Republic of India
Tamil Nadu Disaster Risk Reduction Agency (TNDRRA)
Chennai Metropolitan Development Authority (CMDA)
Tamil Nadu State Water Resources Department (TNWRD)
Greater Chennai Corporation (GCC)

Republic of India

THE PROJECT FOR FORMULATION OF COMPREHENSIVE FLOOD CONTROL MASTER PLAN IN URBANIZED RIVER BASINS IN CHENNAI

Final Report

February 2025

Japan International Cooperation Agency

Pacific Consultants Co., Ltd.
CTI Engineering International Co., Ltd.
Yachiyo Engineering Co., Ltd.

GE
JR
25-033

Table of Contents

List of Figures

List of Tables

Abbreviations

ADB	Asian Development Bank
AI	Artificial Intelligence
B Canal	Buckingham Canal
BCP	Business Continuity Plan
CAFP	Ministry of Consumer Affairs, Food and Public Distribution
CBA	Continuous Building Area
CCCDM	Centre for Climate Change and Disaster Management
CDL	Chart Datum Level
CFCMP	Comprehensive Flood Control Master Plan
CMA	Chennai Metropolitan Area
CMDA	Chennai Metropolitan Development Authority
CMRL	Chennai Metropolitan Rail Limited
CP(s)	Counterpart(s)
Cr.	Crore (10,000,000)
CRA	Commissionerate of Revenue Administration and Disaster Management
CRC	Central Relief Committee
CRRT	Chennai Rivers Restoration Trust
CRZ	Coastal Regulation Zone
CWC	Central Water Commission
CWPRS	Central Water and Power Research Station
CZMP	Coastal Zone Management Plan
D/D	Detailed Design
DDMA	District Disaster Management Authority
DDMP	District Disaster Management Plan
DDRF	District Disaster Response Force
DoE	Department of Environment
DTM	Digital Terrain Model
DWL	Design Water Level
DX	Digital Transformation
EOC	Emergency Operation Centre
ESSO	Earth Science System Organisation
EWS	Early Warning System
F/S	Feasibility Study
FB	Free Board
FRMMP	Flood Risk Management Master Plan
FSI	Floor Space Index
GCC	Greater Chennai Corporation
GDP	Gross Domestic Product
GSDP	Gross State Domestic Product
HHMD	Highways and Minor Ports Department
HHWL	Highest High-Water Level
Hs	Significant Wave Height
HTL	High Tide Line
HWL	High Water Level
IAS	Indian Administrative Service
ICCC	Integrated Command Control Centre
ICZM	Integrated Coastal Zone Management
IIT	Indian Institute of Technology
IMD	Indian Meteorological Department
INCOIS	Indian National Centre for Oceanic Information Services
INR	Indian Rupee
IOBW	Indian Ocean Basin-Wide
IRR	Inner Ring Road
JET	JICA Expert Team

JICA	Japan International Cooperation Agency
Landsat	Land Satellite
LTL	Low Tide Line
M/P	Master Plan
MAWS	Municipal Administration and Water Supply Department
MHA	Ministry of Home Affairs
MIKE21-SW	MIKE21 Spectral Wave Model
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
MOES	Ministry of Earth Sciences
MRTS	Mass Rapid Transit System
MSL	Mean Sea Level
NCCR	National Centre for Coastal Research
NCMC	National Crisis Management Committee
NCSCM	National Centre for Sustainable Coastal Management
NDMA	National Disaster Management Authority
NDMF	National Disaster Mitigation Fund
NDRF	National Disaster Response Force/Fund
NEC	National Executive Committee
NEM	North-East Monsoon
New CMA	New Chennai Metropolitan Area
NGO	Non-Governmental Organization
NIDM	National Institute for Disaster Management
NIOT	National Institute of Ocean Technology
NPO	Non-Profit Organization
PDCA	Plan-Do-Check-Act
PM	Project Management
PWD	Public Works Department
RC	Reinforced Concrete Structure
RIMES	Regional Integrated Multi-Hazard Early Warning System for Africa and Asia
RP	Return Period
RRD	Regional River Development
SCADA	Supervisory Control and Data Acquisition
SCMC	State Crisis Management Committee
SDMA	State Disaster Management Authority
SDRF	State Disaster Response Force/Fund
SEC	State Executive Committee
SOP	Standard Operating Procedure
SWD	Storm Water Drainage
SWM	Stormwater Management
Tm	Mean Wave Period
TN State	Tamil Nadu State
TNCDBR	Tamil Nadu Combined Development and Building Rules
TNDRRA	Tamil Nadu Disaster Risk Reduction Agency
TNHB	Tamil Nadu Housing Board
TNIDM	Tamil Nadu Institute of Disaster Management
TNRDC	Tamil Nadu Road Development Company
TNSCB	Tamil Nadu Slum Clearance Board
TNSMART	Tamil Nadu State Multi-Hazard Assessment and Response Tracking
TNSTC	Tamil Nadu State Transport Corporation Ltd.
TNUIFSL	Tamil Nadu Urban Infrastructure Financial Services Limited
TNWRD	Tamil Nadu Water Resources Department
UNDP	United Nations Development Programme
USD	United States Dollar
WB	The World Bank

Chapter 1. Scope of the Master Plan and Introduction to Study Area

1.1 Scope of the JICA Flood Control Master Plan

A flood control master plan is a comprehensive roadmap designed to address flood disasters by integrating a wide range of measures, both structural and non-structural. Unlike a feasibility study (F/S) or detailed design (D/D), which focuses on evaluating the viability or planning for specific projects, a master plan offers a long-term, holistic vision. It provides a coordinated approach to managing flood risks, identifying multiple interrelated measures, and laying out an implementation plan to achieve a target safety level over time, typically in phases.

Unlike scattered actions or isolated projects that may address only parts of the problem, a master plan takes a comprehensive and integrated approach. It ensures that various measures work together to achieve the target safety level and considers the interconnectedness of the basin's upstream and downstream areas as well as the interaction between fluvial and pluvial floods. This is especially crucial in urbanized basins, where both riverine and urban flooding need to be addressed cohesively.

The JICA comprehensive flood control master plan for urbanized river basins in Chennai includes results of study disciplines and components such as river flood control (Chapter 2), urban flood control (Chapter 3), urban planning and residual risk management (Chapter 4), coastal and river mouth studies (Chapter 5), proposals for improving flood disaster management (Chapter 6), economic analysis (Chapter 7), strategic environmental assessments (Chapter 8) and a phased-based implementation plan and overall recommendations for the successful implementation of the master plan (Chapter 9). It also contributes to the Third Urban Development Master Plan for Chennai. By integrating these components, the plan aims to reduce flood risks and enhance resilience in a sustainable and coordinated manner.

Implementing a flood control master plan requires collaboration among stakeholders, including government agencies, local communities, and technical experts. It also demands long-term commitment, as achieving the desired safety levels and resilience takes significant time and effort. Regular monitoring and periodic reviews are essential to ensure the plan’s effectiveness and relevance. For example, annual stakeholder meetings can help track progress and address challenges, while a more comprehensive review every five years allows for the necessary evaluation and review of the implementation plan based on evolving conditions and situations.

It is important to emphasize again that a master plan is not a feasibility study or a detailed design for a specific project. It is also not limited to addressing a single aspect of flood control. Instead, it is a broad, strategic framework that considers multiple facets of flood control. By adopting this integrated approach, the JICA flood control master plan ensures that flood risks are managed sustainably and comprehensively, providing a clear pathway to achieving safety and resilience in flood-prone areas over the long term.

1.2 Urbanized Basins in Chennai

Table 1-1 provides general information about four basins in the study area and other significant administrative boundaries. The combined area of all four basins is 6,153 km². However, it is important to note that a portion of the Kosasthalaiyar basin lies within Andhra Pradesh State and, as such, is excluded from this study. Consequently, the total area for these four basins within Tamil Nadu State is 5,102 km². Additionally, while the entire Kovalam basin, spanning 782 km², has been modeled and investigated, only the northern part, covering approximately 293 km², is considered part of Chennai's urbanized river basins. Therefore, the total study area for developing the flood control master plan is 4,613 km².

The basin delineation has been conducted using a 2.5 m resolution Digital Terrain Model (DTM). It is worth noting that the Cooum River origin is located very close to the Kosasthalaiyar River at the Kesavaram Anicut.

Various canals, including the Buckingham Canal, are in the basin. Buckingham Canal is a significant waterway parallel to the Bay of Bengal. The Buckingham Canal can be divided into three segments: the south Buckingham Canal in the Kovalam basin (24 km), the central Buckingham Canal between the Adyar and Cooum Rivers (7 km), and the north Buckingham Canal after the Cooum River until the Ennore Creek in the Kosasthalaiyar River (17 km).

Greater Chennai Corporation (GCC) is the civic body responsible for governing and administering the urban areas of Chennai. Chennai Metropolitan Area (CMA) with an area of 1189 km2 is an extensive urban agglomeration that includes Chennai and its surrounding areas. The New Chennai Metropolitan Area (New CMA) with an area of 5904 km2 is an expansion plan by the Tamil Nadu government to further develop the urban areas surrounding Chennai since October 2022.

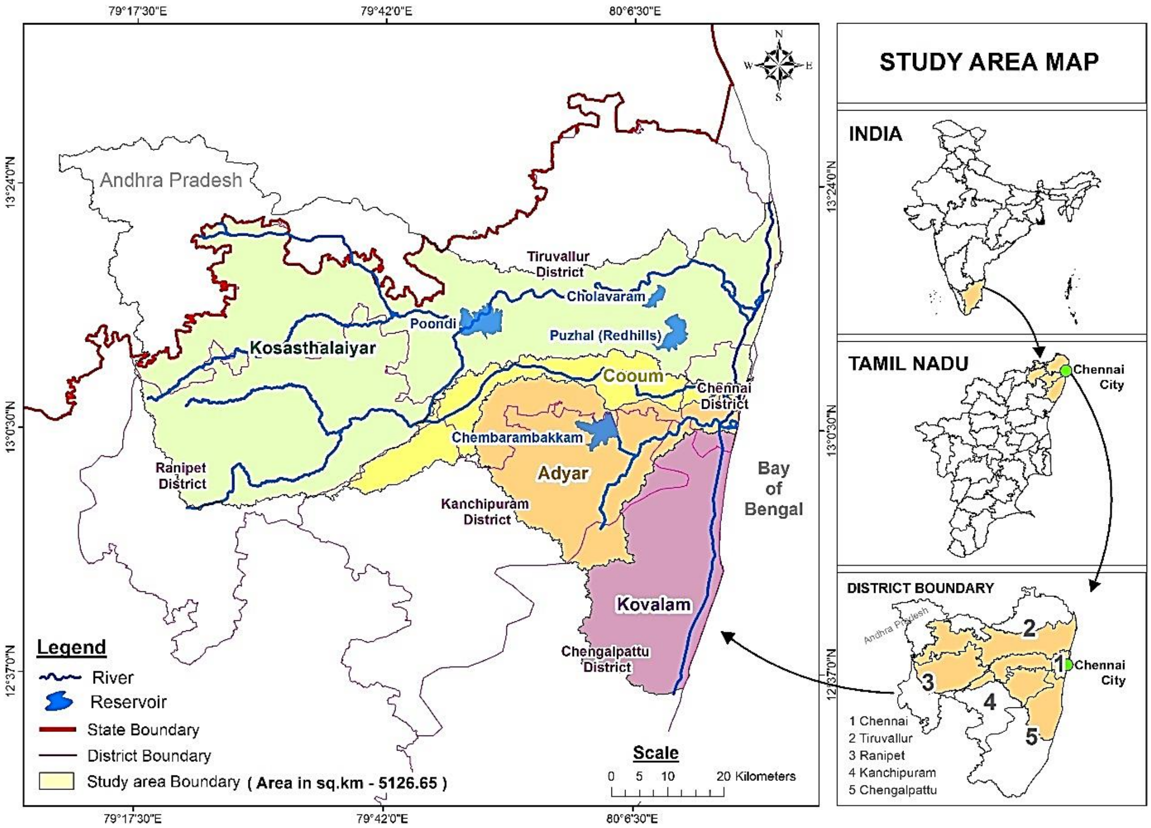
Four major dams and reservoirs in Chennai are Poondi Reservoir (Kosasthalaiyar Basin), Chembarambakkam Reservoir (Adyar Basin), Red Hills Reservoir (Kosasthalaiyar Basin), and Cholavaram Lake (Kosasthalaiyar Basin). Figure 1-1 shows four target basins, rivers, dams, and other related administrative boundaries.

As the terms Fluvial Flood and Pluvial Flood have been used in this master plan, it is important to define them here. Fluvial flooding in Chennai occurs when rivers overflow due to heavy rainfall, causing water to exceed the river's capacity and inundate surrounding areas. This type of flooding is typically prolonged and widespread, affecting riverbanks and low-lying lands. Pluvial flooding, or urban flooding, occurs when intense rainfall overwhelms urban drainage systems, causing water to pool on the surface. This type of flooding can happen even without nearby rivers, especially in urban areas where the drainage system is inadequate to handle heavy rainfall.

Table 1-1: Basin Area, River Length, and Admin Areas

Basin/Admin	Area (km^2)	Main River Length (km)	Avg. Annual Rainfall (mm)
Adyar Basin	854	~ 43.6	1333.0
Cooum Basin	435	~ 73.7	1281.6
Kosasthalaiyar Basin	4,082 (3,031 in TN)	~ 136 (~69.3 from Poondi Dam)	1037.7
Kovalam Basin	782 (293 in north)	No main river	1302.0
Buckingham Canal	N/A	~ 48 km in the Study Area	N/A
GCC	426	N/A	1366.6
CMA	1,189	N/A	1363.4
New CMA	5904	N/A	N/A

Source: JICA Expert Team

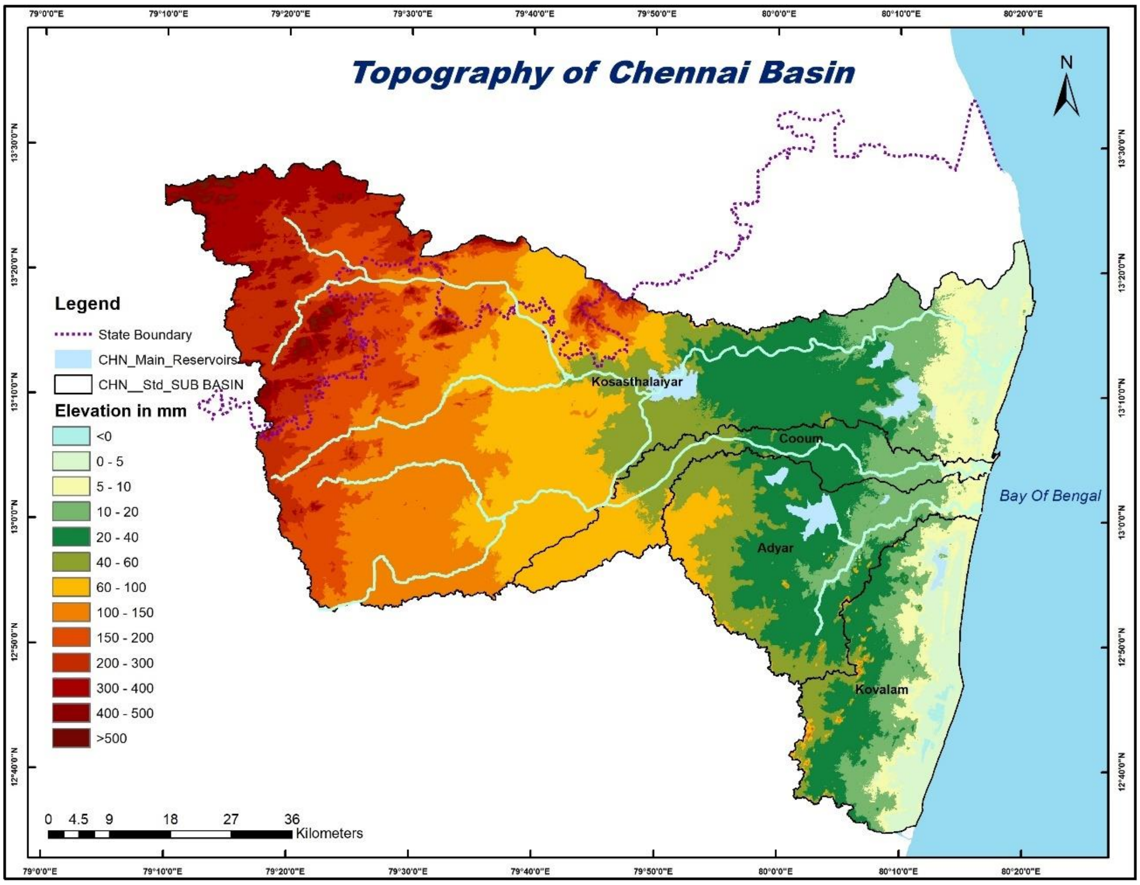


Source: JICA Expert Team

Figure 1-1: Target Basins and Administrative Boundaries

1.3 Topography of the Study Area

The study area exhibits a distinctive low-lying and flat topography, as depicted in Figure 1-2. Due to their low-lying nature, these basins are prone to flood and waterlogging. Most of the Adyar, Cooum, and Kovalam basins are located within low-lying areas, with elevations under 20 meters above mean sea level (MSL). In contrast, the Kosasthalaiyar basin maintains a low and flat topography until reaching the Poondi Dam, where it rises to relatively higher elevations upstream. Table 1-2 summarizes the topographic characteristics of the basins and rivers.



Source: JICA Expert Team

Figure 1-2: Topography of the Study Area

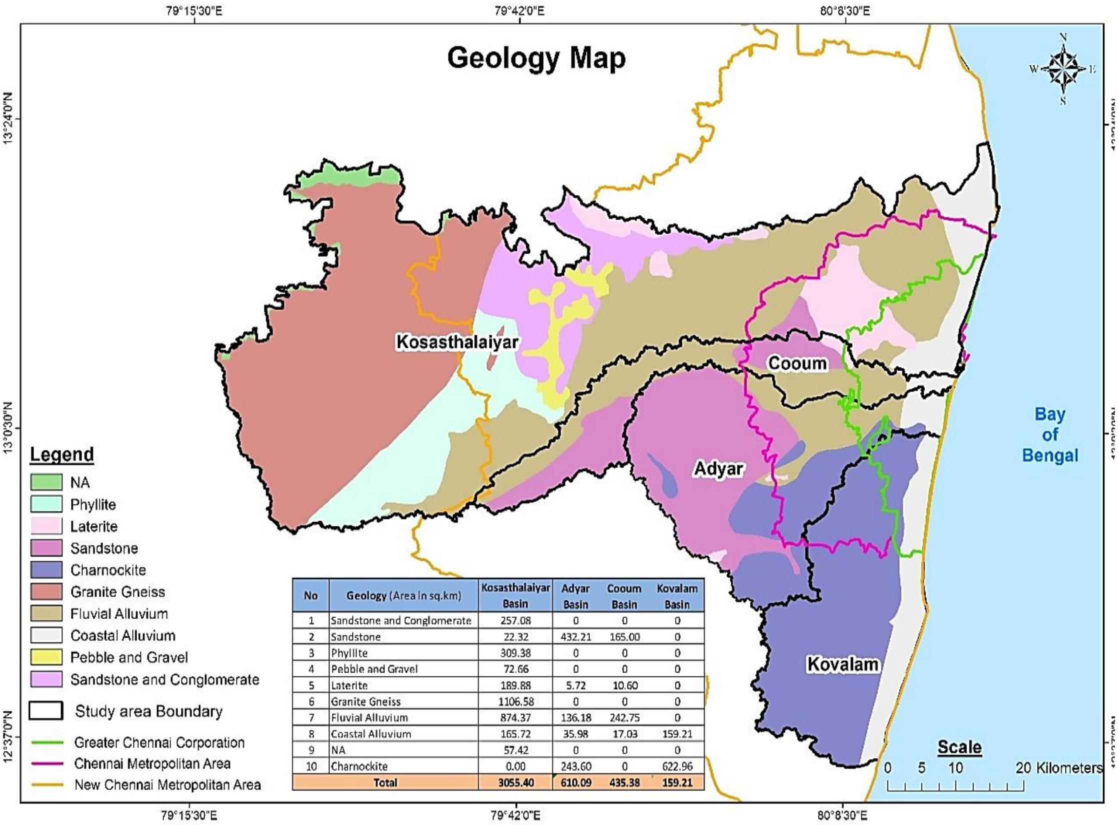
Table 1-2: Basin Topographic Specifications

Basin Name	Highest Elevation Across Basin (above MSL)	Elevation at River Origin (above MSL)	Avg. River Slope (Origin to Outlet)
Adyar	175m	29.7m	0.70 m/km 1:1420
Cooum	101m	65.5m	0.91 m/km 1:1100
Kovalam	169m	N/A	N/A
Kosasthalaiyar (Poondi Dam U/S)	545m	177.5m	2.96 m/km 1:340
Kosasthalaiyar (Poondi Dam D/S)	63m	35.2m	0.50 m/km 1:2020

Source: JICA Expert Team

1.3.1 Geology and soil types of the study area

As depicted in Figure 1-3, the geology of the Chennai basins is diverse, comprising both sedimentary and hard rock formations of different ages. Approximately 60% of the basin is occupied by sedimentary formations, while the remaining 40% consists of hard rock formations. The rocks found in the basin range from Archaean to Proterozoic, Jurassic, Cretaceous, Tertiary, and Quaternary ages, including alluvium deposits. The predominant soil types in the basin include Inceptisols, Alfisols, Entisols, and Vertisols. These soil types are often found in combination due to the varying degrees of weathering of the parent materials. The GCC area is classified into three regions based on its geology: sandy areas, clayey areas, and hard-rock areas. Sandy regions are located along the riverbanks and coastal areas, with rainwater percolating quickly. Clayey areas cover most of the city, and rainwater percolates slowly but is retained in the soil for a longer time. The hard-rock areas are found in certain localities like Guindy, Velachery, Adambakkam, and a part of Saidapet.



Source: JICA Expert Team using - ADB study data

Figure 1-3: Geology Map of Chennai Basin

1.4 Socio-economic Overview

1.4.1 Population

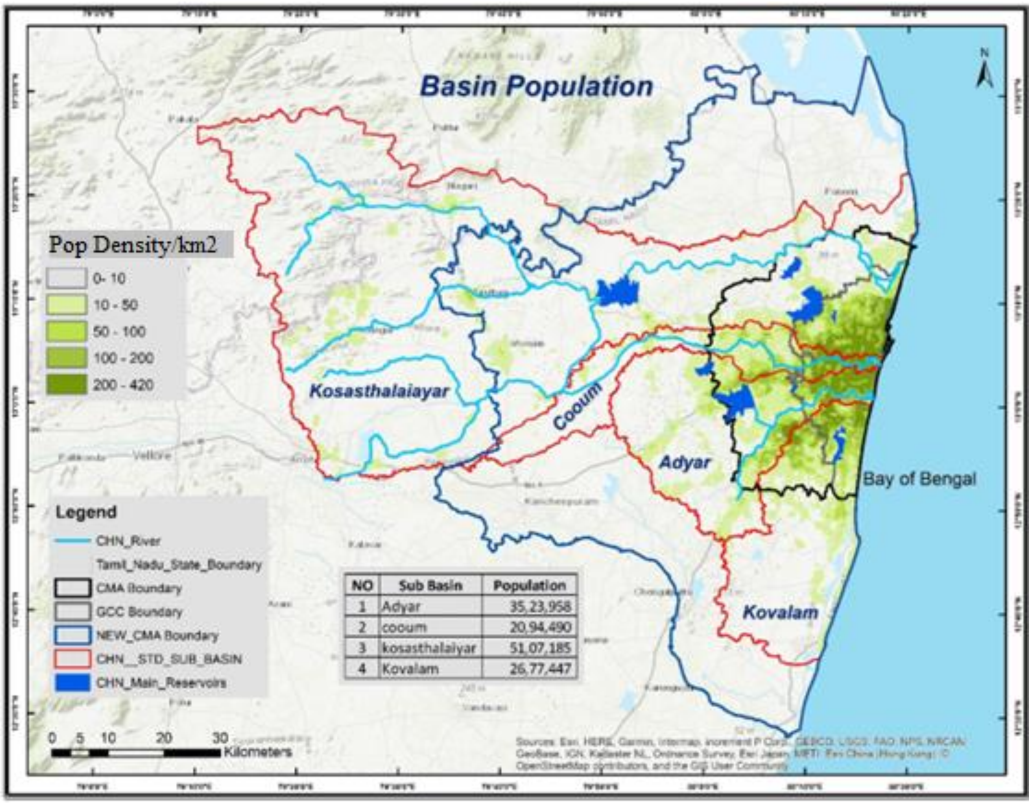
Chennai, the capital of the state of Tamil Nadu, is the fourth largest metropolitan city in India. The Chennai Metropolitan Area (CMA) consists of the city of Chennai, eight municipalities, etc. The estimated population for each administrative boundary and basin is shown in Table 1-3.

Table 1-3: Estimated Population (2022 Est.)

Admin/Basin	Population (2022 Est.)
GCC	6,221,000
CMA	11,503,000
New CMA	15,900,000
Tamil Nadu State	76,536,000
Adyar Basin	3,524,000
Cooum Basin	2,095,000
Kovalam Basin	2,678,000
Kosasthalaiyar Basin	5,107,000
Total Four Basins	**13,404,000**

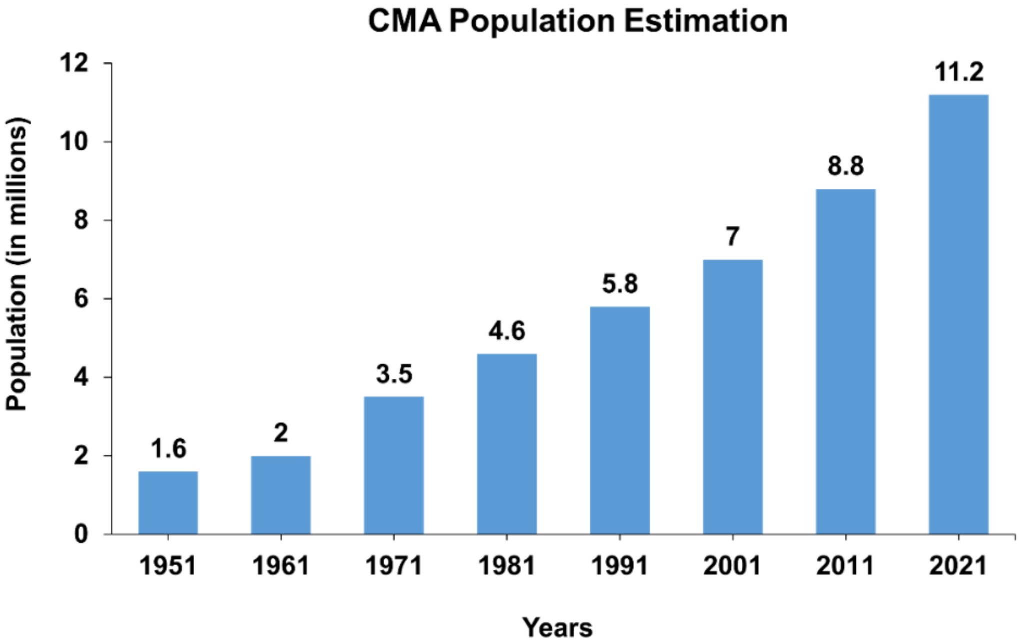
Source: JICA Expert Team using various statistical information and projections

The population of CMA was 11.28 percent of the population of Tamil Nadu state as per the 2001 census. However, the entire CMA forms even less than 1% of the total area (0.914 percent) of the entire Tamil Nadu. Figure 1-5 shows the CMA has experienced higher decadal growth rates for the past 8 decades. The Second Master Plan for CMA, 2026 has projected the population of CMA to reach 11.2 million in the year 2021 and 12.5 million in 2026. Furthermore, with the expansion of CMA, new CMA is further expected to invite an increasing population in terms of attractiveness for industrial activities, educational hubs, and healthcare facilities.



Source: JICA Expert Team based on Esri Data

Figure 1-4: Population Distribution



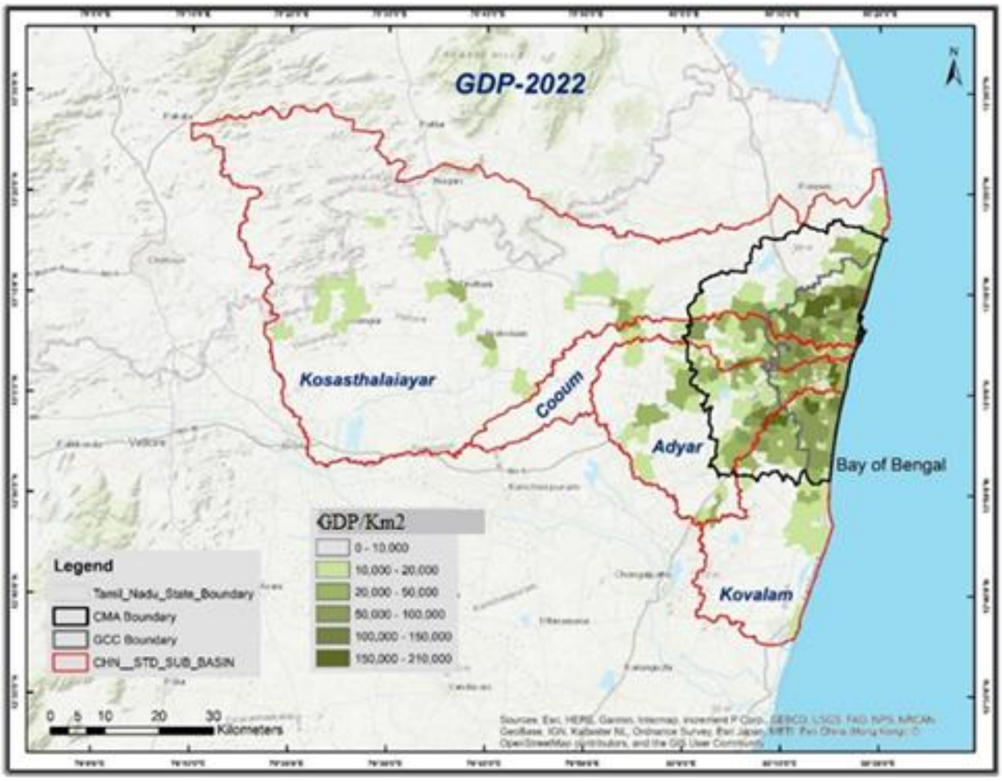
Source: JICA Expert Team based on the population projection – 2nd master plan

Figure 1-5: Population Growth Estimate

1.4.2 Gross State Domestic Product (GSDP)

Tamil Nadu state's Gross State Domestic Product (GSDP) was approximately USD 320.3 billion in FY2022, with a Compound Annual Growth Rate (CAGR) of 11.27% over the past eight years. This stands for 8.8% of India's GDP[1], making it the second largest contributor after Maharashtra state. The CMA had a per capita income of $1,764 in 2018, 31% higher than the national average[2].

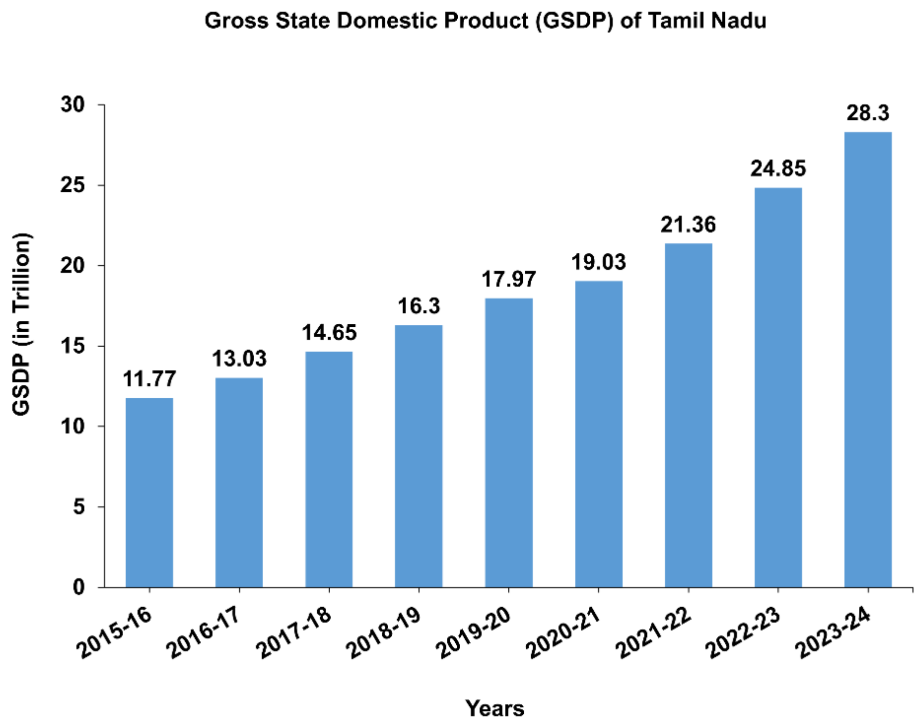
Figure 1-7 shows GDP distribution in the study area. The dominant sectors of the economy in Chennai are fisheries, tourism, manufacturing and processing, banking, exports, and IT. Therefore, being an industrial hub of South India, Chennai Metropolitan Area (CMA) has a GDP of about $786-1,000 million.



Source: JICA Expert Team based on Esri Data

Figure 1-6: GDP Distribution

[1] https://www.msmetamilnadu.tn.gov.in/why-tamilnadu.php
[2] https://www.cgijaffna.gov.in/uploads/pdf/Presentation-on-tamil-nadu-1.pdf



Source: JICA Expert Team based on IBEF, Tamil Nadu and PRS Legislative Research

Figure 1-7: Gross State Domestic Product (GSDP) of Tamil Nadu

1.4.3 City's transport and connectivity

Table 1-4 shows the length of the transportation network for each administrative boundary for a total length of road network of 2780 km. It is found that the transportation networks, both road and rail, resemble a radial pattern originating from the core area of the city.

Table 1-4: Length of the Road and Rail Network in Each Basin

Name of Network	Length in km			
	Adyar	Cooum	Kovalam	Kosasthalaiyar
Road				
National Highway	80.86	46.65	8.97	121.04
State Highway	25.97	0.00	128.29	17.67
Outer Ringroad	19.36	10.38	0.00	30.47
Inner Ringroad	6.40	4.55	5.40	15.06
Chennai Peripheral Ring Road	29.32	5.58	29.29	46.79
Railway				
Railway Network	38.08	41.55	17.88	166.15
Metro Lines	58.24	31.36	43.45	40.75

Source: JICA Expert Team using various statistical information and projection

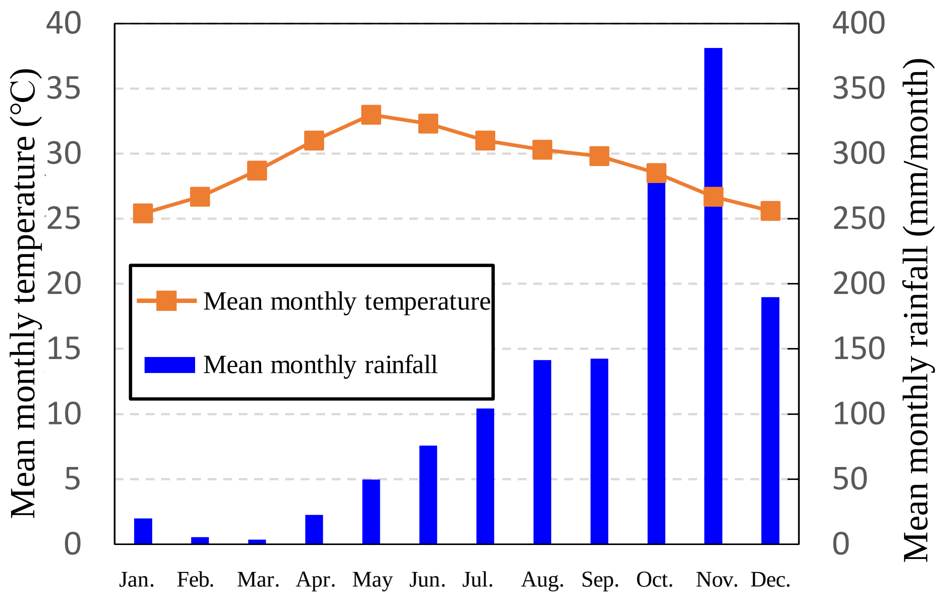
In addition to the radial pattern of roads, circular corridors like Inner Ring Road (IRR) serve as interconnections of radial routes. Nevertheless, to minimize the traffic disruption the Chennai Metropolitan Area (CMA) also comprises Chennai Metro Rail (Phase-I), Metropolitan Transport Corporation (MTC) buses, Sub Urban Rail System, and Mass Rapid Transit System (MRTS).

1.5 Hydrological and Physical Characteristics of Study Basins

1.5.1 Rainfall and climate

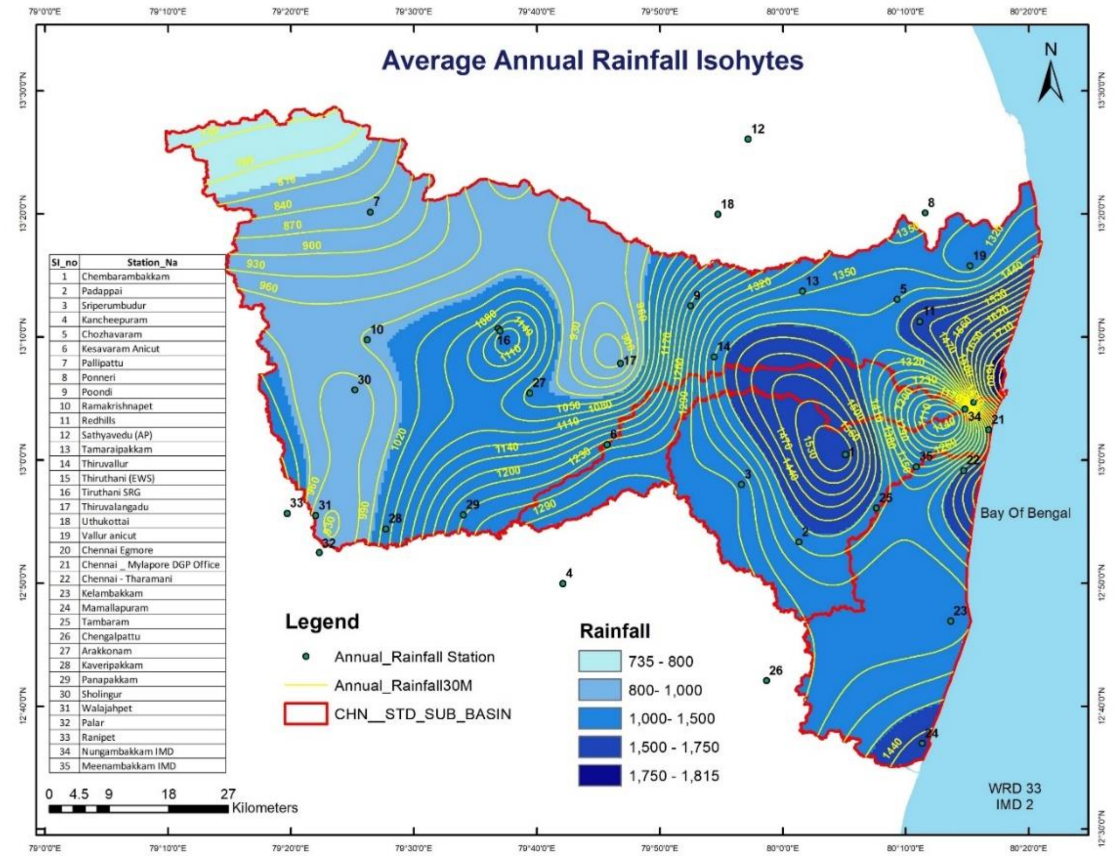
Chennai, located on the southeastern coast of India, experiences a tropical climate influenced by the Bay of Bengal. The rainy months typically span from October to December, with November being the wettest month, receiving a significant portion of the yearly rainfall as in the Figure 1-8.

The long-term (30 years) average annual rainfall for each basin is as follows: Adyar Basin (1,333.0 mm), Cooum Basin (1,281.6 mm), Kovalam Basin (1,302.0 mm) and Kosasthalaiyar Basin (1,037.7 mm). Figure 1-9 shows isohyets for average annual rainfall from 1991 to 2021. Areas near the Bay of Bengal and the middle part of the Adyar (Chembarambakkam Dam) and Cooum Basins receive more rainfall. In the Kosasthalaiyar Basin, the area upstream of Poondi Dam receives much less rainfall compared to the downstream region.



Source: JICA Expert Team based on IMD data from 1991 to 2020

Figure 1-8: Average Monthly Rainfall and Average Monthly Temperature in Major Cities

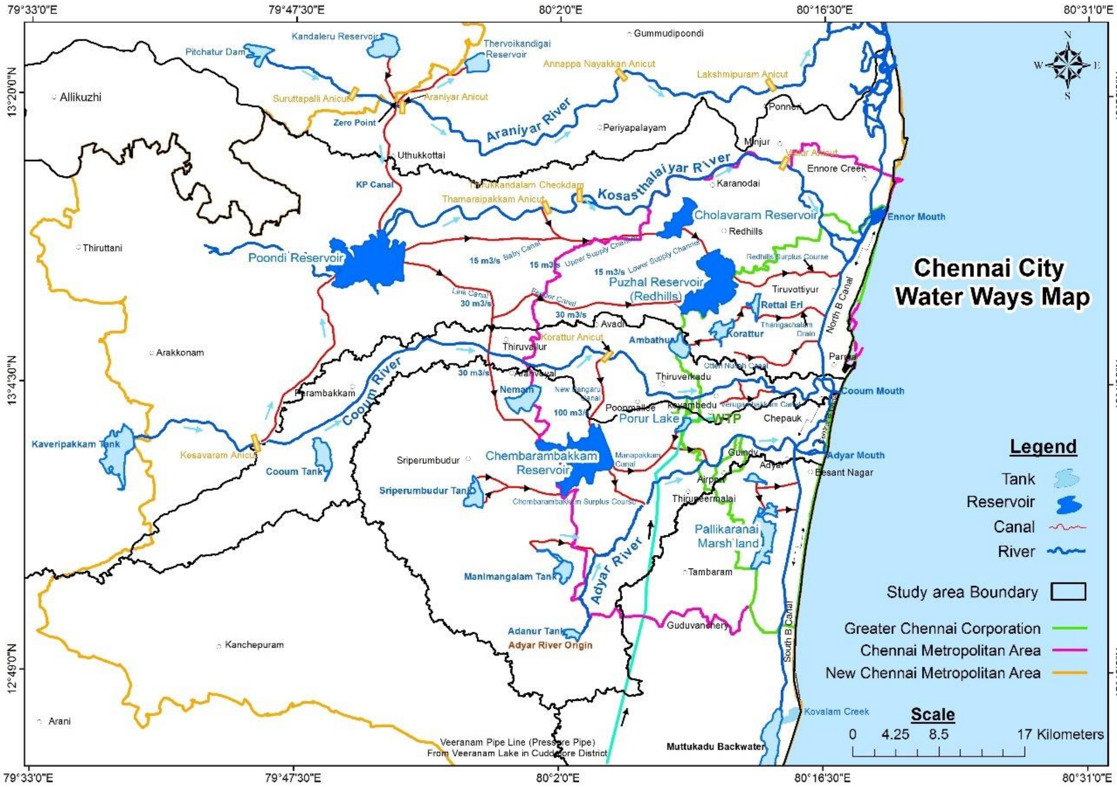


Source: JICA Expert Team using WRD and IMD Stations

Figure 1-9: Average Annual Rainfall Isohyets from 1991 to 2021

1.5.2 Water bodies and drainage system

It is important to note the complex system of major rivers, natural canals, man-made canals, and drainage systems in the study areas. Figure 1-10 provides an overview of major rivers, canals, drainage systems, key dams, and the most important water bodies and tanks in the study areas.



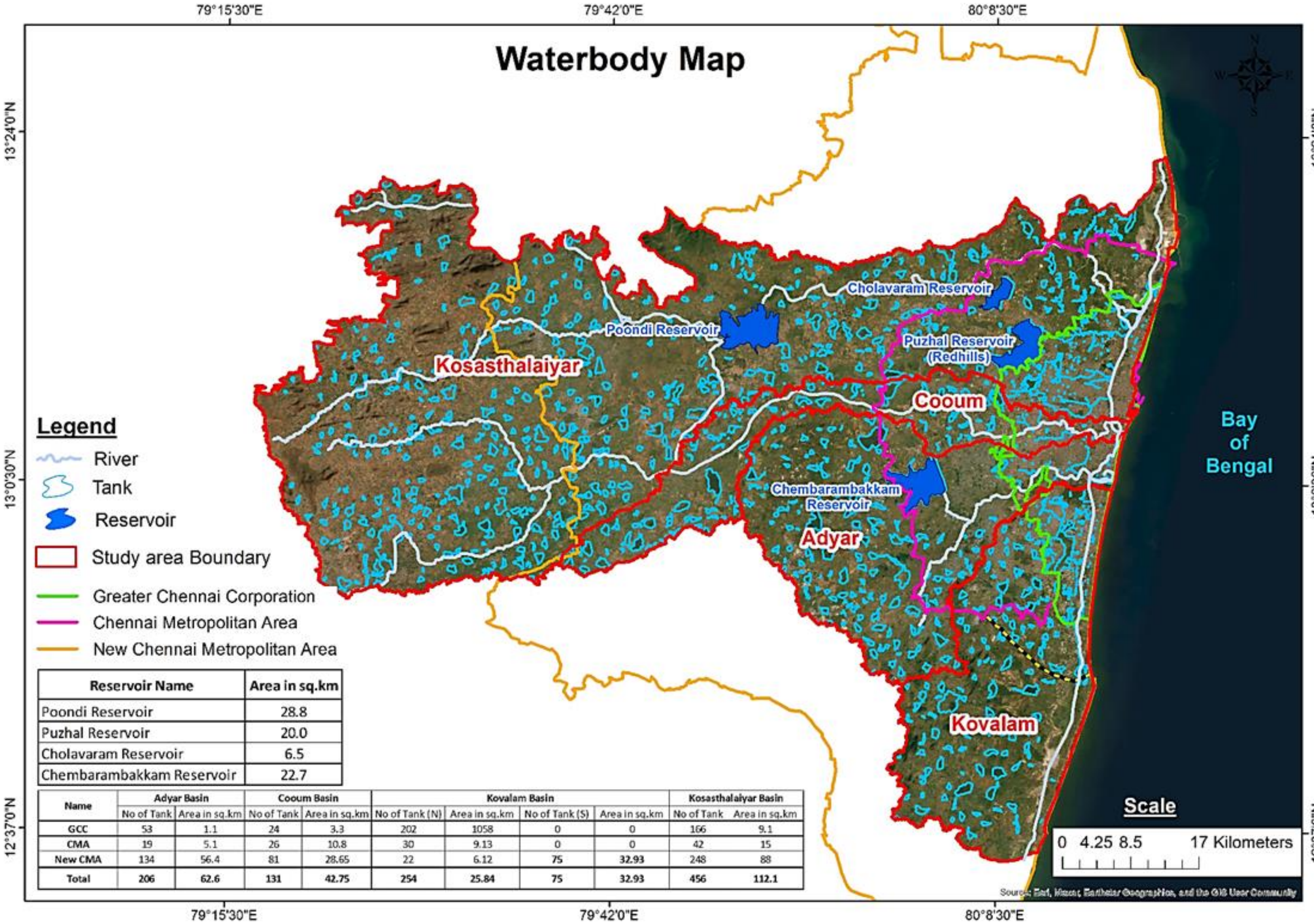
Source: JICA Expert Team using WRD and IMD Stations

Figure 1-10: Water Infrastructure and Hydrographic Features of the Basin

Chennai has various water bodies, lakes, and tanks that contribute significantly to the region's water resources and environmental balance. In Chennai's historical context, "Ery" refers to traditional water bodies and tanks that once graced the city's landscape. Urbanization, expansion, and encroachments resulted in the disappearance or degradation of numerous Erys, as they were transformed into residential and commercial areas. This transformation severely affected Chennai's hydrological balance, leading to issues such as increased vulnerability to flooding. Figure 1-11 shows the location and other details of remaining water bodies, locally referred to as tanks, based on the information collected from TNWRD.

1.5.3 Land Use and Land Cover (LULC) and important infrastructures

Figure 1-12 illustrates the land use/land cover in the study area, focusing specifically on the New CMA as of 2023. Figure 1-13 shows important urban infrastructures for transportation.

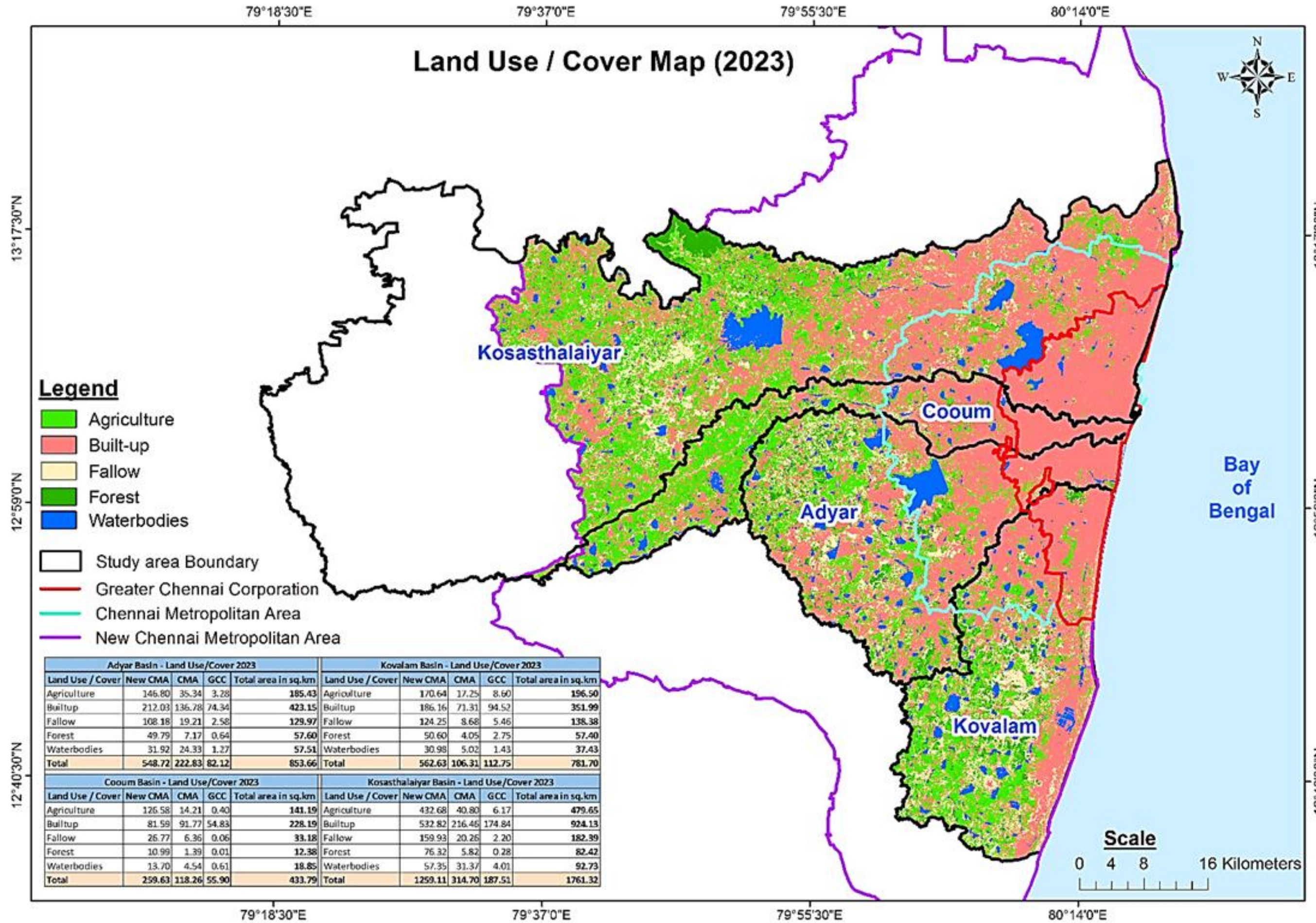


Reservoir Name	Area in sq.km
Poondi Reservoir	28.8
Puzhal Reservoir	20.0
Cholavaram Reservoir	6.5
Chembarambakkam Reservoir	22.7

Name	Adyar Basin		Cooum Basin		Kovalam Basin				Kosasthalaiyar Basin	
	No of Tank	Area in sq.km	No of Tank	Area in sq.km	No of Tank (N)	Area in sq.km	No of Tank (S)	Area in sq.km	No of Tank	Area in sq.km
GCC	53	1.1	24	3.3	202	1058	0	0	166	9.1
CMA	19	5.1	26	10.8	30	9.13	0	0	42	15
New CMA	134	56.4	81	28.65	22	6.12	75	32.93	248	88
Total	206	62.6	131	42.75	254	25.84	75	32.93	456	112.1

Source: JICA Expert Team using TNWRD data

Figure 1-11: Basins and Other Hydrological Elements of the Study Area



Adyar Basin - Land Use/Cover 2023				
Land Use / Cover	New CMA	CMA	GCC	Total area in sq.km
Agriculture	146.80	35.34	3.28	**185.43**
Builtup	212.03	136.78	74.34	**423.15**
Fallow	108.18	19.21	2.58	**129.97**
Forest	49.79	7.17	0.64	**57.60**
Waterbodies	31.92	24.33	1.27	**57.51**
Total	**548.72**	**222.83**	**82.12**	**853.66**

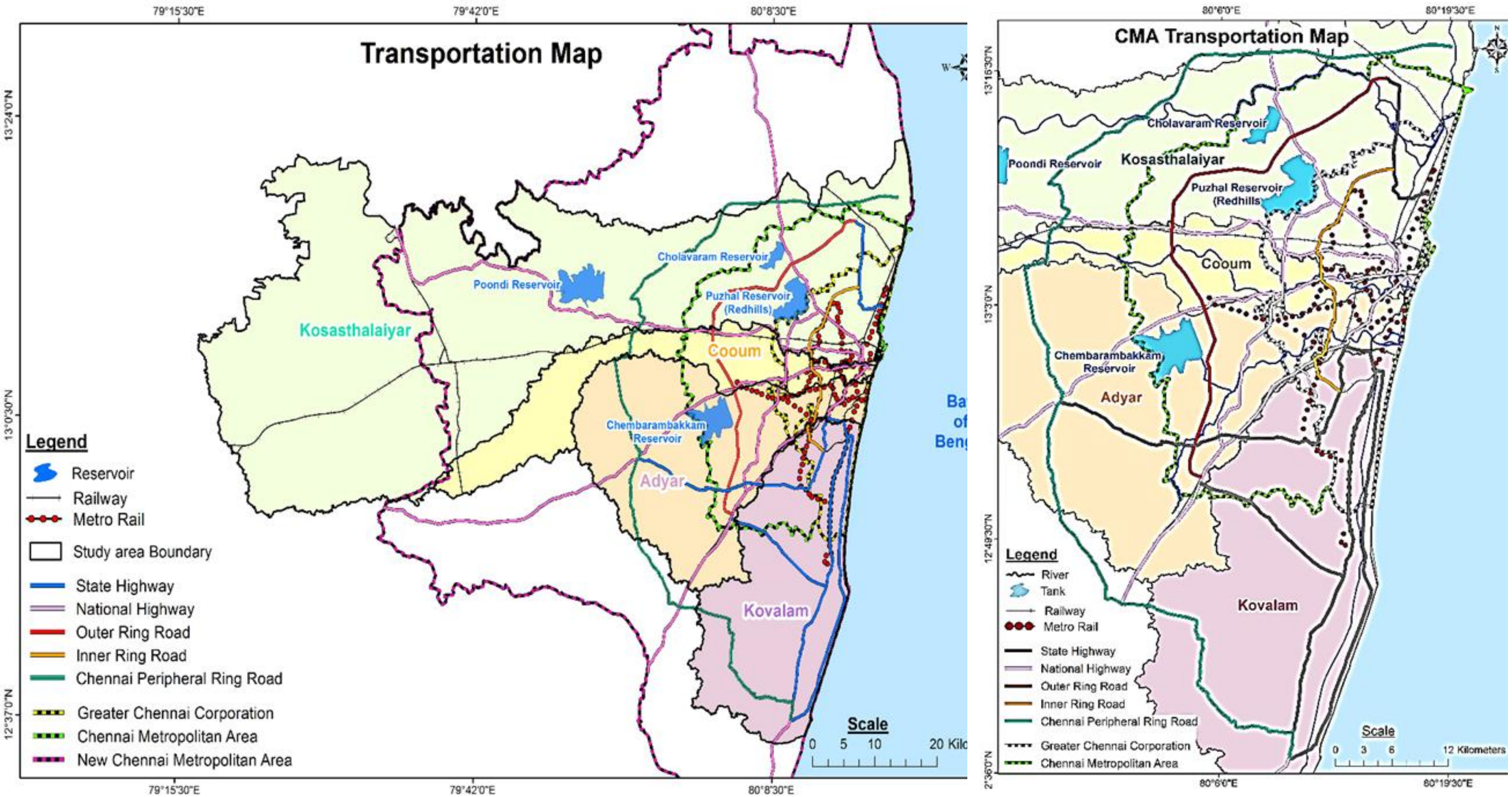
Kovalam Basin - Land Use/Cover 2023				
Land Use / Cover	New CMA	CMA	GCC	Total area in sq.km
Agriculture	170.64	17.25	8.60	**196.50**
Builtup	186.16	71.31	94.52	**351.99**
Fallow	124.25	8.68	5.46	**138.38**
Forest	50.60	4.05	2.75	**57.40**
Waterbodies	30.98	5.02	1.43	**37.43**
Total	**562.63**	**106.31**	**112.75**	**781.70**

Cooum Basin - Land Use/Cover 2023				
Land Use / Cover	New CMA	CMA	GCC	Total area in sq.km
Agriculture	126.58	14.21	0.40	**141.19**
Builtup	81.59	91.77	54.83	**228.19**
Fallow	26.77	6.36	0.06	**33.18**
Forest	10.99	1.39	0.01	**12.38**
Waterbodies	13.70	4.54	0.61	**18.85**
Total	**259.63**	**118.26**	**55.90**	**433.79**

Kosasthalaiyar Basin - Land Use/Cover 2023				
Land Use / Cover	New CMA	CMA	GCC	Total area in sq.km
Agriculture	432.68	40.80	6.17	**479.65**
Builtup	532.82	216.46	174.84	**924.13**
Fallow	159.93	20.26	2.20	**182.39**
Forest	76.32	5.82	0.28	**82.42**
Waterbodies	57.35	31.37	4.01	**92.73**
Total	**1259.11**	**314.70**	**187.51**	**1761.32**

Source: JICA Expert Team using CMDA land use GIS data

Figure 1-12: Land Use of Study Area in the New CMA in 2023



Source: JICA Expert Team using ADB study data

Figure 1-13: Transportation Infrastructures in the Study Area

1.6 Past Major Floods in Chennai

Chennai has experienced several significant floods that have left a lasting impact. Notable floods occurred in 1943, 1976, 1985, 1991, 1996, 1998, 2002, 2005, 2008, 2015, 2020, 2021 and 2023. The Table 1-5 is extracted from the "Flood Risk Reduction: Final Report," provided by the Advisory Committee on Mitigation and Management of Flood Risk in Chennai Metro, published on March 6, 2023. This table originates from the work conducted by the SECON-JBA Study Team in 2021. It provides a summary of significant flood events from 1976 to 2021. It is important to note that there were notable rainfall/flood incidents before 1976, including instances like 520mm of rainfall in 24 hours on October 21, 1845, 460mm in 24 hours on October 24, 1857, and 358mm of rainfall in 48 hours on October 6 and 7, 1943, as documented in the 2nd Chennai Urban Master Plan.

In 2023, Chennai received the highest amount of rainfall since the rain and subsequent floods in 2015. Nungambakkam and Meenambakkam observatories recorded 530mm and 520mm of rain between December 2 and 4, 2023. Chennai recorded a total of 921.4 mm of rain during the 2023 monsoon season.

Table 1-5: Past Major Flood in Study Area

Flood Year	Type of Flooding	Daily Max. Rainfall (mm)	Date of Daily Max Rainfall	Total Rainfall During Monsoon (mm)
1976	Primary Fluvial	452.4 Nungambakkam	11/25/1976	1264.5 (Meenambakkam)
1985	Fluvial & Pluvial	329.0 Nungambakkam	11/13/1985	1271.7 (Nungambakkam)
1996	Fluvial	450.0 Cholavaram &Thamaripakkam 347.0 Nungambakkam	6/14/1996	1704.6 (Nungambakkam)
2005	Fluvial & Pluvial	312.0 Tambaram	12/13/2005	2108.0 (Nungambakkam)
2015	Fluvial & Pluvial	494.2 Tambaram 475.0 Chembarambakkam	12/2/2015	2066.9 (Tambaram)
2021	Primary Pluvial	237.1 Mylapore - DGP Office	12/31/2021	1816.0 (Cholavaram) 1785.0 (Mylapore)
2023	Fluvial & Pluvial	293.4mm Nungambakkam	12/4/2023	921.4 (Nungambakkam)

Source: Advisory Committee on Mitigation and Management of Flood Risk in Chennai Metro "Flood Risk Reduction: Final Report, "2023, originates from the work conducted by the SECON-JBA Study Team in 2021

1.7 Challenges of Flood Management in Chennai

Chennai faces a range of interconnected challenges related to both river and urban flood control, which are intricately linked and require a comprehensive master plan to address. These challenges encompass systemic issues as well as specific issues related to riverine and urban floods, which together compound the flood risk in the city. Below are the major systemic issues followed by those specifically related to urban and riverine flooding.

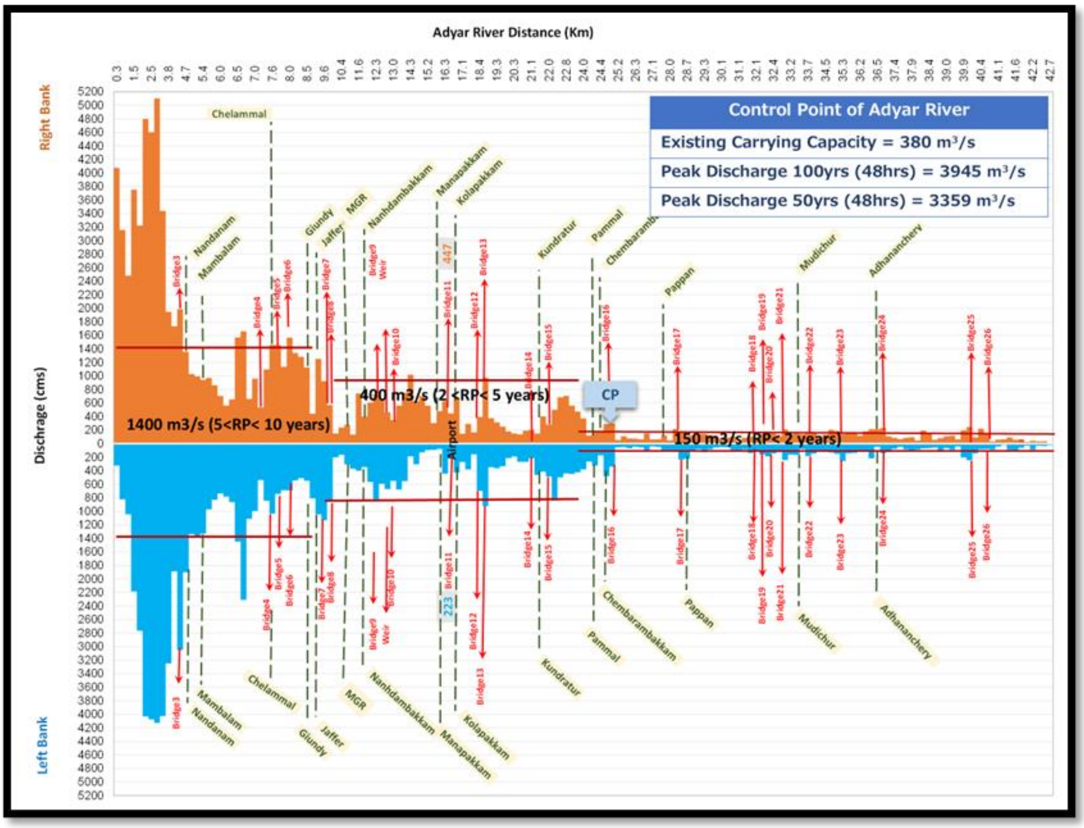
- Scattered Countermeasures and Lack of a Comprehensive Flood Control Master Plan: Flood control efforts in Chennai are currently fragmented, consisting of localized measures without an overarching, coordinated flood control master plan. This scattered approach hampers effective resource allocation and coordination, leaving the city vulnerable to flooding.

- Divided Responsibilities Among Stakeholders: Several agencies are involved in flood management, but the lack of proper coordination and information-sharing between them leads to inefficiencies. This is particularly evident in the management of micro drainages, and river flood control, where there is a lack of an integrated approach. Stakeholders operate in silos with competing financial and technical priorities, such as balancing flood control efforts with addressing other challenges like water supply and scarcity.
- Rapid Urbanization and Land-Use Changes: Chennai's rapid urbanization has significantly impacted the rainfall-runoff ratio, a key indicator of increasing flood risk. In 2006, when the Second Urban Development Master Plan for Chennai was developed, the rainfall-runoff ratio was 0.5. However, due to urban growth and increased impervious surfaces, this ratio has risen to 0.71 by 2024 for the CMA area, representing a significant increase in the amount of runoff generated.
- Encroachments and Reduced Natural Drainage: Encroachments along rivers, waterbodies, and tanks due to urban growth and improper planning and conservation have resulted in reducing the natural drainage capacity in rivers and also flood storage capacity in waterbodies and tanks. These changes disrupt the natural flow of floodwaters and increase the risk of floods. Moreover, encroachments along rivers and drains have reduced their carrying capacities, causing a rise in flow levels during heavy rainfall. It is important to note, that rising water levels in rivers make it difficult for urban drainage systems to efficiently discharge floodwater due to backwater effects, leading to urban flooding. This interaction between riverine and urban flooding must be addressed together comprehensively within a master plan.
- Insufficient Observation Networks: There is a lack of real-time hydrological data and poorly gauged basins, limiting the capacity to predict and manage flood events proactively.

To effectively manage these interconnected issues, a comprehensive flood control master plan is crucial. Such a plan will address the root causes of increased runoff, inadequate drainage, and the growing urban pressures on natural water systems, while also considering both riverine and urban flooding in an integrated manner.

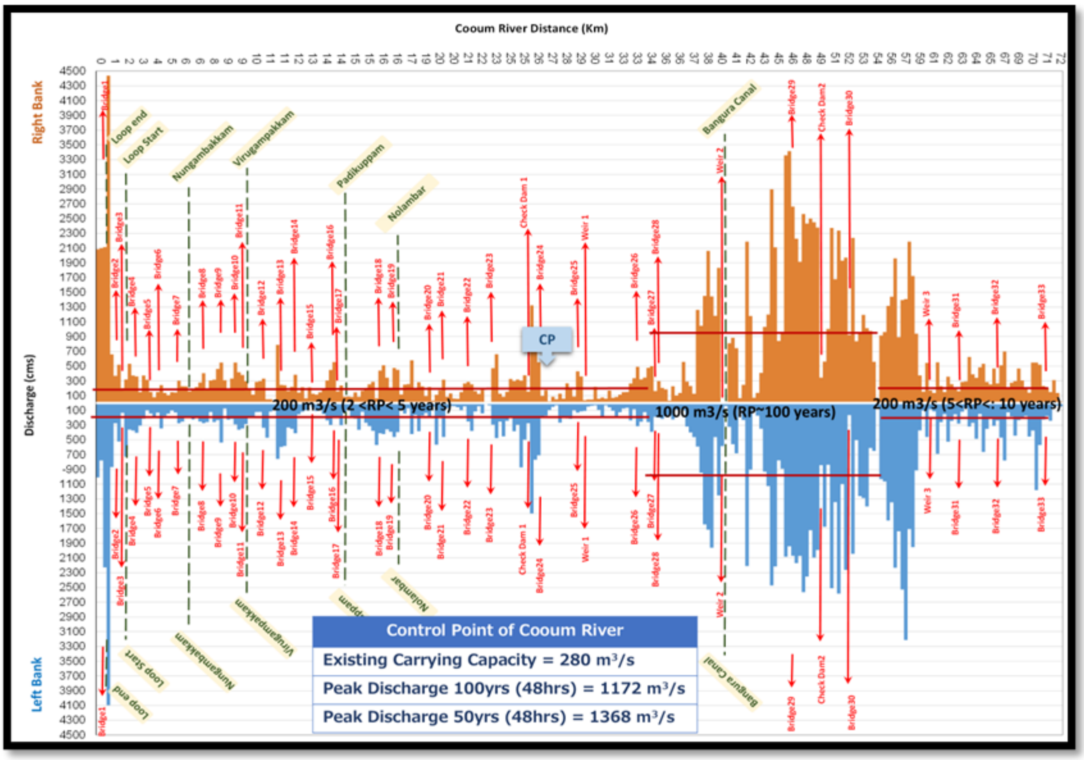
Figure 1-14 to Figure 1-16 illustrates the carrying capacity of three major rivers: Adyar (at the confluence), Cooum (Pathiputtur), and Kosasthalaiyar (Vallur). It highlights the inadequate capacity of these rivers, reflecting a similar situation in other major waterways. The fundamental reason for this inadequate carrying capacity is rapid urbanization, which not only causes encroachments along the rivers but also increases runoff, further exacerbating the issue.

The challenges outlined above highlight the urgent need for a **comprehensive flood control master plan** for Chennai (Figure 1-17). Such a plan will integrate risk assessment, proactive flood management strategies, improved coordination among stakeholders, and infrastructure development. Addressing the physical limitations in river carrying capacities, and urban flood control requires a systematic and multi-sectoral approach. Without an effective, long-term plan, Chennai remains vulnerable to the devastating impacts of flood events.



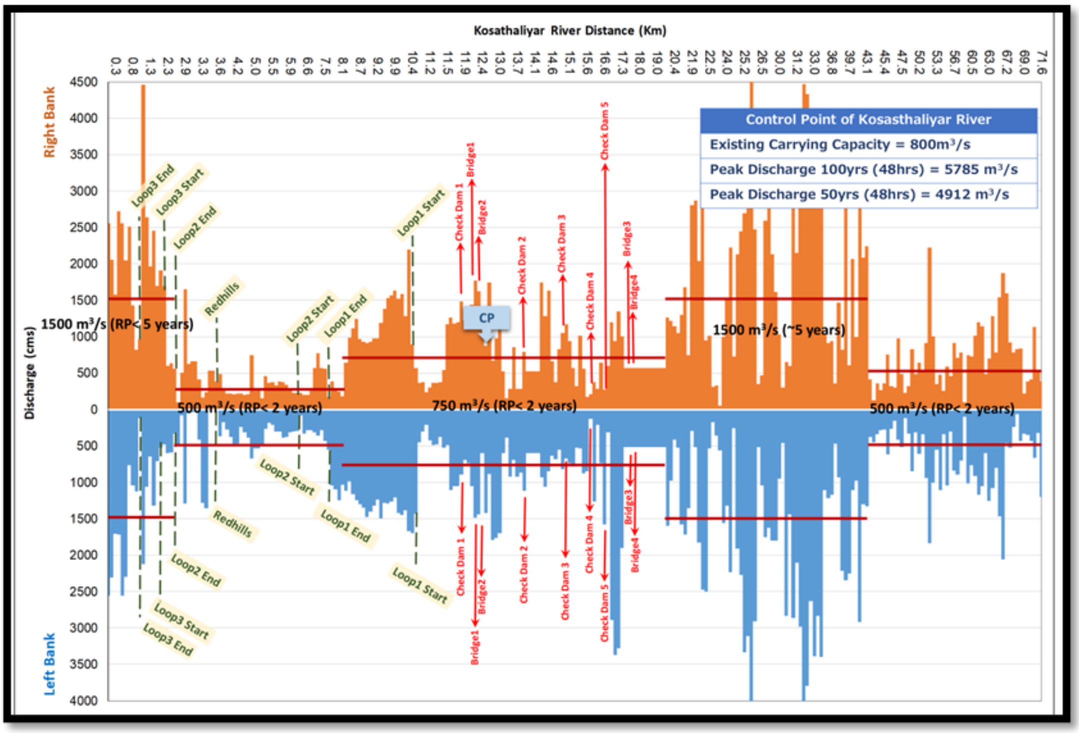
Source: JICA Expert Team

Figure 1-14: Inadequate Carrying Capacity of the Adyar River



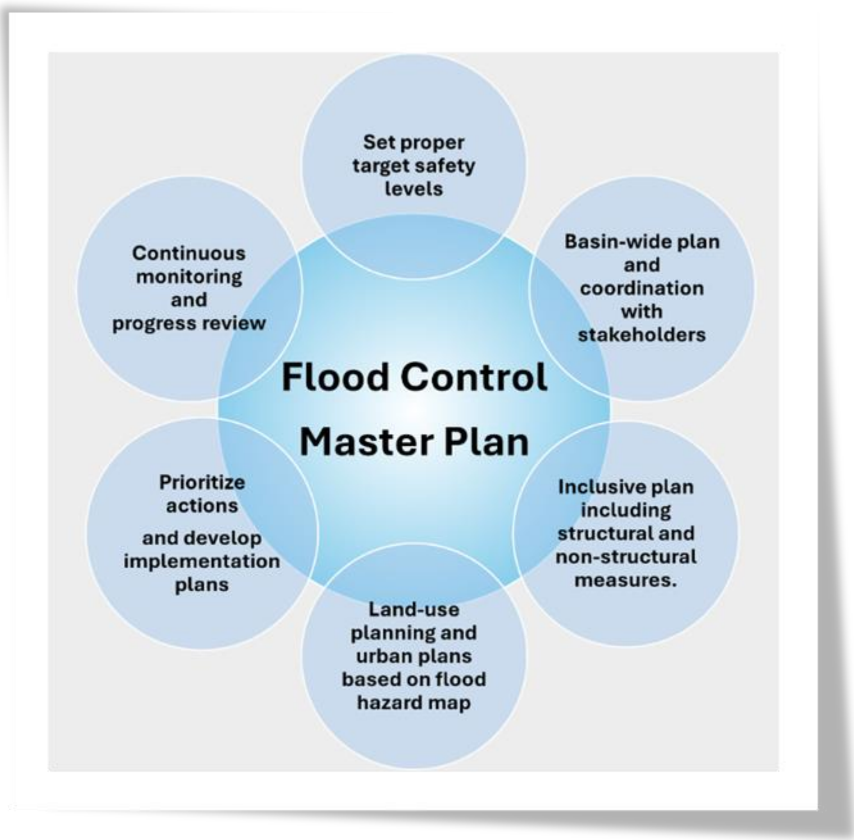
Source: JICA Expert Team

Figure 1-15: Inadequate Carrying Capacity of the Cooum River



Source: JICA Expert Team

Figure 1-16: Inadequate Carrying Capacity of the Kosasthaliyar



Source: JICA Expert Team

Figure 1-17: Concept of the Flood Control Master Plan

Chapter 2. Riverine Flood Management Plan

2.1 Overview of Existing and Ongoing Plans and Flood Control Measures

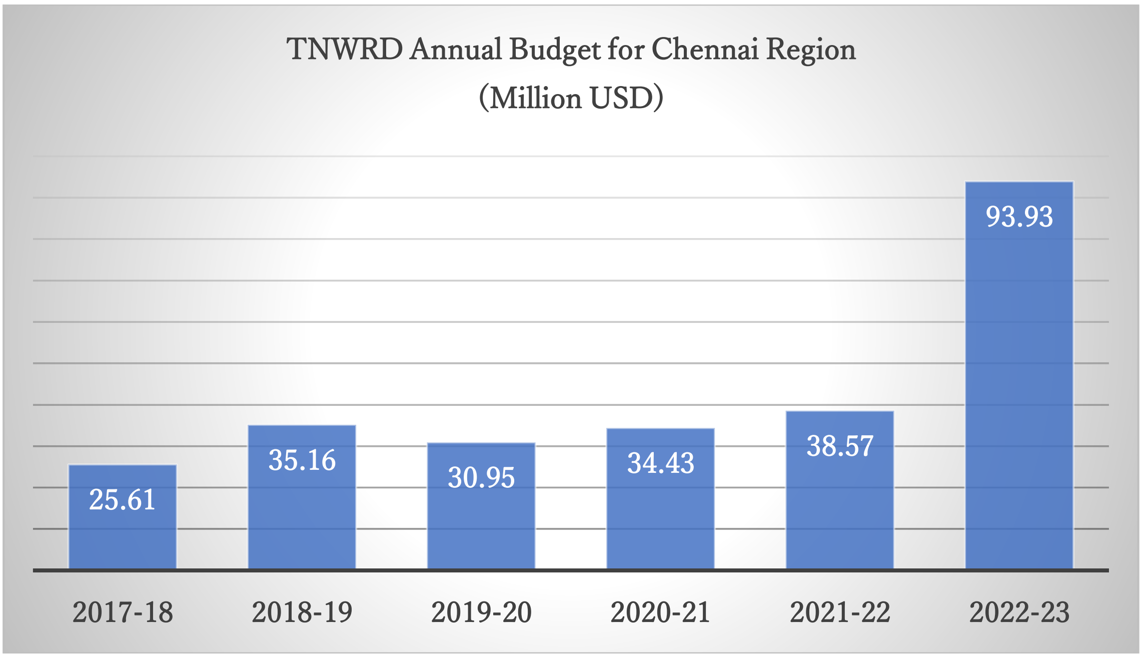
The Tamil Nadu Water Resources Department (TNWRD) oversees water management within Tamil Nadu. Integral to TNWRD's mandate is flood control. Figure 2-1 Has been developed based on the TNWRD annual budget allocated to Palar Basin Circle, which was in charge of the Adyar, Cooum, Kosasthalaiyar, and Kovalam basins from 2017 to 2023. It is important to recognize that the total TNWRD budget significantly surpasses the amount presented in this diagram, which exclusively reflects the annual expenditure of TNWRD for river basins within the Chennai region. Figure 2-2 categorizes TNWRD's annual budget for river and flood control and water resource management projects. It is noteworthy that an exchange rate of 1 US Dollar, equating to 80 Indian Rupees, has been employed.

2.1.1 Major TNWRD projects for riverine flood control

The so-called "Comprehensive Flood Management Plan by TNWRD" includes three major activities for flood control as follows: Structural Measures (river works and flood storage, etc.), Non-structural Measures (developing localized Disaster Management Plans (DDMPs). flood forecasting and early warning systems, etc.) and Administrative and Managerial Changes (improved governance and pre-monsoon inter-departmental coordination, etc.). TNWRD Structural Measures have been divided into three subcategories as follows:

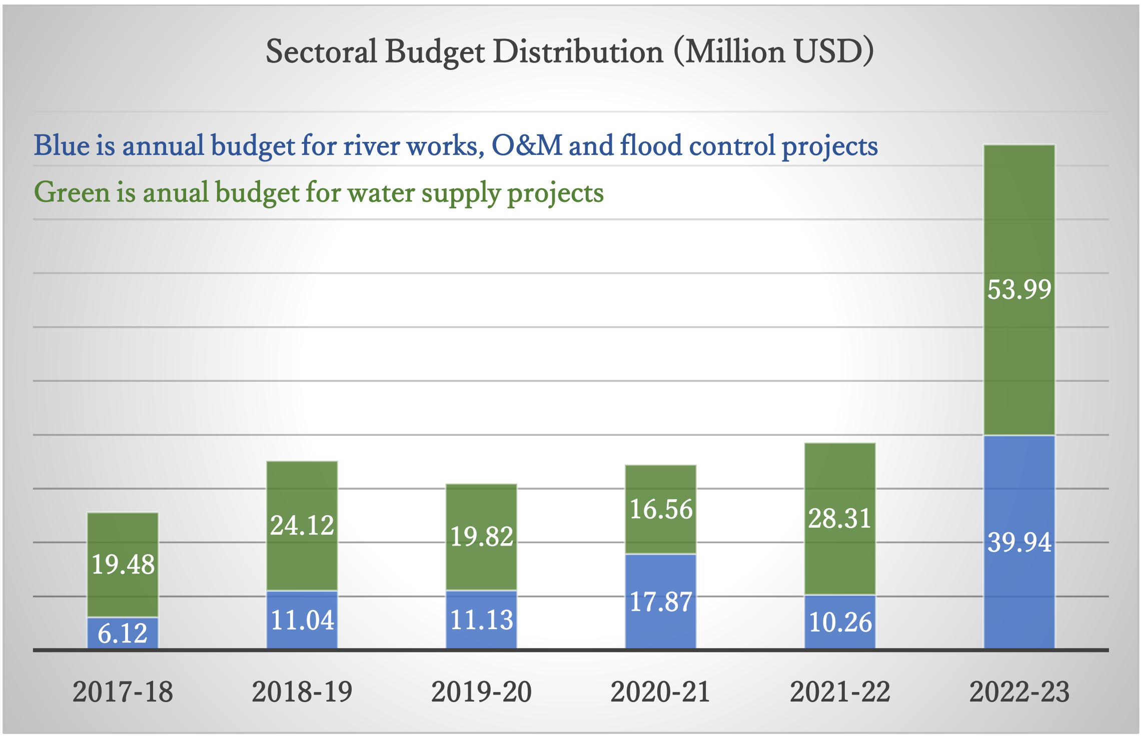
1. Flood Mitigation and River Works: Improving drainage systems, building new channels and diversions, and constructing flood walls and embankments. River management includes widening, desilting, and clearing obstructions to enhance water flow and installing structures to control erosion and stabilize riverbanks.
2. Flood Storage: New tanks and reservoirs and restoring ponds and waterbodies to enhance the flood storage capacity of existing tanks, developing link canals between tanks and rivers, and enabling water transfers between basins further support efficient water management.
3. Climate Change Adaptation Measures: Installing regulators to control water flow, improving groundwater recharge, managing flash floods in streams and tanks, and increasing the capacity of rivers and streams to handle heavy rainfall.

The following pages summarize major projects implemented or planned by TNWRD, focusing on initiatives undertaken between 2022 and 2024.



Source: JICA Expert Team based on TNWRD data

Figure 2-1: TNWRD Annual Budget for Palar Basin Circle (USD)



Source: JICA Expert Team based on TNWRD data

Figure 2-2: Rough Classification of TNWRD Budget for Chennai Region

The most important interventions for riverine flood control related to the JICA Flood Control Master Plan were the widening of about 2km of the Adyar River (downstream of Chembarambakkam surplus course confluence) from about 60m to about 120m river width (bank to bank) and the strengthening of either side of riverbanks at the tail end of Kosasthalaiyar River. The department had spent USD 1.5 million (INR 120 crores) for widening the Adyar River for the length of 1800 meters, including a land acquisition cost of USD 1.13 million (INR 90 crores). In Kosasthalaiyar river tail end from Vellivoyal village to Manali new town for the length of 7 Km, both banks were stabilized, and inlets were constructed to carry around 1700 m^3/s (60000 cusecs). Other major projects are as follows:

1. Formation of Riverine Reservoir Across Cooum River Near Pudumavilangai Village: With an allocation of 7.60 Crore INR (0.95 million USD), a check dam has been erected to boost aquifer recharge and enhance monsoon aqueducts. This check dam is currently in the planning stage, and TNWRD would like to consider the JICA Flood Control Master Plan before finalizing the plan. The riverbed elevation and river channelization plan from the JICA Flood Control Master Plan have already been shared with TNWRD.
2. Reconstruction of Breached Korattur Anicut Across Cooum River: Responding to the breach incident during a heavy flood in 2015, a reconstructed anicut now spans 140 meters in length, adeptly managing a maximum discharge of 103m^3/s (3,627 cusecs).
3. Construction of Illupur Check Dam Across Nagari River: With an allocation of 2.23 million USD (178.6 million INR), a pivotal check dam has been erected near Illupur Village in the Thiruthani Taluk of Thiruvallur District. This endeavor not only aids in groundwater recharge but also engenders an annual storage capacity of 850,000 m^3 (30 Mcft), fostering the stability of 295 ha (730) acres of cultivable land.
4. Construction of Check Dam Across Cooum River in Athigathur Village: A significant allocation of 17.70 Crore INR (2.21 million USD) has been designated to establish a 200-meter-long, 1.5-meter-high check dam in Athigathur village. This check dam was originally constructed for irrigation purposes with not much effect on flood control.
5. Kosasthaliyar Basin Enhancements: Study of increasing the FRL of Poondi Reservoir by two feet to augment capacity and enhance the Redhills (Puzhal) surplus course.

6. Studies on water balance and water audit for Chennai basin and B canal restoration and improvement.
7. Reservoir Operation System Development: An allocation of 32.00 Crore INR (4.00 million USD) has been granted for the development of a reservoir operation system and shutter automation through SCADA. This central control room, situated in the office of the Chief Engineer WRD, will serve as a vital decision support system during monsoon seasons. However, at the time of writing this report, the project has not been completed, and it is ongoing.
8. For 2023-24, a total budget of 85.63 crore INR (approximately USD 10.7 million) has been allocated for improving drainage systems and tributaries, constructing retaining walls, widening channels, and desilting drains.

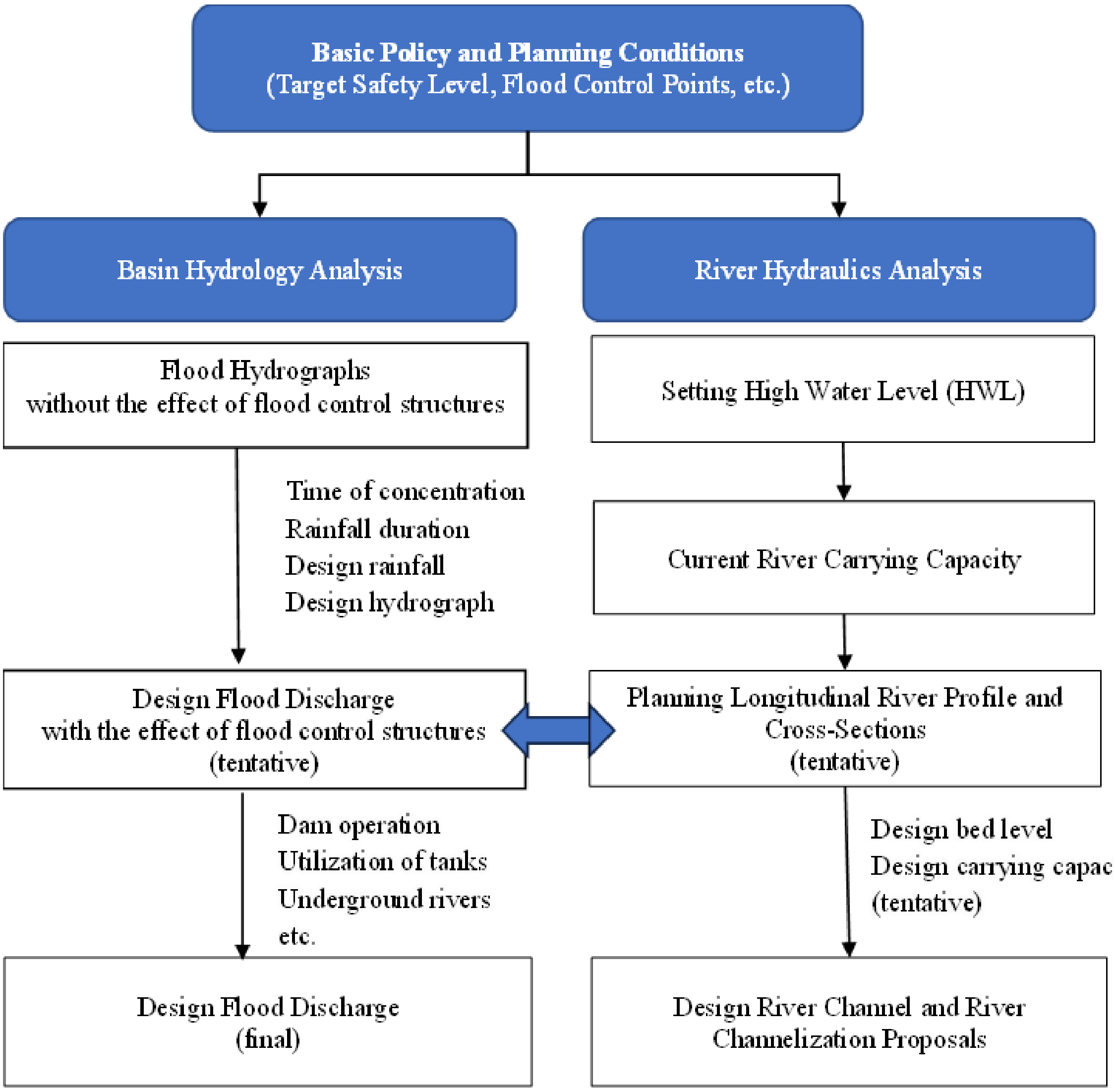
2.2 Basic Policy for Developing River Flood Control Master Plan

The formulation of a comprehensive flood control master plan for the urbanized river basins of Chennai must address both riverine flooding (fluvial) and urban flooding (pluvial). This chapter focuses on river flood control measures for the entire Adyar River (including Chembarambakkam Dam surplus), the entire Cooum River (from Kesavaram Anicut), and the Kosasthalaiyar River system from Poondi Dam (including Red Hills surplus). The proposed measures include interventions such as river channelization through deepening and widening, flood storage in upstream reservoirs and tanks, and the installation of underground river and tidal gates etc.

Figure 2-3 Shows the study process for river flood control. The analysis begins by establishing the target safety level, followed by determining the design hydrograph without considering the effect of flood control facilities. Subsequently, the flow rate, considering storage facilities, is calculated as the Design Flood Discharge. In river channel planning, the design water level for flood protection (High Water Level) is first determined, and then a channel design is developed to ensure this level does not exceed the left and right banks.

Flood control measures generally prioritize managing floods within the river channel, with flood storage facilities addressing excess flows. In this study, special emphasis has been placed on maximizing flood storage in existing tanks and water bodies in each basin for an effective flow reduction downstream. Additionally, river channelization has been considered to improve the carrying capacity of the river. In this context, social impacts such as potential land acquisition and resident relocation have been carefully evaluated. The plan has been divided into two phases: in the first phase, emphasis is placed on river deepening to minimize social impacts, while the second phase, intended for long-term implementation, considers river widening. Moreover, to further reduce social impacts, river channel planning evaluates feasible alternatives, including the potential use of underground drainage channels, to determine the optimal solution.

This revision aligns with the feedback by addressing social considerations and alternative strategies in river channel planning. This approach is necessary due to the extremely low discharge capacity of the river, the presence of numerous tanks and water bodies, and the priority given to tank improvement for flood storage in the cost-benefit (C/B) analysis.



Source: JICA Expert Team

Figure 2-3: Study Flowchart

2.2.1 Scope of study and standards

A flood control master plan is a comprehensive strategy aimed at addressing flood risks by incorporating both structural and non-structural measures. The difference between a master plan and a feasibility study (F/S) or a detailed design (D/D) has been explained in Chapter 1. It provides a coordinated framework for managing flood risks, identifying various interconnected measures, and outlining an implementation plan to achieve a target safety level over time, typically in phases. In this section, the scope of the study and target rivers for riverine flood control, along with basic policies, are outlined.

As previously mentioned, the three rivers currently lack comprehensive basin-wide flood control plans and studies, including the determination of high water levels. It is important to note that the JICA Study Team has engaged in numerous discussions with the Counterpart Agencies (C/Ps) to reach a consensus on key aspects. These include the target level of safety—such as the flood return period to be addressed—the direction of flood control measures and a development timeline that accounts for phased implementation.

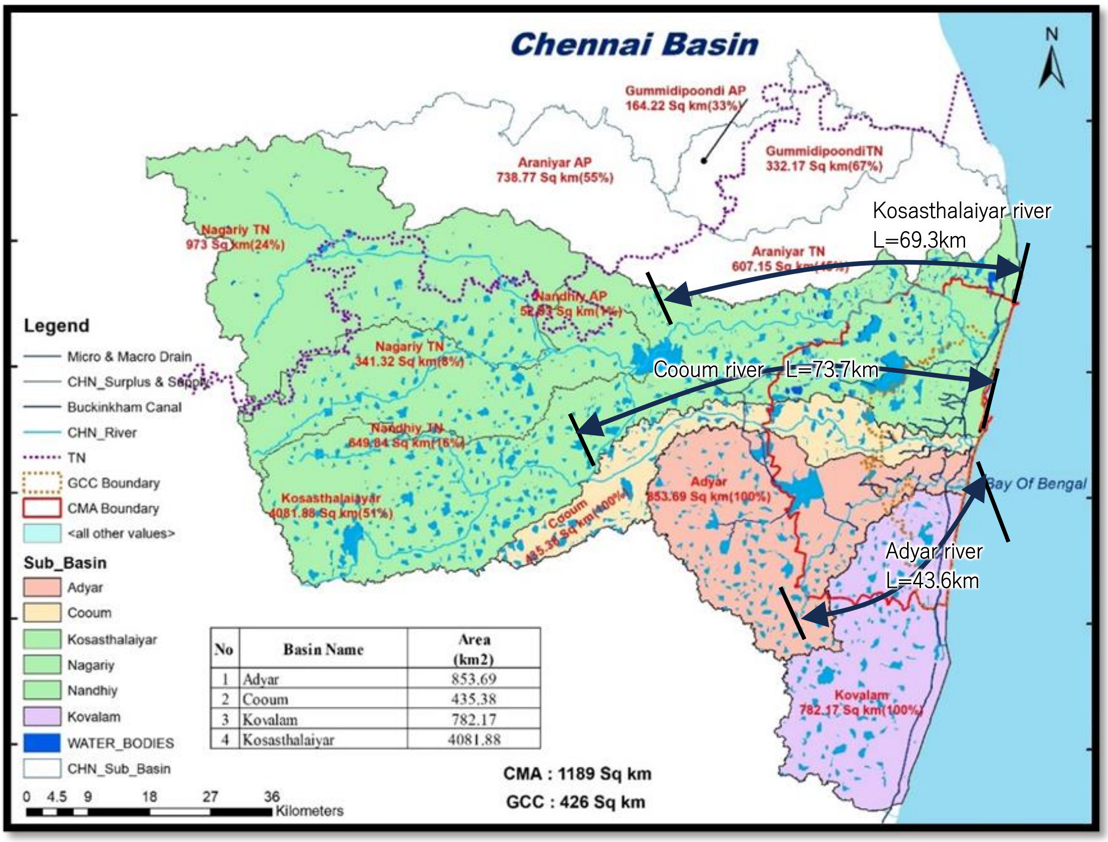
The technical study has referenced the following Japanese standards and guidelines:

- **Draft Technical Standard for River and Sabo**, Japan Ministry of Land, Infrastructure, Transport and Tourism

- **Draft Guidance for Flood Discharge Planning**, Japan Institute of Country-ology and Engineering.
- **Guidance for River Channel Planning Studies**, Sankaido.

2.2.2 Study area and exiting challenges and study steps

The target rivers for fluvial flood control are the Adyar River System (~43.6 km), Cooum River System (73.7 km), and Kosasthalaiyar River System from Poondi Dam (69.3 km) as in the Figure 2-4 . Further details and specifics about these rivers and their basins are explained in Chapter 1.



Source: JICA Expert Team

Figure 2-4: Scope of the Study Area for the River Flood Control

The Chennai metropolitan area is characterized by flat topography, with minimal elevation differences between the upper and lower reaches of the Adyar, Cooum, and Kosasthalaiyar rivers. The Adyar and Cooum River basins are experiencing rapid urbanization, while the Kosasthalaiyar River basin is also undergoing urbanization, particularly along its tributary, the Redhills River, where agricultural lands are being converted. This urbanization has led to a decline in the natural water retention and infiltration capacities of the basins, resulting in increased surface runoff during rainfall events. Compounding this issue, the rising intensity of rainfall due to global warming has further exacerbated flood risks, leading to a decline in the overall safety level against rainfall-related hazards in the Chennai metropolitan area.

Although localized improvements have been made to the Adyar, Cooum, and Kosasthalaiyar rivers, a comprehensive and consistent flood control plan for the entire basin has yet to be developed. To enhance flood safety across the Chennai Metropolitan Area, it is essential to formulate a master plan that outlines a clear timeline, scale, and specific measures for implementation. This plan must account for ongoing urbanization and incorporate not only river widening and excavation but also the use of detention facilities and integrated land use management across the entire basin.

Given these considerations, the master plan should emphasize the importance of coordinated flood control measures, requiring collaboration among organizations responsible for flood management and urban planning in the Chennai Metropolitan Area.

The key challenges in flood control for the three rivers in the Chennai Metropolitan Region include:

- **Developing a Comprehensive Flood Control Plan for the Entire Basin:**
    - Identifying bottleneck locations based on the current river carrying capacity and cross-sectional surveys.
- **Setting Design High Water Discharge Considering Flood Storage in Tanks**
    - Determining discharge distribution (design high water discharge) by evaluating the flood control benefits of existing dams and improved tanks.
    - Assessing the feasibility of in-stream storage and the use of riverside wetlands as retarding basins.
- **Basic Measures and Planning to Improve River Carrying Capacity**
    - Establishing a river channel plan, including cross-sectional shape (widening range), riverbank height (dug channel/embankment), and longitudinal profile (design high water level, design riverbed height).
    - Setting the horizontal alignment of the river channel (straightening and removing meanders).
    - Evaluating the need for riverbank protection (e.g., bank reinforcement).
    - Assessing the sustainability of proposed sections (e.g., river mouth sandbars, sedimentation, and maintenance dredging).
- **Drainage Measures for Tributaries**
    - Improving connecting drainage channels, installing backflow prevention facilities (e.g., gates, pumps, monitoring devices), and addressing missing links.
- **Cost Estimation, Prioritization, and Implementation of Flood Control Measures**
    - Estimating costs, prioritizing actions, and planning the implementation of flood control measures.

2.2.3 Target safety levels

Several factors must be considered when determining the target safety level, including the socio-economic importance of the study area, population density, river basin characteristics, and other aspects such as environmental, geographical, technical, and political considerations. Additionally, effective communication with local authorities and technical experts is crucial in setting the appropriate safety level.

Chennai, the fourth-largest city in India, is expected to have a population exceeding 12 million in the Chennai Metropolitan Area (CMA, 1189 km²) by 2024. The city plays a vital role in socio-economic activities. The basins of the Adyar, Cooum, and Kosasthalaiyar Rivers, which are part of this study, cover areas of over 400 km², with dense urban populations and a high concentration of socio-economic activities.

Drawing on Japanese experience, the rivers in the study area can be classified similarly to Class 1 rivers in Japan. These rivers are the highest priority due to their significant importance, often assigned higher safety levels compared to other river classes. MLIT's technical standards for river erosion control define flood planning scales based on river importance. Class A-B rivers (Figure 2-5), managed by MLIT, follow a 100-year or higher flood probability standard

Given the city's importance, it was agreed with local counterparts (C/Ps) that the target design scale for the river flood (fluvial flood) control master plan should be based on a 100-year return period for rainfall probability. This target safety level aligns with the recommendations of the Chennai Flood Advisory Committee Report (2023) and adheres to national and local standards and guidelines.

Importance of Rivers	Scale of Plans (Annual Exceedance Probability of Target Rainfall)※
Grade A	200 or more
Grade B	100～200
Grade C	50～100
Grade D	10～50
Grade E	10 or less

(※) The inverse of the annual exceedance probability)

Generally, for major sections of first-class rivers, Grades A to B are adopted. For other sections of first-class rivers and second-class rivers, urban rivers are often classified as Grade C, while general rivers are classified as Grade D or E depending on their importance.

Source: River Sand Control Technical Standards (Planning)

Figure 2-5: Guideline Target Safety Level based on the Importance of Rivers

Table 2-1: Basin Area and Population of the Three River Basins under Study

	Adyar	Cooum	Kosasthalaiyar
Basin Area[km2]	854	435	4,082
Population in the catchment area	3,524,000	2,095,000	5,107,000

2.2.4 Target year for the implementation of the Master Plan

The JICA Flood Control Master Plan is designed for implementation in two phases. In consultation with the local counterparts (C/Ps), Phase 1 is targeted for completion within 10 years (e.g., 2026 to 2035), with Phase 2 starting after the completion of Phase 1 (e.g., from 2036 onwards). This study suggests that the full implementation of the master plan should occur over 20 years. However, the timeline, particularly for Phase 2, may be subject to change due to shifts in assets and economic conditions. Therefore, it is expected that the full implementation may take longer than 20 years. Local authorities must prepare for the gradual implementation of the master plan, with annual monitoring of progress and periodic reviews every 5 years or so.

2.3 Hydrology and Hydraulic Analysis

2.3.1 Rainfall statistics and design rainfall

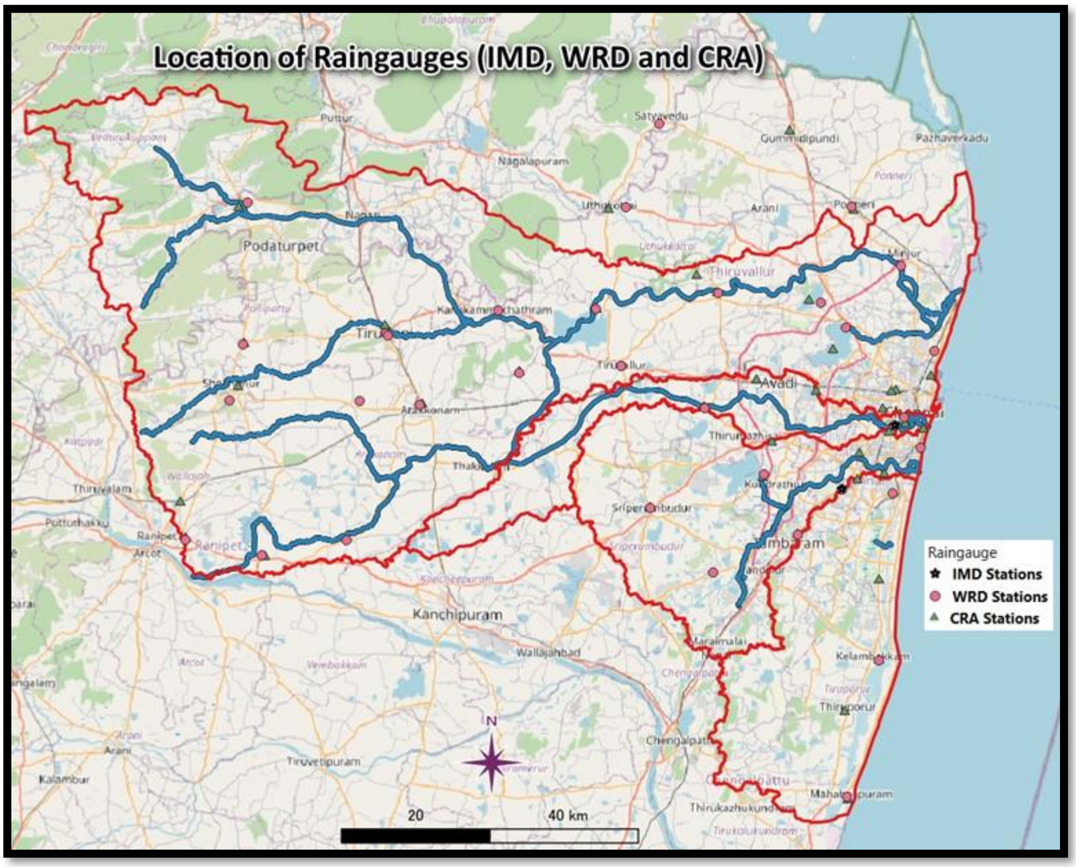
This section details key parameters related to design rainfall, including concentration time, rainfall duration, design rainfall hyetographs, and hydrographs. Before presenting the detailed results, it is important to highlight the availability and limitations of long-term rainfall data in the study area. Table 2-2 summarizes the collected data and its temporal scale. As indicated, only two stations within the study area have long-term hourly rainfall data, while the remaining stations provide long-term daily rainfall data. These limitations must be considered when interpreting the results of this study.

Table 2-2: List of Collected Rainfall Data

Institution	Number of observation stations	Period	Data type
IMD	2 (Inside the target river basins)	1969-2021	Hourly
TNWRD	46 (35 stations: Inside, 11 stations: Outside)	1991-2021	Daily
CRA	37 (34 stations: Inside, three stations: Outside)	1991-2021	Daily

Source: JICA Expert Team

Figure 2-6 shows the locations of selected rainfall stations in this study. To improve the accuracy of the hydrological analysis, it will be necessary to expand the network of hourly rainfall observation stations and gather more comprehensive rainfall hyetograph data across the entire watershed. This will enable a more precise evaluation of the hydrological conditions and allow for the revision of design parameters and rainfall hyetographs.



Source: JICA Expert Team

Figure 2-6: Location of Selected Rainfall Stations

Design rainfall defines the rainfall conditions used to determine runoff volume for the design flood scale. If historical river discharge records exist, flood probability can be calculated from runoff. However, since no flow records exist for the three target rivers, this method is not applicable. Instead, flood-inducing rainfall is considered the design external force, and design rainfall is set for the specified planning scale. Runoff calculations based on this rainfall then establish the design discharge scale. Design rainfall consists of three elements:

Rainfall amount: Total precipitation in the basin during a single event.
Temporal distribution: Duration of the rainfall event.
Spatial distribution: Variation of rainfall across the basin.

2.3.1.1. Temporal distribution of rainfall and water level

Rainfall varies constantly, affecting river water levels accordingly. To assess how river levels respond to rainfall, it is essential to analyze their relationship and determine the rainfall duration needed to evaluate flood peak levels and discharge.

In Chennai, hourly rainfall data is available from only two IMD stations, limiting spatial analysis. Water level observations have been scattered across sites since 2010 (Table 2-3), but major flood events before 2010, which caused significant damage, are not covered. As a result, direct comparisons of rainfall, water levels, and discharge during large-scale floods are not possible.

Table 2-3: List of River Water Level Observations

Competent Authority	Observation period	Observation method	Observation items	Overview
TNWRD	2010-2021	Manual	Water level	➢ Seasonal water level and flow observations were carried out at check dams of the Adyar River, Cooum River, and Kosasthalaiyar River. ➢ Discharge is calculated from the water level and cross-section of the check dam. ➢ Flow observation data is recorded as monthly average values.
IITM	2019-present 2020-present	Automatic	Water level	➢ A total of six automatic water level recorders were installed under the guidance of Professor Balaji of IITM. ➢ The automatic water level recorders at two of the six stations are not functioning. The remaining four observatories are in operation.
CWC JICA	2022-present 2022-present	Automatic Automatic	Water level Water level	➢ Four automatic water level recorders were installed in the Adyar River and one in the Cooum River. ➢ Automatic water level recorders were installed at 15 locations in this project.

Source: JICA Survey Team

Given the data limitations, this study estimated the rainfall duration affecting flood runoff in the three target rivers using Japanese technical standards for cases where hourly rainfall and water level data are unavailable. Two methods were applied:

Method 1: Flood Arrival Time Calculation (Rational Method)

This method estimates the time for rainfall at the basin's furthest point to reach the evaluation point, considering flow path length and terrain gradient. The flood arrival time represents the duration from rainfall onset to peak discharge, helping determine the minimum required rainfall duration. In this study, flood arrival time was calculated using four empirical formulas. The analysis was conducted for two points in each basin: the furthest and centroid (Poondi Dam for Kosasthalaiyar). The results indicate flood arrival times of 20 hours for Adyar, 38 hours for Cooum, and 46 hours for Kosasthalaiyar. Table 2-4 and Table 2-5 show details of parameters utilized in this method and results.

Table 2-4: List of Basin Parameters for the Method 1

Basin		Highest Elevation (m)	Lowest Elevation (m)	Distance (Km)	Flow Path Slope (m/m)	Basin Area (Km^2)	Basin Slope (m/m)
Adyar	Longest Path	50	0	51.1	0.0010	855	0.0374
	Centroid	25	0	35.0	0.0007	855	0.0374
Cooum	Longest Path	95	0	90.8	0.0010	435	0.0337
	Centroid	43	0	52.3	0.0008	435	0.0337
Kosasthalaiyar	Longest Path	174	0	161.4	0.0011	4082	0.0709
	Poondi	38	0	75.4	0.0005	1072	0.0383

Source: JICA Expert Team

Table 2-5: Results of Flood Arrival Time Using Empirical Formulas

Basin		Concentration Time (hrs.)				Max Tc (hrs.)
		Kirpich	Passini	Bransby Williams	Chow	
Adyar	Longest Path	20	20	19	18	**20**
	From Centroid	17	17	13	16	17
Cooum	Longest Path	30	20	38	28	**38**
	From Centroid	22	17	22	20	22

Source: JICA Expert Team

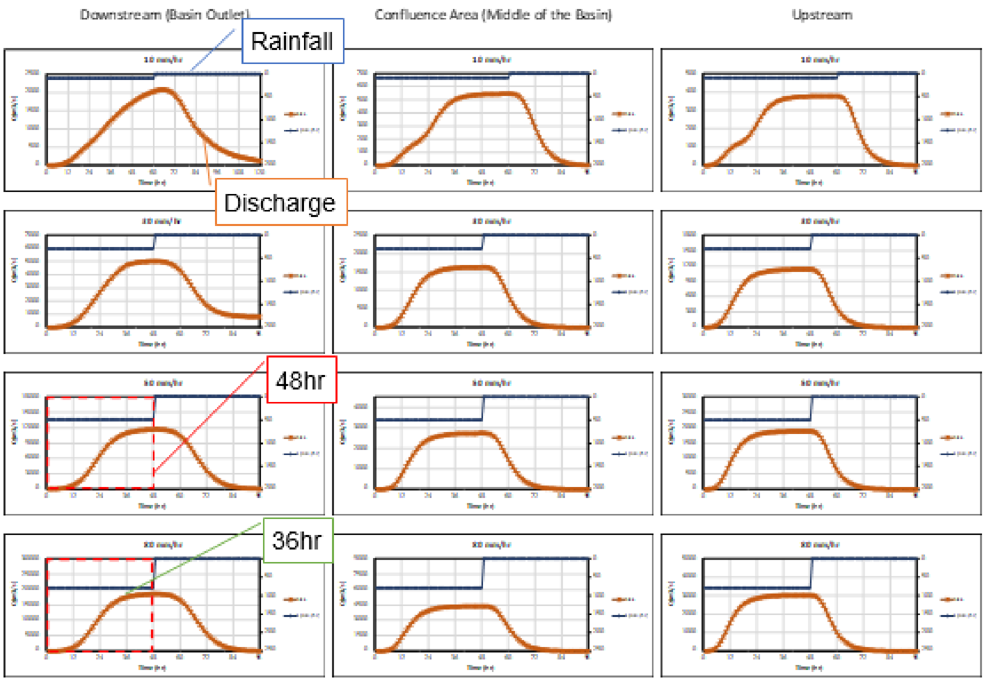
Method 2: Flood Arrival Time Estimation Using Model Rainfall Patterns

Based on Japan's technical standards for planning high water discharges in nationally managed rivers, an evaluation of flood arrival times was conducted using model rainfall patterns. This approach estimates the required flood duration for each basin by applying a runoff calculation model (HEC-HMS) to determine the time to peak runoff under continuous, uniform rainfall across the entire basin.

The study results for the three target rivers are presented in Figure 2-7 to Figure 2-9. Key points of interest included the downstream end (river mouth), the central part of the basin, and the uppermost part of the basin. Runoff patterns were calculated for four scenarios involving continuous, uniform hourly rainfall of 10 mm, 30 mm, 50 mm, and 80 mm across the basin.

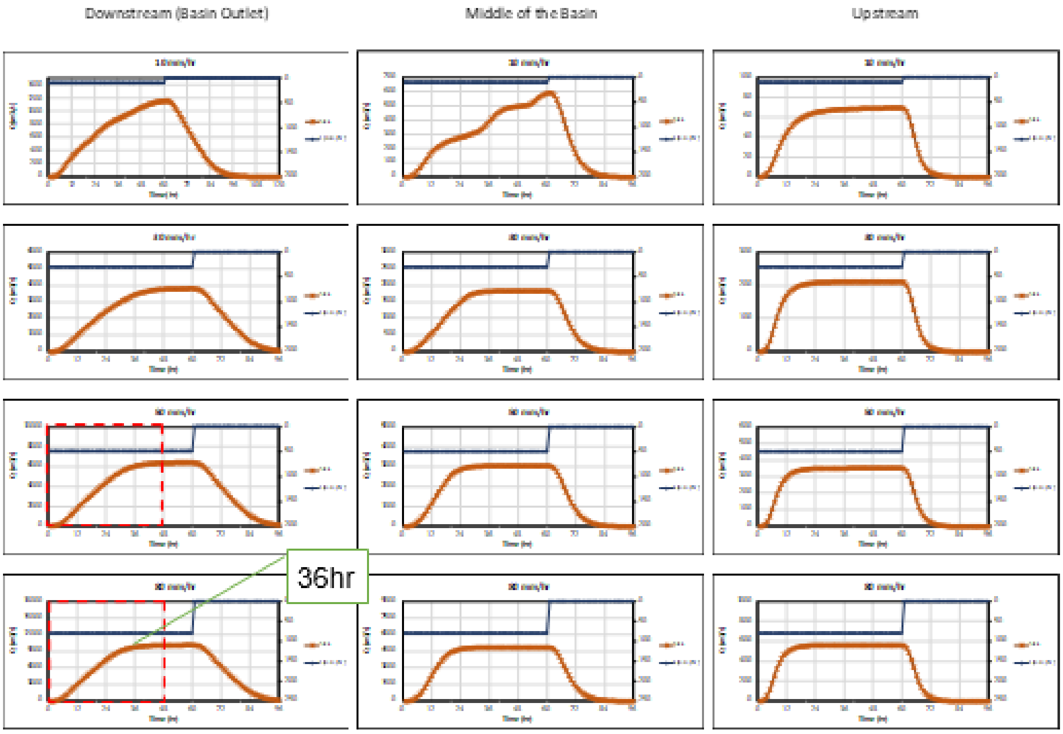
Given the design flood scale with a 100-year recurrence probability and the need to assess impacts during extreme rainfall events, the analysis focused on large rainfall scales of 50 mm/hr and 80 mm/hr. These scenarios are critical for evaluating flood runoff contributions to highly urbanized downstream areas, which are particularly vulnerable to flooding.

The evaluation concentrated on the downstream end (river mouth) to determine the necessary flood duration. The red frames in Figures 2.7 to 2.9 highlight the period within 48 hours from the start of rainfall. The runoff patterns for the Adyar, Cooum, and Kosasthalaiyar rivers indicate that the peak increase in runoff volume occurs within 48 hours of rainfall initiation. Furthermore, the rate of increase in flood runoff begins to decline around 36 hours after rainfall starts for all three rivers. From these observations, it can be inferred that the time contributing to the peak flood runoff is approximately 36 hours from the start of rainfall.



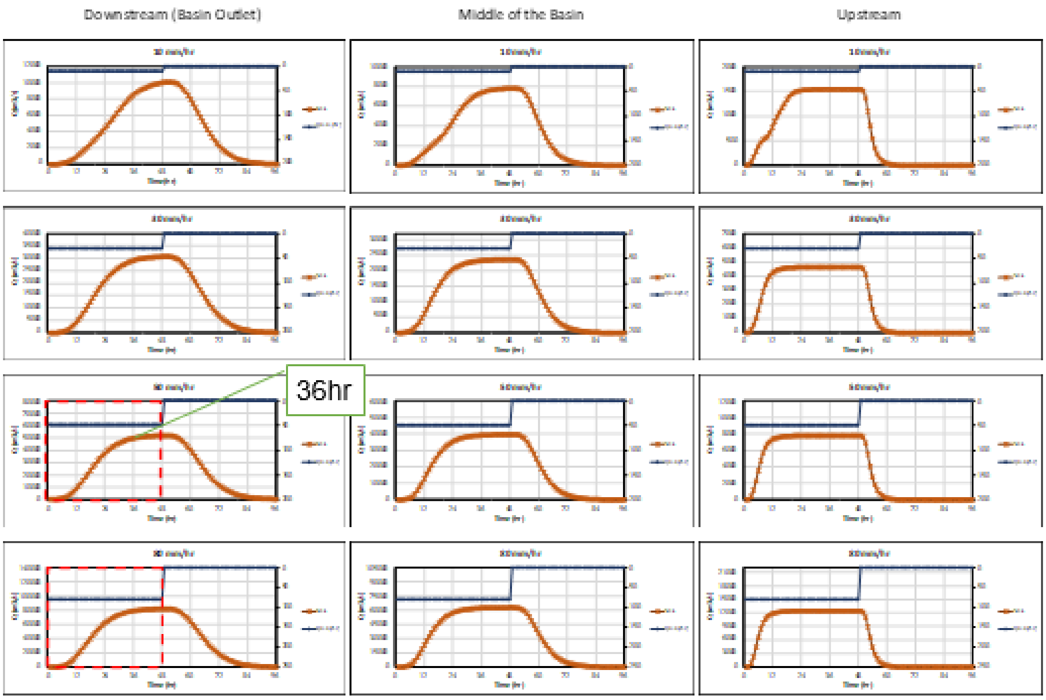
Source: JICA Expert Team

Figure 2-7: Arrival Time Based on Modeling Rainfall Waveform (Adyar)



Source: JICA Expert Team

Figure 2-8: Arrival Time Based on Modeling Rainfall Waveform (Cooum)



Source: JICA Expert Team

Figure 2-9: Arrival Time Based on Modeling Rainfall Waveform (Kosasthalaiyar)

Table 2-6 shows a comparison of these two methods. For safety, a 48-hour rainfall duration is adopted, aligning with available data, spatial rainfall distribution (24-hour basis), and international standards.

Table 2-6: Rainfall Duration Calculation Results

Basin	Method 1	Method 2
Adyar	20 hr	36hr
Cooum	38 hr	36hr
Kosasthalaiyar	46 hr	36hr

Source: JICA Expert Team

2.3.1.2. Rainfall statistical analysis and peak rainfall

The basin's average rainfall was calculated under the conditions shown in Table 2-7. Probable rainfall for different return periods (2 to 400 years) and durations (24, 48, …, and up to 144 hours) has been analyzed using the "Hydrologic Statistics Utility" software by the Japan Institute of Country-ology and Engineering (JICE). This analysis utilized daily rainfall data from 1991 to 2021 (31 years) and applied four probability distribution models: Exponential Distribution, Gumbel Distribution, Square Root Error Term, and Generalized Extreme Value Distribution.

The calculated 48-hour maximum rainfall for a 100-year return period in the study area is as follows: Adyar Basin: 493 mm, Cooum Basin: 371 mm, and Kosasthalaiyar Basin: 299 mm, as displayed in Table 2-9 to Table 2-11.

Since Kovalam lacks a dominant river system, its flood is categorized as urban flood (pluvial flood), and further detailed rainfall statistics are detailed in Chapter 3 of the JICA Flood Control Master Plan, as this chapter is dedicated to river flood control.

To account for climate change, a multiplier of 1.1 was applied to the design rainfall (48hrs, 100-year return period), resulting in adjusted values: Adyar Basin: 542 mm, Cooum Basin: 408 mm and Kosasthalaiyar Basin: 329 mm.

Table 2-7: Conditions for Rainfall Probability Analysis

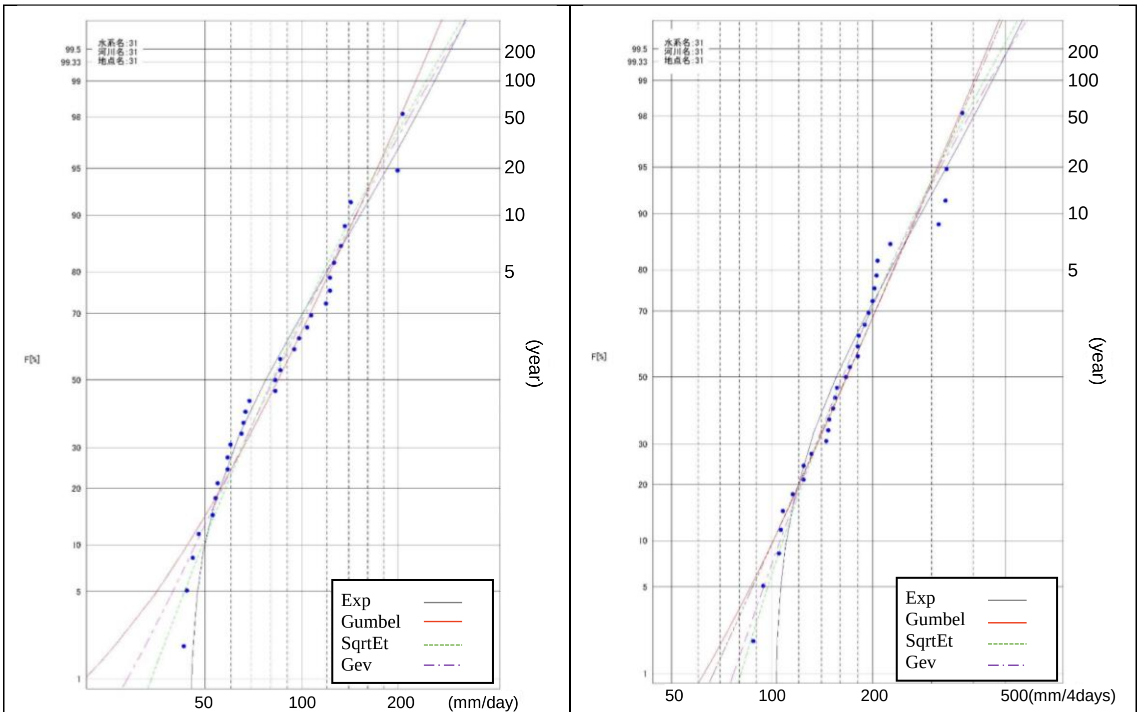
Usage Data	Rain gauge stations of IMD, TNWRD and CRA
Data collection period	1991-2021 (21 years)
Number of observatories included in the calculation	Up to 45 locations (varies from year to year depending on observation conditions)
Rainfall calculation method	Calculate the basin's average rainfall using the Thiessen division method.
Thiessen division pattern	Fixed annually
Probability Analysis Range	Adyar River, Cooum River, Kosasthalaiyar River
Rainfall duration	1st, 2nd, 3rd, 4th, 5th, 6th

Source: JICA Study Team

Table 2-8: Probability Distribution Models

No.	Probability distribution models	
1	Exp	exponential distribution
2	Gumbel	Gumbel distribution
3	SqrtEt	Square-root exponential maximum value distribution
4	Gev	Generalised extreme value distribution

Source: JICA Study Team



Entire four river basins under study (daily rainfall)

Entire four river basins under study (4-day rainfall)

Source: JICA Study Team

Figure 2-10: Example of Rainfall Probability Analysis Results

Table 2-9: Rainfall Probability Analysis in Adyar Basin

Return Period (year)	Probable Rainfall in Adyar Basin					
	24 hours (mm)	48 hours (mm)	72 hours (mm)	96 hours (mm)	120 hours (mm)	144 hours (mm)
2	109.2	157.4	203.1	227.6	248.8	266.5
3	139.1	192.2	240.6	267.4	291.8	313.6
5	176.8	236.1	282.4	311.9	337.9	363.1
10	228.0	295.6	335.0	367	393.6	421.2
20	279.1	355.1	385.4	421.3	444.6	472.8
30	309.0	389.9	414.4	452.1	472.9	500.8
50	346.7	433.8	450.6	490.6	507.3	534.1
80	381.4	474.1	483.8	525.8	537.9	563.1
100	397.8	**493.3**	499.5	542.5	552.0	576.3
150	427.7	528.1	528.0	572.8	577.2	599.6
200	449.0	552.8	548.2	594.3	594.7	615.5
400	500.1	612.3	596.9	646.0	635.4	651.9

Source: JICA Expert Team

Table 2-10: Rainfall Probability Analysis in Cooum Basin

Return Period (year)	Probable Rainfall in Cooum Basin					
	24 hours (mm)	48 hours (mm)	72 hours (mm)	96 hours (mm)	120 hours (mm)	144 hours (mm)
2	96.4	145.4	174.4	195.8	212.8	226.4
3	114.7	174.0	207.2	232.1	252.3	269.4
5	136.7	205.8	243.6	272.5	296.3	317.2
10	166.8	245.7	289.4	323.2	351.6	377.3
20	198.2	284.1	333.4	371.9	404.7	435.0
30	217.3	306.1	358.7	399.9	435.2	468.2
50	242.4	333.7	390.3	434.9	473.3	509.6
80	266.4	358.9	419.2	467.0	508.2	547.6
100	278.1	**370.9**	432.9	482.1	524.7	565.6
150	300.0	392.6	457.7	509.7	554.7	598.2
200	96.4	145.4	174.4	195.8	212.8	226.4
400	114.7	174.0	207.2	232.1	252.3	269.4

Source: JICA Expert Team

Table 2-11: Rainfall Probability Analysis in Kosasthalaiyar Basin

Return Period (year)	Probable Rainfall in Kosasthaliyar Basin					
	24 hours (mm)	48 hours (mm)	72 hours (mm)	96 hours (mm)	120 hours (mm)	144 hours (mm)
2	77.1	109.6	128.9	135.2	157.1	161.7
3	94.6	133.5	155.6	160.9	187.8	189.3
5	114.2	160.2	185.4	193.5	222.1	222.4
10	138.7	193.7	222.7	241.1	265.2	267.2
20	162.3	225.8	258.6	294.8	306.5	313.7
30	175.8	244.3	279.2	329.9	330.2	342.0
50	192.8	267.4	305.0	378.5	359.9	378.9
80	208.3	288.6	328.6	428.2	387.1	414.2
100	215.6	**298.6**	339.8	453.6	400.0	431.5
150	228.9	316.8	360.1	503.1	423.3	463.6
200	238.4	329.7	374.4	541.0	439.9	486.9
400	261.1	360.7	409.0	642.9	479.7	545.4

Source: JICA Expert Team

2.3.2 Setting Flood Control Points

Flood control points were designated for the three target rivers to assess flood runoff volume and manage flood levels and discharge. These points were selected based on the following criteria:

- Upstream of critical urban areas with high population density and valuable assets.
- Downstream of major reservoirs, such as dams.
- Locations where water level and discharge management are feasible.

For this study, flood control points were established upstream of key urbanized areas within the

Chennai Metropolitan Area (CMA) requiring flood protection. These points were positioned at weirs, check dams, and major tributary confluences where flow regulation is possible. The designated flood control points are:

- Adyar River: Downstream of the Chembarambakkam Surplus confluence at Thiruneermalai.
- Cooum River: Downstream of Paruthippattu Weir.
- Kosasthalaiyar River: Downstream of Vallur Anicut.

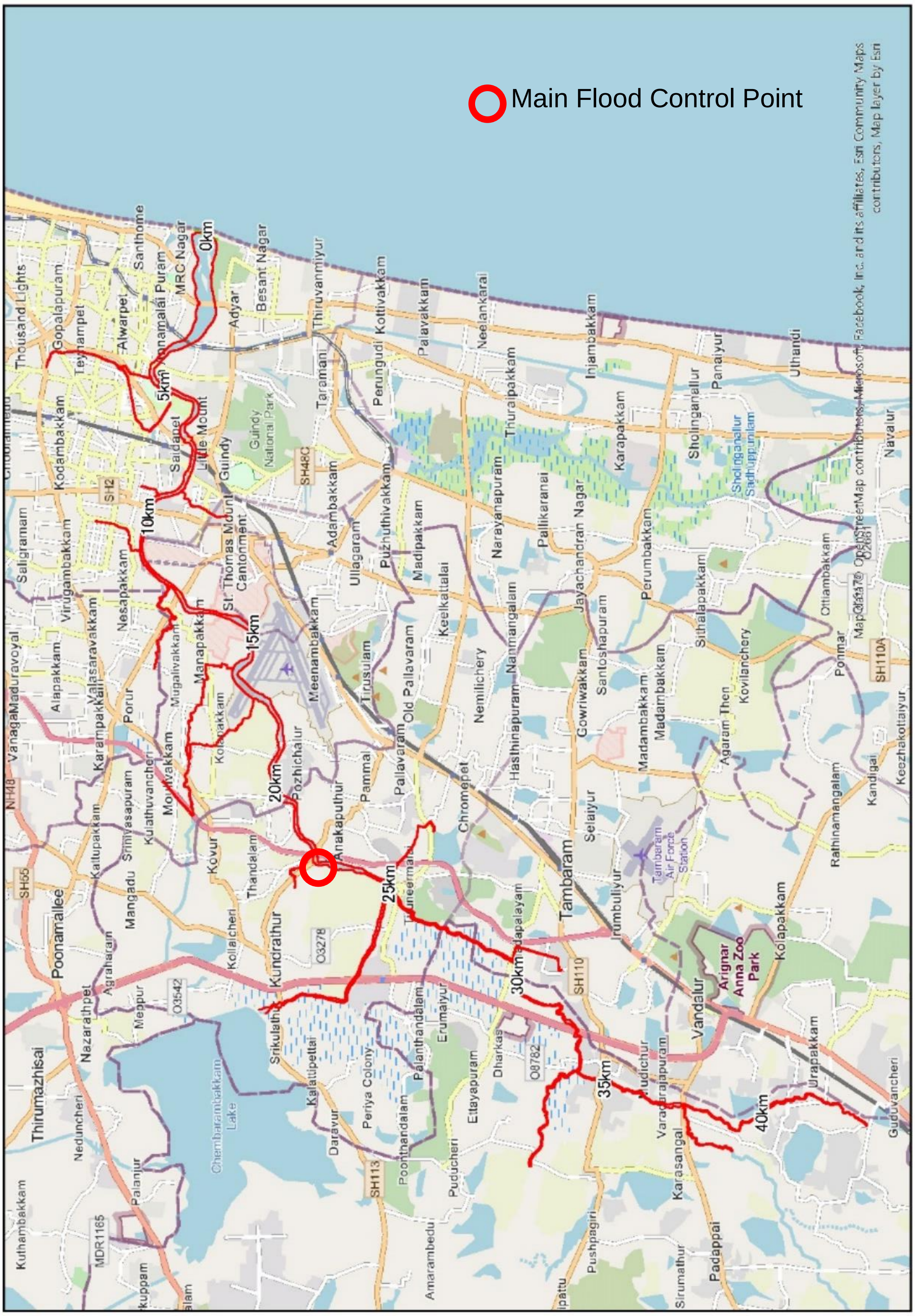
The flood control points in this study are hypothetical reference locations used to analyze river capacity limitations, even though calculations account for the entire river network. Figure 2-11 illustrates selected flood control points for three rivers.

Table 2-12: Flood Control Points

Basin	Location
Adyar	Anakaputhur Bridge: Downstream of Chembarambakkan Junction to Adyar
Cooum	Kaduvetti Check Dam
Kosasthalaiyar	Vallur Anicut

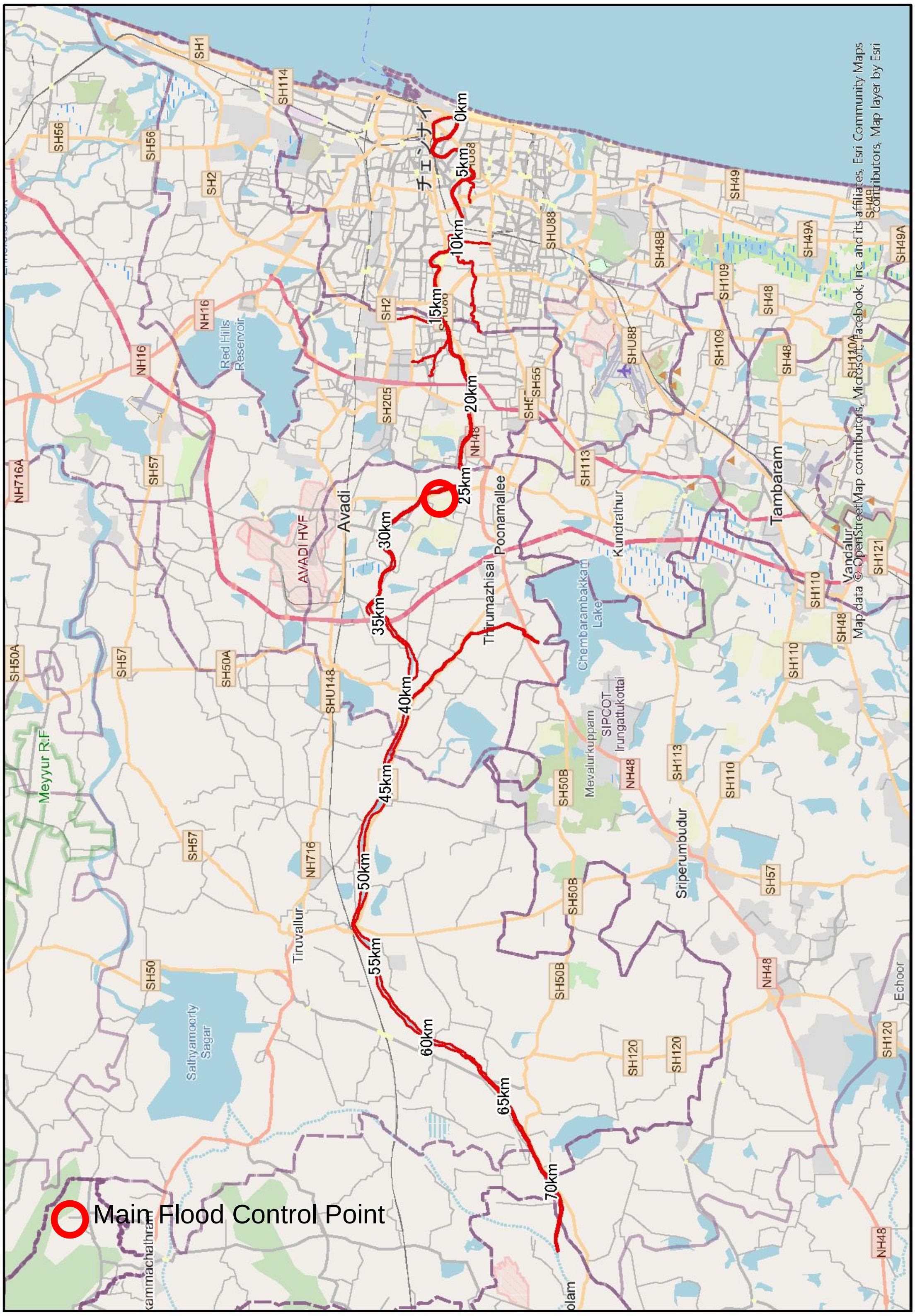
Source: JICA Expert Team

Figure 2-11: Flood Control Points



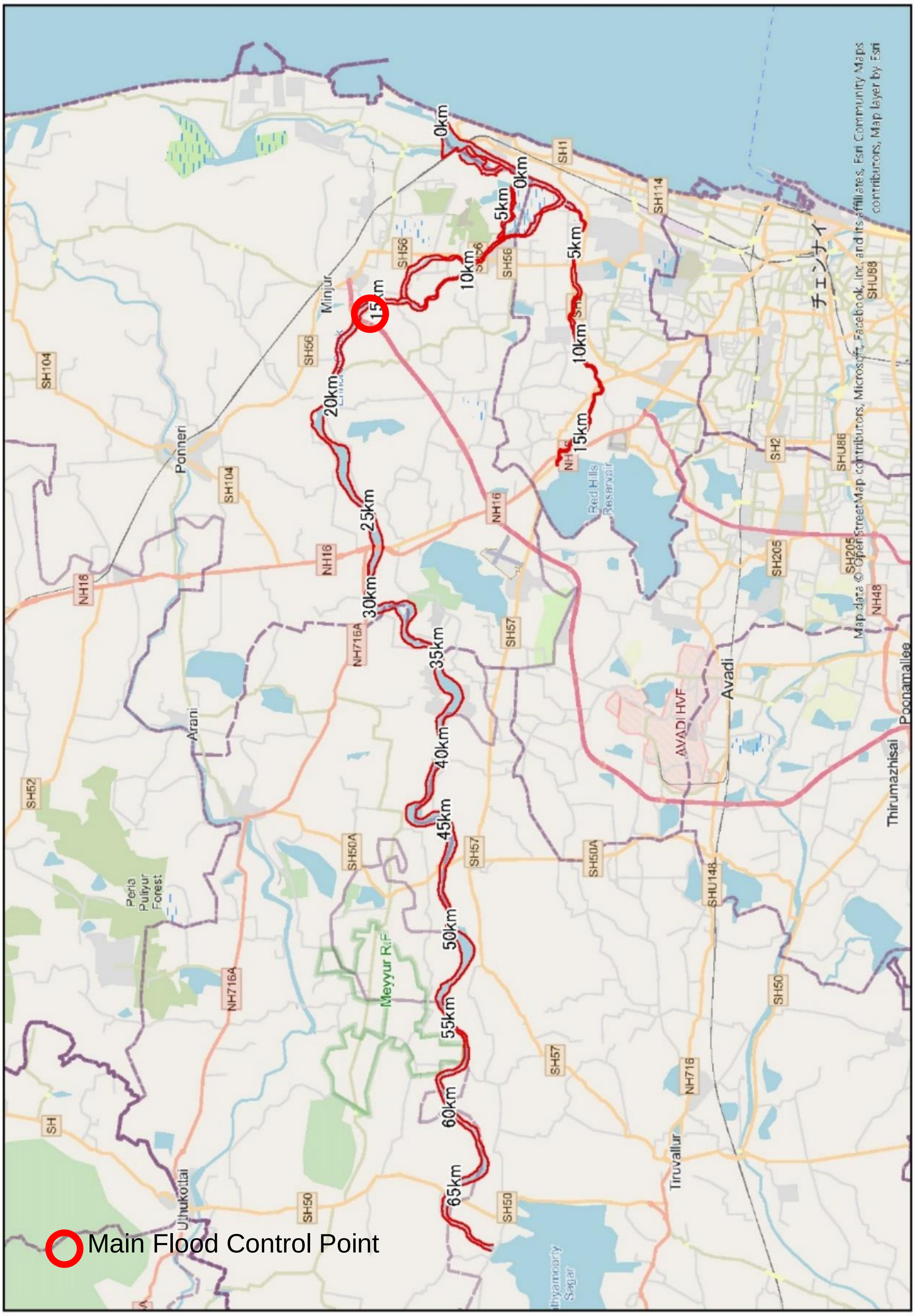
Source: JICA Expert Team

Figure 2-12: Flood Control Point (Adyar River)



Source: JICA Expert Team

Figure 2-13: Flood Control Point (Cooum River)



Source: JICA Expert Team

Figure 2-14: Flood Control Point (Kosasthalaiyar river)

2.3.3 Estimation of basic and design high-water discharge

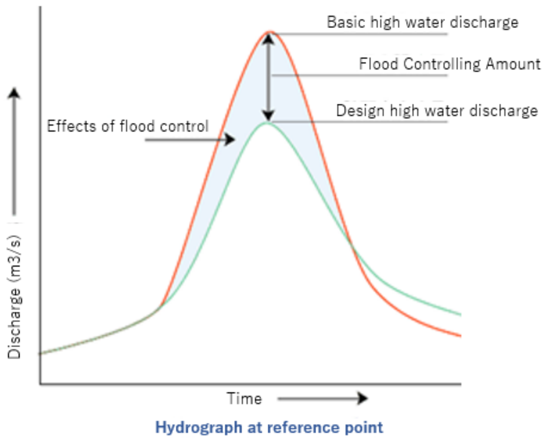
The basic high-water discharge is a crucial parameter in river flood control design. It refers to the flood runoff that is expected to occur under current land use conditions without factoring in the effects of flood control infrastructure such as dams, retarding basins, or reservoirs. This discharge is often referred to as the "pre-regulation discharge" as it reflects the natural flood conditions in the river system, ignoring any management measures or interventions.

The design high water discharge is the modified version of the basic high water discharge that takes into account the reduction in flood runoff caused by the presence and operation of flood control measures. These measures include dams, retarding basins, and reservoirs, which reduce the volume of runoff reaching downstream areas. The design of high-water discharge represents the flood conditions expected after the installation of these flood control facilities.

Figure 2-15 illustrates the distinction between the basic high-water discharge and the designed high-water discharge. When preparing flood control plans, the following methodology is typically employed:

Calculation of Basic High-Water Discharge: The first step is to estimate the expected flood runoff volume under the current land use conditions, disregarding the influence of flood control facilities. This provides a baseline for understanding the natural flood dynamics of the river.

Determination of Design High Water Discharge: The basic high-water discharge is then adjusted to account for the flood control measures already in place, as well as any proposed future infrastructure. This adjustment is made by evaluating various flood control facilities, including dams and retarding basins, within the river basin. By comparing the flood runoff volumes before and after these interventions, the design of high-water discharge can be determined.

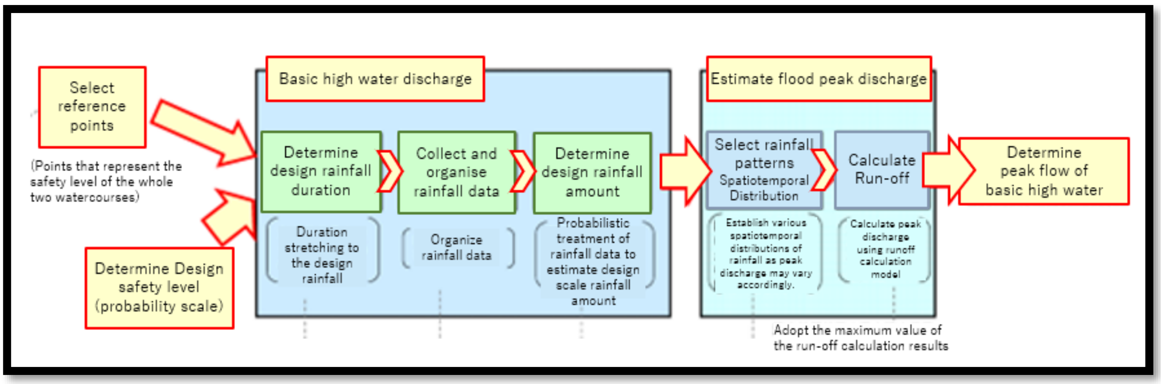


Source: MLIT, Tohoku Regional Development Bureau

Figure 2-15: Basic and Design High Water Discharge

2.3.4 Selection of target rainfall hyetograph

The process for estimating the base high-water discharge is illustrated in Figure 2-16 and Figure 2-15. In the previous stage of the study, the control points, design flood scale, rainfall duration, and probable rainfall were established. Based on these parameters, the rainfall hyetograph is selected in this section.



Source: MLIT, Kuma River System River Development Basic Policy

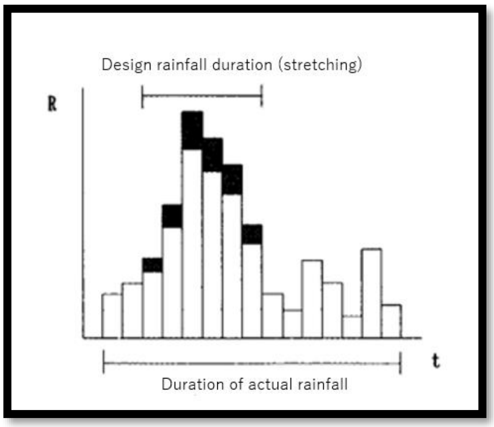
Figure 2-16: Process of Estimating Basic High-Water Discharge

For a design rainfall duration of 48 hours, the historical flood rainfall was extended to reflect a 1/100 occurrence probability, and the corresponding flood runoff volume was calculated under the current basin conditions.

The rainfall patterns were derived from the 10 major floods that caused significant flooding in the Chennai urban area between 1976 and 2020. Using hourly rainfall data from the India Meteorological Department (IMD), these waveforms were compared to the basin's average rainfall during the 48-hour design rainfall period with a 100-year probability. The 48-hour rainfall values were then scaled proportionally to match the 100-year probability, as shown in Figure 2-17.

After scaling the rainfall data to the 100-year probability, runoff calculations were conducted using the HEC-HMS model to determine the peak flood discharge based on the adjusted rainfall waveforms. As a result, the following rainfall pattern, which produced the highest peak flood discharge in each river, were selected for further examination:

- Adyar: Rainfall hyetograph with the pattern of 2005 rainfall
- Cooum: Rainfall hyetograph with the pattern of 2015 rainfall
- Kosasthalaiyar: Rainfall hyetograph with the pattern of 1996 rainfall



Source: Guidance for small and medium-sized river planning (Draft)

Figure 2-17: Scaling the Selected Rainfall Pattern

2.3.4.1. Adyar River

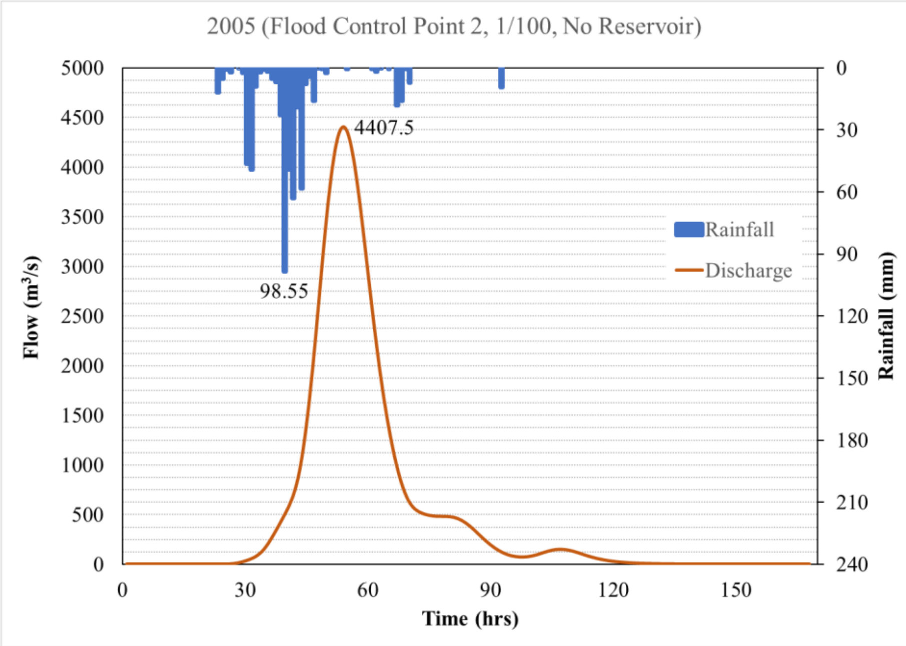
The peak discharge at the control point, Chembarambakkan Dam confluence, is the largest in the 2005 flood (Table 2-13). The rainfall and runoff hydrograph of this flood are shown in Figure 2-18.

Table 2-13: Peak Discharge for 100yrs Return Period in Adyar River

Flood Year	Peak Discharge [m3/s]		Peak Hourly Rainfall [mm]		Total Runoff Volume [MCM]	
	D/S Confluence Flood C.P.	Outlet	D/S Confluence Flood C.P.	Outlet	D/S Confluence Flood C.P.	Outlet
2020	1,897	2,147	62.98	65.85	260.40	334.11
2015	4,029	4,408	58.02	57.35	317.60	389.24
2008	1,587	1,944	51.24	49.15	320.75	394.40
2005	4,408	4,644	98.55	96.96	317.78	391.49
2002	2,119	2,403	81.20	80.98	303.84	377.56
1998	2,026	2,184	68.57	72.02	316.19	389.53
1996	2,651	3,066	29.60	29.34	317.62	391.23
1991	1,959	2,153	73.88	71.09	315.37	389.08
1985	2,262	2,494	33.50	33.56	314.30	396.38
1976	4,120	4,495	58.67	58.61	320.96	394.69

CP=Flood Control Point, D/S: Downstream of the confluence of CBM to Adyar at the upstream of Tiruneermalai

Source: JICA Expert Team



Source: JICA Expert Team

Figure 2-18: Flood Hydrograph in Adyar Basin for 2005 flood scaled for 100-year RP

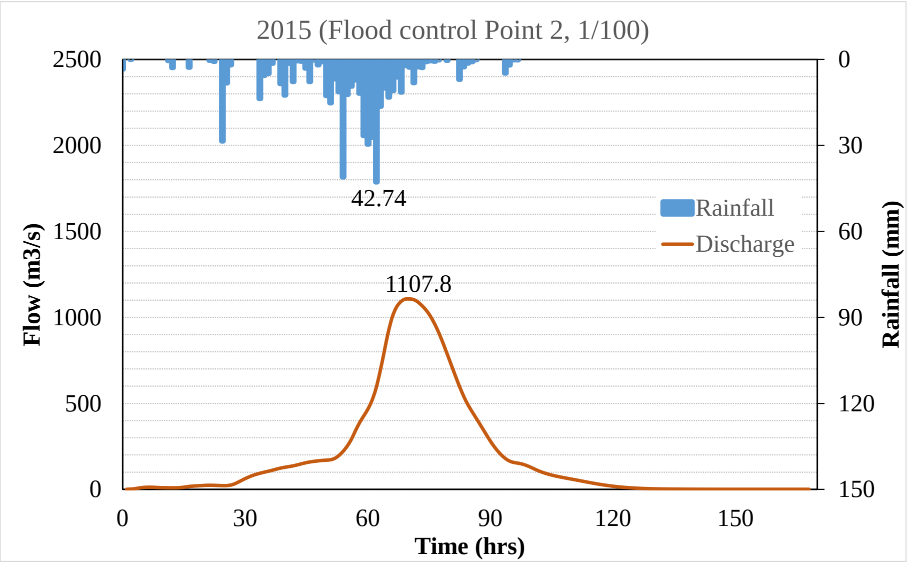
2.3.4.2. Cooum River

The peak discharge at the control point, Paruthippattu Barrage, is the largest in the 2015 flood. The rainfall and flood hydrograph of this flood is shown in Figure 2-19.

Table 2-14: Peak Discharge for 100yrs Return Period in Cooum River

Flood Year	Peak Discharge [m3/s]		Peak Hourly Rainfall [mm]		Total Runoff Volume [MCM]	
	Paruthipatu Weir D/S. (CP)	Basin Outlet	Paruthipatu Weir (CP)	Basin Outlet	Paruthipatu Weir (CP)	Basin Outlet
2020	848	1,043	45.17	44.49	116.05	166.60
2015	1,108	1,592	42.74	42.44	115.97	166.37
2008	698	922	72.12	70.23	116.01	166.56
2005	1,046	1,606	36.84	36.76	116.02	166.57
2002	790	1,132	95.28	90.30	116.02	165.01
1998	749	908	86.72	82.55	115.89	164.68
1996	953	1,314	30.66	28.18	116.01	166.55
1991	713	875	36.41	30.49	115.04	165.48
1985	902	1,015	51.77	46.38	113.41	163.47
1976	1,026	1,557	52.14	51.85	116.04	166.58

CP=Flood Control Point, D/S: Downstream of Paruthipatu
Source: JICA Expert Team



Source: JICA Expert Team

Figure 2-19: Flood Hydrograph in Cooum Basin for 2015 flood scaled for 100-year RP

2.3.4.3. Kosasthalaiyar River

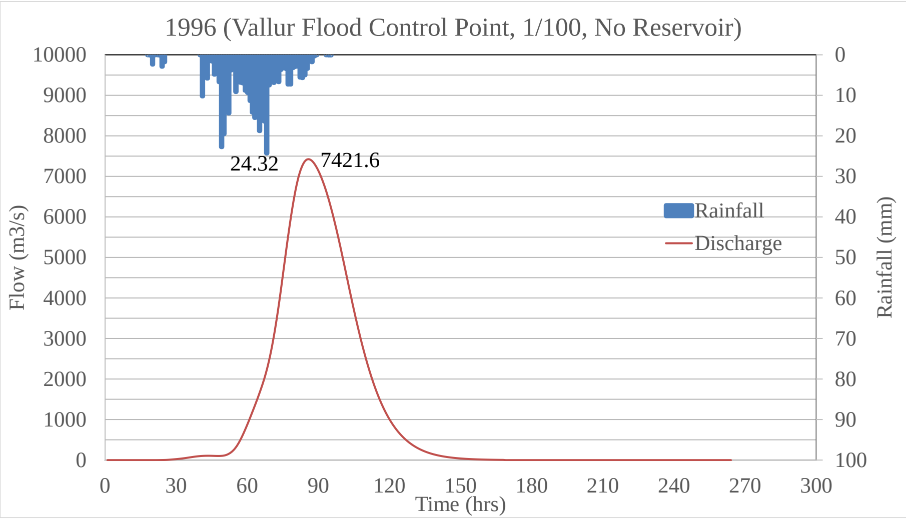
The peak discharge at the control point, Vallur Barrage Point, is the largest for the 1996 flood (Table 2-15). The rainfall and flood hydrograph of this flood are shown in Figure 2-20.

Table 2-15: Peak Discharge for 100yrs Return Period in Kosasthalaiyar River

Flood Year	Peak Discharge [m3/s]		Peak Hourly Rainfall [mm]		Total Runoff Volume [MCM]	
	Vallur Flood Control Point (CP)	Basin Outlet	Vallur Flood Control Point (CP)	Basin Outlet	Vallur Flood Control Point (CP)	Basin Outlet
2020	7,201	7,765	34.46	37.91	765.33	919.58
2015	6,338	7,080	35.06	25.88	692.02	834.56
2008	5,291	5,721	30.97	26.31	745.07	920.65
2005	4,989	5,245	46.97	44.47	768.34	920.84
2002	7,019	7,459	73.28	75.75	767.28	921.89
1998	5,786	6,066	68.61	67.97	761.66	912.58
1996	7,422	8,102	24.32	24.42	770.04	922.55
1991	4,799	5,560	27.76	27.22	754.33	919.74
1985	5,362	4,988	19.45	20.14	725.86	909.50
1976	5,730	6,491	33.42	35.23	768.42	923.77

CP=Flood Contral Point Downstream of Vallur Anicut

Source: JICA Expert Team



Source: JICA Expert Team

Figure 2-20: Flood Hydrograph in Cooum Basin for 1996 Flood Scaled for 100-year RP

2.3.5 Impacts of climate change

To account for the increase in rainfall due to recent global warming, a 1.1 multiplier was applied to the planned rainfall values based on discussions with local counterpart agencies. The adjusted rainfall values for each river basin are as follows: Adyar – 543 mm, Cooum – 408 mm, and Kosasthalaiyar – 329 mm.

The 1.1 multiplier represents the climate change adjustment factor for rainfall in the country. It is derived from the ratio of future climate projections (2080–2100 average) to the present climate baseline (1984–2004 average). While this factor serves as a provisional estimate, it should be revised as more rainfall data becomes available for Chennai in the coming years.

The hyetographs for the planned rainfall were developed using data from hourly rainfall stations. However, it is important to recognize that actual rainfall patterns within the catchment may differ. To enhance accuracy, newly established time-rainfall stations should be used to update the dataset as more observations are accumulated.

2.3.6 Estimation of basic high-water discharge

The discharge distribution along the rivers was calculated under natural runoff conditions, excluding the effects of dams or other hydraulic structures for flood control (Pre-regulation). This represents the flow distribution without flood control measures, using the 100-year return period flood based on the selected rainfall patterns: the 2005 pattern for Adyar, 2015 for Cooum, and 1996 for Kosasthalaiyar. The design hydrograph incorporates a 10% increase in rainfall to account for climate change impacts. The runoff analysis conditions were as follows:

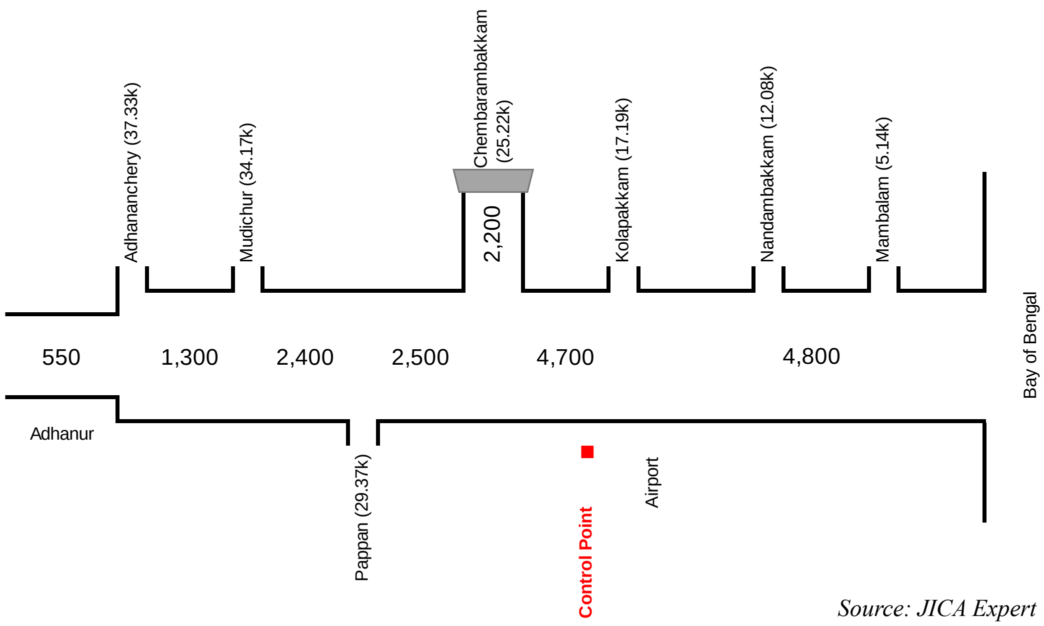
Table 2-16: Runoff Calculation Conditions

	Adyar	Cooum	Kosasthalaiyar
Design flood scale	1/100		
Design rainfall duration	48 [hr]		
Rainfall during the duration of rain (current situation)	493 [mm/48hr]	371 [mm/48hr]	299 [mm/48hr]
Design Rainfall Hyetograph	2005 model	2015 model	1996 model
Impact of climate change	The current amount of rainfall during the duration will be increased by 10% across the board.		
Rainfall plus 10% for Climate Change	543 [mm/48hr]	408 [mm/48hr]	329 [mm/48hr]
Considering existing flood control facilities	No. Pre-regulation discharge simulation		

Based on the runoff analysis results under the specified conditions, the basic high-water discharge for each river was determined. The discharge values were set according to the runoff calculation results, with rounding applied as follows:

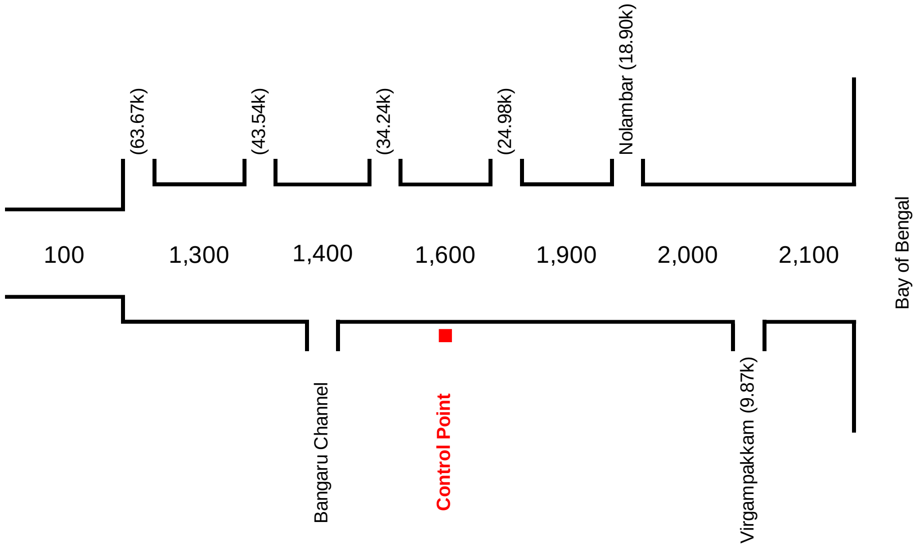
For calculated values of 1,000 m³/s or more, rounding was done in increments of 100 m³/s.

For values between 100 m³/s and 1,000 m³/s, rounding was done in increments of 10 m³/s.



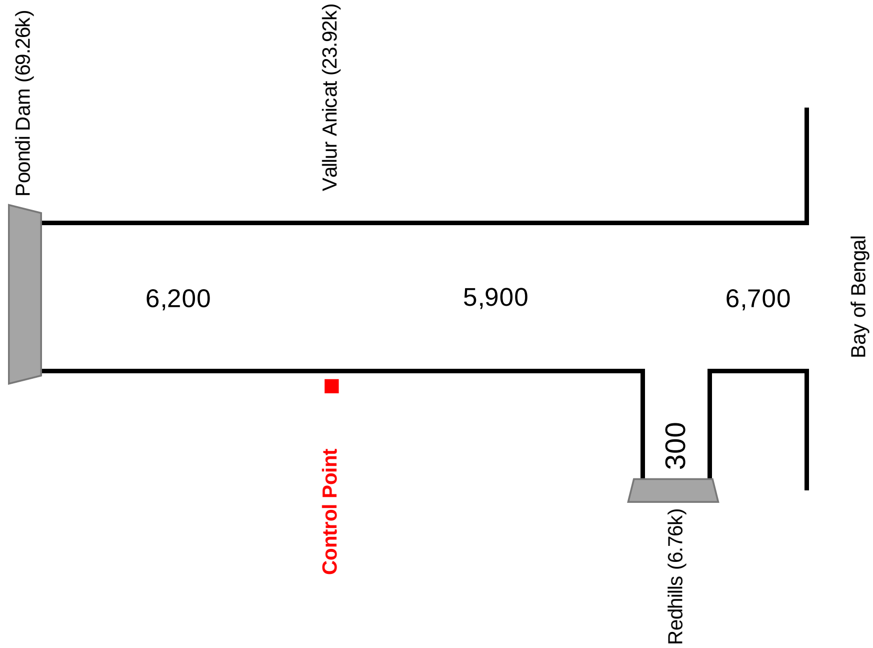
Source: JICA Expert Team

Figure 2-21: Pre-regulation Design Discharge Distribution in Adyar River (100-year RP)



Source: JICA Expert Team

Figure 2-22: Pre-regulation Design Discharge Distribution in Cooum River (100-year RP)



Source: JICA Expert Team

Figure 2-23: Pre-regulation Design Discharge Distribution in Adyar River (100-year RP)

2.3.7 Setting river flood protection zones

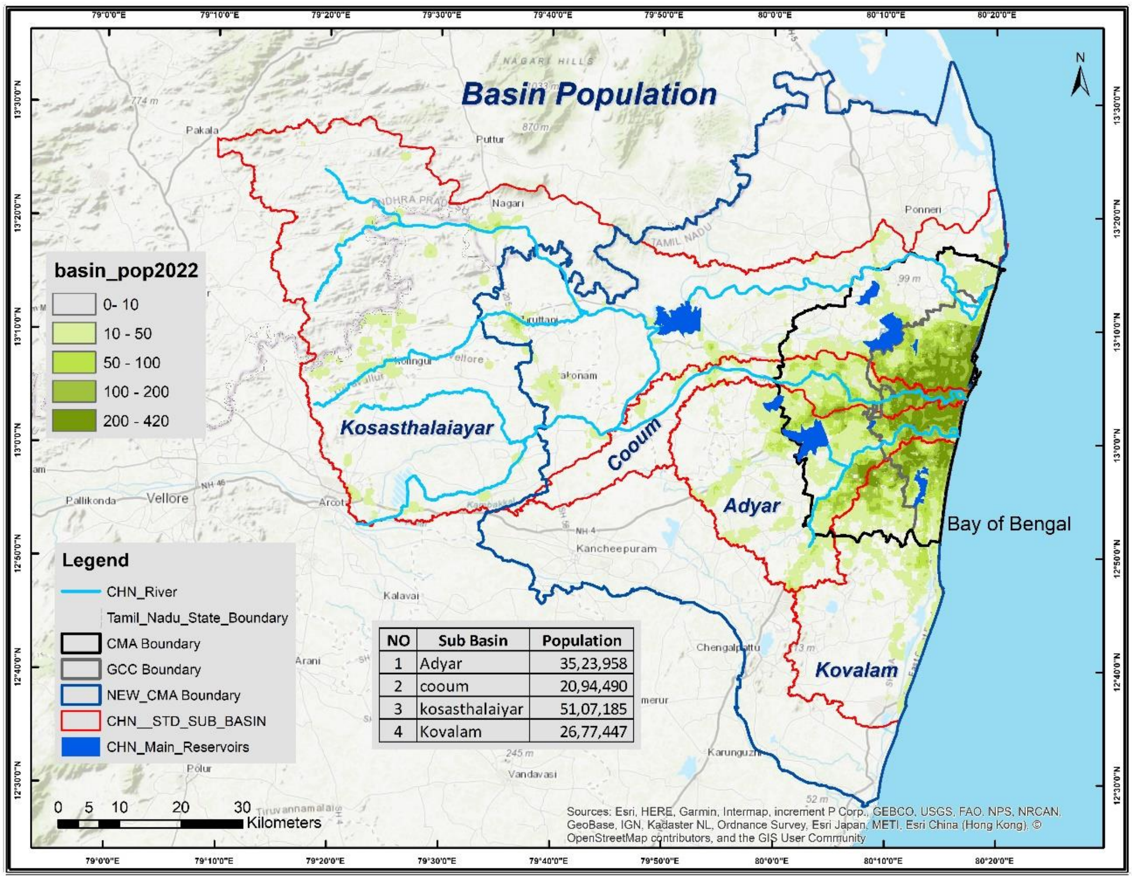
Flood protection zones should be designated based on areas with high population density and asset concentration, ensuring that flood control measures yield the maximum reduction in damage.

The urban administration boundary in the study area is illustrated in Figure 2-24. Entire of the GCC area has been urbanized, with urban expansion extending into the CMA region beyond the GCC boundary. Notably, rapid urbanization is occurring in the Adyar and Cooum basins, where flood control measures are expected to play a critical role in minimizing flood damage.

However, if urban expansion continues at the current rate, it is essential to anticipate the possibility of further urbanization extending into the New CMA area. To address these issues, flood protection zones will be established in two phases:

Phase 1 (Current Focus): Target flood damage reduction within the existing CMA area.

Phase 2 (Future Consideration): Expand flood protection measures to include the New CMA area as urbanization progresses.



Source: JICA Expert Team

Figure 2-24: Administration Boundaries and Flood Protection Zones

2.3.8 Design high-water level (HWL) and embankment height

The design of high-water level (HWL) is an essential parameter for the JICA Flood Control Master Plan. It represents the water level that occurs when the designed flood discharge flows through the improved river channel. This level serves as the basis for the design of river bed deepening, widening, embankments, revetments, and other river-related infrastructure. Setting the HWL correctly is critical to ensuring that floodwaters are contained within the riverbanks and that adjacent infrastructure is protected from inundation.

In the case of the rivers in Chennai, the HWL has been set to match the ground level of the left and right banks for two primary reasons:

First, setting the HWL higher than the natural ground elevation near the riverbanks would necessitate the construction of levees. However, in the event of a breach in the embankment or levee, the flood risk would be concentrated at the breach site, increasing the potential for flooding.

Second, a higher HWL and construction of high elevation embankment than ground elevation would disrupt the connection between the urban drainage system and the river, making it difficult for floodwater to flow into the river and exacerbating inland flooding.

Therefore, to mitigate these risks, the HWL has been set at the ground level of the riverbanks. Given that the rivers in Chennai currently do not have much of embankments, the proposed method to set HWL based on the ground elevation aligns with this existing condition. Figure 2-25 and Figure 2-26 shows the existing condition of Cooum River as an example.

Source: JICA Expert Team

Figure 2-25: Cooum River in Chennai city (Downstream of College Bridge)

Source: JICA Expert Team

Figure 2-26: Example of Cooum River Bridges for Setting HWL

2.3.8.1. Steps toward setting HWL and considerations

River Mouth: For the river mouth (0 km), the HWL is set at M.S.L + 0.5 m (Spring High Tide Level at the Bay of Bengal). This level has been established below the current embankment elevation to ensure that it remains consistent with the natural flow dynamics of the river.

Sea Level Rise Risk: Future predictions for sea level rise in Chennai have a high degree of uncertainty, primarily due to variations in greenhouse gas emission scenarios and the use of regional climate models for South Asia and Southeast Asia, rather than localized models specific to Tamil Nadu or southern India. As a result, most future projections for sea level rise present a wide range of possibilities, making it challenging to apply them for precise flood management planning. However, observed past sea level rise trends have been studied and it has not been incorporated into the HWL setting, as two key studies indicate that past sea level rise has been minimal. A recent report (2024) by the Center for Science and Technology Policy and Research (CSTEP) found that sea level in Chennai rose by 0.68 cm from 1987 to 2021, averaging 0.066 cm per year. Additionally, the Center for Climate Risk Assessment and Adaptation Planning (CCCDM) reported (2017) a relative sea level rise of 5.5 cm along the Chennai coast over the past 100 years (1916–2015). These observations suggest that sea level rise poses a minimal risk to flood management efforts in the region.

HWL Gradient Slope: The gradient for the HWL has been set to match the current riverbed slope, which is critical for maintaining natural river flow and minimizing the risk of erosion or overflow.

Points of HWL Gradient Change: The design of the HWL gradient considers topographic variations and the use of check dams to control the flow of water and ensure effective flood management.

2.3.8.2. Freeboard and considerations for existing embankment and bridges

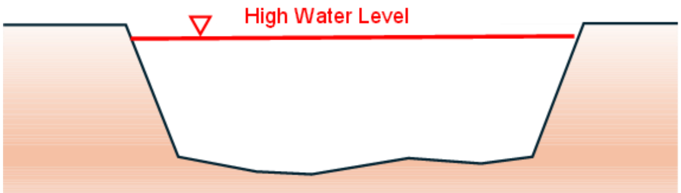
According to the guidelines developed by the Central Water Commission of India (CWC), the design embankment height should include a freeboard of about 1.5 meters above the high-water level. A similar approach is followed in Japan. However, for incised river courses, where the design high water level is almost the same as the ground elevation in Chennai rivers, constructing embankments is not recommended because it could increase the risk of inland flooding as described in the previous section.

In Chennai, the riverbank areas are used as roads, and many bridges are built to match the current riverbank height. If the water level is higher than the ground elevation, adding a freeboard would be required for building new embankments, which would lead to several issues. These include the increased risk of inland flooding, raising road levels, rebuilding bridges, and developing new access roads. To avoid these challenges, the design embankment height will not consider the freeboard in areas with incised channels. Three following cases have been considered in setting freeboard considering CWS guidelines as shown in Figure 2-27:

Case 1: If the current embankment/riverbank height is higher than the design high water level, no freeboard has been considered.
Case 2: If the current embankment/riverbank height is less than the design high water level, the new embankment height will be set by adding the freeboard.
Case 3: The design embankment height for bridges will include the freeboard, taking into account the bridge girder layout.

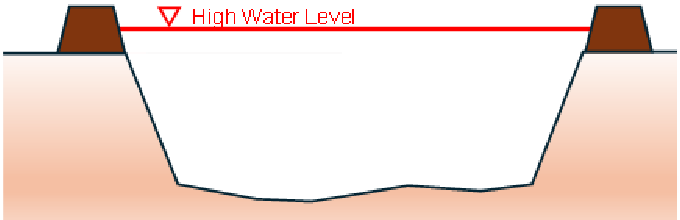
Case 1: No Need Freeboard

Current embankment/riverbank height > design high water level



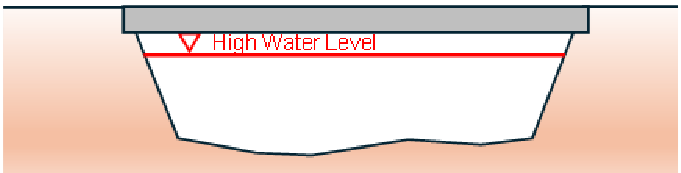
Case 2: 1.5m Freeboard

Current embankment/riverbank height < design high water level



Case 2: 1.5m Freeboard

Considering existing bridges



Source: JICA Expert Team

Figure 2-27: Conceptual diagram of design high water level and embankment height

2.3.9 Setting the tentative design high water level

The Tentative design high water levels for each river are organized below. The design of high-water levels set here will be revised in the future section of this chapter to finalize them, based on the results of the river channel planning.

2.3.9.1. Adyar River

The tentative design high water level for the Adyar River is shown in Table 2-17 and Figure 2-28. The longitudinal positions in the figure are shown in Figure 2-29.

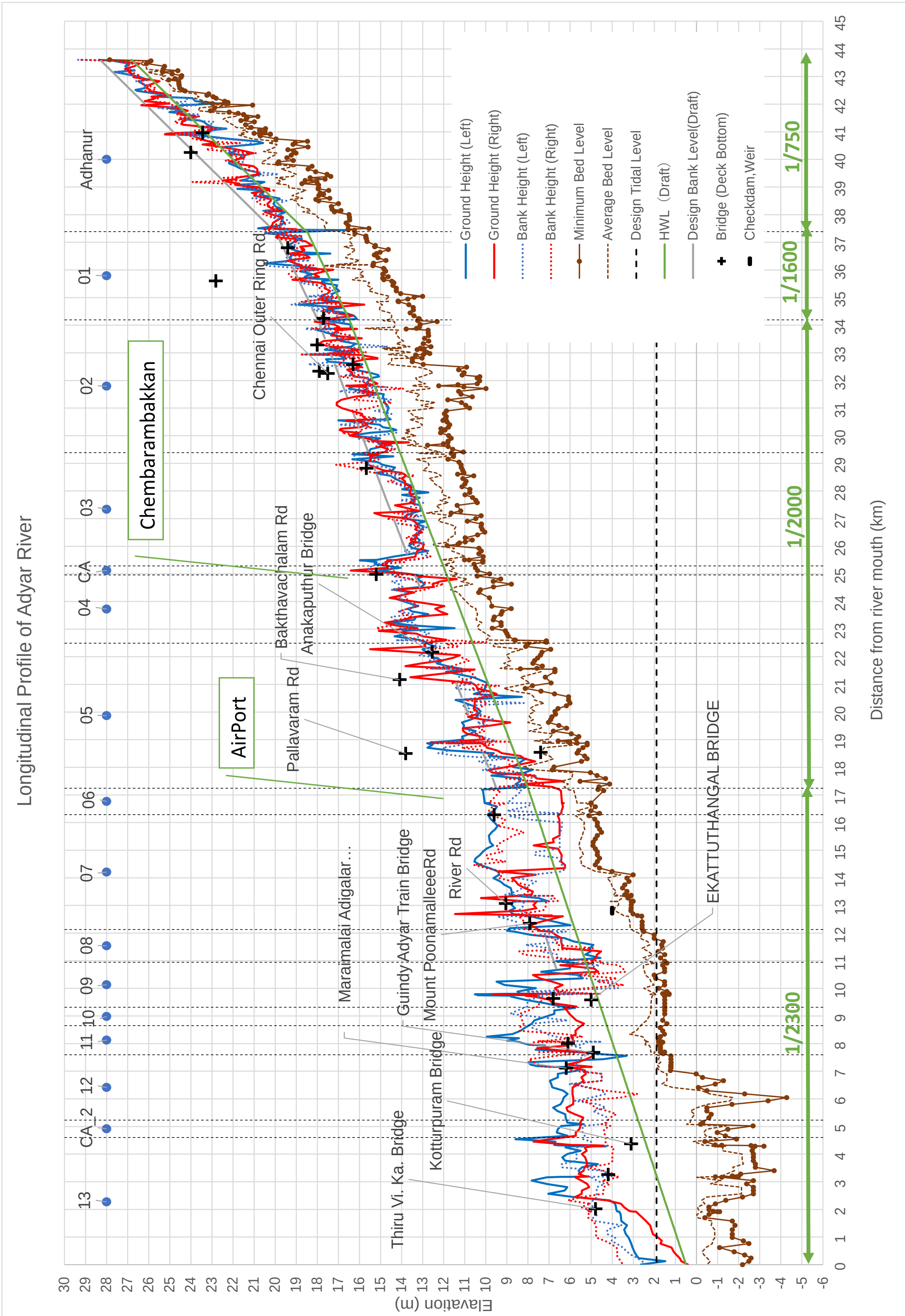
The area surrounding Chennai Airport presents significant construction challenges in the near term. Therefore, the airport location has been designated as a control point, with a downstream slope of 1/2300 and an upstream slope aligned with the existing topographic gradient.

In the tentative design, the high-water level is generally maintained below the current riverbank elevation throughout the entire section, minimizing the need for embankment construction.

Table 2-17: Tentative Adyar River Design High Water Level Longitudinal Plan

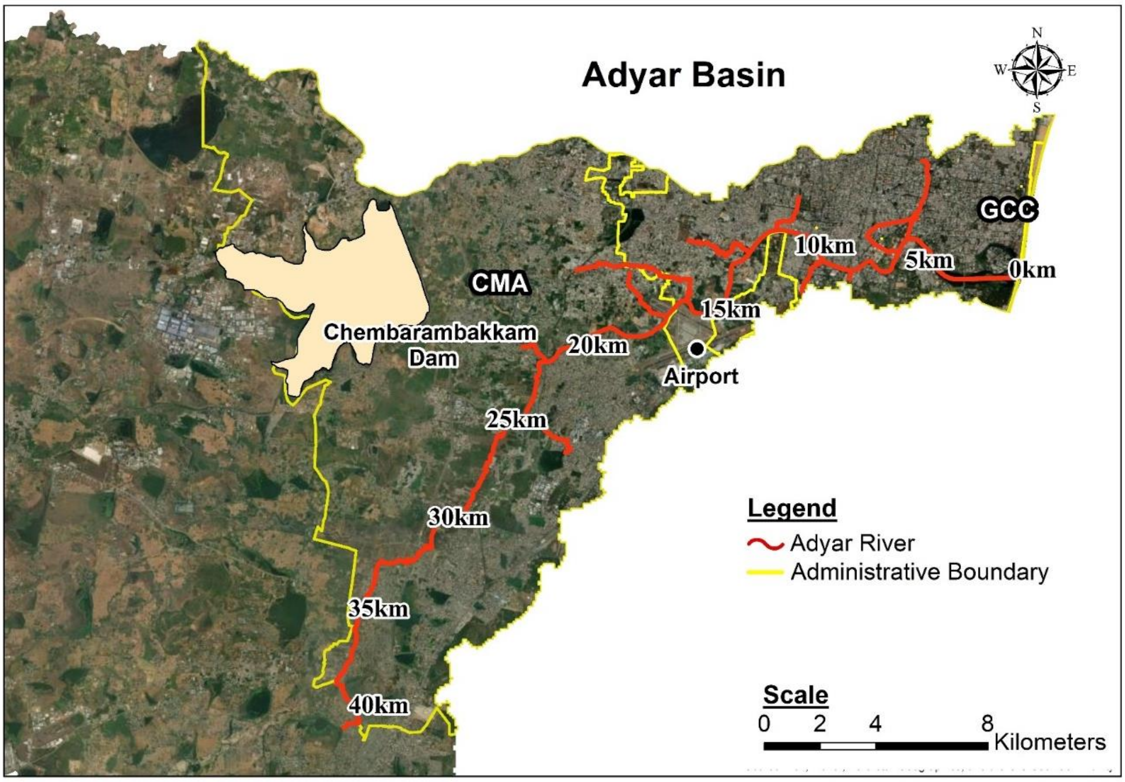
Section Name (HEC-RAS)	Cross Section No.	Distance From Sea (km)	HWL (Draft) (DL+m)	HWL Gradient 1/n	Design Bank Level (Draft) (DL+m)	Design Bank Level Gradient 1/n
Adyar13	0	0.00	0.50	2300	2.00	2300
Adyar_CA2	4794	4.66	2.53		4.03	
Adyar12	5512	5.32	2.81		4.31	
Adyar11	7800	7.64	3.82		5.32	
Adyar10	8873	8.72	4.29		5.79	
Adyar9	9466	9.34	4.56		6.06	
Adyar8	11078	10.98	5.27		6.77	
Adyar7	12270	12.17	5.79		7.29	
Adyar6	16380	16.34	7.60		9.10	
Adyar5	17294	17.29	8.03	2000	9.53	2000
Adyar4	22445	22.53	10.64		12.14	
Adyar_CA	24766	25.00	11.88		13.38	
Adyar3	8446	25.35	12.06		13.56	
Adyar2	12525	29.41	14.08		15.58	
Adyar1	17300	34.23	16.50	1600	18.00	1600
Adhanur	20520	37.44	18.59	750	20.09	750
	26754	43.61	26.81		28.31	

Source: JICA Expert Team



Source: JICA Expert Team

Figure 2-28: Tentative HWL and Design Longitudinal Profile of Adyar River



Source: JICA Expert Team

Figure 2-29: Adyar River Plan View and Chainage at 5 km Intervals

2.3.9.2. Cooum River

In the Cooum River, the two weirs referenced in Table 2-18 will function as control points for determining the design's high-water level. The Pudthuchattiram Dam is essential for diverting water from the Cooum River to the Chembarambakkan Dam, while the Kaduvetti Check Dam plays a crucial role in directing water to tanks such as Thiruverkadu Lake. From a water resource management perspective, adjusting the height of these weirs is challenging. Based on normal operating conditions, a freeboard of 30 cm above the current weir height has been established as the tentative design high water level. Presently, these weirs are fixed structures; however, to enhance flood-carrying capacity, it will be necessary to reconstruct them as movable weirs in the future.

Table 2-18: Cooum River Intake Weir Locations - Tentative Design High Water Level

Name	Distance from Sea [km]	Dam Height [DL+m]	HWL (Tentative) [DL+m]
Kaduvetti Check Dam	26.426	18.347	18.547
Pudthuchattiram Dam	40.928	32.42	32.72

Source: JICA Expert Team

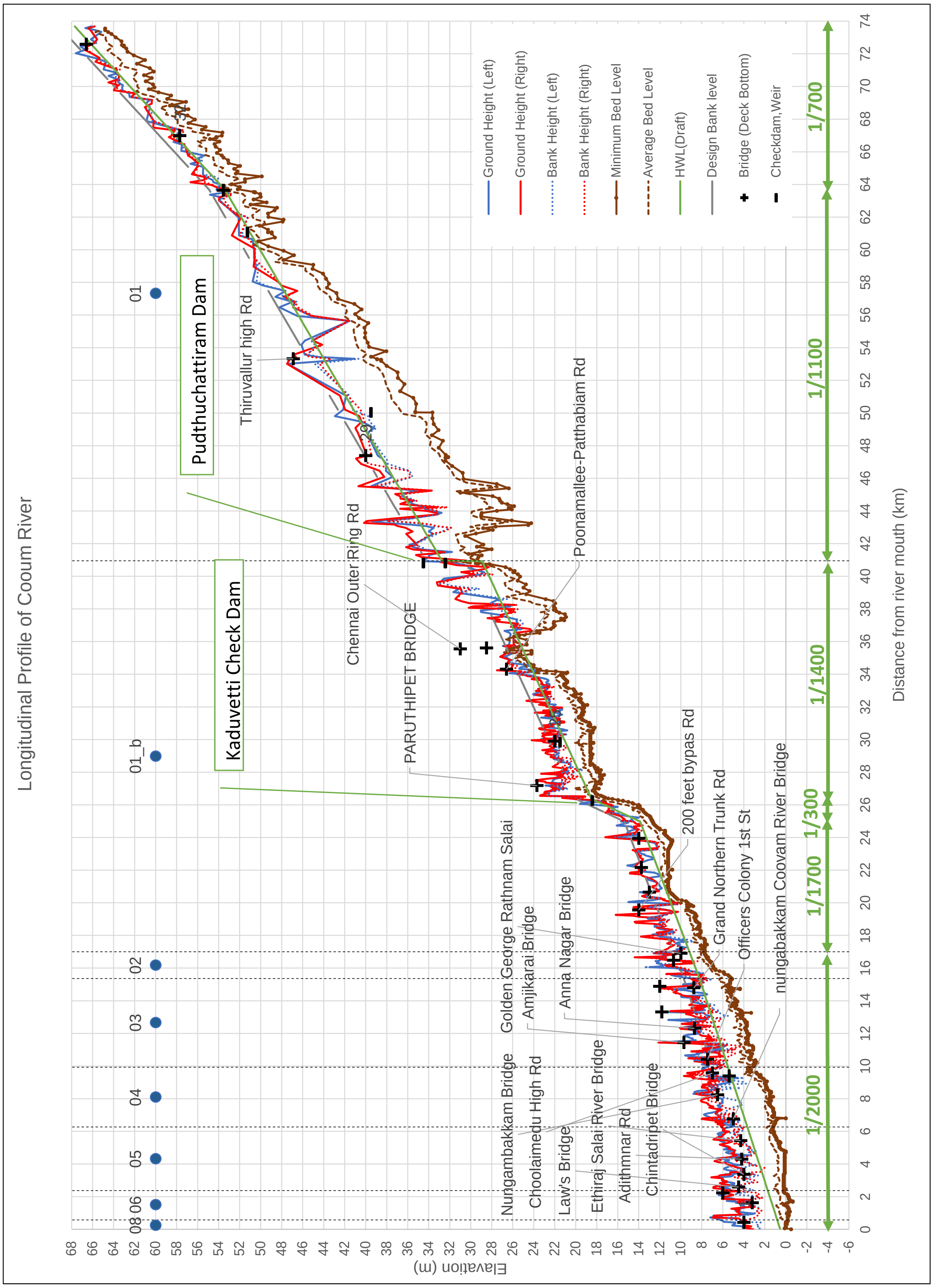
The tentative design high water level for the Cooum River is shown in Table 2-19 and Figure 2-30. The longitudinal positions in the figure are shown in Figure 2-31.

The tentative design high water level for the Cooum River was established similarly to the Adyar River, considering the current riverbank height and topographic slope.

Table 2-19: Tentative Cooum River Design High Water Level Longitudinal Plan

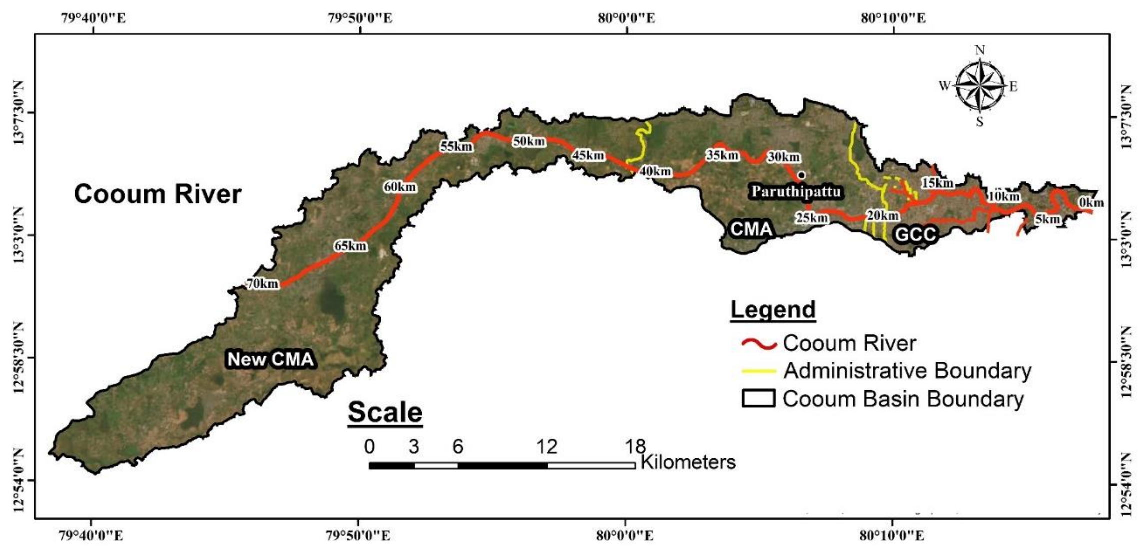
Section Name (HEC-RAS)	Cross Section No.	Distance From Sea (km)	HWL (Draft) (DL+m)	HWL Gradient 1/n	Design Bank Level (Draft) (DL+m)	Design Bank Level Gradient 1/n
Cooum 08	60	0.000	0.50	2000	2.00	2000
Cooum 06	720	0.664	0.87		2.37	
Cooum 05	2460	2.405	1.74		3.24	
Cooum 04	6390	6.315	3.69		5.19	
Cooum 03	10020	9.988	5.53		7.03	
Cooum 02	15421	15.393	8.24	1700	9.74	1700
Cooum 01_b	17402	17.024	9.19		10.69	
	19321	18.957	10.33		11.83	
	25290	25.037	14.07	300	15.57	300
	26668	26.426	18.55	1400	20.05	1400
	34652	34.303	24.17		25.67	
Cooum 01	41349.39	40.958	32.75	1100	34.25	1100
	43864.28	43.785	35.32		36.82	
	63207.30	63.829	53.62	700	55.12	700
	73030.68	73.678	67.69		69.19	

Source: JICA Expert Team



Source: JICA Expert Team

Figure 2-30: Tentative HWL and Design Longitudinal Profile of Cooum River



Source: JICA Expert Team

Figure 2-31: Cooum River Plan View and Chainage at 5 km Intervals

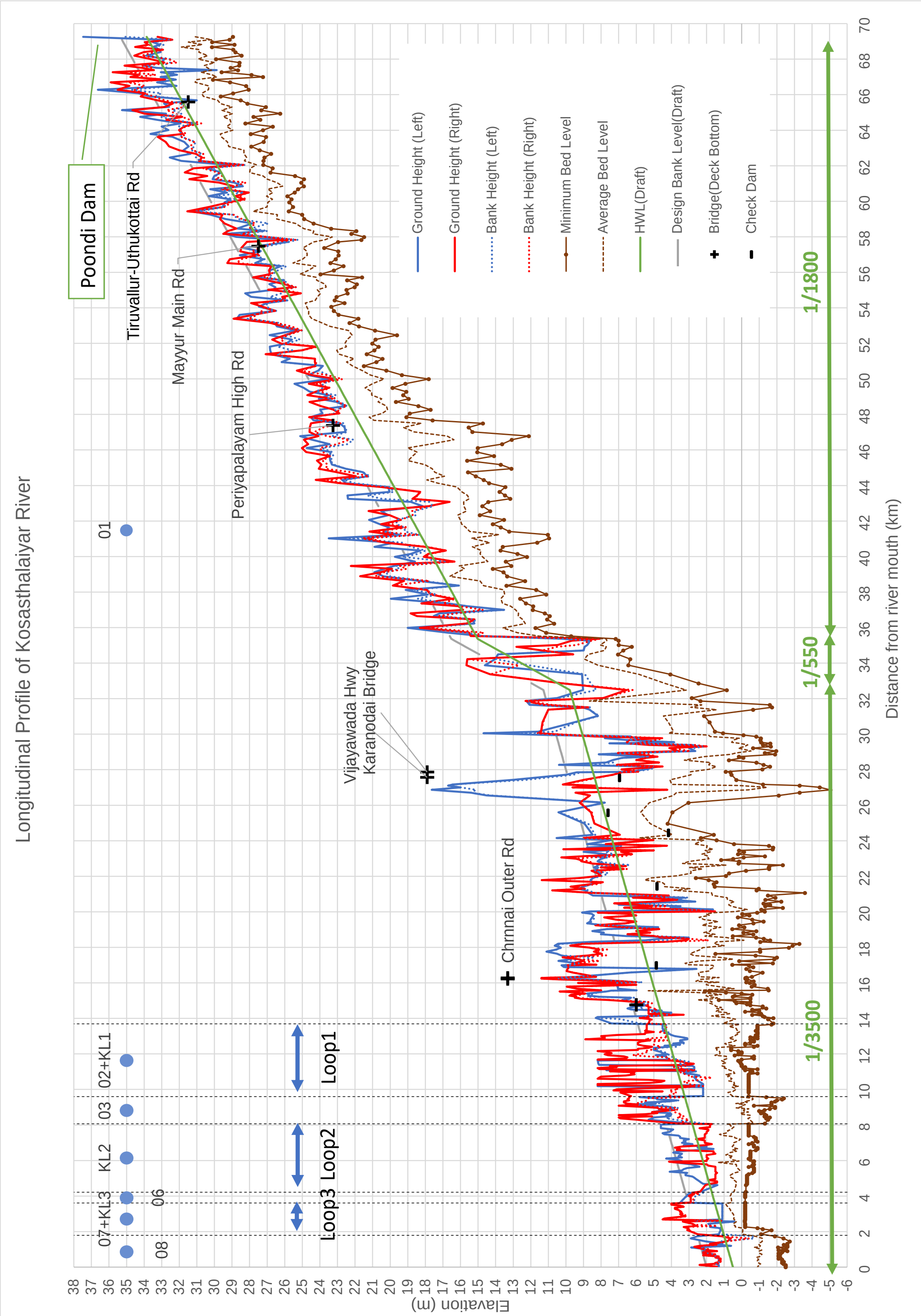
2.3.9.3. Kosasthalaiyar River

The Tentative design high water level for the Kosasthalaiyar River is shown in Table 2-20 and Figure 2-32. The longitudinal positions in the figure are shown in Figure 2-33. In the Kosasthalaiyar River, there are no locations where the current riverbank height changes abruptly, as seen in the Cooum River near the intake weirs. Therefore, the Tentative design's high-water level was set based on the current riverbank height and topographic slope. In the Kosasthalaiyar River, there is a section with a sudden change in topographic slope between the 33k and 36k sections. Therefore, this area was set as the point of gradient change, and the Tentative design high water level was established with three longitudinal gradients for these sections.

Table 2-20: Tentative Kosasthalaiyar River Design High Water Level Longitudinal Plan

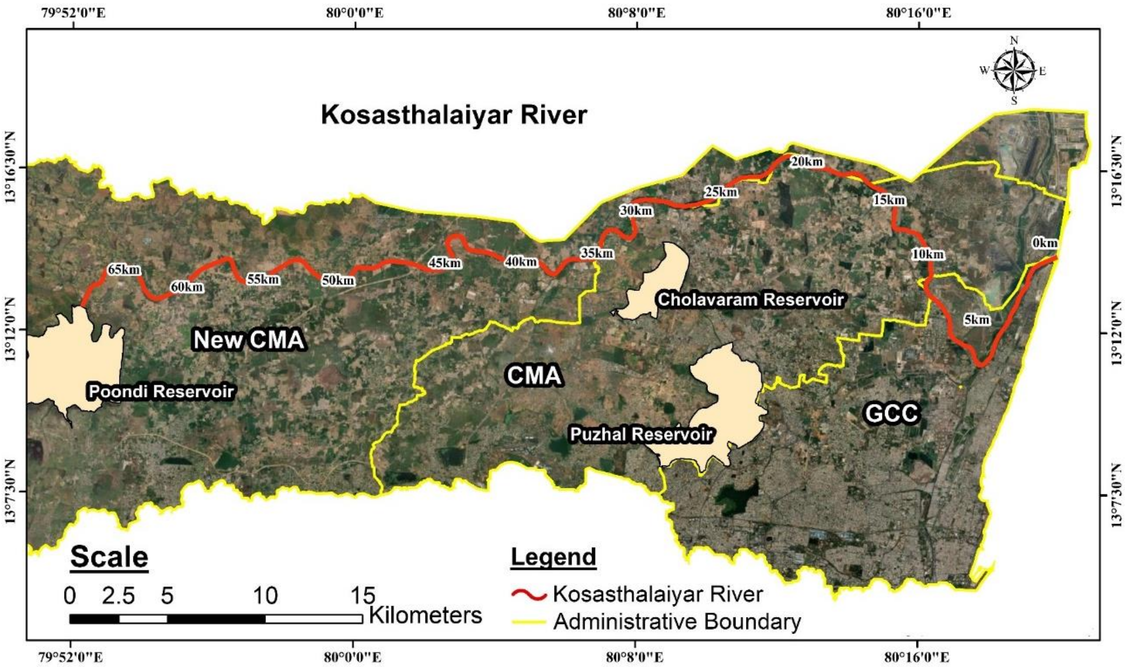
Section Name (HEC-RAS)	Cross Section No.	Distance From Sea (km)	HWL (Draft) (DL+m)	HWL Gradient 1/n	Design Bank Level (Draft) (DL+m)	Design Bank Level Gradient 1/n
Kosas08	2	0.00	0.50	3500	2.00	3500
Kosas07+KL3	493	1.85	1.03		2.53	
Kosas06	185	3.63	1.54		3.04	
KL2	274	4.24	1.71		3.21	
Kosas03	102	8.08	2.81		4.31	
Kosas02+KL1	160	9.63	3.25		4.75	
Kosas01	152	13.72	4.42		5.92	
	18245	31.87	9.60		11.10	
	19517.5	32.86	10.47	550	11.97	550
	22174	35.52	15.11	1800	16.61	1800
	56344	69.26	33.85		35.35	

Source: JICA Expert Team



Source: JICA Expert Team

Figure 2-32: HWL and Design Longitudinal Profile of Kosasthaliyar River



Source: JICA Expert Team

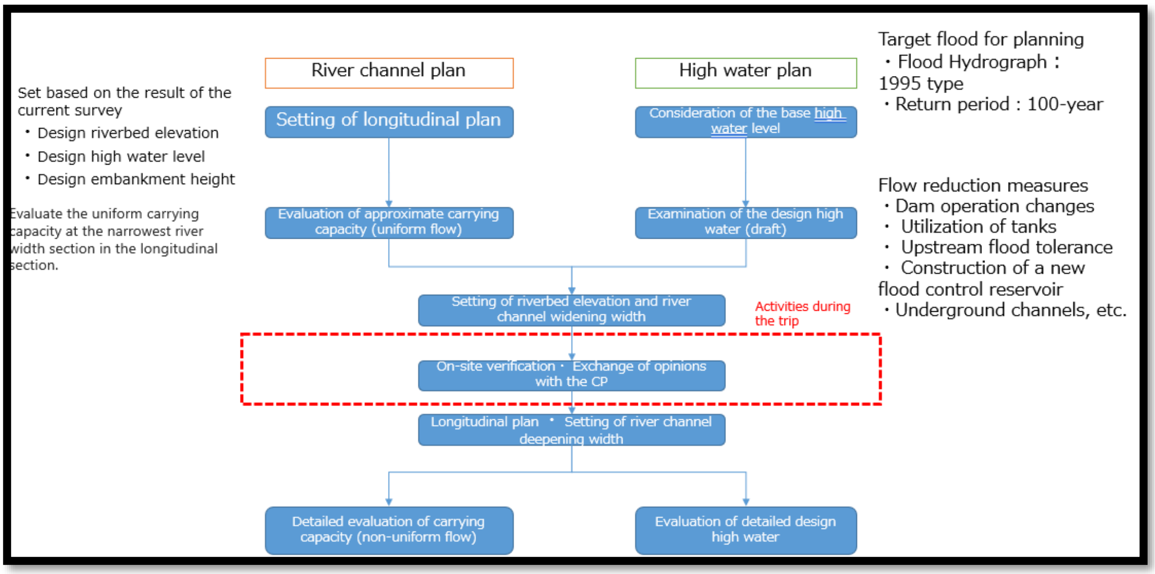
Figure 2-33: Kosasthaliyar River and Rdhills Plan View and Chainage at 5 km Intervals

2.3.10 Consideration of design high water discharge

2.3.10.1. Process of considering the design high water discharge

In formulating the flood control plan, it is essential to ensure safety for the 100-year return period design flood by integrating improvements in the storage capacity of dams and tanks within the watershed with enhancements in the discharge capacity of the three target rivers that convey flood runoff.

The design flood discharge, which serves as the planning criterion for outflow, should be determined by factoring in the anticipated flood runoff reduction from future storage facility developments, such as dams and tanks. Additionally, the maximum discharge capacity achievable through river improvements must be considered to maintain an optimal balance.



Source: JICA Expert Team

Figure 2-34: Flowchart of Evaluating Flood Control Measure

2.3.11 Calculation of future runoff volume

2.3.11.1. Organizing calculation conditions

The future design flood runoff volume for a 1/100 scale event was calculated using the previously developed HEC-HMS model. This calculation considered the impact of watershed storage facilities, including the flood control function of existing dams and the storage effects of tank renovations, in relation to the previously determined design high water discharge.

2.3.11.2. Flood control utilization of existing dams

The existing dams in the Chennai metropolitan area, such as Chembarambakkam, Poondi, and Puzhal, primarily serve as water supply reservoirs and currently do not provide flood control benefits. The feasibility of incorporating flood control functions into these existing dams has been assessed. Two potential methods for adding flood control capacity were considered:

- **Lowering the reservoir water level over an extended period** during the runoff season to create flood storage capacity.
- **Temporarily lowering the reservoir water level just before a flood event** through pre-release.

The first method raised concerns among local CPs regarding reduced water supply capacity during the runoff period and the risk of failing to restore the reservoir level after the flood, potentially affecting water supply functionality. Given the current uncertainties in ensuring a reliable water supply, this option was excluded from the master plan.

For the second method, local CPs are advancing a World Bank-funded dam operation study on pre-release. However, due to uncertainties in maintaining consistent regulation performance during large-scale flood events, such as those with a 100-year return period, the flood control plan does not consider securing flood control capacity through pre-release. Instead, the plan assumes a worst-case scenario where inflow to the dam equals outflow.

As a result, the master plan does not incorporate flood regulation through existing dam reservoirs. However, for Chembarambakkam Dam, where the maximum discharge capacity of outflow facilities is currently 820 m^3/s, this value has been set as the upper limit for discharge volume.

2.3.11.3. Floodwater retention through the rehabilitation of existing tanks

Agricultural reservoirs (tanks) are expected to mitigate peak flood flows by temporarily storing runoff within the catchment. This is achieved through measures such as area expansion and excavation, which help delay peak discharge into river channels.

The Tamil Nadu Water Resources Department (TNWRD) has been actively rehabilitating existing tanks annually, and this strategy is being considered as a practical solution by the local CP. The TNWRD's tank rehabilitation projects for 2024 include:

- Improvement of Porur Tank Surplus Course and Regulator Arrangements: 34 INR Crore
- Deepening and improvement of the existing tank bed of Kolathur Tank: 7.3 INR Crore
- Providing flood regulator arrangements in Ambattur Tank (Both Weirs): 0.98 INR Crore
- Rehabilitation of Cholavaram Tank Bund: 40 INR Crore

For spillage calculations, the total new storage capacity of the rehabilitated tanks, as assumed in the referenced study, was considered at 100%. To account for different levels of staged maintenance, spillage calculations were conducted assuming that **10%, 20%, 50%, 75%, and 90%** of the new storage capacity would be rehabilitated.

2.3.11.4. Other flow reduction measures

After determining the flood runoff contribution from the catchment, additional flow reduction measures were considered to further mitigate flood impacts. These measures include:

a) Diversion channels

A diversion channel can help reduce flood discharge in river channels by redirecting a portion of the flow to an alternate route. In this study, the potential effect of an underground diversion channel was assessed for the Adyar River to evaluate its capacity to lower peak flood discharge.

b) Floodplain storage and retention ponds
As an alternative to diversion channels, floodplain storage areas and retention ponds can be developed along riverbanks to temporarily retain floodwaters, thereby reducing peak discharge downstream. The selection of suitable locations for these facilities will be based on land use patterns and historical flooding conditions along the river.

Due to limitations in channel widening and excavation, the targeted flood control capacities for the Phase 2 improvements are as follows:

Adyar River: 2,500 m^3/s (current capacity: 4,800 m^3/s)

Cooum River: 1,700 m^3/s (current capacity: 2,100 m^3/s)

Third River (not specified in the original text): 2,100 m^3/s (current capacity: 6,700 m^3/s)

These improvements aim to enhance flood resilience while balancing environmental and infrastructural constraints.

Flood control at existing dams is difficult from the perspective of prioritizing the use of dam water, as mentioned above, and to provide this flood control capacity in flood control areas along river channels, it is necessary to develop several large flood control areas.Source*: JICA Expert Team*

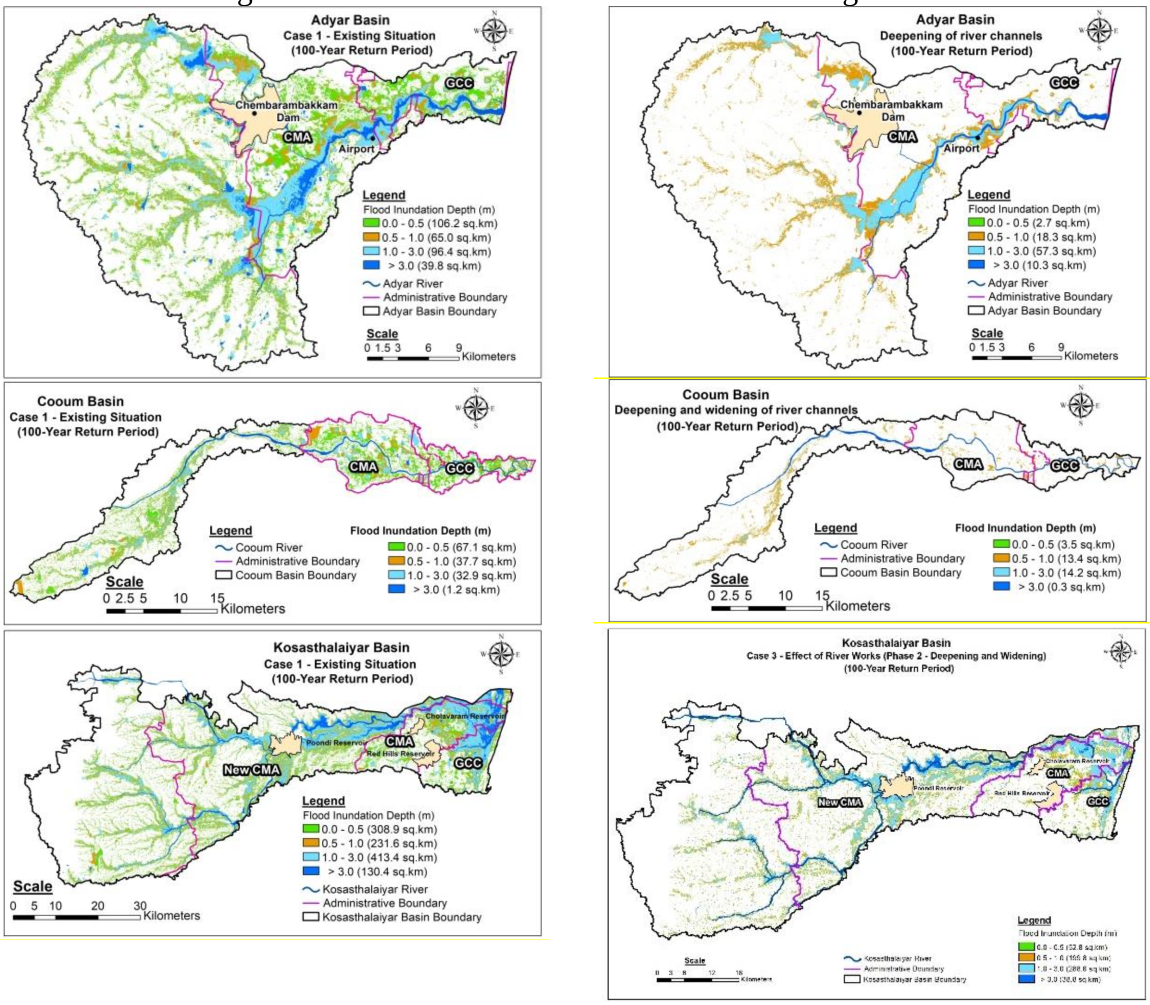
Figure 2-35 shows the inundation situation during the 100-year return period flood and after channel widening and excavation along the river where the retention basin will be constructed. Each river remains inundated over a wide area along the river, and to treat these runoff amounts in the floodplain along the river channel, a facility with a storage function equivalent to the inundation area shown here would be required, which is not feasible considering the need to secure a site.

In addition, the operation of the retention basin, etc., requires an operation that steadily withdraws the peak flood flows of the river, which is considered difficult from a maintenance and management standpoint.

From these points of view, we judged that the proposed development of a floodplain along the river channel was not realistic and excluded it from the study.

Without river channel improvement at existing facilities

With river channel improvement at existing facilities

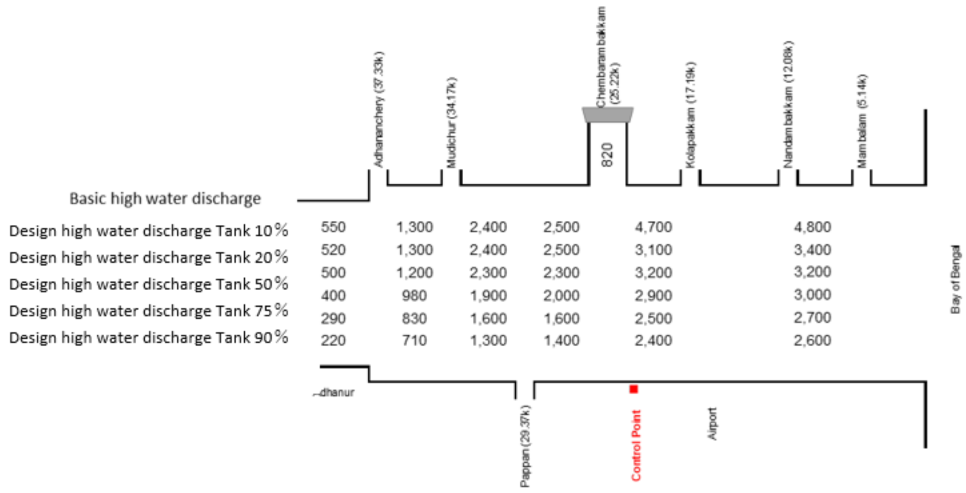


Source: JICA Expert Team

Figure 2-35: Effect of River Channelization on Inundation Area (100-Year RP)

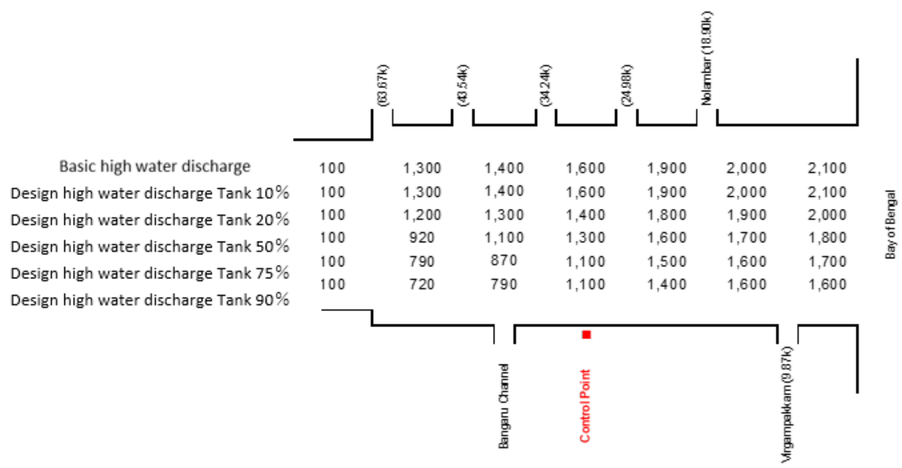
2.3.11.5. Runoff considering watershed storage facilities

The runoff considering the effects of the rehabilitation of existing tanks is shown in Figure 2-36 to Figure 2-38. The calculation conditions are based on those used in the basic high water flow calculation, with runoff calculated for each rehabilitation ratio of the existing tanks. Additionally, the values in the figures are rounded up to the nearest 100 m³/s for values equal to or greater than 1000 m³/s, and to the nearest 10 m³/s for values less than 1000 m³/s.



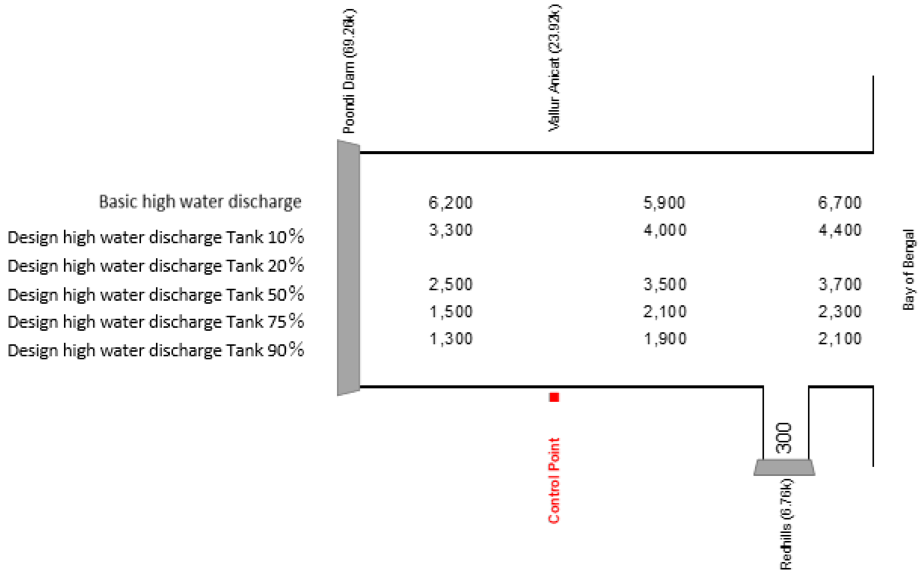
Source: JICA Expert Team

Figure 2-36: Effect of Flood Storage Scenarios in Tanks on Adyar River Flow



Source: JICA Expert Team

Figure 2-37: Effect of Flood Storage Scenarios in Tanks on Cooum River Flow

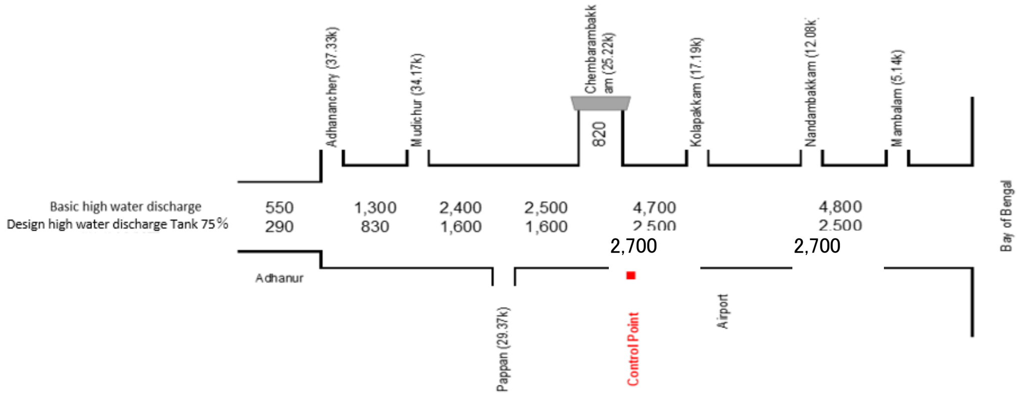


Source: JICA Expert Team

Figure 2-38: Effect of Flood Storage Scenarios in Tanks on Kosasthaliyar River Flow

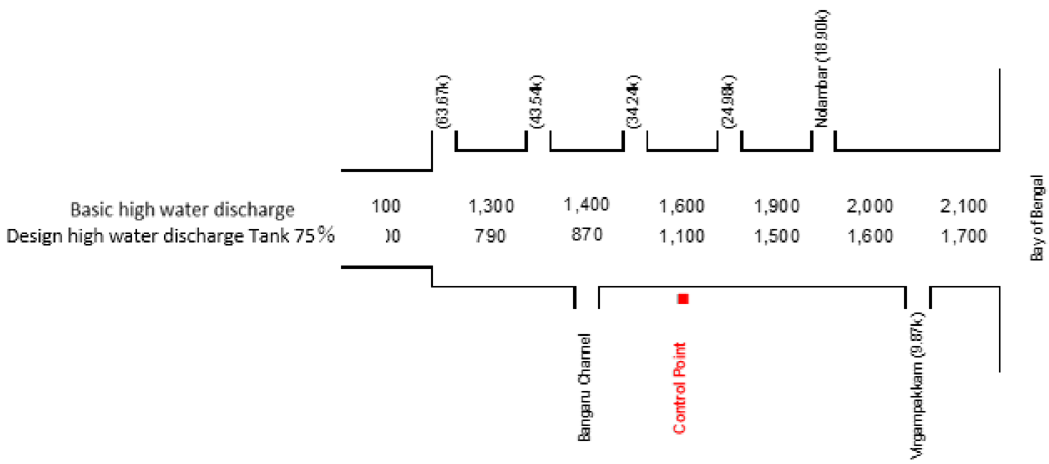
2.3.11.6. Setting of the tentative design high water flow

The current river channel's carrying capacity is below 500 m³/s. Even if runoff suppression is implemented through watershed storage facilities, it will be difficult to convey the tentative design high water flow shown in Figure 2-39 to Figure 2-41. Therefore, it is necessary to improve the carrying capacity by expanding the flow cross-section through river widening and dredging. Therefore, below, the approximate carrying capacity corresponding to the river widening and dredging volume will be calculated based on the current river channel cross-section, and the maximum discharge that can be handled by the river will be determined.



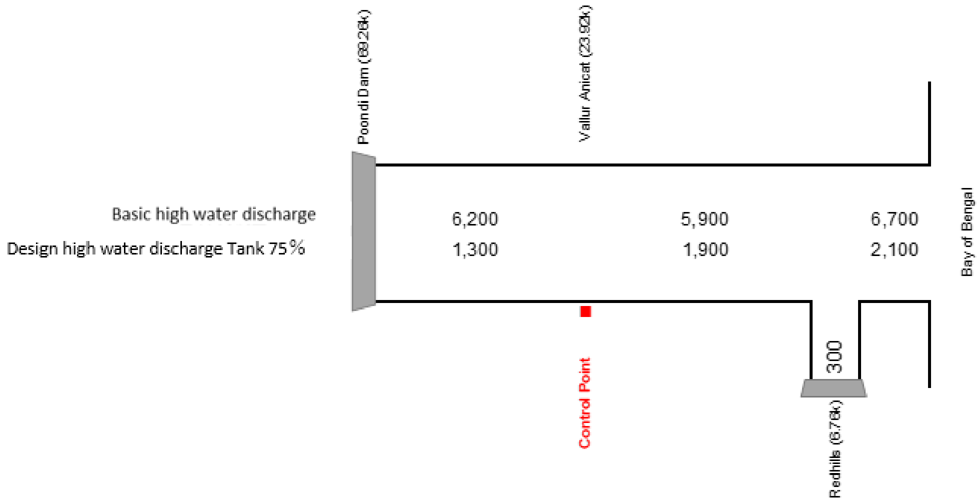
Source: JICA Expert Team

Figure 2-39: Tentative Adyar River Design High Water Flow



Source: JICA Expert Team

Figure 2-40: Tentative Cooum River Design High Water Flow



Source: JICA Expert Team

Figure 2-41: Tentative Kosasthalaiyar River Design High Water Flow

2.3.12 The calculation of the current discharge capacity

The discharge capacity of the current river channel was evaluated based on the results of the non-uniform flow calculation using the HEC-RAS model. The method for calculating discharge capacity using the HEC-RAS model is separately described in the Appendix. For detailed information, please refer to it.

This section summarizes the areas that pose flood control issues based on the characteristics of the discharge capacity in the current river channels of the Adyar River, Cooum River, and Kosasthalaiyar River.

2.3.12.1. Adyar River

Figure 2-42 shows the current carrying capacity of the Adyar River. As shown in this figure, the Adyar River has insufficient carrying capacity for the high-water discharge (tentative). The downstream of the Metro Bridge near 7k from the mouth of the river has a relatively low riverbed height and a large carrying capacity but is significantly insufficient upstream of 7k. Therefore, it is necessary not to solve localized bottlenecks, but to fundamentally improve the carrying capacity by widening and excavating the river channel from the river mouth to the upper reaches of the river.

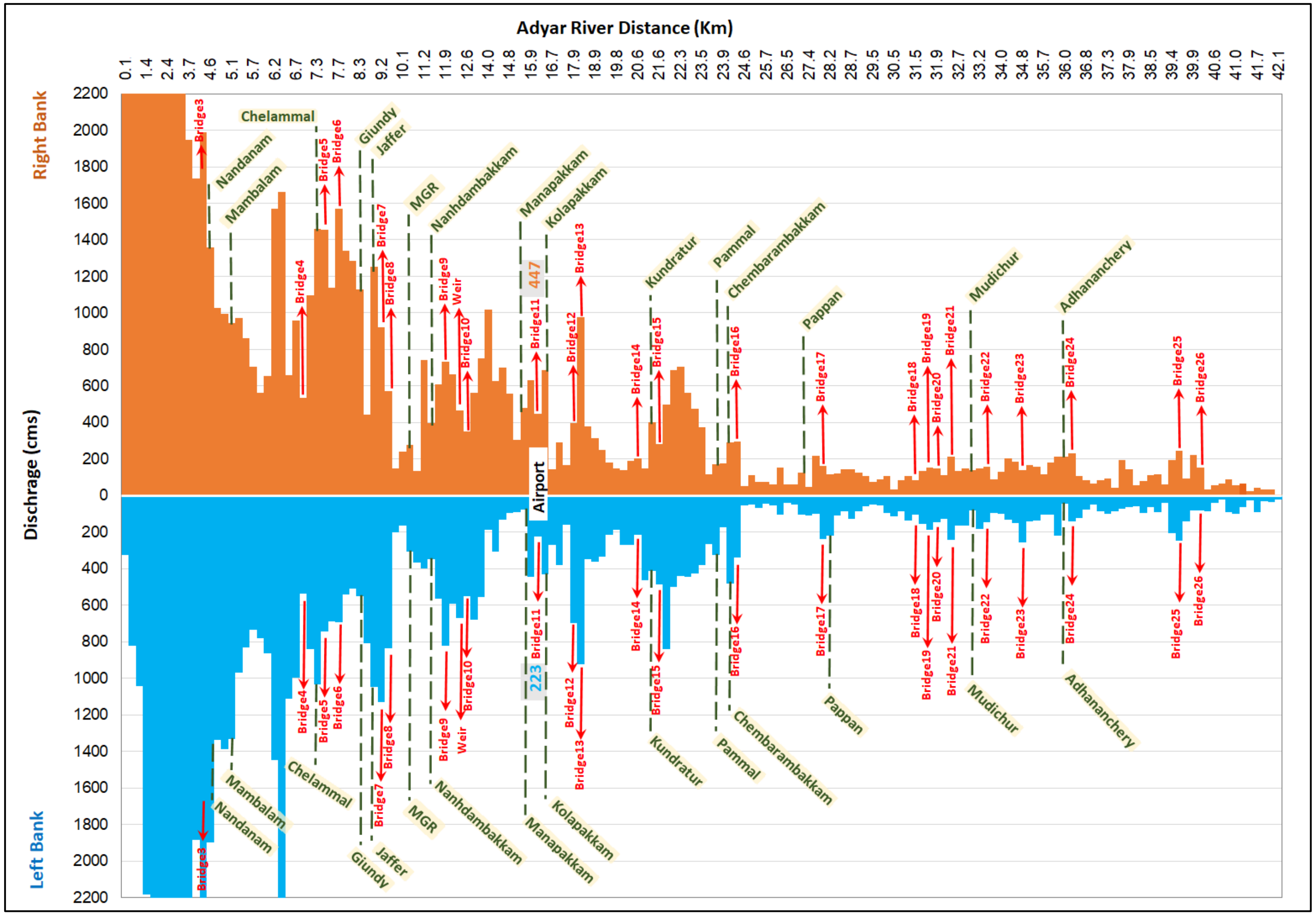
2.3.12.2. Cooum River

Figure 2-43 shows the current carrying capacity of the Cooum River. As shown in this figure, in the Cooum River, there are many sections where the current carrying capacity is about 200 m^3/s from the river mouth to the Bangaru Canal diversion point, and many sections upstream of the diversion point have a carrying capacity of 1000 m^3/s or more, which exceeds the proposed high water discharge (tentative). Therefore, the Cooum River needs to be drastically improved by channel widening and excavation from the Bangaru Canal diversion point to the mouth of the river.

2.3.12.3. Kosasthalaiyar River

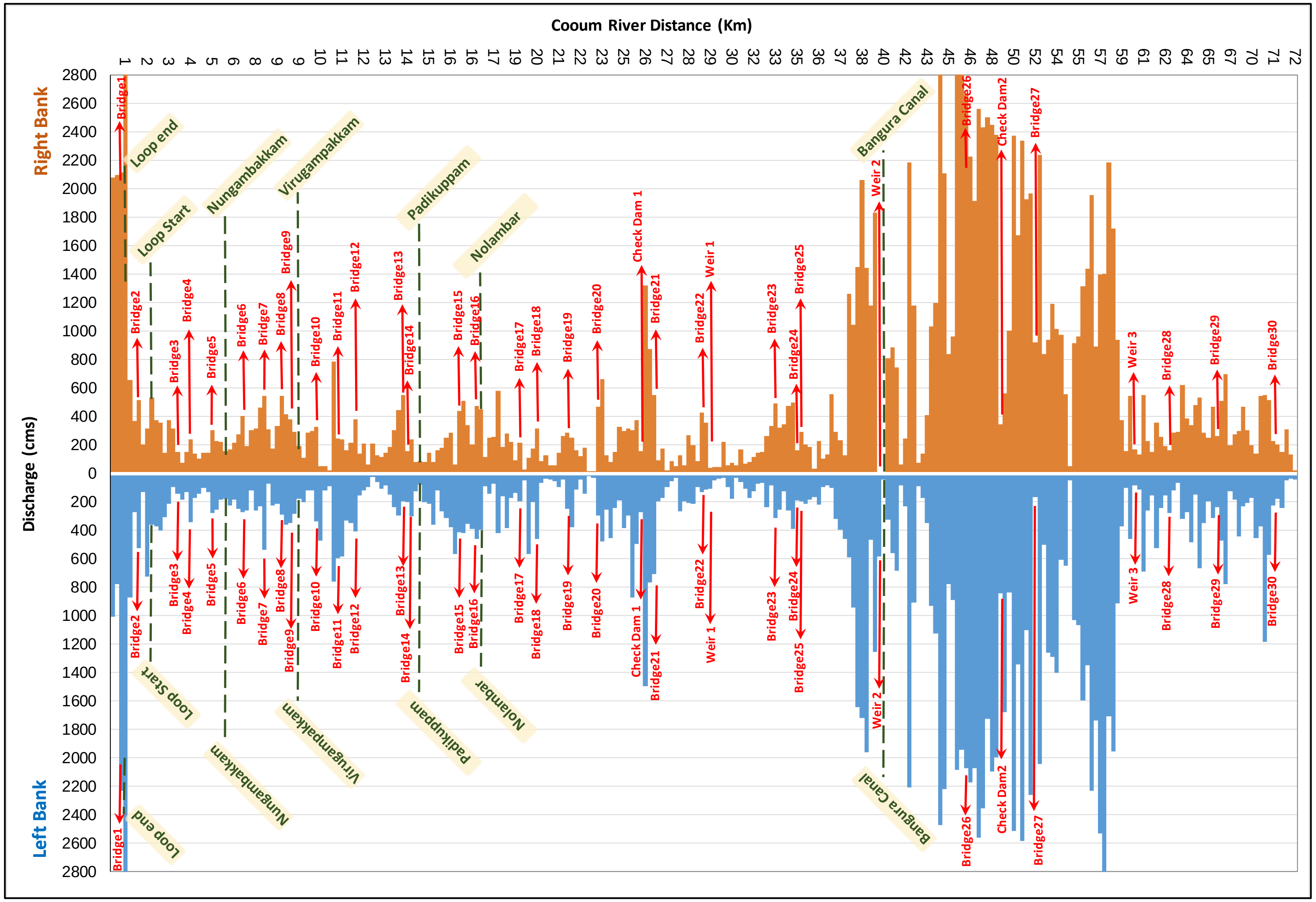
Figure 2-44 shows the current carrying capacity map of the Kosasthalaiyar River. As shown in this figure, the Kosasthalaiyar River has many sections where the carrying capacity is insufficient for the proposed high-water discharge (Tentative). In particular, from the upstream end of the lowest Loop 3 section to the upstream end of the Loop 1 section, the carrying capacity is about

200 m^3/s, which is small. The Kosasthalaiyar River is less urbanized than the Adyar and Cooum Rivers, but there is a concentration of houses, factories, and other assets around 10 km between the Loop 2 and Loop 3 sections, so it is necessary to secure the carrying capacity including this section. Therefore, it is necessary to improve the carrying capacity of the Kosasthalaiyar River by widening and excavating the river channel up to the mouth of the river.



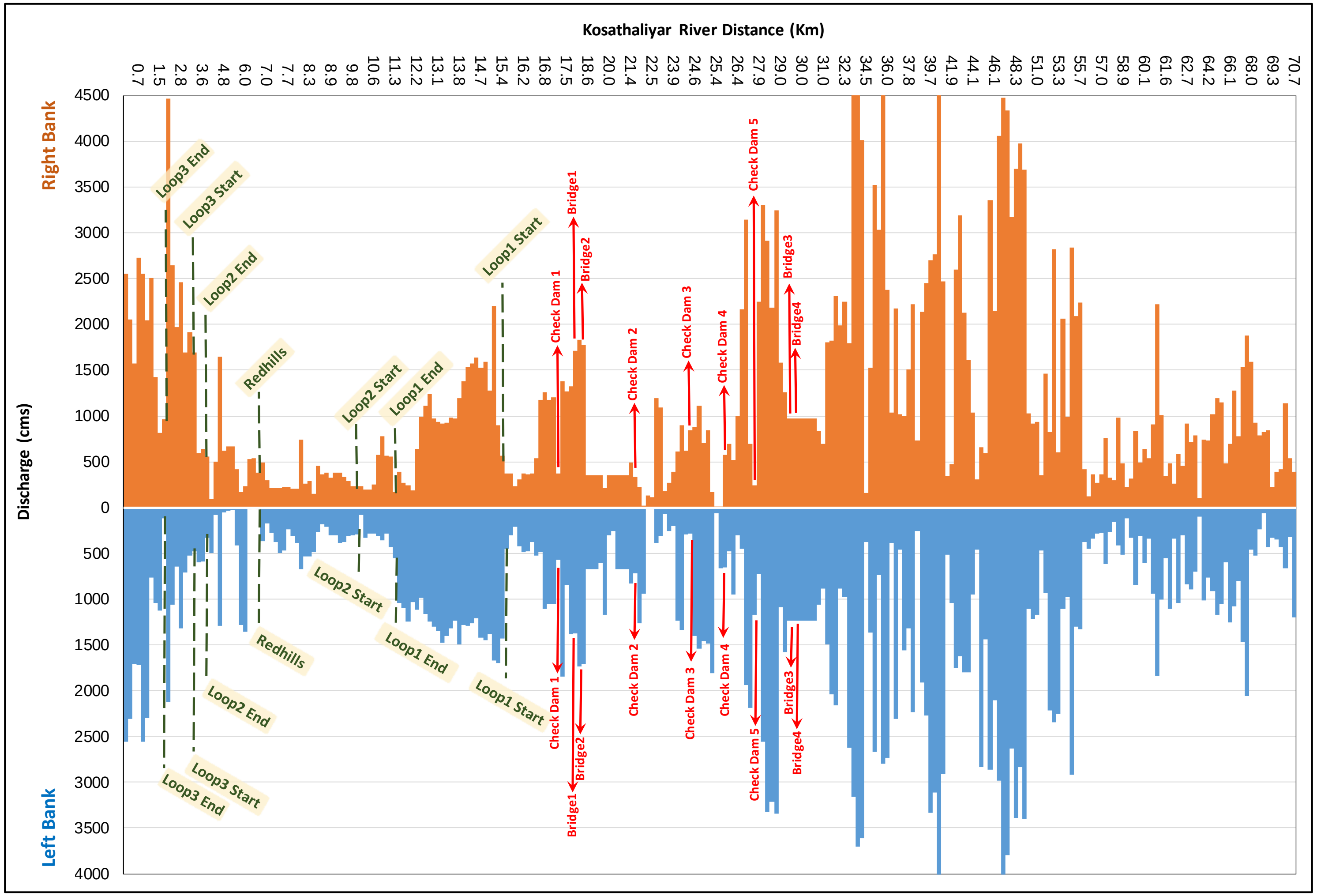
Source: JICA Expert Team

Figure 2-42: Adyar River Carrying Capacity



Source: JICA Expert Team

Figure 2-43: Cooum River Carrying Capacity



Source: JICA Expert Team

Figure 2-44: Kosasthalaiyar River Carrying Capacity

2.3.13 Setting of future tentative design River channel

2.3.13.1. Basic principle for flood control measures

The following outlines the fundamental strategies for designing the planned river channel. In Chennai, the flow capacity is approximately one-tenth of the design flood discharge, making it challenging to address flood control through individual measures alone. The proposed strategies are categorized as follows:

- Measures not requiring land acquisition:
    - Construction of levees (embankments)
    - River channel dredging or excavation
- Increasing the storage capacity of tanks and water bodies
- Optimizing dam discharge operations
- Diversion channel proposals
- River channelization (deepening and widening)
- Implementation of underground bypass tunnels

The table on the following page summarizes the fundamental approaches to these measures. It highlights that the primary strategy involves a combination of river channel excavation, channel widening, reservoir capacity expansion, improved dam discharge operations, and the use of bypass, rather than relying solely on the construction of levees or excavated river channels.

Among these strategies, storage facilities such as reservoirs may not achieve their planned flood control capacity during short-duration, high-intensity rainfall events. In such cases, river channel improvements are expected to provide more reliable flood mitigation. As outlined in the phased maintenance section for river channel rehabilitation, priority is given to dredging and excavation within the existing channel width. Channel widening is often avoided due to the need for relocating houses and other structures, which complicates implementation.

For levee construction, land acquisition is required, and it can also lead to drainage issues. Therefore, levees are only being considered in specific sections where ground levels are low.

The responsibility for implementing these improvements will lie with the relevant authorities in the future.

In the following table, (○) means generally acceptable; (△) means there are some considerations and observations; and (✕) means not accepted or negative.

Table 2-21: Comparison of Main Countermeasures (Case Study: Adyar River Basin)

	Embankment	River channel excavation	River channel widening	Flood Storage in tanks
Planned Scale	・At the reference point, the water level is about 10m higher than the ground level inside the bank, and including the margin, a bank height of 11.5m is required (the width of the embankment site must have a 20% gradient, a top width of 5m, and a bank of about 50m per side).	- Excavation of approximately 10m is required at the reference point.	・A widening of about 400m is required at the reference point.	・Even if all the major reservoirs in the basin are used up at the reference point, the discharge capacity will be around 3,200 m3/s, and it will be difficult to reduce it to the current discharge capacity (500 m3/s) [Evaluation: ×]
Social Impact	・Land acquisition is required for 100m on both sides of the river, and negotiations are difficult in the urbanized downstream area. ・All 26 bridges will need to be replaced, and there are concerns about the impact on the surrounding commercial facilities required to raise the access roads. ・Concerns over new inland flooding due to poor drainage caused by embankments [Rating: ×]	・All 26 bridges need to be rebuilt, or their pier foundations need to be affixed ・Concerns over the impact on underground structures crossing the river [Rating: ×]	・It will be difficult to widen the river by 400m in the urbanized downstream area. ・Replace all 26 bridges [Rating: ×]	・Because the reservoir capacity is almost 100%, it is difficult to empty it by pre-discharging. [Rating: ×]
Environmental Impacts	・Current river environment is largely maintained [Rating: ○]	- The low tide area will be increased from the current 7 km to 22 km, raising concerns that saltwater will invade the groundwater and cause it to become salty, which will have a major impact on plants and animals that use freshwater environments. [Rating: ×]	・If the compound cross-section river channel shape is adopted, the current river environment will be largely maintained. [Rating: ○]	・There are concerns that the temporary disappearance of the water body will hurt the plants and animals currently using the reservoir. [Rating: △]
Cost	・Earth filling volume: 19 million m3 ・Site area: 3.6 million m2 ・Additional costs will be incurred for installation on bridge sections. [Evaluation: △]	Excavated soil volume: 20 million m3 ・Bridge foundation costs ・More maintenance is needed at the river mouth than at present [Rating: △]	Excavated soil volume: 87 million m3 ・Site area: 11 million m2 ・Separate bridge replacement costs required [Rating: △]	Excavated soil volume: 0.32 million m3 [Rating: ○]
Total Evaluation	The high height of the levees raises concerns about land acquisition and the risk of inland flooding.	Apart from maintaining the river channel and preventing saltwater intrusion,	The cost of land acquisition is huge, making this plan difficult to implement on its own.	Inability to cope with the problem by simply expanding the reservoir capacity

Source: JICA Expert Team

Table 2-22: Comparison of Main Countermeasures (Case Study Continue: Adyar River Basin)

	Improving dam discharge operations	**Diversion Channel (Open channel)**	**Diversion Channel (Underground bypass tunnel)**
Concept	A plan to release water from the Chembarambakkam Dam in advance in hopes of reducing flooding.	A plan to divert water from the upstream urban area into a spillway and reduce the amount of water passing through downstream.	A proposal to reduce the amount of water passing through downstream by constructing an underground outfall.
Overview of the Plan	・WB is considering a planned discharge volume of 820m3/s at 1/100 scale	・To install a 3000m3/s class spillway, a river width of 200-400m and a length of about 15km are required.	The actual figures and plans in Japan and other countries are around 100 to 200 m3/s, making this measure difficult to implement alone.
Social impact	・If the flood prediction turns out to be wrong and there is little rainfall, there is concern that it could affect storage capacity. [Rating: △]	・The coastal areas of the Adyar River are urbanized, making it difficult to develop new spillways. [Rating: ×]	- Because the project utilizes an underground area, it requires less house relocation and land acquisition, so the project can be implemented quickly. [Rating: ○]
Environmental impacts	・Current river environment is generally maintained [Rating: ○]	・Concerns about the impact of excavating important areas such as along the coast [Rating: ×]	・The current environment will not be altered, so the impact will be minimal [Rating: ○]
Cost	・The cost is about the same as the cost of a rain gauge, water level gauge, and forecasting system. [Evaluation: Good]	Excavated soil volume: 87 million m3 ・Site area: 11 million m2 ・A new bridge needs to be built at the spillway crossing point [Rating: ×]	・In the case of a scale of 200 m3/s Length: 12km ・The cost is high [Rating: △]
Total Evaluation	Effective if you can operate it reliably	Land acquisition costs are huge, and route selection is difficult	It is appropriate to use it as a complement to other countermeasures.

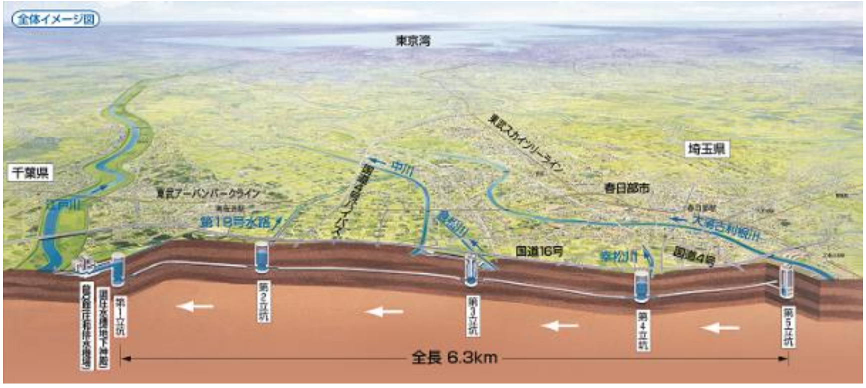
Source: JICA Expert Team

2.3.13.2. Reference: underground bypass tunnels

Underground bypass tunnels are constructed in urban areas where it is difficult to construct drainage channels using open channels. In Japan, there are several examples, such as the Metropolitan Area Outer Discharge Channel by the Ministry of Land, Infrastructure, Transport and Tourism (**Figure 2-45**) and the Tokyo Metropolitan Government's Underground Regulating Pond on the Loop Route 7.

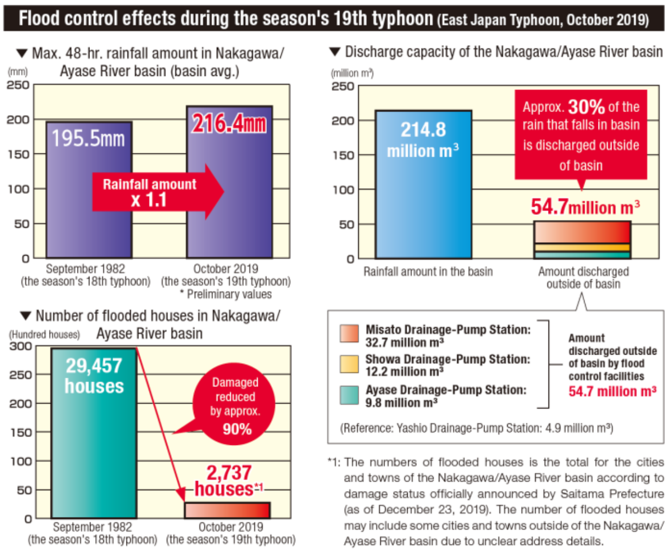
The area around the Outer Discharge Channel used to be an area regularly hit by inland water damage, but as shown in **Figure 2-46**, damage has been reduced to about 10% as a result of the improvement, and the area is highly effective in eliminating inland water damage.

The Chennai metropolitan area is highly urbanized and can be expected to be bypassed from the Adyar River and can also be expected to be effective in areas subject to internal water damage, such as the Kovalam Basin on the tunnel route.



Source: Ministry of Land, Infrastructure, Transport and Tourism

Figure 2-45: Metropolitan Area Outer Discharge Channel Overall view



Source: Ministry of Land, Infrastructure, Transport and Tourism

Figure 2-46: Metropolitan Area Outer Discharge Channel Effects of Maintenance

2.3.13.3. Setting up the tentative river cross-section

The main objective is to designate a tentative 15 to 30-meter width from the current riverbank position. The CP side will finalize the details based on the results of this study in the future.

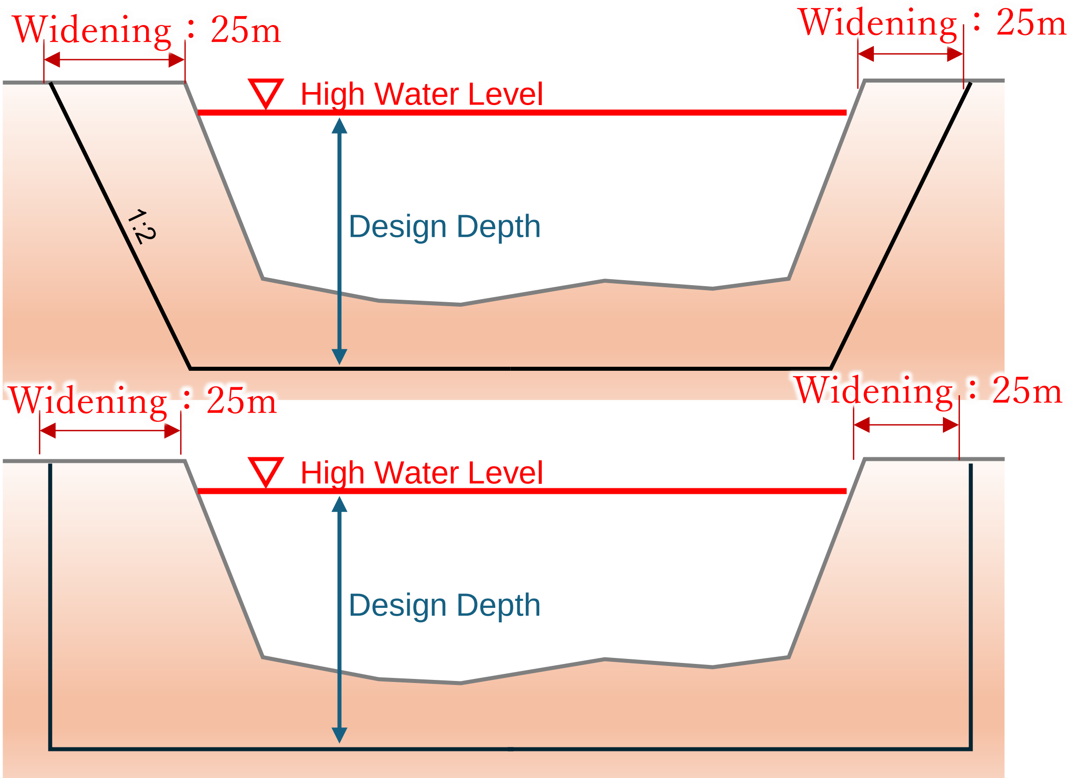
The carrying capacity of the current river channel is shown in Figure 2-42 to Figure 2-44, and in many sections, it is below 500 m³/s. Even with runoff suppression through watershed storage facilities, it is difficult to convey the design high water flow (tentative) shown in Figure 2-39 to Figure 2-41. Therefore, it is necessary to enhance the river's carrying capacity by expanding the flow cross-section through river widening and dredging. To achieve this, the approximate carrying capacity corresponding to the proposed river widening and dredging volumes will be calculated based on the current river channel cross-section. This calculation will determine the maximum discharge the river can handle under improved conditions.

The approach for setting the future design of river channels involves several key considerations. First, the river channel will be widened by 12.5 to 25 meters on both the left and right banks, extending from the current riverbank position, resulting in a total widening of 25 to 50 meters. This decision is based on confirmation from the TNWRD that a 15 to 30-meter width from the current riverbank is going to be considered as the river buffer zone in the Chennai Urban Development Master Plan. To accommodate a 5-meter management access road on both banks, the widening width is set at a maximum of 25 meters per bank.

Second, the river channel will be deepened, with the designed water depth set in 1-meter increments relative to the previously established High-Water Level (HWL). Local authorities have confirmed that there are no restrictions on the dredging depth, allowing the design water depth (the difference between the HWL and the post-dredging riverbed elevation) to be determined to ensure the required carrying capacity.

Third, the river channel cross-section shape will be designed with a riverbank slope of 1:2 (20% slope), based on examples from earth embankments and natural riverbank sections in Japan. However, in sections where the current river width is narrow and achieving the required carrying capacity with a 20% slope is challenging, the maximum carrying capacity achievable with a vertical wall riverbank will be calculated instead.

This comprehensive approach ensures that the river's capacity is optimized while considering practical constraints and design standards. By combining widening, deepening, and appropriate cross-section shaping, the river's ability to handle higher discharge levels will be significantly improved, contributing to effective flood control and river management.



Source: JICA Expert Team

Figure 2-47: Future Design River Channel Cross-Section Concept

2.3.13.4. Carrying capacity calculation method

The carrying capacity of the post-renovation cross-section was calculated using a flow calculation method, as the goal was to roughly determine the necessary cross-sectional shape for multiple rivers. The calculation conditions were established as follows: the flow calculation method was applied, and target sections were identified as continuous stretches of the river with similar conditions, such as segments between tributary confluences. For each continuous section, the average river width across all survey lines was used to set the design cross-section. This involved combining river channel widening (current width, 25 meters from the current bank, and 50 meters from the current bank) with riverbed dredging.

The design water depth was set in 1-meter increments between 2 meters and 7 meters, based on the current cross-section of each river. The carrying capacity for each combination of widening and dredging was then calculated, with the riverbed slope assumed to match the High-Water Level (HWL) slope.

Based on these conditions, the approximate carrying capacity for each river was estimated using a 20% slope cross-section. For the Adyar River, specific sections (7.64 km to 12.08 km and 29.41 km to 34.17 km) showed a shortfall in capacity relative to the previously established tentative design high water flow. To address this, the carrying capacity for these sections was recalculated assuming vertical wall revetments, which provide a more efficient flow profile in narrow or constrained areas. This approach ensures that the river's capacity is optimized to meet the design flood discharge requirements, particularly in critical sections where traditional slope designs may fall short.

Table 2-23: Adyar Carrying Capacity (With 20% Slope in All Sections)

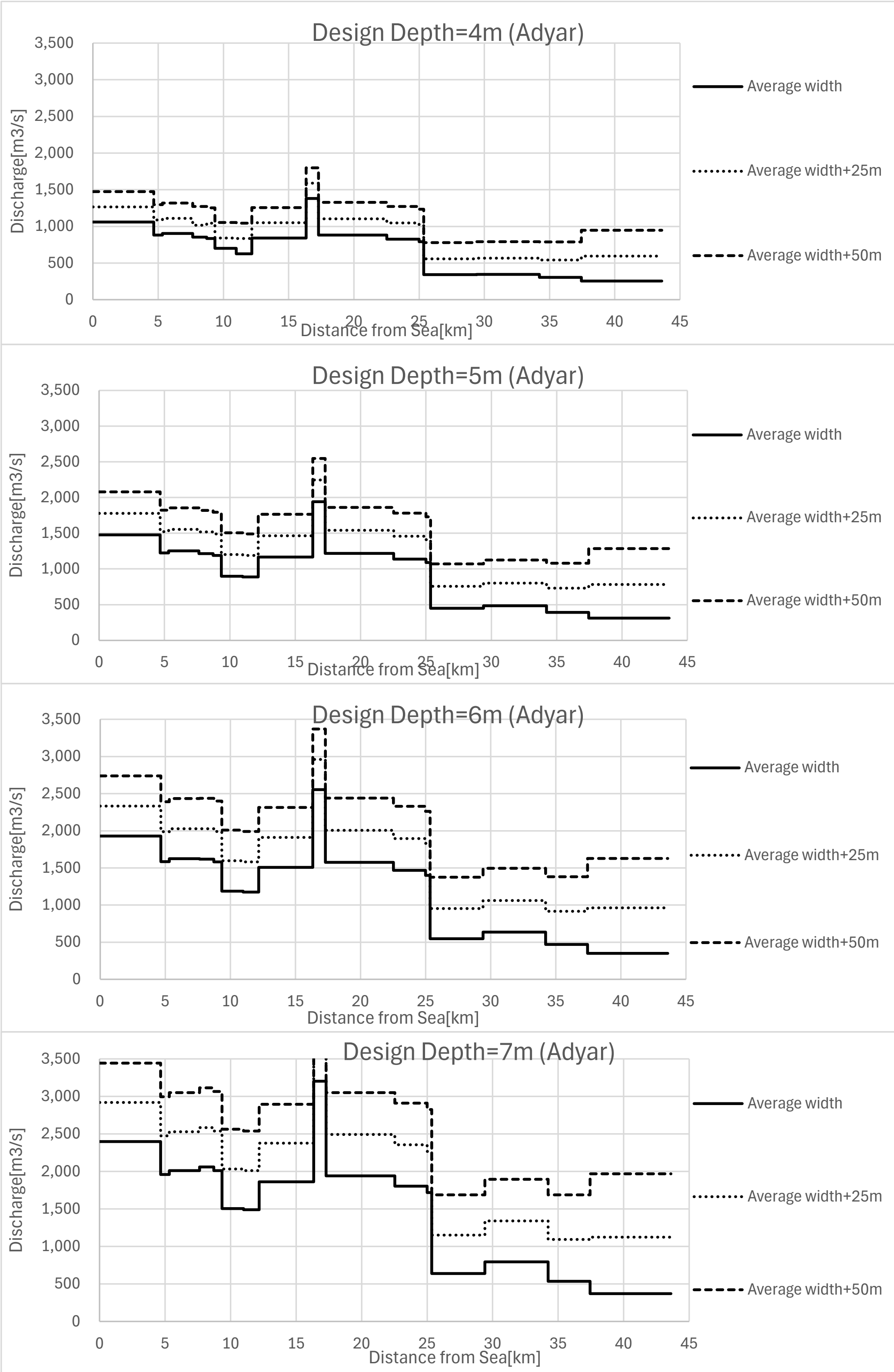
River Section (HEC-RAS)	Distance from Sea[km]			Carrying Capacity（Average Section Width + Widening）[m3/s]												Average River Width [m]
				Design Depth=4m			Design Depth=5m			Design Depth=6m			Design Depth=7m			
				0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	
Adyar13	0.00	～	4.54	1,059	1,267	1,476	1,478	1,779	2,081	1,928	2,333	2,740	2,399	2,920	3,443	147
Adyar_CA2	4.66	～	5.14	882	1,089	1,298	1,223	1,522	1,823	1,584	1,987	2,392	1,958	2,475	2,996	125
Adyar12	5.32	～	7.56	903	1,111	1,319	1,253	1,553	1,854	1,625	2,029	2,434	2,011	2,528	3,050	128
Adyar11	7.64	～	8.58	750	957	1,165	1,034	1,332	1,632	1,331	1,731	2,135	1,634	2,146	2,665	110
Adyar10	8.72	～	9.29	731	938	1,146	1,007	1,305	1,604	1,294	1,694	2,098	1,587	2,099	2,617	107
Adyar9	9.34	～	10.91	700	739	948	720	1,017	1,318	910	1,307	1,711	1,097	1,603	2,120	83
Adyar8	10.98	～	12.08	526	731	938	713	1,007	1,305	901	1,294	1,694	1,086	1,587	2,099	82
Adyar7	12.17	～	16.24	842	1,049	1,258	1,166	1,465	1,765	1,507	1,910	2,315	1,860	2,375	2,896	121
Adyar6	16.34	～	17.19	1,380	1,589	1,798	1,942	2,244	2,547	2,553	2,961	3,370	3,203	3,728	4,255	185
Adyar5	17.29	～	22.46	881	1,104	1,327	1,219	1,540	1,862	1,575	2,006	2,440	1,941	2,494	3,051	118
Adyar4	22.53	～	24.92	825	1,048	1,271	1,139	1,459	1,780	1,467	1,897	2,330	1,803	2,354	2,910	112
Adyar_CA	25.00	～	25.22	791	1,013	1,236	1,089	1,409	1,731	1,401	1,830	2,263	1,719	2,268	2,824	108
Adyar3	25.35	～	29.37	342	558	778	448	755	1,071	548	955	1,376	638	1,150	1,687	57
Adyar2	29.41	～	34.17	251	463	682	320	620	933	380	775	1,191	429	923	1,451	46
Adyar1	34.23	～	37.33	305	544	789	392	730	1,080	470	915	1,382	535	1,093	1,686	48
Adhanur	37.44	～	43.61	257	595	948	312	783	1,286	351	961	1,629	372	1,125	1,967	34

Source: JICA Expert Team

Table 2-24: Adyar Carrying Capacity (20% Slope and Vertical Walls in Green Rows)

River Section (HEC-RAS)	Cross Secton			Distance from Sea			Carrying Capacity（Average Section Width + Widening）[m3/s]												Average River Width [m]
							Design Depth=4m			Design Depth=5m			Design Depth=6m			Design Depth=7m			
							0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	
Adyar13	-2088	～	4678	0.00	～	4.54	1,059	1,267	1,476	1,478	1,779	2,081	1,928	2,333	2,740	2,399	2,920	3,443	147
Adyar_CA2	4794	～	5310	4.66	～	5.14	882	1,089	1,298	1,223	1,522	1,823	1,584	1,987	2,392	1,958	2,475	2,996	125
Adyar12	5512	～	7746	5.32	～	7.56	903	1,111	1,319	1,253	1,553	1,854	1,625	2,029	2,434	2,011	2,528	3,050	128
Adyar11	7800	～	8753	7.64	～	8.58	853	1,018	1,272	1,216	1,518	1,821	1,619	2,028	2,437	2,059	2,585	3,113	110
Adyar10	8873	～	9420	8.72	～	9.29	834	1,043	1,252	1,188	1,490	1,793	1,582	1,990	2,400	2,011	2,537	3,065	107
Adyar9	9466	～	11010	9.34	～	10.91	700	842	1,054	896	1,200	1,505	1,188	1,598	2,010	1,504	2,031	2,562	83
Adyar8	11078	～	12180	10.98	～	12.08	626	834	1,043	887	1,188	1,490	1,176	1,582	1,990	1,489	2,011	2,537	82
Adyar7	12270	～	16292	12.17	～	16.24	842	1,049	1,258	1,166	1,465	1,765	1,507	1,910	2,315	1,860	2,375	2,896	121
Adyar6	16380	～	17914	16.34	～	17.19	1,380	1,589	1,798	1,942	2,244	2,547	2,553	2,961	3,370	3,203	3,728	4,255	185
Adyar5	17294	～	22378	17.29	～	22.46	881	1,104	1,327	1,219	1,540	1,862	1,575	2,006	2,440	1,941	2,494	3,051	118
Adyar4	22445	～	24690	22.53	～	24.92	825	1,048	1,271	1,139	1,459	1,780	1,467	1,897	2,330	1,803	2,354	2,910	112
Adyar_CA	24766	～	24990	25.00	～	25.22	791	1,013	1,236	1,089	1,409	1,731	1,401	1,830	2,263	1,719	2,268	2,824	108
Adyar3	8446	～	12505	25.35	～	29.37	342	558	778	448	755	1,071	548	955	1,376	638	1,150	1,687	57
Adyar2	12525	～	17251	29.41	～	34.17	347	568	791	486	803	1,124	636	1,061	1,494	795	1,339	1,896	46
Adyar1	17300	～	20405	34.23	～	37.33	305	544	789	392	730	1,080	470	915	1,382	535	1,093	1,686	48
Adhanur	20520	～	26754	37.44	～	43.61	257	595	948	312	783	1,286	351	961	1,629	372	1,125	1,967	34

Source: JICA Expert Team



Source: JICA Expert Team

Figure 2-48: Adyar Carrying Capacity with Improvement (20% Slope and Vertical Wall)

Table 2-25: Cooum River Carrying Capacity Calculation Table

River Section (HEC-RAS)	Cross Section			Distance from Sea			Carrying Capacity（Average Section Width + Widening）[m3/s]												Average River Width [m]
							Design Depth=4m			Design Depth=5m			Design Depth=6m			Design Depth=7m			
							0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	
Cooum08	60	～	570	0	～	0.483	1,380	1,604	1,828	1,939	2,262	2,586	2,544	2,980	3,418	3,184	3,746	4,311	174.11
Cooum06	720	～	2400	0.664	～	2.342	1,018	1,241	1,464	1,415	1,737	2,060	1,839	2,272	2,707	2,279	2,835	3,395	133.50
Cooum05	2460	～	6300	2.405	～	6.225	449	667	888	599	911	1,229	747	1,162	1,588	887	1,414	1,958	68.94
Cooum04	6390	～	9930	6.315	～	9.872	463	682	903	620	932	1,250	774	1,191	1,617	922	1,450	1,995	70.62
Cooum03	10020	～	15400.75	9.988	～	15.333	450	669	890	602	914	1,231	750	1,166	1,592	892	1,419	1,962	69.14
Cooum02	15421	～	16980	15.393	～	16.964	605	843	1,084	818	1,160	1,507	1,034	1,491	1,956	1,246	1,828	2,423	81.47
Cooum01_b	17402	～	19261	17.024	～	18.897	729	969	1,210	996	1,340	1,688	1,271	1,733	2,200	1,547	2,136	2,736	94.48
	19321	～	25230	18.957	～	24.977	708	948	1,189	966	1,310	1,658	1,231	1,693	2,160	1,497	2,085	2,684	92.33
	25290	～	26608	25.037	～	26.366	1,779	2,350	2,925	2,433	3,255	4,083	3,109	4,210	5,324	3,789	5,196	6,624	96.42
	26668		34593	26.426		34.243	732	996	1,262	996	1,374	1,757	1,265	1,771	2,285	1,532	2,178	2,836	87.75
	34652	～	41140	34.303	～	40.928	1,955	2,223	2,492	2,759	3,147	3,535	3,637	4,160	4,685	4,574	5,248	5,925	202.67
Cooum01	41349.39	～	43607.45	40.958	～	43.539	2,294	2,597	2,899	3,240	3,678	4,116	4,275	4,866	5,459	5,382	6,144	6,907	209.97
	43864.28	～	63040.18	43.785	～	63.667	2,223	2,525	2,828	3,137	3,574	4,012	4,135	4,726	5,318	5,202	5,963	6,726	204.05
	63207.30	～	73030.68	63.829	～	73.678	1,306	1,681	2,058	1,796	2,336	2,879	2,307	3,032	3,763	2,827	3,754	4,693	105.89

Source: JICA Expert Team

Table 2-26: Kosasthalaiyar River Carrying Capacity Calculation Table

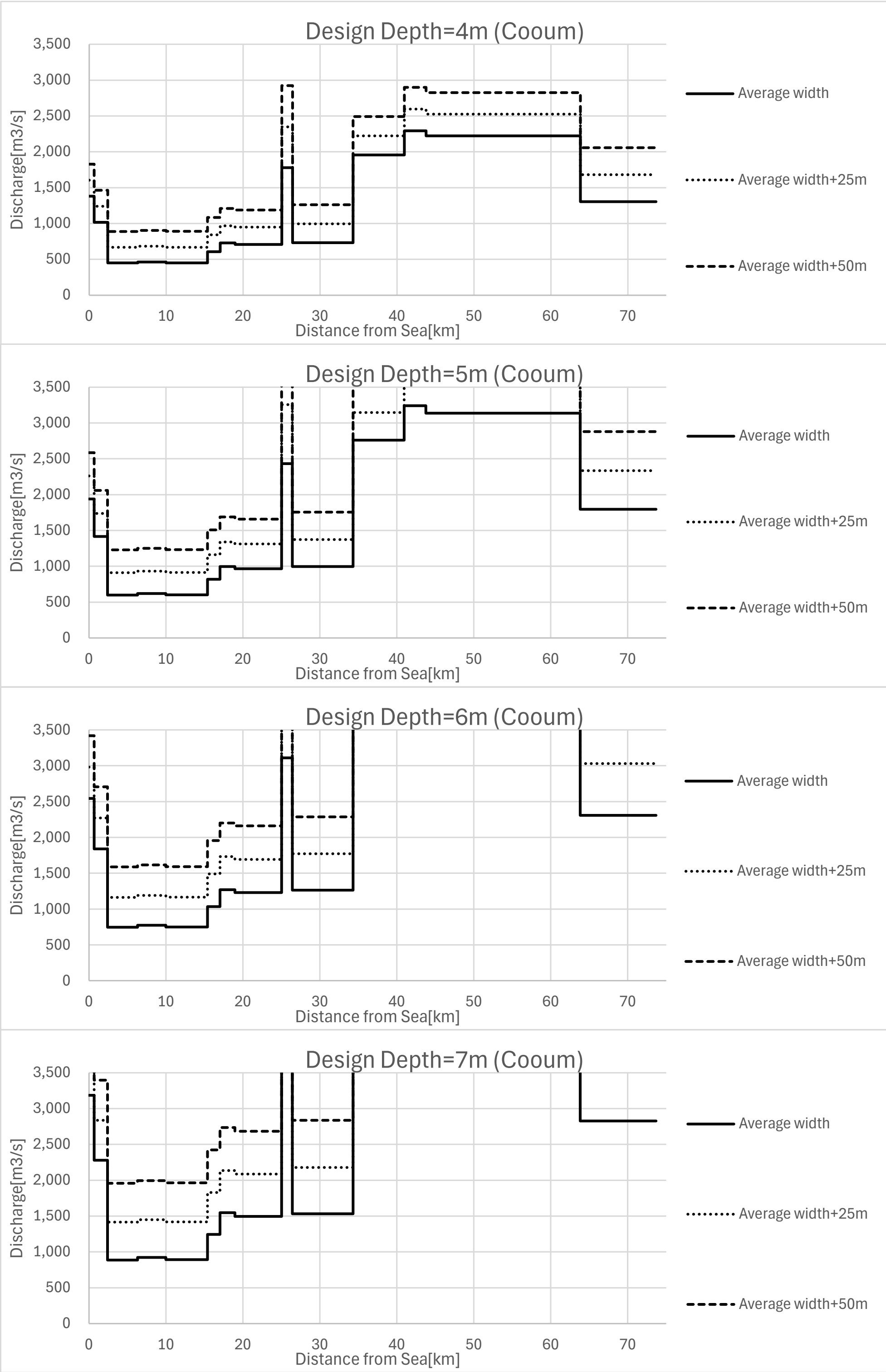
River Section (HEC-RAS)	Cross Section			Distance from Sea			Carrying Capacity（Average Section Width + Widening）[m3/s]												Average Width
							Design Depth=3m			Design Depth=4m			Design Depth=5m			Design Depth=6m			
							0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	
Kosas08	2	~	1727	0.00	~	1.74	2,419	2,525	2,630	3,871	4,041	4,211	5,562	5,809	6,055	7,465	7,800	8,134	589.99
Kosas07+KL	493	~	2198	1.85	~	3.58	2,063	2,169	2,274	3,296	3,466	3,636	4,728	4,975	5,222	6,336	6,671	7,005	505.56
Kosas06	185	~	489	3.63	~	4.18	865	970	1,075	1,362	1,531	1,701	1,926	2,171	2,417	2,545	2,876	3,209	221.13
KL2	274	~	3477	4.24	~	8.05	401	506	610	616	784	952	849	1,090	1,334	1,093	1,418	1,745	110.62
Kosas03	102	~	1442	8.08	~	9.57	423	528	632	651	819	988	899	1,142	1,385	1,161	1,486	1,814	115.88
Kosas02+KL	160	~	4134	9.63	~	13.66	1,153	1,258	1,364	1,827	1,997	2,167	2,599	2,845	3,091	3,455	3,788	4,121	289.62
Kosas01	152	~	18014	13.72	~	31.65	1,100	1,206	1,311	1,742	1,911	2,081	2,476	2,722	2,968	3,287	3,620	3,953	277.07
	18245	~	19517.5	31.87	~	32.86	2,306	2,412	2,517	3,689	3,859	4,029	5,297	5,544	5,791	7,107	7,442	7,776	563.21
	20026	~	21670	33.37	~	35.37	2,963	3,229	3,495	4,696	5,125	5,554	6,684	7,305	7,926	8,887	9,727	10,567	294.74
	22174	~	56344	35.52	~	69.26	1,521	1,668	1,815	2,407	2,644	2,881	3,421	3,764	4,107	4,542	5,006	5,471	274.81

Source: JICA Expert Team

Table 2-27: Redhills River Carrying Capacity Calculation Table

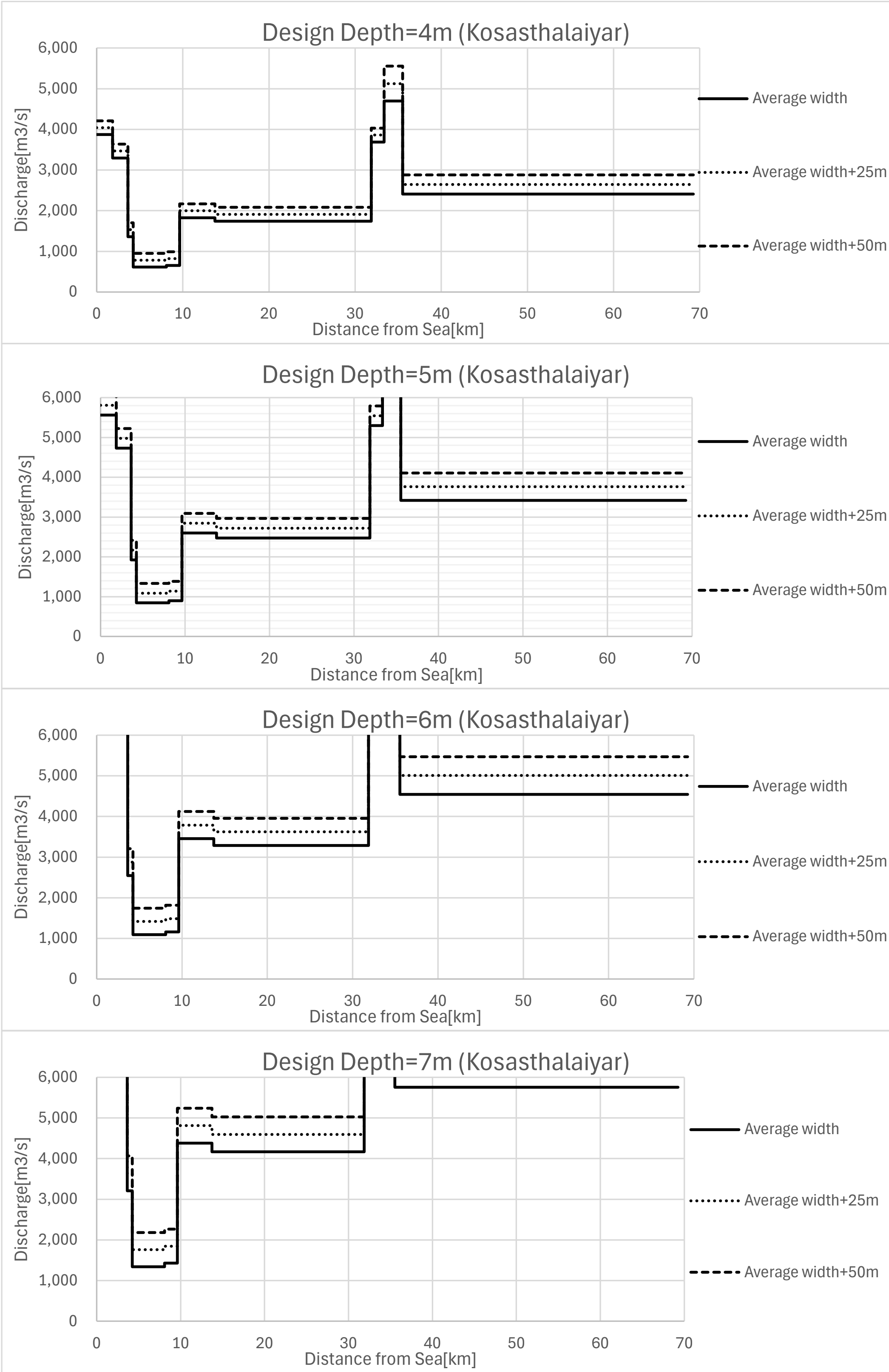
River Section (HEC-RAS)	Cross Section			Distance from Sea			Carrying Capacity（Average Section Width + Widening）[m3/s]												Average Width
							Design Depth=2m			Design Depth=3m			Design Depth=4m			Design Depth=5m			
							0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	0m	+25m widen	+50m widen	
Kosas05	199	~	2510	0.00	~	2.31	165	185	205	316	355	394	497	560	624	702	794	886	216.13
Redhills	151	~	475	2.54	~	2.88	162	182	202	311	350	389	489	552	616	691	782	874	212.95
Redhills	661	~	3669.00*	3.06	~	6.07	18	38	58	30	67	106	40	98	159	48	129	216	32.12
Redhills	3723		9455	6.13		11.81	269	339	410	501	639	778	767	989	1,211	1,054	1,373	1,695	105.23
Redhills	9639		14311	11.98		16.64	205	296	387	371	547	725	550	831	1,116	732	1,133	1,543	66.30
Redhills	14379		14780	16.71		17.10	548	748	948	1,004	1,393	1,784	1,510	2,131	2,758	2,037	2,928	3,830	78.73

Source: JICA Expert Team



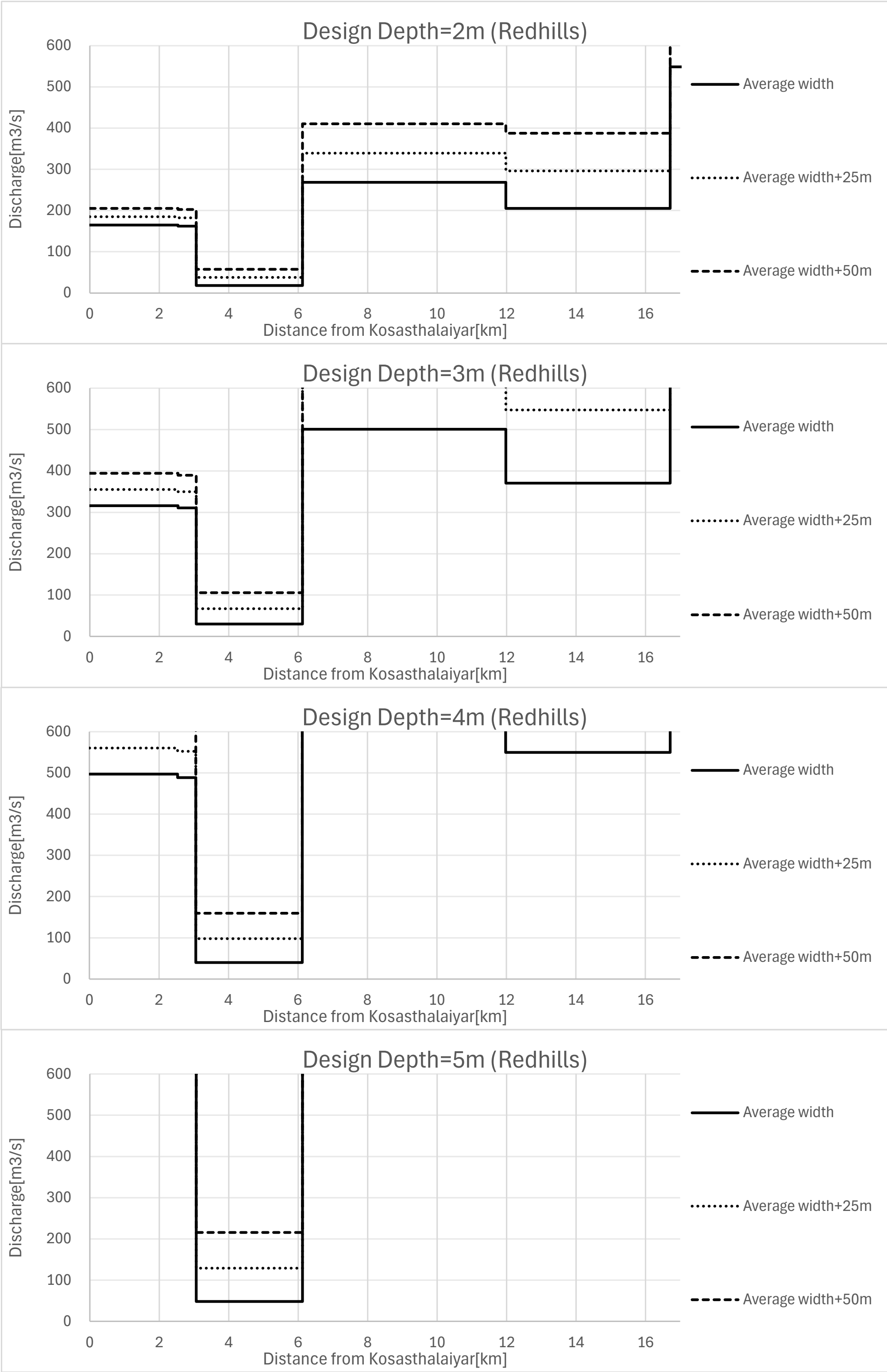
Source: JICA Expert Team

Figure 2-49: Cooum Carrying Capacity with Improvement (20% Slope Cross-Section)



Source: JICA Expert Team

Figure 2-50: Kosasthalaiyar Carrying Capacity with Improvement (20% Slope)



Source: JICA Expert Team

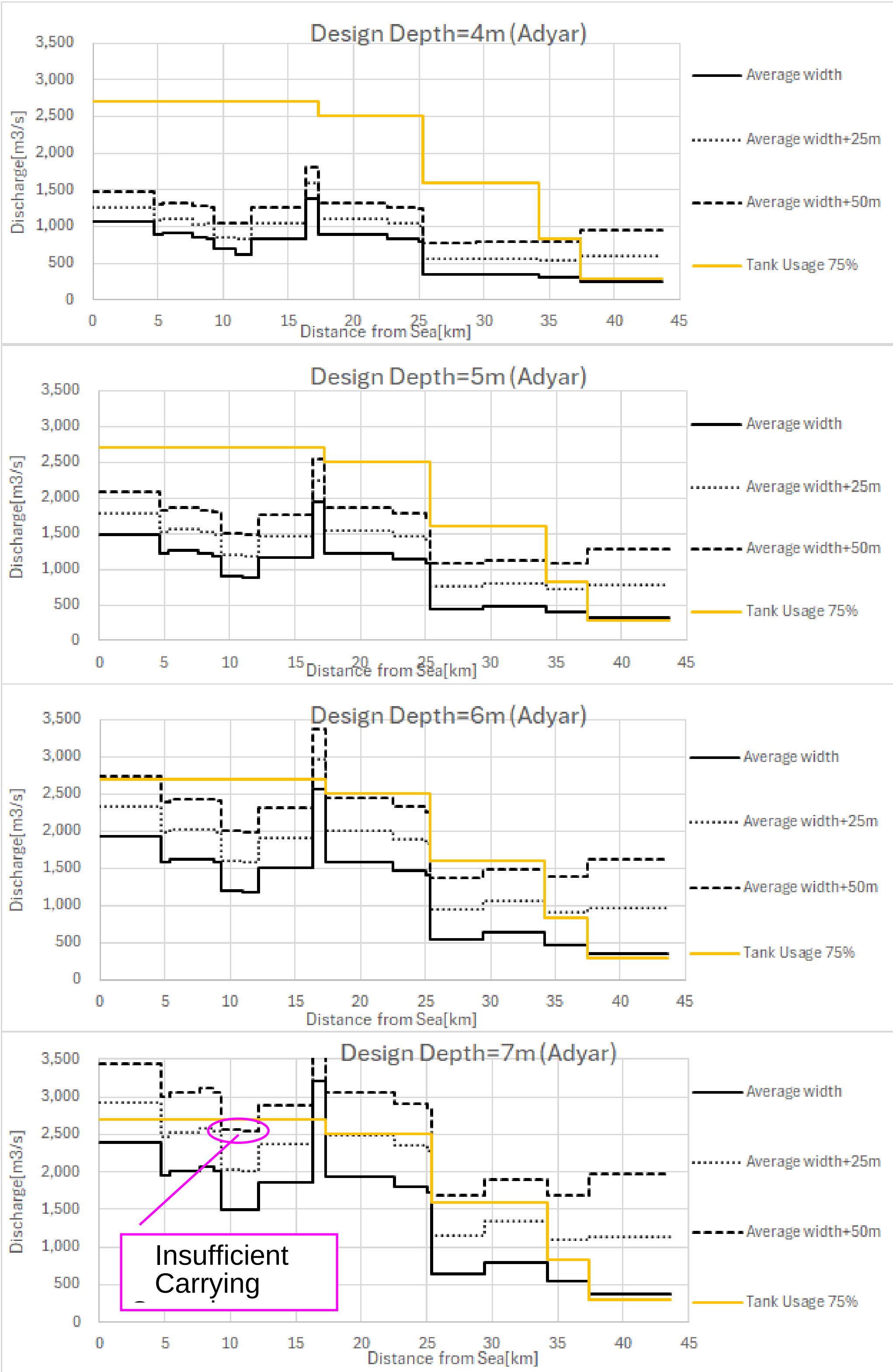
Figure 2-51: Redhills Carrying Capacity with Improvement (20% Slope)

2.3.14 Setting of the future tentative design river channel

The design high water flow (tentative) and approximate carrying capacity for each river, calculated earlier, were compared, and the future river channel plan (tentative) was set. Additionally, the design riverbed elevation (tentative) required to convey the design high water flow (tentative) is shown in Figure 2-55.

2.3.14.1. Adyar River

Figure 2-52 compares the design of high-water flow (tentative) for the Adyar River with the carrying capacity of the post-renovation cross-section. The orange line in the figure represents the design high water flow (tentative). In this diagram, when the carrying capacity indicated by the black line exceeds the orange line, it shows that the design's high-water flow (tentative) can be conveyed below the design's high-water level. The red circles in the figure indicate sections where no widening is applied, and only excavation is used, based on the average river width of the current river channel. The blue circles show sections where widening by 50m and dredging can handle the flow. The pink circles indicate sections where the design high water flow (tentative) cannot be conveyed within the range of the current cross-section setting. As a result, for the Adyar River, a design water depth of 7m and a 50m widening from the current average river width is required for the entire river. The Chennai Airport underpass section does not require widening due to the wide current river width, but excavating to a design water depth of 7m is necessary. Additionally, at the farthest upstream section of Adhanur, dredging to a design water depth of 5m is required. Based on these conditions, the design longitudinal parameters are organized in Table 2-28, and the design riverbed elevation longitudinal profile is shown in Figure 2-55.



Source: JICA Expert Team

Figure 2-52: Comparison of Design High Water Discharge (Tentative) and Carrying Capacity after Improvement of the Adyar River

Table 2-28: Adyar River Design Longitudinal Parameters Table

Section Name (HEC-RAS)	Cross Section No.			Distance From Sea (km)			Design Depth (m)	Avarege River Width (m)	Widening (m)
Adyar13	3290	～	4678	0.00	～	4.54	6.0	146.73	50
Adyar_CA2	4794	～	5310	4.66	～	5.14	7.0	125.37	
Adyar12	5512	～	7746	5.32	～	7.56		127.95	
Adyar11	7800	～	8753	7.64	～	8.58		109.53	
Adyar10	8873	～	9420	8.72	～	9.29		107.23	
Adyar9	9466	～	11010	9.34	～	10.91		91.21	
Adyar8	11078	～	12180	10.98	～	12.08		82.24	
Adyar7	12270	～	16292	12.17	～	16.24		120.60	
Adyar6	16380	～	17194	16.34	～	17.19		185.26	0
Adyar5	17294	～	22378	17.29	～	22.46		118.18	50
Adyar4	22445	～	24690	22.53	～	24.92		111.87	
Adyar_CA	24766	～	24990	25.00	～	25.22		59.46	
Adyar3	8446	～	12505	25.35	～	29.37		56.54	
Adyar2	12525	～	17251	29.41	～	34.17		45.65	
Adyar1	17300	～	20405	34.23	～	37.33	5.0	48.30	
Adhanur	20520	～	26754	37.44	～	43.61		34.12	0

Source: JICA Expert Team

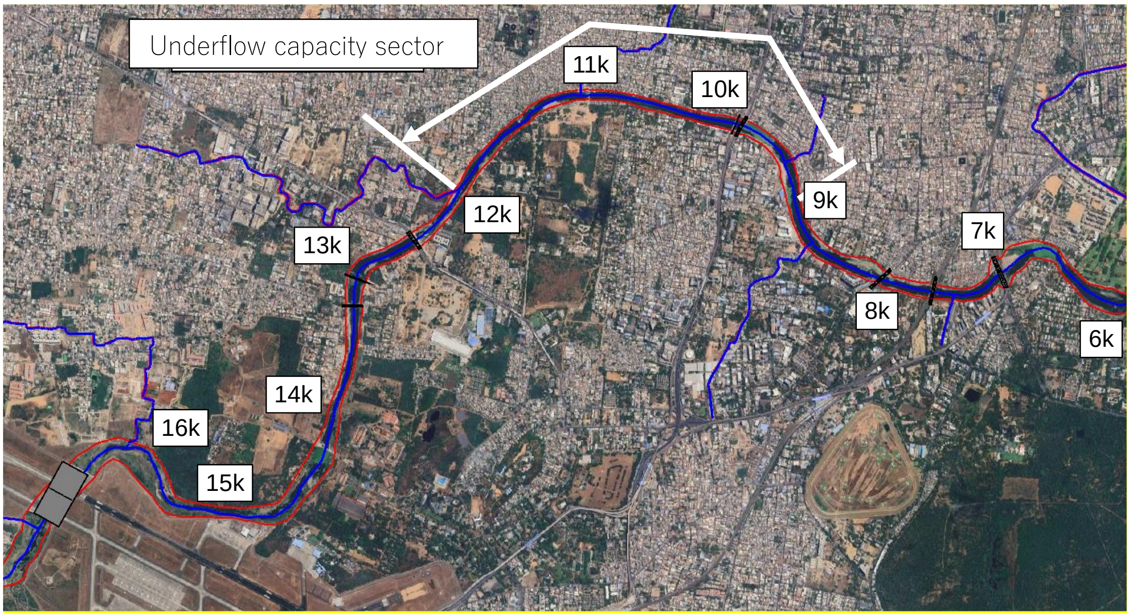
Table 2-29: Adyar River Estimated Number of Properties Impaired by Channel Widening

Distance from Sea [km]			Phase2					
			widening [m]	deepening [m]	Land acquisition area[ha]	Estimated number of objects		Bridge
						Houses	Commercial building	
0.00	～	4.54	50	1.1	22.7	5000～6000	3000～4000	3
4.66	～	5.14	50	1.7	3.0			0
5.32	～	7.56	50	2.8	12.1			1
7.64	～	8.58	50	4.4	5.1			2
8.72	～	9.29	50	4.3	3.6			0
9.34	～	10.91	50	4.1	8.1			2
10.98	～	12.08	50	4.0	5.9			0
12.17	～	16.24	50	4.8	20.8			2
16.34	～	17.19	0	4.7	0.0	800～1000	600～800	1
17.29	～	22.46	50	5.3	26.3			4
22.53	～	24.92	50	6.1	12.3			0
25.00	～	25.22	50	6.6	1.5	500～600	300～400	1
25.35	～	29.37	50	6.1	20.7	400～500	200～300	1
29.41	～	34.17	50	5.4	24.0	200～300	100～150	5
34.23	～	37.33	50	3.3	15.8	120～160	40～80	3
37.44	～	43.61	0	3.6	0.0	0	0	2
Total					182			27

Source: JICA Expert Team

However, in the 9.34k-12.08k section downstream of Chennai Airport, even with a planned water depth of 7m and a widening of 50m, the flow capacity below the HWL could not secure the Design

High Water Discharge (tentative) of 2700m3/s. Although this section is designed to ensure maximum flow capacity as a straight wall section (**Table 2-30**), the flow capacity is still insufficient.



Source: JICA Expert Team

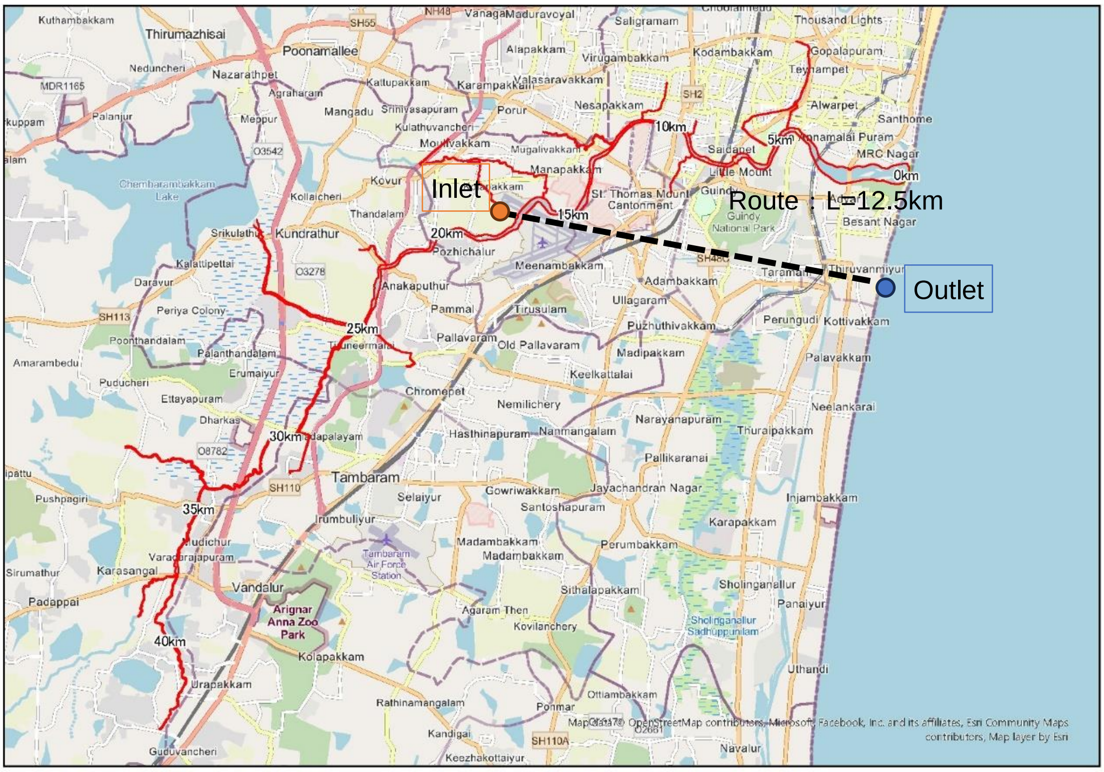
Figure 2-53: Adyar River Neck Section Location Map

Table 2-30 compares the two options for addressing this shortfall: further widening and an underground bypass tunnel. The table shows that the cost would be higher for the underground bypass tunnel, but considering the social and economic impacts of this, including on the airport, the underground bypass tunnel was judged to be more appropriate.

Table 2-30: Comparison of Countermeasures for Insufficient Flow Capacity in the 9.34k to 12.08k Section

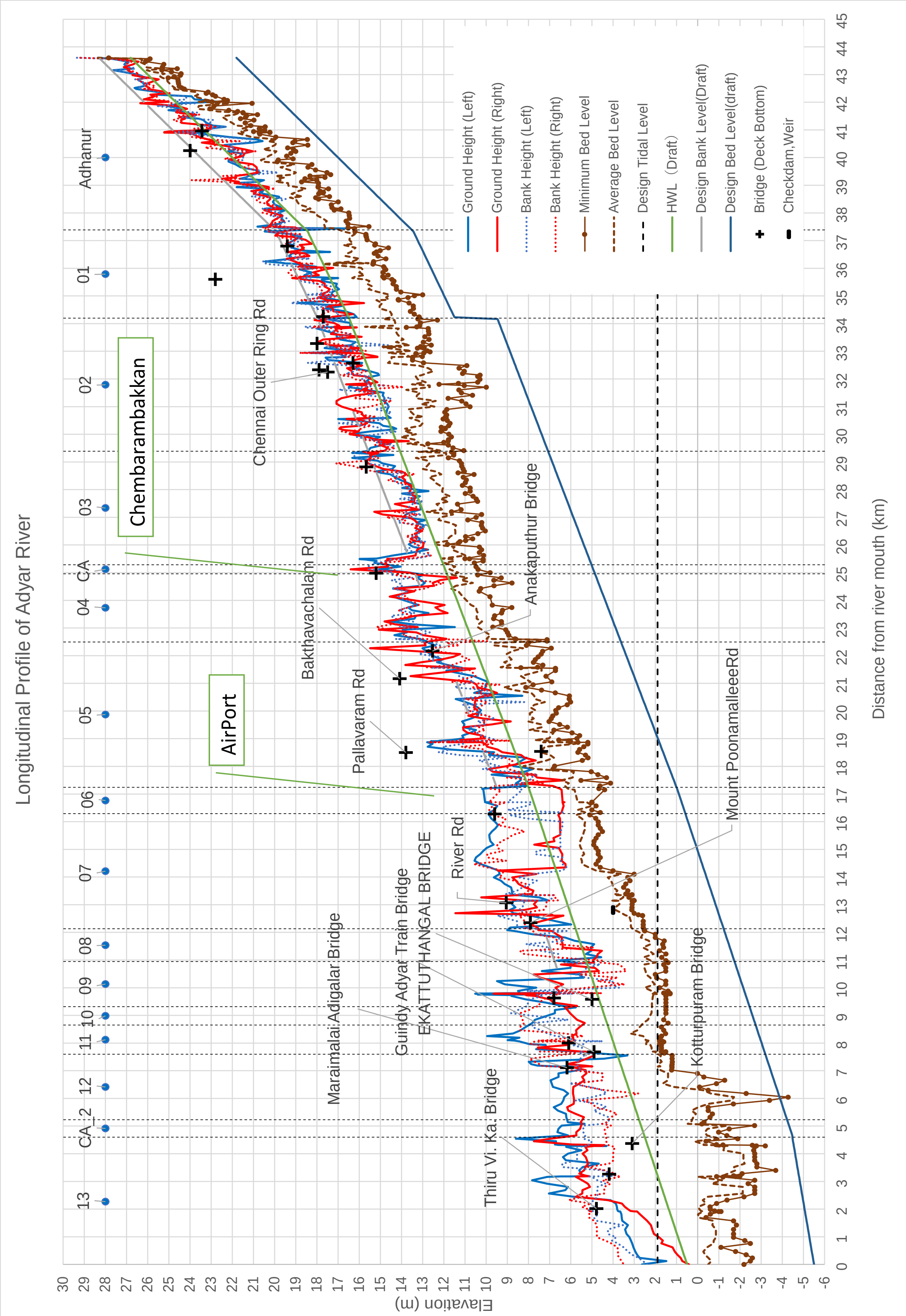
	Further expansion	Underground bypass tunnel
Overview of the measures	・Section: 9.34k to 12.08k (2.74km) ・Widening width 10m: total 60m	m3 /s will be diverted 18.3 km upstream from the airport (**Figure 2-55**)
Certainty of measures	・Can be reliably drained [Rating: ○]	・Can be reliably drained [Rating: ○]
Social impact	・Further widening occurs at 2.74 km. (greater negotiation of house relocation, etc.) ・Difficult to widen on military land downstream of airport [Rating: △]	・The widening area can be reduced by a uniform 10 m because the 200 m3/s flood flow can be reduced downstream of the diversion point. (possible to reduce building relocations of 1,000 residential and 500 commercial buildings). ・Reduced widening of military land downstream of the airport. [Rating: ○]
Effect of developments on airport closures due to flooding	・Since construction will be carried out sequentially from the downstream side, the effects will be seen slowly. [Rating: △]	・The development is relatively unaffected by land negotiations, etc., so the effects are seen early. [Rating: ○]
Cost Crore INR (million USD)	・Construction 5 (3.6) ・Preparation 450 (54) ・Total 460 (58) [Rating: ○]	Underground bypass tunnel ・Construction 8,000 (960) ・Preparation 200 (24) ・Total 8,200 (990) Effect of 10 m widening reduction ・Construction -30 -3.6) ・Preparation -4,400 (-530) ・Total -4,500 (-540) Costs taking into account the effect of the widening reduction ・Construction 7,900 (950) ・Preparation -4,200 -500) ・Total 3,700 (450) [Rating: △]
comprehensive evaluation	Although the cost is cheaper than the right proposal, it was ranked as the next best option due to the risk of a prolonged project with further house relocation. [Rating: ○]	Although the costs are high, this proposal is adopted because it has a low social impact and allows the project to move forward quickly. [Rating: ◎]

Source: JICA Expert Team



Source: JICA Expert Team

Figure 2-54: Adyar River Diversion Channel Route (Tentative)



Source: JICA Expert Team

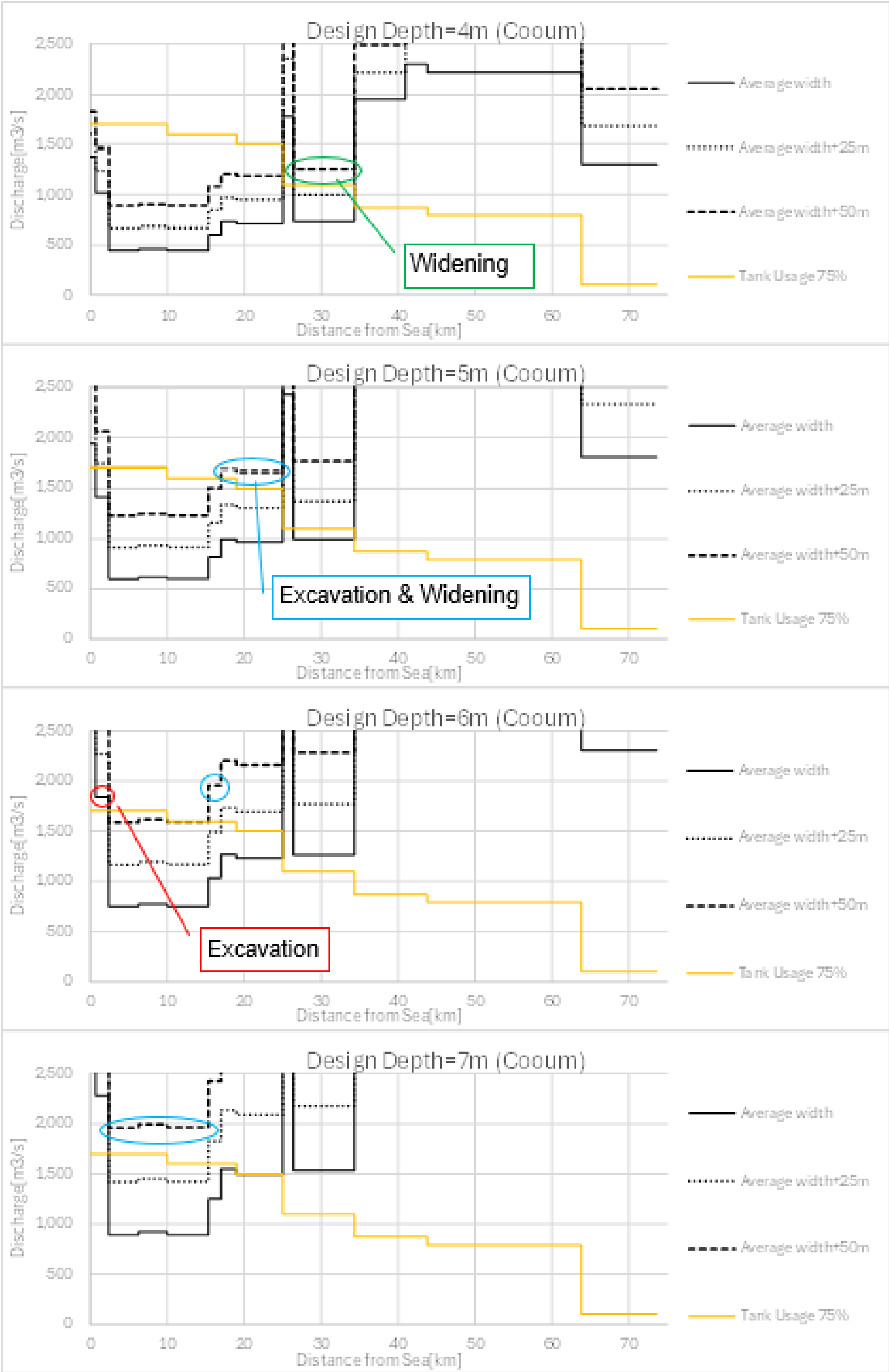
Figure 2-55: Adyar River Design Riverbed Elevation Longitudinal Profile (Tentative)

2.3.14.2. Cooum River

The design high water flow (tentative) for the Cooum River and the post-renovation cross-section carrying capacity were compared in Figure 2-56. As a result, it was confirmed that no river improvements are necessary for the upstream sections from the 34.3k point, as they have sufficient carrying capacity.

Downstream of the 34.3k point, the section from the river mouth to 24.98k requires channel widening and riverbed dredging. In this section, downstream of the Loop section (2.34k), only riverbed dredging is necessary, while upstream of the Loop section, a uniform 50m widening is required. Additionally, for the section between 26.43k and 34.24k, two methods are being considered: one involves riverbed excavation while maintaining the current river width, and the other involves widening the channel to match the current riverbed elevation. This section is located immediately upstream of the steep slope change section (25.04k–26.37k), and there are concerns that changes in sediment transport characteristics due to riverbed dredging may affect the future stability of the river channel. Since there is a significant amount of agricultural land along the riverbanks, the direction is to ensure carrying capacity through channel widening.

Based on these conditions, the design longitudinal parameters are organized in Table 2-31, and the design riverbed elevation longitudinal profile is shown in Figure 2-58.



Source: JICA Expert Team

Figure 2-56: Comparison of Design High Water Discharge (Tentative) and Carrying Capacity after Improvement of the Cooum River

Table 2-31: Cooum River Design Longitudinal Parameters Table

Section Name (HEC-RAS)	Cross Section No.			Distance From Sea (km)			Design Depth (m)	Avarege River Width (m)	Widening (m)
Cooum 08	60	～	570	0.00	～	0.48	4.0	174.11	0
Cooum 06	720	～	2400	0.66	～	2.34	6.0	89.42	
Cooum 05	2460	～	6300	2.41	～	6.23	7.0	68.94	50
Cooum 04	6390	～	9930	6.32	～	9.87		70.62	
Cooum 03	10020	～	15401	9.99	～	15.33		69.14	
Cooum 02	15421	～	16980	15.39	～	16.96	6.0	81.47	
Cooum 01_b	17402	～	19261	17.02	～	18.90	5.0	94.48	
	19321	～	25230	18.96	～	24.98		92.33	
	25290	～	26608	25.04	～	26.37	4.0	96.42	0
	26668		34593	26.43	～	34.24		87.75	50
	34652	～	41140	34.30	～	40.93	－	202.67	－
Cooum 01	41349	～	43607	40.96	～	43.54		209.97	
	43864	～	63040	43.79	～	63.67		204.05	
	63207	～	73031	63.83	～	73.68		105.89	

Source: JICA Expert Team

Table 2-32: Cooum River Estimated Number of Properties Impaired by Channel Widening

Distance from Sea [km]			Phase2					
			拡幅幅 [m]	掘削深 [m]	用地取得 面積[ha]	概算影響物件数		橋梁
						住戸棟	商業棟	
0.00	～	0.48	0	2.0	0.0	1200～1500	500～800	1
0.66	～	2.34	50	2.6	9.3			2
2.41	～	6.23	50	3.0	19.4			4
6.32	～	9.87	50	4.2	18.2			4
9.99	～	15.33	50	4.9	27.3	3500～4500	1500～2000	6
15.39	～	16.96	50	4.7	8.2			2
17.02	～	18.90	50	3.8	9.7			0
18.96	～	24.98	50	4.2	30.4	700～850	300～400	4
25.04	～	26.37	0	0.0	0.0	0	0	0
26.43		34.24	50	0.0	39.4	0	0	3
34.30	～	40.93	0	0.0	0.0	0	0	0
40.96	～	43.54	0	0.0	0.0	0	0	0
43.79	～	63.67	0	0.0	0.0	0	0	0
63.83	～	73.68	0	0.0	0.0	0	0	0
Total			400	29	162	5200～6900	2300～3200	26

Source: JICA Expert Team

The application of an underground bypass tunnel in the Cooum River has been judged to be unfeasible as follows.

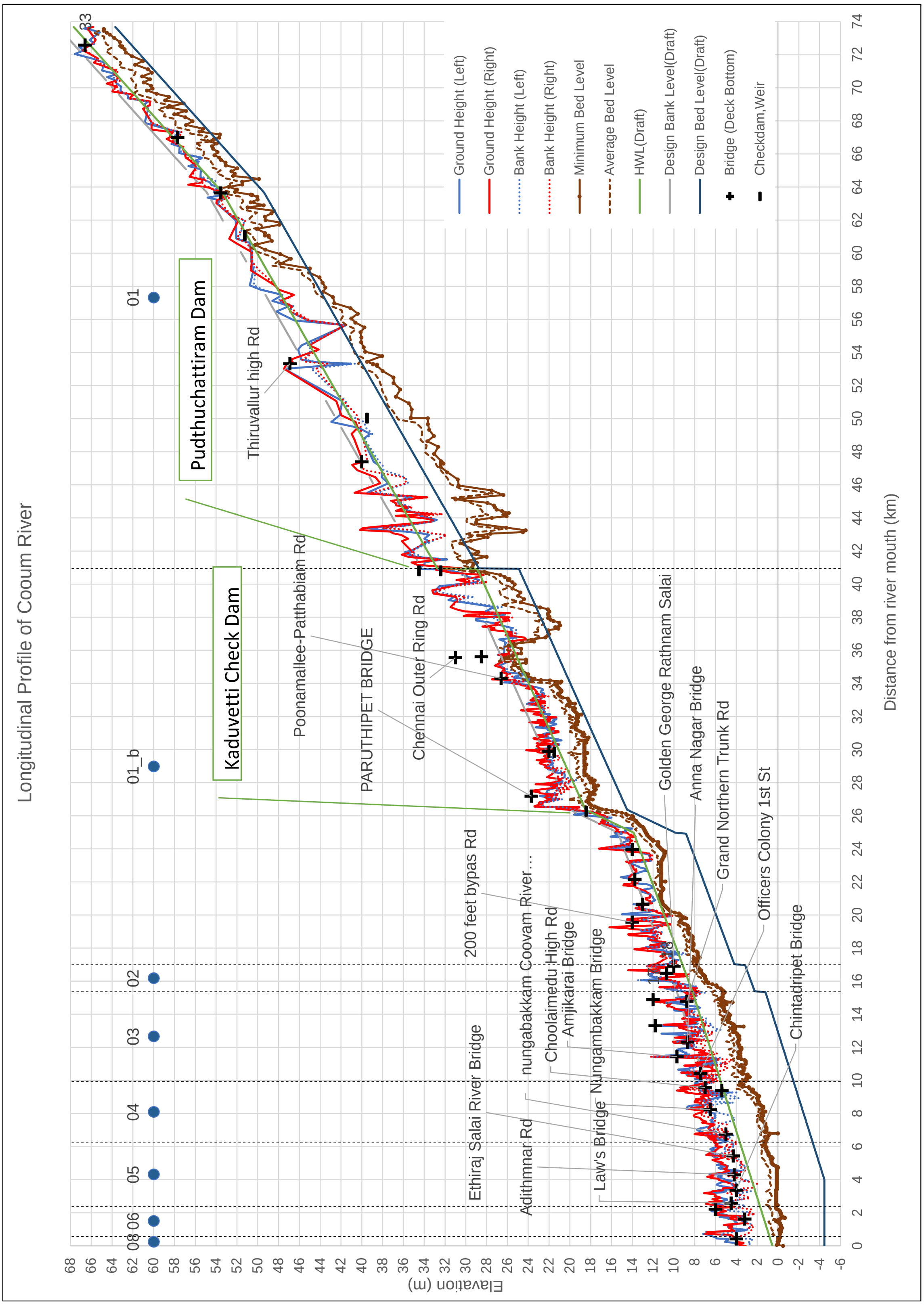
The route of diverting water from the upstream of the 25k point and discharging it into the Bay of Bengal is a possible route in terms of the river channel alignment, but it is long at 20.5km in a straight line and expensive (Figure 2-57).

The Chennai Port is located near the coast, making it difficult to construct discharge facilities.

The river channel can be widened and excavated to ensure sufficient discharge capacity.

Source: JICA Expert Team

Figure 2-57: Cooum River Diversion Channel Route (Tentative)



Source: JICA Expert Team

Figure 2-58: Cooum River Design Riverbed Elevation Longitudinal Profile (Tentative)

2.3.14.3. Kosasthalaiyar River

Figure 2-59 compares the tentative design of high water flow and the post-renovation carrying capacity for the Kosasthalaiyar River. It has been confirmed that no river improvements are necessary for the upstream sections beyond the 31.87-kilometer point, as these sections already possess sufficient carrying capacity. However, downstream of the 31.87-kilometer point, specific measures are required to address the flow requirements. In the section upstream of the most upstream Loop (9.63 km to 31.65 km), the tentative design high water flow can be accommodated by dredging the riverbed to a design depth of 5 meters.

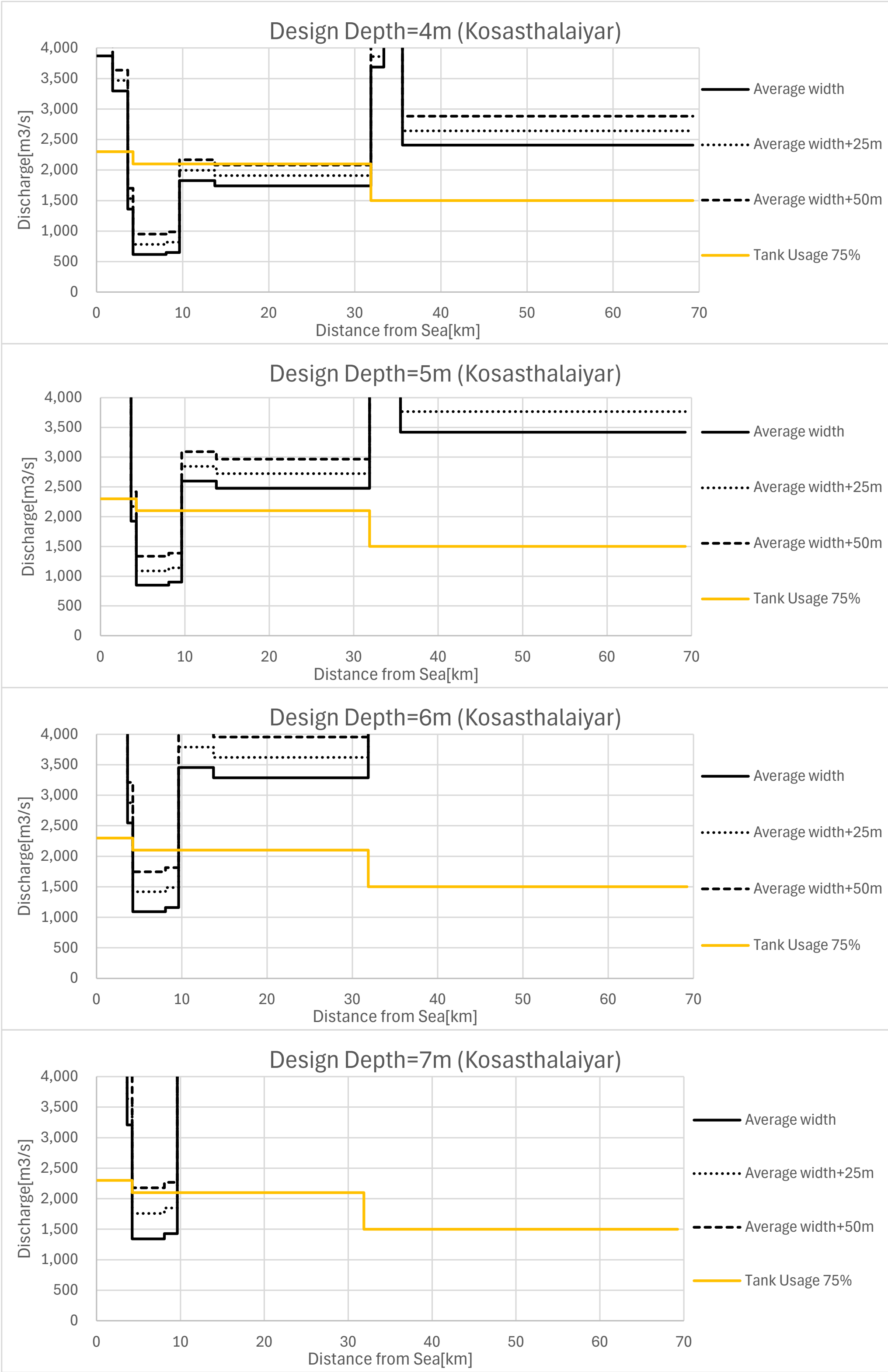
From the river mouth to the upstream end of the lowest Loop section (0 km to 3.58 km), only riverbed excavation is needed. In contrast, the segment from 1.18 km to 9.57 km requires a combination of riverbed excavation and river widening. For the lowest and two-loop sections (3.63 km to 4.18 km), the presence of the Buckingham Canal embankment on the right bank necessitates a 50-meter widening on the left bank, along with riverbed excavation to a design depth of 5 meters.

In the second and upstreammost Loop sections (8.08 km to 9.57 km), the ground elevation is higher than the surrounding areas, and the area is densely populated with houses and factories. As a result, widening is limited to 50 meters, and the riverbed must be dredged to a design depth of 7 meters to ensure adequate flow capacity.

Regarding the second Loop section (4.24 km to 8.05 km), modifications are planned as illustrated in Figure 2-60. This section splits into two channels, spreading over lowlands on the mountain side of the Buckingham Canal levee, which is believed to contribute to flooding in the downstream areas of the Kosasthalaiyar River, including the Redhills River. To address this, the shorter left branch will be designated as the Kosasthalaiyar River, while the right branch will be closed off at the upstream bifurcation point by an embankment to prevent flood flows from entering the Kosasthalaiyar River.

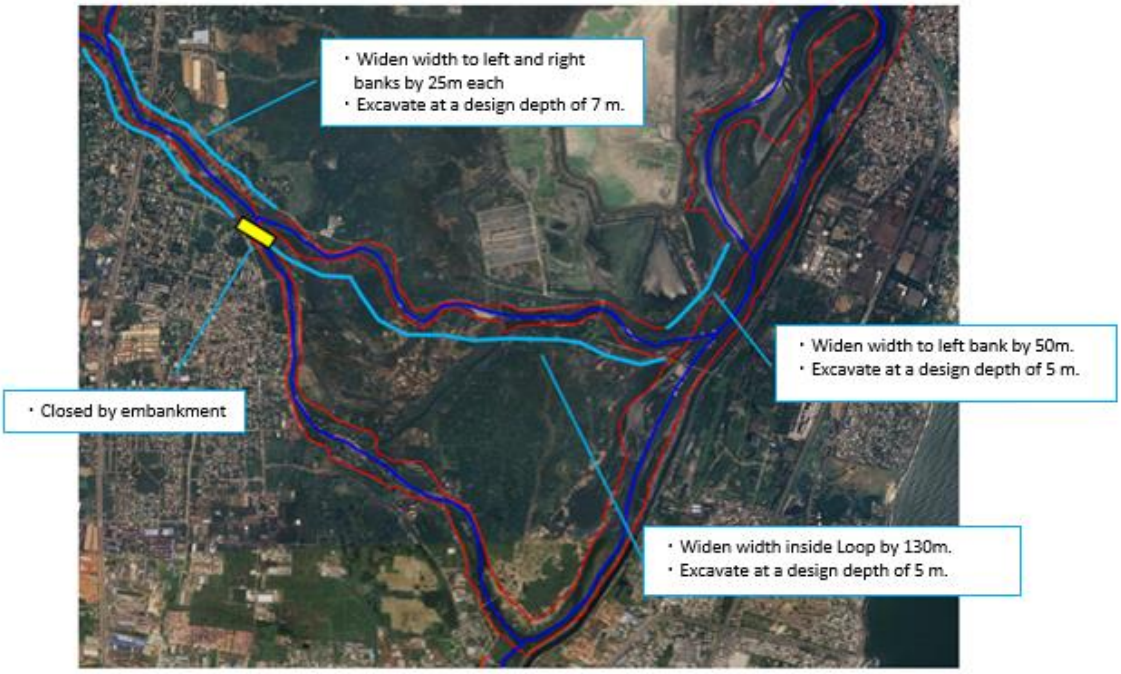
The left bank channel can accommodate the tentative design high water flow by widening it by 50 meters based on the current average riverbank width and ensuring a design water depth of 7 meters. However, achieving a riverbed elevation deeper than DL-4 meters is impractical from a river channel maintenance perspective. Since the area within the Loop is unused land, the design water depth will be set to 5 meters, consistent with the downstream section. An embankment will be constructed 130 meters from the current riverbank on the right bank side of the Loop to secure the required cross-section. The closed right bank channel will be repurposed as a drainage outlet for internal water and as a retention basin, enhancing flood management in the area.

Based on these conditions, the design longitudinal parameters are organized in Table 2-33, and the design riverbed elevation longitudinal profile is shown in Figure 2-62.



Source: JICA Expert Team

Figure 2-59: Comparison of Design High Water Discharge (Tentative) and Carrying Capacity after Improvement of the Kosasthalaiyar River



Source: JICA Expert Team

Figure 2-60: Kosasthalaiyar River Loop 2 Section Surrounding Improvement Plan

Table 2-33: Kosasthalaiyar River Design Longitudinal Parameters

Section Name (HEC-RAS)	Cross Section No.			Distance From Sea (km)			Design Depth (m)	Avarege River Width (m)	Widening (m)
Kosas08	2	~	1727	0.00	~	1.74	3.0	589.99	0
Kosas07+KL3	493	~	2198	1.85	~	3.58	4.0	505.56	0
Kosas06	185	~	489	3.63	~	4.18	5.0	221.13	50
KL2	274	~	3477	4.24	~	8.05	7.0	110.62	130
Kosas03	102	~	1442	8.08	~	9.57		115.88	50
Kosas02+KL1	160	~	4134	9.63	~	13.66	5.0	289.62	0
Kosas01	152	~	18014	13.72	~	31.65	–	277.07	–
	18245	~	19009	31.87	~	32.48		563.21	
	19518	~	21670	32.86	~	35.37		294.74	
	22174	~	56344	35.52	~	69.26		274.81	

Source: JICA Expert Team

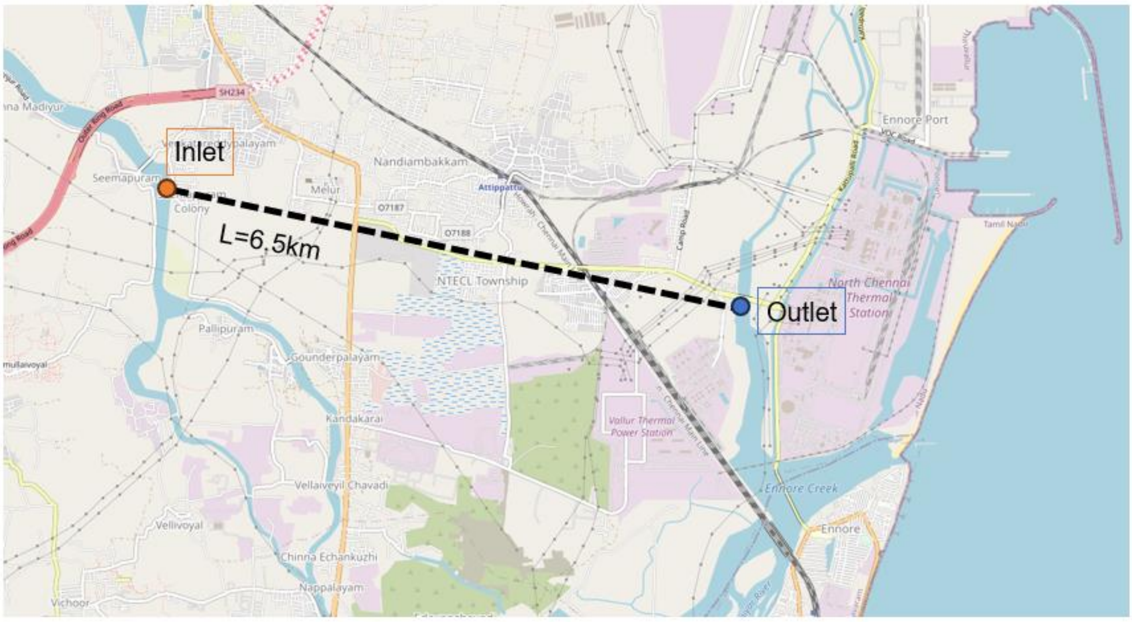
Table 2-34: Kosasthalaiyar River Estimated Number of Properties Impaired by Channel Widening

Distance from Sea [km]			Phase2					
			widening [m]	deepening [m]	Land acquisition area[ha]	Estimated number of objects		Bridge
						Houses	Commercial building	
0.00	～	1.74	0	0.0	0.0			0
1.85	～	3.58	0	2.6	0.0	200～250	30～50	0
3.63	～	4.18	50	3.0	19.4			0
4.24	～	8.05	130	4.2	47.4			0
8.08	～	9.57	50	4.9	27.3	300～400	200～300	0
9.63	～	13.66	0	4.7	0.0			0
13.72	～	31.65	0	0.0	0.0	0	0	0
31.87	～	32.48	0	0.0	0.0	0	0	0
32.86	～	35.57	0	0.0	0.0	0	0	0
35.52	～	69.26	0	0.0	0.0	0	0	0
Total					94			0

Source: JICA Expert Team

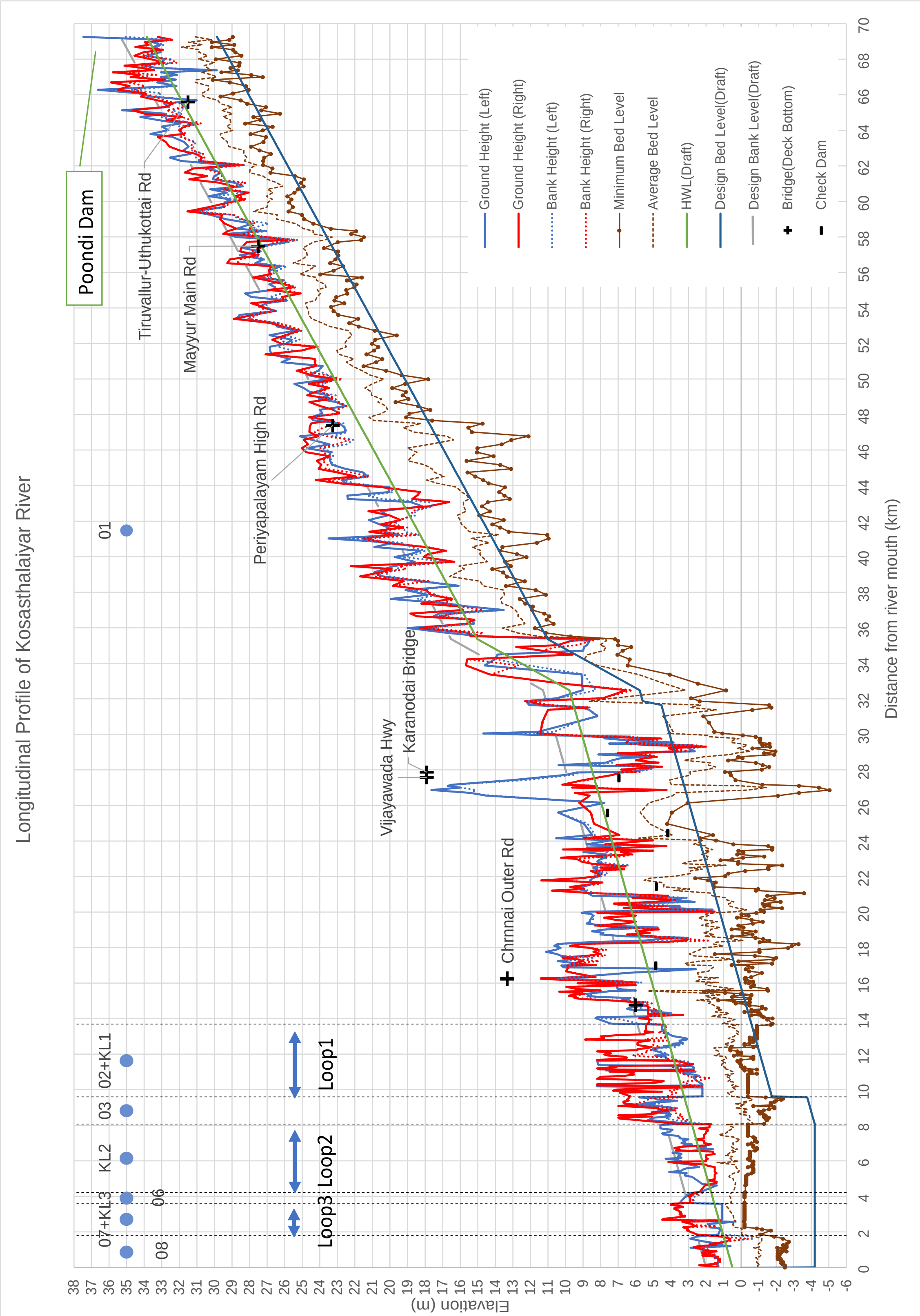
Furthermore, the application of an underground bypass tunnel on the Kosasthalaiyar River was deemed less feasible because the number of houses and other structures relocated is an order of magnitude different than on the Adyar and Cooum Rivers.

Figure 2-61 shows the route that would be taken if installed as a reference.



Source: JICA Expert Team

Figure 2-61: Kosasthalaiyar River Diversion Channel Route (Tentative)



Source: JICA Expert Team

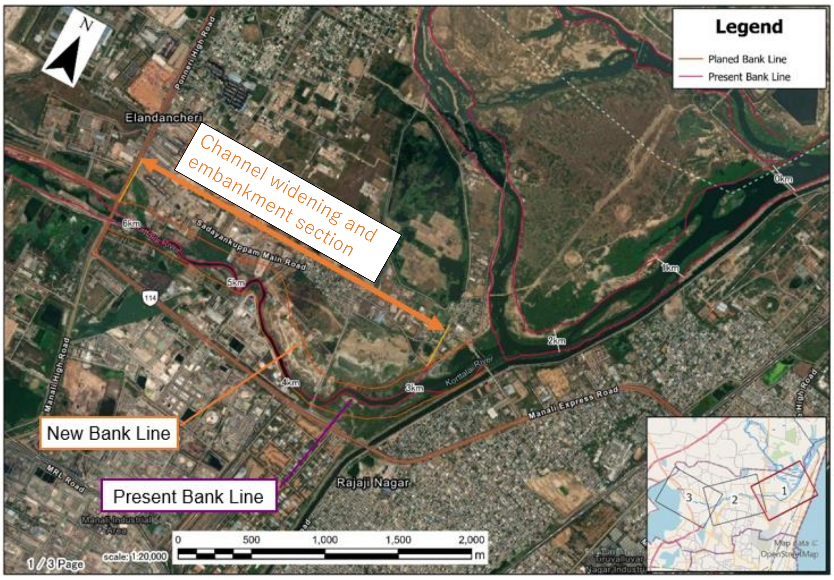
Figure 2-62: Kosasthalaiyar River Design Riverbed Elevation Longitudinal Profile (Tentative)

2.3.14.4. Redhills River

The design high water flow (tentative) and post-improvement carrying capacity of the Redhills River are compared in Figure 2-64. As shown in the figure, the upstream section above 6.07k has a water depth of 2 meters or more below the design high water level, allowing the design high water flow to be carried under the current river conditions. Additionally, the section from the Kosasthalaiyar River confluence to 3.06k can also be managed without widening, with a design water depth of 3 meters.

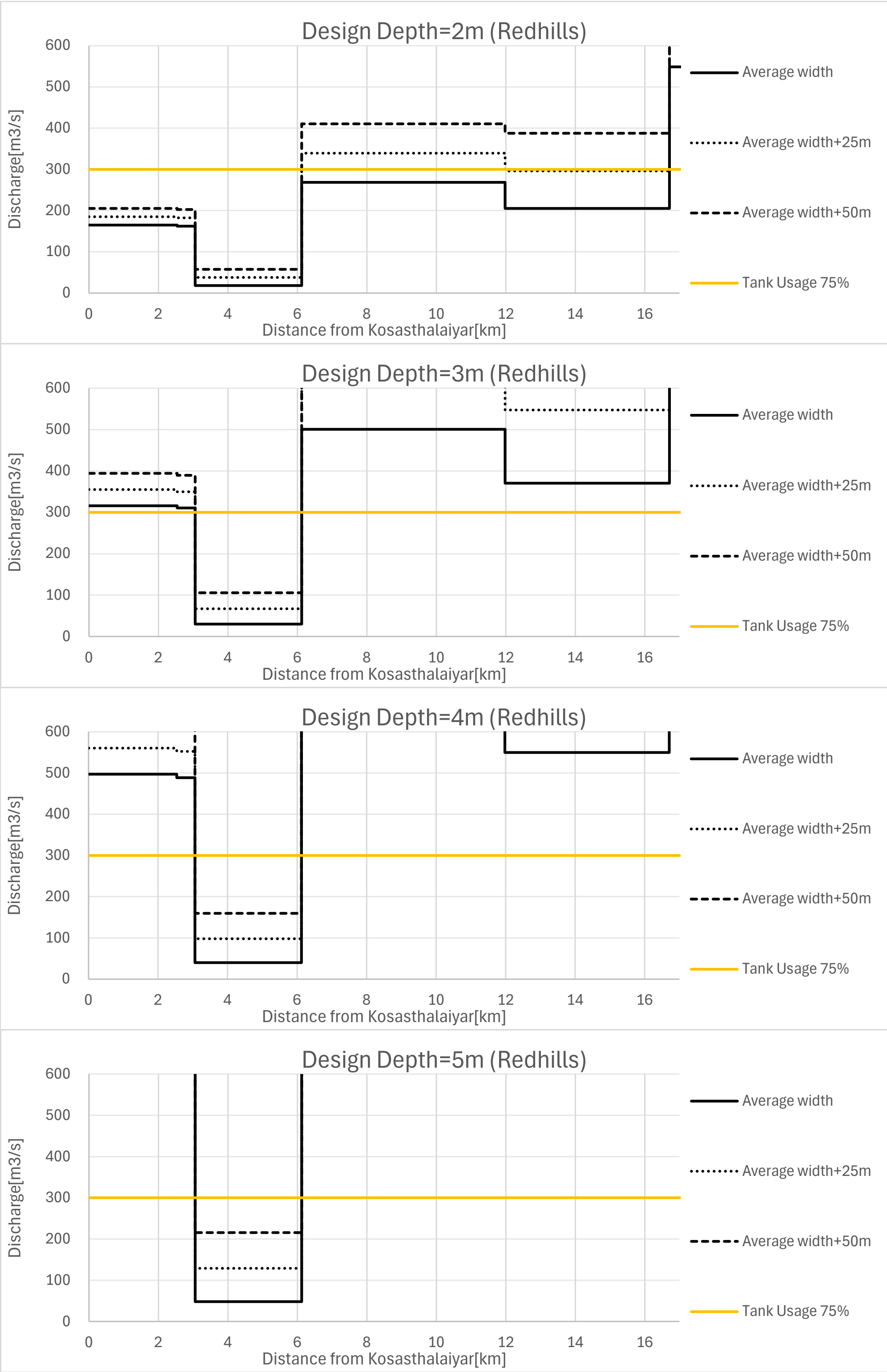
For the section between 3.06k and 6.07k, as shown in Figure 2-63, the current average river width is approximately 32 meters, which is significantly narrower compared to the upstream and downstream sections. Therefore, widening and riverbed excavation within a 50-meter range from the current riverbank location cannot secure a river cross-section capable of carrying the design high water flow. Consequently, for this section, a new riverbank line is set at a position 210 meters from the left bank in the area of the unused land on the left bank, based on the current right bank location of the section connecting to the downstream Kosasthalaiyar River, which has a current river width of 210 meters. Riverbed excavation and embankment construction between these lines will prevent external water flooding from the Redhills River.

Furthermore, the embankment construction in this section may hinder internal drainage around the embankment area. As a countermeasure, on the left bank of the Redhills River, drainage from the old Kosasthalaiyar River channel, and on the right bank of the Redhills River, drainage through the North Buckingham Canal, will be required. Therefore, it will be necessary to develop drainage networks and install backflow prevention pipes at connection points.



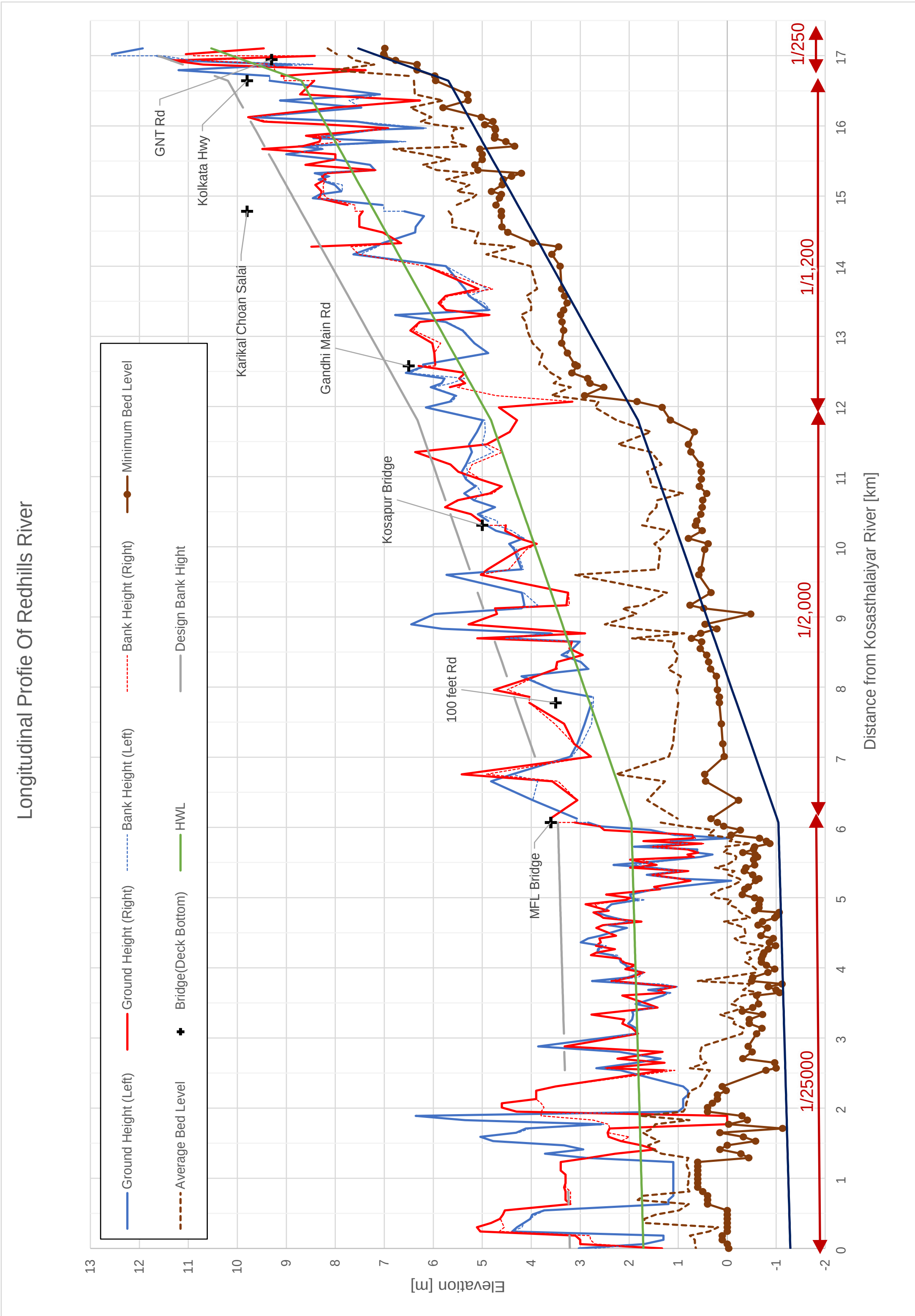
Source: JICA Expert Team

Figure 2-63: Redhills River Embankment Section Location Map



Source: JICA Expert Team

Figure 2-64: Redhills River Comparison of Design High Water Flow (Tentative) and Post-Improvement Carrying Capacity



Source: JICA Expert Team

Figure 2-65: Redhills River Design Riverbed Elevation Longitudinal Profile (Tentative)

2.3.15 Review of river channel planning

2.3.15.1. Review of the design flood water level

In Section 2.3.13, the evaluation of the required river channel shape was conducted based on the approximate discharge capacity calculated using the uniform flow method for average river widths in continuous sections such as between major tributary confluences. However, actual rivers are affected by changes in the cross-sectional shapes along the river, and particularly in the estuary area, the design water depth required by the uniform flow calculation becomes too large compared to the current riverbed elevation, which raises concerns about the possibility of maintaining the riverbed height due to sediment accumulation after riverbed excavation. This raised concerns about the sustainability of the riverbed elevation due to sediment deposition after excavation. Therefore, in this section, the river water level and sediment movement are evaluated using a non-uniform flow model for the estuary areas of the three target rivers. The evaluation assumes that the deepest riverbed elevation is at the current maintenance dredging depth of DL-2m for Adyar River, and the HWL and design riverbed elevation is refined accordingly.

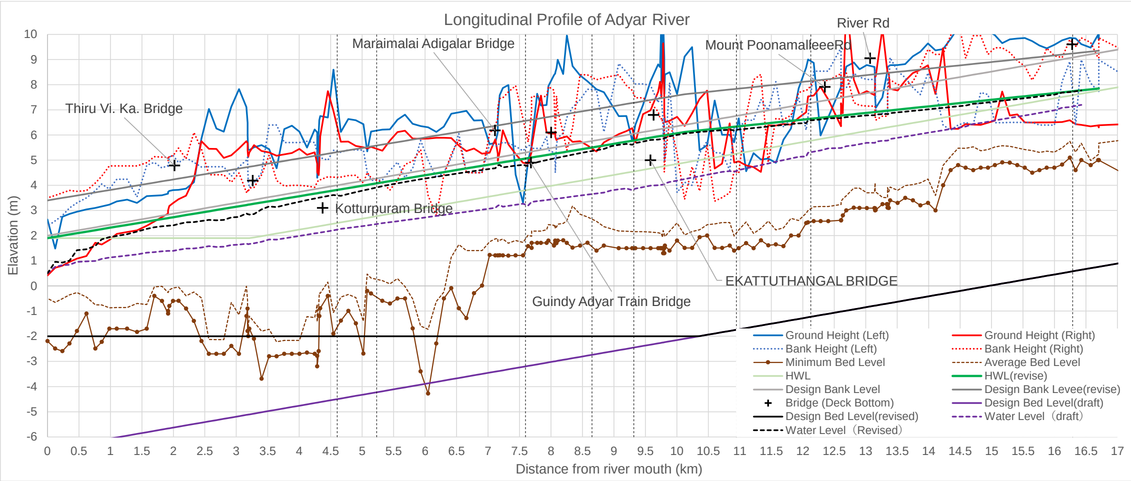
As a result, the design riverbed elevation near the estuary is limited to DL-2.0m. If the 100-year return period water level exceeds the design flood water level (tentative), the design water level (tentative) will be adjusted by increasing it in line with the existing ground elevation, and a revised design water level (proposal) will be set. The section where the design flood water level (tentative) is to be adjusted will, in principle, be limited to the incised areas.

(1) Adyar River

The current riverbed elevation of the Adyar River is approximately DL-2m from the river mouth up to around 4.5 km, and it rises to DL+0m near 7 km from the mouth. Upstream from that point, the riverbed elevation is approximately DL+2m, remaining relatively constant. The longitudinal slope of the design riverbed elevation (tentative) shown is similar to the current riverbed elevation, so the sediment transport characteristics remain unchanged throughout the river. However, in the estuary area, where it becomes a tidal influence area, there is a possibility that sediment transport characteristics could change. Therefore, for the section where the riverbed elevation in the downstream area is limited to the current deepest riverbed level of DL-2m, the water level at the 100-year return period discharge and changes in the friction velocity affecting sediment transport were evaluated using a non-uniform flow model, and the conditions for the estuary area were refined.

The results of the non-uniform flow calculation are shown in Figure 2-66. The green line represents the design riverbed elevation (tentative) and the corresponding water level during the 100-year return period flood. The blue line represents the calculated water level when the design riverbed elevation is set at the lower limit of DL-2m. The yellow line shows the calculated water level for the current riverbed elevation. In the case of the current riverbed elevation, the calculated water level from the river mouth is above DL+2m and significantly exceeds the HWL, but it is confirmed that the water level significantly decreases with the river improvement. Additionally, when the design riverbed elevation lower limit is set at DL-2m, the flow can still occur below the HWL. It should be noted that, near 2 km from the river mouth, the water level exceeds the HWL,

According to the non-uniform flow calculation results shown in Figure 2-67, when the proposed riverbed elevation is applied, the water level during the 100-year return period flood remains below the HWL. However, when the lower limit for the proposed riverbed elevation is set to DL-2m, the calculated water level exceeds the HWL up to around 17.0k from the estuary. Since the ground elevation in the downstream section of the Adyar River is high, the calculated water level remains below the current riverbank elevation, indicating that flooding is unlikely. Therefore, the HWL for the 0k to 17k section was adjusted to ensure that it accommodates the 100-year return period water level in line with the current riverbank elevation.

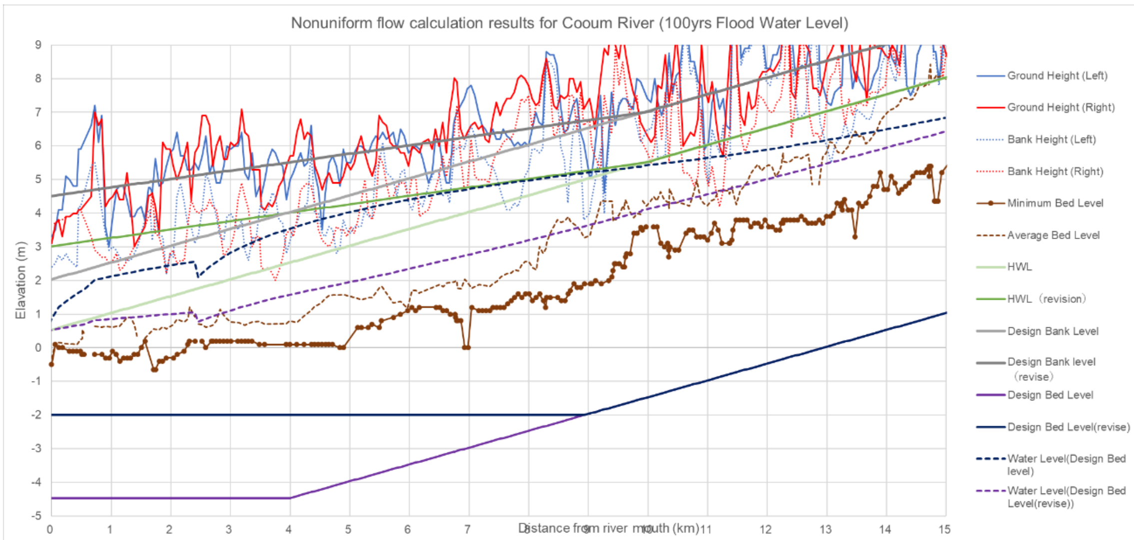


Source: JICA Expert Team

Figure 2-66: Adyar River Non-uniform Flow Calculation Results at the Estuary

(2) Cooum River

The current deepest riverbed elevation of the Cooum River is approximately DL+0m, and maintenance dredging has not been conducted. The proposed plan for the riverbed elevation at the estuary is DL-4.5m, which involves dredging more than 4m below the current riverbed level. Therefore, an impact assessment was carried out based on a lower limit of DL-2m, similar to the Adyar River. According to the non-uniform flow calculation results shown in Figure 2-67, when the proposed riverbed elevation is applied, the water level during the 100-year return period flood remains below the HWL. However, when the lower limit for the proposed riverbed elevation is set to DL-2m, the calculated water level exceeds the HWL up to around 9.5k from the estuary. Since the ground elevation in the downstream section of the Cooum River is high, the calculated water level remains below the current riverbank elevation, indicating that flooding is unlikely. Therefore, the HWL for the 0k to 10k section was adjusted to ensure that it accommodates the 100-year return period water level in line with the current riverbank elevation.



Source: JICA Expert Team

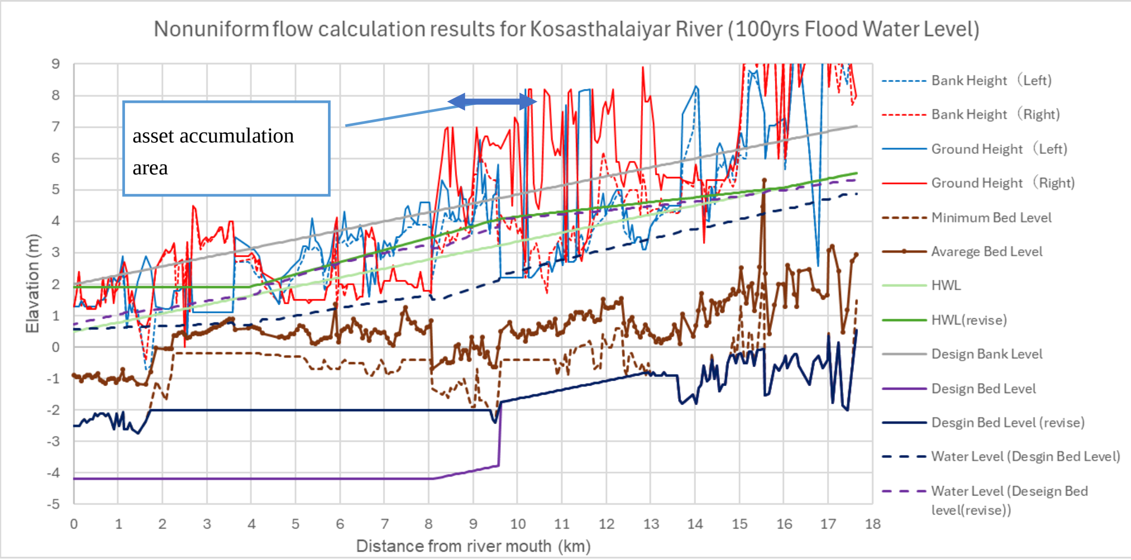
Figure 2-67: Cooum River Non-uniform Flow Calculation Results at the Estuary

(3) Kosasthalaiyar River

The current deepest riverbed elevation of the Kosasthalaiyar River is approximately DL-2m near the river mouth, with upstream sections around DL+0m continuing up to around 18k. The proposed plan for the riverbed elevation at the river mouth is DL-4.2m, which involves a dredging of more than 4 meters compared to the current riverbed elevation. Therefore, an impact assessment was conducted assuming a lower limit of DL-2m, similar to the Adyar River.

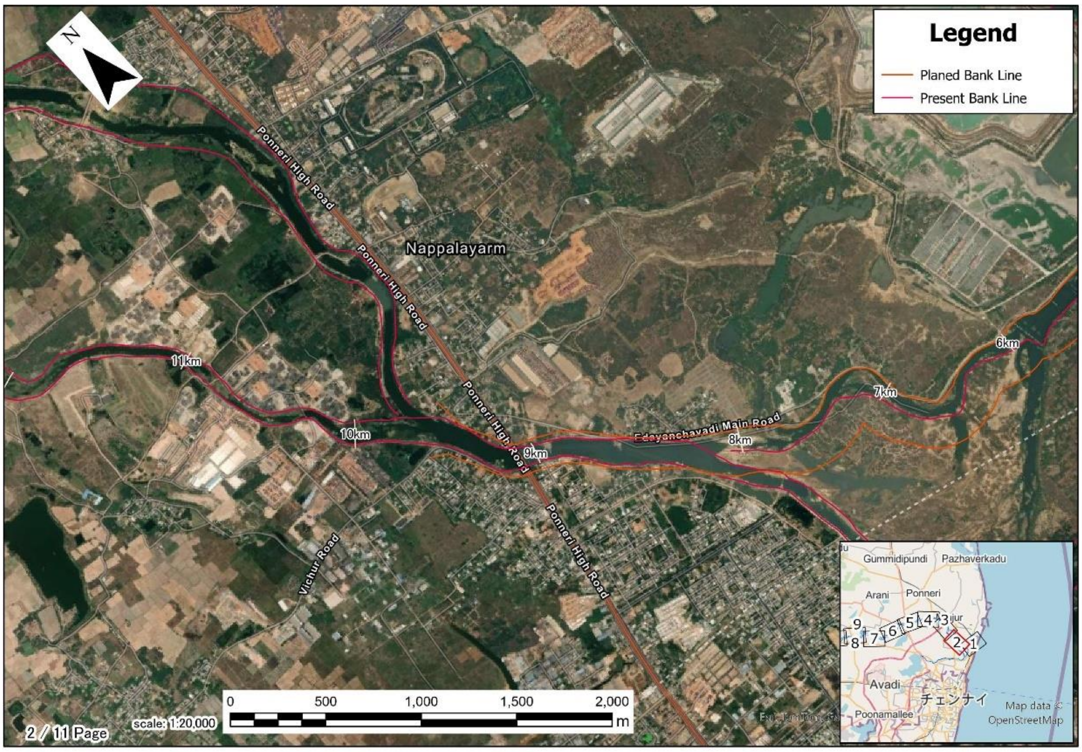
According to the unsteady flow calculation results shown in Figure 2-68, when using the proposed riverbed elevation, the water level during the 100-year return period flow is below the HWL. However, when the riverbed elevation lower limit is set to DL-2m, the water level exceeds the HWL up to around 15.5k from the river mouth.

In the downstream region of Kosasthalaiyar, residential areas are concentrated along the coastal sand dunes and in areas with higher elevations around 8k to 9.6k. The upstream and downstream sections are mostly unused land (Figure 2-69). Therefore, the HWL was revised to include the 100-year return period water level, based on the current riverbank height, for the downstream section up to 16k. Due to the revision of the proposed design flood level, it is necessary to construct an embankment on the right bank of the Loop 2 section, which is downstream of the asset accumulation area. Since the Loop 2 area is currently unused land, the decision to construct the embankment should take into account the future land use within Loop 2.



Source: JICA Expert Team

Figure 2-68: Kosasthalaiyar River Non-uniform Flow Calculation Results at the Estuary



Source: JICA Expert Team

Figure 2-69: Asset Accumulation Area in the Lower Reaches of the Kosasthalaiyar River

2.3.16 Assessment of river channel sustainability and sediment management

For the three rivers under consideration—Adyar River, Cooum River, and Kosasthalaiyar River—the proposed plans include extensive riverbed excavation and channel widening to achieve the necessary carrying capacity for a 100-year probability flood. As outlined in the previous section, the design riverbed elevation in the downstream section is set with a lower limit of DL-2 meters. This involves significantly lowering the current riverbed elevation and maintaining a horizontal riverbed profile over several kilometers from the river mouth. While this design improves flood capacity, it is expected to reduce flow velocity during floods compared to the current river channel. This reduction in velocity may lead to sediment deposition from upstream areas accumulating in the deeper downstream sections, raising concerns about the long-term sustainability of the design cross-sections.

To address these concerns, an analysis was conducted to evaluate changes in sediment transport characteristics resulting from the proposed river channel modifications. This analysis was based on the longitudinal distribution of hydraulic quantities during floods in both the current and design river channels. The goal was to assess the sustainability of the river channels and their ability to maintain the design cross-sections over time.

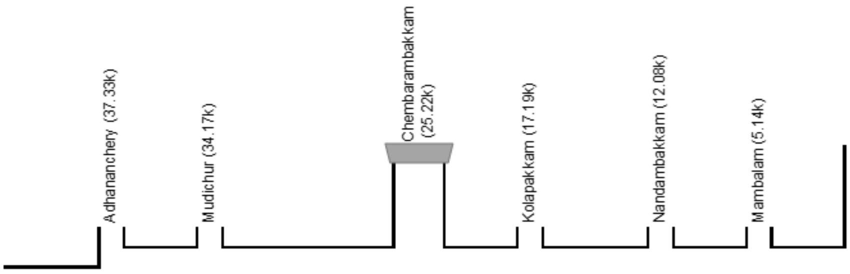
The evaluation process involved the following steps: First, the sediment transport capacity at maximum carrying capacity in the downstream sections of the current river channels was calculated using an unsteady flow calculation model. Next, the sediment transport capacity in the design river channels was analyzed across different flood scales. By comparing these results with the indicators for the current river channels, the potential for sediment deposition in the design channels was assessed. This comparison provided insights into the feasibility of maintaining the proposed cross-sections and identified potential challenges related to sediment accumulation.

This assessment highlights the importance of integrating sediment management strategies into the river channel design to ensure long-term sustainability and functionality. By addressing sediment transport dynamics, the proposed improvements can be optimized to minimize maintenance requirements and enhance the resilience of the river systems.

2.3.16.1. Adyar River

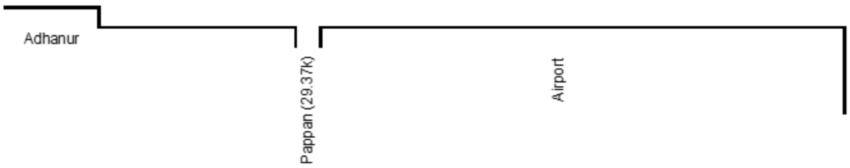
The unsteady flow calculation water levels for the current and design river channels are shown in Figure 2-72. Here, unsteady flow calculations were performed for three discharges: 100-year probability, 10-year probability, and half of the 10-year probability discharge. The unsteady flow calculations were conducted for the downstream section of 11k, where the design river channel has a large water depth and a horizontal riverbed gradient, using the discharges indicated in red in Figure 2-70.

As shown in Figure 2-72, the current river channel significantly lacks carrying capacity for a 100-year probability flood, resulting in calculated water levels that greatly exceed the current ground elevation. The unsteady flow calculations assume that water does not overflow onto the land side from the riverbanks on both the left and right banks, leading to unrealistically high water levels for a 100-year probability flood. In reality, when the river water level exceeds the ground elevation on both banks, flooding occurs, so the calculated water level would only rise to approximately the current ground elevation. Based on this, the carrying capacity of the current river channel in the downstream area of the Adyar River is evaluated to be approximately at the level of a 10-year probability flood.



Tank75%	0.5×Return Period 10yrs	45	140	255	290	650	550
Tank75%	Return Period 10yrs	90	280	510	580	1,300	1,100
Tank75%	Return Period 20yrs	110	390	710	780	1,700	1,500
Tank75%	Return Period 30yrs	190	610	1,100	1,100	2,100	1,900
Tank75%	Return Period 50yrs	200	630	1,200	1,300	2,400	2,100
Tank75%	Return Period 100yrs	290	830	1,600	1,600	2,500	2,500

Bay of Bengal



Source: JICA Expert Team

Figure 2-70: Runoff Calculation Results by Probability Scale (Adyar River, 75% Tank Utilization Rate)

The sediment transport characteristics in the Adyar River were evaluated using the friction velocity. The friction velocity is calculated using the following formula, and a higher value indicates a greater capacity of the river to transport sediment.

$$u_* = \sqrt{gRi_e}$$

Here, (u^*) represents the friction velocity, (g) is the gravitational acceleration, (R) is the hydraulic radius, and (i_e) is the energy gradient.

When examining this indicator longitudinally, if the friction velocity decreases from upstream to downstream, the sediment transport capacity decreases, leading to sediment accumulation.

Based on this perspective, the longitudinal diagram of friction velocity by probability scale (Figure 2-73) reveals the following points:

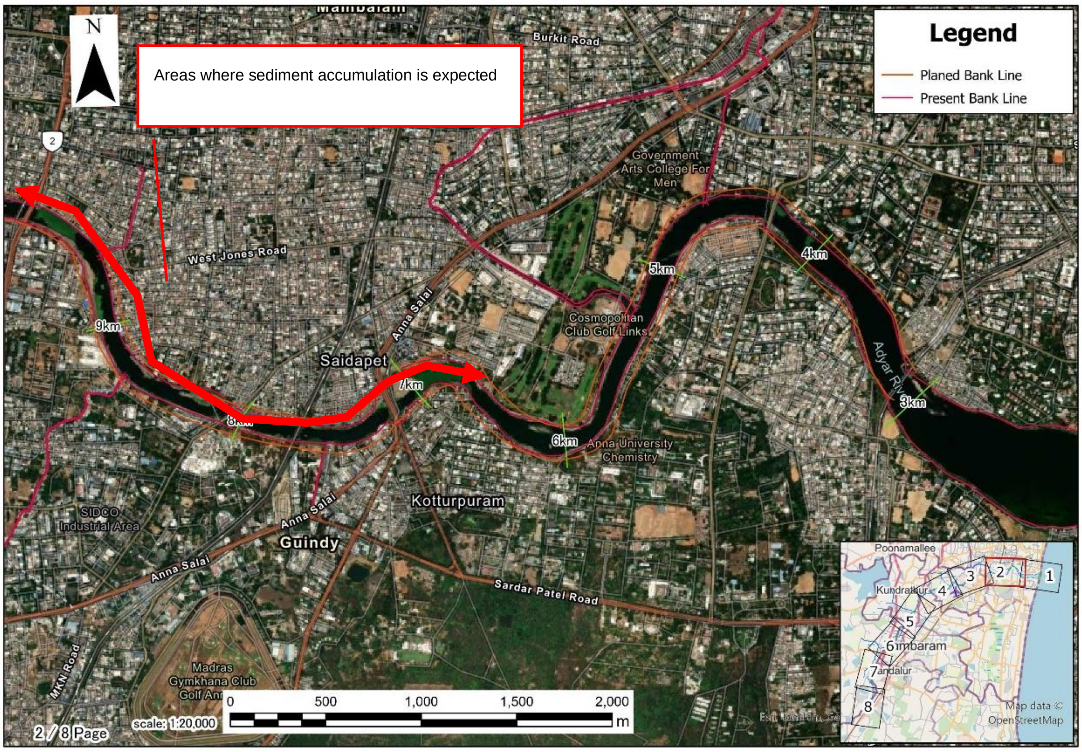
In the current river channel, local water levels change abruptly due to longitudinal changes in the cross-section. This causes longitudinal variations in the energy gradient (i_e) and hydraulic radius (R), leading to changes in the friction velocity.

In the design river channel, the widening and excavation of the riverbed will enlarge the flow cross-section, stabilizing water levels during floods and eliminating abrupt changes in friction velocity. Additionally, the absolute value of the friction velocity will decrease compared to the current river channel.

The longitudinal diagram of friction velocity by discharge scale shows that the areas affected by flood flows from upstream change depending on the flood scale. In the case of a 100-year probability flood, the influence of the flood flow is significant up to around 7k from the river mouth, resulting in high friction velocity. However, downstream of 7k, the friction velocity decreases sharply due to the influence of sea level, suggesting the possibility of sediment accumulation around 7k. As the flood scale decreases, the influence of flood flows from upstream diminishes, and the areas where friction velocity decreases sharply, indicating high potential for sediment accumulation, move upstream.

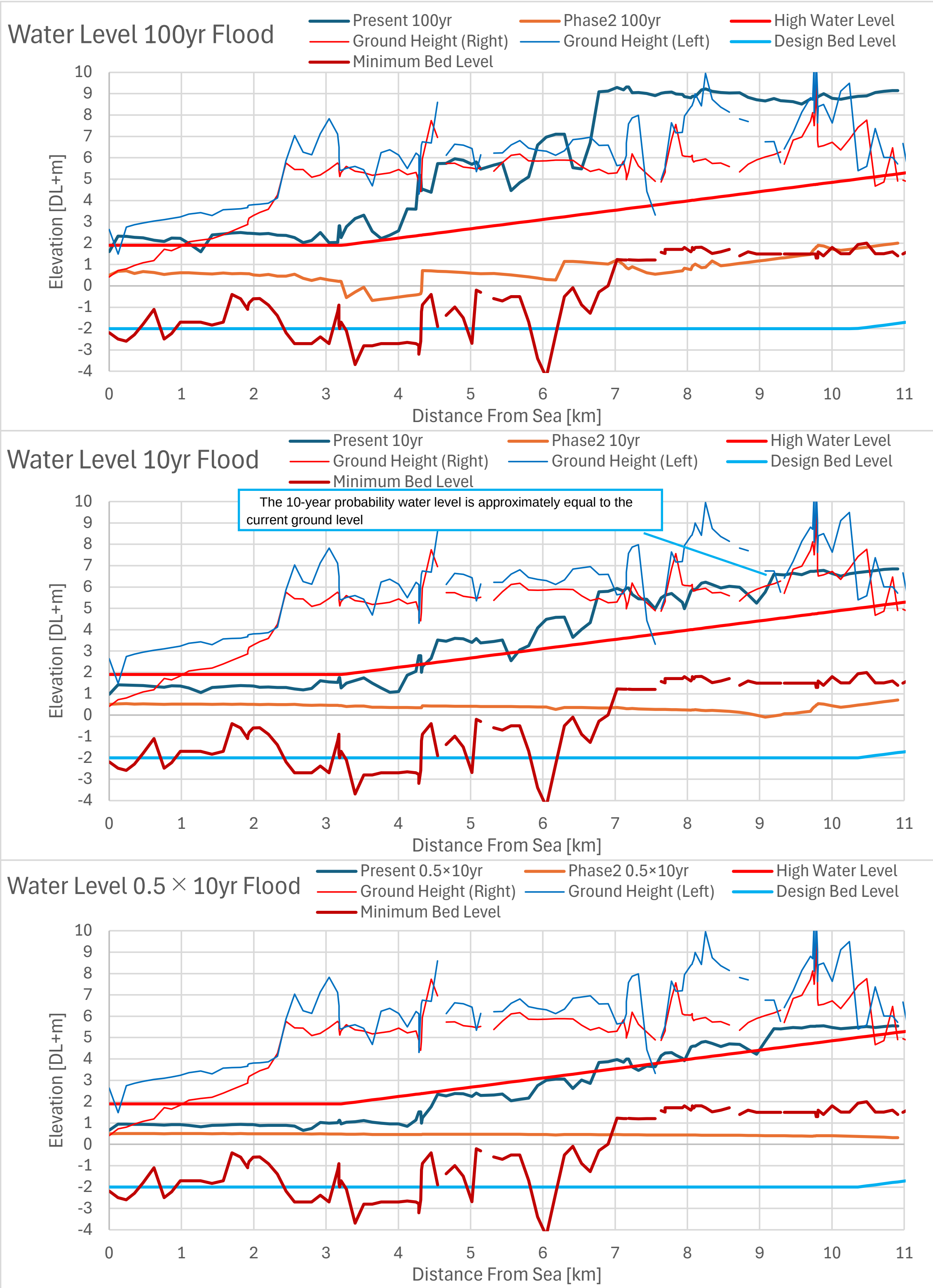
Based on these results, there is a possibility of sediment accumulation in the area from 7k to 11k, including around 10k, which is a point of longitudinal gradient change, during the recession period after the flood peak flow.

Therefore, in the section shown in Figure 2-71, it is necessary to determine the allowable riverbed elevation (amount of sediment accumulation) through hydraulic calculations that consider sediment accumulation and to manage the riverbed elevation as needed.



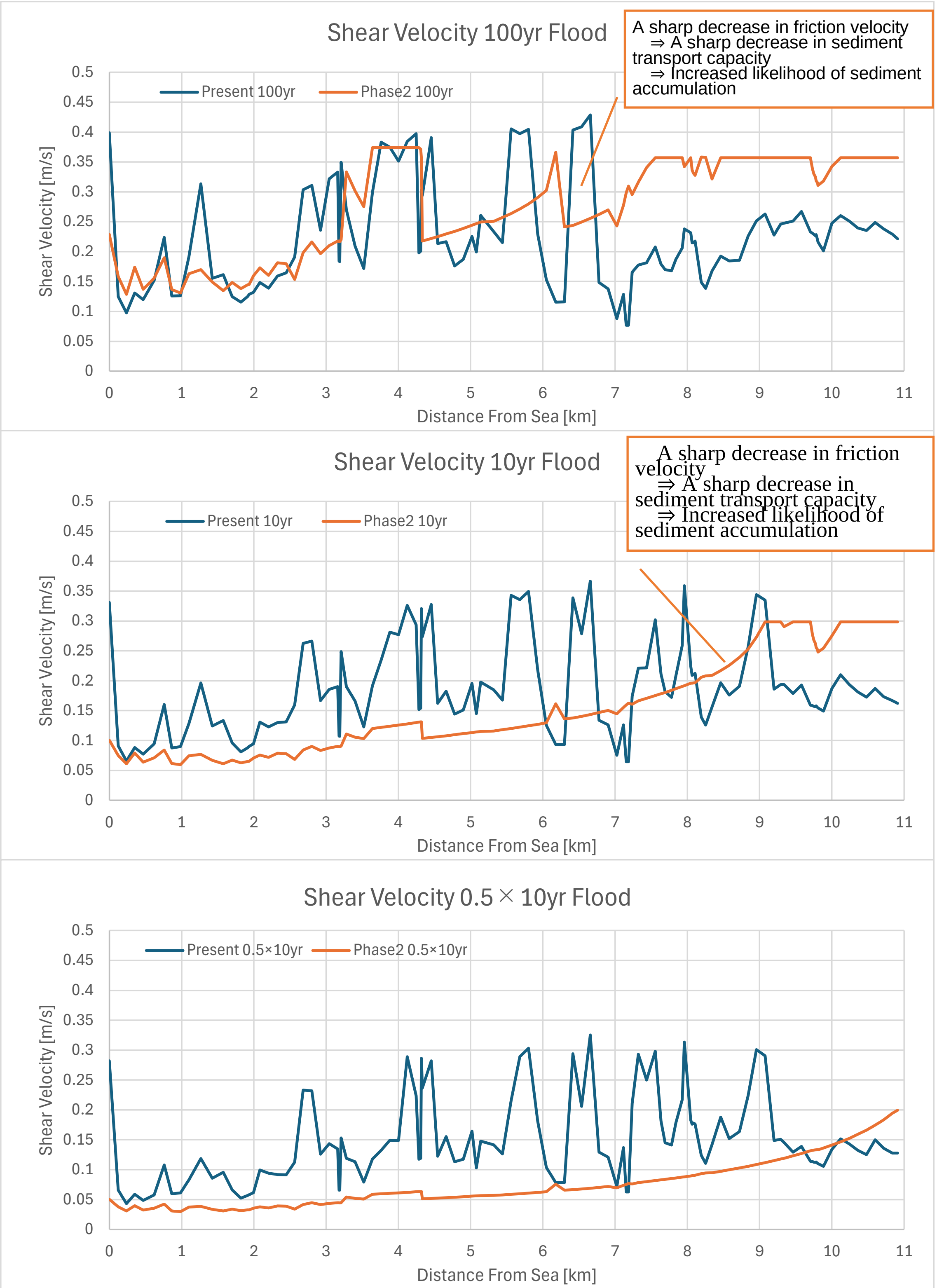
Source: JICA Expert Team

Figure 2-71: Sediment Accumulation Monitoring Section in the Lower Reaches of the Adyar River



Source: JICA Expert Team

Figure 2-72: Longitudinal Diagram of Unsteady Flow Calculation Water Levels by Probability Scale (Adyar River)

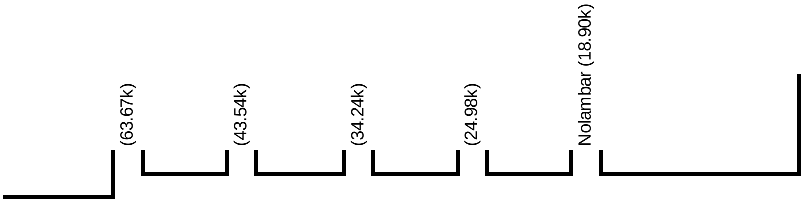


Source: JICA Expert Team

Figure 2-73: Longitudinal Diagram of Friction Velocity by Probability Scale (Adyar River)

2.3.16.2. Cooum River

The non-uniform flow water levels in the current and design river channels are shown in Figure 2-75. The non-uniform flow calculation was conducted using the discharge values in red from Figure 2-74, covering the section up to approximately 15k, including the 9k downstream section where the water depth is large and the riverbed slope becomes horizontal. As shown in Figure 2-75, the downstream area of the Cooum River is evaluated to have about half the carrying capacity of a 10-year return period flood in the current river channel.



Tank75% 0.5×Return Period 10yrs	20	185	405	260	340	380	405
Tank75% Return Period 10yrs	40	370	410	520	680	760	810
Tank75% Return Period 20yrs	60	480	520	680	910	1,100	1,100
Tank75% Return Period 30yrs	60	540	590	780	1,100	1,200	1,200
Tank75% Return Period 50yrs	60	630	690	890	1,300	1,400	1,400
Tank75% Return Period 100yrs	60	790	870	1,100	1,500	1,600	1,700

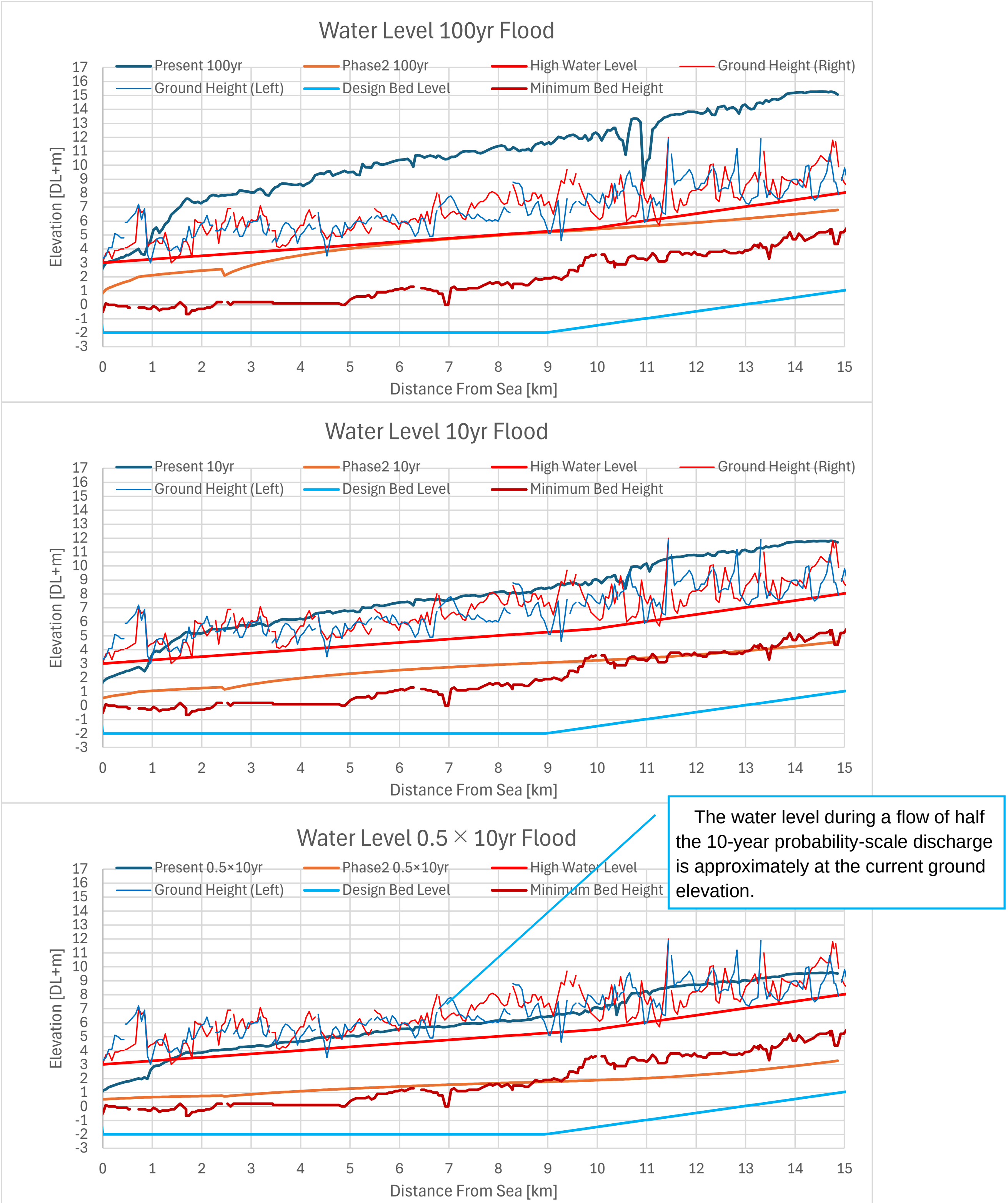
Bay of Bengal

Source: JICA Expert Team

Figure 2-74: Return Period Runoff Calculation Results (Cooum River, 75% Tank Utilization Rate)

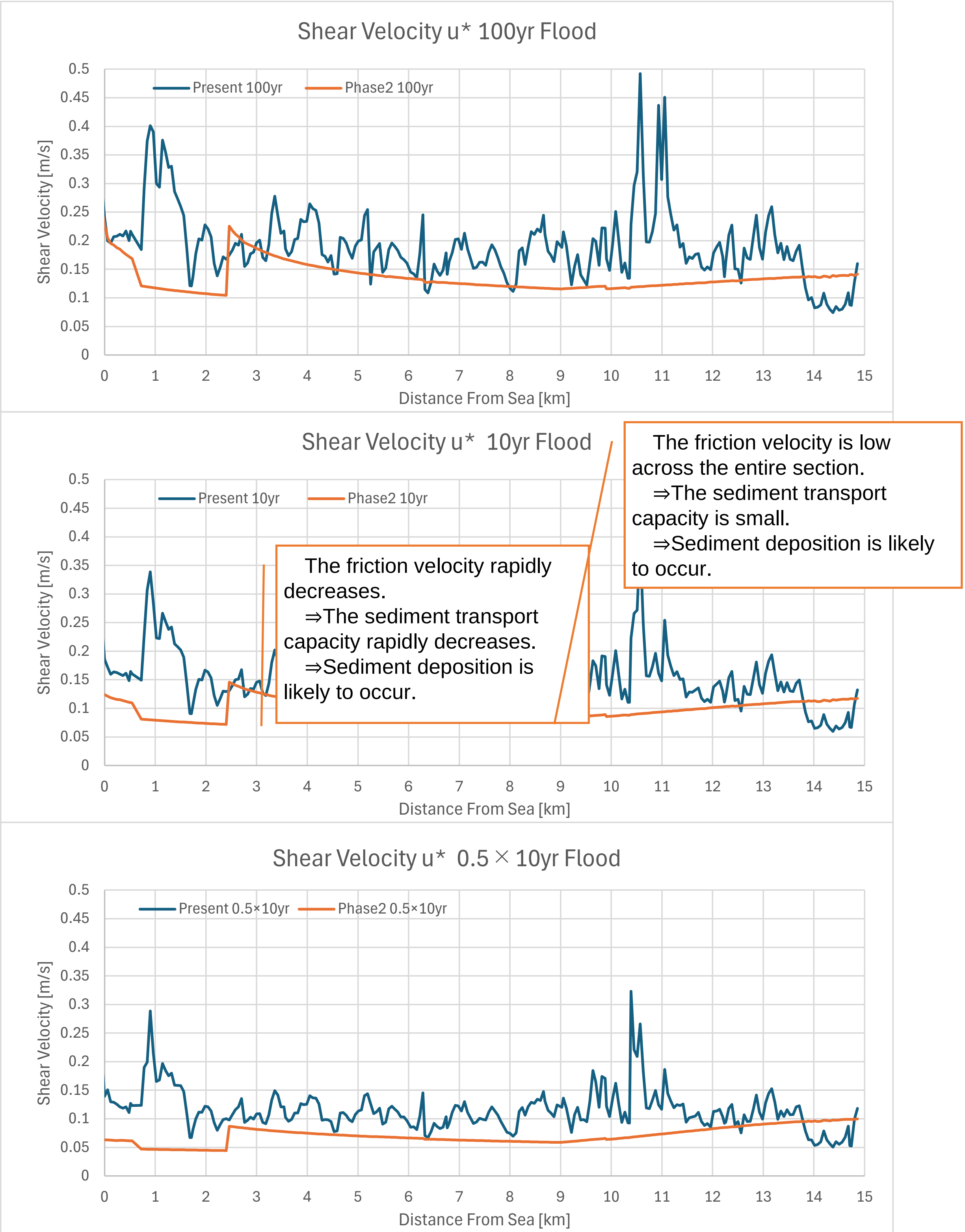
The sediment transport characteristics in the Cooum River were evaluated using the friction velocity u*. By examining the longitudinal profile of friction velocity by return period (Figure 2-74), the following points can be confirmed.

- In the Cooum River, the friction velocity decreases overall when the river channel is upgraded from the current to the design configuration, but the general trend remains unchanged.
- In the design river channel, the friction velocity gradually decreases from the upstream side to around 9k, with a significant drop occurring near 2.5k. The reason is that the area around 9k is a point of change in the longitudinal slope of the design river channel, where the riverbed slope becomes flat downstream of 9k, and the area around 2.5k is the branching point of the loop section, where the flow cross-section expands rapidly. These two locations are considered to have a high potential for sediment deposition.
- Therefore, it is necessary to conduct hydraulic calculations considering sediment deposition in the relevant sections to determine the allowable riverbed elevation (sediment deposition volume), and, if necessary, manage the maintenance of the riverbed elevation.



Source: JICA Expert Team

Figure 2-75: Longitudinal Profile of Non-uniform Flow Water Levels by Return Period (Cooum River)



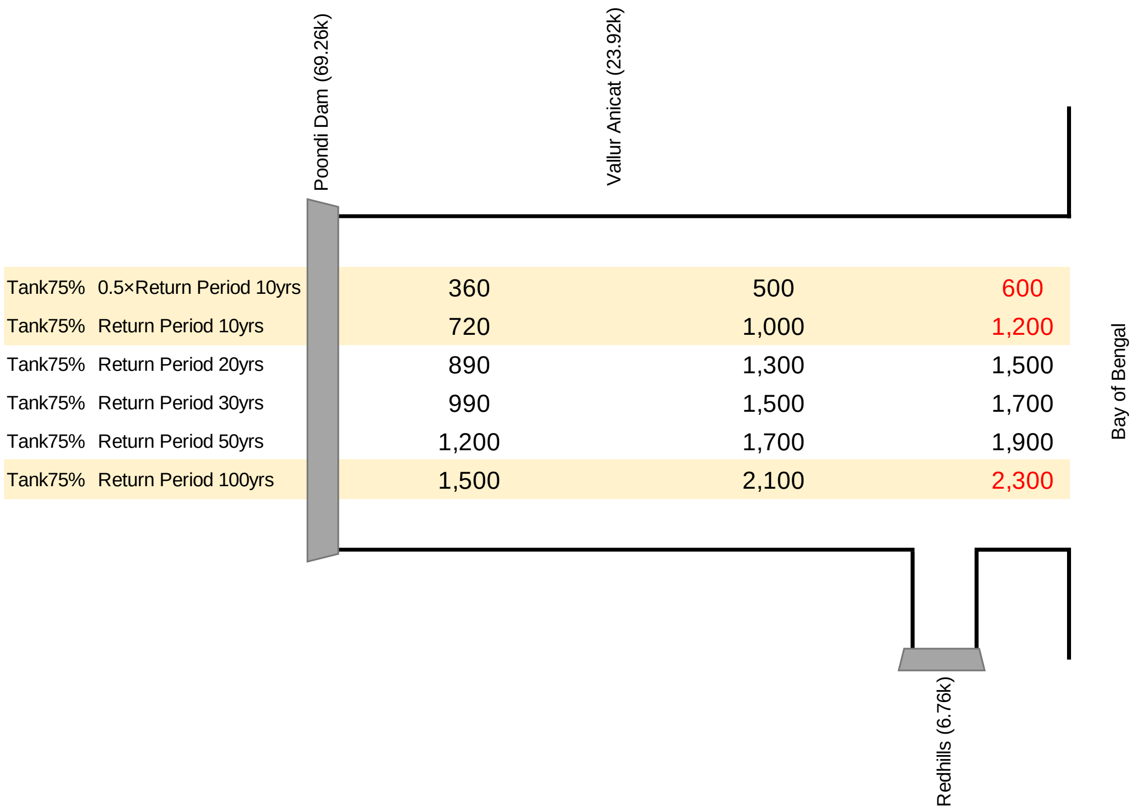
Source: JICA Expert Team

Figure 2-76: Longitudinal Profile of Friction Velocity by Return Period (Cooum River)

2.3.16.3. Kosasthalaiyar River

The non-uniform flow water levels in the current and design river channels are shown in Figure 2-78. The non-uniform flow calculation was conducted using the discharge values in red from Figure 2-77, covering the section up to approximately 15k, including the 9k downstream section where the water depth is large and the riverbed slope becomes horizontal.

As shown before, the downstream area of the Kosasthalaiyar River is evaluated to have about half the carrying capacity of a 10-year return period flood in the current river channel.



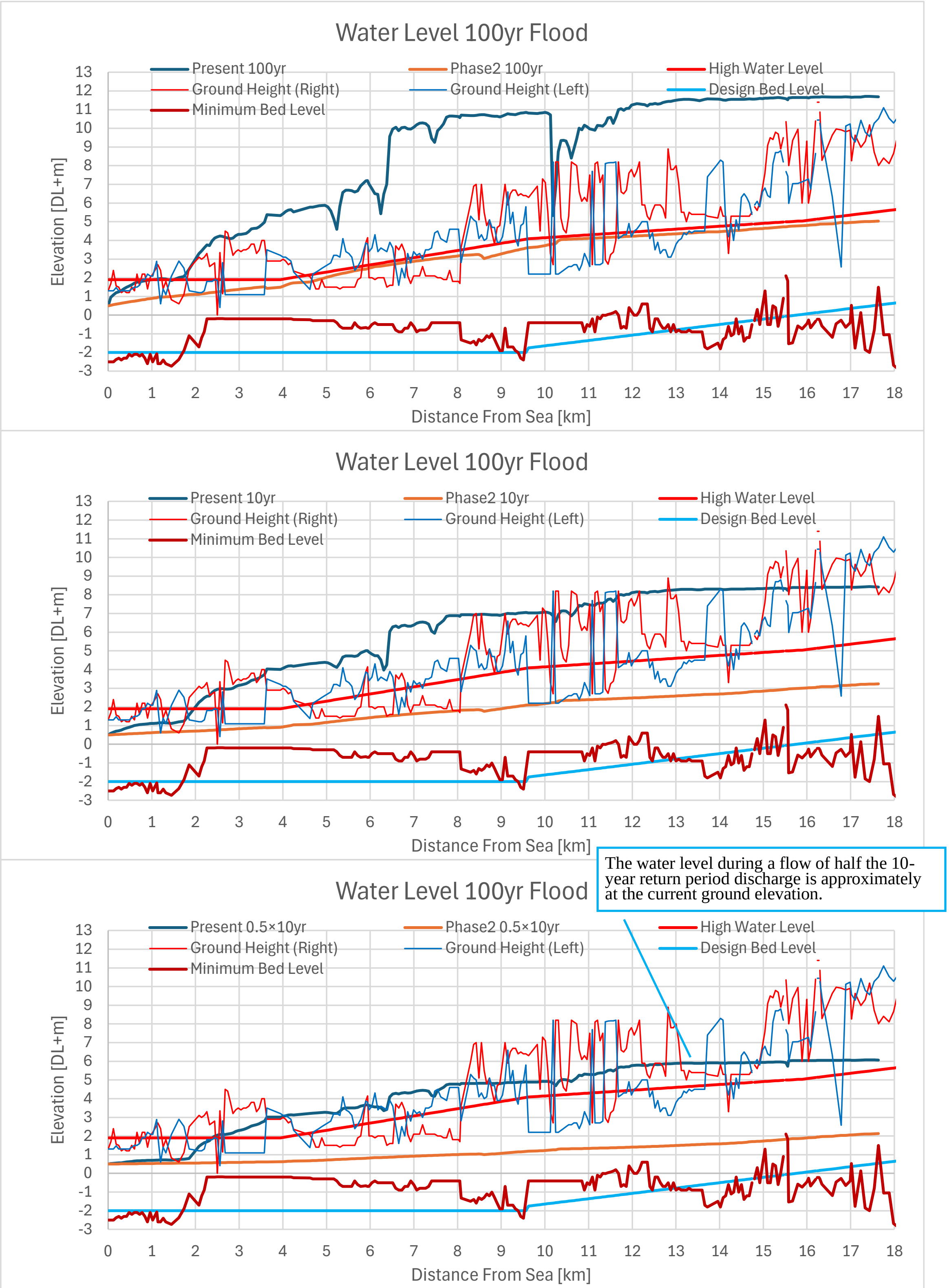
Tank75% 0.5×Return Period 10yrs	360	500	600
Tank75% Return Period 10yrs	720	1,000	1,200
Tank75% Return Period 20yrs	890	1,300	1,500
Tank75% Return Period 30yrs	990	1,500	1,700
Tank75% Return Period 50yrs	1,200	1,700	1,900
Tank75% Return Period 100yrs	1,500	2,100	2,300

Source: JICA Expert Team

Figure 2-77: Return Period Runoff Calculation Results (Kosasthalaiyar River, 75% Tank Utilization Rate)

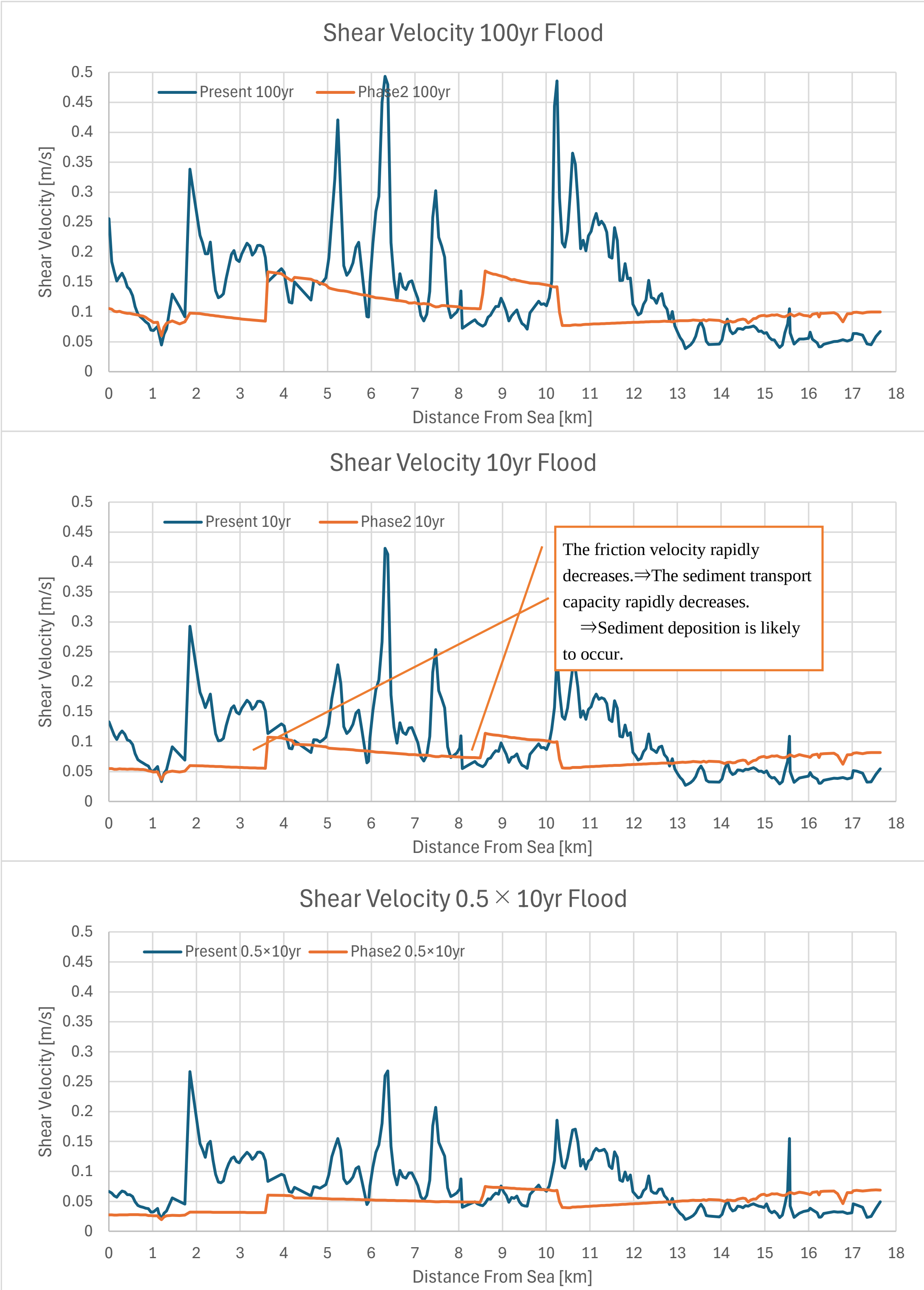
The sediment transport characteristics in the Kosasthalaiyar River were evaluated using the friction velocity u*. By examining the longitudinal profile of friction velocity by return period (Figure 2-79), the following points can be confirmed.

- In the Kosasthalaiyar River, the friction velocity tends to decrease overall when the river channel is upgraded from the current to the planned configuration.
- In the design river channel, the section between 8k and 10k, which connects the two loop sections, has a narrower width compared to the loop sections. As a result, water levels rise upstream due to constriction, and the river width expands downstream, causing the water surface slope to become gentler. Consequently, the friction velocity decreases both upstream and downstream of this section. Additionally, at the downstream loop section branching point (around 3.5k), the friction velocity also decreases due to the expansion of the river width. These two locations are considered to have a high potential for sediment deposition.
- Therefore, it is necessary to conduct hydraulic calculations considering sediment deposition in the relevant sections to determine the allowable riverbed elevation (sediment deposition volume), and, if necessary, manage the maintenance of the riverbed elevation.



Source: JICA Expert Team

Figure 2-78: Longitudinal Profile of Non-uniform Flow Water Levels by Return Period (Kosasthalaiyar River)



Source: JICA Expert Team

Figure 2-79: Longitudinal Profile of Friction Velocity by Return Period (Kosasthalaiyar River)

2.4 Proposed Structural Measures

2.4.1 Flood storage by renovating existing tanks

2.4.1.1. Status of existing tanks

Tanks and waterbodies, primarily under the jurisdiction of TNWRD, have been selected for flood storage improvement. These options require minimal land acquisition, making them practical and feasible after coordination and discussions with the Counterpart Agencies (C/Ps). This approach has been mutually agreed upon by the TNWRD, ensuring alignment and support for the proposal.

This study collected information on the existing tanks and waterbodies from the Tamil Nadu Water Resources Department (TNWRD). Table 2-35 provides an overview of the status of tanks in each river basin.

Table 2-35: Tanks and Waterbodies Areas

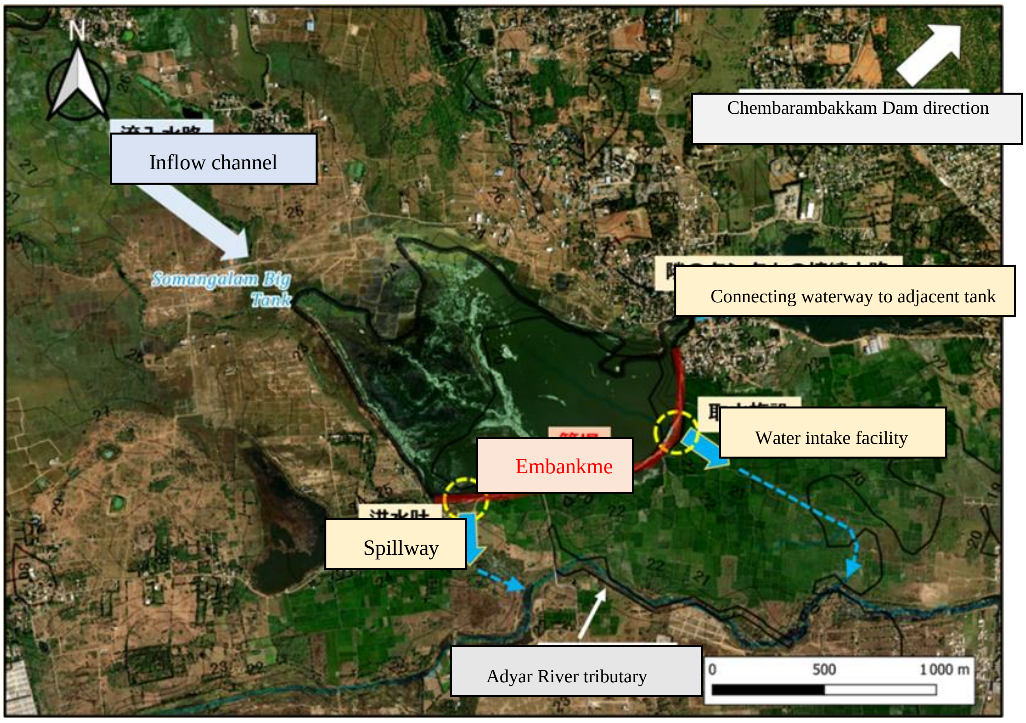
Basin	Basin Area (km^2)	Existing Tank Area (km^2)	Major Dam Area (km^2)	% of Basin Area Covered by Tanks	% Including Dam Areas
Adyar	854	62.6	22.7 (CBM Dam)	7.33%	9.99%
Cooum	435	42.75	N/A	9.83%	N/A
Kosasthalaiyar (in TN)	3031	206.9	55.4 (Three Dams)	6.83%	8.65%
Kovalam (North Part)	293	16.7	~7.0 (Pallikaranai Marshland)	5.67%	8.07%

Source: JICA Expert Team using information from TNWRD

A policy for utilizing selected tanks and waterbodies for flood storage was agreed upon with the counterpart agencies and incorporated into the JICA Flood Control Master Plan. Selected waterbodies were analyzed based on their condition, as compared to the 2011 topographic sheets, to evaluate encroachments or potential area expansions. The study also assessed the connecting drainage systems and identified missing links, creating an inventory of tanks and their interconnections. This analysis was based on TNWRD data and other sources such as satellite images. A detailed and updated bathymetry of the selected tanks and waterbodies is essential during the implementation of the JICA Flood Control Master Plan.

2.4.1.2. Overview of existing tank facilities

As an example of the existing tanks, the specifications of the tank and the current situation at the site are shown below, taking the Somangalam Big Tank in the Adyar River basin. The tank is located about 4 km southeast of the Chembarambakkam Dam but is not connected to the dam. The water discharged from the tank flows into a tributary of the Adyar River located to the south of the tank. Facilities related to the discharge of stored water include intake facilities (gates), spillways, and connecting channels to adjacent tanks. Embankments exist only in the southeastern portion of the tank, where the ground elevation is low, while the inlet channel to the tank is located in the northwestern direction of the reservoir and the upstream portion of the tank is shallow due to sedimentation.



Source: JICA Expert Team

Figure 2-80: Overview of Somangalam Big Tank

Table 2-36: Basic Specifications of Somangalam Big Tank

Name	Somangalam Big Tank
Latitude	12° 56' 45.925" N
Longitude	80° 1' 36.652" E
Village	Somangalam
Subbasin	Adyar
Basin	Chennai
Existing Capacity	1.23 MCM
Area	1.10 km²

Source: JICA Expert Team

The following photographs depict the current condition of the Somangalam Big Tank, from the eastern end of the tank's embankment to the connecting channel with the neighboring tank.

Table 2-37: Photos of Somangalam Big Tank (1)

	
From the eastern end of the tank embankment towards the pond	Embankment status (eastern end of embankment)

Embankment status (eastern end of embankment, pond side slope)

The northeast part of the tank without embankments

The northeast part of the tank without embankments

Connecting the waterway to an adjacent tank

Source: JICA Expert Team

The following photos show the current situation of the Somangalam Big Tank, including the intake facility and the spillway.

Table 2-38: Photos of Somangalam Big Tank (2)

	
Water intake facility (with gate inside the hole)	Top of the water intake facility
	
Slope stairs at the water intake facility installation site	Floodway (behind the river)
	
Spillway (end)	Spillway (river surface)

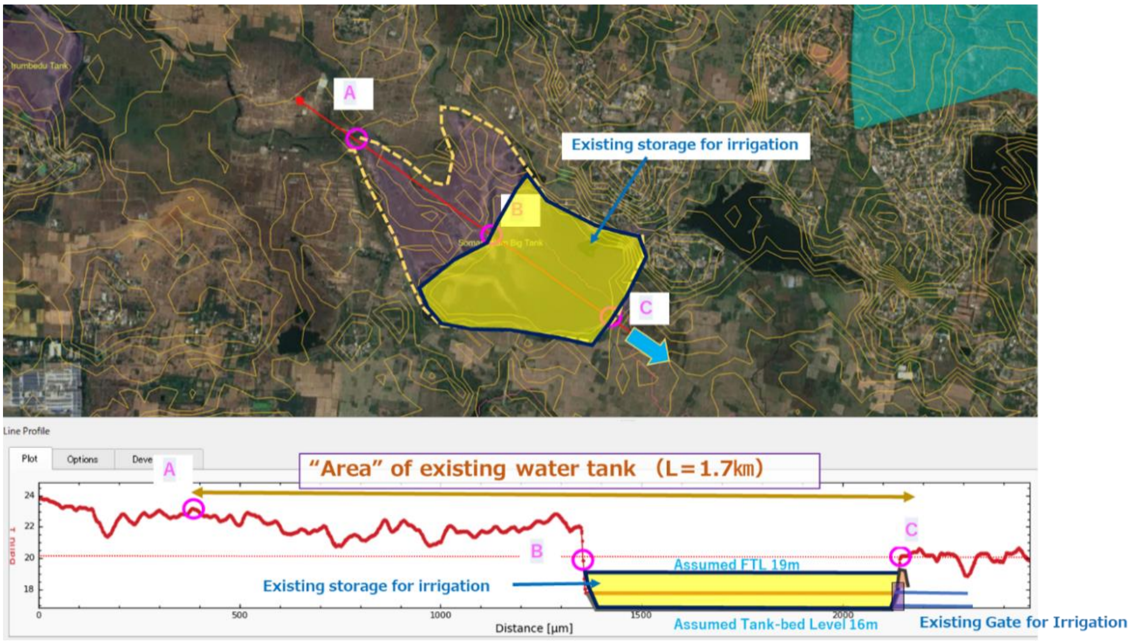
Source: JICA Expert Team

2.4.1.3. Improvement policy for existing tanks

The improvement policy for existing tanks is shown below, using the Somangalam Big Tank in the Adyar River basin as an example.

(1) Topographical conditions and storage capacity of existing tanks

Figure 2-81 shows a longitudinal cross-section (northwest (inlet channel) - southeast (intake facility) direction) of the Somangalam Big Tank based on DEM. It is suggested that within the tank area, the ground is higher on the upstream side (northwest side) due to sedimentation, and only the downstream side (southeast side) is the reservoir area. This is consistent with satellite images and the results of on-site investigations, which show that the reservoir area is concentrated in the downstream area, which is built up in a crescent shape. The existing water storage capacity of the tank is 1.23 M, and the water depth is 3.5m, which roughly corresponds to the water storage capacity when water is stored at a uniform depth in the downstream part of the tank (hatch part), as shown in the figure below. For the Somangalam Big Tank, based on the DEM and local conditions, the bottom elevation is assumed to be approximately +16.0m, and the full water level is assumed to be approximately +19.0m (=spillway crest).



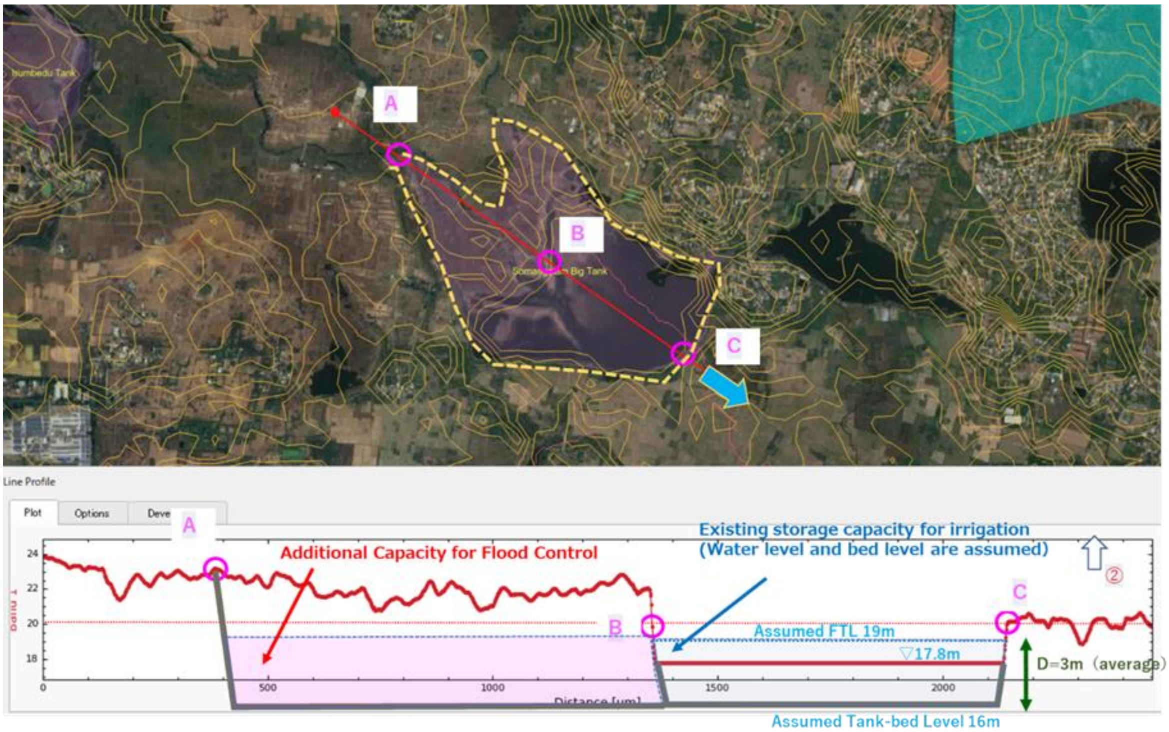
Source: JICA Expert Team

Figure 2-81: Plan and Section of Somangalam Big Tank

(2) Basic concept of improvement of existing tanks

The existing tanks are to be improved (flood control capacity) by excavating areas upstream where the ground is higher, and the pond bottom height is shallower so that the increased storage capacity can be used for flood control. Here, the water is uniformly excavated to a depth of 3-4 m, which is equivalent to the existing storage area (downstream), and the raising of the embankment is not considered. This is because it would be difficult to utilize the existing structures and ancillary facilities (embankments, flood spouts, intake facilities, and connecting channels to neighboring tanks) if the pond bottom elevation or maximum water storage level were to be significantly revised. Although extending the extent of the storage area may lower the permanent storage level, water abstraction is considered possible as the bed height of the irrigation intake facility is at about the current pond bottom level. However, the operational rules for individual tanks, such as changes in the operating water level, need to be considered when designing each tank improvement.

In addition, the tank improvements should include (i) the installation of drainage gates to allow for partial discharge in preparation for the next rainfall when the tank reaches full capacity after the first rainfall of the rainy season and (ii) the installation of topographical slopes or steps on the pond bottom to facilitate drainage and intake and tank maintenance and management.



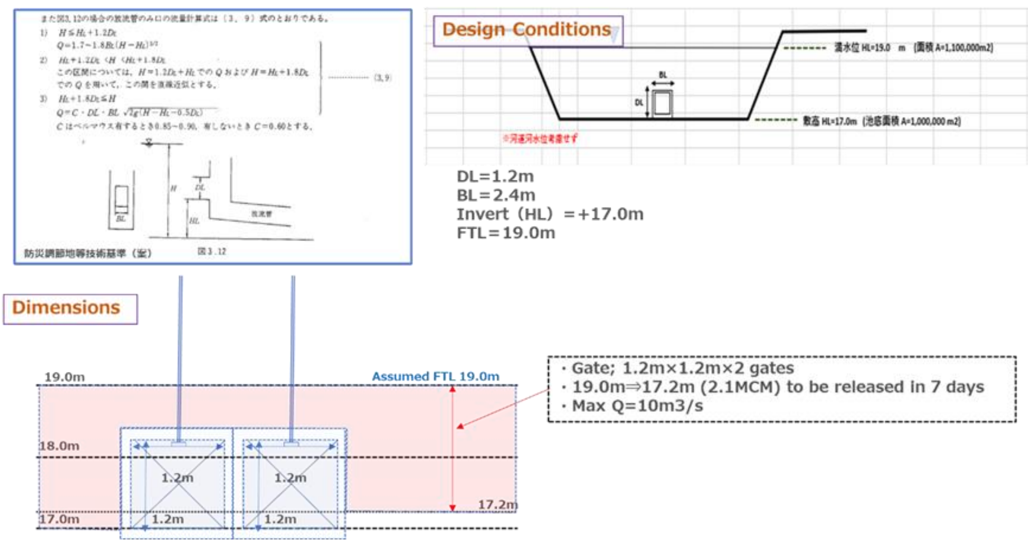
Source: JICA Expert Team

Figure 2-82: Basic Concept of Flood Control Capacity of Somangalam Big Tank

The concept of the proposed improvements at Somangalam Big Tank is shown in the diagram above; the elevation is a reference figure based on existing DEMs and local conditions. For the basic design of individual facilities, the existing structures and topography should be surveyed and scrutinized.

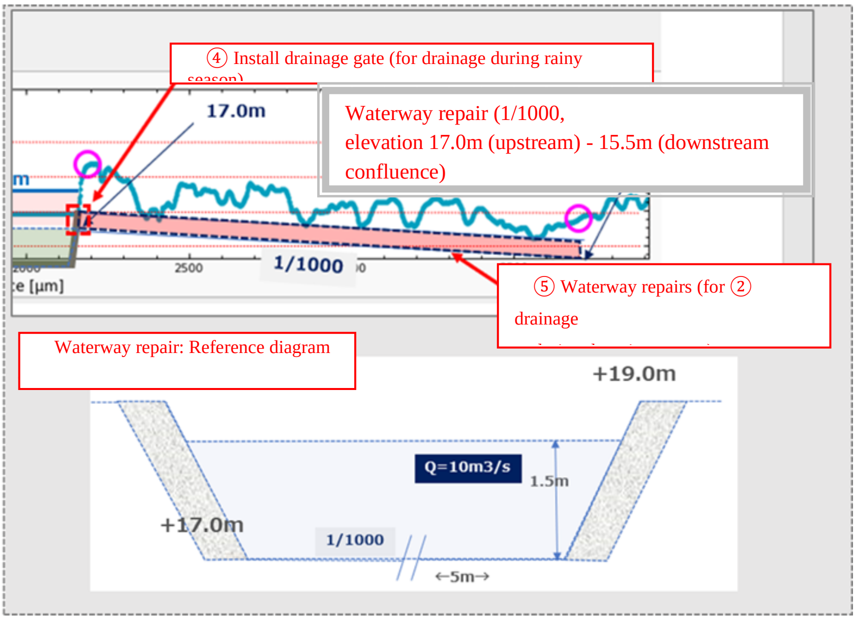
In this concept, a drainage gate bed elevation of +17.0 is assumed for the downstream pond bottom elevation of +15.0 m, leaving a water storage capacity of 2.0 m depth. As for the channel downstream of the gate, it was planned to connect to a tributary of the Adyar River with a gradient of about 1/1000, and the bed elevation of the drainage gate was set to match this elevation. For the pond bottom elevation, a step difference of 2 ft (60 cm) is considered, and the improvement is considered in three stages from +15.0 to +16.2. With this improvement, the Somangalam Big Tank will have an increased storage capacity of approximately 2.51 million m3 (= average depth of 3.4 m after improvement x tank area of 1.10 km2 - existing capacity of 1.23 million m3) for flood control.

Regarding the drainage gate specifications, 2.1 million m3 can be drained from the full water level (+19.0 m) to +17.2 m in seven days by installing two 1.2 m x 1.2 m gates. In addition, the existing drainage channels will be rehabilitated as connection channels to the Adyar River branch. Most of the existing drainage channels are simply dug, with a width of 5 m and a depth of less than 1 m identified on site. By making these around 5 m wide by 2.0 m deep, the required 10 m3/s can flow.



Source: JICA Expert Team

Figure 2-83: Concept of Gates Improvement (Somangalam Big Tank)



Source: JICA Expert Team

Figure 2-84: **Concept of Connecting Link Improvement (Somangalam Big Tank)**

2.4.1.4. Flood control capacity through improvements to existing tanks

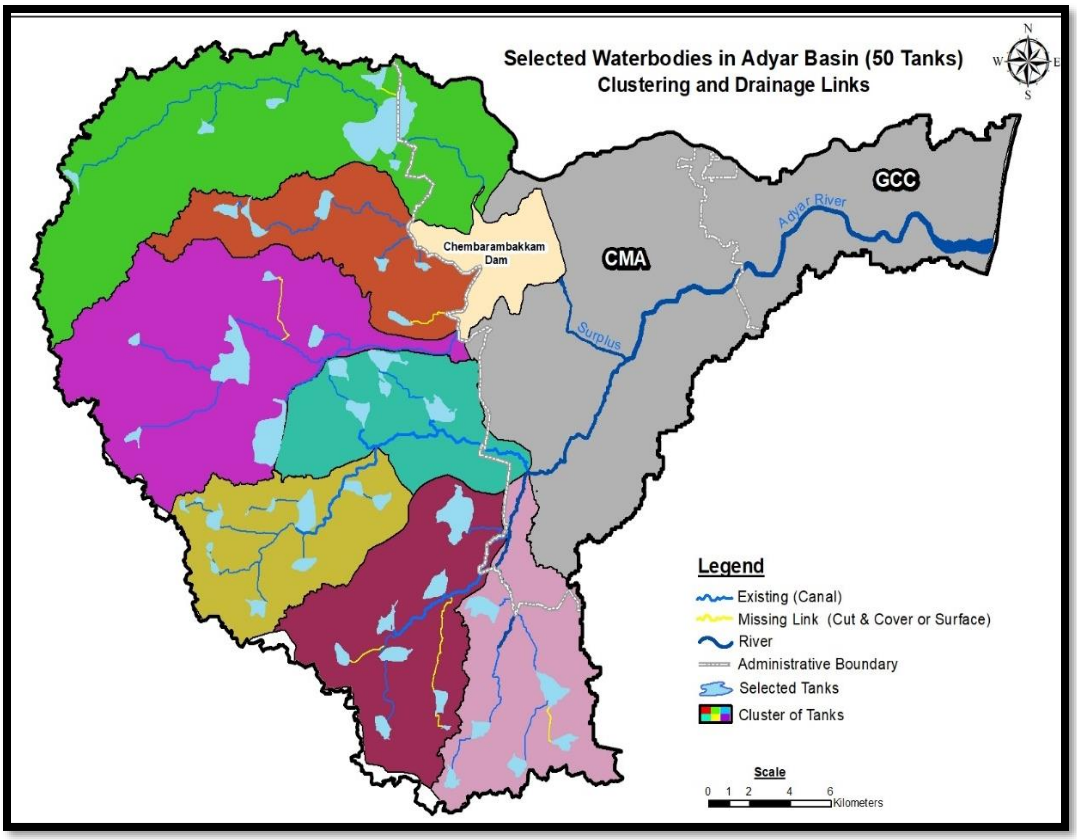
(1) Capacity increase in the Adyar River

The list of existing tanks in the Adyar River is shown below. The combined enhanced capacity of the 50 main tanks is approximately 59MCM, with a total area of approximately 43.1 km^2.

Table 2-39: List of Existing Tanks in the Adyar River (50 Tanks)

NewID	Tank_Name	Cap_MCM	Area (revised)_Km2
A-1	Manimangalam Tank	6.37	2.59
A-2	Koppur Kudippi Thangal	5.60	0.29
A-3	Sriperumbudur Tank	4.93	4.02
A-4	Pillaipakkam Tank	3.45	4.30
A-5	Nemam	2.56	5.98
A-6	Perumattunallur Big Tank	2.06	0.54
A-7	Nandivaram Tank	1.69	1.22
A-8	Mappaedu Big Tank	1.53	0.30
A-9	Gunduperumbedu Tank	1.47	1.52
A-10	Padur	1.37	0.20
A-11	Kayarambedu Tank	1.33	0.57
A-12	Somangalam Big Tank	1.23	1.43
A-13	Adanur Tank	1.16	1.32
A-14	Kolathur Tank	1.07	0.98
A-15	Amarambedu Tank	1.04	1.05
A-16	Padappai Tank	0.99	0.93
A-17	Vallakottai Sundaleri	0.91	0.05
A-18	Vallakottai Maveri	0.91	0.16
A-19	Orathur Tank	0.90	0.81
A-20	Kavanoor Tank	0.84	0.51
A-21	Siruanjur Katteri	0.80	0.57
A-22	Vallakottai Alleri	0.79	0.11
A-23	Valarpuram Tank	0.79	0.89
A-24	Potheri Tank	0.73	0.55
A-25	Maganium Chitteri	0.72	0.46
A-26	Thathanur Tank	0.72	0.15
A-27	Gudapakkam	0.72	0.66
A-28	Vadakkal Vannan Thanal	0.72	0.03
A-29	Peringambakkam Tank	0.71	0.53
A-30	Kattankolathur Tank	0.69	0.06
A-31	Mannur Peria Eri	0.66	0.59
A-32	Mathur Tank	0.62	0.52
A-33	Kattrarambakkam Tank	0.61	0.40
A-34	Mannur Sadai Eri	0.60	1.92
A-35	Pudupakkam Big Tank	0.59	0.32
A-36	Arambakkam Tank	0.59	0.72
A-37	Keevallore Tank	0.55	0.21
A-38	Maganium Periyaeri	0.53	0.49
A-39	Vengadu Tank	0.52	0.66
A-40	Balanallore Thumbanthaglam	0.52	0.09
A-41	Nemili Peria Eri	0.51	0.22
A-42	Pennallore Large Tank	0.49	0.53
A-43	Thandalam Manjanatheri	0.46	0.27
A-44	Balanallore Tank	0.44	0.16
A-45	Thirumanikuppam Big Tank	0.43	0.23
A-46	Thirumangalam Tank	0.42	0.33
A-47	Kanchivakkam Tank	0.41	0.47
A-48	Vallam Hissa Tank	0.41	0.83
A-49	Ninnakarai Tank	0.40	0.46
A-50	Irumbedu Tank	0.40	0.92
	Total	58.95	43.12

Source: JICA Expert Team

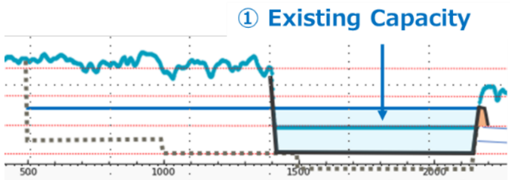
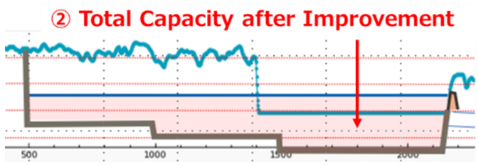


Source: JICA Expert Team

Figure 2-85: Location of Existing Tanks in the Adyar River (50 Tanks)

Improvement of 50 major tanks on the Adyar River (average depth of 3.4m) will increase storage capacity by 88MCM (88 million m3), which will serve as flood control capacity.

Table 2-40: Capacity Increase due to Tank Improvement in the Adyar River (Flood Control Capacity)

(1) Existing total storage capacity 59 MCM (number of tanks = 50) Total water storage capacity in **Table 2-39**	
(2) Total storage capacity after improvement 146.8MCM (number of tanks = 50) Total area 43.1km2 x average depth 3.4m = 146.8 MCM	
(3) Effective Storage Capacity: 117 MCM (= 146.8 × 0.8) *The effective storage capacity is set at 80% of the total storage capacity, considering sedimentation, etc.* Flood Control Capacity: 88 MCM (= 117 × 0.75) *75% of the effective storage capacity is utilized for flood control.*	

Source: JICA Expert Team

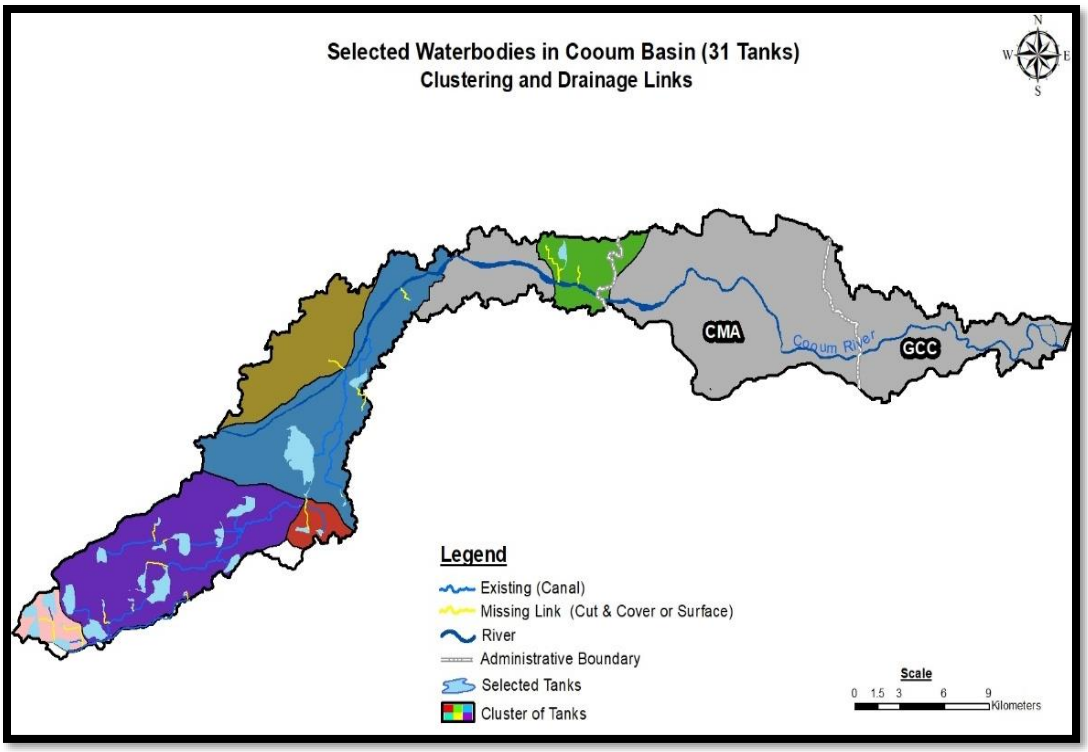
(2) Capacity increase on the Cooum River.

The list of existing tanks in the Cooum River is shown below. The combined existing capacity of the 31 main tanks is approximately 22.9MCM, with a total area of approximately 19.0 km^2.

Table 2-41: List of Existing Tanks in the Cooum River (31 Tanks)

New ID	Tank_Name	Cap_MCM	Area_Km2
C-1	Coovam Big Tank	5.19	4.07
C-2	Valathur Tank	1.83	1.32
C-3	Govindavadi Large Tank	1.42	1.31
C-4	Veliyur Tank	1.42	1.28
C-5	Govindavadi Chitheri	1.39	0.84
C-6	Edayarpakkam Tank	1.37	1.48
C-7	Satharai Tank	1.15	0.60
C-8	Parandur Pudueri Thangal	0.75	0.05
C-9	Thirumalpur Tank	0.72	1.19
C-10	Veliyur Chitheri	0.69	0.11
C-11	Thirur Hissa Tank	0.63	0.06
C-12	Ekanapuram Kali Eri	0.49	0.46
C-13	Kottavakkam Tank	0.48	0.85
C-14	Adigathur	0.47	0.08
C-15	Pudupattu Krishan Thangla	0.44	0.03
C-16	Parandur Large Tank	0.40	1.67
C-17	Elambakkam Tank	0.39	0.15
C-18	Peria Karumbur Malattu Thangal	0.38	0.11
C-19	Pallambakkam Tank	0.38	0.38
C-20	Parandur Kattupattur	0.32	0.09
C-21	Akkampuram Tank	0.31	0.30
C-22	Peria Karumbur Tank	0.29	0.56
C-23	Kavankolathur Tank	0.28	0.01
C-24	Veppamchittu Periya Eri	0.25	0.63
C-25	Perumalpattu Pudi Eri	0.23	0.01
C-26	Thandalam Soothiram Thangal	0.23	0.16
C-27	Kannan Thangal large tank	0.23	0.18
C-28	Pudupakkam Chitheri	0.22	0.02
C-29	Pullalur Peria Eri	0.20	0.86
C-30	Mappaedu Karai Thangal	0.20	0.01
C-31	Puddpattu Large Tank	0.20	0.13
	Total	22.94	18.99

Source: JICA Expert Team

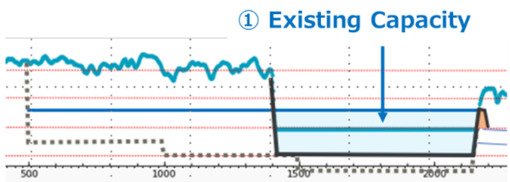
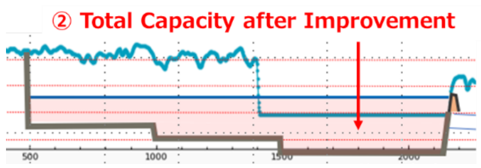


Source: JICA Expert Team

Figure 2-86: Location of Existing Tanks in the Cooum River (31 Tanks)

The improvement of 31 tanks on the Cooum River (average depth of 3.2m) will increase storage capacity by 38MCM (38 million m^3), which will provide flood control capacity.

Table 2-42: Capacity Increase due to Tank Improvement in Cooum River (Flood Control Capacity)

<table>
<tr><td>(1) Existing total storage capacity
<u>22.9 MCM (Number of tanks = 31)</u>
Total water storage capacity in the previous table.</td><td>
</td></tr>
<tr><td>(2) Total storage capacity after improvement
<u>60.8MCM (number of tanks = 31)</u>
Total area 19.0km2 x average depth 3.2m = 60.8 MCM</td><td>
</td></tr>
<tr><td colspan="2">(4) Effective Storage Capacity: 50 MCM (= 62.7 × 0.8)
The effective storage capacity is set at 80% of the total storage capacity, considering sedimentation, etc.
Flood Control Capacity: 38 MCM (= 50 × 0.75)
75% of the effective storage capacity is utilized for flood control.</td></tr>
</table>

Source: JICA Expert Team

(3) Capacity increase in Kosasthalaiyar River

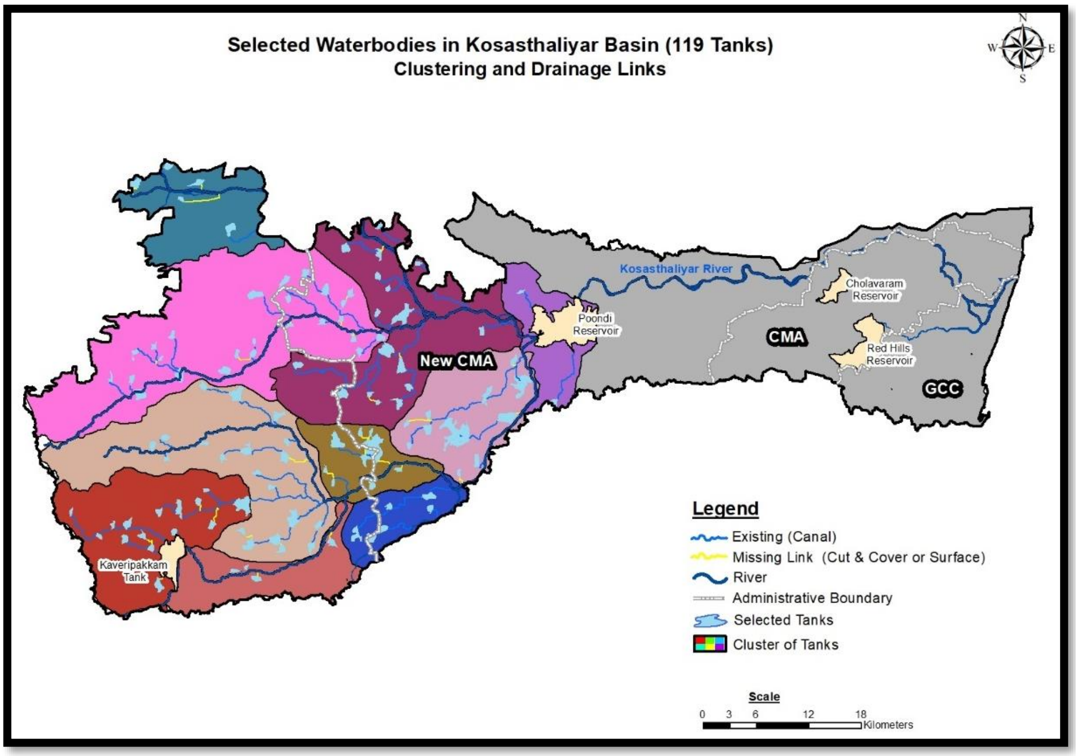
The list of existing tanks on the Kosasthalaiyar River is given below: The combined existing capacity of the 112 tanks is 115.2MCM, with a total area of approximately 81.3km^2.

Table 2-43: List of Existing Tanks in Kosasthalaiyar River (112 Tanks)

NewFID	Tank_Name	Cap_MCM	Area_Km2
K-57	Thuraiyur Tank	0.96	0.60
K-58	Valluvampakkam Tank	0.94	0.51
K-59	Peruvalayam Tank	0.91	0.64
K-60	Nangamangalam Tank	0.77	0.64
K-61	Jaderi	0.53	1.05
K-62	Manjakuppam Tank	0.72	0.58
K-63	Kolathur Tank	0.79	0.77
K-64	Perumanallur Tank	0.65	0.32
K-65	Chivada Tank	1.08	0.59
K-66	Panderavedu Tank	2.39	1.09
K-67	Ponnimangadu Big Tank	1.28	0.86
K-68	Nemili Tank	0.69	0.70
K-69	Arungulam Big Tank	0.64	0.54
K-70	Mamandur Periya Eri	0.58	0.34
K-71	Arumbakkam Tank	0.41	0.38
K-72	Pallipattu Tank	1.48	0.93
K-73	Veliagaram Cheruvu	2.05	1.26
K-74	Alamelumangapuram Tank	0.85	0.79
K-75	Maddur Big Tank	1.28	0.84
K-76	Murukampattu Tank	0.94	0.96
K-77	Satheranjayapuram Tank	0.62	0.59
K-78	Krishnasamudram Tank	2.00	1.23
K-79	Suriyanagaram Tank	0.78	0.47
K-80	Velanjeri Tank	0.60	0.49
K-81	Perungalathur	0.44	0.44
K-82	Kunnathur Tank	1.14	0.46
K-83	Nachiyarkuppam Tank	0.43	0.38
K-84	Tiruttani Big Tank	0.72	0.50
K-85	Agoor Big Tank	0.55	0.44
K-86	Chellathur Tank	0.51	0.49
K-87	Valarpuram tank	0.70	0.70
K-88	Kilanthur periya eri	0.62	0.47
K-89	Athipattu	0.42	0.51
K-90	Cherukkanur Chitteri	0.63	0.25
K-91	Mudhur hissa tank	3.32	2.01
K-92	Vilakkanampudi Tank	0.62	0.38
K-93	Kilanthur chitheri	0.55	0.51
K-94	Cherukkanur Big Tank	1.08	0.58
K-95	S.Agraharam Tank	0.68	0.45
K-96	Srikaligapuram Big & Smal	0.54	0.46
K-97	Vellur hissa tank	2.93	1.32
K-98	Vellathur Tank	0.63	0.27
K-99	Paravathur tank	0.78	1.03
K-100	Ayyaneri Tank	1.89	1.07
K-101	Veeramangalam Tank	0.69	0.36
K-102	Erumbi Tank	0.68	0.51
K-103	Vengapattu tank	0.65	0.62
K-104	Kilpakkam tank	0.77	0.59
K-105	Paranji tank	1.42	1.65
K-106	Polur big tank	1.83	1.37
K-107	Sholinghar tank	3.52	1.39
K-108	Mambakkam	0.53	0.37
K-109	Kavanoor tank	0.67	0.70
K-110	Uthurkannigal tank	0.44	0.29
K-111	Minnal periya eri	0.65	0.87
K-112	Kavanur chitheri	0.44	0.16
	Total	115.24	81.31

NewFID	Tank_Name	Cap_MCM	Area_Km2
K-1	Senrampalayam Tank	0.54	0.28
K-2	Pandur Tank	2.36	1.08
K-3	Palaiyanur Betha Cheruvu	0.97	1.17
K-4	Mosur Nammaneri	0.50	0.49
K-5	Manavur Hissa Tank	2.76	2.03
K-6	Puliyamangalam Tank	0.47	0.35
K-7	Mosur Big tank	0.98	0.92
K-8	Melpakkam Big Tank	0.52	0.44
K-9	Ammanur Vadakkeri	0.50	0.34
K-10	Nagavedu Tank	3.00	1.82
K-11	Pulivalam Tank	0.78	0.55
K-12	Avadam Big tank	0.54	0.44
K-13	Ammanur Therkkeri	0.56	0.33
K-14	Cheyyur Tank	0.45	0.36
K-15	Kunnathur Tank	1.13	1.09
K-16	Nandhimangalam Tank	0.54	0.67
K-17	Polipakkam tank	0.51	0.39
K-18	Beddekalakattur Big Tank	4.44	1.96
K-19	kilandurai Tank	0.69	0.60
K-20	Perumuchi Banal Eri	1.92	1.59
K-21	Melkalathur tank	1.28	0.95
K-22	Uriyur tank	0.67	0.81
K-23	Palayapalayam Tank	0.51	0.48
K-24	Soorai Tanki	0.41	0.32
K-25	Ochalam Tank	0.41	0.31
K-26	Anathapuram Tank	0.71	0.33
K-27	Kattupakkam Big Tank	0.45	0.42
K-28	Sirunamalli Tank	0.58	0.32
K-29	Illupaithandalam Tank	0.65	0.59
K-30	Velithangipuram tank	0.49	0.40
K-31	Banavaram Tank	0.75	0.28
K-32	Takkolam Big tank	1.06	0.95
K-33	Mahendravadi Tank	5.13	2.61
K-34	Mangalam big Tank	0.73	0.52
K-35	Govindacheri Tank	1.38	1.07
K-36	Pinnavaram Tank	0.42	0.51
K-37	Murungai Tank	0.68	0.50
K-38	Vangur tank	0.76	0.56
K-39	Kilveethi big Tank	2.01	1.83
K-40	Melakuppam Tank	0.45	0.29
K-41	Olugur Tank	1.18	0.80
K-42	Punnai Tank	0.84	0.61
K-43	Pudur Tank	1.21	0.62
K-44	Chittathur Tank	0.62	0.34
K-45	Pallur Chitteri	0.65	0.57
K-46	Synapuram Big Tank	0.83	1.18
K-47	KarnavoorTank	0.93	0.44
K-48	Pallur Big Tank	1.40	1.15
K-49	Ponnappnthangal Tank	0.43	0.44
K-50	Pandiyapakkam Tank	0.58	0.55
K-51	Uliyanallur Tank	2.21	1.27
K-52	Ammoor Allikulam Tank	0.82	0.34
K-53	Sengadu Tank	1.18	0.65
K-54	Siruvalayam Tank	1.45	1.15
K-55	Asanallikuppam Tank	0.74	0.73
K-56	Vettankulam Tank	1.07	0.75

Source: JICA Expert Team

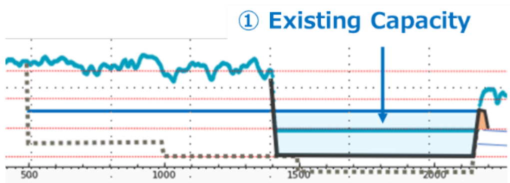
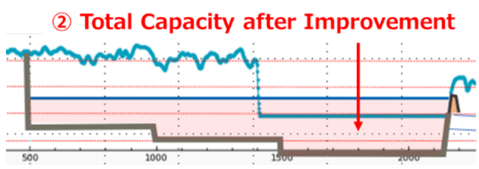


Source: JICA Expert Team

Figure 2-87: Location of Existing Tanks on the Kosasthalaiyar River (112 Tanks)

Improvement of 112 tanks (average depth 3.4m) on the Kosasthalaiyar River will increase storage capacity by 161 cm (161 million m3), which will serve as flood control capacity.

Table 2-44: Capacity Increase due to Tank Improvements in Kosasthalaiyar River (Flood Control Capacity)

(1) Existing potential storage capacity 276.5 MCM (Number of tanks = 112) Total water storage capacity in the previous table.	
(2) Calculation of potential existing capacity Total area 81.3 km2 x average depth 3.3m = 268.3 MCM	
(5) Effective Storage Capacity: 215 MCM (= 268.3 × 0.8) *The effective storage capacity is set at 80% of the total storage capacity, considering sedimentation, etc.* Flood Control Capacity: 161 MCM (= 215 × 0.75) *75% of the effective storage capacity is utilized for flood control*.	

Source: JICA Expert Team

2.4.1.5. Flood control capacity through the installation of new tanks

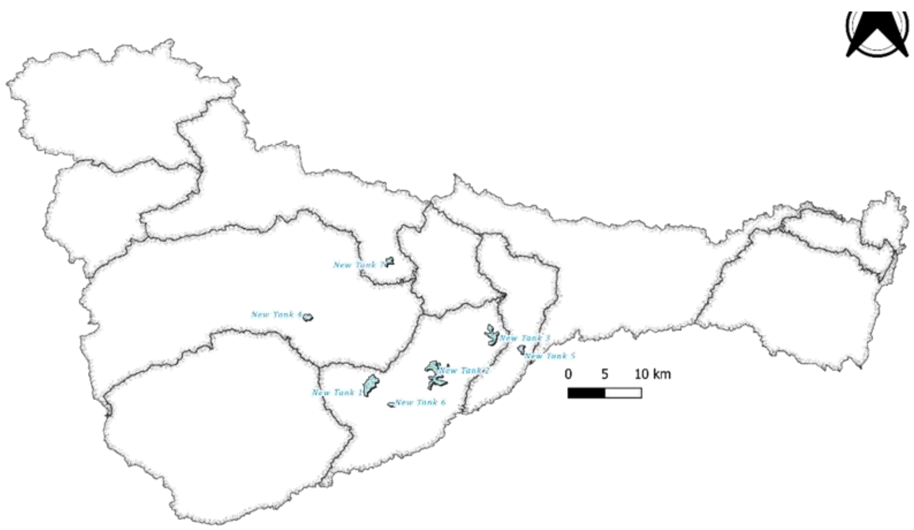
(1) Capacity increase in Kosasthalaiyar River

As for the Kosasthalaiyar River, since there is unused and undeveloped land within the basin, in addition to improving the flood control capacity of the existing tanks, consideration was given to securing flood control capacity through the development of new tanks. The following seven locations have been identified as potential sites: The construction policy for new tanks will be the same as the improvement policy for existing tanks, which will be to ensure storage capacity by evenly excavating the on-site ground surface. The total area of the following seven new tanks is 12.25 km^2.

Table 2-45: List of Potential Locations for New Tanks on the Kosasthalaiyar River (7 Tanks)

Sl no	Lattitude	Longitude	Peremeter Length_Km	Area_Sq km
New Tank 1	13.058	79.656	9.179	2.966
New Tank 2	13.072	79.740	23.195	4.678
New Tank 4	13.140	79.577	4.216	0.804
New Tank 3	13.119	79.810	10.334	2.033
New Tank 5	13.102	79.847	4.144	0.644
New Tank 6	13.033	79.683	2.850	0.366
New Tank 7	13.210	79.679	4.958	0.765
				12.257

Source: JICA Expert Team

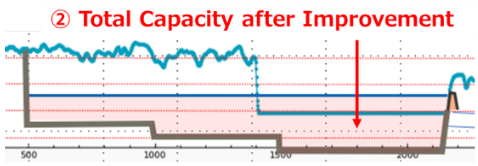


Source: JICA Expert Team

Figure 2-88: Location Map of Potential New Tank Sites along the Kosasthalaiyar River (112 Tanks)

The new tank will also be excavated to an average depth of 3.4m, just like the existing tank, which will enable a storage capacity of 42MCM.

Table 2-46: Increase in Capacity of the Kosasthalaiyar River due to New Tanks (Flood Control Capacity)

Total Flood Control Capacity: 52.7 MCM (*Total area: 12.25 km² × Average water depth: 4.3 m*) Effective Storage Capacity: 42 MCM= 52.7 × 0.8 (*80% of the total storage capacity, considering sedimentation*) Flood Control Capacity: 31.6 MCM= 42.1 × 1.0 (*New tanks are used exclusively for flood control.*)	

Source: JICA Expert Team

2.4.1.6. Flood control capacity of existing and reservoirs

The flood control capacity to be secured by rehabilitating existing tanks and developing new tanks in the three rivers of Adyar, Cooum and Kosasthalaiyar is shown in the table below.

Table 2-47: Estimation of Flood Control Capacity of Three Basins (Adyar, Cooum, Kosasthailiyar)

Summary of Flood Storage Capacity Estimation	Adyar Basin	Cooum Basin	Kosasthaliyar Basin
Average excavation depth	3.4 m	3.2 m	3.4 m
The selected number of waterbodies, tanks, and areas	50 (43.1 km²)	31 (19km²)	112 (81.3 km²)
a) Additional flood storage capacity by improving existing tanks and water bodies	88 MCM	38 MCM	161MCM
(1) Capacity of tanks after improvement (MCM)	146.6 MCM (43.1km²*3.4m=146.6)	60.8 MCM (19km²*3.2m=60.8)	276.5 MCM (81.3km²*3.4m=276.5)
(2) Current capacity of tanks and water bodies	58.5 MCM	22.8 MCM	115.2 MCM
Additional flood storage capacity=(2) - (1)	88MCM (146.6-58.5=88.1)	38MCM (60.8-22.8=38)	161MCM (276.5-115.2=161.3)
b) Flood storage capacity of new tanks	No need	No need	42 MCM (7 new tanks, 12.25km²) (12.25km²*3.4m=41.7)
Total flood storage capacity in tanks and waterbodies (a+b)	**88 MCM**	**38 MCM**	**203MCM**

Source: JICA Expert Team

2.4.1.7. Study of flood control effectiveness of existing tanks and reservoirs

In this study, the effects of flood storage capacity in tanks and reservoirs were calculated and compared for five scenarios (see below) using the HEC-HMS model. The increase in flood storage capacity here refers to the percentage of the maximum developed capacity of the tanks and reservoirs in each river, as summarized in the previous section.

Based on these conditions, the runoff analysis in Chapter 2.2 was conducted and the flood storage capacity was set to use 75% of the enhanced flood storage capacity to ensure flood control safety during a rainfall event with a 100-year return period as the designed flood flow in this master plan.

Scenario 1: Baseline conditions (existing conditions: no improvements)

The amount of runoff was calculated under the existing conditions. No tank or reservoir improvements are considered in this case.

Scenario 2: Using 25% of enhanced flood storage capacity
Scenario 3: Using 50% of enhanced flood storage capacity
Scenario 4: Using 75% of enhanced flood storage capacity
Scenario 5: Using 90% of enhanced flood storage capacity

The below tables respectively summarize the simulation results of the above five scenarios' peak discharge (100-year and 50-year return period) at flood control points over the three years.

Table 2-48: Simulation Results of the Effect of Utilizing Waterbodies and Tanks in the Adyar Basin on Peak Flood Hydrograph for 100 and 50 Years Return Period

Decreases in Peak Flood Hydrograph at Confluence with CBM Surplus					
Return Period	No Storage	15 MCM (25%)	42 MCM (50%)	87 MCM (75%)	102 MCM (90%)
50	3789 m3/s	3510 m3/s	3027 m3/s	2530 m3/s	2251 m3/s
100	4417 m3/s	4167 m3/s	3687 m3/s	3194 m3/s	2894 m3/s

Source: JICA Expert Team

Table 2-49: Simulation Results of the Effect of Utilizing Waterbodies and Tanks in the Cooum Basin on Peak Flood Hydrograph for 100 and 50 Years Return Period

Decreases in Peak Flood Hydrograph at Paruthippattu					
Return Period	No Storage	10 MCM (25%)	27 MCM (50%)	38 MCM (75%)	43 MCM (90%)
50	1313 m3/s	1172 m3/s	1001 m3/s	890 m3/s	859 m3/s
100	1522 m3/s	1395 m3/s	1208 m3/s	1070 m3/s	1018 m3/s

Source: JICA Expert Team

Table 2-50: Simulation Results of the Effect of Utilizing Waterbodies and Tanks in the Kosasthailiyar Basin on Peak Flood Hydrograph for 100 and 50 Years Return Period

Decreases in Peak Flood Hydrograph at Poondi Dam (Dam Inflow)					
Return Period	No Storage	52 MCM (25%)	138 MCM (50%)	203 MCM (75%)	225 MCM (90%)
50	5022 m3/s	3978 m3/s	2561 m3/s	2016 m3/s	1839 m3/s
100	6152 m3/s	5166 m3/s	3502 m3/s	2598 m3/s	2426 m3/s

Source: JICA Expert Team

2.4.2 Flood storage in the upstream of Kosasthalaiyar Basin

In the upstream area of the Kosasthalaiyar basin, outside the new CMA (Chennai Metropolitan Area), the predominant land uses include agricultural land, natural forests and tanks. Most of the tanks and reservoirs in this area are formed based on the natural topography and are uncontrolled. Some of them are used for agriculture.

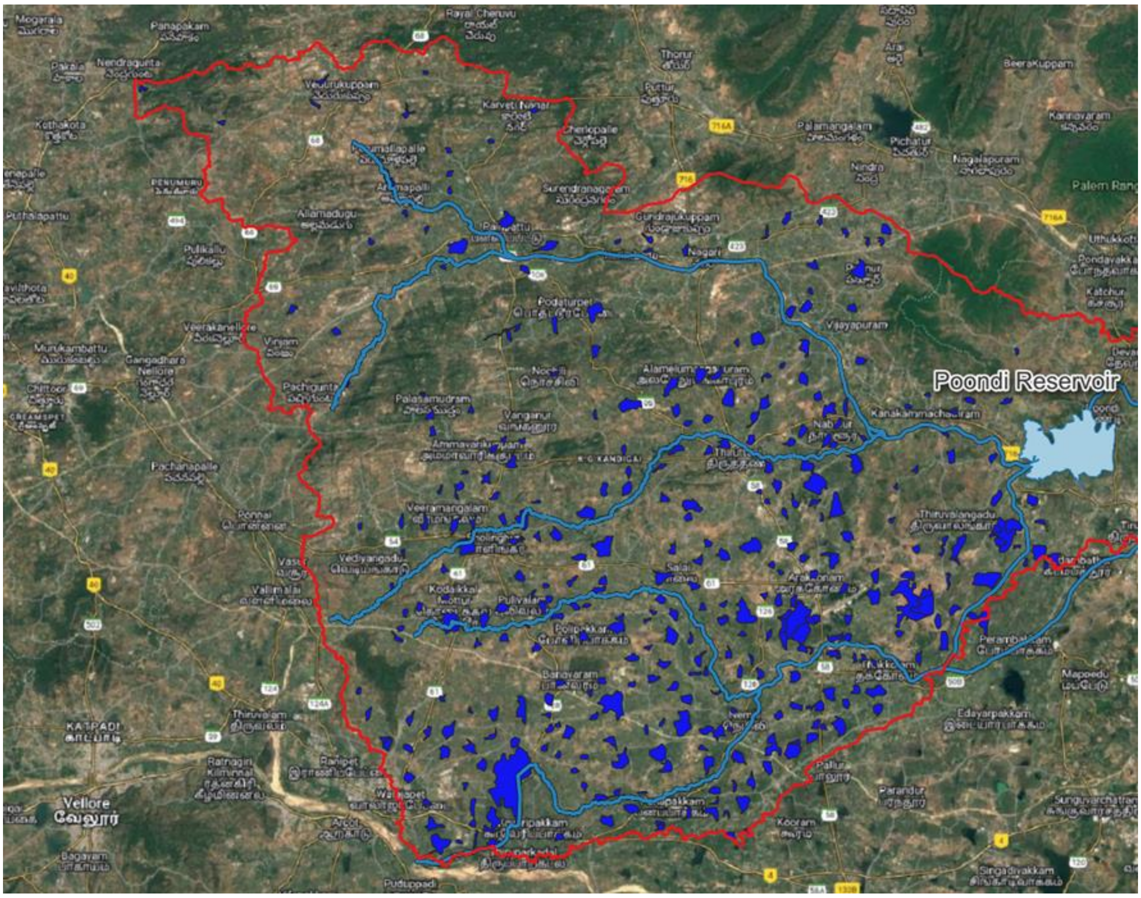
The master plan needs to control flooding due to high runoff from this area. The study team's plan needed to reduce the runoff volume for the 100-year return period flood from 945 m3/s to 400 m3/s. Three options were considered as measures to achieve this goal.

The first option was to build new dams and reservoirs. However, initial studies by the TNWRD raised concerns about environmental impacts, lack of funds, and challenges related to operation and maintenance of such dams far from Chennai. For these reasons, this option was ruled out.

The second option was to construct a new continuous flood control levee along the New CMA boundary. This continuous levee structure was welcomed by the TNWRD for both flood control and transportation purposes, as it would not only act as a barrier to prevent upstream floodwaters from entering the New CMA area, but would also allow for road use of the upper surface. However, it was difficult to obtain a firm written endorsement of the solution from TNWRD due to concerns about funding availability, social and environmental impacts, and feasibility due to a lack of detailed studies.

As a third option, the use of existing tanks and waterbodies was explored. In this regard, 380 natural ponds and reservoirs in the upstream area of Poondi Dam have been identified (Figure 2-89). The simulation result using HEC-HMS shows a flood storage depth of only 0.5 meters (less than 2 feet) in these 360 tanks and waterbodies are sufficient to retain floodwaters generated in this area, preventing them from flowing downstream toward Poondi Dam during a rainfall event with a 100-year return period.

Currently, these tanks and water bodies function naturally as flood storage areas. However, for long-term conservation and protection, two important concerns must be addressed: first, the risk that these water bodies will be reduced with development as the current Chennai urban area expands into the new CMA area. Since development could lead to the disappearance or significant reduction of these tanks and water bodies, it is critical that the current tanks and water bodies be maintained and preserved in order to continue to effectively reduce flood runoff.



Source: JICA Expert Team

Figure 2-89: Location of Selected 380 Natural Tanks and Waterbodies Upstream of Poondi Dam

2.4.3 River improvement

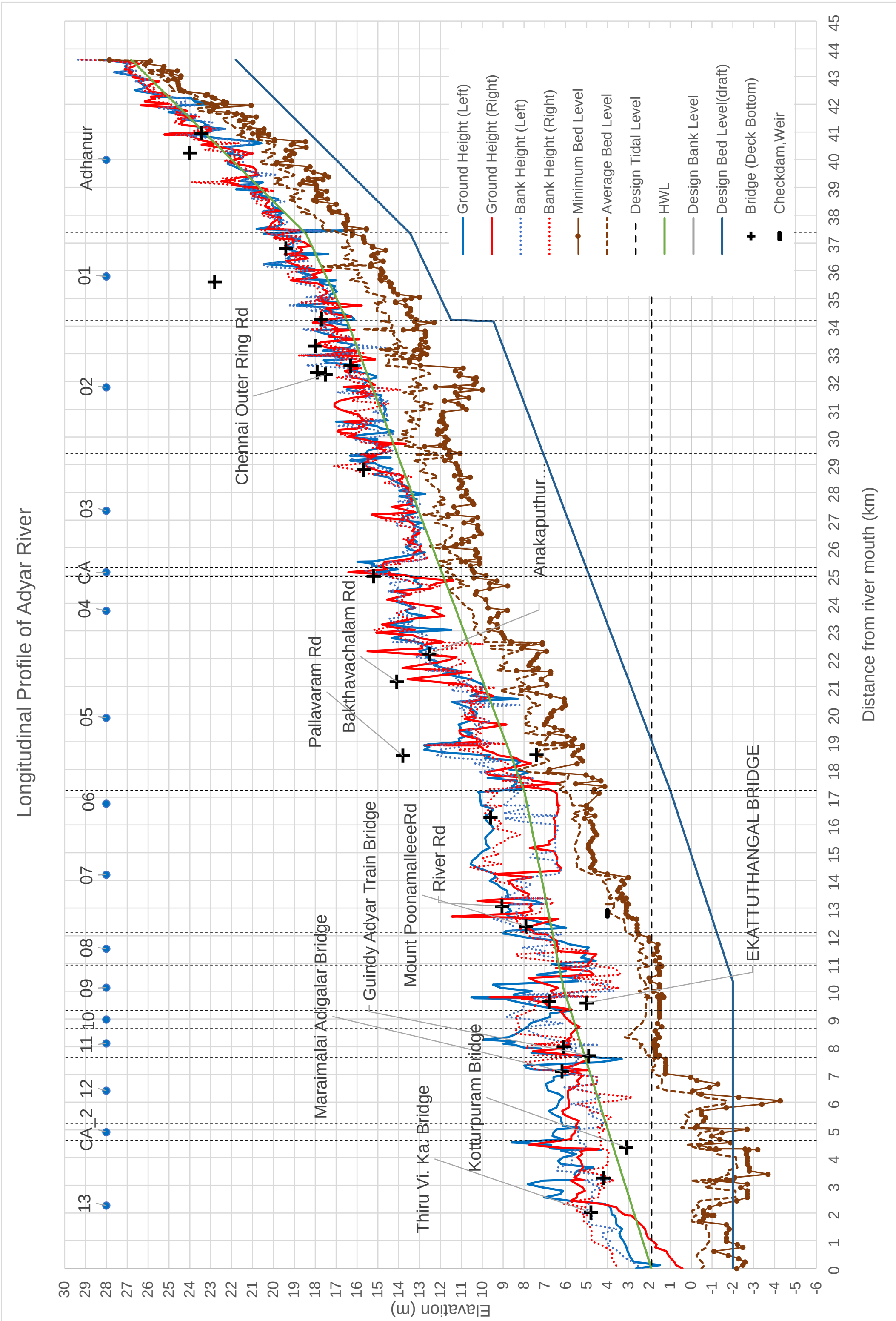
(1) Longitudinal planning

The designed high water levels, designed riverbed elevations, and designed levee heights of the target rivers are summarized in Figure 2-90 to Figure 2-93.

The design high water level is set at a position that envelops the current riverbank elevation and the ground elevation behind it, starting from the mean lunar high tide level (DL) of the Bay of Bengal + 0.5 m, and is planned as a dug river channel without the construction of embankments. Based on this, the estimate has been revised based on the design high tide level in the Bay of Bengal (DL+1.9m) and the non-uniform flow calculation water level based on the minimum riverbed elevation at the river mouth examined in 2.3.15

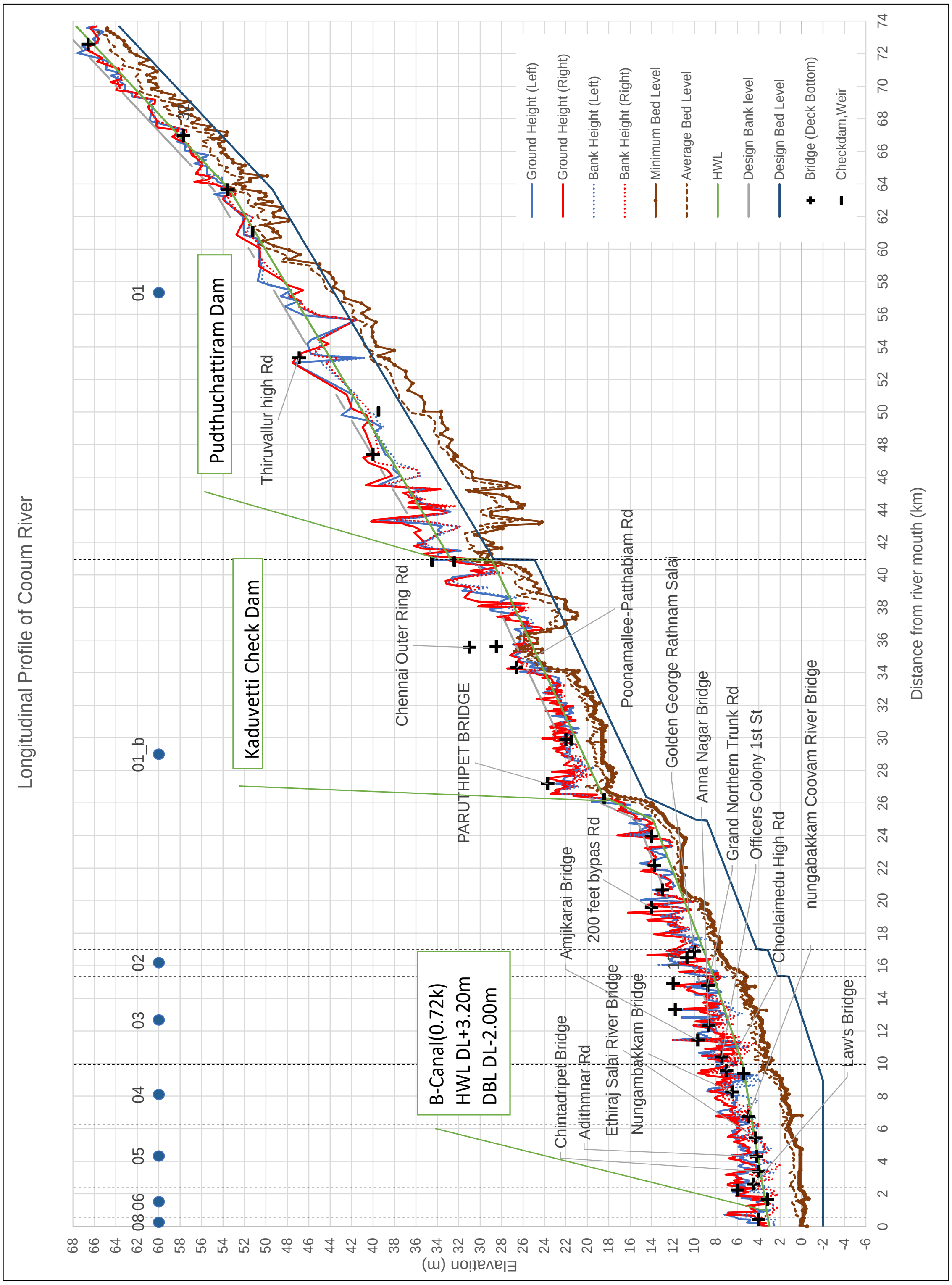
Embankments will be necessary in some sections where the current riverbank height and background height are low. The embankment section needs to be built up to the design embankment height because there is concern that it may collapse if the water overflows. The allowance for embankments will be 1.5m, following Indian standards.

The design riverbed elevation was set based on the design water depth in the uniform flow calculation summarized in Section 2.3.10, and taking into account the sustainability of the river mouth, the minimum riverbed elevation was set at DL-2m.



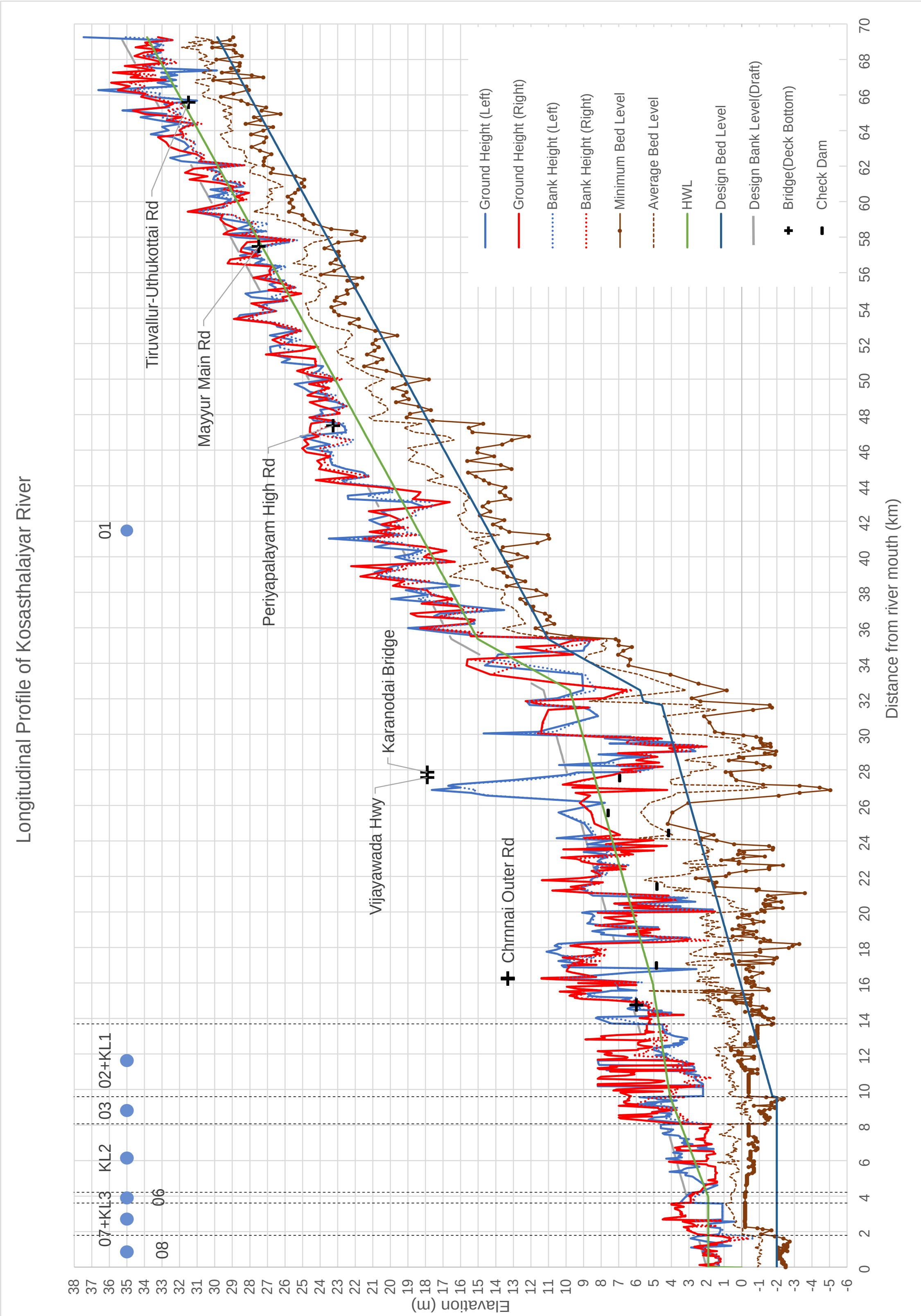
Source: JICA Expert Team

Figure 2-90: Design Longitudinal Profile of the Adyar River



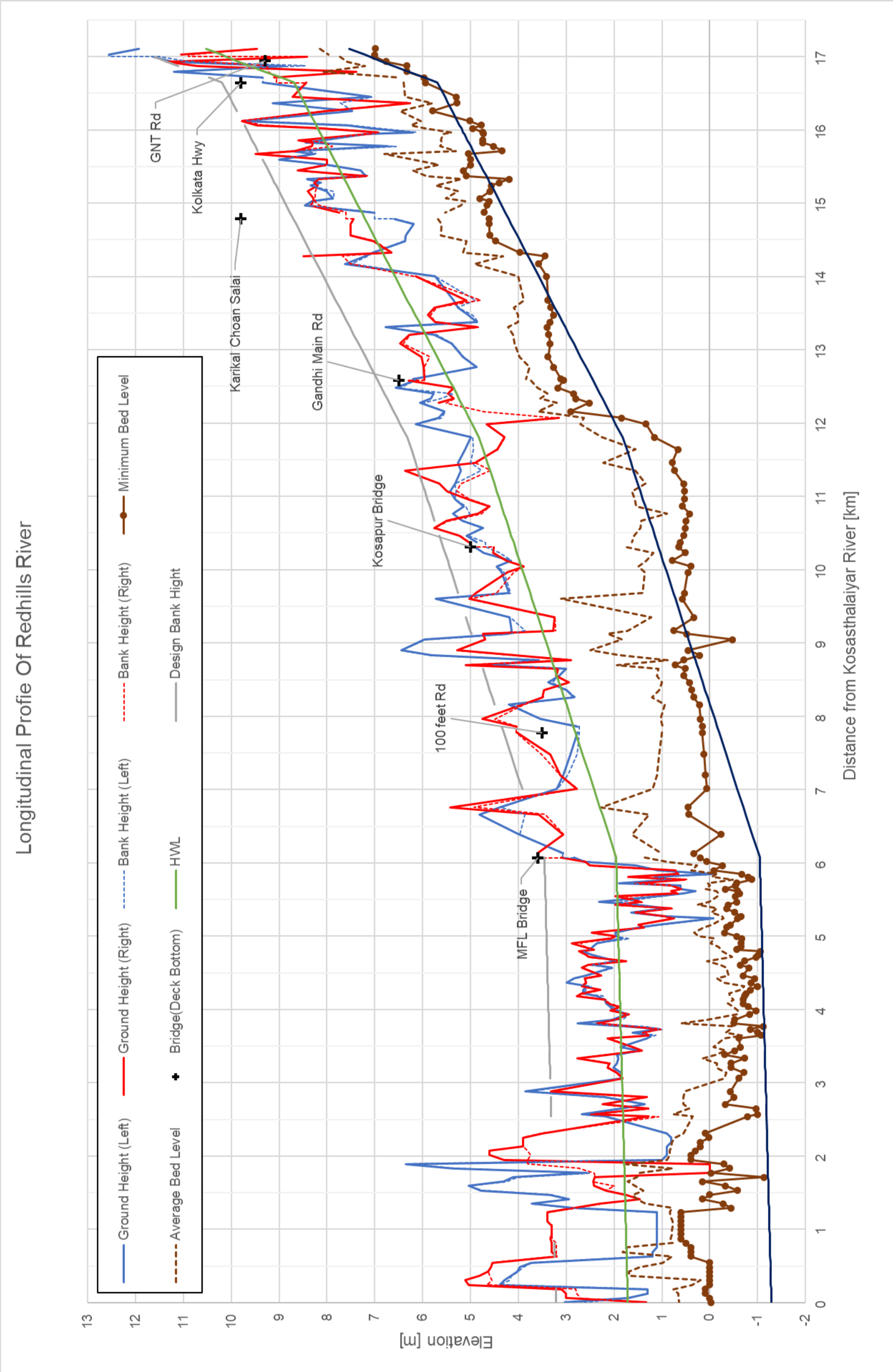
Source: JICA Expert Team

Figure 2-91: Design Longitudinal Profile of the Cooum River



Source: JICA Expert Team

Figure 2-92: Design Longitudinal Profile of the Kosasthalaiyar River



Source: *JICA Expert Team*

Figure 2-93: Design Longitudinal Profile of the Redhills River

(2) Cross-sectional and floor plan

The river cross-sectional shape was determined based on the necessary river width to convey the design high water discharge, as outlined in Section 2.3.13, considering the average river width of continuous sections with similar river conditions, such as between tributary confluence points. The required width of river expansion for each river's continuous sections is organized as detailed in Section 2.3.14.3.

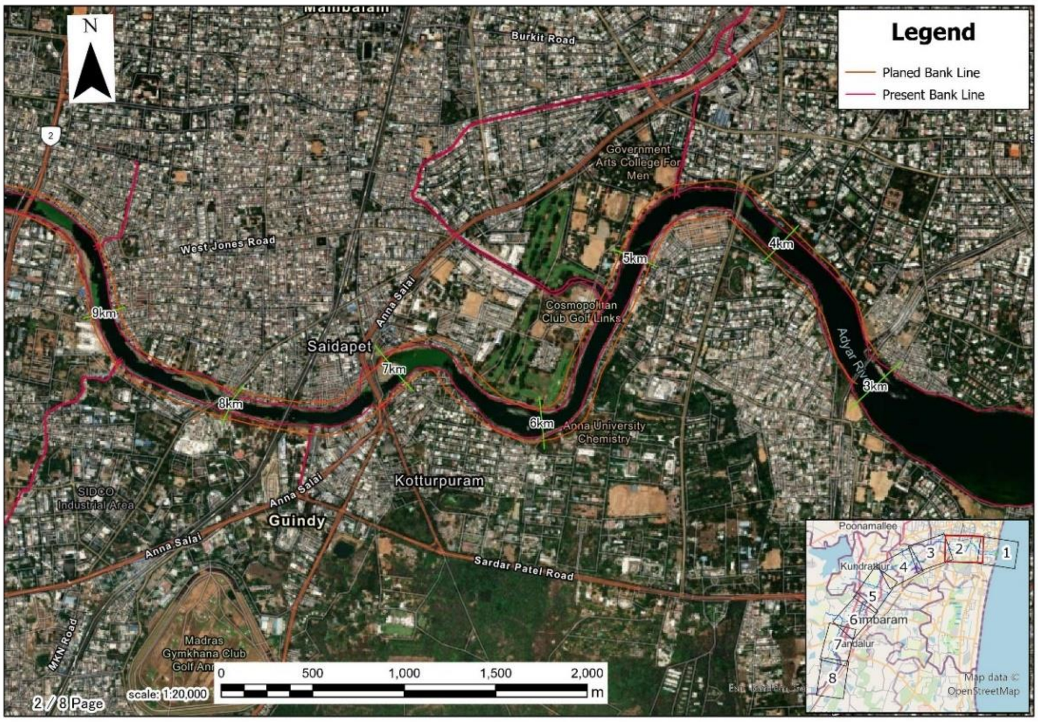
Figure 2-94 shows the conceptual plan of the river alignment for the Cooum River. The pink line represents the current riverbank position, while the orange line indicates the riverbank position after securing the required river width. In this way, the future river expansion line was established, and based on this, various project costs were calculated.

As mentioned earlier, in this study, the approximate required river width for each continuous section was examined using uniform flow calculations. In the future, when conducting detailed river channel design, it will be necessary to use water level calculations that take into account the effects of upstream and downstream cross-sections, such as through non-uniform flow calculations, and to consider adjustments to the river alignment and width expansion

The plan views for each river will be shown on the following pages.

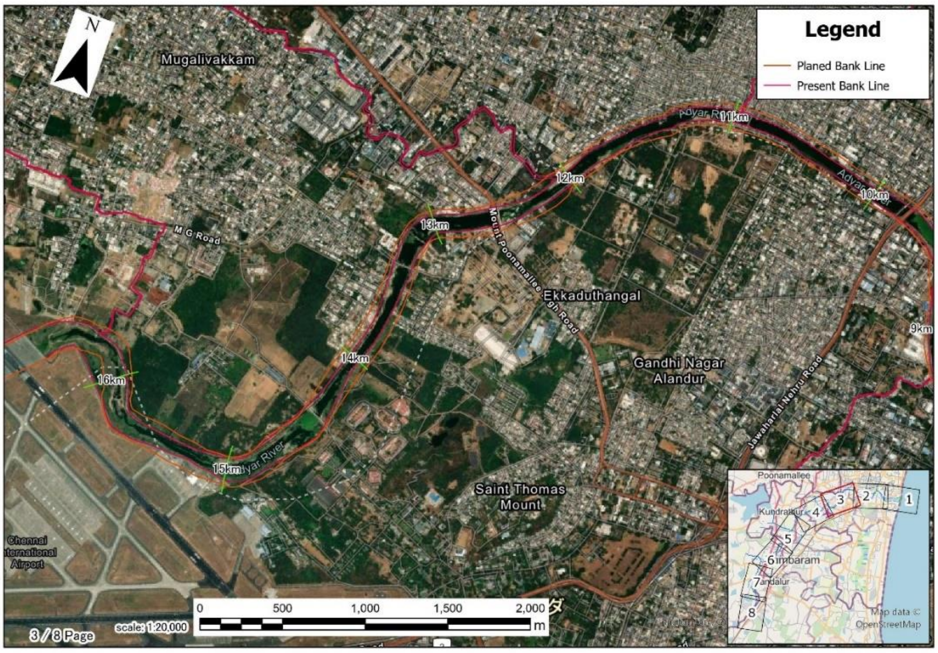
Source: JICA Expert Team

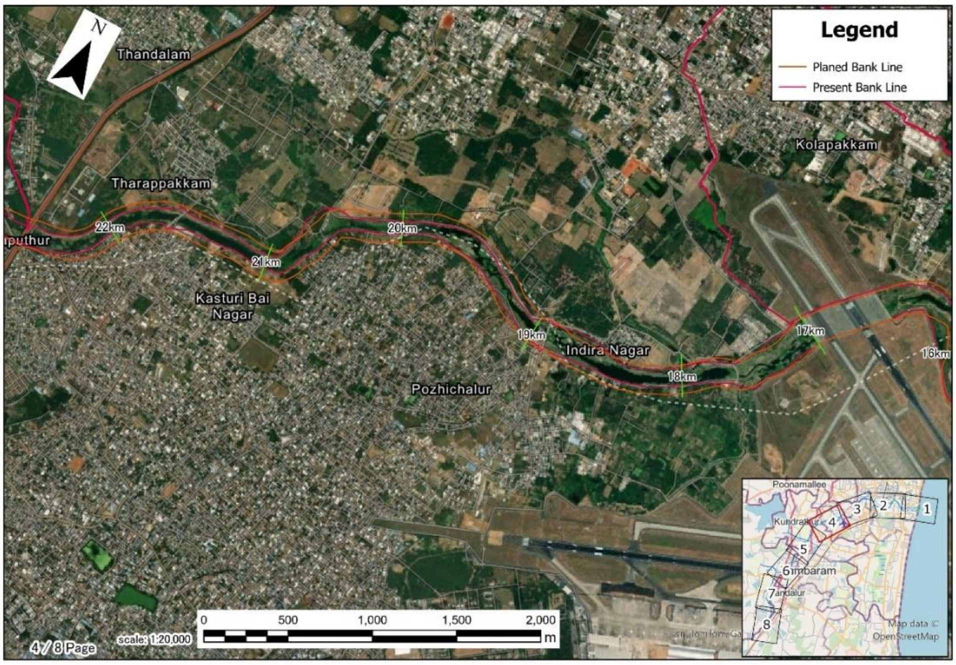
Figure 2-94: Image of River Channel Widening Line (Cooum River)



Source: JICA Expert Team

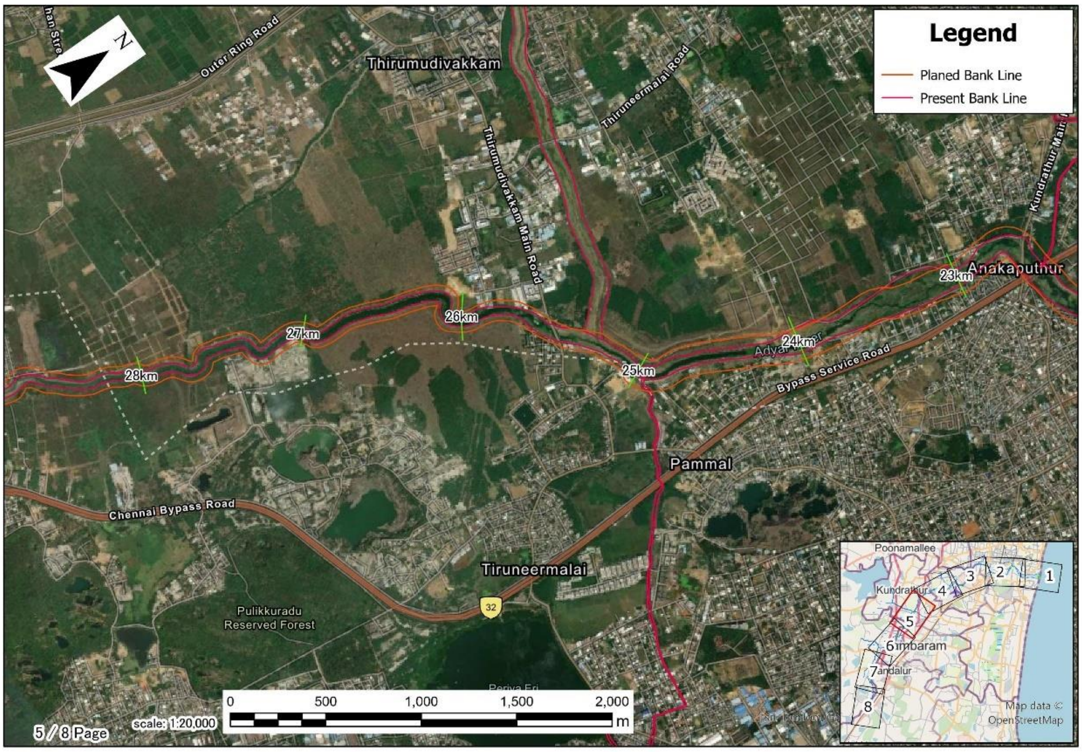
Figure 2-95: Plan View of the Adyar River Dredged Channel (1/4)

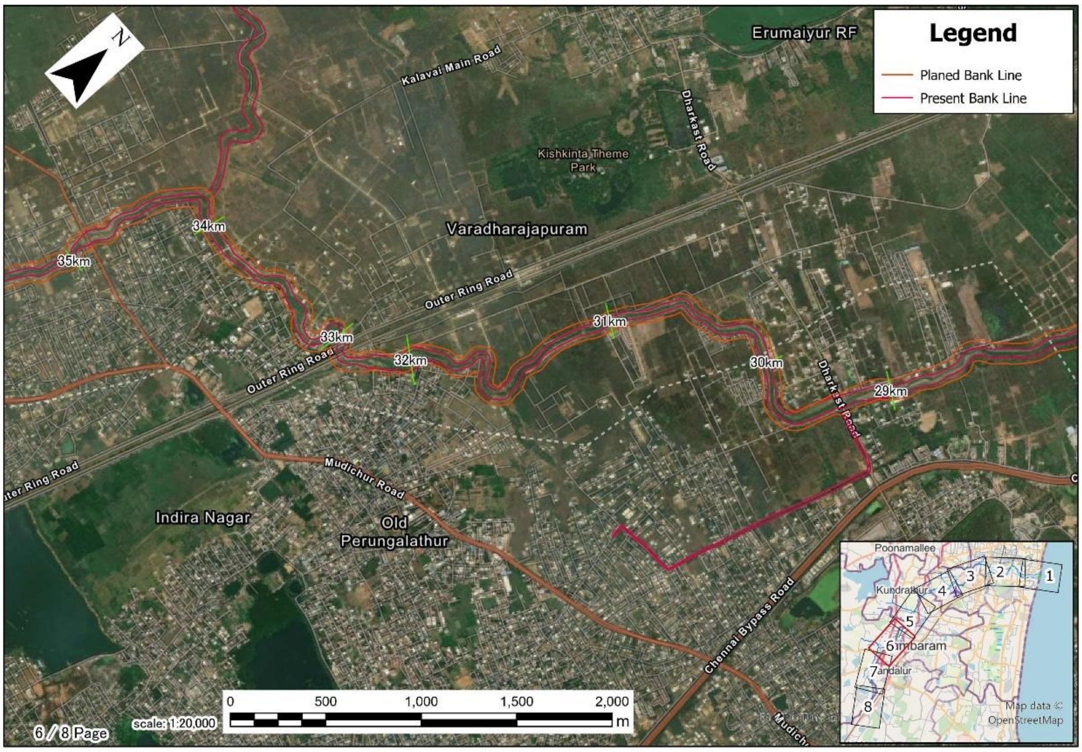




Source: JICA Expert Team

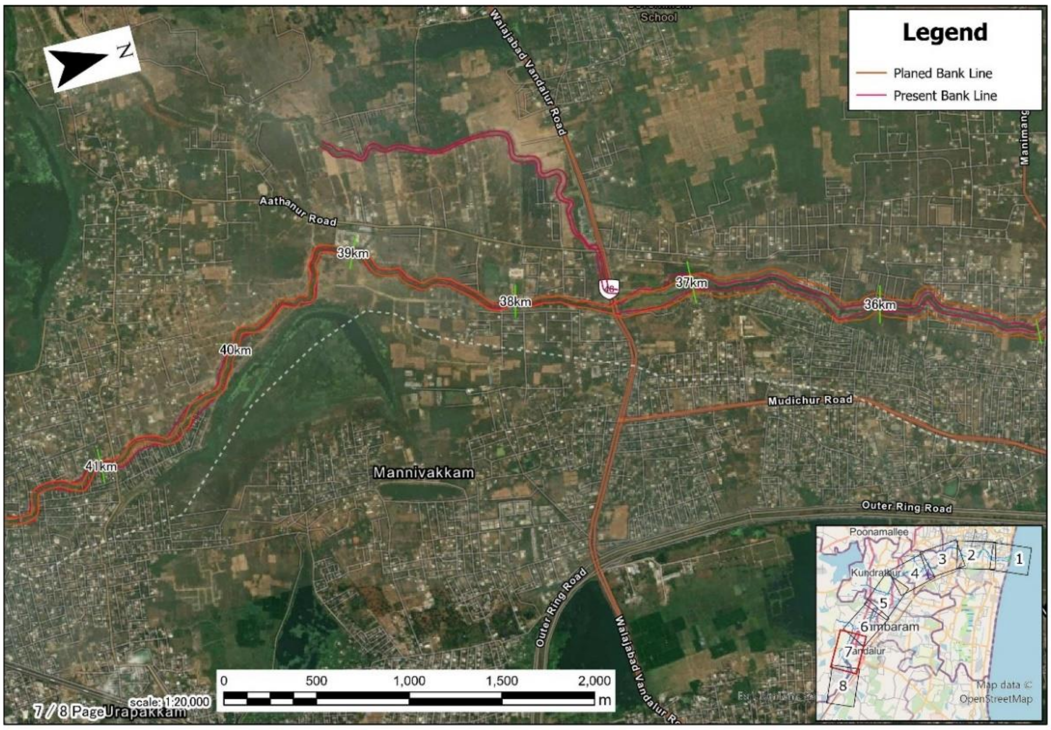
Figure 2-96: Plan View of the Adyar River Dredged Channel (2/4)

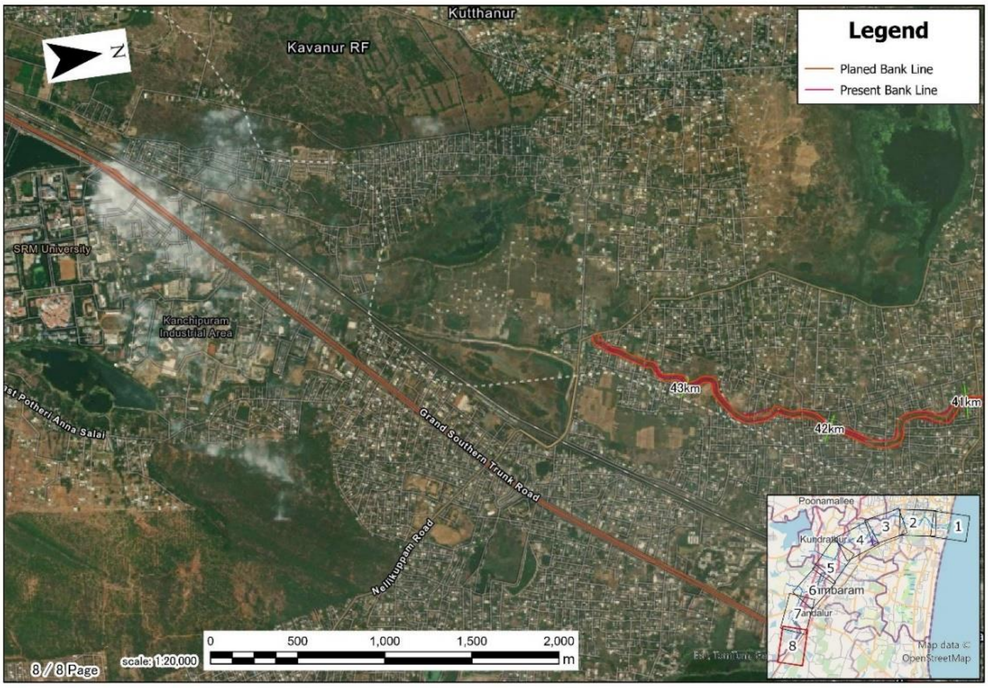




Source: JICA Expert Team

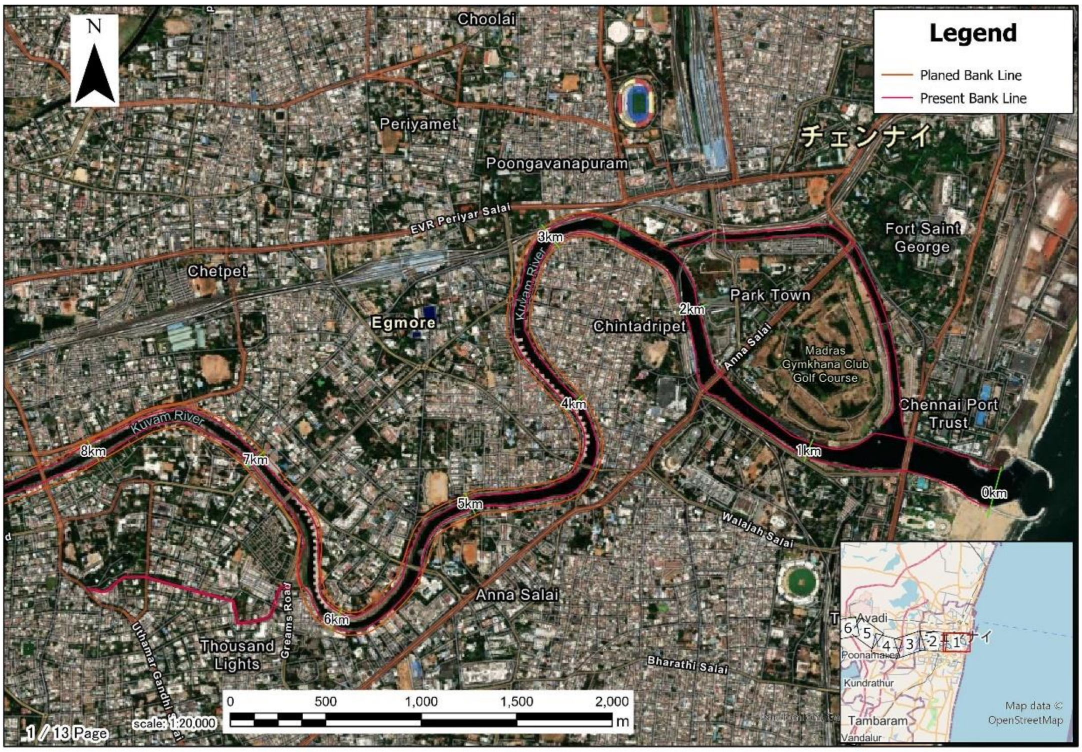
Figure 2-97: Plan View of the Adyar River Dredged Channel (3/4)

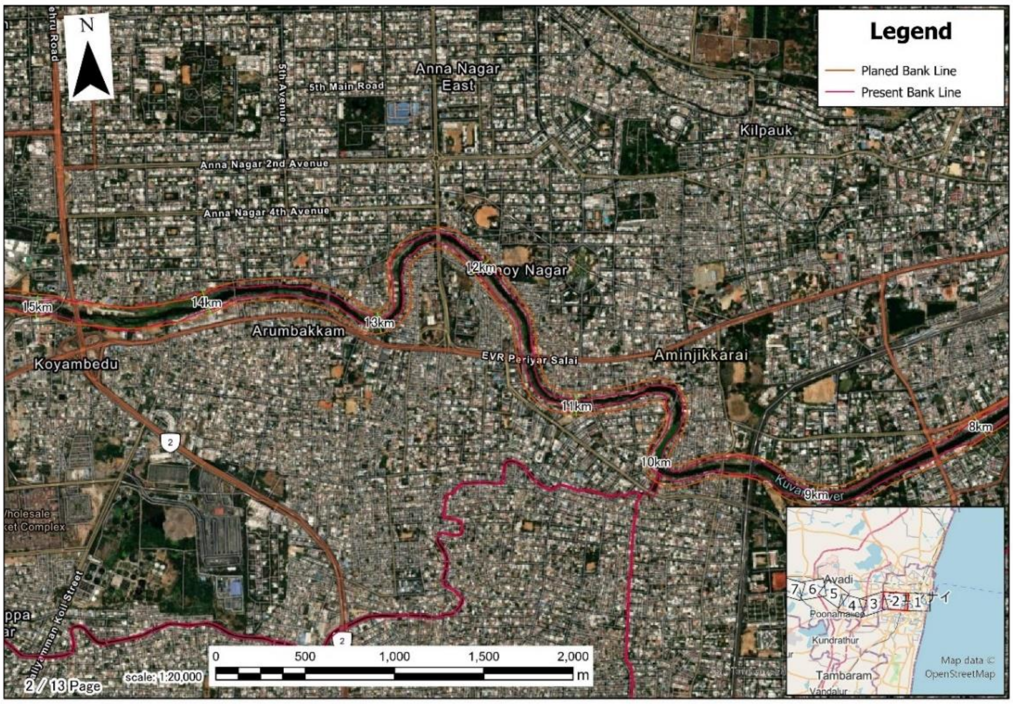




Source: JICA Expert Team

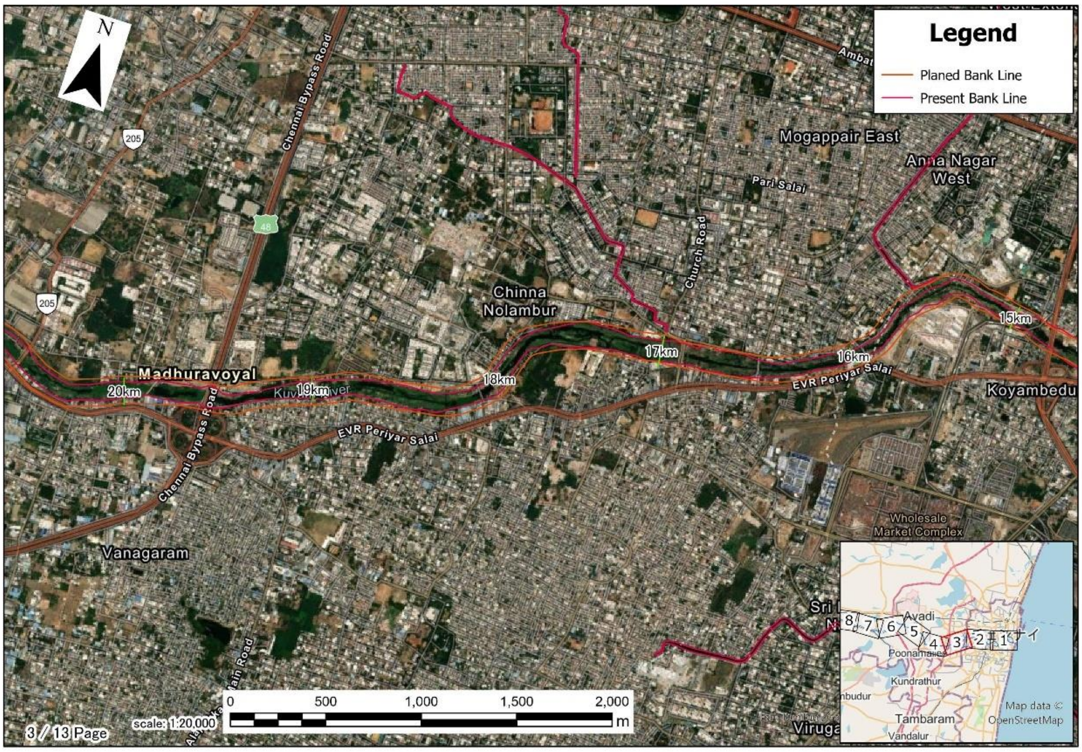
Figure 2-98: Plan View of the Adyar River Dredged Channel (4/4)

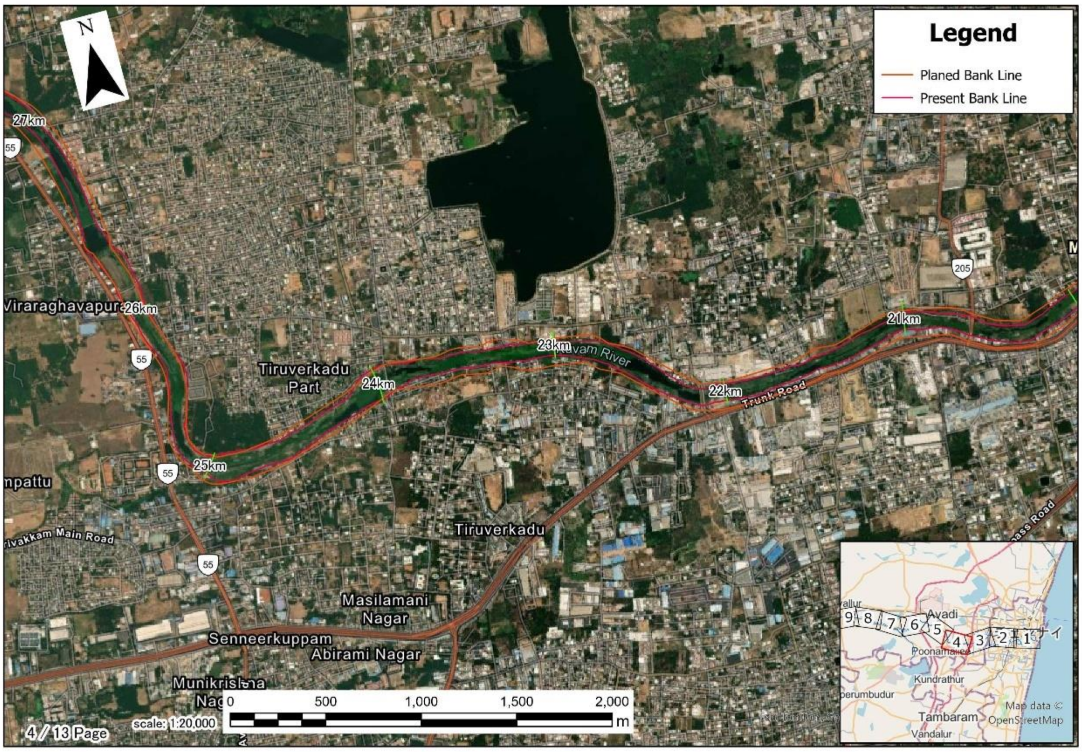




Source: JICA Expert Team

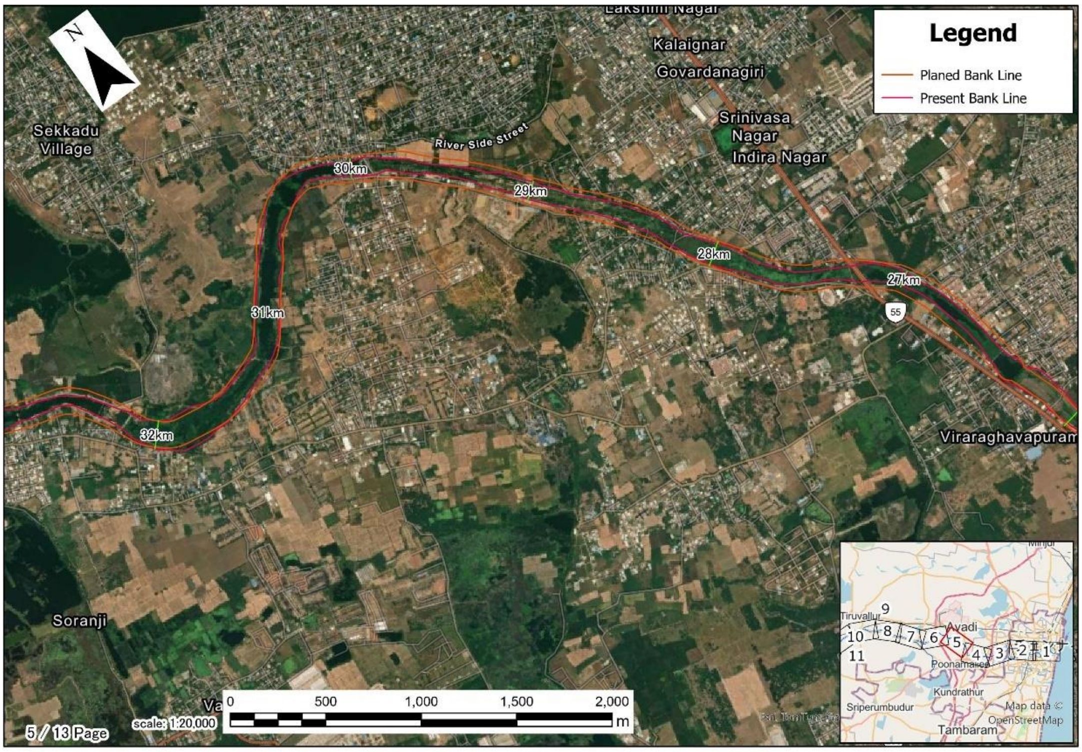
Figure 2-99: Cooum River Excavation River Channel Plan (1/7)

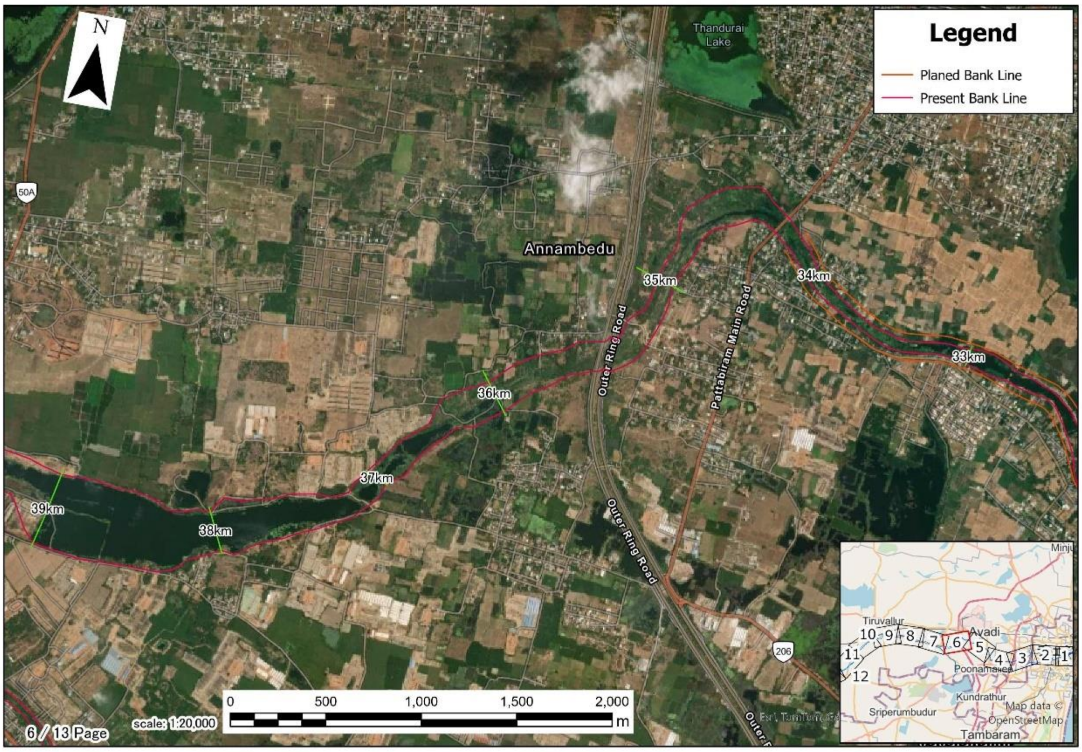




Source: JICA Expert Team

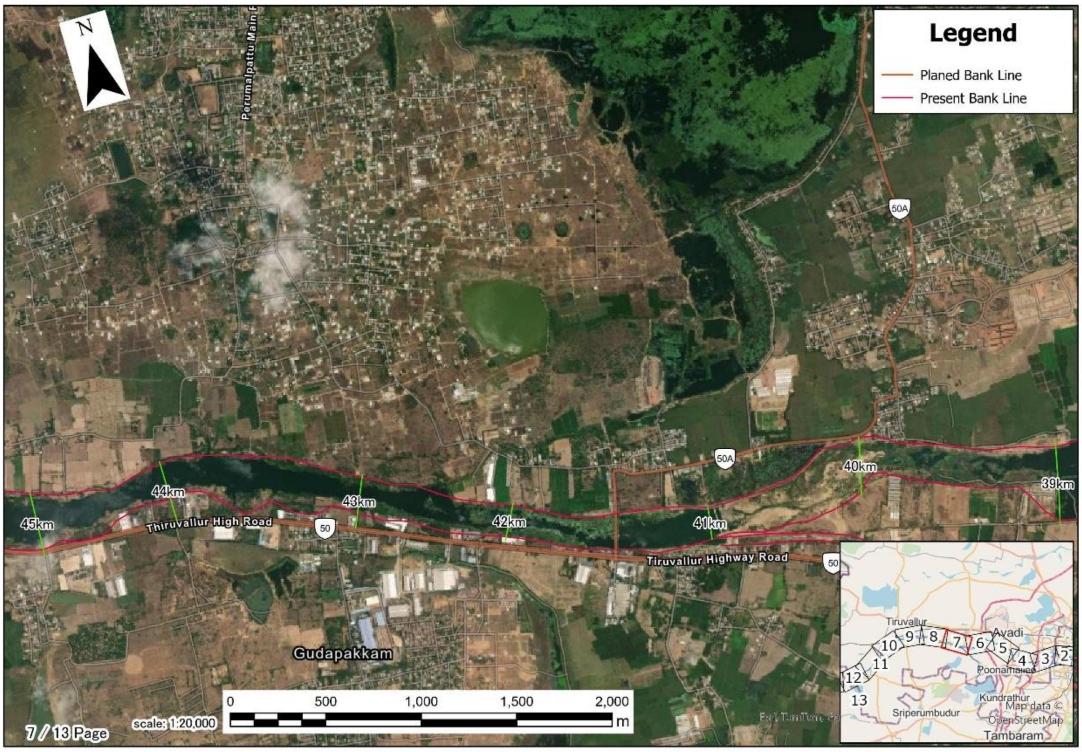
Figure 2-100: Cooum River Excavation River Channel Plan (2/7)

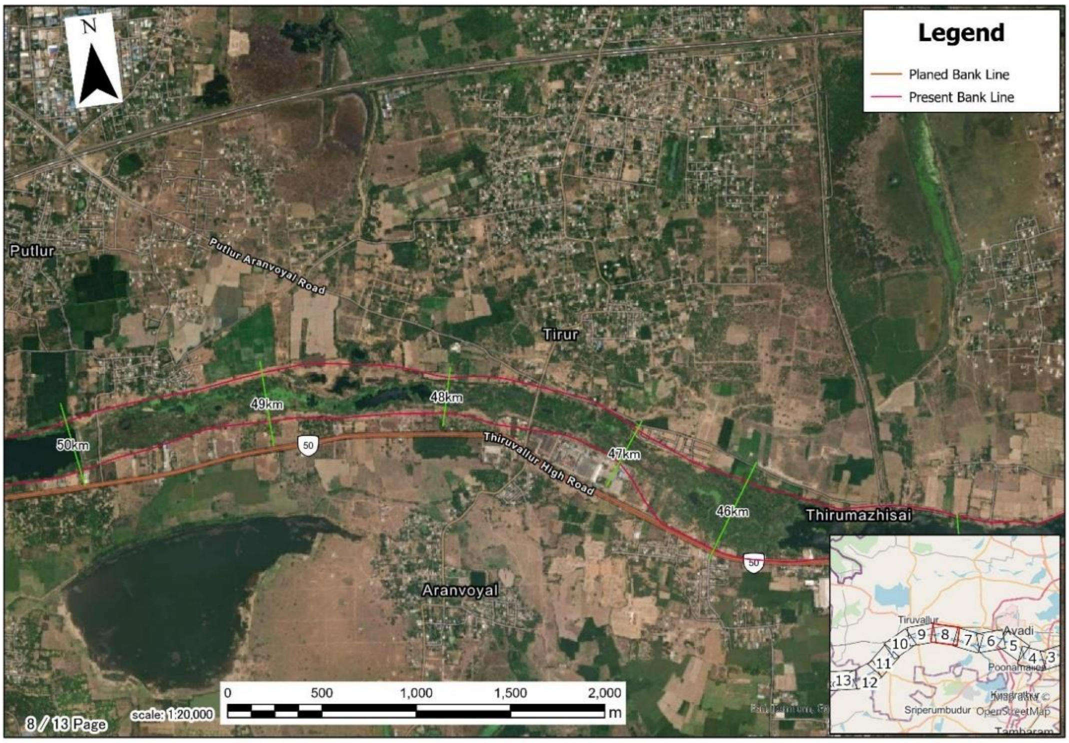




Source: JICA Expert Team

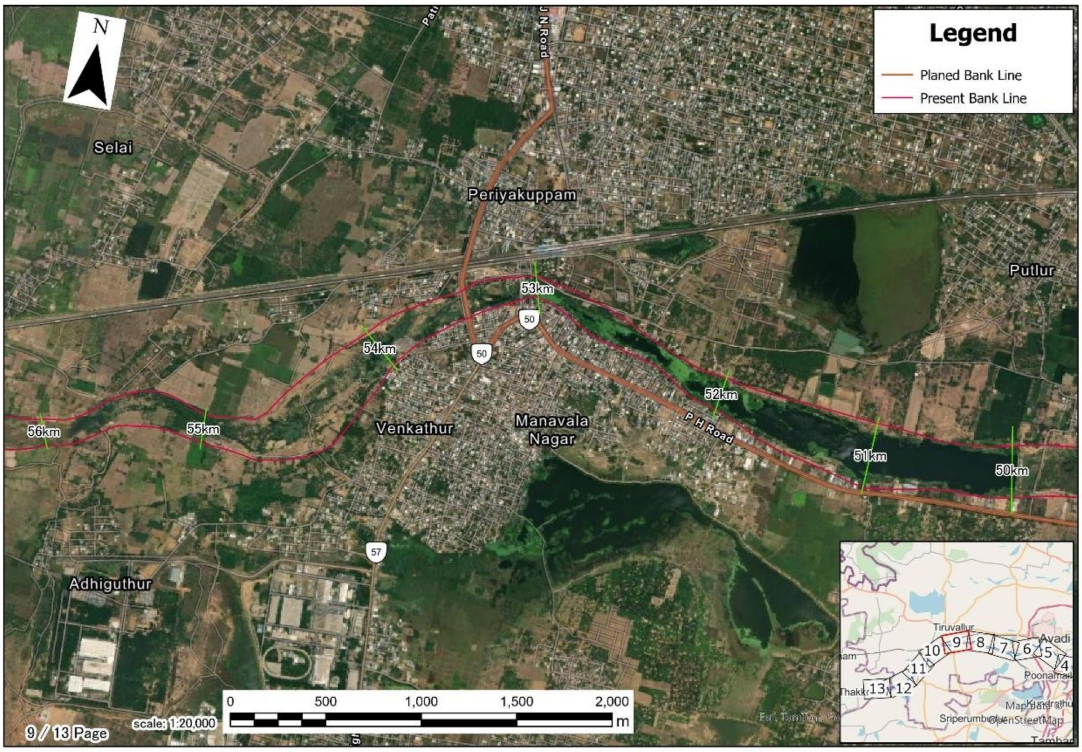
Figure 2-101: Cooum River Excavation River Channel Plan (3/7)

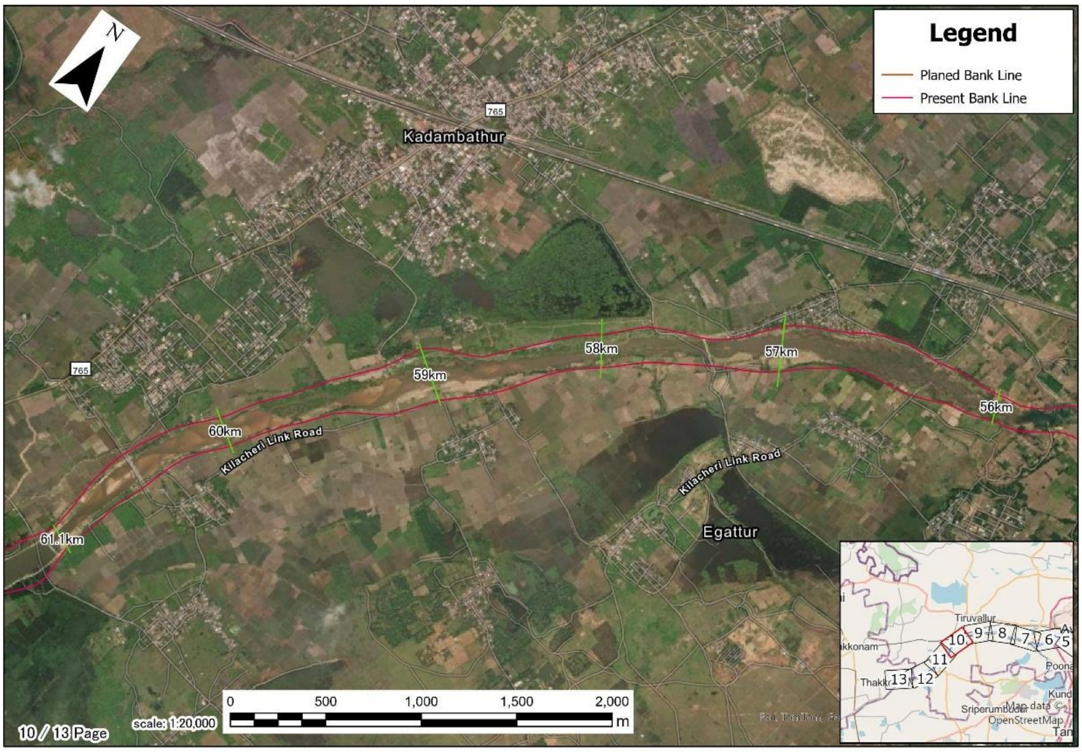




Source: JICA Expert Team

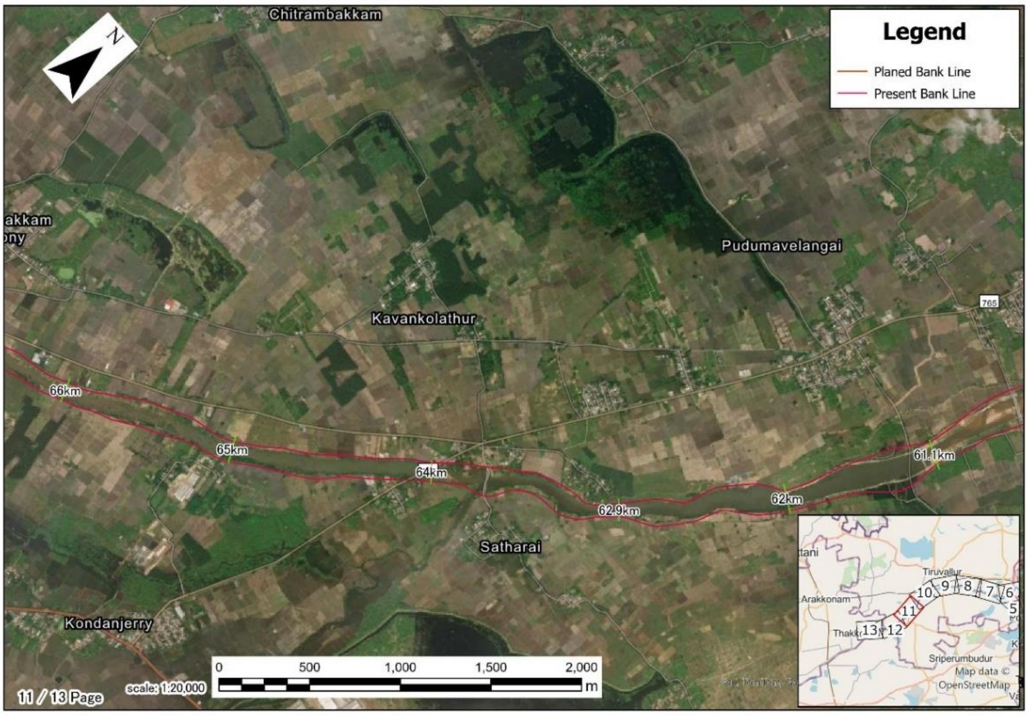
Figure 2-102: Cooum River Excavation River Channel Plan (4/7)

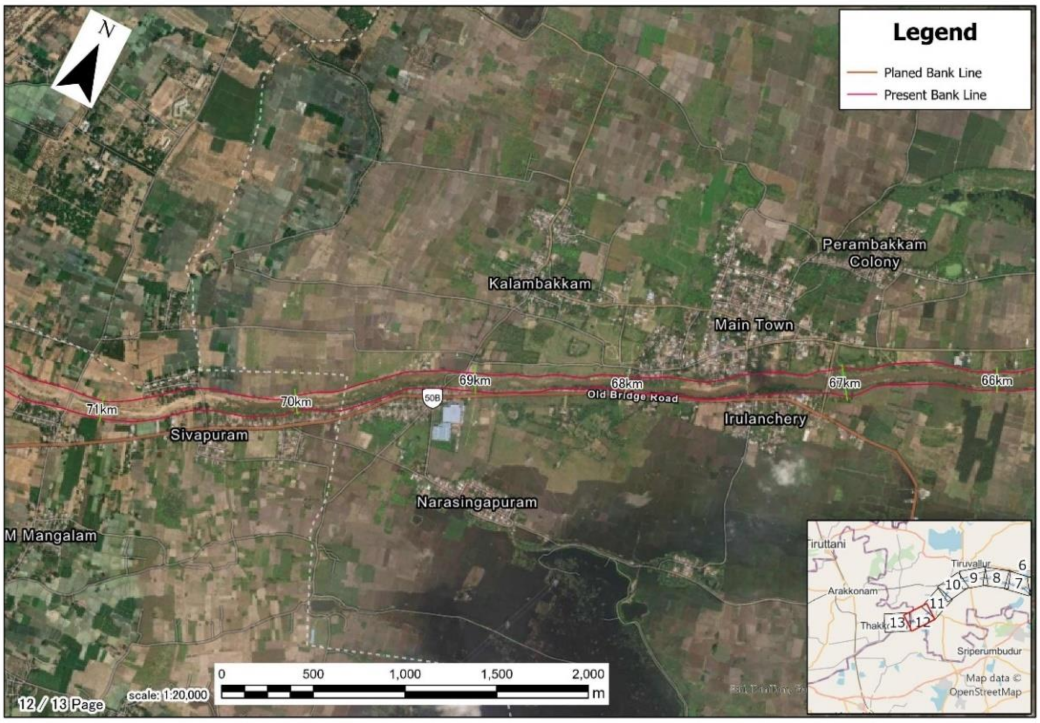




Source: JICA Expert Team

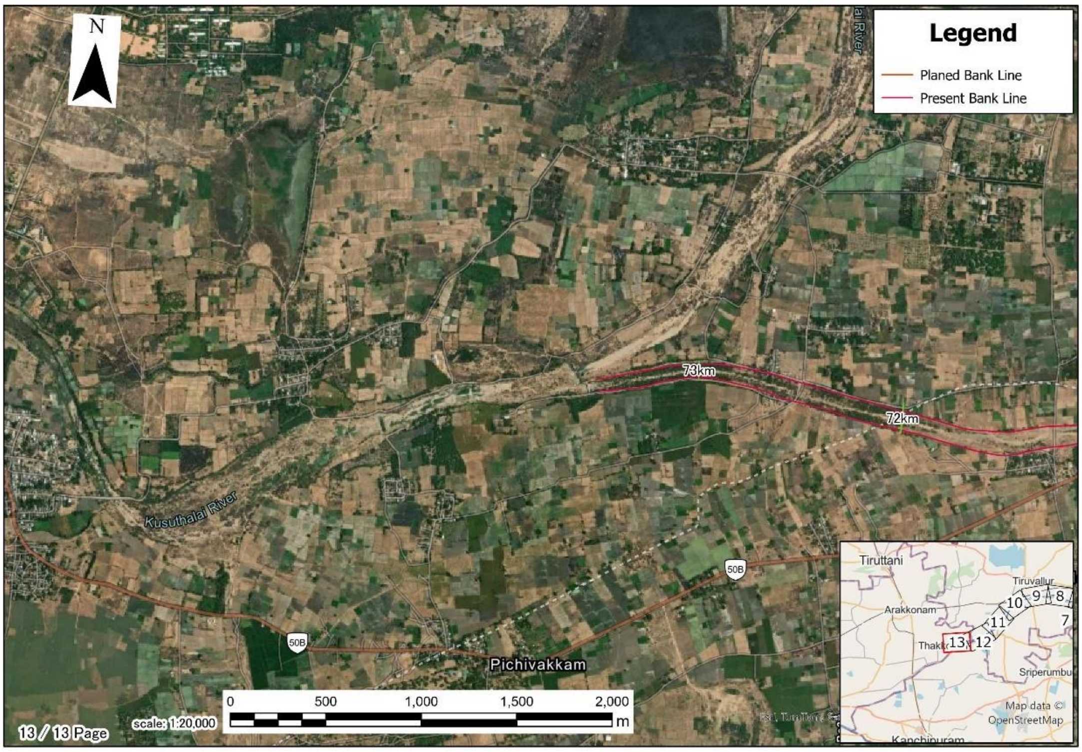
Figure 2-103: Cooum River Excavation River Channel Plan (5/7)





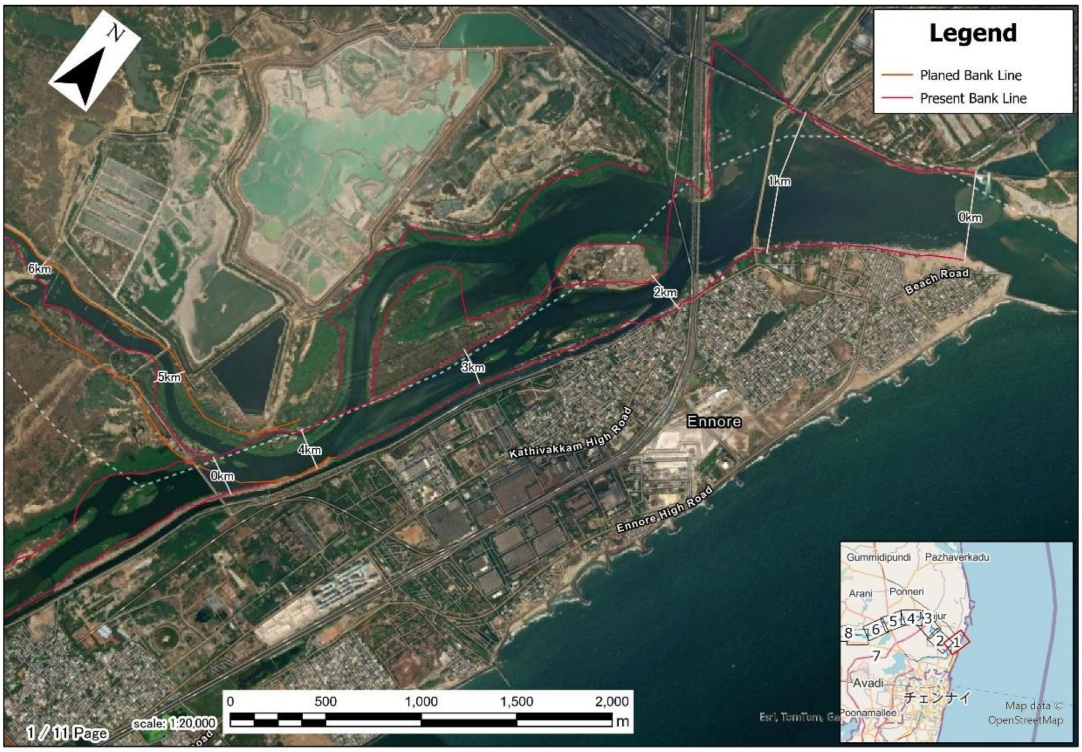
Source: JICA Expert Team

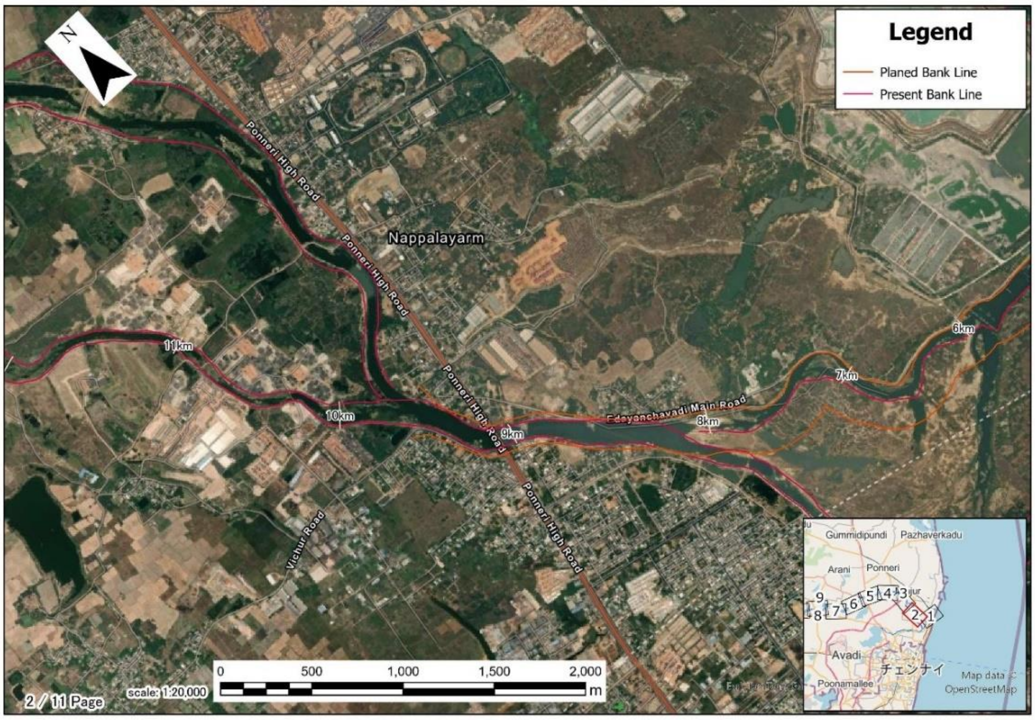
Figure 2-104: Cooum River Excavation River Channel Plan (6/7)



Source: JICA Expert Team

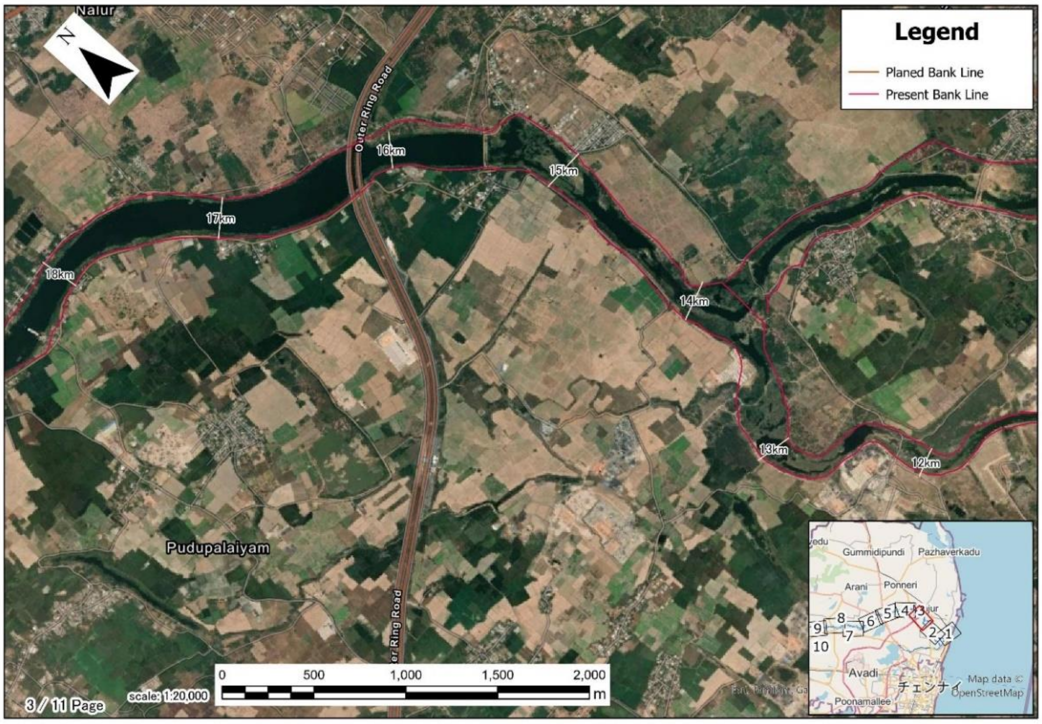
Figure 2-105: Cooum River Excavation River Channel Plan (7/7)

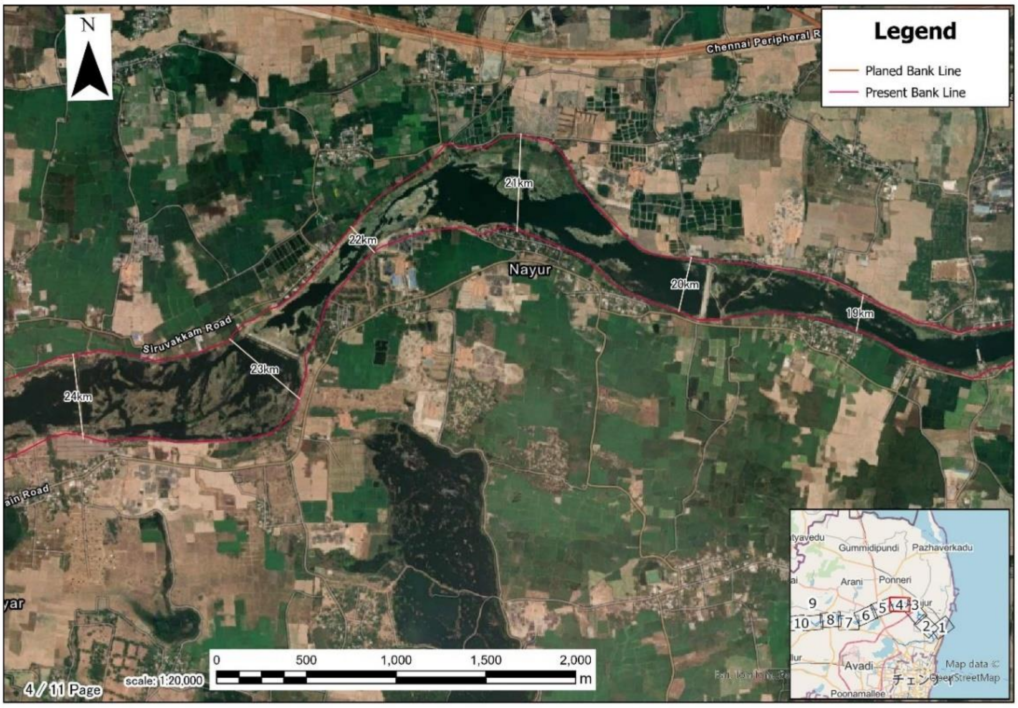




Source: JICA Expert Team

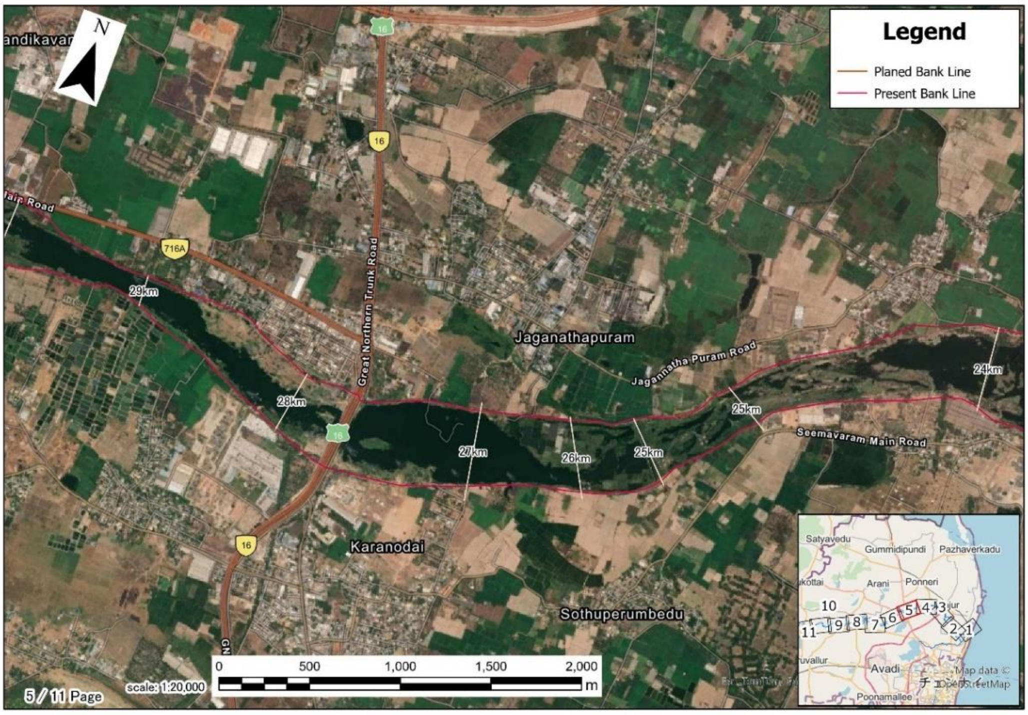
Figure 2-106: Kosasthalaiyar River Excavation River Channel Plan (1/6)

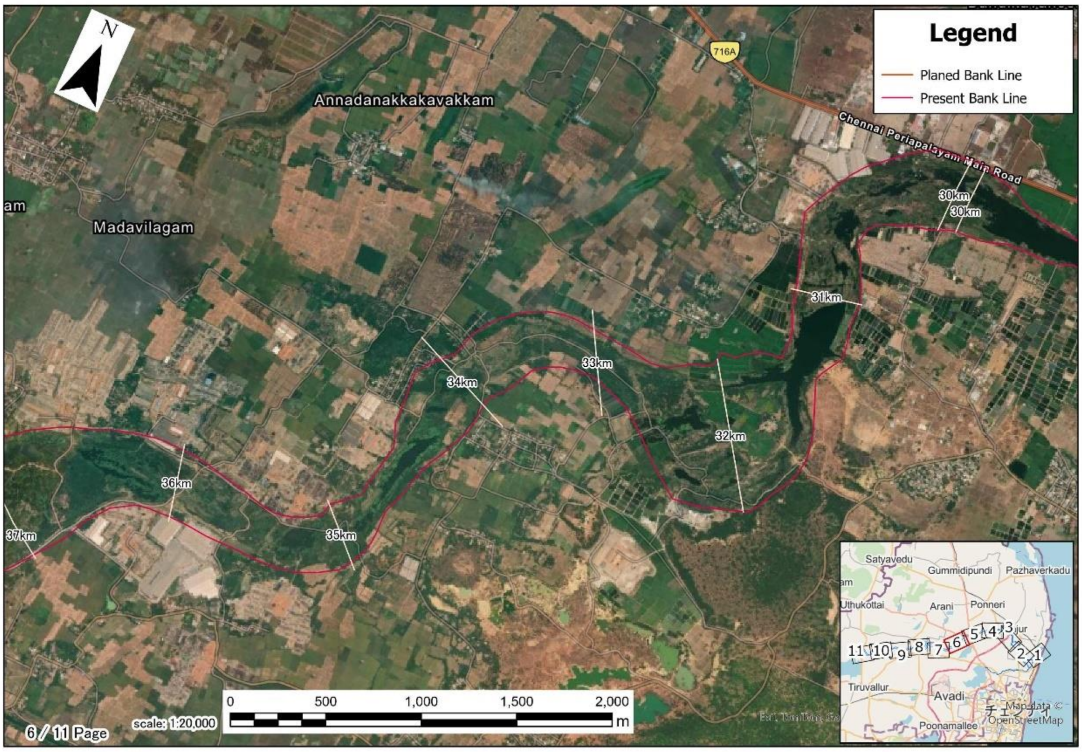




Source: JICA Expert Team

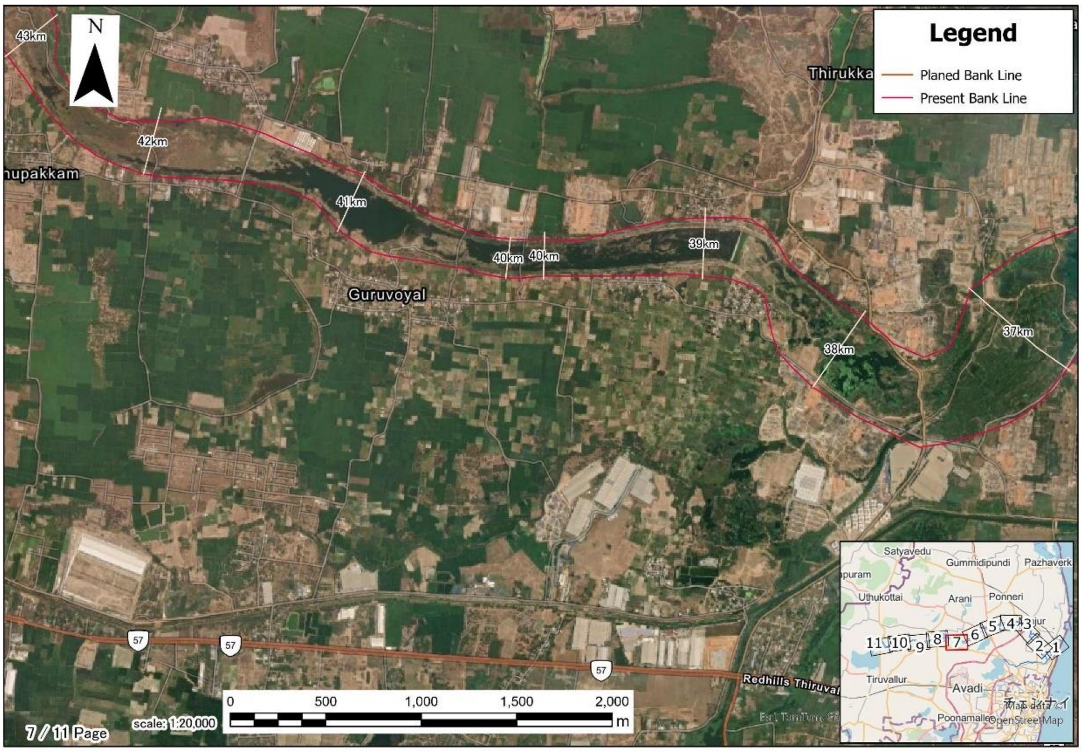
Figure 2-107: Kosasthalaiyar River Excavation River Channel Plan (2/6)

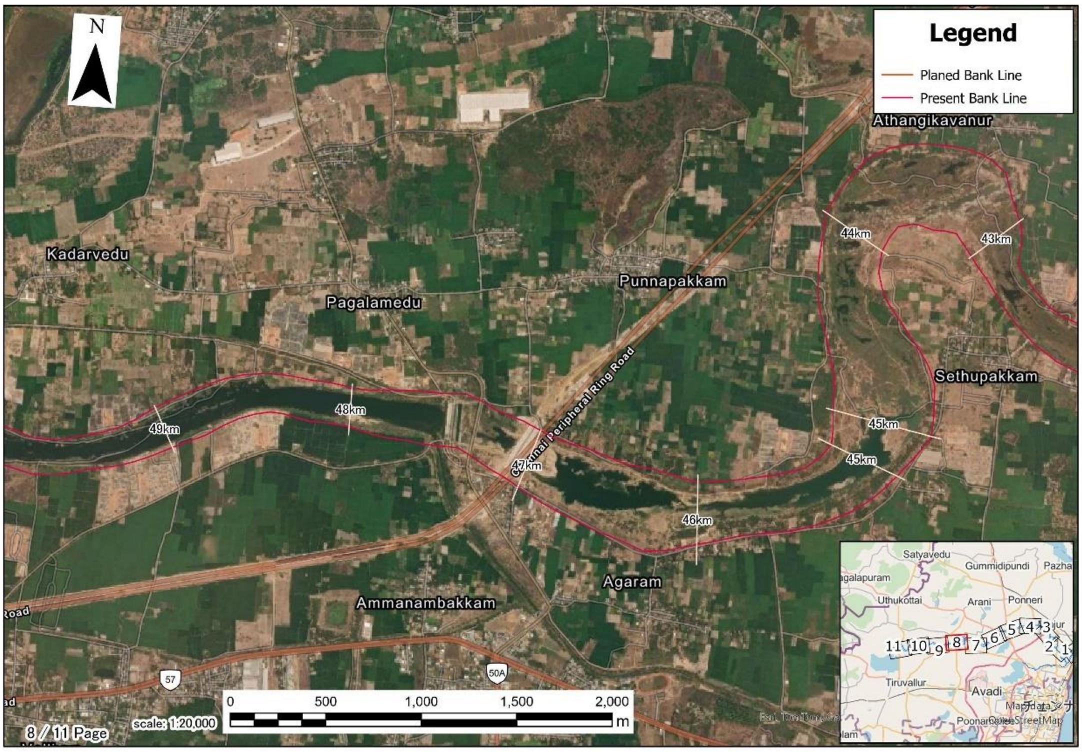




Source: JICA Expert Team

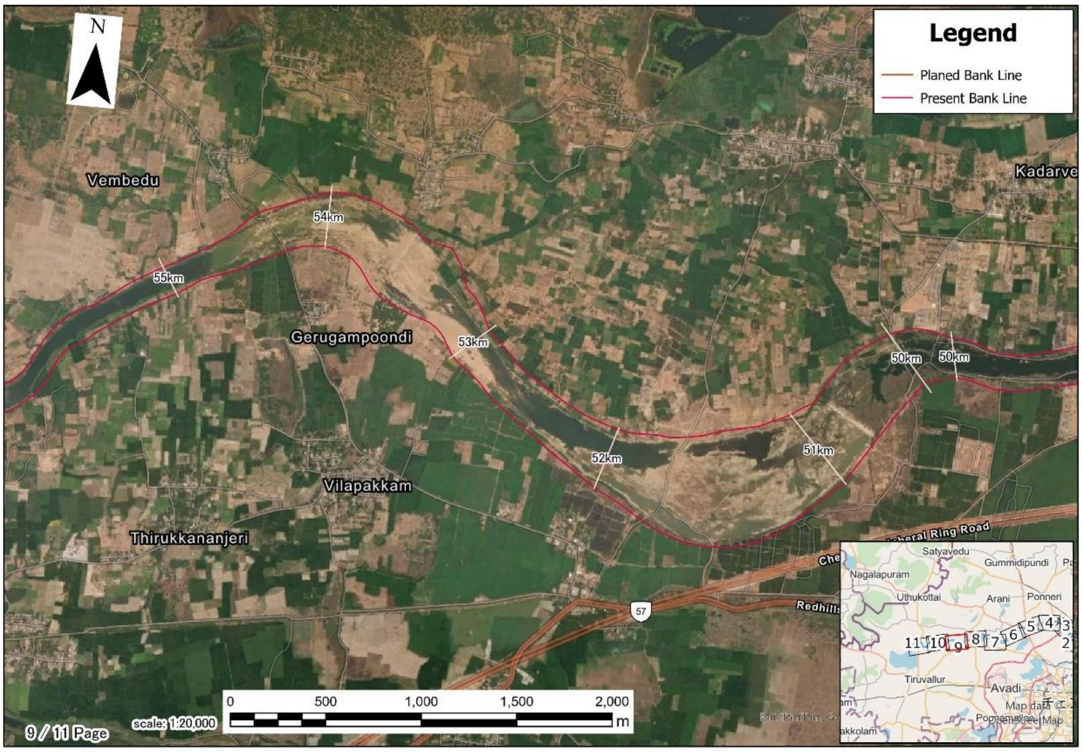
Figure 2-108: Kosasthalaiyar River Excavation River Channel Plan (3/6)

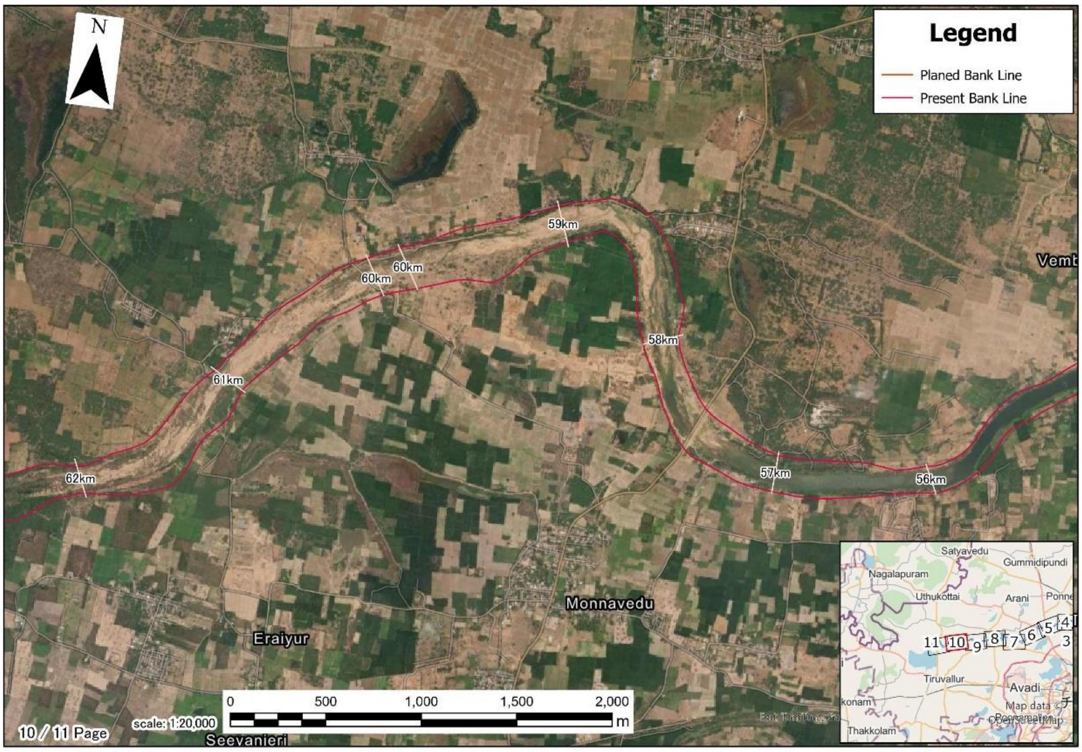




Source: JICA Expert Team

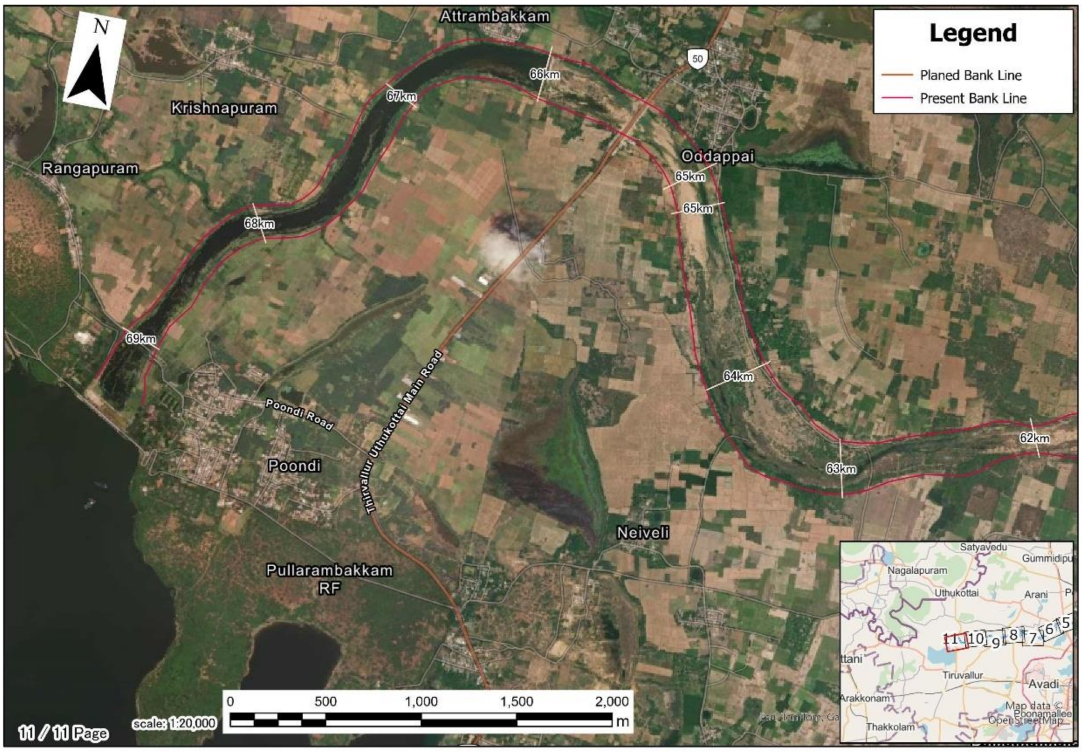
Figure 2-109: Kosasthalaiyar River Excavation River Channel Plan (4/6)





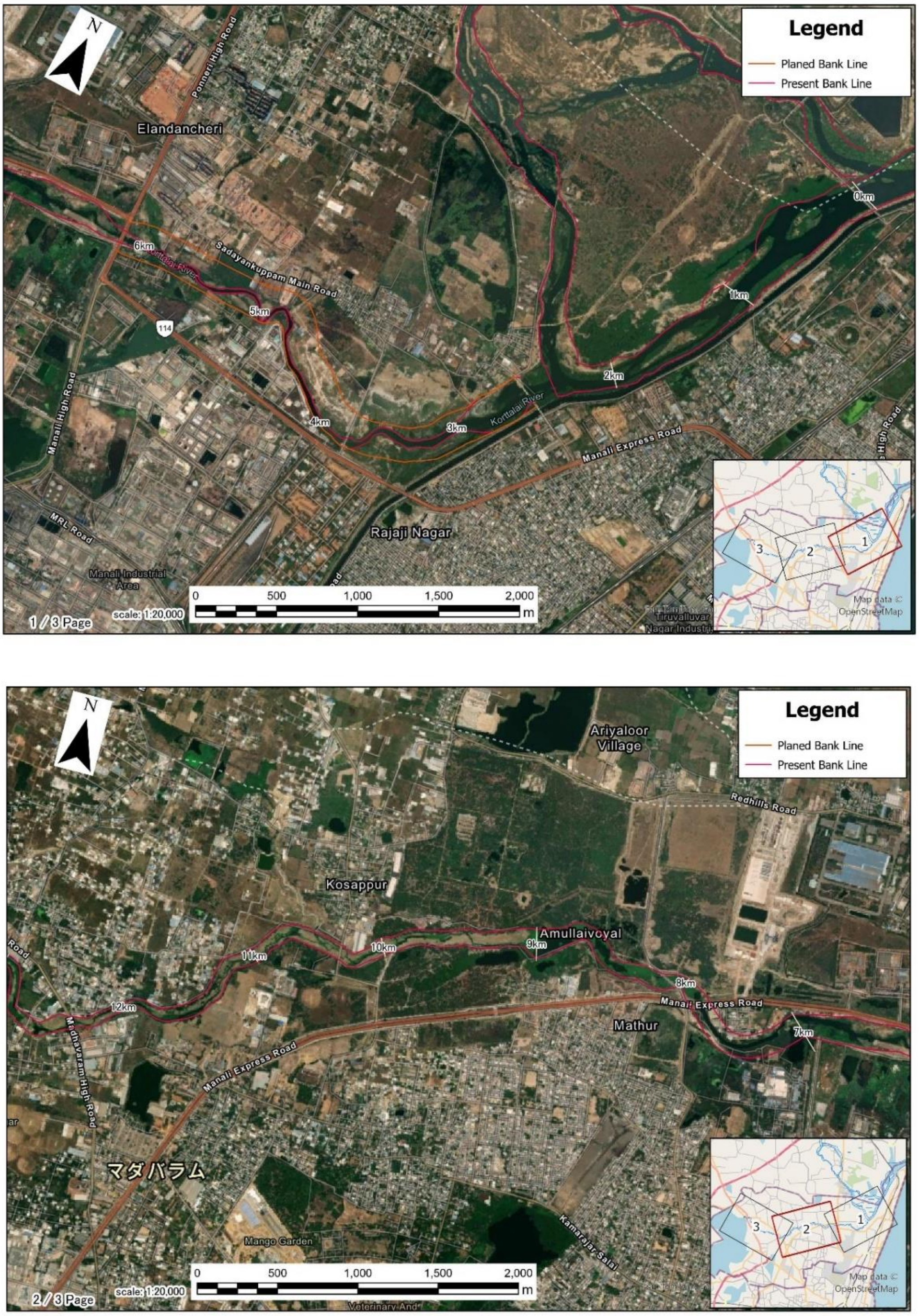
Source: JICA Expert Team

Figure 2-110: Kosasthalaiyar River Excavation River Channel Plan (5/6)



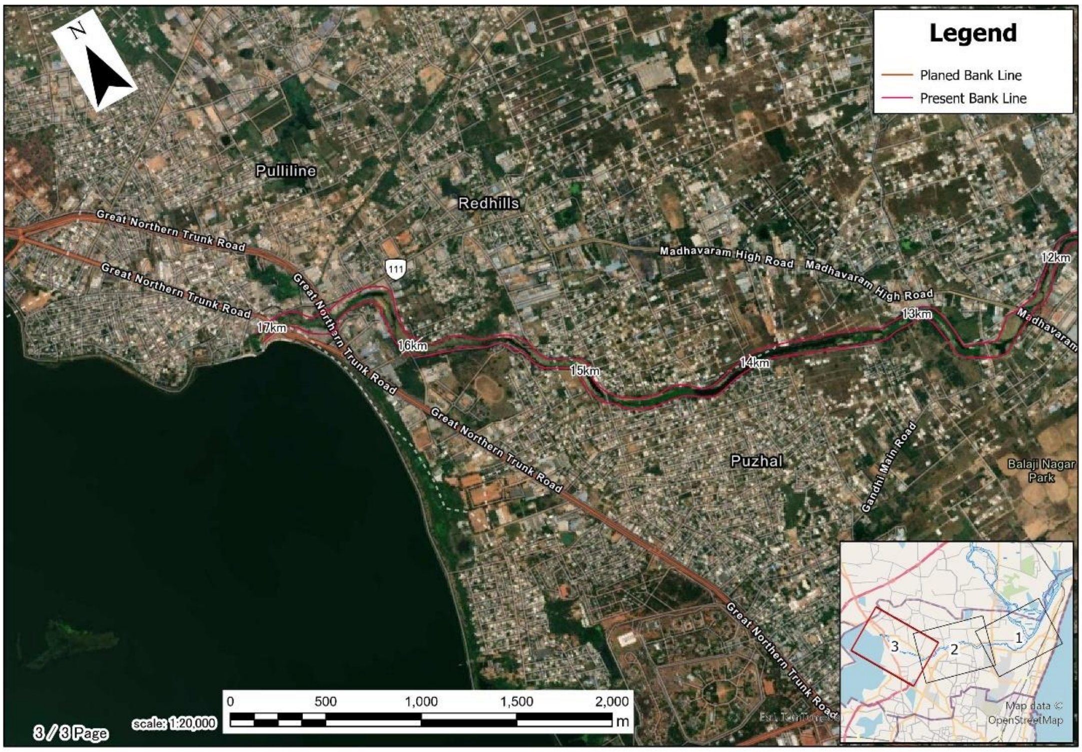
Source: JICA Expert Team

Figure 2-111: Kosasthalaiyar River Excavation River Channel Plan (6/6)



Source: JICA Expert Team

Figure 2-112: Redhills River Excavation River Channel Plan (1/2)

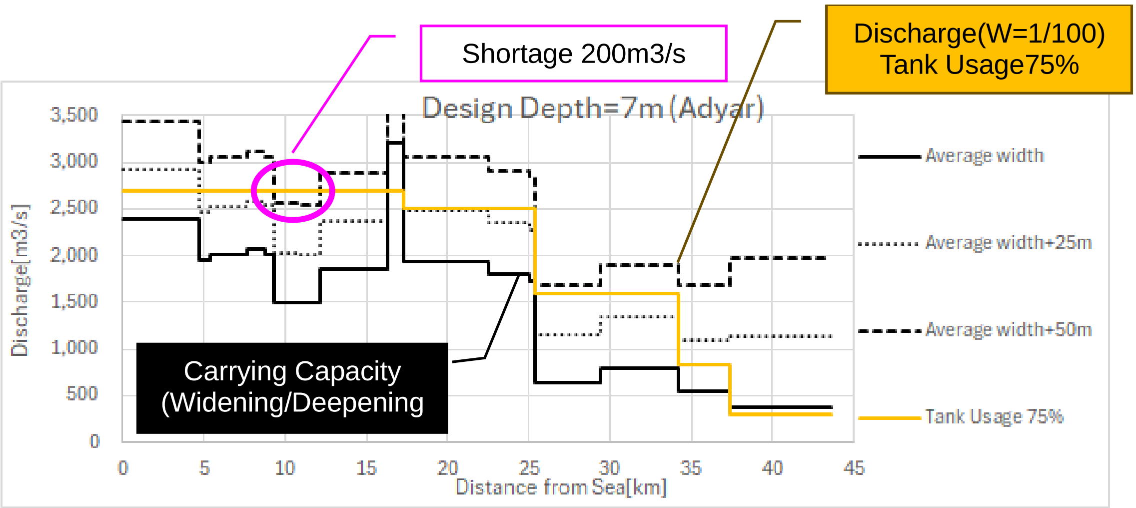


Source: JICA Expert Team

Figure 2-113: Redhills River Excavation River Channel Plan (2/2)

2.4.4 Underground bypass tunnel

The underground bypass tunnel to be installed in addition to the river channel widening and excavation described in2.3.13.3 was studied as follows (in the 9.34k - 12.08k section, the 100-year probability scale flood could not be discharged only with river channel rehabilitation and catchment storage facility construction, and approximately 200m3 /s of the shortfall in discharge capacity was secured by the underground bypass.



Source: JICA Expert Team

Figure 2-114: Longitudinal Profile of Adyar River Carrying Capacity and Relationship with Design High-Water Flow (Preliminary) for the 100-Year Flood

(1) Consideration of route options

The route for the underground bypass tunnel was selected based on its effectiveness in reducing the flood peak flow in the section downstream of Chennai Airport, where carrying capacity is insufficient. Factors such as project cost (flow path length), feasibility of constructing intake facilities, and flood control effectiveness during moderate and small-scale flows were also considered. As a result, the following two locations were selected (Figure 2-115).

Route Option 1: Intake near the airport
Route Option 2: Intake near upstream of the Chembarambakkam River confluence

A) Flood peak flow reduction effect of the Adyar River

Floods naturally reduce peak flow as they spread downstream due to factors such as channel storage. This is also true for flood regulation by dams and flow control by bypass tunnels. Therefore, flood control facilities are more effective when located closer to the section where flood control is to be applied. Since the underground bypass tunnel is a countermeasure for the insufficient carrying capacity in the densely urbanized area downstream of Chennai Airport, its location should be as close as possible to this section for optimal effectiveness.

B) Feasibility of intake facility construction

Downstream of the Chembarambakkam River confluence (25 km), urbanization has progressed along the Adyar River, and suitable locations for constructing intake facilities along the river are limited, with the only feasible site being the agricultural land on the right bank near Chennai Airport at 18.3 km. Upstream of the Chembarambakkam River confluence, there is still a significant amount of agricultural and unused land along the river, making the construction of intake facilities possible. However, as the river moves upstream, the distance between the Adyar River and the coastline increases, so a location closer to the downstream section is more advantageous in terms of both route length and flood control.

From the above perspectives, the following two locations were selected as intake points.

Route 1: Right bank near 18.3 km of the Adyar River (Figure 2-116)

Route 2: Right bank near 26.4 km of the Adyar River (Figure 2-117)

C) Construction cost (Route length)

The construction cost of the underground bypass tunnel is primarily composed of intake facilities, discharge facilities, the underground water conveyance tunnel, and management facilities. If the design flow of the bypass tunnel remains the same, the project cost will increase or decrease depending on the length of the underground water conveyance tunnel.

The lengths of Route 1 and Route 2 are as follows, with the shorter Route 1 being more advantageous (Figure 2-115). It should be noted that Route 1 is design to pass directly under Chennai Airport, and confirmation has been obtained from TNWRD that there are no restrictions on the construction of a bypass tunnel directly under the airport.

Route1: L=12.5km
Route2: L=17.0km

D) Flood control effectiveness during moderate and small-scale flooding

Both Route 1 and Route 2 pass through the Kovalam area, which experiences significant internal flooding. Measures to mitigate internal flooding in this area are being considered separately in this master plan. In addition, the underground bypass tunnel can also be utilized for inland drainage during moderate and small-scale flows.

In a comparison of Route 1 and Route 2, Route 2, which passes through the Pallikaranai Wetland, is considered more advantageous in terms of internal water collection and the construction of intake facilities.

However, in order to actually collect internal water from the Kovalam area, in addition to the construction of intake facilities, further consideration is needed regarding the management and operation of water intake from both the Adyar River and the Kovalam area.

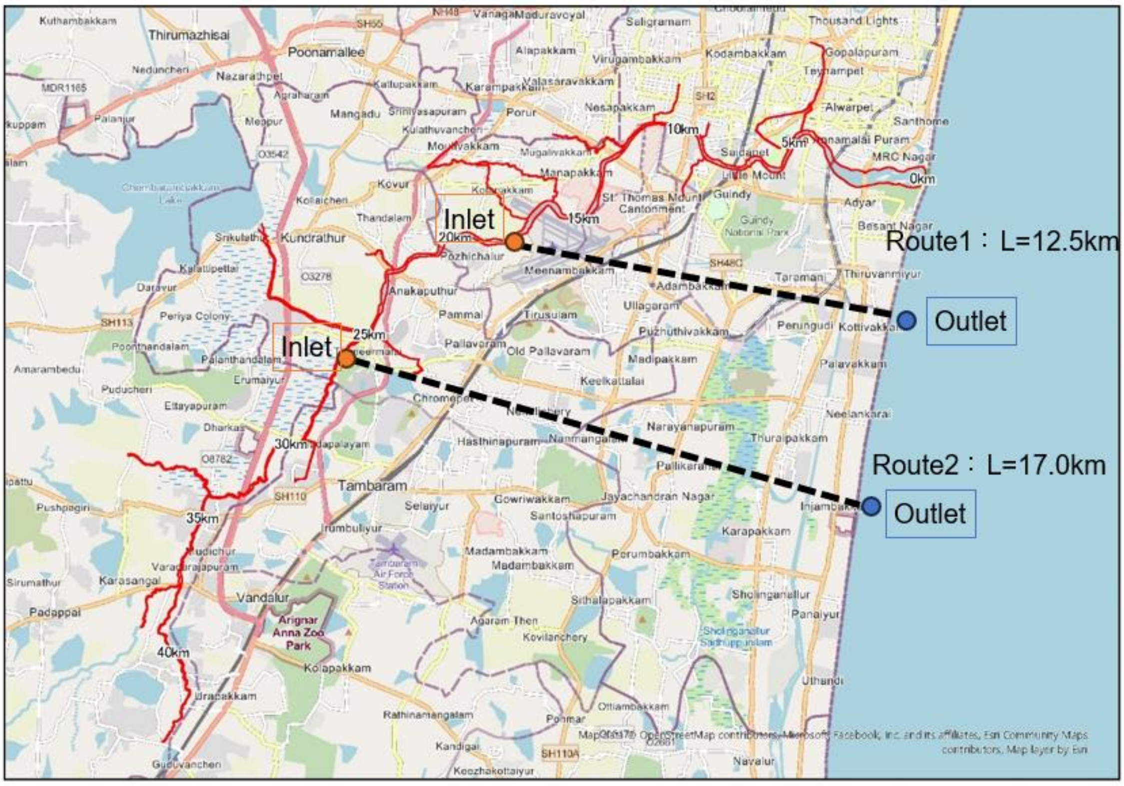
E) Summary of route comparison

The results of the above comparison are summarized in Table 2-51. Based on this, the necessary parameters will be organized with the focus on the development of Route 1.

Table 2-51: Bypass Tunnel Route Comparison Table

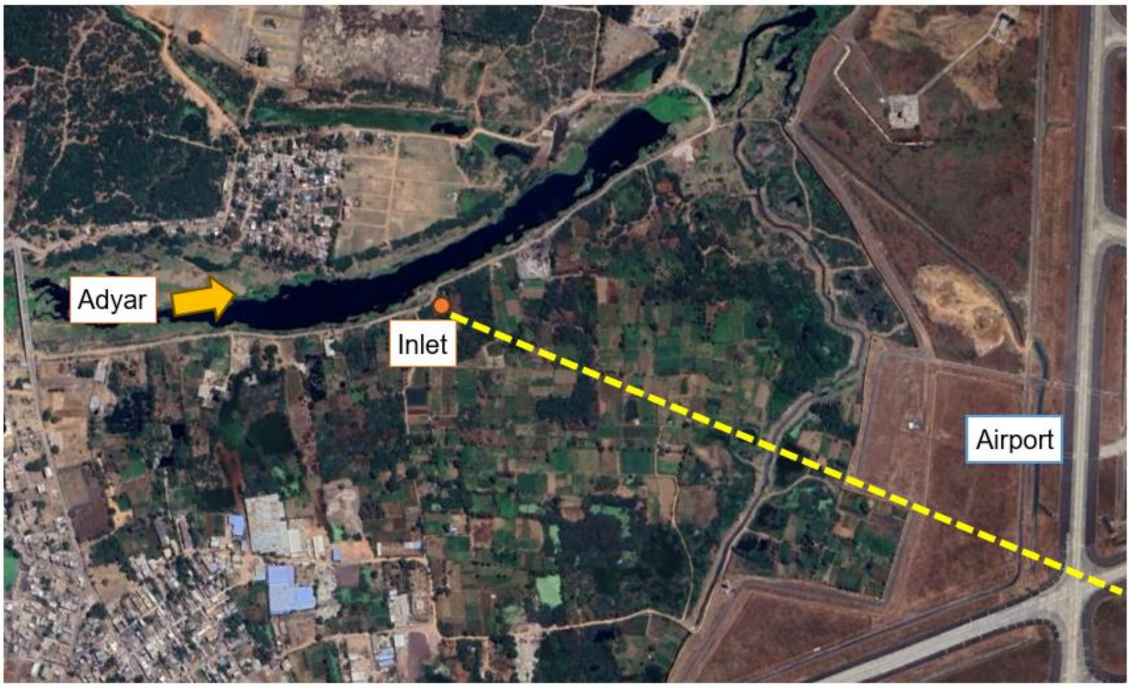
Assessment item	Route1	Route2	Assessment standards
A）Flood Peak Flow Reduction Effect of the Adyar River	○	△	It is advantageous to be closer to the downstream section of the Airport where the carrying capacity is insufficient.
B）Feasibility of Developing the Water Intake Point.	○	○	Presence of Farmland and Unused Land
C）Construction Costs (Route Extension)	○	△	A shorter extension is advantageous
D）Flood Control Effect During Small to Medium Floods	△	○	It is advantageous to easily divert internal flooding in the Kovalam area.
E）Overall Evaluation	○	△	

Source: JICA Expert Tea



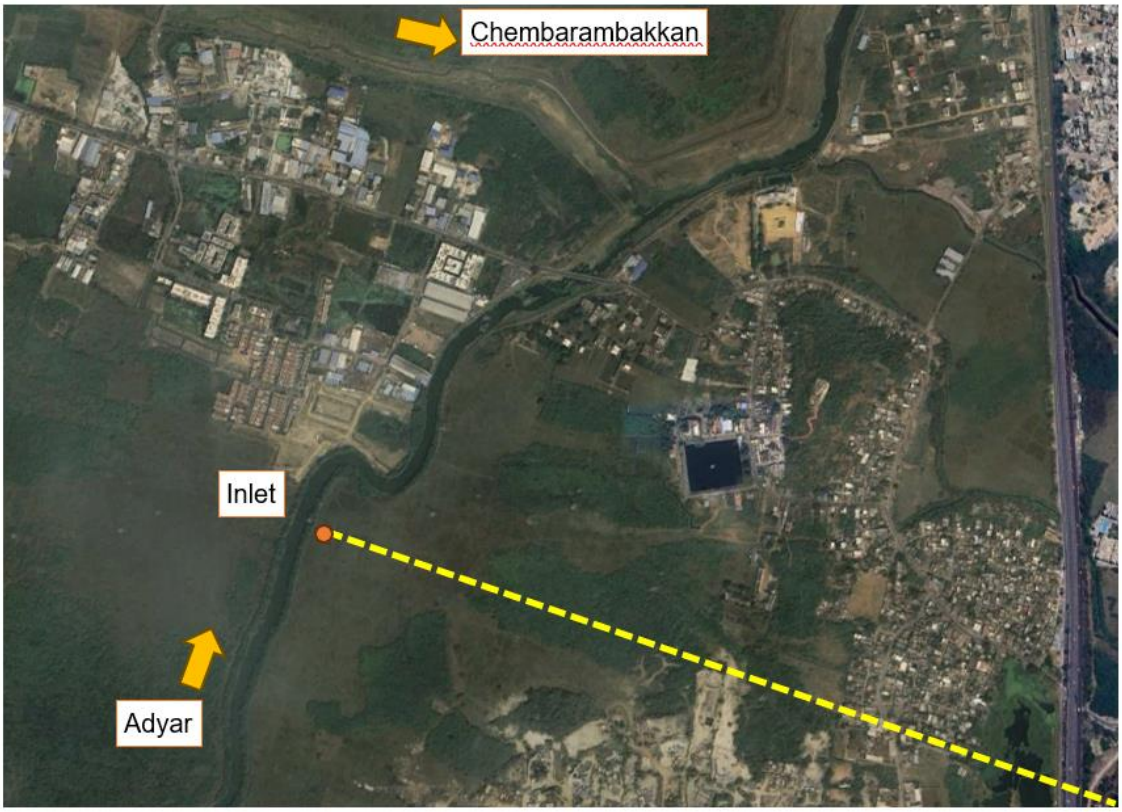
Source: JICA Expert Team

Figure 2-115: Proposed Route Location Map of the Underground Bypass Tunnel



Source: JICA Expert Team

Figure 2-116: Condition of the Water Intake Point (Route 1 Tentative)



Source: JICA Expert Team

Figure 2-117: Condition of the Water Intake Point (Route 2 Tentative)

(2) Outline specifications of the underground bypass tunnel

Summarized the specifications of the underground bypass tunnel for Route 1 proposal.

A) Hydraulic conditions

The hydraulic conditions for the intake and discharge sides have been summarised. Note that the intake conditions at the intermediate shaft are not considered here.

The specifications at the intake and discharge points are as shown in Table 2-52. Since the method of drawing water from the Adyar River into the intake facility is not yet determined, the hydraulic conditions on the intake side are set at the design high-water level of the Adyar River. The hydraulic conditions on the discharge side consider the worst-case scenario, using a high tide level of DL+1.9m. In this case, the head difference between the intake and discharge sides is about 6.5m, and the water surface gradient is about 1/2000.

Under these conditions, the discharge through a circular tunnel was calculated using uniform flow calculations, and the results are summarised in Table 2-53. Here, the discharges for tunnel diameters ranging from 9m to 15m were calculated.

Based on the calculation results for Route 1, a bypass tunnel with an internal diameter of approximately 11m is required to secure a diversion discharge of 200m³/s. The storage capacity of the underground bypass tunnel with an internal diameter of 11m is about 1.19 million m³. This is 2.2 times the capacity of the Tokyo Metropolitan Area Outer Underground Discharge Channel (Kanda River section: 540,000 m³). By adjusting the intake conditions from the Adyar River, the internal water storage effect in the Kovalam area can also be expected.

Table 2-52: Outline Specifications of the Bypass Tunnel

		Unit	Route1
Bypass Tunnel Length		km	12.5
Inlet	Adyar River Kilopost	k	18.009
	Adyar River HWL	DL.+m	8.38
Outlet	Bengal Bay HHWL	DL.+m	1.90
WL Difference(Inlet-Outlet) ΔH		m	6.483
WL Gradient(1/n)		-	1,928

Source: JICA Expert Team

Table 2-53: Relationship Between Tunnel Diameter and Discharge for Route 1

Route1

Diameter	Area	10% Reduction Area	Conversion Diameter	Conversion Area	Roughness Coefficient	Gradient	Wetted Perimeter	Hydroulic Radius	Velocity	Discharge	Volume
m	m2	m2	m	m2			m	m	m/s	m3/s	m3
15	176.715	159.043	14.230	159.043	0.015	1928	44.71	3.56	3.538	563	2,208,932
14	153.938	138.544	13.282	138.544	0.015	1928	41.73	3.32	3.379	468	1,924,226
13	132.732	119.459	12.333	119.459	0.015	1928	38.74	3.08	3.216	384	1,659,154
12	113.097	101.788	11.384	101.788	0.015	1928	35.76	2.85	3.049	310	1,413,717
11	95.033	85.530	10.436	85.530	0.015	1928	32.78	2.61	2.877	246	1,187,915
10	78.540	70.686	9.487	70.686	0.015	1928	29.80	2.37	2.700	191	981,748
9	63.617	57.256	8.538	57.256	0.015	1928	26.82	2.13	2.517	144	795,216

Source: JICA Expert Team

B) Facility shape

The inflow water from the Adyar River is directed to an underground tunnel through an intake facility and an inflow shaft. The drainage from the underground tunnel is primarily discharged into the Bay of Bengal using a siphon system for natural drainage. The longitudinal gradient of the underground bypass tunnel is set at i=1/2000, with an internal diameter of 11 meters. Figure 2-118 shows a 3D image of the bypass tunnel, and Figure 2-120 provides an overview diagram of the bypass tunnel.

The intake facility will have an intake gate installed on the right bank levee of the Adyar River. After removing sediment and debris through a sedimentation basin and a debris screen, the flood flow will be introduced through an intake shaft.

Drainage facilities are to be naturally drained during the flood period using the head difference between the Adyar River and Bengal Bay.

The feasibility of natural drainage was examined by pressure calculations using steady flow. In the pressure calculations, pipe friction loss (coefficient 0.015) is considered for the main section and inflow (coefficient 0.5) and outflow (coefficient 1.0) for the shaft section. The head difference was calculated at 3.88 m based on the following conditions

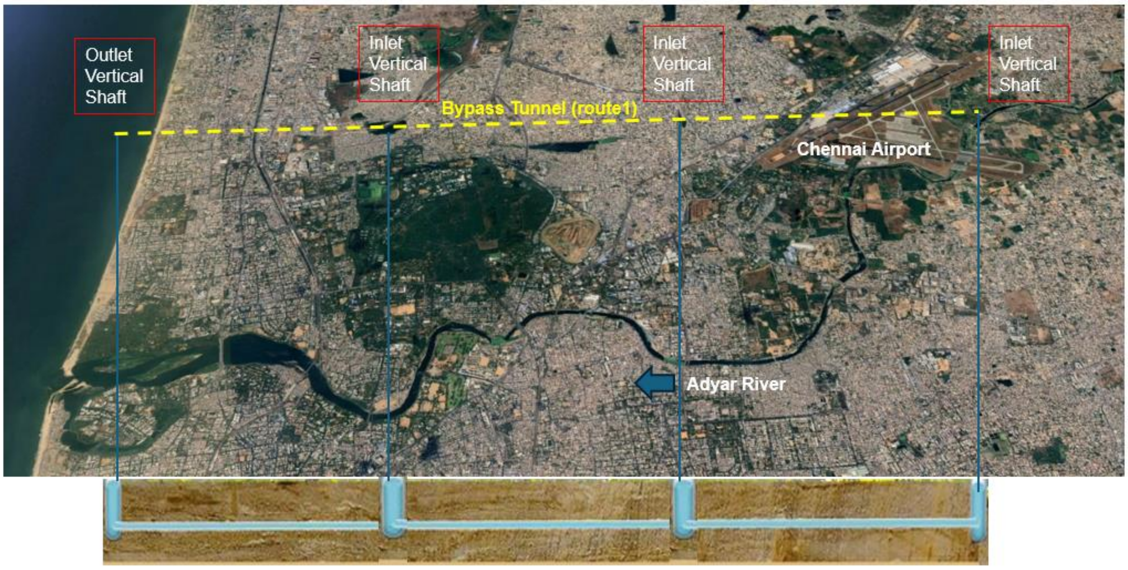
Downstream end: spring mean high tide level + 2 m = DL + 2.5 m

Upstream end: HWL-2m=DL+6.38m

The result of the calculation was 190 m3/s, which was generally capable of flowing the planned 200 m3/s, and natural drainage was generally possible. However, in actual operation, it is possible that the frictional losses in the pipe may be greater, and losses due to the various inflow characteristics of floods may occur, making natural drainage impossible.

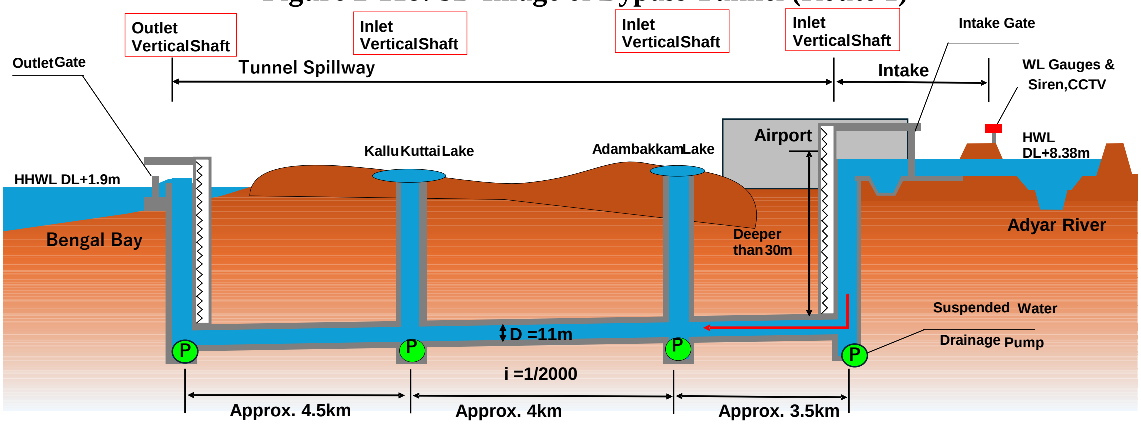
In addition, post-flood drainage will be switched to pump drainage when the head difference no longer occurs after flooding in the Adyar River, and the tunnel will be drained. As the drainage facilities will be located on the sea, gates will be installed to prevent the inflow of seawater.

Regarding the intake facility for internal water removal in the Kovalam area, which is located midway along the bypass tunnel route, intake from Kallu Kuttai Lake and Adambakkam Lake, situated on Route 1, is being considered. However, the facility shape and specifications have not been examined at this time. This will need to be reviewed in detail in the future, including specific damage mitigation effects.



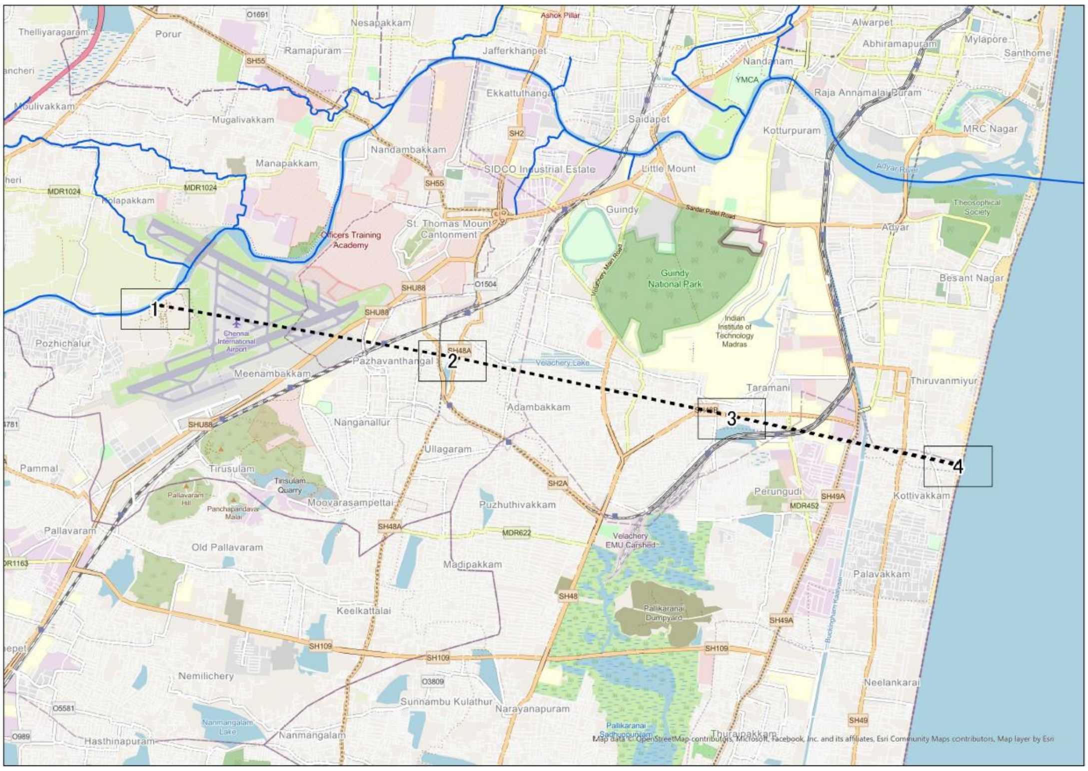
Source: JICA Expert Team

Figure 2-118: 3D Image of Bypass Tunnel (Route 1)



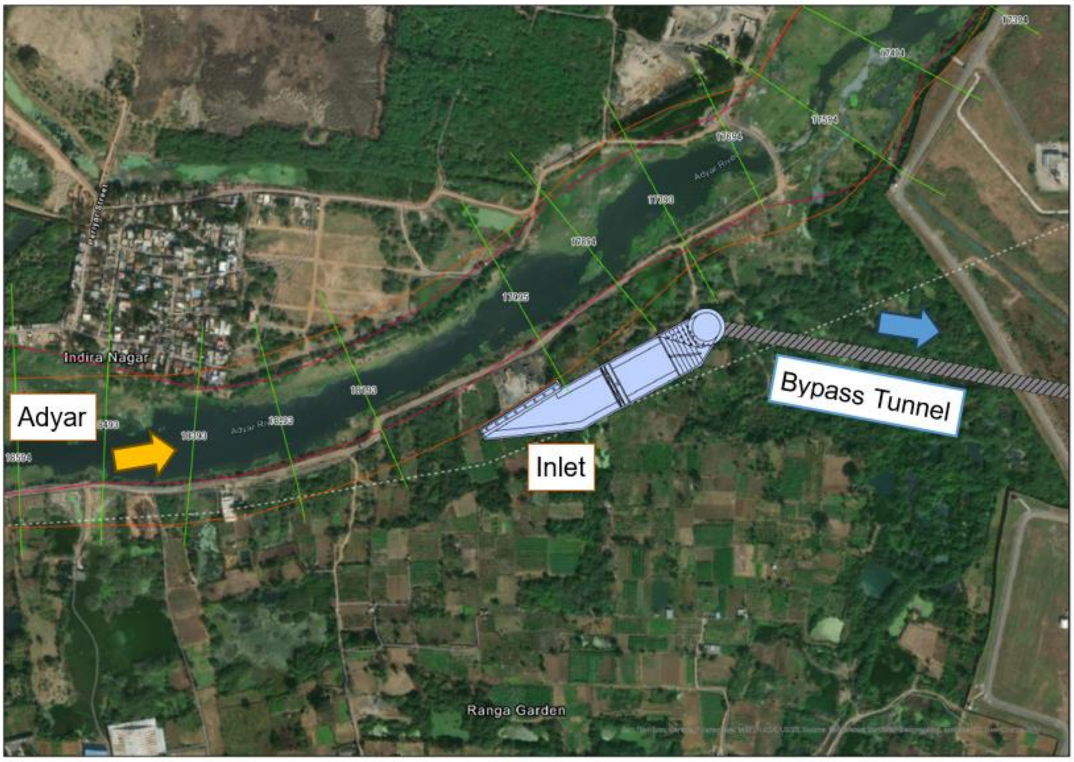
Source: JICA Expert Team

Figure 2-119: Overview Diagram of Bypass Tunnel (Route 1)



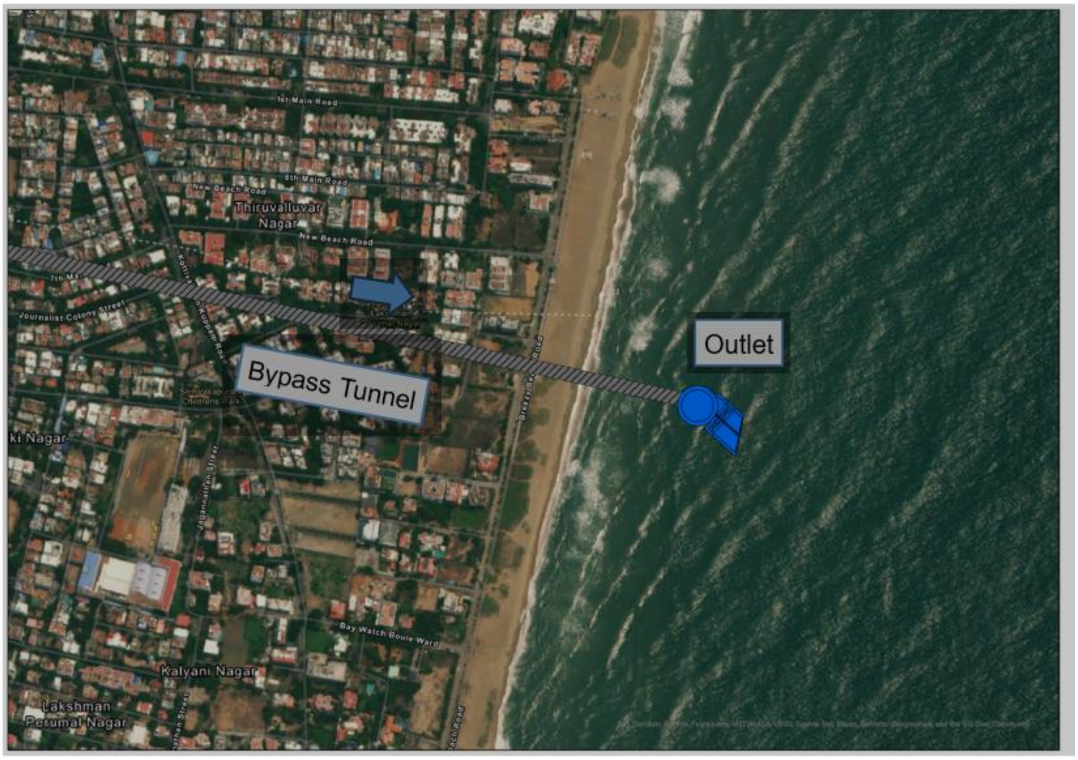
Source: JICA Expert Team

Figure 2-120: Proposed Route Map of Underground Bypass Tunnel (Route 1)



Source: JICA Expert Team

Figure 2-121: Image of Intake Facility (near Adyar River 18.3k)



Source: JICA Expert Team

Figure 2-122: Image of Discharge Facility

Source: JICA Expert Team

Figure 2-123: Image of Intermediate Intake Facility (Adambakkam Lake)

Source: JICA Expert Team

Figure 2-124: Image of Intermediate Intake Facility (Kallu Kuttai Lake)

2.5 Consideration of Phased Development

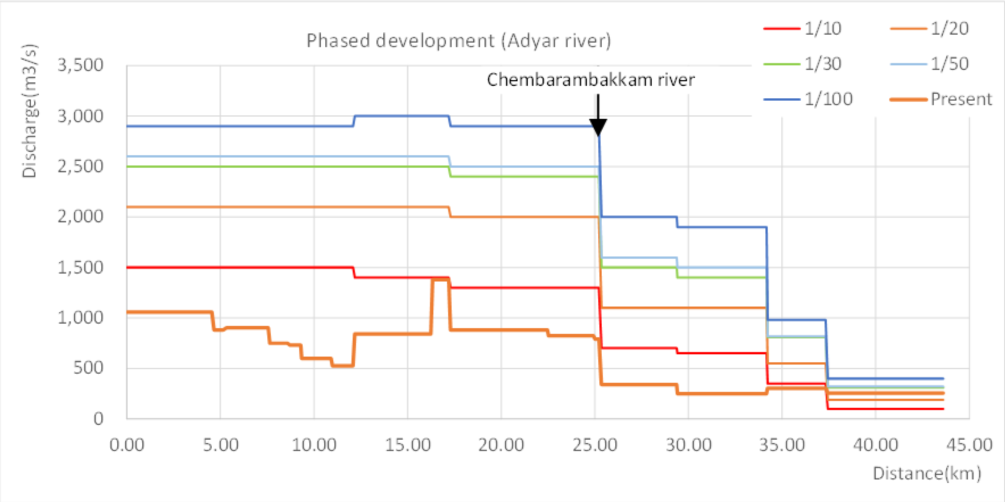
A large amount of land acquisition is required for the improvement of river channels and the functional enhancement of reservoirs (tanks), and it will take time to complete the entire development. On the other hand, given the importance of the Chennai Metropolitan Area, a sense of speed is required in implementing flood control measures. Therefore, we have considered a phased approach, where projects that can yield results relatively quickly would be implemented over a period of about 10 years (Phase 1), and the remaining projects would be implemented thereafter, while land acquisition, etc., would be undertaken in parallel.

2.5.1 Basic procedure

1) Target scale of development

The current flood safety rating of the Adyar River, the Cooum River, and the Kosasthalaiyar River in their downstream areas where the rivers pass through urban areas is less than 1/10 (rainfall events with a 10-year return period) (Figure 2-125 shows the current flood safety rating of the Adyar River as an example).

As will be described later, the flood control safety level that can be achieved in each river by river channel deepening without widening the river channel and simply enhancing the functionality of reservoirs (tanks) is approximately 1/10, so the target scale of phased development was set at 1/10, which is the scale that can be realistically developed. The project cost for river channel deepening without widening and maintenance of tanks (excluding underground channel) to achieve the target scale is about INR 27,000 million, as described below. Considering TNWRD's annual budget of USD 10-40 million (800-3,500 million INR), the project will take approximately 10 years.



Source: JICA Expert Team

Figure 2-125: Current Flood Safety Level of the Adyar River

2) River channel improvement

River channel improvement work is expected to take time because the land acquisition required for river channel widening will require the relocation of many residential and commercial facilities, as shown in Table 2-54.

Table 2-54: Approximate Width of Each River

Adyar River

Section [km]	Widening width [m]	No. of affected properties
0.0 - 20.06	50	Residential building 5000-6000 Commercial building 3000-4000
20.06 - 24.31	50	Residential building 800-1000 Commercial building 600-800 Part of the area is adjacent to military land.
24.31 - 28.44	50	Residential building 500-600 Commercial building 300-400
28.44 - 33.54	50	Residential building 400-500 Commercial building 200-300
33.54 - 36.72	25	Residential building 200-300 Commercial building 100-150
36.72 - 39.80	25	Residential buildings 120- 160 Commercial building 40-80
39.80 - 42.60	none	Residential Building 0 Commercial Building 0
Chembarambakkam Surplus (River)	none	Residential Building 0 Commercial Building 0

Cooum River

Section[km]	Widening width [m]	No. of affected properties
0.00 - 9.83	50	Residential building 1200-1500 Commercial building 500-800
9.83 - 18.84	50	Residential building 3500-4500 Commercial building 1500-2000
18.84 - 25.42	25	Residential building 700-850 Commercial building 300-400
25.42 - 79.02	none	Residential Building 0 Commercial Building 0

Kosasthalaiyar River

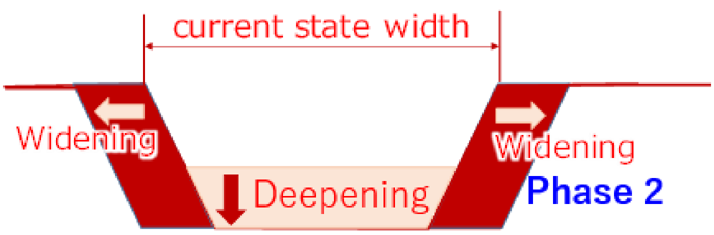
Section [km]	Widening width [m]	No. of affected properties
0.00 - 4.24	25	Residential building 200-250 Commercial building 30-50
4.24 - 13.66	50	Residential building 300-400 Commercial building 200-300
13.66 - 32.86	50	Residential building 200-300 Commercial building 100-150
32.86- 72.00	none	Residential Building 0 Commercial Building 0
Redhills Surplus (River)	none	Residential Building 0 Commercial Building 0

Source: JICA Expert Team

For this reason, the project will be implemented in stages in the following order as shown in Figure 2-126.

Phase 1: River channel deepening within the current river channel
(widening in some areas)

Phase 2: River channel widening



Source: JICA Expert Team

Figure 2-126: River Channel Improvement Procedure

In addition, because there is no need to widen the upstream side of each river in the future (see the widening widths in Table 2-54), if the entire river is developed in Phase 1, there is a risk that the upstream side of the river will have a greater carrying capacity than the downstream side. In this case, the upstream/downstream balance of flood safety could be reversed, as the elimination of upstream flooding would make the downstream side more susceptible to flooding.

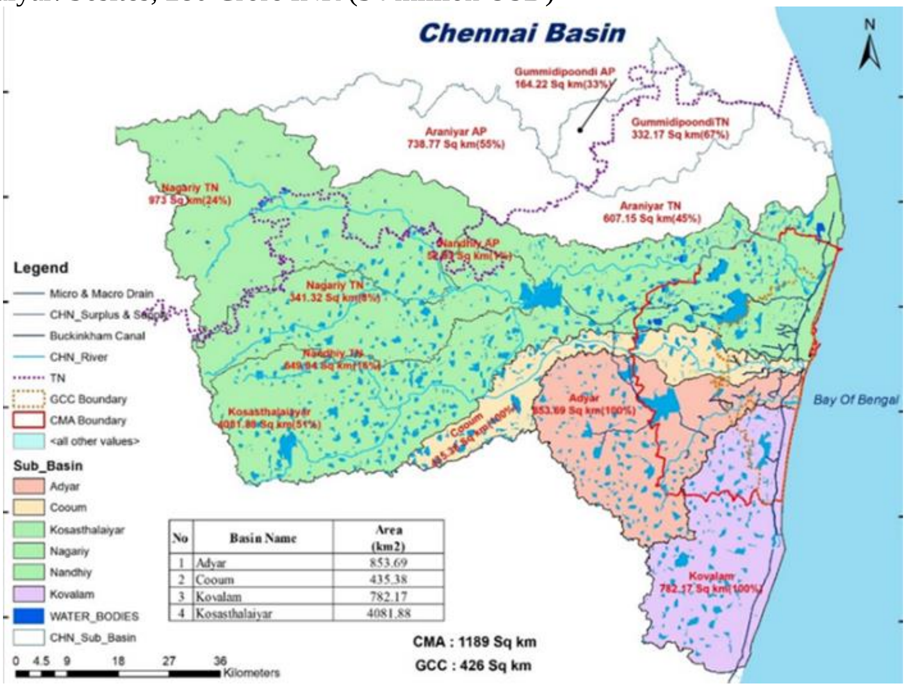
For this reason, appropriate development sections for Phase 1 in each river were examined in the next section.

3) Enhancement of reservoir (tank) functions

As described in 2.3.11, the TNWRD is currently implementing several tank and reservoir improvement project works each year, and it is expected that the reservoirs will be progressively upgraded over the development period. Therefore, it was decided and planned that half of the total improvement work would be implemented in Phase 1 of the development.

The project cost of this improvement will be as follows. Details of the cost calculation are described below.

Adyar: 25site,160 Crore INR (20 million USD)
Cooum:16site,130 Crore INR (16 million USD)
Kosasthalaiyar: 56sites, 280 Crore INR (34 million USD)



Source: JICA Expert Team

Figure 2-127: Image of the Completed Reservoir

2.5.2 Improvement sections of each river in Phase 1

1) Adyar River

Figure 2-128 shows the carrying capacity that can be achieved by each river channel improvement (deepening, deepening + widening) in the Adyar River and the discharge distribution at each probability scale (Table 2-55 shows the tabulated results.).

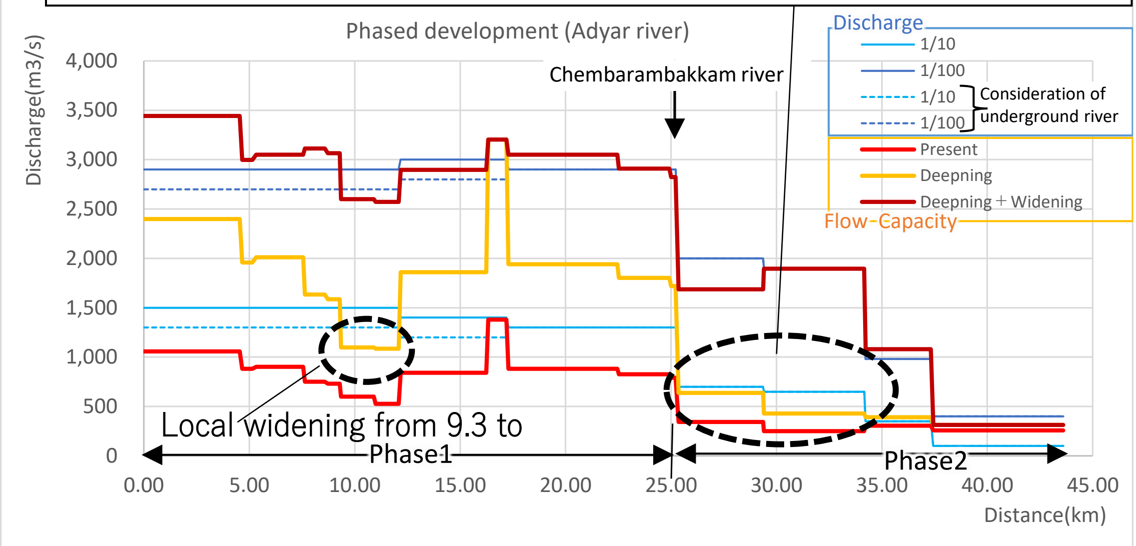
As can be seen from the figure, by simply deepening the river channel to the design riverbed height, it is possible to handle runoff volume of up to rainfall events with a 10-year return period downstream of the Chembarambakkam River confluence (25.2 km), with the exception of some sections.

On the other hand, upstream of the confluence with the Chembarambakkam River (25.2 km), there is a section where the discharge capacity is not sufficient to handle the runoff volume during rainfall events with a 10-year return period. If the river channel in this section is widened, there is a risk that excessive flood waters will flow into the downstream section, from the perspective of the upstream-downstream balance of flood control safety.

Therefore, the river channel improvement section in Phase 1, which will involve only river channel deepening, will be 0.00 to 25.2 km, and the upstream area will be addressed in Phase 2.

Chembarambakkam River: Improvement work will not be made in Phase 1 for the following reasons.

- It is not possible to secure a 1/10 scale discharge capacity, only with river channel deepening
- Widening the channel to increase its carrying capacity can cause excessive flood flows



Source: JICA Expert Team

Figure 2-128: Carrying Capacity Evaluation of Staged Construction (Adyar River)

Table 2-55 shows the specific numbers from Figure 2-128. The colors of the carrying capacity columns indicate the scale of discharge that can accommodate each design discharge at each rainfall probability. For example, River Section 13 has a carrying capacity of 2,399 m3/s by channel deepening, which can accommodate a design discharge of 1,900 m3/s (discharge considering underground channels), which is the design discharge of a 20-year return period, so it is highlighted in the same color given to the 20-year return period (other).

Table 2-55: Carrying Capacity Evaluation of Phased Construction (Adyar River)

River Section (HEC-RAS)	Distance from Sea			Phase1 Tank Usage:50%							
				Design Discharge [m3/s]					Carrying Capacity[m3/s]		
				Return Period [yrs]					Present	Deepning	Deepning + Widening
				1/10	1/20	1/30	1/50	1/100			
Adyar13	0.00	~	4.54	1,500	2,100	2,500	2,600	2,900	1,059	2,399	3,443
Adyar_CA2	4.66	~	5.14	1,300	1,900	2,300	2,400	2,700	882	1,958	2,996
Adyar12	5.32	~	7.56	1,500 1,300	2,100 1,900	2,500 2,300	2,600 2,400	3,000 2,800	903	2,011	3,050
Adyar11	7.64	~	8.58						750	1,634	3,113
Adyar10	8.72	~	9.29						731	1,587	3,065
Adyar9	9.34	~	10.91						600	1,097	2,599
Adyar8	10.98	~	12.08						526	1,086	2,573
Adyar7	12.17	~	16.24	1,400	2,100	2,500	2,600	3,000	842	1,860	2,896
Adyar6	16.34	~	17.19	1,200	1,900	2,300	2,400	2,800	1,380	3,203	3,203
Adyar5	17.29	~	22.46	1,300	2,000	2,400	2,500	2,900	881	1,941	3,051
Adyar4	22.53	~	24.92						825	1,803	2,910
Adyar_CA	25.00	~	25.22						791	1,719	2,824
Adyar3	25.35	~	29.37	700	1,100	1,300	1,600	2,000	342	638	1,087
Adyar2	29.41	~	34.17	650	1,100	1,400	1,500	1,900	251	429	1,896
Adyar1	34.23	~	37.33	350	550	810	820	980	305	392	1,080
Adhanur	37.44	~	43.61	100	190	310	320	400	257	312	312

*Red numbers indicate discharges when discharges are reduced in underground rivers.
**The red frame indicates the scope of the improvement project.

Chembala Bakan Junction point of upstream (25.25k), excavation alone cannot secure 1/10 return periods.

In [illegible] between 9.3 and 12.1k, where a 1/10th scale flood control safety level cannot be achieved through excavation alone, will be addressed by implementing minimal widening that requires little house displacement (the widening width is approximately 10 meters, as shown in Figure 2-130). However, there is still a shortfall of approximately 200 m³/s to achieve the target safety level of 1/10 in this area. One option is to implement additional widening, which would require more land acquisition and resettlement. Another option is to construct an underground bypass to address the 200 m³/s deficit.

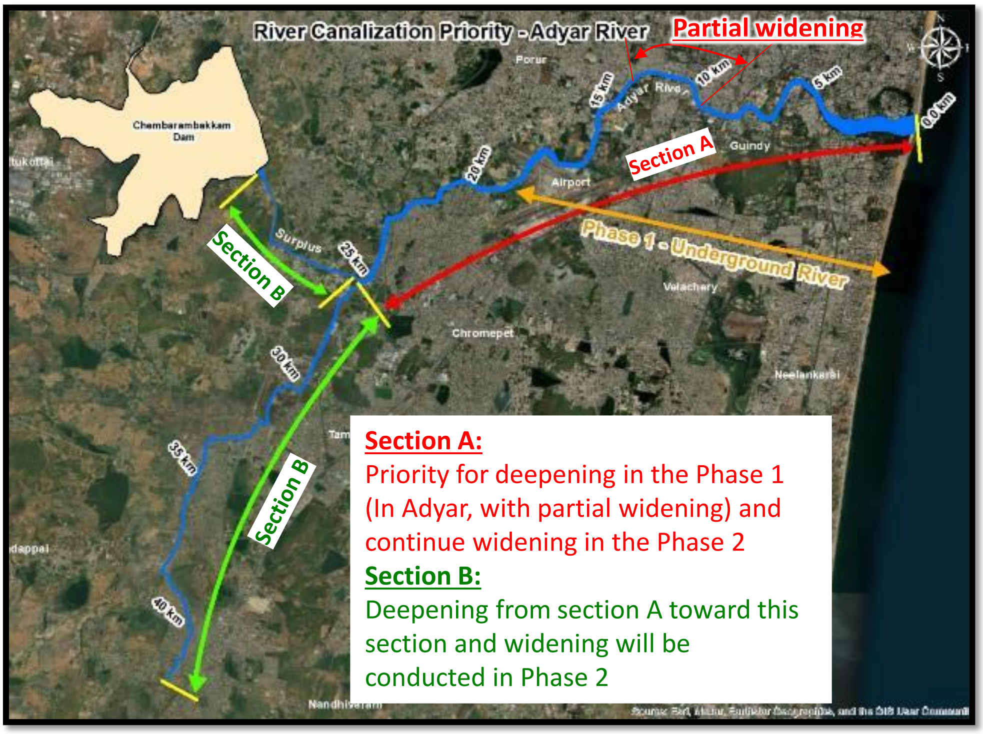
Table 2-56 compares these two options: one for an underground bypass tunnel and the other for further widening of the river channel. The option of widening the river channel would necessitate negotiations for relocating houses, which could potentially delay the project beyond the 10-year timeframe for Phase 1. In contrast, the underground bypass tunnel has been chosen due to its economic advantages and the potential to prevent urban flooding in the Kovalam basin.

Table 2-56: Comparison of Options to Bridge the Adyar Bottleneck Deficit

Case	Extra river widening		Underground bypass tunnel	
Overview	The river channel widened by an additional 10m without constructing an underground bypass tunnel.		200 m³/s diverted through an underground bypass tunnel.	
Land acquisition	5ha		2ha	
No of the affected buildings	Residential: 900 Commercial facilities: 60		Residential: 80 Commercial facilities: None	
Project cost	Preparation	Construction	Preparation	Construction
	900 Cr. INR 110 Mil. USD	30 Cr. INR 3.6 Mil. USD	200 Cr. INR 24 Mil. USD	8,000 Cr. INR 1,000 Mil. USD
Merit	Lower cost compared to the underground bypass tunnel.		1. Can be implemented quickly. 2. Expected to have an early positive impact on improving Chennai Airport's runway, which frequently closes due to flooding, thereby boosting economic activity. 3. The route passes through the Kovalam Basin, an area prone to inland flooding, providing additional flood mitigation benefits.	
Disadvantages	May not be completed within the 10-year Phase 1 period due to time-consuming negotiations related to house relocations.		Expensive option	
Evaluation	Not selected		Although the underground bypass tunnel is costly, it was chosen due to its significant economic benefits and early project effectiveness.	

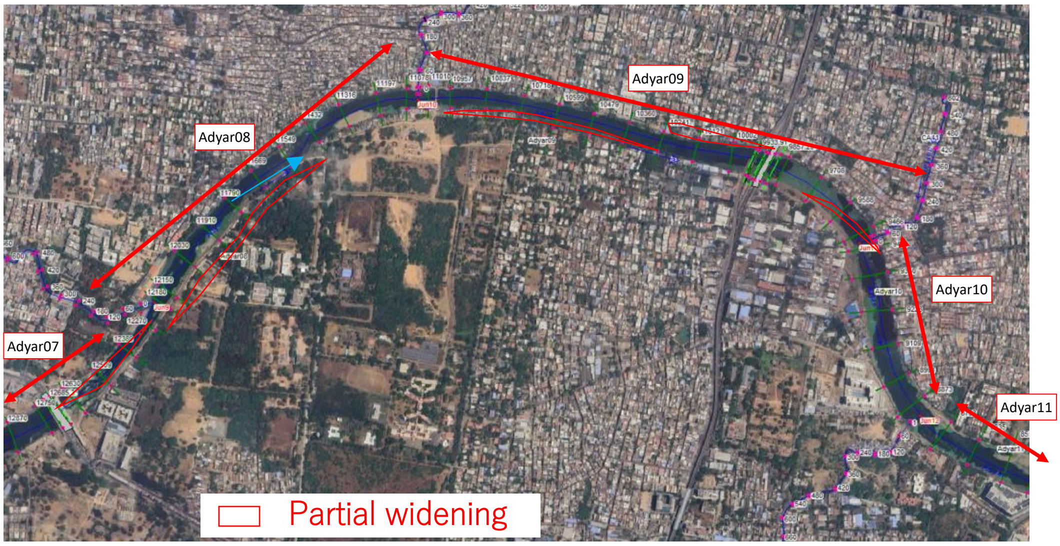
Source: JICA Expert Team

Table 2-56 shows the approximate construction section, and the main project cost in Phase 1, not including land acquisition, is approximately 530 Crore INR (64 million USD) for excavation and 8,600 Crore INR (1,000 million USD) for the underground bypass tunnel (see below for details of the cost calculation). Details of the cost calculations are given below).



JICA Expert Team

Figure 2-129: Priority Master Plan Implementation (Adyar River)



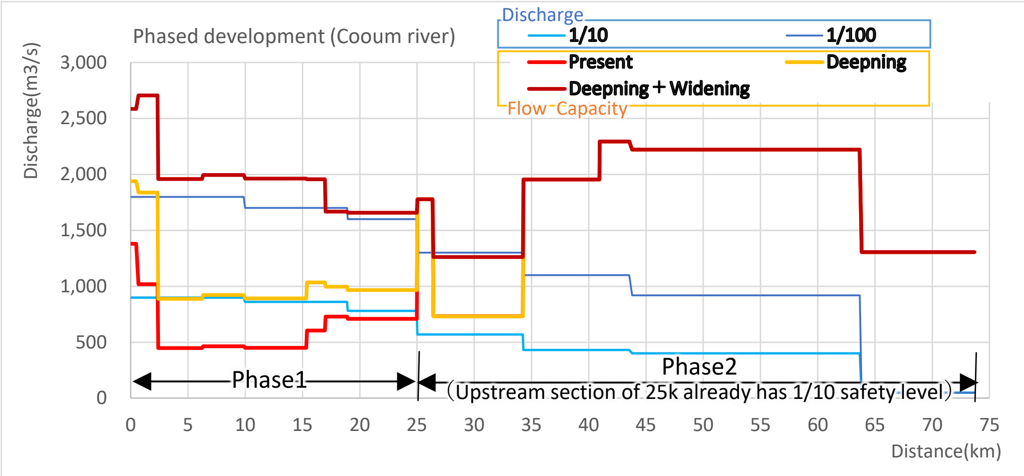
Source: JICA Expert Team

Figure 2-130: Plan View of the Partial Widening Area

2) Cooum River

Since the Cooum River has a carrying capacity of more than a 10-year return period flood at 25.0 km upstream, it was decided in Phase 1 to deepen the river channel from point 0.0 to 25.0 km to maintain the balance between upstream and downstream flood control safety. (Although the discharge for a rainfall event with a 10-year return period is secured at 2.3 km downstream in terms of carrying capacity, it was decided to start deepening the river channel at 0.0 km considering that the deepened riverbed becomes smoother and shallower as it goes downstream.)

The project cost of this improvement will be approximately 420 Crore INR(50 million USD). Details of the cost calculation are described below.



Source: JICA Expert Team

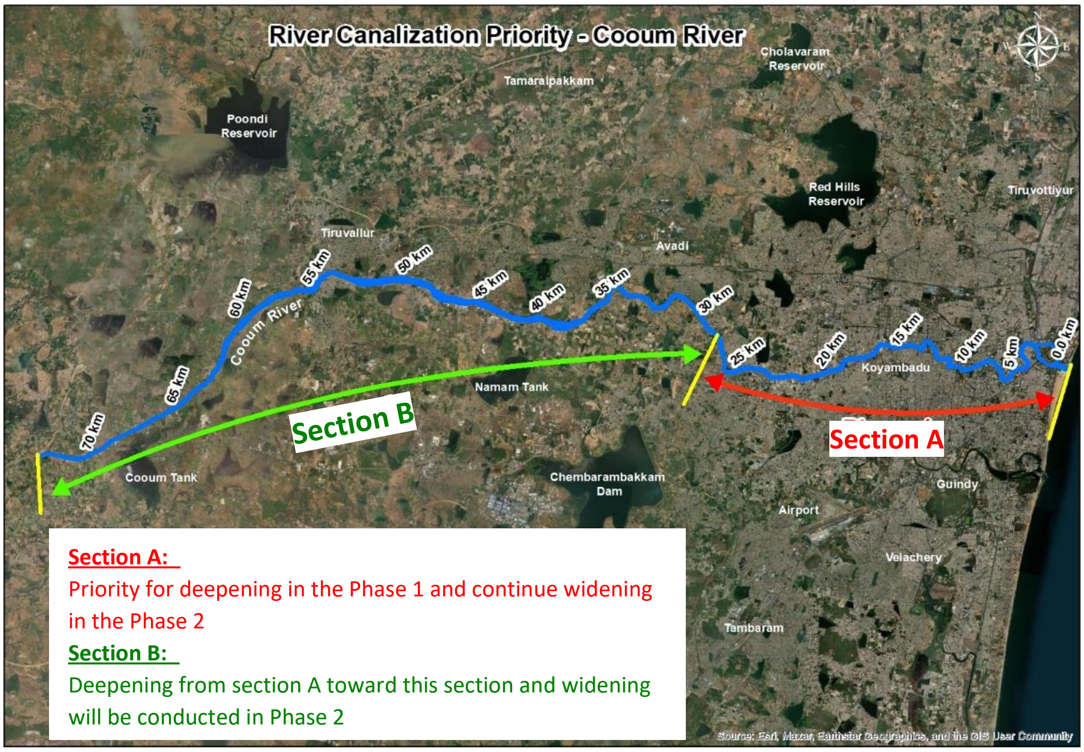
Figure 2-131: Carrying Capacity Evaluation of Staged Construction (Cooum River)

The colours of the hatches in the table are set in the same way as in Adyar River.

Table 2-57: Carrying Capacity Evaluation of Phased Construction (Cooum River)

Outflow Point	River Section (HEC-RAS)	Distance from Sea			Phase1 Tank Usage:50%							
					Design Discharge [m3/s]					Carrying Capacity[m3/s]		
					Return Period [yrs]					Present	Deepning	Deepning＋Widening
					1/10	1/20	1/30	1/50	1/100			
8	Cooum08	0	～	0.483	900	1,200	1,300	1,500	1,800	1,380	1,939	2,586
	Cooum06	0.664	～	2.342						1,018	1,839	2,707
	Cooum05	2.405	～	6.225						449	887	1,958
	Cooum04	6.315	～	9.872						463	922	1,995
7	Cooum03	9.988	～	15.333	860	1,100	1,300	1,500	1,700	450	892	1,962
	Cooum02	15.393	～	16.964						605	1,034	1,956
	Cooum01_b	17.02	～	18.897						729	996	1,668
6		18.96	～	24.977	780	1,100	1,200	1,400	1,600	708	966	1,658
5		25.04	～	26.366	570	750	860	1,100	1,300	1,779	1,779	1,779
		26.426		34.243						732	732	1,262
4		34.3	～	40.928	430	590	700	830	1,100	1,955	1,955	1,955
	Cooum01	40.96	～	43.539						2,294	2,294	2,294
3		43.79	～	63.667	400	540	640	760	920	2,223	2,223	2,223
3-2		63.829	～	73.678	50	40	40	40	50	1,306	1,306	1,306

Source: JICA Expert Team



Source: JICA Expert Team

Figure 2-132: Precedence Diagram (Cooum River)

3) Kosasthalaiyar River

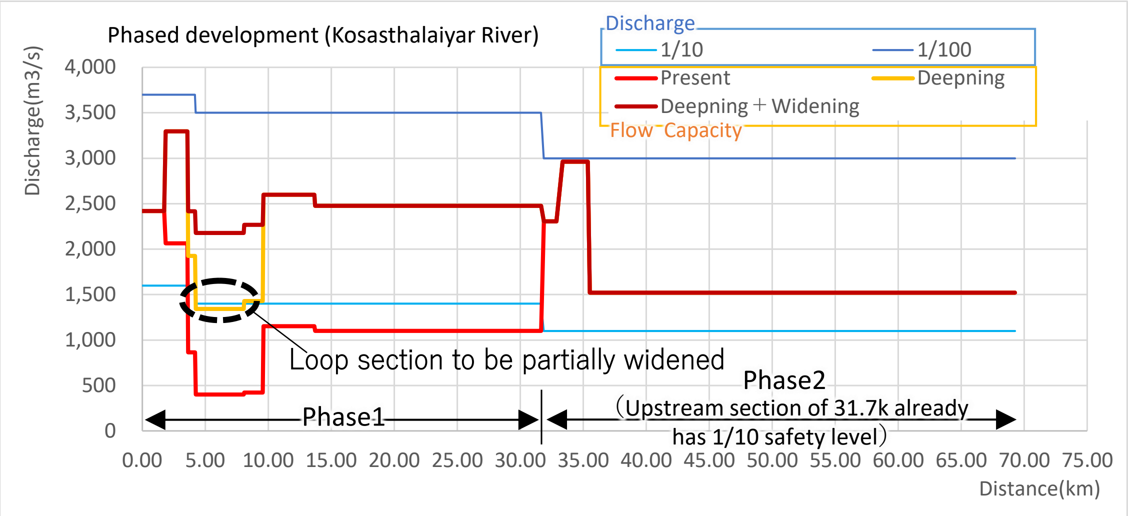
The improvement aimed at accommodating a rainfall event with a 10-year return period in Phase 1 is as follows.

As can be seen from Figure 2.75, the downstream reach of the Kosasthalaiyar River has three braided sections. The area where the carrying capacity is insufficient for a rainfall event with a 100-year return period is from the upstream end of the most downstream Loop 3 (3.6 km) to the downstream end of the most upstream Loop 1 confluence (9.6 km). Targeting this area (from 3.6 to 9.6 km), it was decided to make partial changes to the diverted flow paths and widen some of them, as shown in Figure 2-133.

(Although the discharge for a rainfall event with a 100-year return period is secured at 3.6 km downstream in terms of carrying capacity, it was decided to start deepening the river channel at 0.0 km considering that the deepened river bed becomes smoother and shallower as it goes downstream.)

At Redhills, the carrying capacity is inadequate for a rainfall event with a 100-year return period only in the 3.1 km to 6.1 km reach. Since the width of the river in this section is narrower than in the upstream and downstream reaches, it was decided to provide the carrying capacity cross-section by constructing an embankment and deepening the channel to match the width of the river downstream (210 m), as shown in Figure 2-133. It was also considered that the area surrounding the river channel is mainly agricultural land.

The project cost of this improvement will be approximately 330 Crore INR(40 million USD). Details of the cost calculation are described below).



Source: JICA Expert Team

Figure 2-133: Carrying Capacity Assessment for Staged Construction (Kosasthalaiyar River)

Table 2-58 shows the specific numbers from Figure 2-136. The highlighted colors in the table are defined in the same way as in Adyar River. Table 2-59 shows the carrying capacity assessment of the Redhills River tributary, which has a carrying capacity that can accommodate a rainfall event with a 100-year return period at 6.0 km upstream. Therefore, the Phase 1 improvement will be implemented from 0.0 to 6.0 km. The red frame indicates the project area for development.

Table 2-58: Carrying Capacity Evaluation of Phased Construction (Kosasthalaiyar)

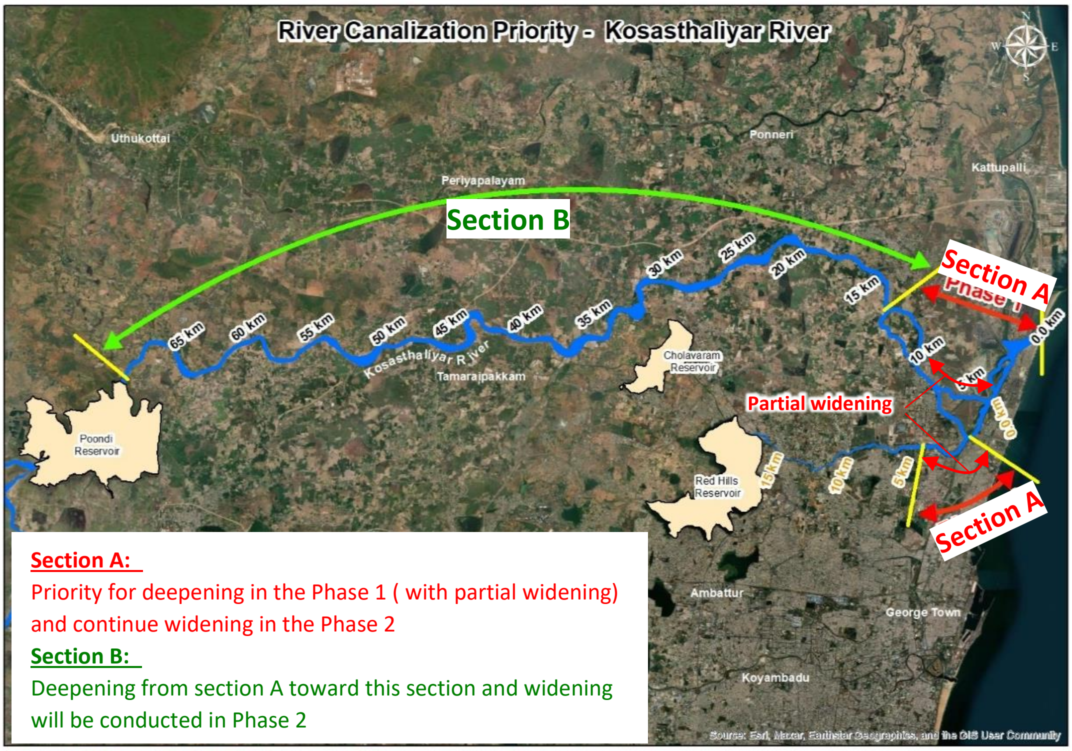
River Section (HEC-RAS)	Cross Secton			Distance from Sea			Phase1 Tank Usage:50%							
							Design Discharge [m3/s]					Carrying Capacity		
							Return Period [yrs]					Present	Deepning	Deepning + Widening
							1/10	1/20	1/30	1/50	1/100			
Kosas08	2	~	1727	0.00	~	1.74						2,419	2,419	2,419
Kosas07+KL	493	~	2198	1.85	~	3.58	1,600	2,100	2,600	3,200	3,700	2,063	3,296	3,296
Kosas06	185	~	489	3.63	~	4.18						865	1,926	2,417
KL2	274	~	3477	4.24	~	8.05						401	1,342	2,179
Kosas03	102	~	1442	8.08	~	9.57	1,400	2,000	2,500	3,000	3,500	423	1,429	2,268
Kosas02+KL	160	~	4134	9.63	~	13.66						1,153	2,599	2,599
Kosas01	152	~	18014	13.72	~	31.65						1,100	2,476	2,476
	18245	~	19518	31.87	~	32.86						2,306	2,306	2,306
	20026	~	21670	33.37	~	35.37	1,100	1,700	2,100	2,600	3,000	2,963	2,963	2,963
	22174	~	56344	35.52	~	69.26						1,521	1,521	1,521

Source: JICA Expert Team

Table 2-59: Carrying Capacity Assessment for Staged Construction (Redhills River)

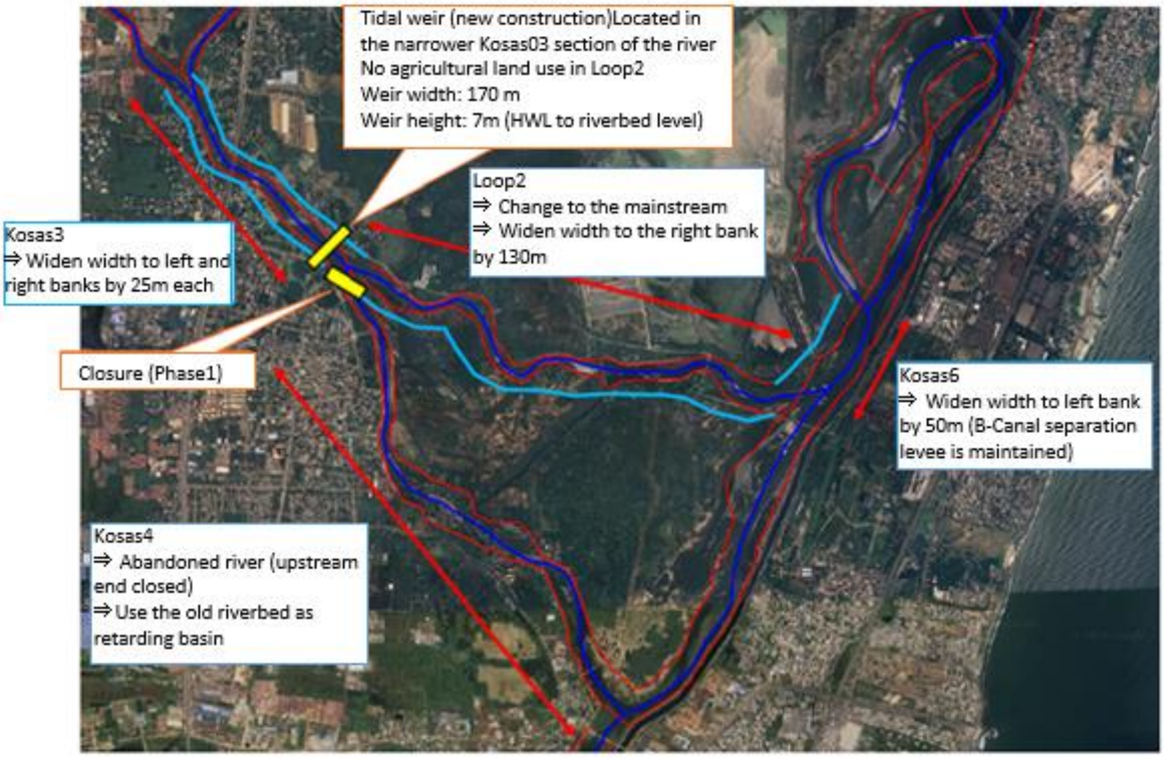
Outflow Point	River Section (HEC-RAS)	Distance from Sea			Phase1 Tank Usage:50%							
					Design Discharge [m3/s]					Carrying Capacity		
					Return Period [yrs]					Present	Deepning	Deepning + Widening
					1/10	1/20	1/30	1/50	1/100			
⑪	Kosas05	0.00	~	2.31						165	316	394
	Redhills	2.54	~	2.88						162	311	389
	Redhills	3.06	~	6.07	170	200	230	260	300	18	30	306
	Redhills	6.13		11.81						269	501	778
	Redhills	11.98		16.64						205	371	725
	Redhills	16.71		17.10						548	1,004	1,784

Source: JICA Expert Team



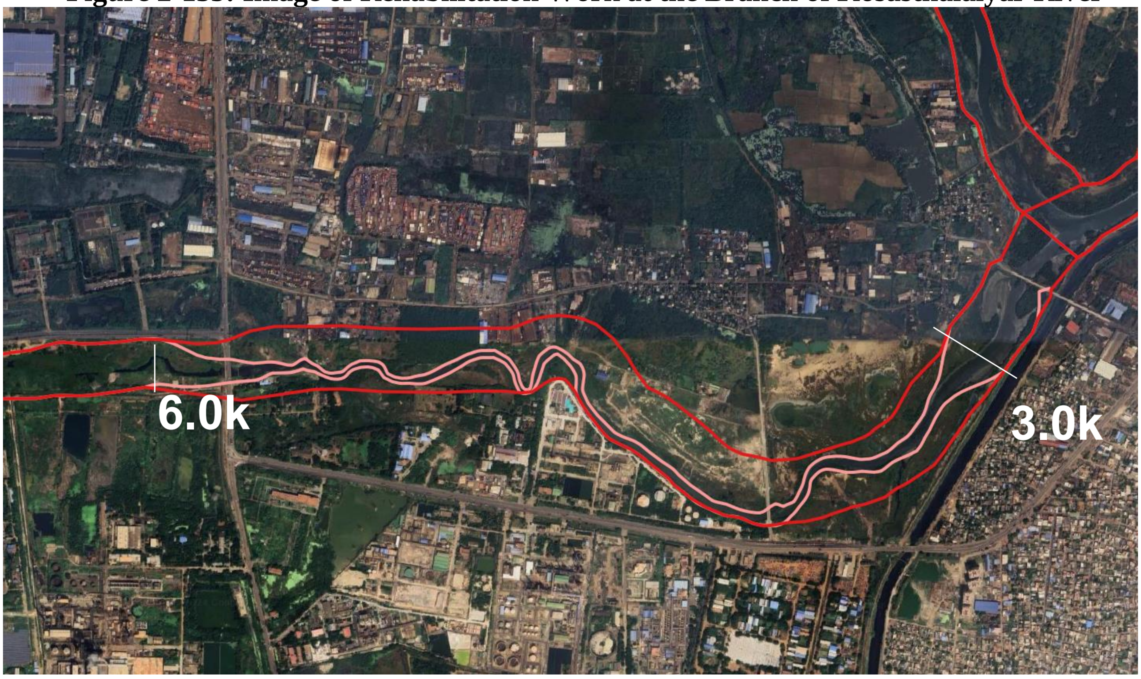
Source: JICA Expert Team

Figure 2-134: Priority Map (Kosasthalaiyar River)



Source: JICA Expert Team

Figure 2-135: Image of Rehabilitation Work at the Branch of Kosasthalaiyar River



Source: JICA Expert Team

Figure 2-136: Redhills Widening

2.6 Consideration of Non-structural Measures

2.6.1 Flood forecasting and effect of pre-releasing from major dams

The project, titled "Consulting Services for Planning, Setting-up and Operationalizing a Real-Time Flood Forecasting and Spatial Decision Support System for Adyar, Cooum, Kosasthaliyar, Nagariyar, Nandhiyar, and Kovalam Basins", focuses on establishing a robust flood forecasting and early warning for Chennai and its surrounding basins. Funded by the World Bank under Loan

No. 8488-IN (Project No. P150395) and managed by the Tamil Nadu Urban Infrastructure Financial Services Limited (TNUIFSL), the initiative is implemented on behalf of the Commissionerate for Revenue Administration & Disaster Management, Greater Chennai Corporation (GCC), and the Commissionerate of Municipal Administration. Launched in 2018, the project consists of a development phase, completed in September 2022, and an implementation phase extending until September 2025, ensuring operational continuity and capacity building for real-time flood forecasting and decision-making.

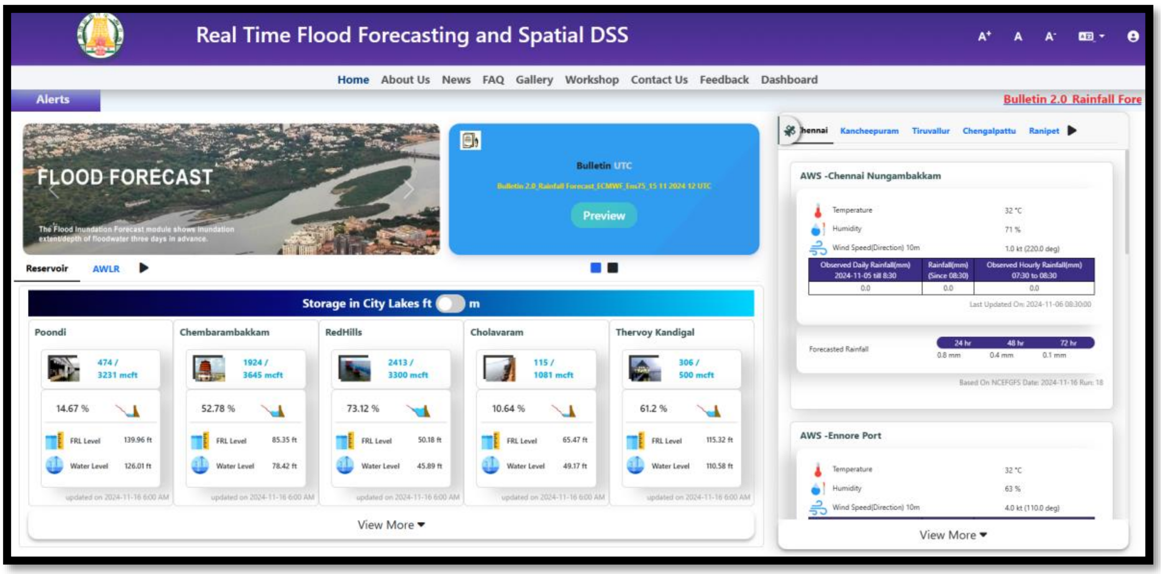
One of the objectives of this project is to provide reliable flood forecasting to enhance the operation of four major dams: Chembarambakkam Dam, Poondi Dam, Cholavaram Dam, and Red Hills (Puzhal Dam). Table 2.53 below displays the specifications of these dams.

Table 2-60: Specification of Major Dams in the Study Area

	Dam Reservoir			
	Chembarambakkam	Poondi	Redhills	Cholavaram
Catchment area (km^2)	357.42	1968.40	59.27	28.49
Full reservoir level (m)	26.03	42.67	15.30	19.96
Freeboard (m)	2.70	1.53	3.00	1.41
Gross storage volume (MCM)	103.21	91.49	93.45	30.61
Flood control volume and elevation	12.55 MCM @25.42m (12%)	14.58 MCM @42.06 (16%)	17.82 MCM @14.69m (19%)	4.89 MCM @19.35m (16%)
Design flood discharge (m^3/s)	936.15	3398.00	212.37	131.68
Probable Maximum Flood, PMF (m^3/s)	2,284	13,881	1,403	275

Source: JICA Expert Team

One of the main objectives of this flood forecasting project is to provide TNWRD officials with decision criteria for pre-releases from the four main dams. This criteria information will be based on real-time flood forecasts, which will allow dam officials to take proactive flood management measures during heavy rainfall events. The project aims to use this system to optimize flood control and reservoir operations, effectively manage increased dam inflows, and reduce flood damage downstream of the dams, thereby protecting critical infrastructure and local communities during peak rainfall events.



Source: JICA Expert Team

Figure 2-137: Website for the Real-time Flood Forecasting Project

A "What-If" analysis was carried out to simulate the effects of pre-release from Chembarambakkam Dam and Poondi Dam under various scenarios. This analysis considered pre-releasing water up to 24 hours in advance and assessed the impact of different storage levels in the dams. The study focused on evaluating the effect of varying storage levels, ranging from 80% to 95% full, on flood management. These dams primarily serve as water supply sources for Chennai, especially during the monsoon season, when TNWRD officials aim to maximize flood storage to prevent downstream flooding. The analysis incorporated rainfall events with a 100-year return period to assess the outflow under each pre-release scenario.

While the flood forecasting study is still ongoing, the initial findings emphasize the significant role of pre-release in reducing peak flood discharge in downstream areas, as shown in the accompanying table. However, due to the inherent uncertainty associated with flood forecasting, it was determined in the Master Flood Management Plan developed by this project that, from a safety standpoint, the runoff calculations would not take into account pre-release from the main dams.

Table 2-61: Simulation Effect of Pre-release for Different Scenarios

Dam	Pre-release Time and Discharge	Initial Dam Storage (% of Full Capacity)	Peak Outflow with Pre-release (m^3/s)	Peak Outflow in the JICA Master Plan (m^3/s)
Chembarambakkam	12hrs 150m^3/s	80%	470	820
		85%	500	820
		90%	530	820
		95%	570	820
Chembarambakkam	24hrs 100m^3/s	80%	400	820
		85%	430	820
		90%	470	820
		95%	500	820
Poondi	24hrs 200m^3/s	80%	1430	2100
		85%	1460	2100
		90%	1500	2100
		95%	1550	2100

Source: JICA Expert Team

2.6.2 Operation of tanks and waterbodies

The flood storage capacity of selected waterbodies and tanks, as discussed in earlier sections, is a key component of this master plan. In addition to structural measures such as dredging tanks, expanding foreshore area, and elevating surrounding bunds/buffers of these waterbodies, the following four non-structural measures are proposed to ensure their effective management and operation:

1. Conservation and protection of selected tanks and waterbodies

It is essential to prevent further encroachment and changes in land use of these tanks and water bodies. As highlighted in the Urban Planning chapter of this report, conservation efforts should therefore be prioritized through spatial planning measures, such as designating these areas as protected zones in the Third Urban Master Plan or similar planning initiatives.

2. Lowering water levels in tanks and waterbodies before monsoon and heavy rainfall

Lowering water levels before the onset of the monsoon or heavy rainfall provides sufficient storage capacity to accommodate excess floodwaters. This proactive measure ensures that tanks and waterbodies are well-managed and prepared to handle incoming rainwater, thereby enhancing flood resilience.

3. Regular monitoring and maintenance of waterbody facilities

Routine checks and maintenance of critical infrastructure such as gates, connecting drains, and other facilities are vital. This involves clearing blockages, dredging, and cleaning drains regularly to ensure their ability to efficiently discharge excess water downstream.

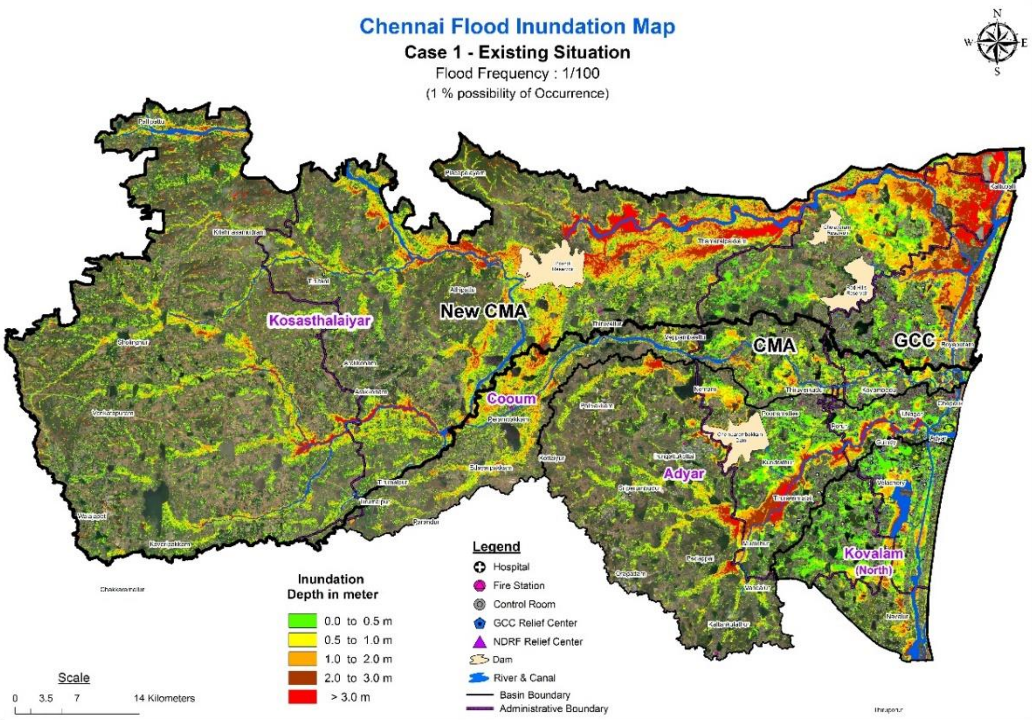
4. Cluster-based management of tanks and waterbodies

Managing water bodies and tanks in clusters based on their outfalls and downstream connections, whether they discharge into dams or rivers—streamlines operations and addresses maintenance challenges. Cluster-based management ensures coordinated flow, improves operational efficiency, and strengthens flood control measures. It is equally important to establish a central control room like a SCADA system (TNWRD has a plan for this, but still at the conceptual level) for monitoring water levels in waterbodies and tanks. The control room can also be equipped with additional facilities, such as systems for controlling automated gates, CCTV for real-time monitoring of waterbodies, gates, and connected drainage systems, and other necessary facilities to enhance the operation of waterbodies and tanks during monsoon season.

These non-structural measures complement structural interventions and are vital for ensuring the long-term sustainability, operational efficiency, and flood resilience of selected tanks and water bodies.

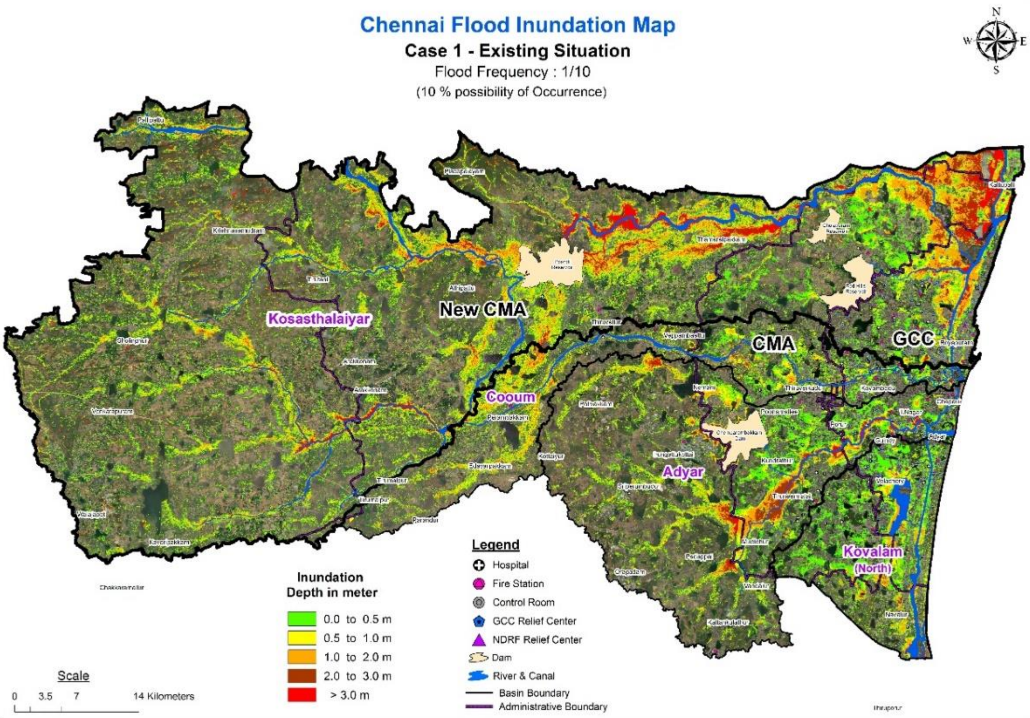
2.6.3 Flood hazard map creation

Flood hazard maps have been developed at multiple scales to provide a comprehensive understanding of flood risks across various levels. These include basin-level maps as well as detailed maps for administrative regions such as CMA and Greater Chennai Corporation (GCC). Additionally, specific maps have been created for GCC's 15 zones and 200 wards, ensuring varying levels of detail to address localized flood risks effectively. These maps incorporate flooding scenarios for different return periods, including 10, 20, 50, and 100 years, while accounting for a 10% increase in rainfall due to climate change. Figure 2-138 and Figure 2-139 showcase examples of the developed flood hazard maps for the study area, illustrating potential flooding patterns for both rainfall events with 100 and 10-year return period across the four basins of Adyar, Cooum, Kosasthalaiyar and Kovalam Rivers.



Source: JICA Expert Team

Figure 2-138: Flood Inundation Map for 1/100 Flood



Source: JICA Expert Team

Figure 2-139: Flood Inundation Map for 1/10 Flood

Table 2-62 outlines the various administrative scales and formats at which the flood hazard maps have been prepared, along with their potential users, highlighting how these maps can be utilized.

Table 2-62: Flood Hazard Maps – Scales, Formats, Users, and Distribution

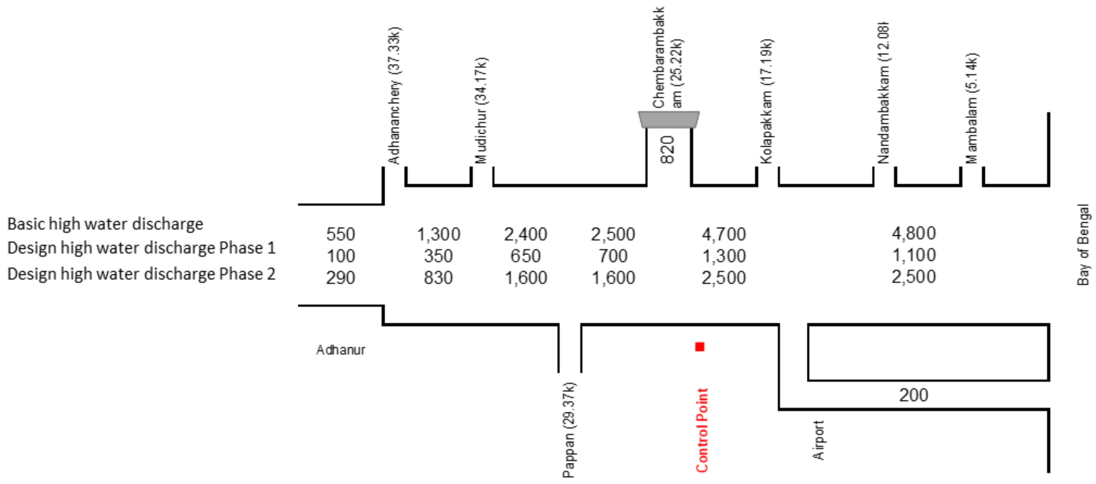
Admin	Format	Potential Users	How to use/Distribute
Basin	SHP, JPEG, A0 Print	TNDRRA, TNWRD	• TN Government GIS Databases (Online and open to government agencies) • TNDRRA Emergency Control Room and • TNWRD Basin Managers • It will not be open to the public
CMA	SHP, JPEG, A0 Print	TNDRRA, CMDA, MAWS, HUDD, CRRT	• TN Government GIS Databases (Online and open to government agencies) • TNDRRA Emergency Control Room • Annex to the 3rd Urban Development Master Plan • MAWS/HUDD will distribute it to other major cities in TN as a pilot • It will be open to the public as an annex to the Chennai master plan
GCC	SHP, JPEG, A0 Print	TNDRRA, CMDA, GCC, TNUIFSL	• TN Government GIS Databases (Online and open to government agencies) • TNDRRA Emergency Control Room • GCC Disaster Management Control Room • TNUIFSL will be used as supplementary information for the World Bank flood forecasting project • Will be shown using the website of GCC
GCC Zones (15)	SHP, JPEG, A1 Print	TNDRRA, GCC, TNUIFSL	• TNDRRA Emergency Control Room • GCC Disaster Management Control Room • Will publicize using GCC Zones offices
GCC Wards (200)	SHP, JPEG, A3 PDF	TNDRRA, GCC	• TNDRRA Emergency Control Room • GCC Disaster Management Control Room • GCC ward offices will discuss it using ward community meetings and will add information for 2015 and 2023.

Source: JICA Expert Team

2.7 Design Discharge Distribution Plan

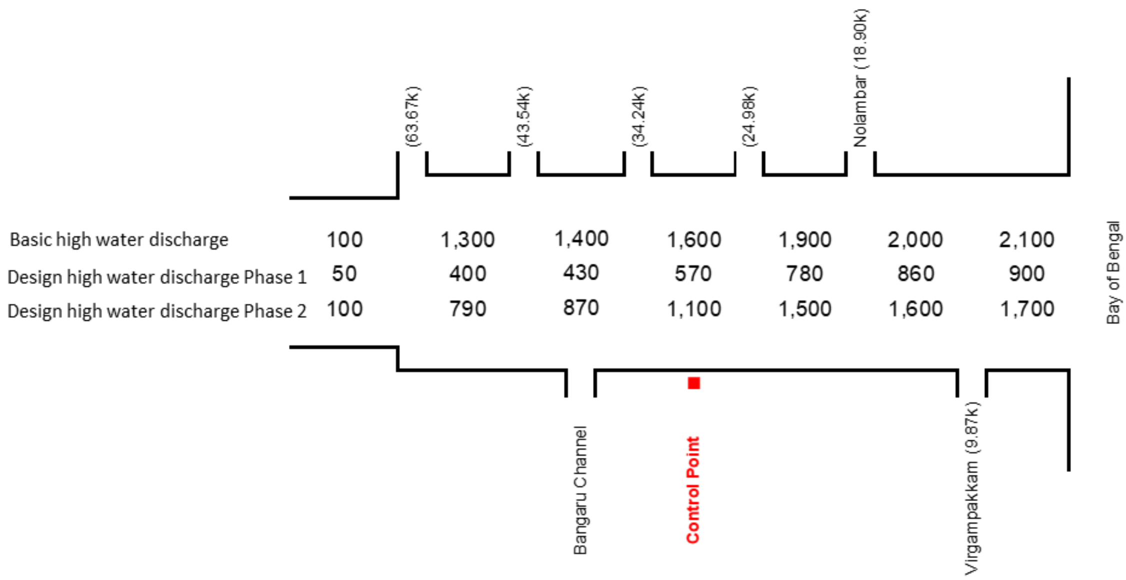
Based on the results of the study so far, the design discharge allocation proposals for Phase 1 and Phase 2 have been summarized as follows:

Phase 1: 10-year return period (basin storage facility improvement: 50%),
Design period: 10 years
Phase 2: 100-year return period (basin storage facility improvement: 75%),
Design period: 20 years



Source: JICA Expert Team

Figure 2-140: Adyar River Design High Water Discharge Distribution



Source: JICA Expert Team

Figure 2-141: Cooum River Design High Water Discharge Distribution

Source: JICA Expert Team

Figure 2-142: Kosasthalaiyar and Redhills Design High Water Discharge Distribution