project is underway through D/D.

However, other rivers located in the central and southern parts of the country are paddy fields and no improvement plan has been proposed.

The rivers in the south-south, which are still in the condition of natural rivers, flow down between the heights of natural embankments. Planning a normal continuous dike for such a natural river lacks rationality and economic efficiency both in terms of project cost and flood mitigation effect.

Eventually, urbanization in the basin will progress, assets to be protected will accumulate, and such rehabilitation methods will become more appropriate.

Therefore, in this M/P, the land use assumed in 2030 and the inundation simulation result of the 25-year return period were overlaid, and the places where the residential land/urban area and the inundation area overlap were extracted.

Since each area in the Bolgoda basin has different characteristics in terms of topography, land use status, and asset distribution, the characteristics were identified for each of the 14 areas (sub-basins) shown in the figure below. In addition, the priority area was set based on information such as the estimated flood area and distribution of the number of flooded houses by area, and the flood countermeasure plan was examined. The main measures are shown below.

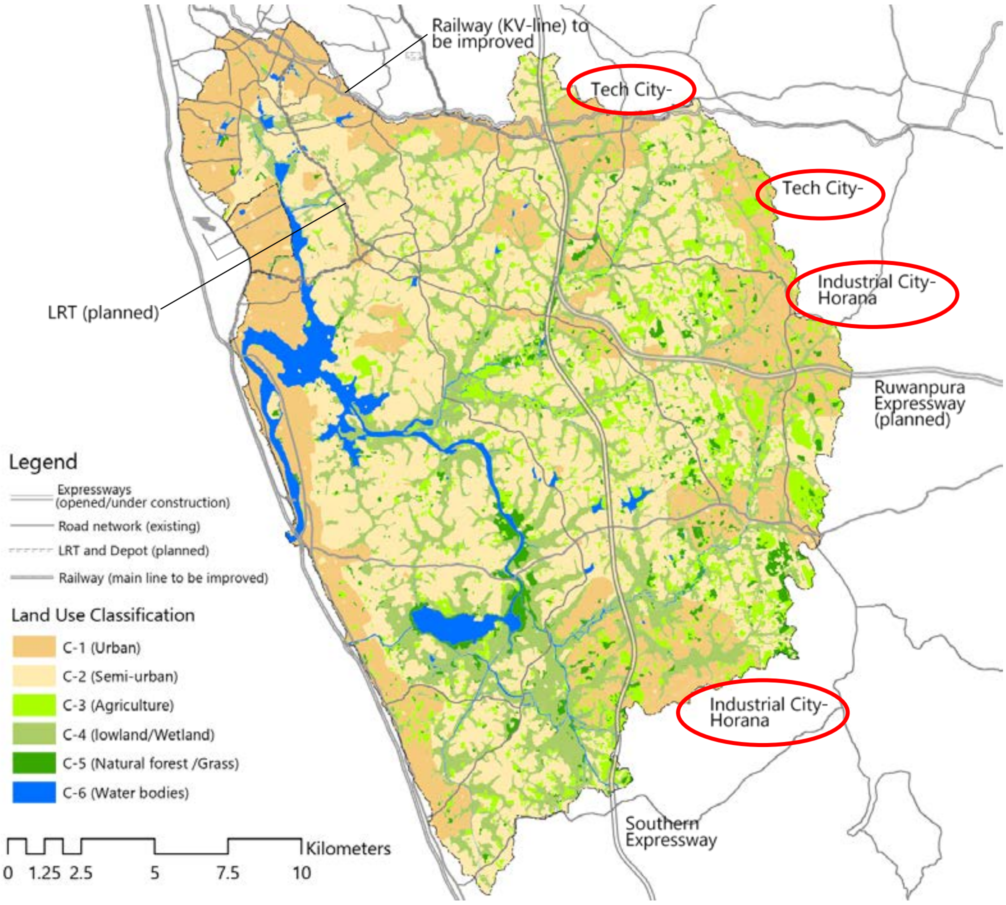
- Insufficient drainage capacity in the area ⇒ River improvement in some sections
- Flooding from rivers in the area ⇒ Embankment construction along some rivers

Figure 6.6.9 Sub-basin Division Map in the Bolgoda Basin

(2) Future Land Use in 2030

In planning flood countermeasures, the general condition of future land use in the Bolgoda basin was reorganized.

- Wetlands and farmlands are widely distributed along the main rivers (lowlands) in the Bolgoda basin (see Figure 6.6.10).
- The urban areas in the so-called land use category, where assets are concentrated, are limited to the northern area of Weras Ganga, the coastal area, and the upstream edge (see Figure 6.6.10).
- The urban development areas (industrial estate) planned for the future, which are shown in Figure 6.6.10 (red circle), are distributed in the upstream area of the tributary, and it is expected that the urban areas will expand due to the construction of expressways. On the other hand, the area around Bolgoda Lake has not yet been developed.
- This is partly because Bolgoda Lake and Bolgoda Ganga have been designated as nature reserves by the Ministry of the Environment, and it is unlikely that large-scale urban development will continue in the future.



Source: JICA Study Team

Figure 6.6.10 Bolgoda Basin (2030) Future Land Use Patterns in Bolgoda Basin (2030) (Reshown)

(3) Important Public Facilities, Road and Traffic Conditions

The distribution of public facilities in the Bolgoda basin is inevitably concentrated in areas such as Moratuwa-Rathmalana and Panadura, which have municipalities.

Those are distributed in a relatively densely populated area along the main road and have a smaller total population than the Kalu Oya basin or Mudun Ela sub-basin, but important public facilities such as hospitals and fire stations are distributed with a certain density. In addition, most of the facilities are located in the hills, and the inundation risk of lowlands is low.

Depending on the urbanization situation in the basin, the arterial road network has different development statuses in the Colombo district (north side) where urbanization is progressing and Kalutara district (south side) where urbanization is low.

In the Colombo prefecture, the highways and district road networks between GN and the district are maintained. The Ruwanpura Expressway is planned in the eastern center of the basin in order to connect to the existing expressway (Southern Expressway) that crosses the basin.

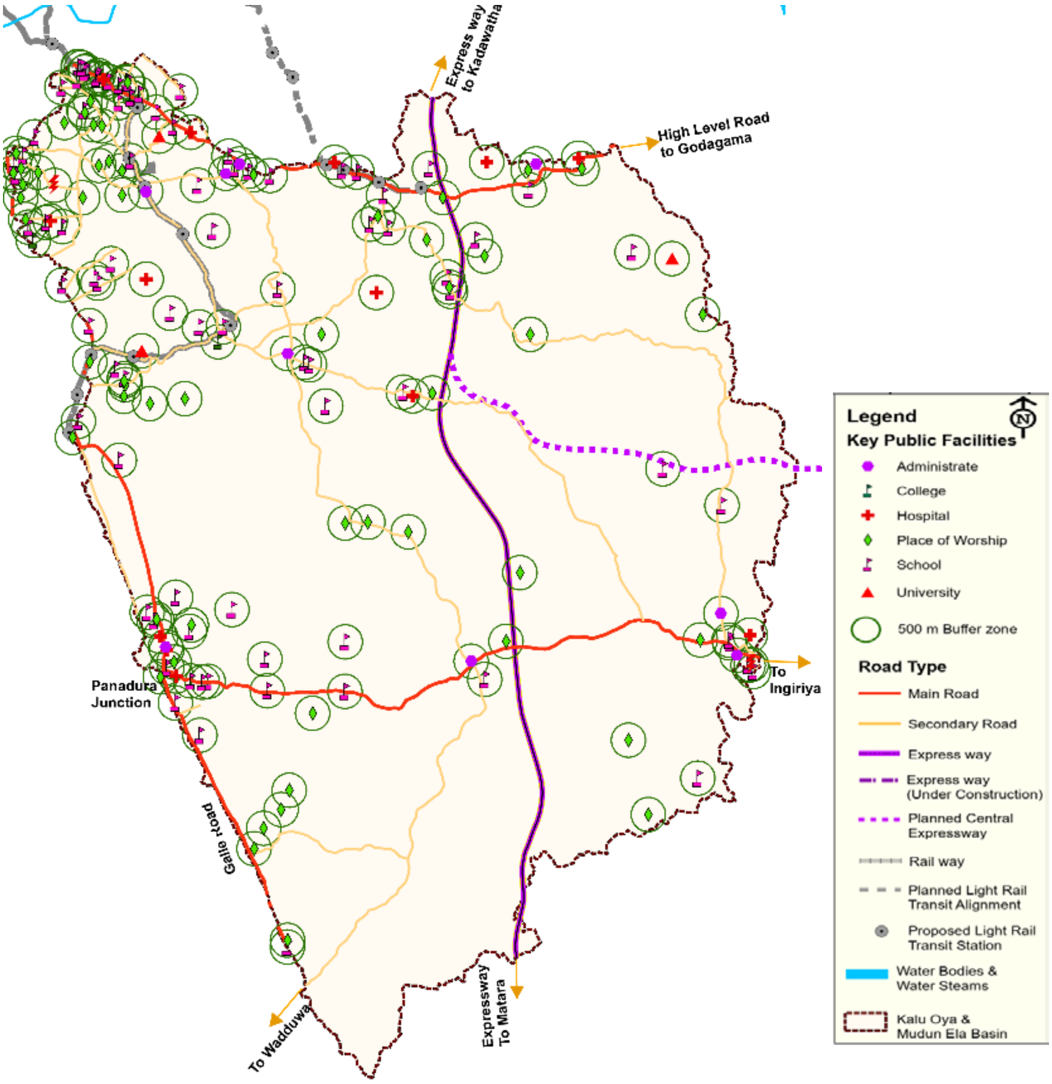


Figure 6.6.11 Public Facilities and Major Road Network in the Bolgoda Basin (Reshown)

(4) Distribution of General Assets in Bolgoda Basin (number of households distribution)

In planning flood countermeasures, the general condition of the residential area (distribution of the number of households) in the Bolgoda basin was reorganized.

- The area where general assets are concentrated is Weras Ganga basin in the northwestern part of the basin and the west side of Bolgoda Lake (01_Weras Ganga、13_North Bolgoda Lake、14_River Mouth in Figure 6.6.12), similar to the tendency of the urban area distribution, and the area over 20 houses/ha is widely distributed. (See Figure 6.6.12).
- Even in the downstream part of Panape Ela (07_Lower Panape Ela in Figure 6.6.12), a part of more than 40 houses/ha is distributed and it is close to the downstream channel of Panape Ela, so it can be said that the damage risk in case of flooding is relatively high.
- In the upstream area, although urban development such as industrial parks is being promoted, the number of households is only slightly found in the upstream area of Maha Oya (including upstream of tributaries) and upstream of Panape Ela.

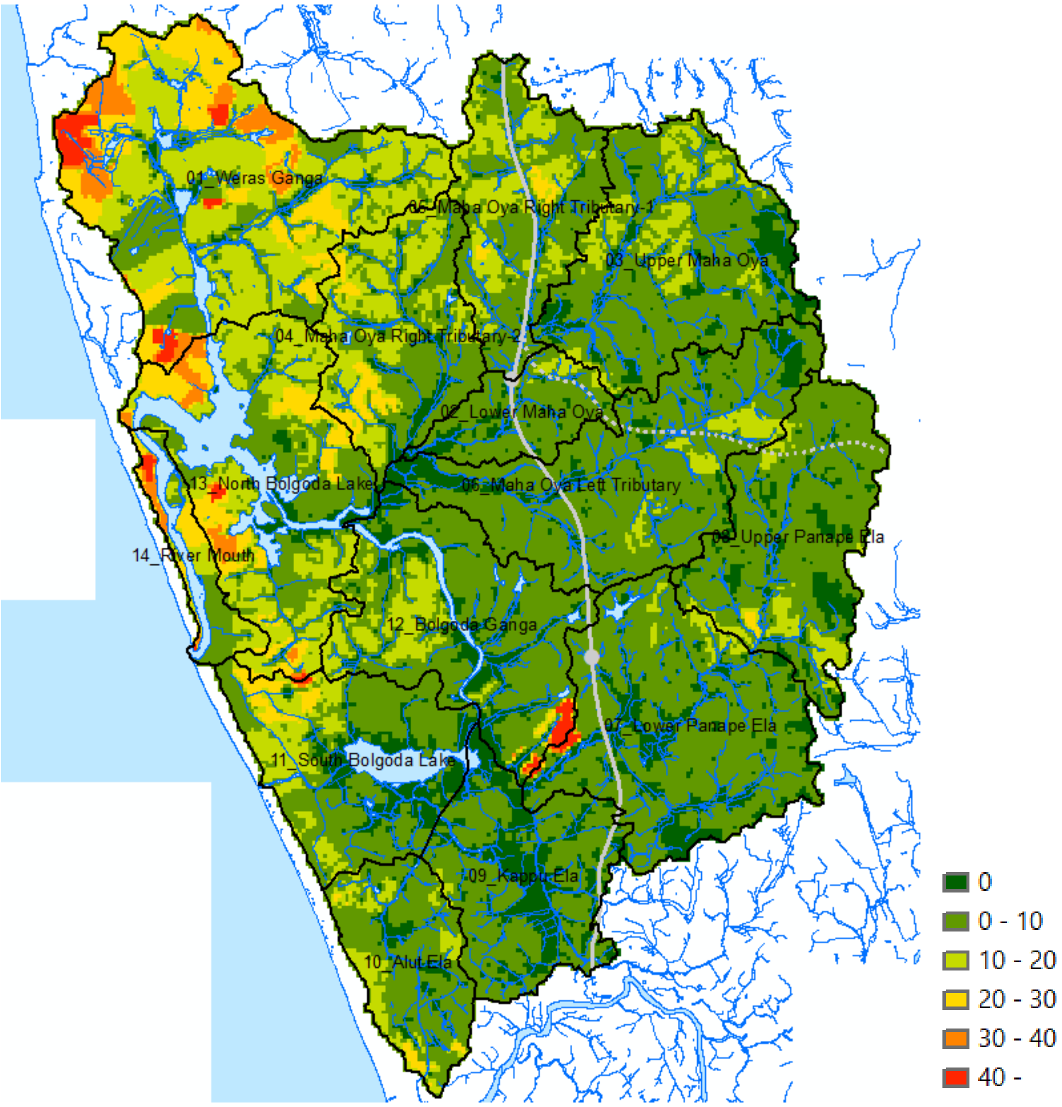


Figure 6.6.12 Future Distribution of Households (2030) in the Bolgoda basin (units/ha)

(5) Assumed Inundation Area and Urban Distribution

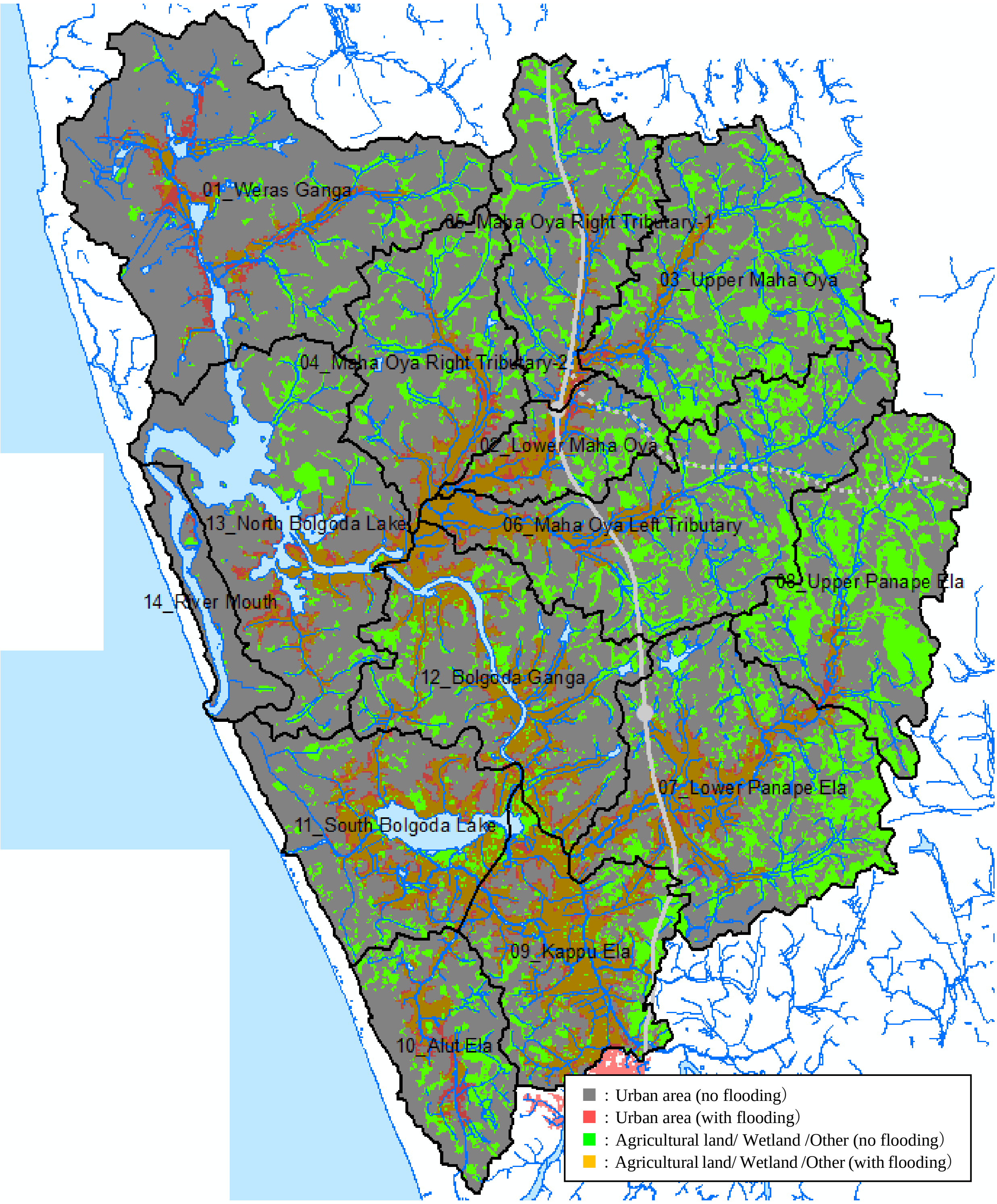
Figure 6.6.13 shows a superposed map of assumed flooded areas (25-year probability) and urban distribution, Table 6.6.7 shows the flooded area in urban areas by district, and Table 6.6.8 shows the estimated number of flooded houses. 5, as shown in Figure 6.6.14.

- When confirming the superposition of the assumed flooded area and the urban distribution, Weras Ganga basin (01_Weras Ganga), Maha Oya basin (02_Lower Maha Oya, 03_Upper Maha Oya), and Alut Ela basin (10_Alut Ela) tend to be flooded in the urban area.
- In other areas, it is assumed that some urban areas (residential areas) located mainly on the edge of wetlands and farmlands will be flooded.
- The estimated inundation area in the urban area is the largest in the Weras Ganga basin (01_Weras Ganga) with 327 ha.
- On the other hand, the expected number of inundated houses is approximately 2,600 in the Weras Ganga basin (01_Weras Ganga) where general assets are concentrated, approximately 300 households are inundated in the downstream area of Panape Ela (07_Lower Panape), South Bolgoda Lake and North Bolgoda Lake.

Table 6.6.7 Estimated Inundation Area (25-Year Return Period) in Urban Areas and Ratio

No	Sub basin name	Basin Area (ha)	Urban Area (ha) and Ratio		Estimated Flood Inundation Area (ha) and Ratio (%)							
					2-yr		5-yr		10-yr		25-yr	
		(1)	(2)	(3)=(2)/(1)	(4)	(5)=(4)/(2)	(6)	(7)=(6)/(2)	(8)	(9)=(8)/(2)	(10)	(11)=(10)/(2)
1	Weras Ganga	5,583	4,682	83.9%	38	0.8%	78	1.7%	136	2.9%	230	4.9%
2	Lower Maha Oya	1,061	604	56.9%	26	4.3%	60	9.9%	73	12.1%	79	13.2%
3	Upper Maha Oya	3,329	2,022	60.8%	2	0.1%	23	1.1%	28	1.4%	35	1.7%
4	Maha Oya Right Tributary 2	2,635	1,805	68.5%	42	2.3%	60	3.3%	61	3.4%	75	4.2%
5	Maha Oya Right Tributary 1	2,419	1,724	71.3%	21	1.2%	48	2.8%	61	3.6%	71	4.1%
6	Maha Oya Left Tributary	3,762	2,224	59.1%	36	1.6%	55	2.5%	67	3.0%	72	3.3%
7	Lower Panape Ela	3,890	1,980	50.9%	63	3.2%	104	5.3%	129	6.5%	158	8.0%
8	Upper Panape Ela	2,914	1,601	54.9%	8	0.5%	24	1.5%	29	1.8%	32	2.0%
9	Kappu Ela	2,483	884	35.6%	15	1.6%	74	8.3%	128	14.5%	177	20.0%
10	Alut ela	1,639	1,083	66.0%	29	2.7%	40	3.7%	57	5.3%	92	8.5%
11	South Bolgoda Lake	2,731	1,497	54.8%	21	1.4%	65	4.4%	99	6.6%	151	10.1%
12	Bolgoda Ganga	3,352	1,885	56.2%	40	2.1%	72	3.8%	111	5.9%	157	8.3%
13	North Bolgoda Lake	3,767	2,499	66.3%	45	1.8%	78	3.1%	117	4.7%	159	6.4%
14	River Mouth	754	552	73.2%	2	0.3%	2	0.3%	3	0.6%	8	1.5%

Source: JICA Study team



Source: JICA Study team

Figure 6.6.13 Superposed Map of Assumed Inundation Area (25-year Return Period) and Land Use Map in the Bolgoda Basin

Table 6.6.8 Assumed Number of Inundated Households (25-Year Return Period) and Ratio in the Bolgoda Basin

No	Sub basin name	Number of House hold	Number of Affected Household							
			2-yr		5-yr		10-yr		25-yr	
		(1)	(2)	(3) =(2)/(1)	(4)	(5) =(4)/(1)	(6)	(7) =(6)/(1)	(8)	(9) =(8)/(1)
1	Weras Ganga	94,990	205	0.2%	329	0.3%	735	0.8%	1,467	1.5%
2	Lower Maha Oya	4,634	23	0.5%	72	1.6%	194	4.2%	272	5.9%
3	Upper Maha Oya	17,482	1	0.0%	2	0.0%	2	0.0%	12	0.1%
4	Maha Oya Right Tributary 2	22,901	52	0.2%	102	0.4%	140	0.6%	246	1.1%
5	Maha Oya Right Tributary 1	19,777	10	0.0%	43	0.2%	138	0.7%	226	1.1%
6	Maha Oya Left Tributary	17,719	17	0.1%	37	0.2%	71	0.4%	109	0.6%
7	Lower Panape Ela	10,862	12	0.1%	53	0.5%	119	1.1%	204	1.9%
8	Upper Panape Ela	12,184	1	0.0%	122	1.0%	130	1.1%	143	1.2%
9	Kappu Ela	3,441	0	0.0%	1	0.0%	11	0.3%	55	1.6%
10	Alut Ela	10,530	3	0.0%	51	0.5%	129	1.2%	316	3.0%
11	South Bolgoda Lake	15,913	10	0.1%	32	0.2%	82	0.5%	197	1.2%
12	Bolgoda Ganga	19,925	0	0.0%	6	0.0%	66	0.3%	191	1.0%
13	North Bolgoda Lake	41,607	27	0.1%	120	0.3%	203	0.5%	394	0.9%
14	River Mouth	10,653	0	0.0%	0	0.0%	0	0.0%	65	0.6%

Source: JICA Study team

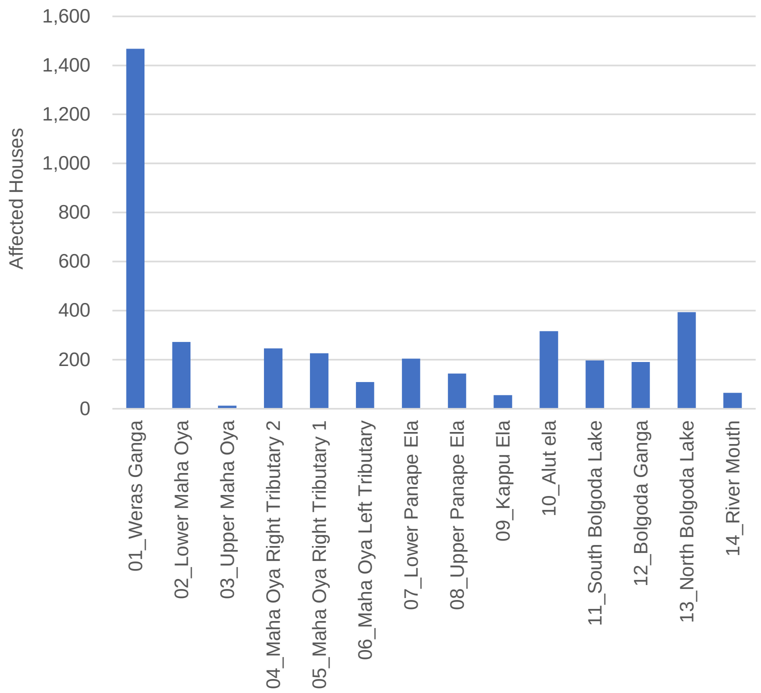


Figure 6.6.14 Assumed Number of Inundated Households in the Bolgoda Basin (25-Year Return Period)

(6) The setting of Priority Areas for Measures

Information obtained from future land use, general assets, assumed inundation area (25-year return period), etc., was comprehensively examined, and the priority areas for countermeasures were divided into four groups (priorities (1) to (4)) and set.

Although there is no clear standard, this study basically set areas with 200 or more inundated houses as priority areas and examined the direction of measures according to the characteristics of each area for each group. The outline is shown below.

Table 6.6.9 Countermeasure Priority District Setting Table

No	Name of District	Future Land Use	Flooding of Important Facilities	General asset distribution	Assumed inundation of Urban area	Assumed inundated households	Priority	Reason of selection
1	Weras Ganga	densely built-up area		large		More than 200 households	Priority (1)	It is expected that more than 200 households will be affected by the disaster, and general assets are large, it will be subject to drainage measures.
2	Lower Maha Oya		Highway IC		More than 10%	More than 200 households	Priority (2)	Since high-speed IC, which is an important facility, is expected to be inundated and more than 200 households are expected to be inundated, it will be subject to drainage measures.
3	Upper Maha Oya							
4	Maha Oya Right Tributary 2					More than 200 households	Priority (2)	It is expected more than 200 households will be affected by flooding.
5	Maha Oya Right Tributary 1		Highway IC			More than 200 households	Priority (2)	Since high-speed IC, which is an important facility, is expected to be inundated and more than 200 households are expected to be inundated, it will be subject to drainage measures.
6	Maha Oya Left Tributary							
7	Lower Panape Ela			large		More than 200 households	Priority (3)	Since general asset distribution is relatively large and more than 200 households are expected to be inundated, it will be subject to drainage measures.
8	Upper Panape Ela							
9	Kappu Ela				More than 10%			
10	Alut Ela				More than 10%	More than 200 households	Priority (3)	Since general asset distribution is relatively large and more than 200 households are expected to be inundated, it will be subject to drainage measures.
11	South Bolgoda Lake			large	More than 10%	More than 200 households	Priority (4)	General assets are distributed and the expected number of affected households is large, it will be subject to drainage measures. However, it is difficult to take structural measures because it corresponds to a nature conservation area, and measures are taken by non-structural measures such as land-use regulations.
12	Bolgoda Ganga			large	More than 10%	More than 200 households	Priority (4)	Same as above
13	North Bolgoda Lake	densely built-up area		large		More than 200 households	Priority (4)	Same as above
14	River Mouth	densely built-up area		large				

Priority Area (1) :Flood control is being implemented as a priority project in the existing plan, and it is necessary to complete the flood control measures in the asset concentration area. Develop flood countermeasures that are consistent with existing plans.

- The most concentrated area is the Weras Ganga area in the northwestern part of the basin, which is the target of flood protection.

Priority Area (2) :Planning flood control measures for expressways, their approach roads and their surrounding urban areas.

- Since there are urban development plans such as industrial parks in the upper tributaries and it is expected that industrial and commercial economic activities will become active in the future, the expressways and their access roads are the targets for flood protection.

Priority Area (3): Planning of local flood countermeasures

*However, the improvement plan should be appropriately changed according to future urban development and changes in the surrounding area.

- According to the assumed flood inundation map, In particular, inundation is expected in urban areas near the edges of wetlands and farmlands. Therefore, these areas are subject to flood protection.

Priority Area (4): Setting Natural Returning basin

- South Bolgoda Lake, around Bolgoda Ganga, and North Bolgoda Lake are set as nature reserves. It is an area where the appearance of a natural river is secured and wetlands and farmland are spread. It will be set as an area that maintains the natural retarding basin effect from the viewpoint of environmental protection.

(7) The policy of improvement in Bolgoda Basin

1) Weras Ganga Right Embankment: Priority (1)

The embankment was proposed in JICA 2003 M/P and F/S. The construction has not begun and SLLDC has begun studying land acquisition. Since the HWL. is set to 1.5 m and the structure is constructed in the nearby river improvement, these specifications will be followed on this right embankment.

2) Maha Oya Basin: Priority (2)

The flow capacity of the section of the expressway is small, which is a bottleneck, and dredging and embankment will be carried out in this section (4.0km). In addition, surrounding embankments will be constructed in two districts (5.9km) to protect the settlement.

3) Alut Ela Basin: Priority (3)

Dredging and embankment will be carried out in the most upstream section of 3.4km to reduce the risk of inundation.

4) Panape Ela Basin: Priority (4)

Due to flooding in the middle reaches of Panape Ela, three embankments will be constructed to protect the residential area, with a total length of 6.7 km.

5) Maha Oya Tributary Basin: Priority (2)

A surrounding embankment will be installed along the road upstream of the tributary where inundation is expected to prevent local inundation.

6) South Bolgoda Lake Basin Priority (4)

This area has the appearance of a natural river and is an area where wetlands and agricultural land spread and is designated as a nature reserve. It should be conserved as an area that preserves natural water retention for environmental protection. However, since the development of resort facilities and villas is underway around Bolgooda Lake (lakeshore), urban development management measures including the promotion of building structures resistant to flood damage (piloti method, etc.) should be implemented. In addition to preventing and reducing inundation damage, the disorderly development of the area with high inundation risk will be suppressed. Dredging and obstruction of Thalpitiya Ela, which connects Bolgoda Lake to the sea, will be carried out to reduce the risk of residential areas distributed on the edges of agricultural and wetlands.

7) Drainage Improvement in Moratuwa-Rathmalana

This facility was proposed in JICA 2003 M/P and F/S. The construction has not begun. The gate structures, pumping stations and the primary canal improvement will be conducted along with the Weras Ganga right bank embankment project.

Table 6.6.10 Improvement Plan in Bolgoda Basin

No	Measure	Specification
(B1)	Weras Ganga Improvement	Embankment (Right bank) (L=3.0 km) Channel dredging (L=2.0 km W=100 m)
(B2)	Maha Oya Improvement	Channel widening and dredging (L=4.0 km W=30 m) Surrounding Dike (L=5.9 km)
(B3)	Alut Ela Improvement	Channel widening and dredging (L=3.4 km W=20 m)
(B4)	Panape Ela Surrounding Dike	Surrounding Dike (L=6.7 km)
(B5)	Maha Oya Surrounding Dike	Surrounding Dike (L=1.0 km)
(B6)	Thalpitiya Ela Improvement	Channel dredging (L=4.0 km)
(B7)	Drainage Improvement in Moratuwa-Rathmalana	Improvement of urban drainage system

** Above Number applicate in Figure 6.6.15.*

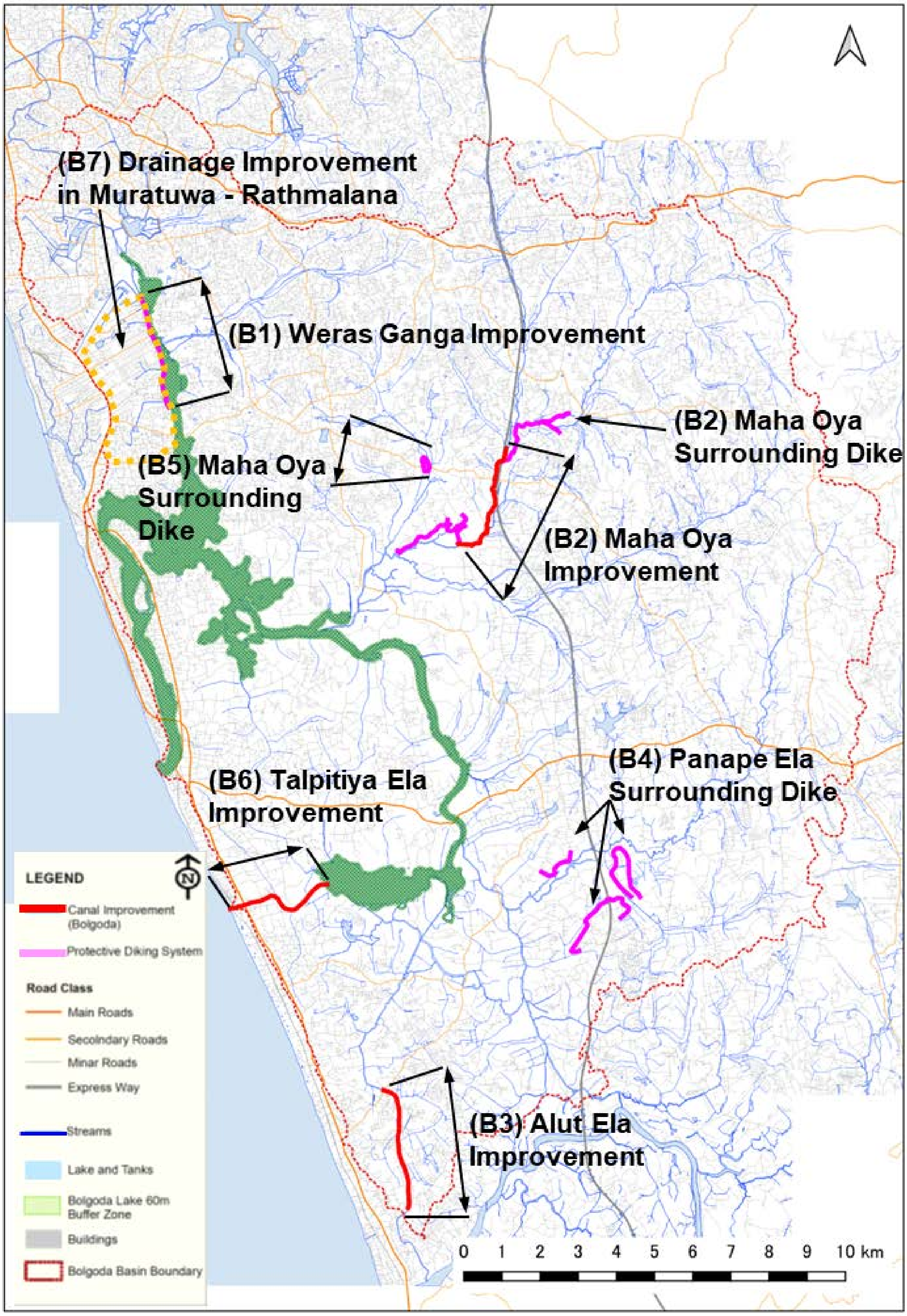


Figure 6.6.15 Location Map of River Improvement Plan in the Bolgoda Basin