No.

MINISTRY OF DISASTER MANAGEMENT AND HUMAN RIGHTS

DEPARTMENT OF IRRIGATION OF THE MINISTRY OF IRRIGATION AND WATER MANAGEMENT

COMPREHENSIVE STUDY ON DISASTER MANAGEMENT IN SRI LANKA

FINAL REPORT

(SUPPORTING REPORT)

MARCH 2009

JAPAN INTERNATIONAL COOPERATION AGENCY

ORIENTAL CONSULTANTS CO., LTD.

ASIAN DISASTER REDUCTION CENTER

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Supporting Report A

Current Condition and Master Plan Formulation

Supporting Report A Current Condition and Master Plan Formulation

A.1 Kelani River Basin

A.1.1 Basin Overview

The Kelani River is the second largest river in the country. The river originates in the central hill country of the island, and flows in a mainly to west until it reaches the sea at the northern boundary of the city of Colombo. The river basin, which is located entirely in the wet zone of the country, has an area of 2,292 km^2 and an annual runoff of 3,417 mil. m^3. A location map of the Kelani River is shown in Figure A.1.1.

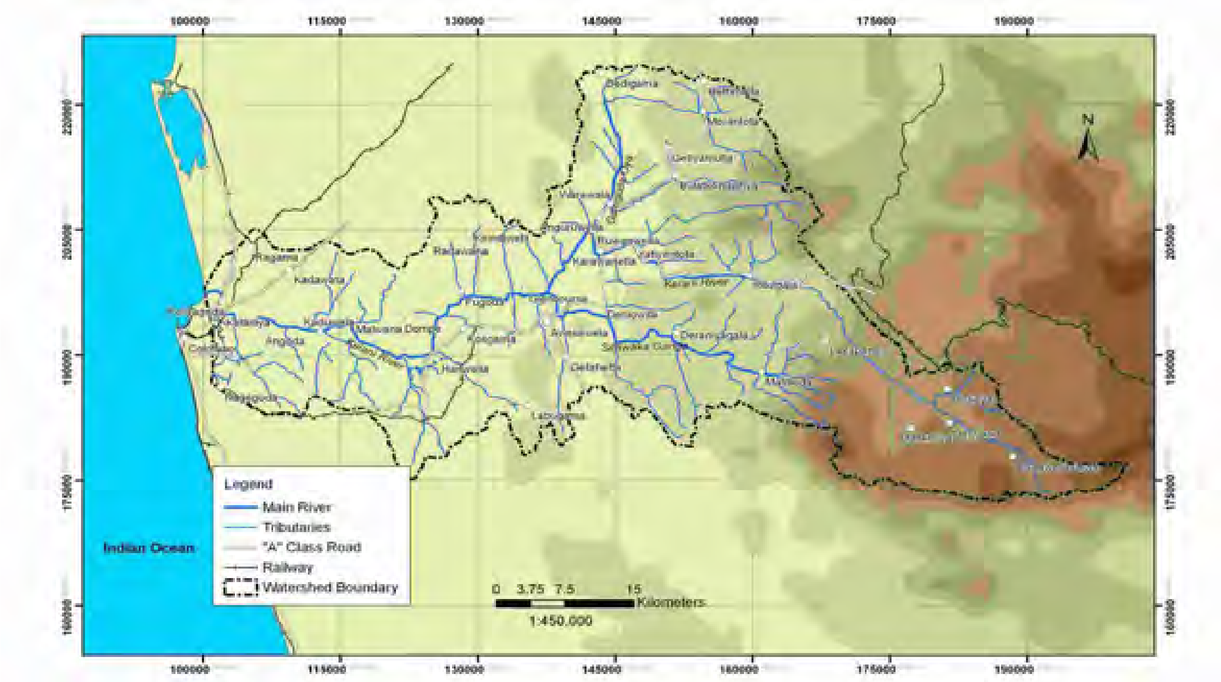
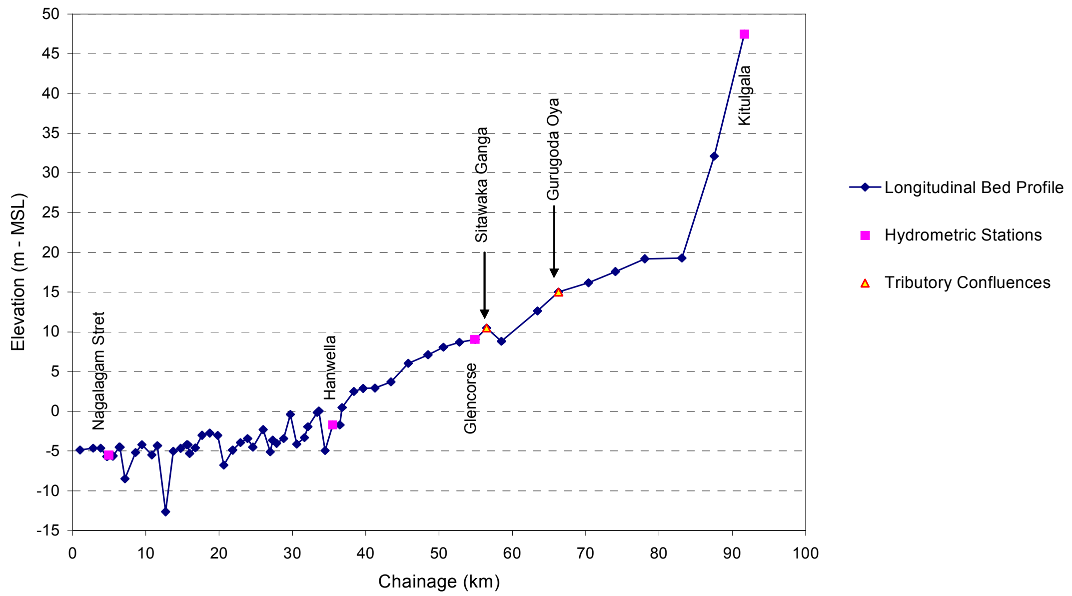


Figure A.1.1 Location Map of Kelani River Basin

The Kelani River basin comprises of two distinct types of topography, i.e. a mountainous upper region and a flat coastal plain. Approximately two-hirds of the entire catchment is occupied by the mountainous region where the peaks and ridges rise to over 2,000 m msl. Valley slope is very steep and the mountain streams are characterized by numerous waterfalls and rapids. Vegetation in this region is mainly tea, rubber and grass. Exposed bedrocks can also been seen in many places.

The coastal plain is very flat with scattered low hills rising to about 100 m msl. The vegetation in this area is a mixture of rubber, coconut, paddy and tea gardens. Downstream of Pugoda, the river bed slope flattens considerably and river valleys open out revealing wide flood plains. The river in this area is also intersected by several small streams with flat wide valleys. In order to control inundation of these lands during minor floods, several Minor Flood Protection Schemes (MFPs) have been constructed by DOI. The city of Colombo and its suburbs adjacent to the north and south banks of the river are protected by flood bunds acting as major flood protection schemes.

The river bed material in the lower reaches consists of fine sand, and between Hanwella and Colombo, the bed profile becomes very irregular due to sand mining activities in the river. Recently DOI is proceeding bank protection works at the existing North Bund to stabilize the river banks and the bund against erosion. A longitudinal profile of the Kelani River (Kitulgala ~ river mouth) is shown in Figure A.1.2.



Source: Hydrology Division of DOI and LHI

Figure A.1.2 Longitudinal Profile of Kelani River

A.1.2 Past Significant Floods

(1) Historical flood

The severity of floods in the low laying areas in lower reaches of the Kelani River has been observed by the gauge post reading of Nagalagam Street at Colombo by DOI as given in Table A.1.1. As seen in the record, the severest flood in terms of water level after 1940's occurred in June 1947 with gauge post recording of 12.85 feet.

Table A.1.1 Gauge Reading at Nagalagam Street during Significant Floods in Kelani River

Year	Date/Month	Water Level (ft)
1837	-	13.50
1872	-	11.98
1891	-	9.80
1904	-	9.90
1906	-	10.80
1913	-	11.00
1922	-	12.60
1925	-	11.50
1928	July	9.08
1930	May	10.91
1930	October	9.83
1933	May	9.95
1936	MAy	9.43
1937	May	10.33
1939	May	9.35
1940	May	11.00
1942	July	8.17
1943	May	6.58
1944	May	6.00
1947	August	12.85
1947	October	6.00
1952	May	8.25
1952	October	6.00
1955	October	8.00
1957	December	6.25
1963	October	6.42
1966	September	8.67
1966	October	9.00
1967	October	9.17
1971	September	7.33
1975	May	6.58
1989	June	9.20
1999	April	6.60
2006	November	5.65
2008	April 29	5.75
2008	May 31	5.90

Nature of Flood	Water Level (ft)	Areas Going under Water
Minor	5.00' to 7.00'	Short stretch under new Kelani Bridge on Grandpass, Ambatale Road, land between river and Ambatale at Kotuwila, Wennawatta, Kelanimulla and a small section of Farguson Road
Major	7.00' to 9.00'	Area near Madampitiya Road, most of Farguson Road, portion of Mattakuliyo, entire Grandpass, Ambatale Road, and stretches between Ambatale and Hanwella
Dangerous	9.00' to 12.00'	Railway main line between Maligawatta Kelani railway bridge, Kelaniya - Biyagama Road, and low lying areas at Kelaniya
Critical	12.00' and above	a. Blosmandhal Road, Prince of Wales Avenue, Nagalagam Street, parts of Grandpass, Urugodawatta Road, North and of Baseline Road, Section of Dematagoda Road, Armour Street, Skinnara Road (South), and Panchikawatta
		b. Tample Road, Temple Lane, Old Kolonnawa Road, Area South of Baseline Avenue, South end of Baseline Road, sections of Macarthy Road, Kynsey Road, Gregory's Road, Bullers Road, East end of Castle Street, sections of Kotta Road, Battaramulla, Parliament Area, Modelfarm Road, Koswatta Road and parts of Thinnbirigasyaya
		c. Wallasa, Kelaniya, Biyagama, Ambatale, Kaduwela

Source: *"Scheme of Organization and Standing Orders to Safeguard City of Colombo from Floods in Kelani Ganga, DOI, April 1993"*
Based on the above, updating was undertaken for those after 1999 by the Study Team.

In order to protect urban area of Gampaha District, the Major Flood Protection schemes to construct of flood bund at right bank side had been started at the beginning of last century. The land side of the flood bund is called as "Protected Area", versus the riparian area between river course and flood bund is called as "Unprotected Area". Recently frequent flooding in the unprotected area became one of social problems requiring practical countermeasures in Colombo. On the other hand, as for the protection of the unprotected area, the Minor Flood Protection schemes has been implemented and installed small scale sluice gates at both banks along the mainstream.

In recent 20 years, June 1989 flood is the most significant in the Kelani River and reached to the "Dangerous" level apart from few flood events which reached minor flood levels.

(2) Flood in June 1989

The latest major flood of June 1989 affected several towns along the river to varying degrees and damaged to road, bridge, public utilities and personal properties, etc. The flood also disrupted traffic and communications, not only causing to people of disturbing work (in order to protect their properties during the floods and also to clean-up afterward), but also causing considerable inconvenience to the affected people. The inundation area of June 1989 flood is shown in Figure A.1.3 based on the same prepared by DOI.

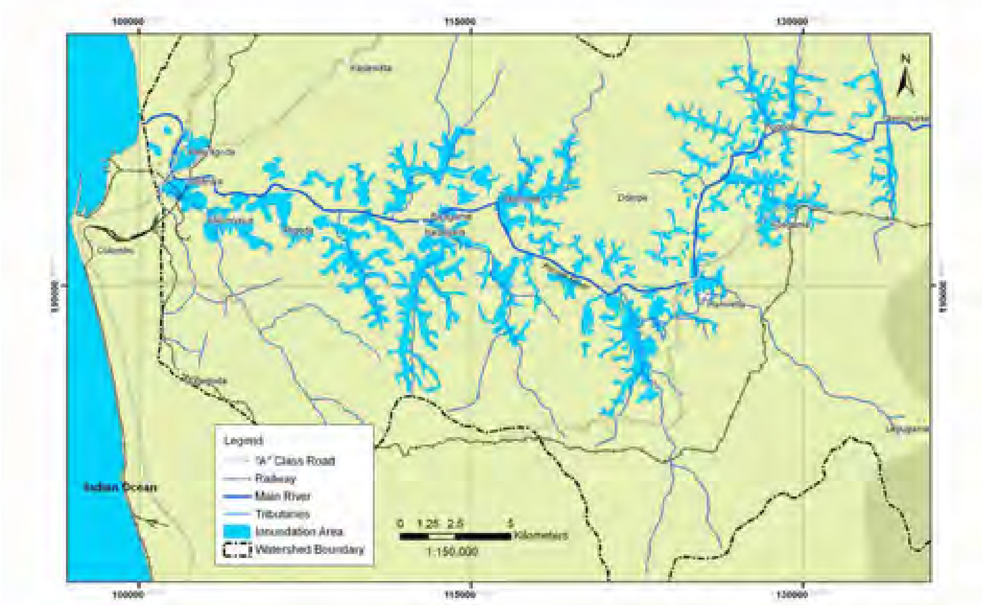


Figure A.1.3 Inundation Area due to June 1989 Flood in Kelani River Basin

(3) Flood in October 2006

On October 27 to 29, 2006 during the First Field Work of the current study, minor scale of flood occurred in the Kelani River basin. According to a newspaper on October 29, over 20,000 families have been displaced and around 6,000 houses have been damaged due to heavy rainfall in Colombo, Kalutara, Gamhpaha, Puttalam and Ratunapura. In the evening of October 27, several low lying areas in Colombo along the Kelani River were inundated. However, no overtopping of the flood bund along the Kelani River has been observed and the maximum water level at Nagalagam Street was 5.65 ft (between 5.00 and 7.00 ft of Minor Flood water level) in November. DMC uploaded the "Disaster Situation Report" summarizing flood and landslide disasters on their web-site on October 28, 2007.

(4) Flood in May 2008

The torrential rainfall hit the Kelani River basin twice during about one month from the end of April to the beginning of June 2008. The second flood occurred on May 30 to June 1 was a little larger than the previous one occurred Apr.28. In fact, the water level of the Kelani rose up to GL 5.90 ft at Nagaragam G/S on May 31, which was the 3rd highest within the latest three decades. Considerably wide area from Hanwella to Kelanimulla (Colombo side) and from Pugoda to Maluwana (Gampaha side) was inundated during both floods. Based on the site reconnaissance and interviews to the affected people by the Study Team, the average inundation depth in the areas seems to be between 0.5 to 1.0m in the basin during the two flood events.

A.1.3 Review of Previous Flood Management Studies

(1) "Flood Control of the Kelani Ganga, International Engineering Company, San Francisco, 1948"

This report proposed the construction of a flood control and hydro power reservoir at Glencourse in combination with a levee system at downstream of the Kelani River.

(2) “Kelani Flood Protection Scheme, Dr. Mylvaganam, Irrigation Department, 1948”

Dr.Mylvaganam, the author of the report, rejected the above recommendations due to considerable inundation of land, which would occur if the construction of reservoir at Glencourse is realised. This report proposed instead the construction of four reservoirs further upstream and a levee on the lower river reaches.

(3) “Diversion Canal, Irrigation Department, 1950”

A 1,000 m wide canal to divert the flood water from Peliyagoda to the sea through a stabilized sea outfall was proposed in the report.

(4) “Kelani Ganga Basin Scheme, Technopromexport, USSR, 1961”

This report proposed an ambitious scheme for the multi-purpose development of the Kelani River basin. The report proposed the construction of three dams at Holombuwa, Nawata-Pulusella, an 80 km long trans-basin diversion canal to allow the irrigation of 59,000 ha of agricultural land in the North-west Province, and a 33 MW hydroelectric power development.

Flood control of the entire basin would be provided by partial retention of flood discharge in the dams, coupled with the construction of a 100 km long levee system from Pugoda to Colombo (distance between levees 600 to 900 m). Construction of the levees system alone would require the resettlement of 32,100 people (1961 figures). None of recommendations proposed in the above reports have been implemented due mainly to the high cost involved and the social implications.

(5) “Kelani Ganga Flood Protection Study, DHI, March 1992”

The first attempt for comprehensive flood protection study applying the mathematical modeling technology (by MIKE 11) in the Kelani River basin was conducted by DHI under DANIDA (Danish International Development Agency) from 1990 to 1992. Final Report was submitted in March 1992 to Irrigation Department (belong to the Ministry of Land and Land Development at that time).

Flood control measures were proposed by dividing into three categories of target areas: Colombo and environs, rural population centres and agricultural areas. It is noteworthy that the study decided to concentrate in providing individual flood protection to a number of separate areas rather than flood protection for the entire river basin at the initial stage. Construction of flood control reservoirs and total embanking of the river were rejected based on the preliminary study results.

Regarding the Colombo flood protection scheme, all three options in deferent return periods for embankment height resulted in negative IRRs. Majority of the costs of these schemes was land acquisition. As for the rural population centres, the study concluded that three (Avissawella, Hanwella and Kaduwella) of six selected areas were justifiable with a scale of 25 to 50 year return periods. The flood protection for agricultural areas along the Kelani River was concluded to be not viable. However, Akkarawita and Ambatale were selected among few candidate areas for detailed evaluation. The study assessed utilization of these areas as flood retarding zone with flood water diverted into the areas in a controlled manner (referred to as “optimized spillway”).

(6) "Wetland Site Report and Conservation Management Plan, Colombo Flood Detention Areas, Central Environmental Authority/Euroconsult, Ministry of Transport, Environmental and Women's Affairs, January 1995"

This study started in September 1991 and was carried out by Natural Resources Management Division of the Central Environmental Authority. Technical and financial assistance was provided by the Netherlands Government. The study identified the Colombo Flood Detention Areas (CFDA) composed of 400 ha of marshlands and traversing canals, in particular, Colombo's remaining low-lying lands in Kolonnawa Marsh, Kotte Marsh and Heen Marsh. In fact, the areas serve as "basins" where storm water can temporarily be detained before it flows into the river. In order to conserve the area for use as (1) flood water detention area, (2) recreational and educational area and (3) nature conservation area, various action plans were recommended and categorized either into: "management as a detention area", "management for recreation and education", "nature conservation: water level management", "nature conservation: water quality management", etc. The final report was submitted in January 1995.

(7) "Western River Basin Sector Project, TA3030-SRI, DHI, July1999"

The study was aimed towards multi-sector development of the western river basins, consisting of the Maha Oya, Attanagalu Oya, Kelani, Bolgoda, and Kalu River basins. The study recommended various countermeasures for water resources development, water quality conservation, land use and environmental conservation, and flood management in respective river basins.

A.1.4 Basic Concept for Flood Management Planning

A.1.4.1 Planning Scale

From the results of review on the existing national or regional development plans, it was clarified that no specific criteria/guideline defining appropriate or target scale of protection level (planning scale) exists in Sri Lanka. Therefore, based on a series of discussions and agreement of DOI, the planning scale of four river basins were decided taking into consideration the following: (i) current channel capacity, (ii) experienced maximum flood peak discharge and (iii) future land use conditions. The planning scale as target to formulate Master Plan was set as follows:

Table A.1.2 Planning Scale of Kelani River Basins

River Name (km^2)	Safety Level (Flow Capacity)	Experienced Max. Peak Flood	Future Land Use	Planning Scale
Kelani (2,292)	- South Bund 100-year probability (Colombo side) - North Bund 30-year (Gampaha side) - Non-flood bund section 2~3-year	Aprrox.60~70-year (June 1989 flood)	Sprawl of Metropolitan Colombo area will proceed and urbanization will be further progressed. Low lying wetland located along the Kelani will be encroached and decreased if any effective land use regulation/ordinance is not introduced.	20-year ($3,400\ m^3/s$ at river mouth) (in case excluding natural retarding basins)

Source: National Census in 2000

In accordance with the record of the National Census in 2000, the population in the river basin was assessed with size of population of major cities as shown in Table A.1.3

Table A.1.3 Current Population in River Basin and Major Cities

River Name	Population (thousand)	Population in Major Cities (thousand)
Kelani	2,772	Greater Colombo (2,211), Others (562)

Source: JICA Study Team

A.1.4.2 Target Period for Implementation

Considering the required period of implementation of the proposed Master Plan, the target period was set for 15 years starting Year 2010 and ending Year 2024.

In terms of development in the study area, basic direction and trend should be noted with the latest documents of national development policy, i.e. "Mahinda Chintana: Vision for A New Sri Lanka, A Ten Year Horizon, Development Framework 2006 – 2016 Discussion Paper, Department National Planning and ministry of Finance and Planning". The development policy in this document is aiming at raising the GDP growth rate in excess of 8%. Based on the review of economic policies during past two and half decades, a long term development program covering 2006 to 2016 has been prepared within the broad policy of the President. The program covers total 11 sectors such as: (i) agriculture and irrigation, (ii) industry, (iii) economic infrastructure, (iv) tourism, (v) urban development and human settlements, (vi) livelihood development and social protection, (vii) education, (viii) health, (ix) sports and culture, (x) science and technology and (xi) environment. The document consists of 16 chapters. In particular, flood management activities will be able to contribute in removing vulnerability and risks which is an absolute obstacle in achieving the goals of the program. Therefore, earlier implementation of the proposed Master Plan expected aiming at firm progress of the "A Ten Year Horizon" in the related development sectors.

A.1.4.3 Basic Conditions for Formulation of Master Plan

(1) Common Conditions

In order to set alternative structural measures, the following preambles are applied in the current Study:

1) Unprotected Area

The areas, where is not prevented from overtopping of flood discharge by flood bund or other structures are called the "Unprotected areas". Actually, such area is situated at the downstream of the Kelani, Gin and Nilwala. Most of the areas are threatened by habitual flooding since flow capacity of low water channel is relatively small against magnitude of peak discharge.

Taking into account the area of subject area and required budget, it is anticipated that protection by structural measures is not feasible. In this sense, this Study prioritizes non-structural measures for the unprotected area over structural measures. The location of unprotected area at downstream of the Kelani River is shown in Figure A.1.4

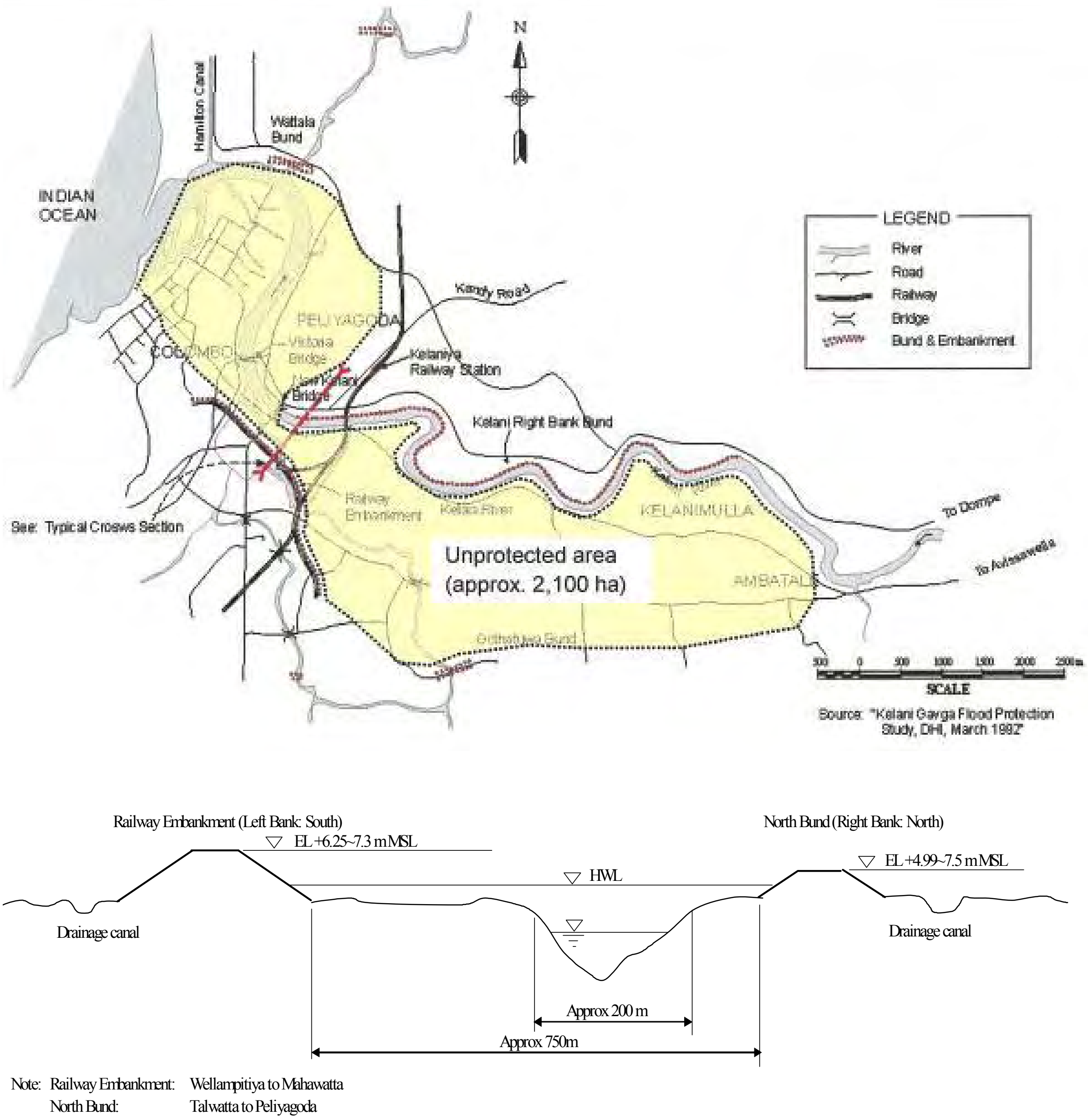


Figure A.1.4 Location Map of Unprotected Area in Kelani River Basin

2) Early warning and monitoring system

In the Kelani River basin, pilot project of installation of automatic water level and rain gauges was conducted in association with community-based disaster management component of this Study. Similar project was conducted in the Kalu River basin as well in year 2008. It will be verified and recognized through the Pilot Projects that such early warning and monitoring system can be effectively applied as one of non-structural measures in the Study area with careful examination of hydrological feature and communication network.

Considering the size of required budget and construction procedure/period, such early warning system is able to introduce in a short period of time, as compared with other structural measures such as construction of flood bund and river training works, etc. Therefore, in the proposed Master Plan in the four river basins, the early warning and monitoring systems are included in the short-term plan. As for the Kelani and Kalu, further extension to supplement the monitoring stations of water level and rainfall are being considered after execution of the Pilot Project.

3) Dam and reservoir schemes

To create flood control and reservoir is one of effective options for reducing flood peak discharge in the basin. In fact, some potential dam schemes have been identified and proposed in the respective four river basins since the 1960's.

Considering the objective in the current Study which focuses on disaster management, particularly on flood management, the single purpose of flood control is envisaged for dam scheme in combination with other structural measures. In the Kelani, synthetic reservoir storage volume corresponding with dam height, which is estimated by required flood retarding pocket against design flood, is duly examined.

4) Minor Flood Protection Schemes (MFPs)

The criteria of improvement or new construction of MFPs along the Kelani River is set to estimate required cost for evaluation of the proposed component of the Master Plan. Among the total 44 structures, 24 are located at Colombo side and 20 are located at Gampaha side. The purpose of the structures is to simply prevent the back water intrusion into land side from the mainstream of the Kelani during flooding. Based on the current conditions as well as discussions with Colombo Regional Office, DOI obtained through site reconnaissance, the following criteria including the extent of improvement were applied. Current status and structural feature of each MFPs is presented in Table A.1.4.

Table A.1.4 Current Condition and Proposed Betterment of Minor Flood Protection Schemes along Kelani River

No.	Name of Minor Flood Protection Schemes	Right or Left	No. of gate and size	Type of Gates	Bund Top Level (EL.m)	Protection Level (EL.m)	Protected Area (ha)	Design Discharge (m3/s)	Year Constructed	Operation / Maintenance Conditions: Gate / Hoist / Approach Deck	Frame / Pier / Column	Epron / Wall / Abutment	Revetment / Slope Protection	Approach / Connection Canal	Note	Evaluation: Extent of Repair / Reconstruction
1	Senasumgoda	R	7 nos. 4' 0" x 4' 6" (W)	Flap Gate	-	-	141.8			NR	NR	NR	None	NR	In good condition at present. Crossing over the Senasungaoda Oya.	–
2	Pugoda	R	10 nos. 4' x 4' 6" (W) 2 rows	Flap Gate	13.4	12.8	108.5			NR	NR	NR	None	NR	Newly constructed in 2006. Crossing over the Pugoda Oya and flood bund is connected.	–
3	Nikawela	R	6 nos. 4' 0" x 6' 0" (W)	Flap Gate	11.6	10.1	91.1			Gate damaged	NR	NR	None	NR	Gates shall be replaced	○
4	Kapugoda (Giridara)	R	5 nos. 4' 0" x 6' 0" (W)	Flap Gate	11.1	10.4	137.7			Gate damaged	NR	NR	None	NR	Gates shall be replaced	○
5	Modarakada	R	2 nos. 4' 6" x 5' 0" (W)	Lifting Gate	-	-	96.0			NR	NR	NR	None	NR	-	–
6	Yattowita	R	2 nos. 4' 9" x 5' 0" (W)	Lifting Gate	-	-	87.1			NR	NR	NR	None	NR	-	–
7	Kadatiyawatta (Wellgama)	R	2 no. 4' 6" x 5' 0" (W)	Flap Gate	-	9.1	93.6			Gate damaged	NR	NR	None		Wooden flap gate was broken and being not able to shut off. Flood bund is connected.	○
8	Mora Ela	R	2 nos. 4' 6" x 6' 0" (W)	Flap Gate	-	8.1	88.3			Gate damaged	NR	NR	NR	NR	Gates shall be replaced	○
9	Gontota Ela	R	1 no. 3' 0" dia.(C.I.)	Flap Gate	-	-	30.4			NR	Grouting of concrete barrel is required to stop leakage	NR	NR	NR	Barrel (concrete body) shall reconstructed (location of leakage shall be properly investigated).	○
10	Modarakadawatta	R	2 nos. 2' 6" dia. (C.I.)	Flap Gate	-	-	70.9			NR	NR	NR	NR	NR	-	○
11	Wellawata	R	2 nos. 1' 6" dia. (C.I.)	Flap Gate	-	-	64.8			NR	NR	NR	NR	NR	-	○
12	Malwala Pahuruoya	R	7 nos. 4' 0" x 5' 0" (W) rows	Flap Gate	7.2	6.6	643.5			Improvement required	Improvement required	Improvement required	Improvement required	Improvement required	Wooden stop logs is installed and design of total structure seems different from others located neaby. Flood bund shall be constructed, Water pipe is crossing over the canal, which is vulnerable to damage during flood. Reconstruction is recommended.	○
13	Yabaraluwa	R	3 nos. 3' 0" dia. (C.I.)	Flap Gate	6.7	6.1	80.2			Gates damegd with no hoist deck.	NR	Cracks are seen on the crest of wall.	None	NR	Demolition and reconstruction is recommended.	○
14	Kukulawala	R	3 nos. (W)	Lifting Gate	-	-	75.3			No approach and hoist deck.	NR	NR	NR	NR	Redesign for connection of flood bund for easier access to gate hoist is required. Partial repair is necessary.	○
15	Rakgahawatta	R	6 nos. 4' 6" x 5' 6" (W)	Flap Gate	-	-	22.1			New construction					Totally collapsed due to torrential rainfall on May 04 and 05, 2007. New structure shall be provided at same location. Elctric-driven sluice gate shall be provided considering size of required opening.	○
16	Pattiwila	R	4 nos. 1' 6" dia. (C.I.) 2 nos. 6' 0" x 4' 0"	Flap Gate Lifting Gate	5.8	5.2	111.4		1933	Gates damegd with no hoist deck.	Much leakage from right abutment and gate opening as well	NR	None	NR	Demolition and reconstruction is recommended.	○
17	Bollegala Pelawatta	R	1 no. 3' 0" x 3' 0" (W)	Flap Gate	-	-	8.5			NR	NR	NR	NR	NR	-	–
18	Seethawaka	R	1 no. 4' 6" x 4' 6" (W)	Lifting Gate	-	-	68.9			NR	NR	NR	NR	NR	-	–
19	Koskumbura	R	1 no. 3' 0" x 3' 0" (W)	Flap Gate	-	-	9.3			No hoist deck	NR	NR	NR	NR	Hoist deck is to be provided for safe operation.	○
20	Nagahawattha	R	3 nos. 3' 0" dia.	Flap Gate	-	-	121.5			NR	NR	NR	NR	NR	-	–
	Total						2,150.8									
1	Ranwela Muttetupola	L	1 no.	Lifting Gate	7.9	7.3	14.2			NR	NR	NR	NR	NR	-	–
2	Madapana	L	1 no.	Lifting Gate	7.9	7.3	12.2			NR	NR	NR	NR	NR	-	–
3	Wanahagoda	L	1 no.	Lifting Gate	9.1	9.1	60.8			NR	NR	NR	NR	NR	-	–
4	Dasawella	L	Bund only	Lifting Gate	11.6	11.0	81.0			NR	NR	NR	NR	NR	-	–
5	Koratota	L	5 nos. 5.5' x 5'	Lifting Gate	5.3	4.6	126.0			NR	NR	NR	NR	NR	-	–
6	Akkarawita	L	6 nos. 5' x 4'	Lifting gate	9.8	9.1	135.6			NR	NR	NR	NR	NR	-	–
7	Kahatapitiya II	L	1 no. 2' 0" dia.	Flap Gate	10.4	9.9	-			NR	NR	NR	NR	NR	-	–
8	Kahatapitiya I	L	3 nos. 3' 0" dia.	Flap Gate	10.4	9.9	16.2			NR	NR	NR	NR	NR	-	–
9	Brandigampala II	L	4 nos. 4' 0" dia.	Lifting Gate	11.6	10.7	-			Gates damaged and no approach to hoist is	Improvement required	Not connected with flood bund	NR	Need repair	Overall design concept is necessary to review. Demolition and reconstruction is recommended.	○
10	Brandigampala I	L	2 nos. 4' 0" dia.	Lifting Gate	11.6	10.2	121.5			Same condition as Brandigampala II	Improvement required	Not connected with flood bund	NR	Need repair	Same as Brandigampala II	○
New	Pussari Oya	L	<To be designed>							New construction					One major tributary withour control strctures near the confluence with Kelani. Wide beneficial area for agriculture is expected. Eco tourism plan is currently contemplating by Ceylon Civil Engineering Consulting Bureau..	○
11	Palawatta Wela	L	1 no. 4' 0" dia.	Flap Gate	9.8	9.1	13.0			NR	NR	NR	NR	NR	-	–
12	Meegoda	L	1 no. 2' 0" dia.	Lifting Gate	7.6	6.7	14.6			NR	NR	NR	NR	NR	-	–
13	Henpita	L	4 nos. 5' x 4' 2 nos.	Flap Gate Lifting Gate	8.5	7.6	50.2		1947	All gates heavily damaged	NR	NR	NR	NR	Gates and hoist deck shall be reconstructed.	○
14	Ranala	L	3 nos. 3' 0" dia.	Flap Gate	7.9	7.3	50.6			NR	NR	NR	NR	NR	-	–
15	Undugoda	L	Bund only		-	-	-			NR	NR	NR	NR	NR	-	–
16	Rada Ela	L	1 no. 12" dia.	Flap Gate	6.6	5.6	20.3			NR	NR	NR	NR	NR	-	–
17	Bomiriya	L	8 nos. 5' x 4' (2 rows)	Flap Gate	6.2	5.6	1,214			NR	NR	NR	Protected by gabion mattress, but deformation follwong the change of river bed is seen partially.	NR	-	–
18	Hewagama	L	2 nos. 5' x 4'	Flap Gate	6.1	5.6	81.0			NR	NR	NR	NR	NR	-	–
19	Weliwita	L	3 nos. 5' x 5'	Flap Gate	5.9	5.3	232.3			NR	NR	NR	NR	NR	-	–
20	Ambatale	L	4 nos. 5' x 4' (2 rows)	Flap Gate	5.8	5.2	-			NR	NR	NR	Slope failure at US and DS of the structure has occurred.	NR	Bank protection works with revetment (stone masonry) shall be provided.	○
21	Nirmawila	L	1 nos. 2' 0" dia.	Lifting Gate	-	-	20.3			NR	NR	NR	NR	NR	-	–
22	Kelanimulla	L	2 nos. 6' x 5.5'	Lifting Gate	-	-	20.3			Gate leaves damaged	Many cracks are developed at center pier, which will threaten safety operation of	Partition wall is not properly designed.	NR	NR	Prtition wall for sealing by gates and hoist deck shall be reconstructed. Flood bund is to be connected.	○
23	Sedawatta	L	10 nos. 5' x 4' (2 rows)	Flap Gate	-	2.1	20.3			NR	NR	NR	None	Grasses cover the canal section.	This gate is located at outlet of the Kittanpaua drainage canal. Canalization is required properly.	○
24	Grand Pass	L	2 nos. 6' x 5'	Lifting Gate	-	1.5	-			NR	NR	NR	NR	NR	-	–
	Total						2,304.1									

Source: Updated based on the information from DOI and in "Kelani Ganga Flood Protection Study, DHI, March 1992" and field reconnaissance by the Study Team.

Remarks: (W), Wooden (C.I.), Cast iron
Evaluation: -: No requirement of repair ○: Repair required

Note: Staff gauge shall be installed at both land and river sides for monitoring at every MFPs.

For improvement:

(A) If main body of the structure is still stable and usable with partial reinforcement (change of te leaves and provision of hoist deck, etc.), it is to be selected to save on the cost.

(B) Existing number and size of the gates and type of gate shall be maintained as they exist at present for replacement and renewal (size of gate opening is maintained as it is), which is subject to further review of appropriate opening of the gate.

For new construction:

(A) If the main body of the structure is totally or partial damaged, which affects proper installation of gates, demolition of the existing one and reconstruction at the original or other appropriate location nearby is selected.

(B) Existing number and size of the gate and type of gate shall be maintained as exists at present for reconstruction (size of gate opening is maintained as it is).

(2) Current condition of flood damage

- Habitual flooding in the unprotected area at downstream area having no flood bund (inundated by 3-year probable flood)
- Inundation by intensive rainfall in land side at downstream area having flood bund
- Bank erosion at meandering section that threatens collapse of the North Bund (existing from Talwatta to Peliyagoda at Gampaha (left bank) side

Longitudinal profile and flow capacity of the Kelani River are shown in Figure A.1.5 and Figure A.1.6.

(3) Basic strategy of flood protection to be implemented

1) Target area: From Hanwella to river mouth

(Unprotected area, area without flood bund at downstream and meandering section threatened by serious erosion at left bank)

2) Sale of countermeasures:

Short-term target	Long-term target
1/5 (Q_{peak}=2,300 m^3/s)	1/20 (Q_{peak}=3,400 m^3/s)

3) Basic strategy of flood protection:

- To raise flood protection level at habitual flooding area from 2~3-year probability to 5-year probability of flow capacity of low water channel
- Since dam schemes at upstream area (Nawata-Purusella and Yogama) include many issues such as large scale of relocation of main road, involuntary resettlement and complex rule of allocation of multi-purpose benefit, etc., it is not considered as a short-term measure. Thus, as a long-term

measure, single purpose flood control dam is assumed and compared with other alternatives in this Study.

- To strengthen retarding function of flood peak at low lying wet land in the stretches with non-flood bund along the Kelani River (by allowing overtopping excess flood discharge over 5-year return period into the retarding basin)
- To strengthen safety of the existing flood bund and extension/improvement of MFPs
- To promote and proceed non-structural measures in the unprotected area

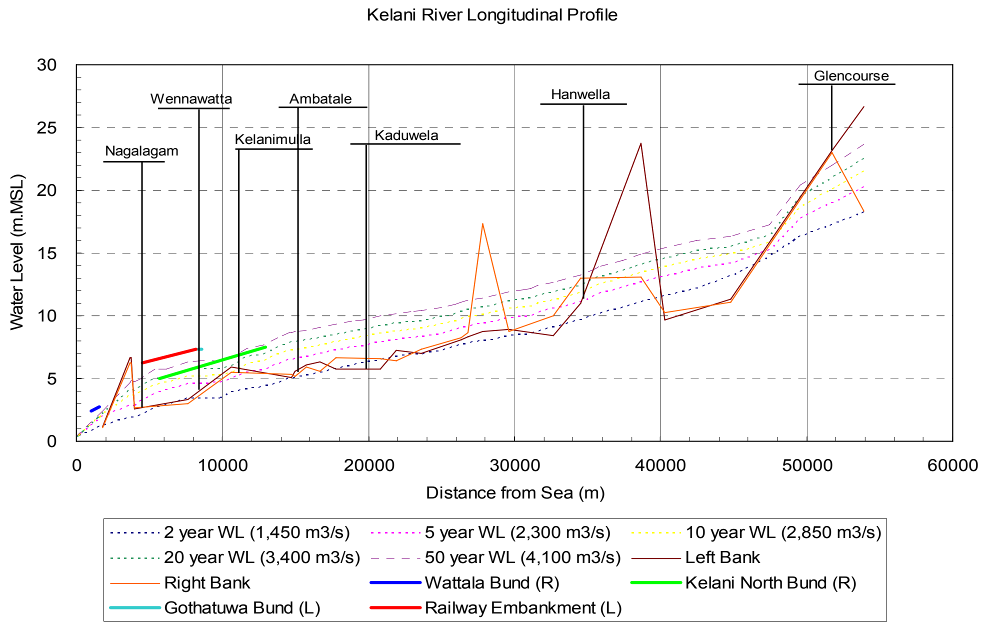


Figure A.1.5 Longitudinal Profile of Kelani River

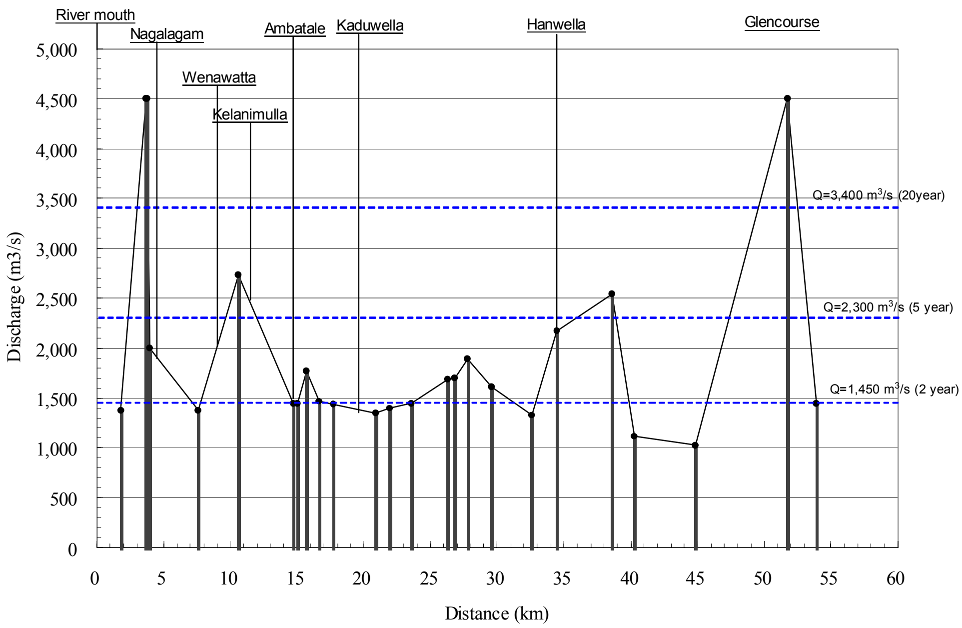


Figure A.1.6 Flow Capacity along Kelani River

(4) Key Issues for Contemplating Short and Long-Term Alternative Plans

1) Dam and reservoir scheme

- At the most upstream area of the Kelani mainstream, Caselieigh, Maskeliya and Laxapana Dams are situated, and Labugama and Kalutuwawa dams are situated in a tributary. The objectives of these dams are hydropower and water supply except flood control. On the other hand, large scale dams were proposed at Yogama and Nawata-Purusella in the past and DHI studied on these schemes in 1991. Although potential requirement of dam construction had been accepted by the Government of Sri Lanka, none of those schemes have been realized yet due to negative environmental effects such as resettlement of affected people, social environmental issue and large scale of relocation of existing road, etc.
- Although dam construction at upstream valley on the Kelani River will be one of the most effective flood management measures, many issues of social environmental aspects need to be settled first prior to implementation. Therefore, it was judged that earlier implementation of dam scheme will be quite difficult and was not included in short-term plan. However, as a long-term plan, this is still very much a possibility. In the current Study, as one of alternative long-term plan, single purpose dam scheme was preliminarily assessed in scale and compared with other alternative plans in terms of economic (cost and benefit) and environmental viability and possibility of realization of the plan.

2) Non-flood bund stretches (area of natural retarding basins)

- Through the site reconnaissance of present condition of the wetland, where is candidate site for flood retarding basins located between Ambatale and Hanwella at left and between Malwana and Pugoda at right, current conditions were confirmed as follows:

  A) Area with perennial flooding by probable flood of 2 to 3-year, which is not protected by flood bund, is lying between river mouth to approximately 50 km upstream. In the lowly undulated area, natural retarding basins (wetland) are located and classified into three categories, i.e. (i) wetland (most of area is under water throughout year), (ii) abandoned land (mainly grassland) and (iii) cultivated land (mainly paddy).

  B) By means of its rereading function, flood peak discharge in Colombo Metropolitan area has decreased; thus playing vital function of protection against flooding. If such disordered development is accelerated, the safety level of core center of Colombo city will be remarkably deteriorated.

  C) On the other hand, the retarding area and its surroundings are utilized for agricultural field but are habitually hit by flooding.

  D) At the surrounding areas of the retarding basins, which is neighboring fringe area on the land having a little higher elevation, a crushing plant and other factories are constructed after reclamation. The grading of ground surface is rather poor and any mitigation measure to surrounding environment has not been conducted.

E) Because these areas are adjacent to east side of Colombo Metropolitan area and convenient for access, land development is accelerated recently (construction of new road, information technology center, college and new Outer Ring Road of Colombo, etc.)

- If flood bund is constructed along the mainstream of Kelani, the function of reducing flood peak discharge in the retarding basins will be diminished and flood risk will increase in the Colombo Metropolitan area at downstream. The retarding basins at non-flood bund section is left as it is, since habitual flooding cannot be solved. In addition, implementation of dam scheme at upstream valley cannot be expected in early stage due mainly to social and environmental issues.
- Under such conflicting situation, earlier implementation of countermeasures considering the balance in the entire river basin shall need to proceed. It is recommended that large scale floods should be retarded in the natural retarding basins along the non-flood bund stretches. During normal conditions, the retarding basins and peripheral areas can be utilized for cultivation and/or limited land use under control. Therefore, to develop the areas as multi-purpose retarding basins is promising by exploiting present function of flood retention.
- In concrete, low dike, overflow weir and drainage facilities shall be provided along the non-flood bund stretches of mainstream with certain scale (to meet 5-year probable flood), which does not adversely affect to the flood bund stretches at downstream. If excess flood (larger scale of 5-year probable flood) occurs, flood water will be allowed overtopping across the overflow weir. With remaining possibility to realize the dam scheme in the long term, the land use control, restriction of land reclamation activities, establishment of law/guideline for compensation of inundation damage, resettlement of residents in critical areas, peripheral enclosure dike of the restating basin are recommended.

3) <u>Unprotected area at downstream</u>

- There are approximately 100,000 people are living in the unprotected area at river side of the South Bund, as well as some people also living in the narrow strip of land in front of the North Bund. While they do not encounter problems during dry season, however, their land is frequently inundated even by small-scale flooding, and forces them to evacuate to the flood bund or higher ground in the vicinity during larger scale of floods. Land development, in particular housing construction, is recently very progressive in the area.
- Although the area is hit by flooding frequently, effective structural measure is very difficult to introduce in the short term. Therefore, institutional strengthening on land use control and development restriction shall be implemented during the earlier stage. However, it is difficult to force resettlement on the people who are living in the unprotected area at present, thus ensuring the evacuation activities in association with installation of early warning and monitoring system is inevitable to ensure saving of human life and mitigation of damage due to flood disasters. In principle, non-structural measure shall be undertaken in this area. As for the long term measure, construction of new large scale of flood bund will not be so advantageous and thus it should be wait for development of retarding basins in the middle stream and/or dam construction in the upper reaches. In conclusion, non-structural measures shall be rather emphasized and introduced than structural measures in the unprotected area.

4) Inland drainage

- In the Colombo Metropolitan area, inundation due to insufficient drainage of rainwater frequently occurs almost every year. As for the inland drainage improvement, construction of new pumping station is on-going by SLLRDC and UDA. DOI is in charge of management of existing flood bund and MFPs. However, since the responsibility of drainage in Colombo among concerned agencies is not yet clearly demarcated, it seems difficult for DOI to solely undertake drainage improvement. In order to cope with such situation, Flood Coordination Committee meeting is regularly (principally once a month) held chaired by DMC at present. Improvement of drainage canal is implemented step by step by DOI coordinating with other governmental agencies.
- In the short term, repair and rehabilitation of existing structures such as sluice gate and appurtenant facilities at MFPs and flood bund is required, since some of those are already obsolete and/or heavily damaged. In the long term, installation of additional pumping station will be considered. However, in the case of the Kelani River basin, there is no pumping station which is under control of DOI. On the other hand, existing one is installed by UDA and a new one is scheduled to implement by SLLRDC. Taking account the current situation, DOI should coordinate with other agencies for inland drainage improvement with demarcating responsibility and consulting plans in long term. Under such situation, because it is expected that new pumping station will be implemented by SLLDRC, long term plan for the drainage improvement is not recommended in the current Study.

(5) Setting alternative plans

Based on the basic direction of structural measures as above mentioned, alternative plans were set as follows:

Table A.1.5 Structural Measure Element of Alternative Plans (Kelani River)

Short-term	S1: Repair of MFPs and existing flood bund + construction of small flood bund (5-year)	S2: Repair of MFPs and existing flood bund
Long-term	L1: Retarding basin	L1: Retarding basin
	L2: Dam and reservoir	L2: Dam and reservoir
	L3: Heightening	L3: Flood bund

A.1.4.4 Design Standards and Guidelines

Design standards and guidelines for river structures in Sri Lanka are provided in the "Technical Guidelines for Irrigation Works, A.J.P. Ponrajah, 1988 (hereinafter referred to as "the Guideline")" published by DOI. Some design criteria for the structures proposed in this Study, however, are not described in the Guideline, therefore, international standards are also applied. Japanese standards [1, 2] are mainly applied in consideration of the similarity in features between the rivers in Sri Lanka and Japan. An outline of the Guideline in Sri Lanka is summarized as follows:

1 "Government Ordinance for Structural Standard for River Administration Facilities" compiled by the Japan Institute of Construction Engineering, and published by the Japan River Association.

2 "Manual for River Works in Japan" supervised by the Ministry of Land, Infrastructure and Transport, Government of Japan, and compiled by the Japan River Association.

(1) Purpose of the Guideline

The Guideline was prepared for young engineers in DOI to provide them with a proper guideline for following systematic procedures in preparing designs and contributing to improvement of their technical level. However, this Guideline mainly focuses on structures in agricultural projects rather than flood control projects even though DOI is responsible for planning, designing and implementing flood control projects as well as irrigation projects.

(2) Contents of the Guideline

With reference to structures for flood control, the Guideline covers the following contents:

- Design procedures
- Hydrology and design of embankments for minor reservoirs
- Bund top level and slope protection for earth embankments
- Hydraulic design for irrigation sluices
- Hydraulic design of canals and related structures
- Design of profile (LS) of field and distribution canals
- Drawings and drafting standards

Design parameters for the other structures which are excluded from the Guideline are normally determined from general reference books in Sri Lanka.

A.1.5 Alternative Structural Measures

A.1.5.1 Alternative Plans

Based on the discussions in Section A.1.4 three alternative plans for the Kelani River were contemplated as follows:

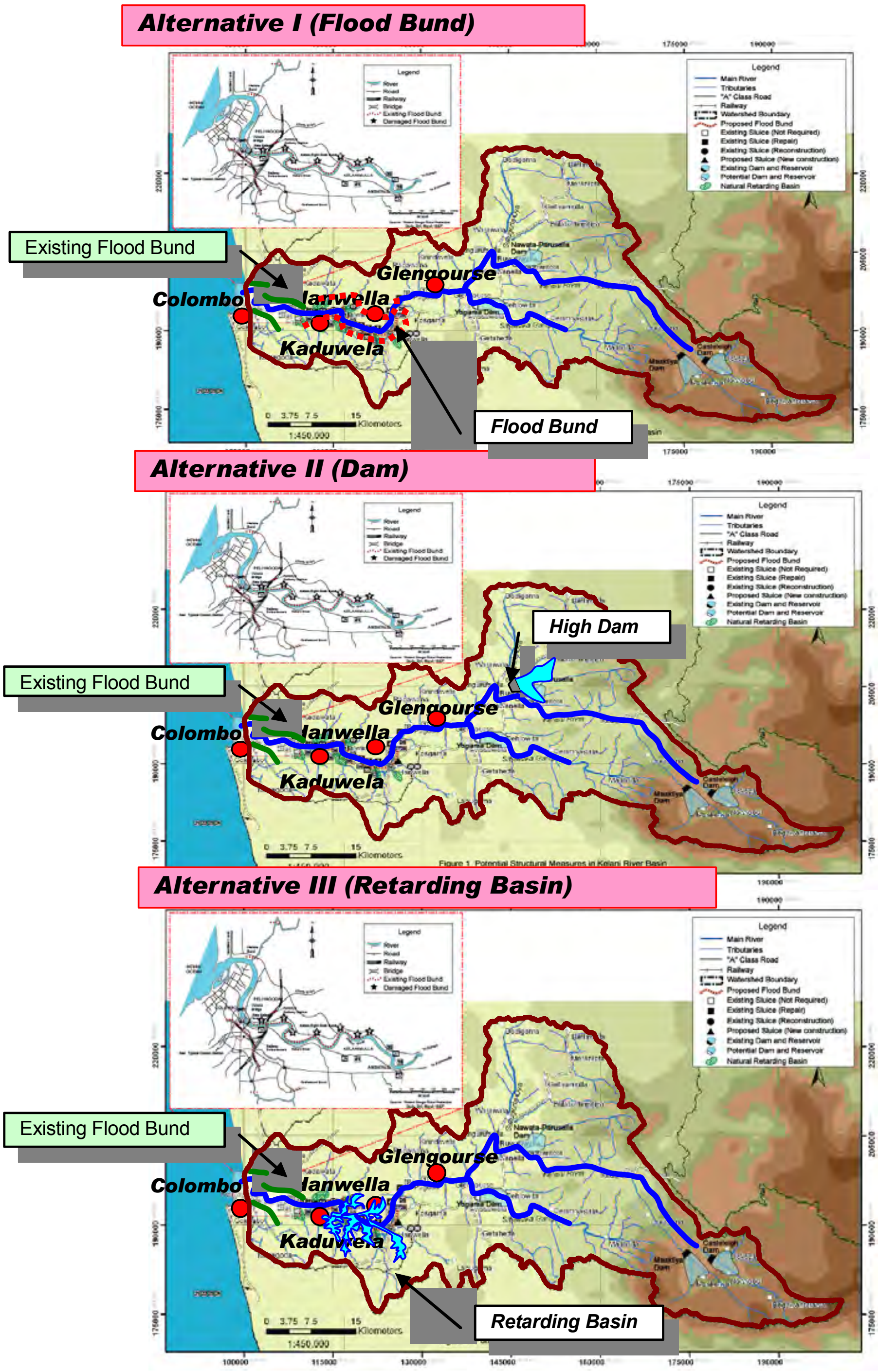


Figure A.1.7 Alternative Plans for Kelani River Basin

A.1.5.2 Distribution of Design Flood Discharge

A.1.5.3 Principal Feature of Structural Measures

(1) Improvement of existing sluices (Minor Flood Protection)

In the Kelani River basin, there are eight (8) kinds of countermeasures to be proposed. The locations of those structures are shown in Figure E.1.1 (Plate No. KN-00).

There are existing sluices along the flood bund of the Kelani River mainstream on the both river bank from Senasungoda to Nagahawatta as measures of MFPs. The numbers of sluices are 20 locations for the right bank and 24 locations for the left bank. As shown in Table A.1.6, nine sluices out of the 44 shall be improved.

Table A.1.6 List of Existing Sluices to be Improved (9 locations)

Structure No.	Name of Minor Flood Protection Schemes	Right or Left	No. of gates and size		Type of Gates
3	Nikawela	R	6 nos.	4' 0" x 6' 0" (W)	Flap Gate
4	Kapugoda (Giridara)	R	5 nos.	4' 0" x 6' 0" (W)	Flap Gate
7	Kadatiyawatta (Wellgama)	R	2 nos.	4' 6" x 5' 0" (W)	Flap Gate
8	Mora Ela	R	2 nos.	4' 6" x 6' 0" (W)	Flap Gate
14	Kukulawala	R	3 nos.	No data	Lifting Gate
19	Koskumbura	R	1 no.	3' 0" x 3' 0" (W)	Flap Gate
33	Henpita	L	4 nos. 2 nos.	5' 0" x 4' 0" (W) 5' 0" x 4' 0" (W)	Flap Gate Lifting Gate
40	Ambatale	L	4 nos. (2 rows)	5' 0" x 4' 0" (W)	Flap Gate
43	Sedawatta	L	10 nos. (2 rows)	5' 0" x 4' 0" (W)	Flap Gate

Notes: (W) wooden, (C.I.) cast iron

Source: Irrigation Department

The improvement feature of existing MFPs is described in Table A.1.7 as below:

Table A.1.7 Improvement Feature of Existing MFPs (9 locations)

Structure No.	Description of Improvement
3	Gates shall be replaced.
4	Gates shall be replaced.
7	Gates shall be replaced.
8	Gates shall be replaced.
14	Redesign for connection of flood bund for easier access to gate hoist is required. Partial repair is necessary.
19	Hoist deck is to be provided for safe operation.
33	Gates and hoist deck shall be reconstructed.
40	Bank protection works with revetment (stone masonry) shall be provided.
43	This gate is located at outlet of the Kittanpaua drainage canal. Canalization is required properly.

Source: JICA Study Team

The typical section and plan for the improvement are shown in Figure E.1.2 (Plate No. KN-01).

(2) New sluice (Minor Flood Protection Schemes) including reconstruction

As listed in Table A.1.8, seven sluices out of the 44 existing ones shall be reconstructed and one sluice shall be newly constructed at Pussari Oya, which is a major tributary from left bank of the Kelani River:

Table A.1.8 List of Sluices to be Newly Constructed Including Reconstruction (9 Locations)

Structure No.	Name of Minor Flood Protection Schemes	Right or Left	No. of gate and size		Type of Gates
9	Gontota Ela	R	1 no.	3’ 0” dia.(C.I.)	Flap Gate
12	Malwala Pahuruoya	R	8 nos. (2 rows)	4' 0" x 4' 6" (W)	Flap Gate
13	Yabaraluwa	R	3 nos.	3' 0" dia. (C.I.)	Flap Gate
15	Rakgahawatta	R	6 nos.	4' 6" x 5' 6" (W)	Flap Gate
16	Pattiwila	R	2 nos.	6' 0" x 4' 0" (W)	Lifting Gate
29	Brandigampala II	L	2 nos.	4' 0" x 6' 0" (W)	Lifting Gate
30	Brandigampala I	L	5 nos.	4' 0" x 6' 0" (W)	Lifting Gate
New	Pussari Oya	L	20 nos. (2 rows)	4' 6" x 6' 0" (W)	Flap Gate
42	Kelanimulla	L	2 nos.	6' 0" x 5.5' (W)	Lifting Gate

Notes: (W) wooden, (C.I.) cast iron

Source: Irrigation Department

The reconstruction of the seven sluices shall follow the existing structural design and material.

For the new sluice at Pussari Oya, a new sluice design shall be developed. According to the DOI, the sub-catchment area of the Pussari Oya River flowing into the Kelani River is 104.6 km^2. Discharge at Pussari Oya was therefore estimated to be 195.4 m^3/s by using the formula defined by the Guideline[3]. In order to apply a realistic design to be constructed by the DOI, gate size was determined to be 1.4 m x 1.8 m, similar to the existing sluice gates at Pugoda. Tentatively, a 20 gates (10 gates x 2 rows) design was determined based on discharge information and the gate sizes subject to further verification with the design discharge.

The schematic feature of this structural measure is shown in Figure E.1.3 (Plate No. KN-02).

(3) Bank protection (revetment)

There are existing flood bunds along the Kelani River between Talwatta and Peliyagoda on Gampaha (North) side. The river bank including flood bunds at the seven locations are seriously eroded and they shall need to be protected with revetment works, which will be composed of sand and gravel filling, earth filling, steel sheet piles, gabion mattresses, rubble works, and sod facing. Total length to be provided for the revetment is 670 m.

The schematic feature of this structural measure is shown in Figure E.1.4 (Plate No. KN-03).

(4) Flood bund

Construction sites of new flood bunds were determined based on flood inundation map of scale 1:10,000. In order to determine flood bund height, longitudinal profile including water surface level was prepared based on steady flow calculation (non-uniform flow) with the following condition:

[3] Technical Guidelines for Irrigation Works, A.J.P. Ponrajah, 1988, Irrigation Department, Sri Lanka

Table A.1.9 Case of Hydraulic Calculation in Kelani River

Case	Distance (m)	Discharge (m^3/s)	Bund Width	Boundary Condition	Roughness Coefficient	Cross Section
Case 1	0 – 55,500	2,300 (5-year)	200 m	Sea water level: 0.411 m MSL	Low water channel: 0.035 High water channel: 0.050	56 sections in total
Case 2	0 – 55,500	2,300 (5-year)	500 m			
Case 3	0 – 55,500	3,400 (20-year)	200 m			
Case 4	0 – 55,500	3,400 (20-year)	500 m			

Source: JICA Study Team

The result of hydraulic calculations for Cases 1 and 2 is shown in Figures E.1.5 and E.1.6 respectively.

The freeboards are set as 1.0 m for less than 2,000 m^3/s discharge and 1.2 m for less than 5,000 m^3/s discharge based on the Japanese standard[4]. Crest width is set as 4.0 m according to the existing flood bund as shown in the drawings in Figure E.1.7 (Plate No. KN-06).

(5) Heightening /reinforcement of existing flood bund

The flood bunds will be heightened by earth material to meet the design discharge of 20-year probable flood in Alternative I.

The typical section of the heightened flood bund is shown in Figure E.1.7 (Plate No. KN-06).

(6) Dam and reservoir

There are two dams studied by the government of Sri Lanka in the past as shown in Table A.1.10. The locations of those dams are shown in Figure E.1.1 (Plate No. KN-00).

Table A.1.10 Features of Dams in Kerani River Basin

Item	Yogama Dam	Nawata-Parusella Dam
River	Sitawaka	Kelani
Purpose	- Flood Control - Power Generation	- Flood Control - Irrigation - Power Generation
Limit of H.F.L. to be Studied	152.4 m M.S.L.	106.7 m M.S.L.
Reservoir Capacity	988 MCM	1,060 MCM
Reservoir Area	21.8 km^2	28.0 km^2
Maximum Dam Height	132.6 m	86.9 (m)

Source: Irrigation Department, studied in 1960

In the current study, Nawatha-Parusella dam is assumed to be implemented in Alternative II providing approximate size of reservoir for retarding the flood peak discharge.

(7) Retarding Basin

Lower land around downstream reach of the Kelani River shall be effectively used as retarding basins. Available area for seven retarding basins is preliminarily estimated to have a total surface area is 47.3 km^2. The retarding basins include concrete overflow weir with open type intake, headrace channel and outlet. Also, some parts of the land around the retarding basins are necessary to be closed by ring levees.

[4] Government Ordinance for Structural Standard for River Administration Facilities.

Location of the retarding basin is shown in Figure E.1.9 (Plate No. KN-08).

(8) Flood forecasting and early warning system

Out of the existing gauging stations, gauging facilities at the following numbers of stations shall be automated.

Table A.1.11 Gauging Stations to be Automated in Kelani River Basin

Station	Existing	Scheme			
		Pilot Project	Master Plan	Japanese Grant Aid	Total
Rain gauge	31	8 (1)	9	3	20 (1)
Hydrometric gauge	9	6	3	-	9
Total	40	14 (1)	12	3	29 (1)

Notes: ( ) means station to be newly installed.

Source: JICA Study Team

The location map of those gauging stations is shown in Figure E.1.10 (Plate No. KN-09).

A.1.6 Promising Non-Structural Measures

(1) General

The non-structural measures can be introduced with less cost and time for planning. Therefore, in order to reduce the risk of flood disaster in the target river basins, it is quite essential to introduce effective non-structure measures at the earliest time possible. Taking account of characteristics of hydrology and flood occurrence in the past, promising non-structural measures are contemplated as follows:

In Kelani River basin, based on the basic concept as discussed in Section A.1.4, non-structural measures has a rather important role in reducing risk level of flood prone area along mainstream. In fact, the early warning and evacuation system has been installed in the Kelani and Kalu River basins as Pilot Project through the current JICA Study. It is quite essential to effectively utilize and enhance this system to the maximum extent in the future. Total 8 rain gauges and 6 water level gauges were installed in the Kelani by the Pilot Proejct. Further, enhancement of communication network and improvement of contents of warning bulletin to be conveyed to the local people are recommended.

In particular, the unprotected area in between the North Bund and railway Embankment, which is about 2,100 ha exposed to habitual flooding in Wellampitya, Wennawatta, Kotuwila, etc. needs to prioritize non-structural measures.

Based on the Interview Survey conducted through the current Study, out of 30 interviewees in the aforesaid three GNs, 67% replied that introduction of appropriate early warning system has the highest priority among the six kinds of countermeasure options (i.e. (a) structure, (b) early warning, (c) proper instruction, (d) staff for mitigation activities, (e) support for evacuations, and (f)others). Construction of structures (flood bund, canal and pumping station, etc.) shares 23% and the remaining 10% is for other reasons (supply of food and boat, etc.).

(2) Flood Forecasting and Early Warning System

In the Kelani River basin, the Pilot Project was undertaken within the current Study aiming at improvement and modernization of existing early warning system of DOI as well as dissemination system of required flood information to the end. Taking account of further grade up of the system in the future, installation of additional monitoring stations (rainfall and water level observation) is recommended aiming at enhancement of flood forecasting function.

(3) Management of Flood Retarding Basins (Flood Zoning)

1) Management of Flood Retarding Basins

As mentioned in Section A.1.4, particularly in the Kelani River basin among the four, retarding of flood peak discharge is quite important, since the Colombo Metropolitan area, which has more than 5.3 million population, is located at most downstream part of the Kelani.It is forecasted the population will become 7 million in 2030. It was verified that the low lying wetland at both Colombo and Gampaha side, which is declared to be preserved of flood protection area5, can be utilized as natural retarding basin to reduce the flood peak discharge. Further, the hydraulic analysis in the current Study verified that the wetland can achieve very important function as a natural retarding basin. Therefore, preservation of the wetland is one of most important flood management measures in the Kelani River basin. In concrete, following action would be indispensable:

(i) Delineation and legal designation of the retarding area for flood management
(ii) Restriction of land use in the retarding basin by law
(iii) Strengthening of penalization against illegal activities in the retarding basin

In fact, since the low lying area is originally a habitual flooding zone, damage to human settlement in such area has a certain aspect of artificial disaster. In order to mitigate such situation at minimal level, management and monitoring of land use in the lowland and prohibiting housing development in the flood prone area will be inevitable.

In the point of view, flood zoning with hazard mapping is essentially recommended. In order to facilitate preparation of the tools for flood management, topographic maps in digital format with contour 0.5 m will be required.

In more concrete, legal procedure for strengthening of land use control is preliminarily discussed as presented below:

2) Recommended Procedure

(i) Preparation of flood hazard map showing zoning/classification of appropriate land use by the DOI
(ii) Land use control by urban planning or physical planning to prevent disordered new development based on the flood hazard map and other development plans concerned
(iii) Affected land should be acquired and managed as a public land owned by the DOI
(iv) Appropriate relocation place and program for existing residents with compensation or subsidence should be considered.

[5] "National Physical Planning Policy, Detailed Policy Report, September 2002"

(v) Necessary disaster prevention measures, such as water-resistant housing, etc., should be promoted for the in habitants.

3) Conversion of Land

Conversion of land is subject to legal and physical restrictions of the following law:

(i) Land protected as reservations under the Crown Lands Ordinance
(ii) Provisions under the Coast Conservation Act
(iii) Provisions under the Urban Development Authority Law
(iv) Provisions under the Agrarian Development Act
(v) Provisions under the National Environment Act
(vi) Provisions under the Fauna and Flora Protection Ordinance

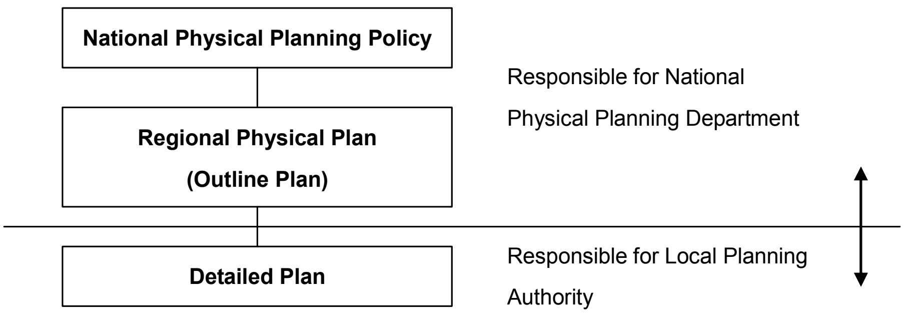
Urban underutilized land, homesteads and agricultural lands are necessary to be converted for urban uses. According to the prevailing laws conversion of land is regulated by the provisions of the following laws.

(i) Housing and Town Improvement Ordinance No. 19 of 1915 as amended
(ii) Town and Country Planning Ordinance No. 13 of 1946 as amended
(iii) Urban Development Authority Law No. 41 of 1978 as amended

4) Procedure for approval of physical planning

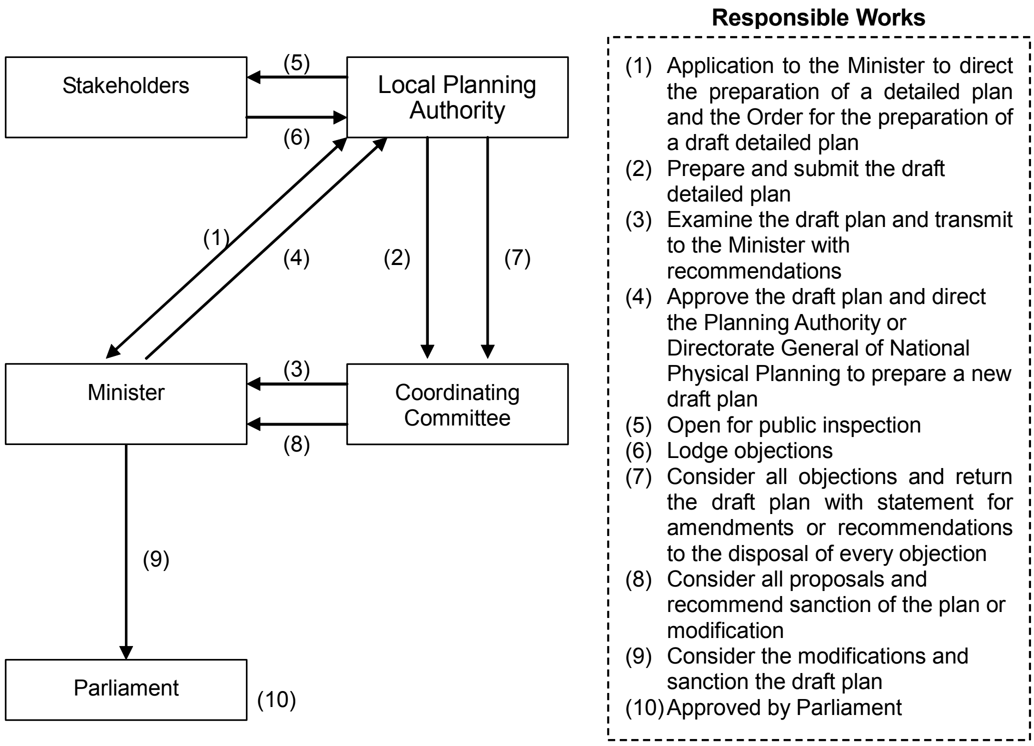
According to the Town and Country Planning Ordinances which authorize the formulation and implementation of a National Physical Planning Policy, the structure of the physical plan is shown in Figure A.1.8 and the procedure to approve a physical plan at the local level is shown in Figure A.1.9.

However, the procedure for approval of a development plan mentioned in the Urban Development Authority Law is almost same with the procedure as shown in Figure A 1.6.2. During the Study period, only the Town and Country Planning Ordinance and the Urban Development Authority Law are available for the Study Team.



Source: Prepared by Study Team based on the Town and Country Planning Ordinance

Figure A.1.8 Structure of Physical Plan



Source: Prepared by Study Team based on the Town and Country Planning Ordinance

Figure A.1.9 Procedure of Physical Planning

(4) Installation of Rainwater On-site Storage and Rainfall Infiltration Facility

Urbanization will trigger an increase of flood runoff volume from land into the river channel. In parallel with it, increasing the channel capacity normally has severe limitation and difficulty of land acquisition, etc. In order to cope with this problem, installation of rainfall infiltration facilities and on-site rainwater storage tank, etc. shall become obligatory for every entity of new development including governmental agencies. Especially, in connection with the urban development in Colombo Metropolitan area, to legalize the installation of such facilities for regulating local runoff shall be integrated in the new development plan.

(5) Promotion of Water-resistant Architecture

In principle, it is desirable to relocate the houses, which are located in the flood prone area such as low lying area and flood retarding basin, to safer zone. However, if the situation does not allow it, countermeasures such as promotion of water-resistant building construction, heightening of building foundation, construction of column-supported housing (piloti style), change to multi-storied housing and water proofing of wall/housing material, etc. shall be introduced.

(6) Promotion of Flood Fighting Activities

In the flood prone area, in particular in the unprotected area along the Kelani, the interview survey conducted in the current Study verified that self-defense flood fighting activities are already part of the usual reaction during flood. Flood fighting activities such as information dissemination in the communities, evacuation to safer area and removal of their properties in house/building, etc. shall be further propagated to mitigate flood damage. In particular, the effective linkage between early warnin environment and the supply of infrastructure services to hotels and adjacent communities will be improved, (c) development will be undertaken according to prepared zoning plans and accompanying guidelines.

A.2 Kalu River Basin

A.2.1 Basin Overview

The Kalu River, originating in the central hills of Sri Lanka, flows through Ratnapura and Horana and empties into the Indian Ocean at Kalutara with a total length of about 100 km and catchment area of 2,690 km^2. Between the source of the river and Ratnapura town, the river stretch is characterized by a narrow bed and high banks on both sides and river drops from 2,250 m to 14 m MSL within its first 36 km before it reaches Ratunapura town. It joins the Wey River at Ratnapura and then travels 75 km to meet the sea at Kalutara. A location map is shown in Figure A.2.1.

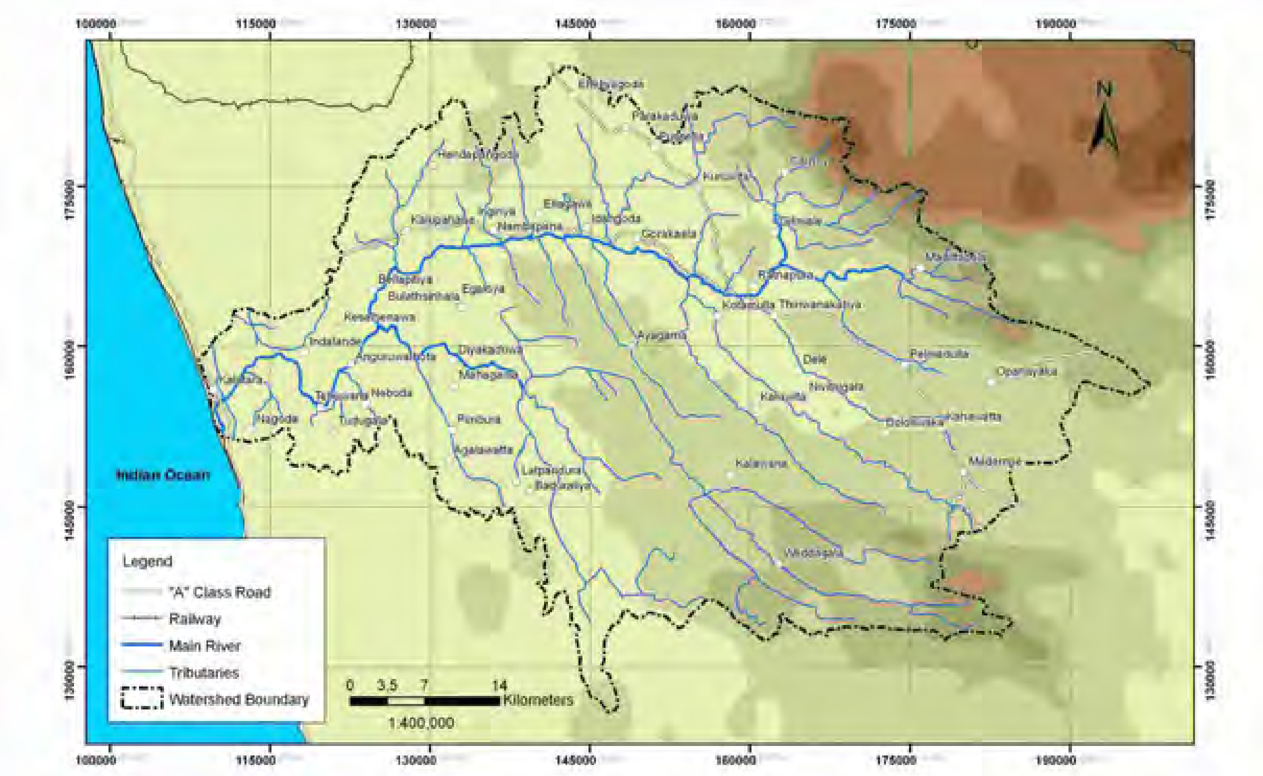
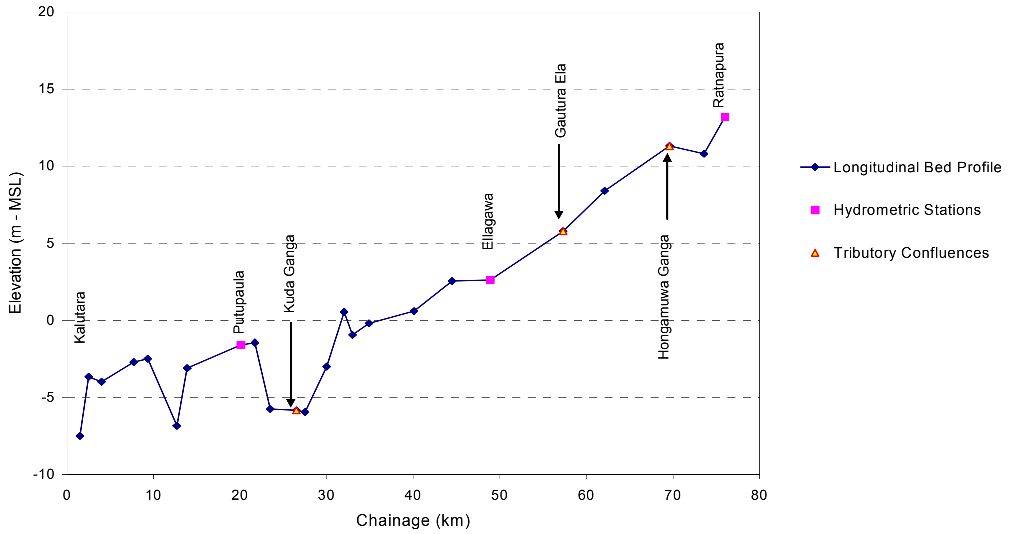


Figure A.2.1 Location Map of Kalu River Basin

There is no significant development of water resources in the Kalu River basin aside from rural drinking water supply and minor irrigation schemes. The only notable development is across Kukule River, which is a tributary of the Kuda River where 80 MW hydropower scheme is functioning. The low dam at Kukule is 16 m height and 110 m long. It has a storage capacity of 1.6 MCM and generates 317 GWh of annual energy.

The Kalu River is the third longest river in the country, however, it discharges the largest volume of water to the sea. Magnitude of the annual flow volume is approximately 4,032 MCM. The river basin lies entirely within the wet zone of the country and average annual rainfall in the basin is 4,040 mm with ranging from 6,000 mm in mountainous areas and 2,000 mm in the low plain.

The main cause of flooding in Ratnapura town is the very high annual rainfall falling in the catchment of 604 km^2 above Ratnapura. The river bed elevation at Ratnapura is only 11.70 m (38.4 ft) MSL and the length of the river course up to Kalutara is 76.5 km from Ratunapura. The gradient of the riverbed is only 0.15 m per km (1/6,700). This shows the inadequacy to create higher velocities to discharge floods. In addition, there is a bottleneck at Ellagawa, which is about 30 km downstream of Ratnapura town and 47 km upstream from Kalutara. However, it was verified that the bottleneck does not have notable backwater effect to the upstream riparian areas. Figure A.2.2 shows the longitudinal profile of the mainstream of the Kalu River.



Source: Hydrology Division of DOI

Figure A.2.2 Longitudinal Profile of Kalu River

A.2.2 Past Significant Floods

(1) Historical Flood

Ratnapura is most vulnerable to floods in the Kalu River basin and it is known to start flooding when river water level rises to 18.3 m (61.0 ft) MSL due mainly to its topographic condition. Based on the past experiences, DOI classifies the level of flood at Ratnapura town as below. Now a water level gauging station is operated at the steel truss bridge in the centre of the town.

Table A.2.1 Classification of Flood at Ratnapura

Classification	Water Level (m MSL)
Normal	18.3
Minor	20.1
Major	21.3
Critical	24.4

Source: DOI

Serious floods with over the critical water level have occurred in 1913, 1940, 1941, 1947 and 2003 as tabulated in Table A.2.2.

Table A.2.2 Recorded High Water Levels at Ratnapura

Order	Year	Water Level (m. MSL)
1	1947	24.8
2	1913	24.6
3	1941	24.4
4	1940	23.9
5	2003	21.5

Source: DOI

As seen in Table A.2.3, Ratnapura has not experienced serious floods between 1950's and 1990's except perennial minor flooding. Annual flood damage in Ratnapura and Kalutara districts were estimated in the "Pre Feasibility Study Assessment of Kalu Ganga Flood Protection with Special Reference to Ratnapura, Jul, 2004" as follows:

Table A.2.3 Annual Flood Damages in Kalu River Basin

Unit: Rs. mil.

Year	Annual Flood Damages		Year	Annual Flood Damages	
	Ratnapura	Kalutara		Ratnapura	Kalutara
1984	0.37	0.27	1994	3.01	2.19
1985	0.22	0.16	1995	5.64	1.31
1986	1.10	0.80	1996	N.A.	0.55
1987	0.05	0.03	1997	2.18	0.42
1988	0.23	0.17	1998	0.46	3.34
1989	3.94	2.88	1999	7.69	8.70
1990	3.11	2.27	2000	2.72	1.17
1991	6.34	4.62	2001	0.08	0.74
1992	12.42	9.06	2002	0.25	1.63
1993	2.41	1.76	2003	50.61	21.76

Source: "Pre Feasibility Study Assessment of Kalu Ganga Flood Protection with Special Reference to Ratnapura

In the table above, it is obvious that May 2003 was outstanding in terms of flood damage as well. The total damage is thus estimated at approximately Rs. 73 mil.

(2) Flood in May 2003

Flooding in the Kalu River basin in May 2003 occurred due to heavy rainfall brought about by a tropical low pressure weather system over the southwestern part of the island between 11th to 19th May 2003.

It has been reported that this was due to an indirect effect of a cyclonic storm which started 700 km north east of Sri Lanka in the Bay of Bengal, and traveled north eastward towards Myanmer. It should be noted that a storm so far away from the island had such a strong effect was due to a freak combination of geography of the island and prevailing wind patterns at the time.

The heaviest monthly rainfall amount of 897 mm was recorded in May 2003 at Kalawana. Monthly rainfall of Ratnapura for the same month was 702 mm and half of this has been received on the 17th of May 2003 (= 354.5 mm). The accumulated rainfall from 16th to 18th May was recorded 432.2 mm at Ratnapura.

The Pre Feasibility Study in Kalu Ganga in 2004 presented a depth-duration curve at Ratnapura. Based on the estimate, the 3-day rainfall is equivalent to 15-year return period as follows:

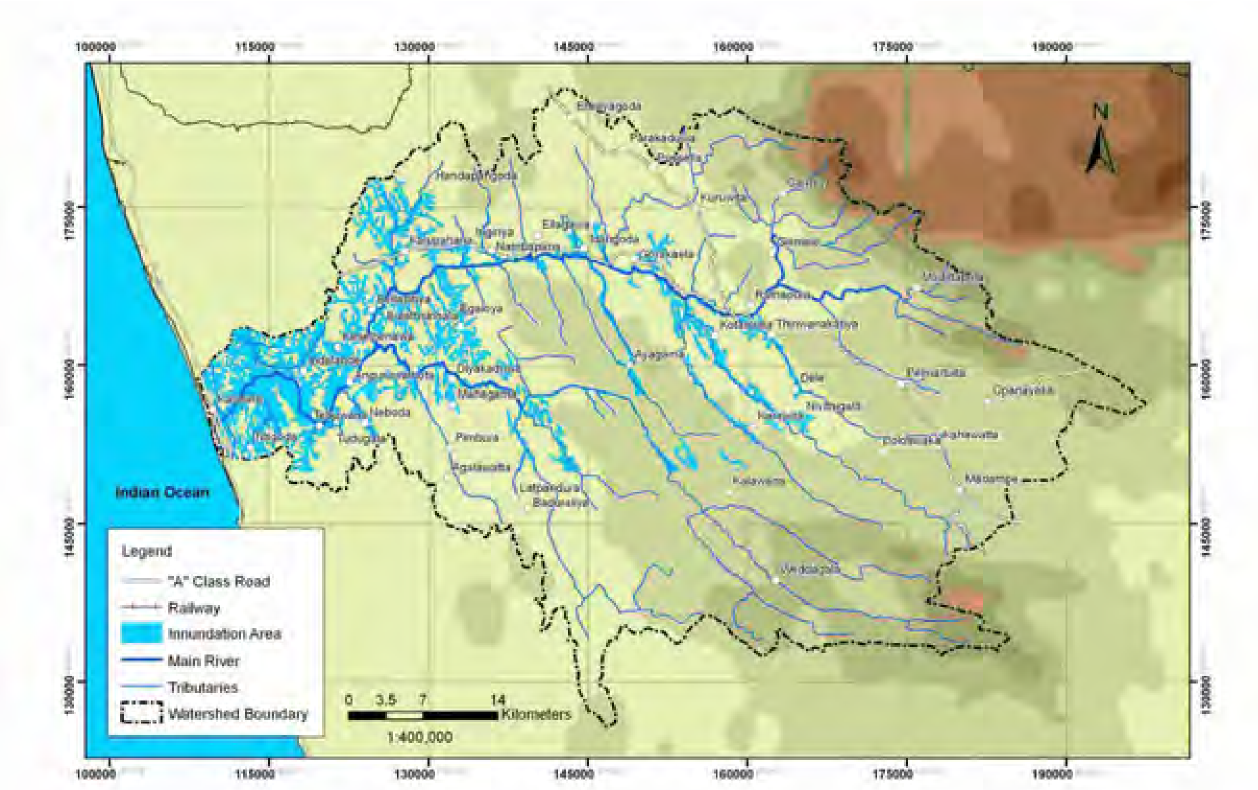
Table A.2.4 Depth Duration Curve at Ratnapura

Duration (days)	Depth in mm				
	10-year	25-year	50-year	100-year	200-year
0	0	0	0	0	0
1	244	315	377	447	527
2	328	410	479	555	638
3	380	463	531	603	682
4	415	496	560	627	716
5	455	540	607	677	750

Source: "Pre Feasibility Study Assessment of Kalu Ganga Flood Protection with Special Reference to Ratunapura

Further, it is reported that heavy rainfall over the upper catchment caused not only flooding, but also landslides. In one instance a landslide blocked the major tributary Delgoda Ganga and caused clogging in the channel area by building up of water volume. Sudden breach of this temporary dam caused serious flooding in the downstream area of Delgoda Ganga.

As the floods in the upper basin received over the next 24 hours, the downstream areas of the Kalu River, such as Ingiliya and Anguruwathota, were inundated by the flood water. The inundation area of the May 2003 flood is shown in Figure A.2.3



Source DOI

Figure A.2.3 Inundation Area due to May 2003 Flood in Kalu River Basin

The flood damage at Ratnapura District is summarized as follows:

Table A.2.5 Summary Statistics of Flood Damage due to May 2003 Flood in Ratnapura District

Item	Number
Number of families affected	34,473
Number of deaths	122
Number of refugee camps	30
Numbers of people in camp	1,613
Number of houses totally damaged	2,544
Number of damaged partially damaged	8,683
Number of schools damaged	47
Number of wells affected	4,452

Source:"Pre Feasibility Study Assessment of Kalu Ganga Flood Protection with Special Reference to Ratunapura, DOI, July 2004"

A.2.3 Review of Previous Flood Management Studies

(1) "Feasibility Report on Multipurpose Development of the Nilwala Ganga, Gin Ganga and Kalu Ganga Basins, Engineering Consultants Inc., 1968"

A comprehensive study for the flood protection of the Kalu River was conducted by the Engineering Consultant Inc. (ECI), Denver, Colorado, U.S.A. in 1968. The recommended plan is the so-called "Master Plan (original)" to date. The scope of the study covered development of water resources of the three major river basins, namely the Kalu, Gin and Nilwala. It was defined mainly to investigate the in-basin multipurpose water resources development options for the river basins and trans basin diversions.

As for the flood protection scheme, the study proposed a concrete dam with 79m high to be constructed at Malwala upstream of Ratnapura. The capacity of the reservoir would be 561 MCM, which would inundate approximately 1,800 ha of land. A flood control storage has been provided above elevation 76.2 m MSL. The cost of dam and power plant was estimated at Rs 112 mil (1968 price level). The study concluded that flood control schemes in the Kalu River basin was not feasible.

(2) "Kalu Ganga Multipurpose Project Feasibility Study, TAMS Consultants Inc., 1989"

This study did not considered flood control as one of the multipurpose aspects. Therefore, no separate storage has been provided in the reservoirs for the regulation of floods. Any regulation of floods achieved was only incidental. The criteria for selection of lands in the lower river basin to be protected are not clearly mentioned. The methods adopted in quantifying flood benefits are the same as those applied in the ECI Study. This study also concluded that structural options for flood protection in the Kalu River basin cannot be economically justified.

(3) "Ratnapura Multipurpose Project, Pre-feasibility Study, China Gehouba Construction Group Corporation, 1999"

The study carried out by the Chinese Group has exclusively dealt with the feasibility of construction of the reservoir upstream of Ratnapura, which has been firstly proposed in the ECI Study and later studied by TAMS. The study recommended a 70.8 m high concrete faced rock fill dam and a power plant of 33 MW capacity as the preferred project option for multipurpose development of Ratnapura reservoir. The reservoir has a capacity of 528 MCM and inundates 1,710 ha of agricultural land. Compared to previous studies, the dam and reservoir was designed to be able to provide protection against floods up to 50-year return period. Notable feature of this proposal compared with the proposal by ECI is that despite lower maximum reservoir level compared to ECI proposal, the reservoir is able to regulate floods up to 50-year return period. The annual energy generation of 112 GWh from the project is comparable to those proposed by ECI. The Study Report Item (4) Pre Feasibility Study in 2004 hereunder noted that the elevation-area-capacity curves used by the Chinese Study give higher reservoir capacities at lower elevations compared to the curves used in the ECI Study. Therefore, a larger volume of storage was available at a lower elevation.

The peak flood of Chinese Study for 50-year return period (1,587 m^3/s) is close to the peak of 10-year flood peak of ECI Study (1,450 m^3/s). For comparison, the peak of 50-year flood in ECI Study is 2,141 m^3/s. The reduced flood peak has allowed catering of 50-year flood. In addition to the above, the ECI Study permanently allocated a flood absorption storage above normal operating level of 76.2 m MSL while the Chinese Study has planned to use a part of storage below the normal operating level (82 m MSL) of their proposal by lowering the reservoir below this level before flood season.

Aside from the mentioning that flood bund will be provided in the downstream area, the study did not provide any details on flood protection for the lower basin.

(4) "Pre Feasibility Study Assessment of Kalu Ganga Flood Protection with Special Reference to Ratnapura, Drainage and Flood Protection Branch, Irrigation Department, July, 2004"

This study was carried out by the DOI itself to intensively review the previous studies and to find practical solution of the flood problems in the Kalu River basin, which became one of the most vital issues in the sector. Based on the updated information on the meteorological and hydrological analyses, the study concluded that Malwara Dam scheme at upstream of Ratnapura (50-year return period) and protection of low-lying area of Kalutara District against magnitude of 10 year probable flood by construction of drainage system would be feasible. Regarding the Malwara Dam construction, the study recommended to conduct further feasibility study to particularly assess in detail its social, natural and environmental soundness.

A.2.4 Basic Concept for Flood Management Planning

A.2.4.1 Planning Scale

From the results of review on the existing national or regional development plans, it was clarified that no specific criteria/guideline defining appropriate or target scale of protection level (planning scale) exists in Sri Lanka. Therefore, based on a series of discussions and agreement of DOI, the planning scale of four river basins were decided taking into consideration the following: (i) current channel capacity, (ii) experienced maximum flood peak discharge and (iii) future land use conditions. The planning scale as target to formulate Master Plan was set as follows:

Table A.2.6 Planning Scale of Kalu Basin

River Name (km^2)	Current Safety Level (Flow Capacity)	Experienced Max. Peak Flood	Future Land Use	Planning Scale
Kalu (2,719)	- Ratnapura: 2-year - Kalutara: 10-year	Approx.30-year (May 2003 Flood)	Urbanization of Ratnapura and Kalutara will be proceeded. Among other area, industrial and residential development near Horana will be progressed as well.	30-year (2,300 m^3/s at river mouth)

Source: JICA Study Team

In accordance with the record of the National Census in 2000, the population in the river basin was assessed with size of population of major cities as shown in Table A.2.7:

Table A.2.7 Current Population in River Basin and Major Cities

River Name	Population (thousand)	Population in Major Cities (thousand)
Kalu	1,127	Kalutara (136), Ratnapura (115), Others (876)

Source:National Census in 2000

A 2.4.2 Target Period for Implementation

Considering the required period of implementation of the proposed Master Plan, the target period was set for 15 years starting year 2010 and ending year 2024.

As mentioned in Section A.1.4.2 for the Kelani, the flood management activities will be able to contribute in removing vulnerability and risks which is an absolute obstacle in achieving the goals of the program of the "A Ten Year Horizon" in the related development sectors.

A.2.4.3 Basic Conditions for Formulation of Master Planning

(1) Common Conditions

In order to set alternative structural measures, the following preambles are applied in the current Study:

1) Early warning and monitoring system

In the Kelani River basin, pilot project of installation of automatic water level and rain gauges was conducted in association with community-based disaster management component of this Study. Similar project was conducted in the Kalu River basin as well in year 2008. It was verified and recognized through the Pilot Project that such early warning and monitoring system can be effectively applied as one of non-structural measures in the Study area with careful examination of hydrological feature and communication network.

Considering the size of required budget and construction procedure/period, such early warning system is able to introduce in a short period of time, as compared with other structural measures such as construction of flood bund and river training works, etc. Therefore, in the proposed Master Plan in the four river basins, the early warning and monitoring systems are included in the short-term plan.

As for the Kelani and Kalu, further extension to supplement the monitoring stations of water level and rainfall are being considered after execution of the Pilot Project.

2) Dam and reservoir schemes

To create flood control reservoir is one of effective options for reducing flood peak discharge in the basin. In fact, some potential dam schemes have been identified in the Kalu since the 1960's. However, not even a single project has been realized yet in the Study Area except for the hydropower project in the Kukule Ganga, Kalu River, by CEB due mainly to financial and environmental issues.

Considering the objective in the current Study which focuses on disaster management, particularly on flood management, the single purpose of flood control is envisaged for dam scheme in combination with other structural measures. In case of Malwala Dam at Ratnapura in the Kalu River, detailed flood routine to assess the outflow discharge into the downstream reaches for the alternative options was carried out, since the reservoir volume curves is available.

(2) Current condition of flood damage

- Habitual flooding at Ratnapura (inundation occurs by 2-year probable flood)
- Inundation at downstream area (no-flood bund in most of stretches) (by 10-year probable flood)

(3) Basic strategy of flood protection to be implemented

1) <u>Target area</u>: (i) Ratnapura area, (ii) Downstream non-flood bund stretches (Kalutara)

2) <u>Scale of countermeasures:</u>

Ratnapura	Short-term target	Long-term target
	1/10 (Q_{peak}=850 m^3/s)	1/30 (Q_{peak}=1,130 m^3/s)
Kalutara	Short-term target	Long-term target
	1/10 (Q_{peak}=1,700 m^3/s)	1/30 (Q_{peak}=2,300 m^3/s)

3) <u>Basic strategy of flood protection:</u>

- To raise the flood protection level at downstream area
- Since the Malwala dam scheme involves many issues (relocation of national road, temple, school, resettlement of residents, etc.) to be solved, it is not considered as short-term measure. Thus, as a long-term measure, single purpose flood control dam is assumed and compared with other alternatives in the current Study. As for multi-purpose dam scheme, the pre-feasibility study conducted by DOI was referred to.
- To prioritize the flood protection measures at Ratnapura and Kalutara
- To protect agricultural area deployed at middle reach against inundation

(4) Key Issues for Contemplating Short and Long-Term Alternative Plans

1) <u>Flood protection at Ratnapura urban area and development strategy of Malwala Dam</u>

- Ratnapura urban area is located at the confluence of the Kalu River and Wey Ganga. Since the flow capacity is small, 2-year probable flood (400~500 m^3/s) causes inundation. In Ratnapura, as the economic development center of the region (120,000 of population), Ratnapura District, Ratnapura New Urban Development Plan is currently proceeding and further development is presumed. At approximately 3 km upstream from the confluence with the Wey Ganga, Malwala Dam site is located. The dam scheme has been originally proposed by the Three Basin Master Plan (by ECI, 1968) and then the Chinese group reviewed the dam scheme in 1999. After the devastated flood in May 2003, DOI updated by himself the pre-feasibility study, and based on that study, economic viability (EIRR) can be assured by harnessing of hydropower benefit as a multi-purpose dam development. However, as well as those in other three river basins, due mainly to social environmental issues the scheme has not been realized despite the Government of Sri Lanka's existing aspiration of implementation.

- Although Ratnapura area is habitual inundation area, there is yet an effective countermeasure against flooding that has to be undertaken. Therefore flood management countermeasure(s) shall be implemented at soonest possible time.

2) Malwala Dam single purpose scheme

- Without river improvement at downstream area, the required reservoir storage volume is computed 333 MCM to reduce down the design peak discharge (1/30=1,130 m^3/s) to 400 m^3/s, the current flow capacity of the river channel. This is almost same scale of gross storage volume of the Malwala Dam (dam height: 70 m).
- In order to protect Ratanpura area by only the Malwala Dam, it is required to allocate the all reservoir storage to flood peak retention and to operate as a flood control dam. This might cause drastic deterioration of the economic viability due to decrease of the power benefit.
- In addition, since the Malwala Dam site is located upstream of the confluence of the Wey Ganaga along the Kalu River mainstream, retarding effect of flood discharge from the Wey Ganga cannot be expected. Thus, protection of Ratnapura area may not be completely ensured with only by the Malwala dam.

3) Flood Wall (Ring Levee)

- In reality, earlier implementation of any dam scheme seems difficult under current situation. Taking into account of such conditions, ring levee scheme with flood wall in Ratnapura town proper was considered as a countermeasure to protect Ratnapura. The required height is estimated at H=2.9 m for 10-year probable flood (850 m^3/s) and H=4.0 m for 30-year probable flood (1,130 m^3/s) respectively.

- The area where the flood wall is to be constructed is congested urban zone, thus land acquisition seems to be very difficult. In order to cope with this problem, concrete parapet wall supported by sheet piling foundation will be applied. Therefore, among the construction cost of the flood wall, portion of foundation treatment (steel sheet piling) shares majority of the total construction cost. It was also verified that cost will not change so much even if the height of wall varies (construction cost of flood wall per meter is estimated at $4,320/m for H=2.9m and $4,530/m for H=4.0m).

- In view of the above, the flood wall height for short-term measure is to be set for 30-year probable flood. If this scheme (H=4.0 m) is applied for entire Ratnapura urban area, total direct construction cost will be $35 mil. Since the total cost is considered to be too high, priority of protection area was considered to squeeze initial investment for short-term measure.

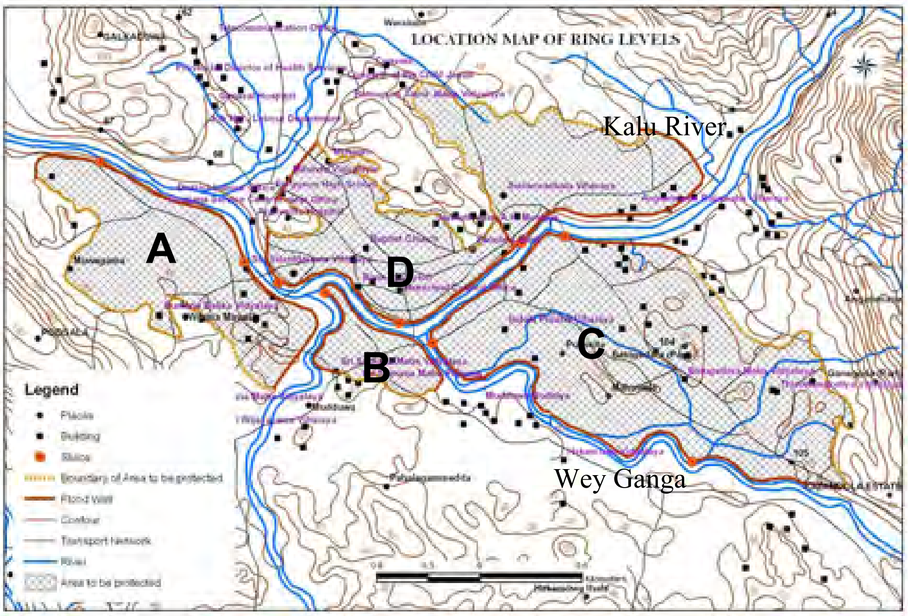
- Further, although the Malwala dam scheme has been studied to pre-feasibility level, construction of flood wall (or flood bund) has not been totally examined till date. Under such situation, further study of flood wall scheme will be necessary at equivalent level of the dam scheme.
- In order to assure further safety against excess flooding beyond 10-year probability, some areas allowing temporary overtopping and retarding of flood water shall be designated.

The major dimension of the flood wall is tabulated as follows:

Table A.2.8 Principal Feature of Ring Levee at Ratnapura

Area	Bank	Protected Area (ha)	Length (km)	Type of Levee	Nos. of Sluice
A	Left	86	2.5	Earth bund	2
B	Left	18	1.7	Earth bund	1
C	Left	224	4.5	Earth bund	3
D	Right	151	4.2	Concrete wall	3
Total		479	12.9		9

Source: JICA Study Team



Source: JICA Study Team

Figure A.2.4 Location Map of Ratnapura Ring Levee Scheme

- This countermeasure was taken up as the Priority Project after formulation of the master plans for the four river basins. The layout and dimensions of flood bund were further reviewed and elaborated in the succeeding phase on the current Study. The details are presented in Main Report.

4) Bypass Canal

- As an alternative scheme of dam and flood wall schemes, bypass canal detouring the Ratnapura urban area can be considered. In fact, the idea of bypass has been known from the earlier time same as Malwala dam scheme. According to the site reconnaissance carried out in the current study, the bypass route was assumed to connect a tributary running at north of Ratnapura. The total length is approximately 9 km.
- Further, the maximum flow capacity of the canal was estimated at approximately 200 m^3/s. Although the bypass canal is planned to accommodate the 1/10 peak discharge, it is not enough against bigger scale of flood discharge and thus combination with dam and/or flood wall schemes will be necessary.
- The construction cost of the bypass canal is estimated at approximately $20 mil. However, approach canal of bypass from the mainstream of the Kalu and the river improvement and required structures at outlet point, etc. will increase the construction cost furthermore.

5) Flood Bund at Kalutara Area

- Being distinguished from the Gin and Nilwala River Basins, there is no flood bund and other protection structure at downstream area near Kalutara.
- Compared with the other river basins, installation of flood management structures has been delayed and same level of flood protection is expected to be implemented. However, possibility of construction of Malwala Dam remains at the upstream. For the time being, flood management structure which can function firmly against small scale flood (10-year probable flood) shall be installed.
- In addition, drainage facilities (sluice and pump house) shall be installed. In the future, when dam construction is judged impossible, heightening and extension of flood bund, which is proposed by the current study, shall be designed.

6) Preliminary assessment of social impact of Malwala Dam

- According to the interview survey with affected GNs regarding the creation of reservoir of Malwala Dam conducted by the current study, following social impact were preliminarily verified:
    - Among the total 13 GNs (12 GNs in Ratnapura and 1 GN in Perumadula) , interviews were conducted at 5 GNs.
    - The population is continuously increasing in most of GNs
    - Major livelihood source of the affected people is labor force for tea and rubber plantation farms
    - There are many gem exploring agents and factories are operating near the riverbed.
    - Historical and cultural heritage temples are located there with old Buddhist fine arts considerably preserved.
    - Majority of the affected people are landowners, with some illegal settlers.
    - Majority of the affected people are Sinhalese, with some Tamils (approx. 5%).

- The planned reservoir area of Malwala Dam is shown in Figure A.2.5:

Figure A.2.5 Planned Reservoir Area of Malwala Dam

(5) Setting Alternative Plans

Based on the basic conditions of structural measures mentioned, alternative plans were set as follows:

Table A.2.9 Structural Measure Element of Alternative Plans (Kalu River)

Short-term	S1: Ratnapura Ring Levee + Flood bund at Kalutara area
Long-term	L1: Extension of ring levee
	L2: Malwala Dam (flood control)
	L3: Bypass canal + heightening of flood bund at Kalutara area
	L4: Malwala Dam (multi-purpose)

Further detailed configuration with quantitative information of alternative plans for the Kalu River is presented in Section A.2.5 below.

A.2.5 Alternative Structural Measures in Target River Basins

A.2.5.1 Alternative Plans

Based on the discussions in Section A.2.4 three alternative plans for the Kalu River were contemplated as follows:

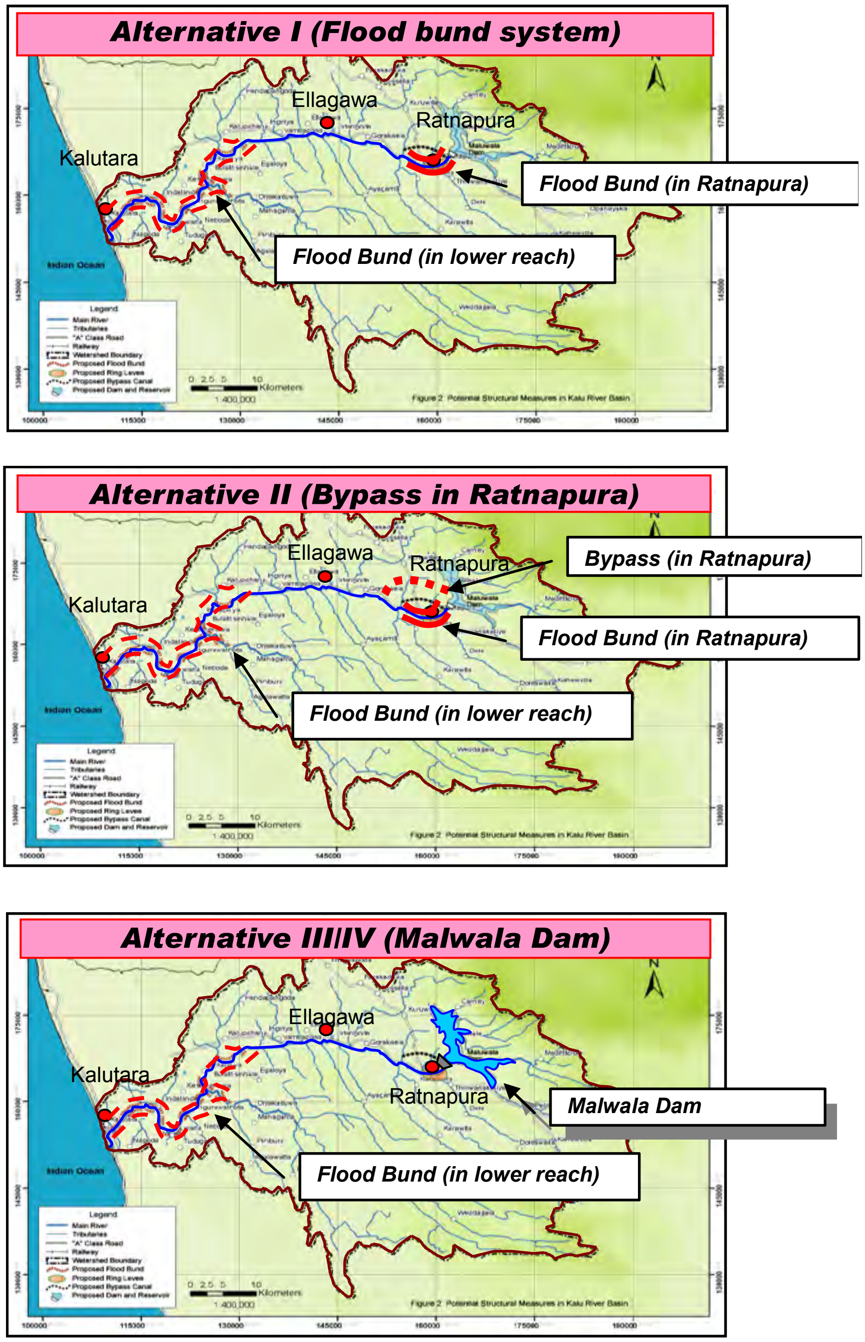
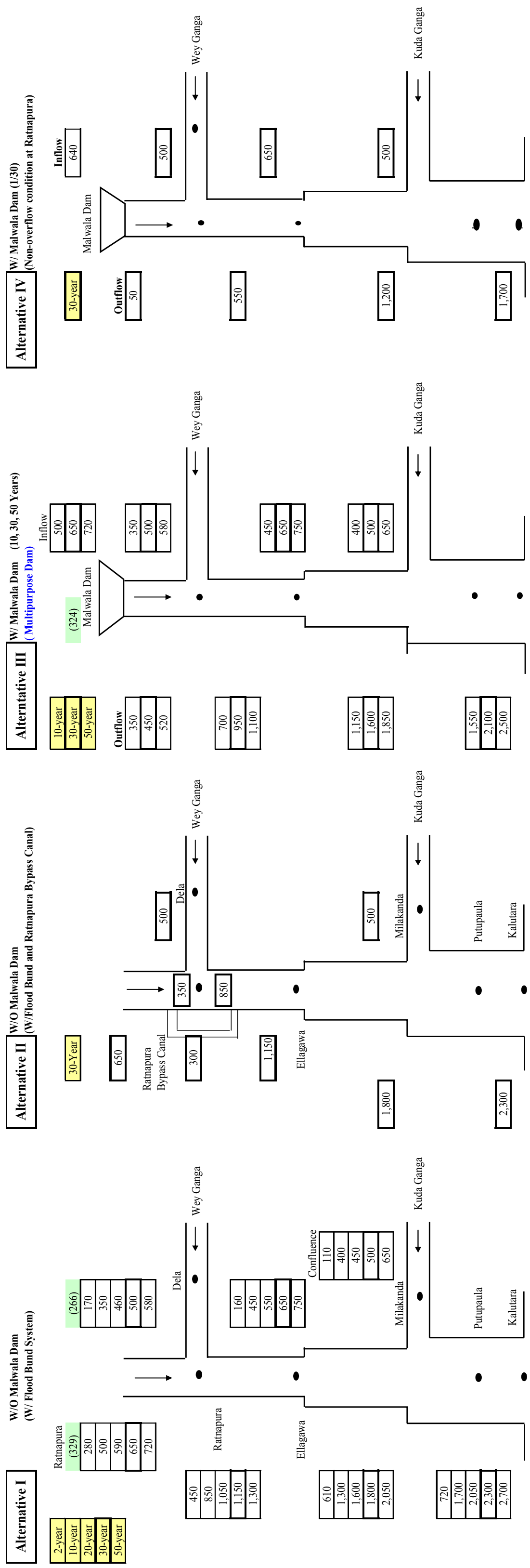


Figure A.2.6 Alternative Plans for Kalu River Basin

A.2.5.2 Distribution of Design Flood Discharge



A.2.5.3 Principal Feature of Structural Measures

(1) New sluice and pumping stations (Minor Flood Protection Schemes)

In accordance with the new flood bunds construction mentioned below, 24 sluices and 13 pumping stations also shall be newly installed with specifications of the following tables:

Table A.2.10 Specification of Sluices

Site	Gate Type	No. of Gate	Gate Size
24 sites	Lifting Gate	2	1.5 x 1.5 m

Source: JICA Study Team

Table A.2.11 Specification of Pumping Stations

Station	Discharge	Head	Install Capacity	No. of Gate	Gate Size
13 stations	5.0 m^3/s	10.0 m	0.60 MW	4	1.5 x 1.5 m

Source: JICA Study Team

The layout of sluices and pumping stations are shown in Figure E.2.2 (Plate No. KA-01).

(2) Flood bund

Construction sites for the new flood bunds were determined based on inundation map. In order to determine height of flood bund, longitudinal profile including water surface level was prepared based on steady flow calculation (non-uniform flow) with the following condition:

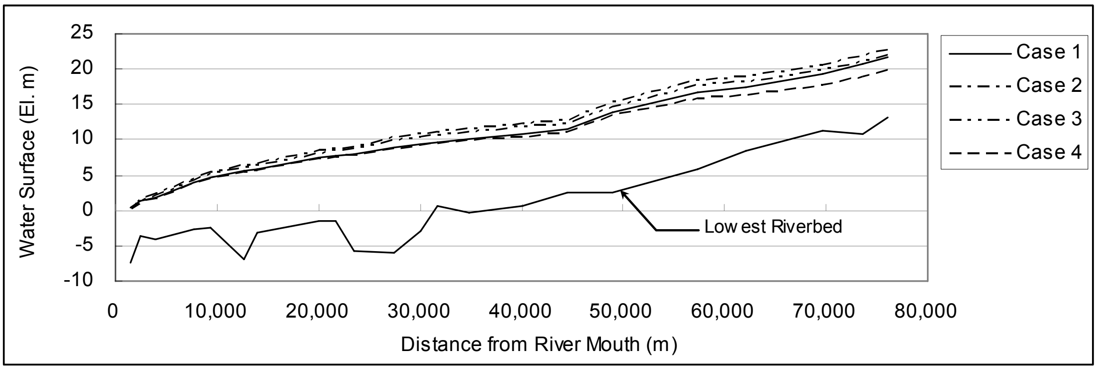
Table A.2.12 Required Case of Hydraulic Calculation in Kalu River

Case	Distance (m)	Discharge (m^3/s)	Bund Width	Boundary Condition	Roughness Coefficient	Cross Section
Case 1	57,300 – 76,000	850 (10-year)	100 m	Sea water level: 0.4 m MSL	Low water channel: 0.035 High water channel: 0.050	22 sections in total
	30,000 – 48,900	1,300 (10-year)				
	1,500 – 25,500	1,700 (10-year)				
Case 2	57,300 – 76,000	1,150 (30-year)	100 m			
	30,000 – 48,900	1,800 (30-year)				
	1,500 – 25,500	2,300 (30-year)				
Case 3	57,300 – 76,000	950 (30-year)	100 m			
	30,000 – 48,900	1,600 (30-year)				
	1,500 – 25,500	2,100 (30-year)				
Case 4	57,300 – 76,000	550 (30-year)	100 m			
	30,000 – 48,900	1,200 (30-year)				
	1,500 – 25,500	1,700 (30-year)				

Notes: Case 3 has Malwala Dam with discharge of 30-year
Case 4 has Malwala Dam with discharge of 30-year (Non-overflow condition at Ratnapura)

Source: JICA Study Team

The result of hydraulic calculations is shown in Figure A.2.7 below:



Source: JICA Study Team

Figure A.2.7 Result of Hydraulic Calculation in Kalu River

The freeboards are set as 1.0 m for less than 2,000 m^3/s discharges and 1.2 m for less than 5,000 m^3/s discharge based on the Japanese standard[6]. Crest width is set as 4.0 m as Sri Lankan standard design of existing flood bunds in other river basins.

Locations and sections of bunds are shown in Figures E.2.3 and E.2.4 (Plate No. KA-02 and KA-03).

(3) Dam and reservoir

In the 2004 pre-feasibility study on a multipurpose dam carried out by DOI, Malwala Dam was proposed with the features as shown in Table A.2.13. The location of the dam is shown in Figure E.2.1 (Plate No.KA-00).

Table A.2.13 Features of Malwala Dam

Item	Malwala Dam
River	Kalu
Purpose	- Flood Control (10-year flood) - Power Generation
Dam Type	Rockfill Dam
Dam Height	63.0 m
Crest Elevation	75.0 m M.S.L.
Catchment Area	329 km^2
Reservoir Volume	278.0 MCM
Maximum Water Level	73.0 m M.S.L.
Normal High Water Level	54.0 m M.S.L.
Spillway	Chute Type, Radial Gate (8 nos. x 8m x 6m)

Source:Pre Feasibility Study Assessment of Kalu Ganga Flood Protection with Special Reference to Ratnapura, Irrigation Department, July 2004

Dam scale to be used for hydraulic calculation estimating flood control capacity is basically following the past study result shown in the above table.

This alternative structural measure is shown in Figures E.2.5 to E.2.6 (Plate No. KA-04, KA-05).

6 Government Ordinance for Structural Standard for River Administration Facilities.

(4) Bypass Canal (new floodway)

Bypass canal shall be constructed at the middle reach of the Kalu Ganga from the downstream site of the proposed Malwala Dam to the downstream site of Ratnapura town in order to protect Ratnapura town from flooding. The upper part of the bypass canal is assumed to be constructed by excavation and the lower part can be constructed by improvement of the Maha Ela River. The total length of the canal is estimated to be 9.0 km. Bank protection with wet cobble masonry is necessary for the bending part of the canal, the distance of 0.9-4.1 km from the downstream confluence with the Kalu River. The parameters of the canal are shown in Table A.2.14 below:

Table A.2.14 Parameters of Ratnapura Bypass Canal

Length	Discharge	Velocity	Bed width	Water Depth	Bed slope	Slope gradient	Roughness coefficient	Free board	Height
9.0 km	200 m^3/s	1.25 m/s	20 m	5.3 m	1/3000	2	0.035	0.8 m	6.1 m

Source: JICA Study Team

A plan and longitudinal profile of the bypass canal are shown in Figure E.2.7 (Plate No. KA-06).

(5) Ring Levee

Ring levee shall be constructed along the Kalu River and the Way Ganga River in the part of both rivers throughout Ratnapura town. Concrete flood wall and earth flood bund are proposed at wide area and narrow area. In addition, there are assumed to be two types of flood wall height according to existence of the Malwala Dam. Free boards are set as 0.6 m for concrete flood wall and 1.2 m for earth flood bund. The total length of the ring levee is estimated to be 12.9 km. In accordance with the levee construction, sluices are also necessary at 9 locations in total.

A plan and typical section of flood wall (ring levee) is shown in Figure E.2.8 (Plate No. KA-07).

(6) Flood forecasting and early warning system

Out of the existing gauging stations, gauging facilities at the following stations shall be automated:

Table A.2.15 Gauging Stations to be Automated in Kalu River Basin

Station	Existing	Scheme		
		Pilot Project	Master Plan	Total
Rain gauge	26	6 (1)	6 (1)	12 (2)
Hydrometric	7	4	3	7
Total	33	10 (1)	9 (1)	19 (2)

Notes: ( ) means station to be newly installed.

Source: JICA Study Team

This alternative structural measure is shown in Figure E.2.9 (Plate No. KA-08).

A.2.6 Promising Non-Structural Measures

The same concept of the early warning and evacuation system as introduced in the Kelani River basin was also applied in the Kalu River basin in 2008. It is recommended to enhance the system in the future aiming at more precise meteorological and hydrological information to be collected.

(1) Installation of Rainwater On-site Storage and Rainfall Infiltration Facility

Urbanization will trigger an increase of flood runoff volume from land into the river channel. In parallel with it, increasing the channel capacity normally has severe limitation and difficulty of land acquisition, etc. In order to cope with this problem, installation of rainfall infiltration facilities and on-site rainwater storage tank, etc. shall become obligatory for every entity of new development including governmental agencies. Especially, in connection with the urban development in Kalutara and Ratnapura in the basin, to legalize the installation of such facilities for regulating local runoff shall be integrated in the new development plan.

(2) Promotion of Water-resistant Architecture

In principle, it is desirable to relocate the houses, which are located in the flood prone area such as low lying area and flood retarding basin, to safer zone. However, if the situation does not allow it, countermeasures such as promotion of water-resistant building construction, heightening of building foundation, construction of column-supported housing (piloti style), change to multi-storied housing and water proofing of wall/housing material, etc. shall be introduced in particular in the low lying Ratnapura urban area.

(3) Promotion of Flood Fighting Activities

In the flood prone area, in particular in the unprotected area along the Kelani, the interview survey conducted in the current Study verified that self-defense flood fighting activities are already part of the usual reaction during flood. Flood fighting activities such as information dissemination in the communities, evacuation to safer area and removal of their properties in house/building, etc. shall be further propagated to mitigate flood damage. In particular, DMC, DOI and Ratnapura Municipality should coordinate to achieve efficient flood fighting.

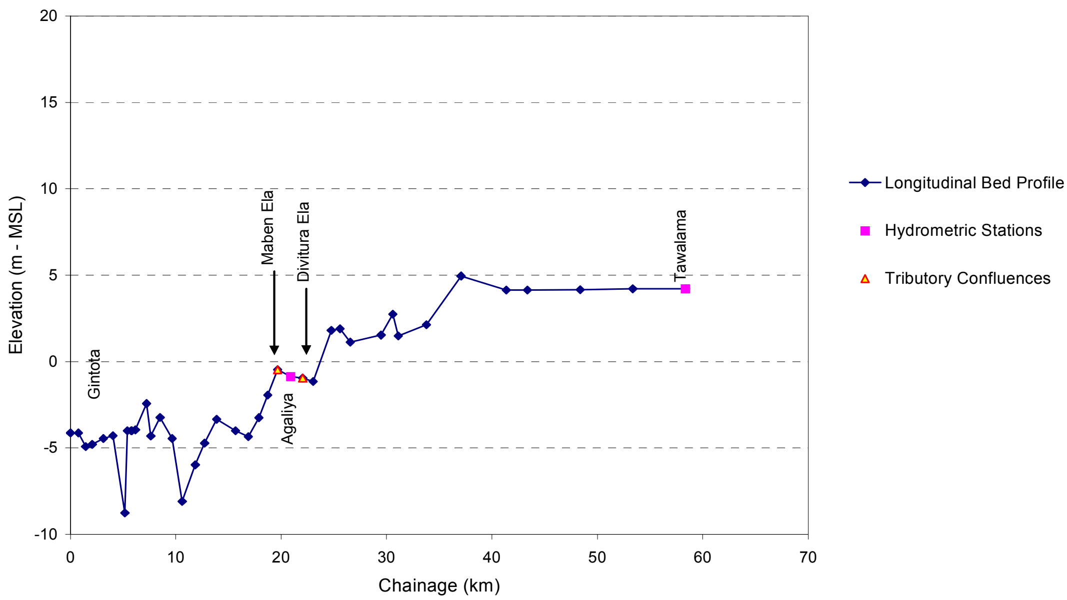
A.3 Gin River Basin

A.3.1 Basin Overview

Gin River originates from the mountainous region in southern side of Sinharaja forest and runs through Tawalama, Neluwa and Agaliya and into sea at Gintota, Galle. The basin area of the river is 932 km^2 with an average annual runoff of 1,268 MCM. The catchment, which covers with a variety of types of vegetation, has an estimated average annual rainfall of around 3,290 mm. The river provides irrigation water mainly for paddy cultivation and also for tea, rubber, subsidiary crops and vegetable plantations.

As flooding was a major hazard in lower reaches of the river, a flood protection scheme which included a levee system and some pumping stations was implemented in 1970s. In addition, the bypass canal Kapu Ela connected to main stream at Holuagoda also discharges water flow into Indian Ocean at Galle. However, although the construction of levee system at most downstream area has been proceeded, the area upstream of Agaliya experiences more flooding than before. A location map of the Gin River is shown in Figure A.3.1. Longitudinal profile is shown in Figure A.3.2.

Figure A.3.1 Location map of Gin River Basin



Source: LHI

Figure A.3.2 Longitudinal Profile of Gin River

A.3.2 Past Significant Floods

(1) Historical Flood

According to the annual maximum water levels after 1979 at Tawalama and Agaliya available, May 2003 flood was the worst one. Significant floods have occurred in the basin in 1979, 1993, 1999 and 2003.

(2) Flood in May 2003

Until early morning on 17th of May 2003, mainly upstream area of the Gin River have received a heavy rainfall over 350 mm in Sinharaja Forest and flood water has overtopped the flood bund at Nelwa approximately 20 km upstream from the river mouth. After flood water rampaged into the land side and it has gradually move to downstream in three to four days. The flood water could not be released even the sluice gate has been opened because the water level of Gin River was rather high. The flood discharge was so fast and inundation depth was over 2.0 m. Most of the road has been under water and evacuation was quite difficult. Total 17 people were dead due to the extraordinary flood and it caused damage to a lot of infrastructure and agricultural crops, etc.

At the bridge of Galle-Colombo national highway in Gintota, the water level has reached upto 60 cm under the brige girder. In order to drawdown the water level, the sand bar at the river mouth was excavated and partially removed on May 2003. During the flood, it was reported that information desemination system at Nelwa, Tawalama, Nagoda, Baddegama, Niyagama and Galle did not satisfactorily function and timely relief activties were quite difficult and evetually delayed. Those local town centers have been heavily damaged, which had been never experienced since the devastated flood in 1947 in the basin. The extent of flood damages in the Gin River basin due to May 2003 flood can be summarized as below:

Table A.3.1 Summary of Flood Damage in Gin River Basin due to May 2003 Flood

Structure/Crops	Damegd Quantities
Bridge pier	Concrete: 16 nos., Culvert: 194 nos., Suspension and wooden bridges: 19 nos.
Road section damaged	A class road 419 sites, Common road 88 sites
Flood management structures	Damaged flood bund: 30 km, Deblis deposition at pumping house: 10nos., Sand deposition in canal: 15 km, Partial Repair at weir: 3 sites.
Electric and telehphone facilities	Subsitututed electric poles: 86 nos., Damaged transmission lines: 197 nos.
Power generation and transmission facilities	High voltage power cable: 85 km, Low voltage power cable: 575 km, Electric poles: 660 nos., Household electric meter: 12,000 nos., Transformer: 94 units
Other infrastructure	Temple, mosque, church (9 sites), Hospital (bed nos. 115) 1 no., Public school: 50 nos. Public building: 94 nos.
Agricultural crops	Coconut: 26 ha (Rs.0.9 mil.) Tea: 1,254 ha (Rs.2.8 mil.) Paddy: 809 ha (Rs.3.2 mil.) Cinnamon: 260 ha (Rs.260 ha) Banana: 201 ha (Rs.1.4 mil.) Vegetable: 9 ha (Rs.0.2 mil.)
Office and factory, etc.	Tea factory 5, Small hydropower station 11, Shop 853, Fuel stand 4, Rice mill 5, Village market 6, etc.

Source: "Report on Flood Disaster Research 2003, IDI, September 2004"

The inundation area due to May 2003 flood in the Gin River basin is shown in Figure A.3.3

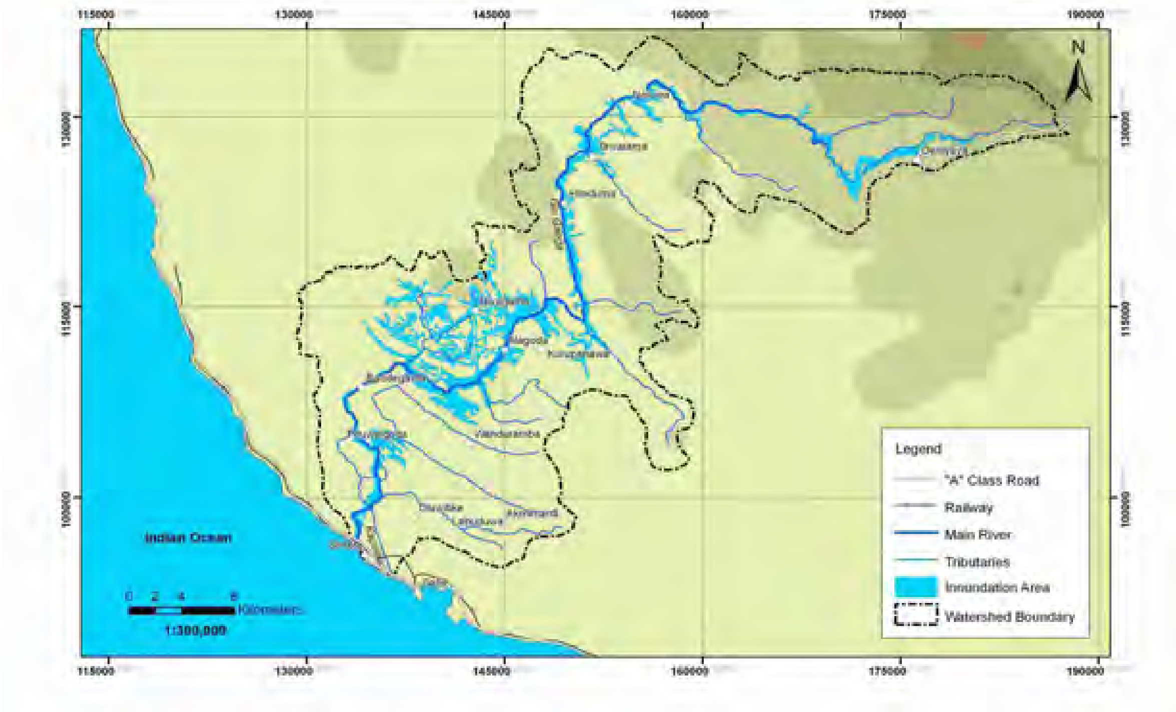


Figure A.3.3 Inundation Area due to May 2003 Flood in Gin River Basin

A.3.3 Review of Previous Flood Management Studies

"Feasibility Report on Multipurpose Development of the Nilwala Ganga, Gin Ganga and Kalu Ganga Basins, Engineering Consultants Inc., 1968"

The ECI Study recommend the flood control project comprising of 54 individual flood bunds with a total length of 29.6 km and 22 pumping stations. The pumping stations were planned to drain local flood water from the land side of the flood bunds protecting paddy fields from damage. The envisaged paddy land is 14,416 acres (=5,700ha) for existing and 1,250 acres (500 ha) for new development. An IRR of 8.86% and benefit-cost ratio of 1.5 were derived in economic analysis and anticipated to increase if the world price for rice continued to rise.

After the Master Plan Study, in fact, some of the recommendations were realized under the technical and financial assistance of Chinese Government in 1970's.

A.3.4 Basic Concept for Flood Management Planning

A.3.4.1 Planning Scale

From the results of review on the existing national or regional development plans, it was clarified that no specific criteria/guideline defining appropriate or target scale of protection level (planning scale) exists in Sri Lanka. Therefore, based on a series of discussions and agreement of DOI, the planning scale of Gin River basin was decided taking into consideration the following: (i) current channel capacity, (ii) experienced maximum flood peak discharge and (iii) future land use conditions. The planning scale as target to formulate Master Plan was set as follows:

Table A.3.2 Planning Scale of Gin River Basin

River Name (km^2)	Safety Level (Flow Capacity)	Experienced Max. Peak Flood	Future Land Use	Planning Scale
Gin (932)	- Flood bund section 20-year - Non-flood bund section: 2~5-year (Pumping facilities is designed to cope with 10-year flood in landside)	Approx.20-year (May 2003 Flood)	As regional development center, urbanization of Galle will be continued. However, no drastic change of land use is presumed from current situation (mainly agriculture- driven land use)	30-year (1,900 m^3/s at river mouth)

Source: Study Team

In accordance with the record of the National Census in 2000, the population in the river basin was assessed with size of population of major cities as shown in Table A.3.3

Table A.3.3 Current Population in River Basin and Major Cities

River Name	Population (thousand)	Population in Major Cities (thousand)
Gin	490	Galle (104), Baddegama (66), Nagoda (45), Others (275)

Source: National Census in 2000

A.3.4.2 Target Period for Implementation

Refer to A.1.4.2

A.3.4.3 Basic Conditions for Formulation of Master Plan

(1) Common Conditions

In order to set alternative structural measures, the following assumptions are applied in the current Study:

1) Unprotected Area

The areas, where is not prevented from overtopping of flood discharge by flood bund or other structures are called the "Unprotected areas". Actually, such area is situated at the downstream of the Kelani, Gin and Nilwala. Most of the areas are threatened by habitual flooding since flow capacity of low water channel is relatively small against magnitude of peak discharge.

Taking into account the area of subject area and required budget, it is anticipated that protection by structural measures is not feasible. In this sense, this Study prioritizes non-structural measures for the unprotected area over structural measures.

2) Early warning and monitoring system

In the Kelani River basin, pilot project of installation of automatic water level and rain gauges was conducted in association with community-based disaster management component of this Study. Similar project was conducted in the Kalu River basin as well in year 2008. It will be verified and recognized through the Pilot Projects that such early warning and monitoring system can be effectively applied as one of non-structural measures in the Study area with careful examination of hydrological feature and communication network.

Considering the size of required budget and construction procedure/period, such early warning system is able to introduce in a short period of time, as compared with other structural measures such as construction of flood bund and river training works, etc. Therefore, in the proposed Master Plan in the four river basins, the early warning and monitoring systems are included in the short-term plan. As for the Kelani and Kalu, further extension to supplement the monitoring stations of water level and rainfall are being considered after execution of the Pilot Project.

3) Dam and reservoir schemes

To create flood control and reservoir is one of effective options for reducing flood peak discharge in the basin. In fact, some potential dam schemes have been identified and proposed in the respective four river basins since the 1960's. However, not even a single project has been realized yet in the Study Area except for the hydropower project in the Kukule Ganga, Kalu River, by CEB due mainly to financial and environmental issues.

Considering the objective in the current Study which focuses on disaster management, particularly on flood management, the single purpose of flood control is envisaged for dam scheme in combination with other structural measures. In the Kelani, Gin and Nilwala River basins, synthetic reservoir storage volume corresponding with dam height, which is estimated by required flood retarding pocket against design flood, is duly examined. However, in case of Malwala Dam at Ratnapura in the Kalu River, detailed flood routine to assess the outflow discharge into the downstream reaches for the alternative options was carried out, since the reservoir volume curves is available.

(2) Current condition of flood damage

- Habitual flood damage in middle stream since flood bund does not exist (by 2 to 5-year probable flood)
- Inundation at downstream floodway area (river area outside of existing flood bund, inundation occurs by 2-year probable flood)
- Insufficient drainage of land side at downstream stretches with flood bund
- Aging pumping facilities at downstream area, insufficient budget for proper operation and maintenance, and inefficient operation of pumping facilities due to lack of appropriate communication system between existing pumping stations.
- Running cost for operation and maintenance

(3) Basic strategy of flood protection to be implemented

1) Target area: i) Non-flood bund area in middle reaches, (ii) Floodway area at downstream flood bund stretches, and (iii) Inundation area at land side (drainage area subject to existing pumping station)

2) Scale of countermeasures:

The downstream stretches with flood bund have been already improved to cope with 20-year probable flood. The pumping station has been installed to manage 10-year probable flood. Considering the current conditions, target scale of improvement was set as follows:

Gin River	Short-term target	Long-term target
	1/10 (Q_{peak}=1,450 m^3/s)	1/30 (Q_{peak}=1,900 m^3/s)

3) Basic strategy of flood protection:

- Since dam schemes at upstream area (Jasmin dam, etc.) include many issues such as large scale of relocation of main road, involuntary resettlement and complex rule of allocation of multi-purpose benefit, etc., it is not considered as a short-term measure. Thus, as a long-term measure, single purpose flood control dam is assumed and compared with other alternatives in the current Study.
- To raise flood protection level at habitually flooded area in the middle stretches non-flood bund section (tributaries from right bank, i.e. Divitura Ela, Maben Ela and Therun Ela (to protect against 10-year probability by increasing current scale of 2 to 5-year channel capacity)
- To upgrade and modernize the existing pumping facilities (total 10 pumping stations)
- To undertake non-structural measures at non-flood bund stretches at downstream
- In the Gin River basin, river channel width is relatively small compared with the Kelani River and appropriate site for retarding basin could not be found, which will meet required volume and area of flood control.

(4) Key Issues for Contemplating Short and Long-Term Alternative Plans

1) Dam Schemes

- In the Three River Basin Master Plan in 1968, Hiniduma, Jasmin, Madugeta and Mediripitiya Dam schemes in the Gin River basin were studied. At present, DOI is conducting a study of development plan which aims to transfer surface water from Mediripitiya Dam to the southeast dry zone (Hanbantota District) via reservoir group in the Nilwala upstream.
- Although the dam schemes in the Gin River basin will be effective in the aspect of flood retarding function, many social environmental issues need to be addressed prior to implementation to mitigate impact. From the mitigation purposes, construction of low dam group in the mainstream and/or tributaries might be one of alternatives. However, due to limitation of appropriate damsite and low level of economic viability, realization of the dam scheme in short-term seems not feasible. Therefore, dam construction scheme is excluded in the short-term plan in the current study.
- However, as a long-term plan, possibility of dam construction including such trans-basin development cannot be eliminated in case enhancement of land use and economic activities is expected. Under such situation, in the current study, as one of alternative long-term plan, single purpose dam scheme (at Jasmine damsite) was preliminarily assessed its scale and compared

with other alternative plans in terms of economic (cost and benefit) and environmental viability and possibility of realization of the plan.

2) Protection of Non-Flood Bund Middle Reaches (extension of existing flood bund)

- The middle reaches, which do not have existing flood bund at present, are habitual flooding zone by only 2 to 5-year probable flood. Farmers, in particular, who are residing three tributaries in the Divitura Ela, Maben Ela and Therun Ela, are suffering from agricultural crop damage due to frequent inundation.
- On the other hand, flood bund exists at the downstream reaches between the river mouth to Agaliya with almost 1/20 safety level. Therefore, flood risk at downstream reaches is relatively low.
- Under such current situation, disparity between the area with and without flood bund is remarkable and needs of the residents for extension of the flood bund become increasing and confirmed through a series of community development workshop. Although Phase 3 development scheme of flood bund construction for extension has been contemplated by China assisted project, its implementation has not been committed until present.
- If flood bund is constructed to protect the area along the non-flood bund section, retarding function in the low-lying area will diminish and flood peak discharge will increase at downstream. However, in the downstream area of the Gin River, flood bund has been constructed to protect 20-year scale of flood with keeping long distance between flood bunds. In fact, no overtopping has occurred by the May 2003 flooding.
- Therefore, construction of flood bund along the non-flood bund stretches will be assessed, including drainage facilities of landside such as sluices and pumping stations.
- As for the long-term schemes, comparison with heightening of flood bund, construction of high dam or a series of low dams will be required.

3) Protection of Unprotected Area at Downstream Area

- Approximately 4,000 people (subject to verification) live in the unprotected floodway area between flood bund and river course. Even small scale floods which annually occur cause inundation, and during a large scale of flood, the people require evacuation to higher place and flood bund.
- In the habitual flooding zone, effective and instant countermeasure is difficult to be realized under current condition. Taking into account this situation, non-structural measures of institutional strengthening such as cogent ordinance/guideline of land use and development restriction shall be undertaken. If flood bund is placed at middle reaches, the safety level of the unprotected area will deteriorate. However, it should be noted that additional structural measures along the downstream area will mean inefficiency of infrastructure investment.
- Therefore, assistance during evacuation together with installation and improvement of early warning and communication systems is required from aspect of lifesaving and disaster mitigation perspectives.

- Since the unprotected area has certain stretches having sufficient width and flat area to cope with the design discharge, which is not like the similar zone in the Kelani River downstream, construction of the mound dike is proposed in the current study. The mound dike will provide as evacuation sites during floods in the short-term, and in the long-term, the area will be transferred to the affected people for resettlement.
- As for the long-term plan, construction of new flood bund along the river course at downstream reaches where flood bund already exists is not recommended. Therefore construction of dam scheme will be one option to achieve the long-term target.

4) Drainage Improvement in Protected Area

- In order to safely drain rain water in landside at downstream reaches having flood bund, ten pumping stations (average design capacity Q=7 m^3/s) has been with installed through a financial assistance from the Government of China. However, DOI currently encounters many problems, i.e. deterioration of over-aged pumping facilities (electrical system, building, control gate, trash rack, raking devices, etc.), heavy load of operation cost (annual electricity fee of approximately Rs.15 mil.) and lack of effective communication system between pumping stations.
- The area is protected by flood bund system from flooding of scale 20-year probable flood and flood water in the river course and rain water in the land side is completely separated at present. Although rehabilitation of the existing pumping facilities is likely to improve drainage conditions, its impact in terms of effectiveness will be limited compared with those for the structural measures against flooding of the Gin River. However, since three pumping stations in the Nilwala River have similar problems, renewal and/or modernization of the both systems simultaneously can be strategically realized.

(5) Setting Alternative Plans

Based on the basic conditions of structural measures as above mentioned, alternative plans were set as follows:

Table A.3.4 Structural Measure Element of Alternative Plans (Gin River)

Short-term	S1: Flood bund at middle reaches (low dike: extent of distance to be place shall be compared) + rehabilitation of existing pumping stations + Mound dike
Long-term	L1: Heightening of low dike
	L2: Dam construction

Further detailed configuration with quantitative information of alternative plans for the Gin River is presented in succeeding Section A.3.5

A.3.5 Alternative Structural Measures in Target River Basins

A.3.5.1 Alternative Plans

Based on the discussions in Section A.3.4, three alternative plans for the Gin River were contemplated as follows:

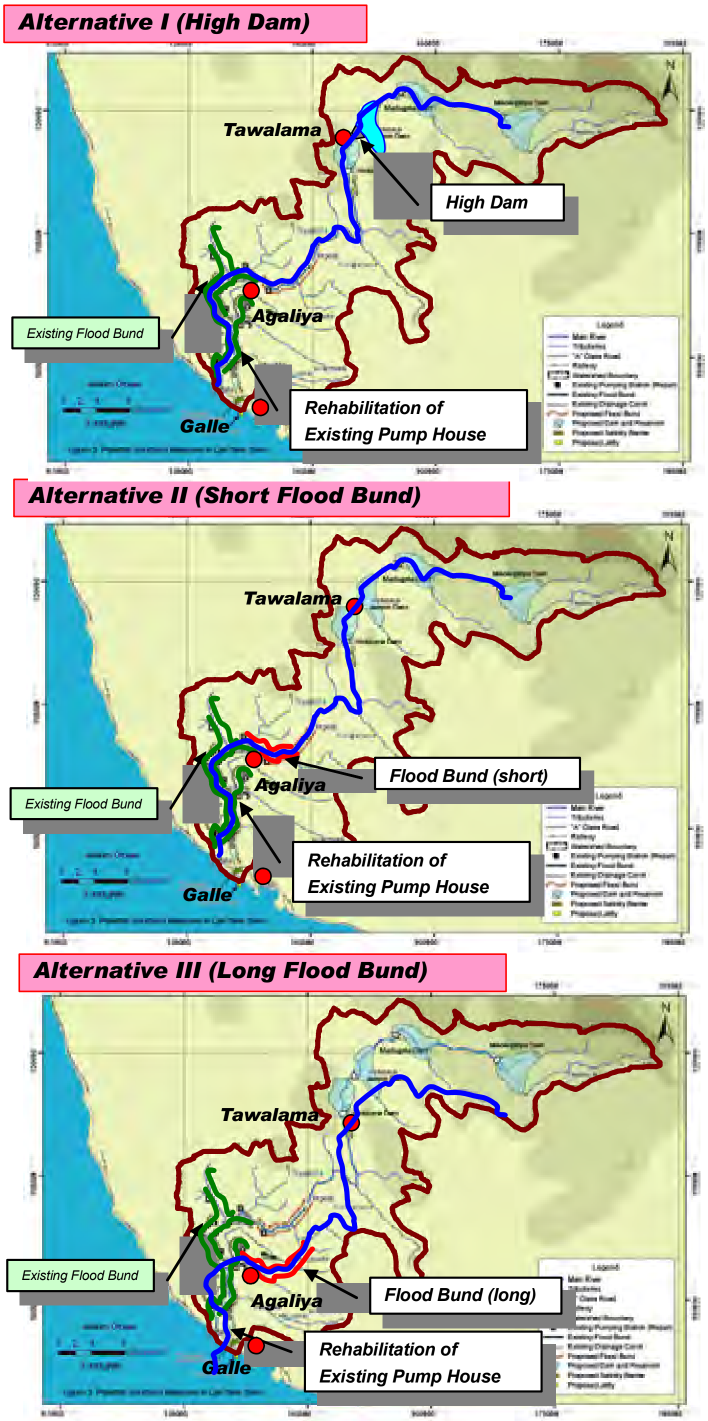
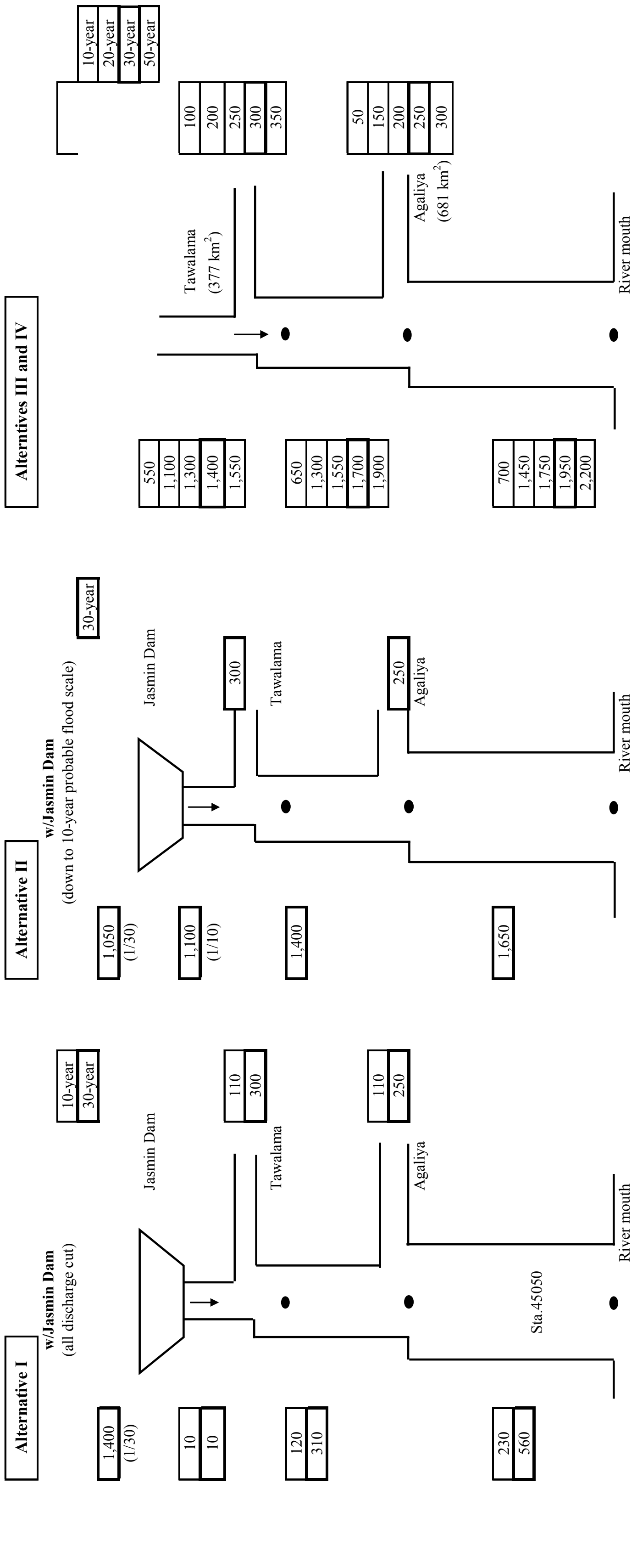


Figure A.3.4 Alternative Plans for Gin River Basin

A.3.5.2 Distribution of Design Flood Discharge



A.3.5.3 Principal Feature of Structural Measures

(1) New sluice and pumping station

In accordance with the new flood bunds construction as mentioned below, nine sluices and eight pumping stations also shall be newly installed with specifications of the following Tables.

Table A.3.5 Specification of Sluices

Station	Gate Type	No. of Gate	Gate Size
9 sites	Lifting Gate	2	1.5 x 1.5 m

Source: JICA Study Team

Table A.3.6 Specification of Pumping Stations

Station	Discharge	Head	Install Capacity	No. of Gate	Gate Size
8 stations	5.0 m^3/s	10.0 m	0.60 MW	6	1.5 x 1.5 m

Source: JICA Study Team

The location of this alternative structural measure is shown in Figure E.3.1 (Plate No. GN-00).

(2) Flood bund

Construction sites of new flood bunds were determined based on inundation map. In order to determine height of flood bund, longitudinal profile including water surface level was prepared based on steady flow calculation (non-uniform flow) with the following condition:

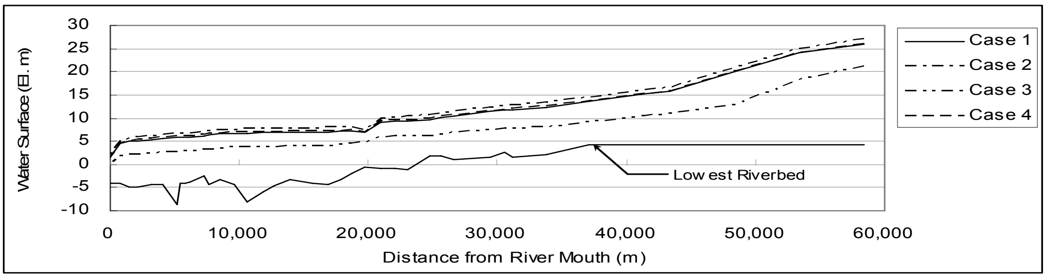
Table A.3.7 Case of Hydraulic Calculation in Gin River

Case	Distance (m)	Discharge (m^3/s)	Bund Width	Boundary Condition	Roughness Coefficient	Cross Section
Case 1	23,039 – 58,365	1,300 (10-year)	150 m	Sea water level: 0.4 m MSL	Low water channel: 0.035 High water channel: 0.050	40 sections in total
	0 – 22,045	1,450 (10-year)				
Case 2	23,039 – 58,365	1,700 (30-year)	150 m			
	0 – 22,045	1,950 (30-year)				
Case 3	23,039 – 58,365	310 (30-year)	150 m			
	0 – 22,045	560 (30-year)				
Case 4	23,039 – 58,365	1400 (30-year)	150 m			
	0 – 22,045	1,650 (30-year)				

Notes: Case 3 has Jasmin Dam (all discharge cut)
Case 4 has Jasmin Dam (down to 10-year probable flood scale)

Source: JICA Study Team

The results of hydraulic calculations are shown in Figure A.3.5 below:



Source: JICA Study Team

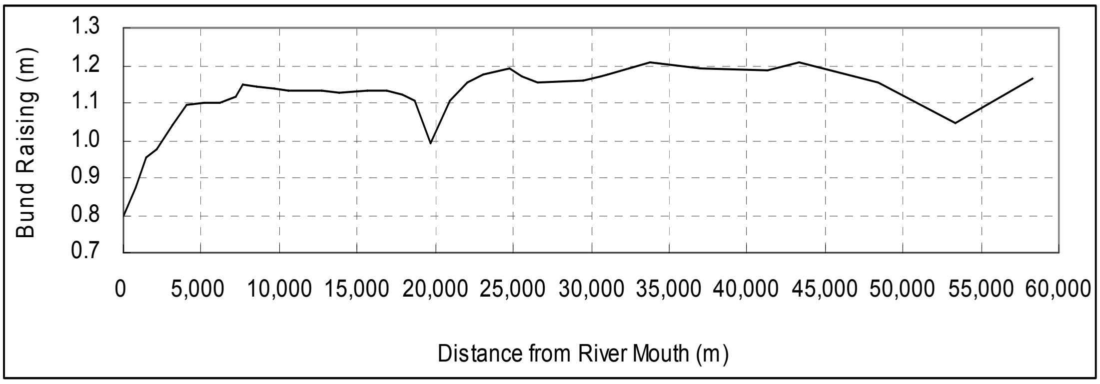
Figure A.3.5 Result of Hydraulic Calculation in Gin River

The freeboards are set as 1.0 m for less than 2,000 m^3/s discharge based on the Japanese standard[7]. Crest width is set as 4.0 m as Sri Lankan standard design of existing flood bunds in other river basins.

Locations and sections of bunds are shown in Figures E.3.2 and E.3.3 (Plate No. GN-01 and GN-02).

(3) Heightening of flood bund

If flood bunds are constructed against the 10-year flood as mentioned above, they shall be heightened by earth embankment up to the scale of 30-year flood in a long term plan. Also, the existing flood bunds along the downstream reach of the Gin River shall be heightened at the same time. The height of bund raising is estimated to be the difference between the bund height for 10-year and 30-year as shown in Figure A.3.6



Source: JICA Study Team

Figure A.3.6 Height of Bund Raising against 30-year Flood

(4) Rehabilitation/ modernization of existing pumping stations

In the Gin River basin, there are 10 existing pumping stations, however those pumping facilities are obsolete with some no longer working. All pumping stations shall be rehabilitated by civil works on the pumping stations and replacement of equipments with the same capacity as the existing ones.

This alternative structural measure including the characteristics of the pumping facilities is shown in Figure E.3.4 (Plate No. GN-03).

(5) Mound dike

In order to provide evacuation places for people living in riverside land, mound dike shall be constructed by widening the existing flood bund. There are three mound dikes to be proposed and those areas are estimated to be 51,000 m^2 (51ha) in total. The heights of the mound dikes shall be set to the same elevation as the existing flood bunds there.

This alternative structural measure is shown in Figure E.3.4 (Plate No. GN-03).

(6) Dam and reservoir

In the 1968 master plan study on a multipurpose dam carried out by ECI, Jasmin Dam was proposed with the features as shown in Table A.3.8. The location of the dam is shown in Figure E.3.1 (Plate

[7] Government Ordinance for Structural Standard for River Administration Facilities.

No.GN-00). In the current study, the same location of the Jasmin Dam was assumed and required size of reservoir and dam height in the corresponded Alternative Plans were examined.

Table A.3.8 Principal Features of Jasmin Dam

Item	Jasmin Dam
River	Gin
Purpose	- Flood Control - Power Generation
Dam Type	Earthfill Dam
Dam Height	64.0 m
Crest Elevation	79.9 m MSL
Catchment Area	363 km^2
Maximum Water Level	76.8 m MSL
Normal High Water Level	68.6 m MSL
Spillway Gate	Radial gate (3 nos. x 4.6m x 7.3m)

Source: Feasibility Report on Multipurpose Development of the Nilwala Ganga, Gin Ganga, Kalu Ganga Basins, ECI , September 1968

Dam scale to be used for hydraulic calculation estimating flood control capacity basically follows the past study results shown in the above table.

This alternative structural measure is shown in Figure E.3.5 (Plate No. GN-04).

(7) Flood forecasting and early warning system

Out of the existing gauging stations, gauging facilities at the following stations shall be automated.

Table A.3.9 Gauging Stations to be Automated in Gin River Basin

Station	Existing	Scheme		
		Master Plan	Japanese Grand Aid	Total
Rain gauge	17	8 (4)	3	11 (4)
Hydrometric	7	5 (2)	-	5 (2)
Total	24	13 (6)	3	16 (6)

Notes: ( ) *m*eans station to be newly installed.

Source: JICA Study Team

This alternative structural measure is shown in Figure E.3.6 (Plate No. GN-05).

A.3.6 Promising Non-Structural Measures

(1) Flood Forecasting and Early Warning System

It is recommended that a similar system as introduced in the Kelani and Kalu should be also extended to the Gin River basins in order to secure the local residents and their property in the unprotected area at downstream part of the Gin, where the flood bund forms the boundary.

(2) Installation of Rainwater On-site Storage and Rainfall Infiltration Facility

Urbanization will trigger an increase of flood runoff volume from land into the river channel. In parallel with it, increasing the channel capacity normally has severe limitation and difficulty of land acquisition, etc. In order to cope with this problem, installation of rainfall infiltration facilities and on-site rainwater storage tank, etc. shall become obligatory for every entity of new development including governmental agencies. Especially, in connection with the urban development in Galle and its suburban areas to legalize installation of such facilities for regulating local runoff shall be integrated in the new development plan.

(3) Promotion of Water-resistant Architecture

In principle, it is desirable to relocate the houses, which are located in the flood prone area such as low lying area and flood retarding basin, to safer zone. However, if the situation does not allow it, countermeasures such as promotion of water-resistant building construction, heightening of building foundation, construction of column-supported housing (piloti style), change to multi-storied housing and water proofing of wall/housing material, etc. shall be introduced.

(4) Promotion of Flood Fighting Activities

In the flood prone area, in particular in the unprotected area along the Kelani, the interview survey conducted in the current Study verified that self-defense flood fighting activities are already part of the usual reaction during flood. Flood fighting activities such as information dissemination in the communities, evacuation to safer area and removal of their properties in house/building, etc. shall be further propagated to mitigate flood damage. In particular, the effective linkage between early warning and monitoring system with such flood fighting activities to be installed under the current Study, is highly expected.

(5) Resettlement

In order to ensure appropriate evacuation during flood and to aim at future permanent resettlement of the people living in the unprotected area in the Gin River basins, construction of “mound dike” is proposed in the current Study. The following basic concept for mound dike construction is applied:

1) Mound dike will be constructed by earth material in the river side adjacent to the existing flood bund or low hill avoiding direct hitting by turbulent flow and hazardous reduction of flow area, etc.

2) For the time being, the filled area, which should be owned by the government, will be used as a temporary evacuation area for the affected people when they need to evacuate from their places due to inundation.

3) Evacuation center and other public structures (school, temple, community hall, day care center, etc.) can be constructed on the mound mainly by local governments with appropriate access road and proper drainage network.

4) People shall be given an incentive to own the land on the mound dike in the future with specific conditions for permanent resettlement from their original place.

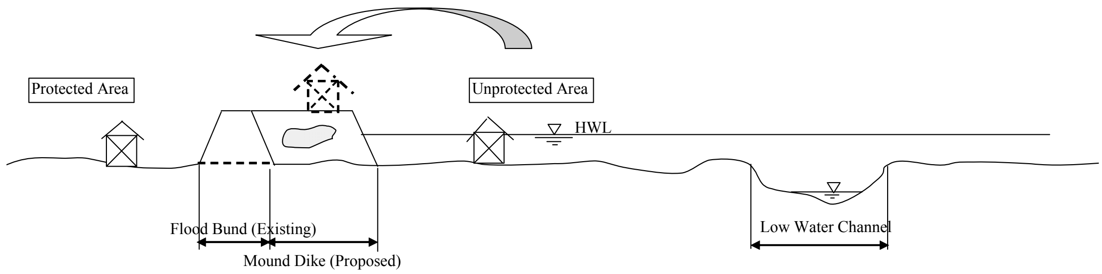


Figure A.3.7 Schematic Feature of Mound Dike

The final location and appropriate size of the mound dike shall be further examined through stakeholder meetings and/or consultations by the executing agencies during the detailed design and implementation stage in the future.

A.4 Nilwala River Basin

A.4.1 Basin Overview

The Nilwala River has catchment area of 960 km^2 and its length is 78 km. The basin is located adjacent to the Gin River basin at south and is entirely in the wet zone of the country. The annual mean rainfall is approximately 2,890 mm. It varies from 2,000 mm at the coast to 4,500 mm in the upstream mountainous area. The river originates at 1,050 m msl near Deniyaya Hills and drops to 12 m msl within the first 36 km and reaches Pitabeddara. It has a gentle slope down to the sea in the last 42 km downstream reaches from Pitabeddara to Matara. Annual mean discharge to the sea has been estimated as 1,152 MCM. A plan of the Nilwala River is shown in Figure A.4.1

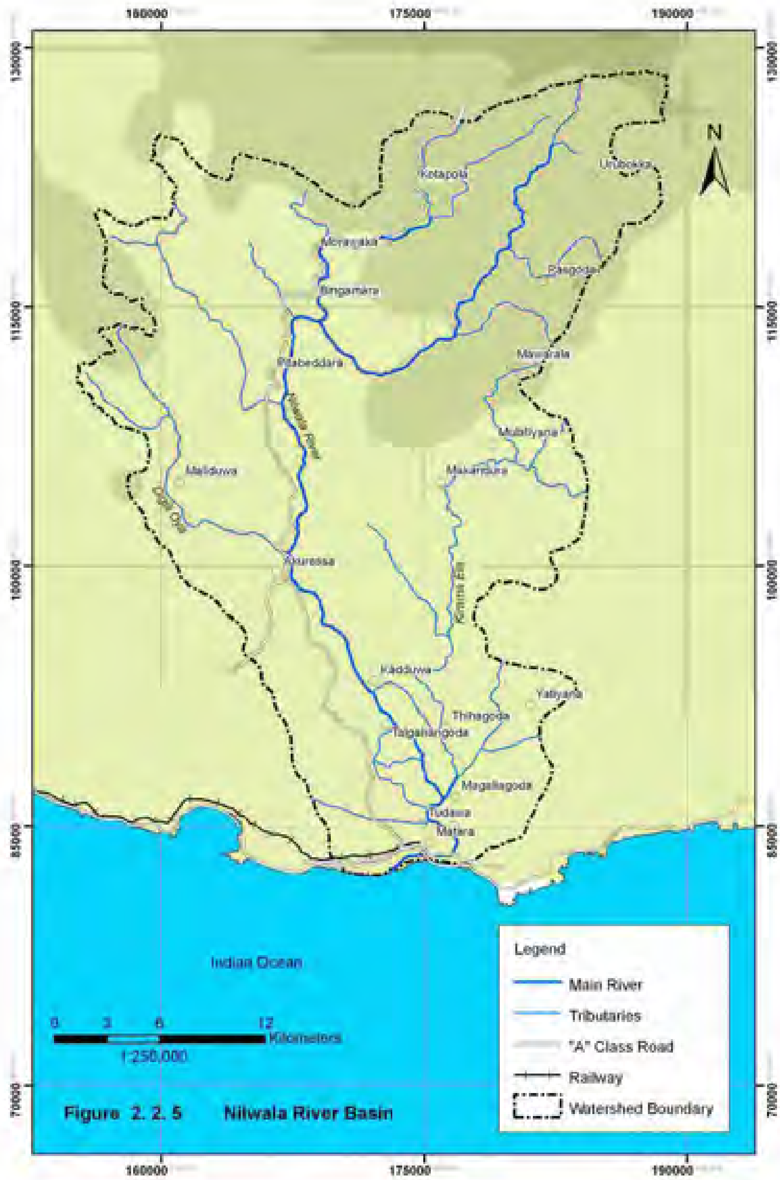
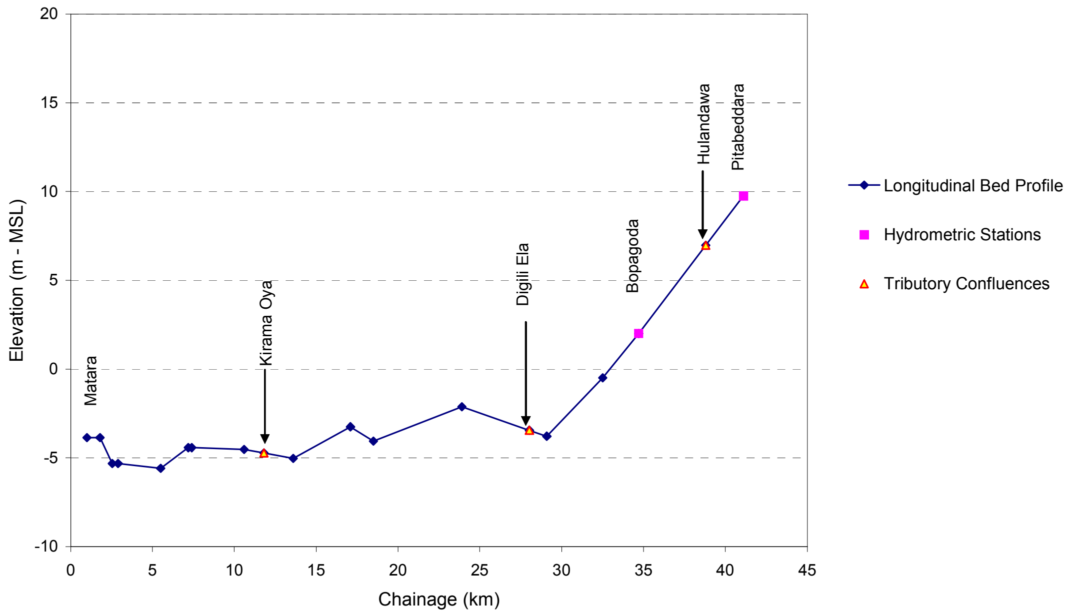


Figure A.4.1 Location Map of Nilwala River Basin

Nilwala river is characterized by excessive flows during wet season which causes flooding, but considerably drying out during dry season. The river flow is not sufficient during the dry season to meet the irrigation requirement.

North of Matara city and its suburbs often get flooded during the rainy season. To cope with this problem a flood protection scheme was initiated by DOI in 1979 with the assistance from the Government of France. This flood protection scheme included a levee system and three pumping stations. A longitudinal profile of the Nilwala River is shown in Figure A.4.2



Source: Galle Regional Office of DOI and LHI

Figure A.4.2 Longitudinal Profile of Nilwala River

A.4.2 Past Significant Floods

(1) Historical Flood

According to the annual maximum water levels after 1978 at Pitabeddara and Bopagoda available in DOI, May 2003 flood was the worst one. Significant floods are recorded in 1978, 1993, 1999 and 2003 as same as those occurred in the Given River basin.

(2) Flood in May 2003

The Nilwala River basin, as same as the Kalu and Gin River basins, has been inundated widely in May 2003. On May 17, flooding occurred at Kotapola and due to landslide happened at Diyadawa in Paskoda and Batazula in Basukoda, casualties has risen to 43 people. The water level at upstream area has acutely risen from 17th to 18th of May. On 18th, flooding has expanded in Akuressa and Aturaliya. Early in the morning, a part of existing flood bund was cut off to reduce the water level by villagers at Kaduwa. It triggered to extend the inundation area in the right bank area. On the other hand, the left bank area was protected without overtopping the flood bund.

On 19th May the inundated area was further extended. However, most of the pumping facilities did not work properly because of mal function of submerged pumps and/or poor maintenance in routine operation. Therefore, it should be waited for drawdown of the water level in the Nilwala River naturally. In Matara, inundation has lasted for more than 10 days at maximum. The affected people evacuated to the temporary houses or evacuation center. Only in Matara, 30 sites of temporary housing area have been developed for the people who had lost or damaged their houses. It has been reported that approximately total 8,000 people evacuated. The downtown of Matara was not affected by inundation and traffic interruption in long duration along Matara-Galle Road has been avoided.

Maximum water level at Bopagoda Gauging Station of 35ft (10.7m) was recorded at 4:30 am on May 18. In addition, daily discharge at Pitabeddara was obtained 2,900 m^3/s from water level measured by DOI, which is far beyond normal discharge of May, approximately 500 m^3/s.

The flood damage is summarized in Table A.4.1 and inundation areas are delineated in Figure A.4.3

Table A.4.1 Summary of Flood Damage due to May 2003 Flood in Nilwala River Basin

Item	Damaged Number
Damage to houses	47,637 (26% of total)
Affected people	145,875 (19% of total)
Totally damaged	5,562
Partially damaged	2,138
Causalities	30 (by flood), 34 (by landslide)
Missing	17
Damaged well	2,941

Source: "Report on Flood Disaster Research 2003, IDI, September 2004"

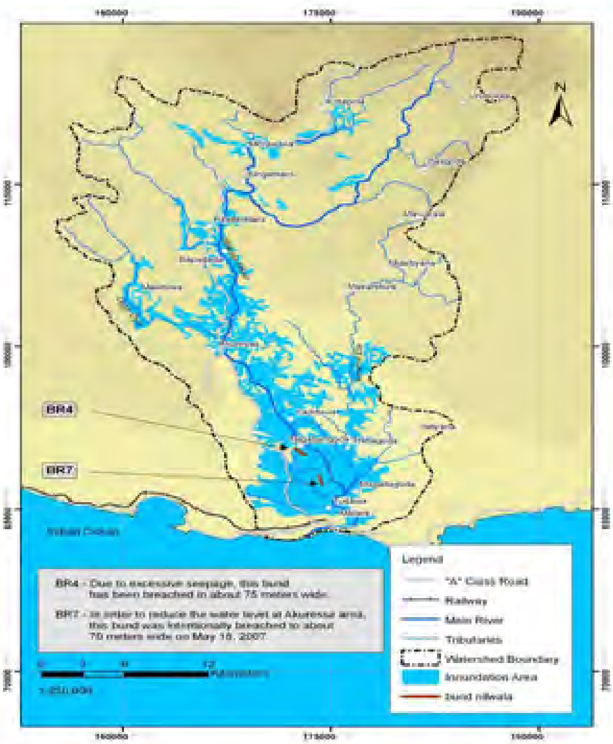


Figure A.4.3 Inundation Area due to May 2003 Flood in Nilwala River Basin

A.4.3 Review of Previous Flood Management Studies

(1) "Concept Paper, Flood Protection for Nilwala Ganga Basin, DOI, 2004"

This study aimed to develop a proposal to safeguard the Nilwala River basin with consideration of current development already taking place in the basin. The study stood on its position that 64 m high dam at Bingamara to absorb 100-year flood as recommended in ECI Report in 1968 would not be necessary, since the basin has been protected against 10-year flood by flood bund. However, low dam scheme with 40 m in height of Bingamara dam was recommended with multipurpose function of hydropower, irrigation and drinking water supply in Matara District.

A.4.4 Basic Concept for Flood Management Planning

A.4.4.1 Planning Scale

From the results of review on the existing national or regional development plans, it was clarified that no specific criteria/guideline defining appropriate or target scale of protection level (planning scale) exists in Sri Lanka. Therefore, based on a series of discussions and agreement of DOI, the planning scale of four river basins were decided taking into consideration the following: (i) current channel capacity, (ii) experienced maximum flood peak discharge and (iii) future land use conditions. The planning scale as target to formulate Master Plan was set as follows:

Table A.4.2 Planning Scale of Nilwala River Basin

River Name (km^2)	Safety Level (Flow Capacity)	Experienced Max. Peak Flood	Future Land Use	Planning Scale
Nilwala (971)	- Flood bund section 10~20-year	Approx.20-year (May 2003 Flood)	As regional development center, urbanization of Matara will be continued. However, no drastic change of land use is presumed from current situation (mainly agriculture- driven land use)	30-year (2,200 m^3/s at river mouth)

Source: Study Team

In accordance with the record of the National Census in 2000, the population in the river basin was assessed with size of population of major cities as shown below:

Table A.4.3 Current Population in River Basin and Major Cities

River Name	Population (thousand)	Population in Major Cities (thousand)
Nilwala	459	Matara (75), Paskoda (56), Akuressa (47), Others (281)

Source: National Census in 2000

A.4.4.2 Target Period for Implementation

Refer to A.1.4.2.

A.4.4.3 Basic Conditions for Formulation of Master Planning Scale

(1) Common Conditions

In order to set alternative structural measures, the following preambles are applied in the current Study:

1) Unprotected Area

The areas, where is not prevented from overtopping of flood discharge by flood bund or other structures are called the “Unprotected areas”. Actually, such area is situated at the downstream of the

Kelani, Gin and Nilwala. Most of the areas are threatened by habitual flooding since flow capacity of low water channel is relatively small against magnitude of peak discharge.

Taking into account the area of subject area and required budget, it is anticipated that protection by structural measures is not feasible. In this sense, this Study prioritizes non-structural measures for the unprotected area over structural measures.

2) Early warning and monitoring system

In the Kelani River basin, pilot project of installation of automatic water level and rain gauges was conducted in association with community-based disaster management component of this Study. Similar project was conducted in the Kalu River basin as well in year 2008. It will be verified and recognized through the Pilot Projects that such early warning and monitoring system can be effectively applied as one of non-structural measures in the Study area with careful examination of hydrological feature and communication network.

Considering the size of required budget and construction procedure/period, such early warning system is able to introduce in a short period of time, as compared with other structural measures such as construction of flood bund and river training works, etc. Therefore, in the proposed Master Plan in the four river basins, the early warning and monitoring systems are included in the short-term plan. As for the Kelani and Kalu, further extension to supplement the monitoring stations of water level and rainfall are being considered after execution of the Pilot Project.

3) Dam and reservoir schemes

As for one of flood management measures reservoir is one of effective options for reducing flood peak discharge in the basin. In fact, some potential dam schemes have been identified and proposed in the respective four river basins since the 1960's. However, not even a single project has been realized yet in the Study Area.

Considering the objective in the current Study which focuses on disaster management, particularly on flood management, the single purpose of flood control is envisaged for dam scheme in combination with other structural measures. In the Nilwala River basins, synthetic reservoir storage volume corresponding with dam height, which is estimated by required flood retarding pocket against design flood, is duly examined.

(2) Current condition of flood damage

- Inundation damage at middle reaches has no flood bund (inundation occurs by 2 to 5-year probable flood)
- Inundation damage at floodway in the downstream flood bund stretches (inundation occurs by 2 year probable flood)
- Damage due to stagnation of rainwater at land side in the downstream flood bund stretches
- Aging pumping facilities at downstream area, insufficient budget for proper operation and maintenance and inefficient operation of pumping facilities due to lack of appropriate communication system between existing pumping stations.

(3) Basic strategy of flood protection to be implemented

1) Target area: (i), Non-flood bund area in middle reaches, (ii) Floodway area at downstream flood bund stretches, and (iii) Inundation area at land side (drainage area subject to existing pumping station)

2) Scale of countermeasures:

Downstream Area (Matara)	Short-term target	Long-term target
	1/10 (Q_{peak}=1,900 m^3/s)	1/30 (Q_{peak}=2,200 m^3/s)

3) Basic strategy of flood protection:

- Since dam schemes at upstream area include many issues such as large scale of relocation of main road, etc. as seen in the case of the Gin River, it is not considered as a short-term measure. Thus, as a long-term measure, single purpose flood control dam is assumed and compared with other alternatives in the current Study.
- To raise flood protection level at habitual flooding area in the middle stretches non-flood bund section (Akuressa and its vicinity) (to protect against 10-year probability by increasing current scale of 2 to 5-year channel capacity)
- To upgrade and modernize the existing pumping facilities (total of three pumping stations)
- To undertake non-structural measures at non-flood bund stretches at downstream

(4) Key Issues for Contemplating Short and Long-Term Alternative Plans

1) Dam Schemes

- In the past Master Plans in 1968 and 1987, Digili Oya Dam, Hulandawa Dam, Hulandawa-Bingamara Dam, Atu Ela DA, Siyambalagoda Dam and Urawa Dam schemes in the Nilwala River basin were studied. At present, as stated in previous section for the Gin River, DOI is conducting a study of trans-basin development plan which aims to divert water from Mediripitiya Dam in the upstream of the Gin to the southeast dry zone (Hanbantota District) via reservoir group (Kotapora, Urawa) in the Nilwala upstream.
- On the other hand, in February 2007, a technical proposal focusing flood management in the Nilwala River basin prepared by a French Consultant was submitted to DOI. This proposal includes construction of four multi-purpose dams (hydropower and flood control), floodway at Matara, mini-hydropower, and transferring water resources to the eastern dry area.
- However, the dam schemes are planned with height of 70 m or more and involve similar environmental problems at those in the Kalu and Gin River basins. Any dam scheme has not been realized yet.
- Regarding the dam schemes, in the Nilwala River basin, similar social issues can be pointed as seen in other three target river basins and realization of the dam scheme in short-term seems to be difficult. Therefore, dam construction scheme is excluded in the short-term plan in the current study. As a long-term plan, possibility of dam construction including such trans-basin development cannot be eliminated in case enhancement of land use and economic activities is

expected. Single purpose dam scheme (at Siyambalagoda damsite) was preliminarily assessed its scale and compared with other long-term alternative plans in terms of economic (cost and benefit) and environmental viability and possibility of realization of the plan.

2) Protection of Non-Flood Bund Middle Reaches (extension of existing flood bund)

- The middle reaches, where no flood bund exits at present, are habitually flooded zone by only 2 to 5-year probable flood. Farmers, who cultivate at low-lying agricultural area near Akuressa, are suffering from flood damage due to frequent inundation occurring once every 2 to 5-years.
- On the other hand, flood bund exists at the downstream reaches with almost 1/10~1/20 safety level. Therefore, flood risk at downstream reaches is relatively low compared with that in the middle and upstream reaches under such current situation, disparity between the area with and without flood bund is remarkable.
- The flood bund at downstream reaches 5as been completed in 1984 with the official assistance of the Government of France. The development plan was considered in a three-phases project of "Nilwala Ganga Flood Protection Scheme". Implementation has been realized up to Phase 2.
- If flood bund is constructed to protect the area along the non-flood bund section, it is anticipated that retarding function in the low-lying area will diminish and flood peak discharge will increase at downstream. However, the Nilwala River flood bund in the downstream area is has been already placed to protect 10 to 20-year scale of flood. Therefore, low flood bund with scale of 10-year probability, which does not affect the downstream flood bund stretches, was assessed including drainage facilities of land side such as sluices and pumping stations as well.
- As for the long-term schemes, comparison with heightening of flood bund, construction of high dam or a series of low dams, bypass canal detouring Akuressa, where is being considered for future development as regional economic center. The plan will consist of approximately 8 km long canal at east of Akuressa to accommodate 300 m^3/s of design discharge.

3) Protection of Unprotected Area at Downstream Area

- Approximately 5,000 people (subject to verification) live in the unprotected floodway area between flood bund and river course. Even small scale floods which annually occur causes inundation, and during a large scale flooding, the people require evacuation to higher place and flood bund.
- In the habitual flooding zone, effective and instant countermeasure is difficult to be realized under current condition. Taking into account this situation, non-structural measures of institutional strengthening, such as cogent ordinance/guideline of land use and development restriction, shall be undertaken. If flood bund is placed at middle reaches, the safety level of the unprotected area will deteriorate. However, it should be noted that additional structural measures along the downstream area will mean inefficiency of infrastructure investment.
- Therefore, assistance during evacuation together with installation and improvement of early warning and communication systems is required from lifesaving and disaster mitigation perspectives.

- Since the unprotected area has certain stretches that have sufficient width and flat area to cope with the design discharge, which is not like the similar zone in the Kelani River downstream, construction of the mound dike, with same concept as a pilot project in the Gin River basin, is proposed.

4) Drainage Improvement in Protected Area

- Through financial assistance from the Government of France, three pumping stations (average design discharge of 32 m^3/s per station) have been installed to drain rainwater in the downstream flood bund stretches.
- However, DOI is currently encountering many problems, i.e. breaking down of 13 units of pumping facilities out of total 26 units and aging, if not obsolete, appurtenant facilities (electrical system, building, control gate, trash rack, raking devices, etc.), heavy load of operation cost (annual cost of diesel fuel at approximately Rs.5.0 mil.) and lack of communication system between pumping stations.
- Further, it should be noted that Southern Highway to connect Colombo and Matara is under construction. The route crosses the flood prone area of the Nilwala, Gin and Kalu River basins and construction of large scale of embankment at low elevation is ongoing as of May 2008.
- The subject area is protected by flood bund system from flooding of scale 1/10 to 1/20 scale and flood water in the river course and rain water in the land side is not completely separated at present because of discontinuity of the flood bund. Rehabilitation of existing pumping station is therefore required. Since the pumping stations in the Gin River basin have similar problems, simultaneous upgrading and improvement of facilities will be ideal.
- In connection with the construction of Southern Highway, substantial review of drainage system in the downstream area will be required.

(5) <u>Protection of Matara City</u>

- Matara city is capital of District and has a population of approximately 95,000. Frequent flooding occurred at the lowly undulated wet land, which is located northern part of Matara, at downstream unprotected area. On the other hand, the center of the City has 0.5 to 1.0 m higher ground elevation and the flood is regulated in natural retarding basin in the Kerama Ela. In addition, due to over bank flow in the unprotected area, peak discharge is usually reduced and safety level of Matara against flood is relatively high. In fact, it is reported that the magnitude of damage due to May 2003 flood was not so devastated.
- As in the 1968 Master Plan prepared by ECI and the proposal submitted by the French group, a bypass canal diverting from just upstream of Matara and directly empty to the sea.
- Because dimensions of the bypass canal are of diameter 20 m, length of 1 to 2 km, the possibility of the plan is evaluated to be not so highly feasible. Therefore, in the current Study, the bypass canal at Matara is excluded as an alternative plan in the current Study.

Table A.4.4 Structural Measure Element of Alternative Plans (Nilwala River)

Short-term	S1: Flood bund at middle reaches (low dike:) + rehabilitation of existing pumping stations + Mound dike
Long-term	L1: Heightening of low dike
	L2: Dam construction
	L3: Bypass canal at Akuressa

A.4.5 Alternative Structural Measures in Target River Basins

A.4.5.1 Alternative Plans

Based on the discussions in the previous Section, three alternative plans for the Nilwala River were contemplated as follows:

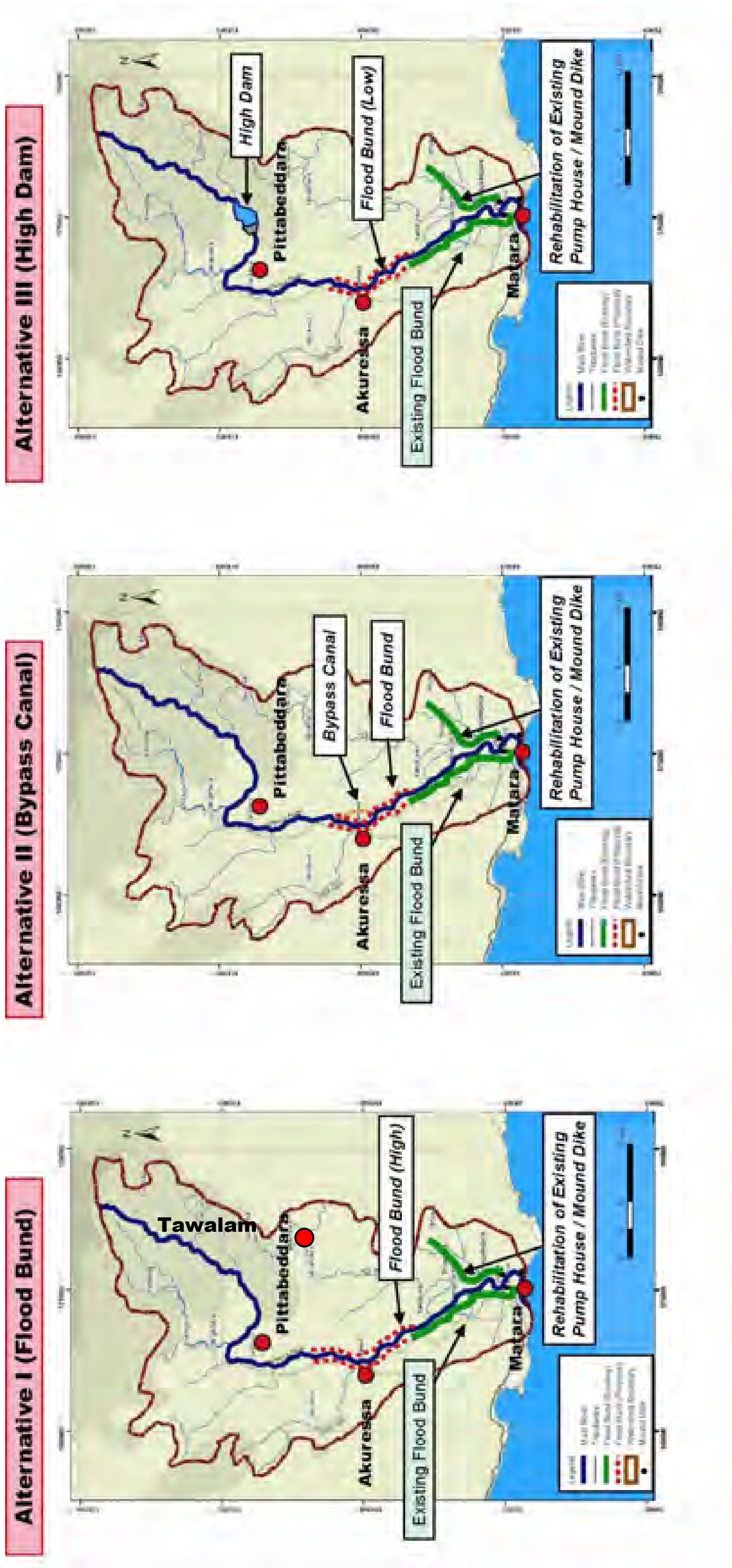
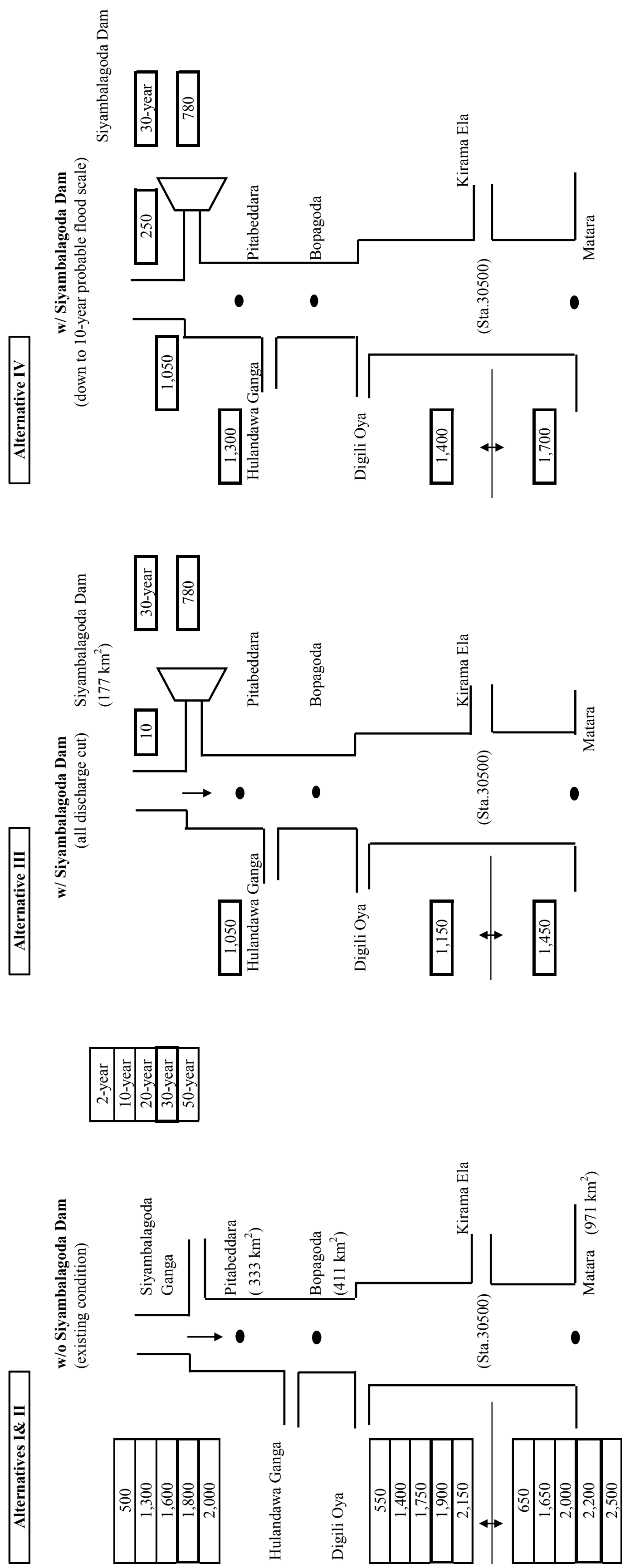


Figure A.4.4 Alternative Plans for Nilwala Rive Basin

A.4.5.2 Distribution of Design Flood Discharge



A.4.5.3 Principal Feature of Structural Measures

(1) Flood bund

Construction sites of new flood bunds were determined based on 5-year flood discharge inundation map. In order to determine height of flood bund, longitudinal profile including water surface level was prepared based on steady flow calculation (non-uniform flow) with the following conditions:

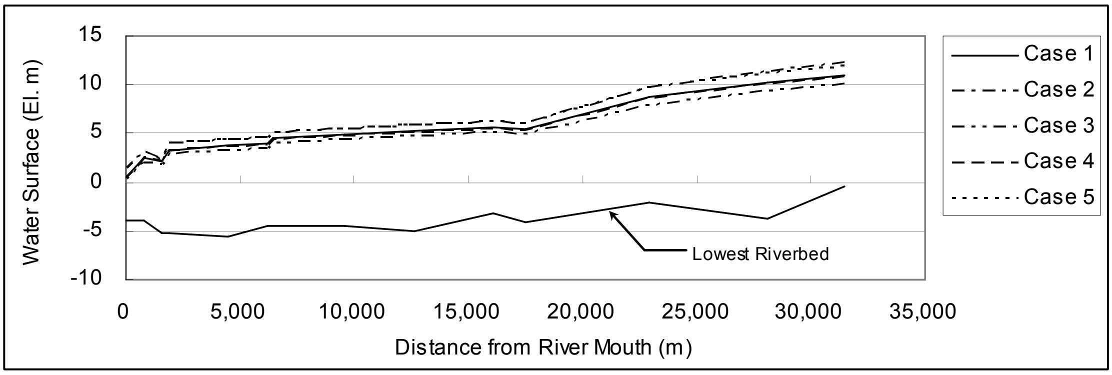
Table A.4.5 Required Case of Hydraulic Calculation in Nilwala River

Case	Distance (m)	Discharge (m^3/s)	Bund Width	Boundary Condition	Roughness Coefficient	Cross Section
Case 1	31,500	1,300 (10-year)	150 m	Sea water level: 0.4 m MSL	Low water channel: 0.035 High water channel: 0.050	14 sections in total
	12,600 – 28,100	1,400 (10-year)				
	0 – 9,600	1,650 (10-year)				
Case 2	31,500	1,800 (30-year)	150 m			
	12,600 – 28,100	1,900 (30-year)				
	0 – 9,600	2,200 (30-year)				
Case 3	31,500	1,050 (30-year)	150 m			
	12,600 – 28,100	1,150 (30-year)				
	0 – 9,600	1,450 (30-year)				
Case 4	31,500	1,300 (30-year)	150 m			
	12,600 – 28,100	1,400 (30-year)				
	0 – 9,600	1,700 (30-year)				
Case 5	31,500	1,800 (30-year)	150 m			
	28,100	1,400 (30-year)				
	12,600 – 22,900	1,900 (30-year)				
	0 – 9,600	2,200 (30-year)				

Note: Case 3 has Siyambalagoda Dam (all discharge cut)
Case 4 has Siyambalagoda Dam (down to 10-year probable flood)
Case 5 has Akuressa Bypass with capacity of 500 m^3/s

Source: JICA Study Team

The results of hydraulic calculations are shown in Figure A.4.5 below:



Source: JICA Study Team

Figure A.4.5 Results of Hydraulic Calculation in Nilwala River

The freeboards are set as 1.0 m for less than 2,000 m^3/s and 1.2 m for less than 5,000 m^3/s based on the Japanese standard[8]. Crest width is set as 4.0 m as Sri Lankan standard design of existing flood bunds in other river basins.

Locations and sections of bunds are shown in Figures E.4.2 and E.4.3 (Plate No. NW-01 and NW-02).

[8] Government Ordinance for Structural Standard for River Administration Facilities.

(2) New sluice and pumping station

In accordance with the new flood bunds construction as mentioned below, 11 sluices and two pumping stations also shall be newly installed with specifications of the following Tables:

Table A.4.6 Specification of Sluices

Site	Gate Type	No. of Gate	Gate Size
11 sites	Lifting Gate	2	1.5 x 1.5 m

Source: JICA Study Team

Table A.4.7 Specification of Pumping Stations

Station	No. of Pump	Discharge	Head	Install Capacity	No. of Gate	Gate Size
2 station	5	20.0 m^3/s	4.5 m	1.08 MW	4	1.5 x 1.5 m

Source: JICA Study Team

The location of this alternative structural measure is shown in Figure E.4.1 (Plate No. NW-00).

(3) Rehabilitation/ modernization of existing pumping stations

There are three pumping stations at Tudawa, Magallagoda and Talgahangoda in the downstream reaches of the Nilwala River, however these facilities are obsolete. These three pumping stations shall be rehabilitated by civil works on the pumping stations and equipment replacement with the same capacity as the existing ones.

The location of this alternative structural measure is shown in Figure E.4.4 (Plate No. NW-03).

(4) Mound dike

In order to provide evacuation places for people living in riverside land, mound dike shall be constructed by widening the existing flood bund. There are three (3) mound dikes to be proposed and those areas are estimated to be 620,000 m^2 in total. The heights of the mound dikes shall be set to the same elevation as the existing flood bunds there.

This alternative structural measure is shown in Figure E.4.4 (Plate No. NW-03).

(5) Bypass canal (new floodway)

Bypass canal shall be constructed at the middle reach of the Nilwala River from the upstream site of Akuressa pumping station to the downstream site of Akuressa town in order to protect Akuressa town from flooding. The canal is assumed to be constructed by excavation with the total length of the canal estimated to be 3.15 km. Bank protection with wet cobble masonry is necessary for the bending part of the canal. The parameters of the canal are shown in Table A.4.8 below:

Table A.4.8 Parameters of Akuressa Bypass Canal

Length	Discharge	Velocity	Bed width	Water Depth	Bed slope	Slope gradient	Roughness coefficient	Free board	Height
3.15 km	545 m^3/s	1.56 m/s	50 m	5.7 m	1/2600	1:2	0.035	1.0 m	6.5 m

Source: JICA Study Team

A plan and profile of the bypass canal is shown in Figure E.4.5 (Plate No. NW-04).

(6) Dam and reservoir

In the feasibility study on multipurpose dam which was carried out by the DOI in 2004, Hulandawa-Bingamala Dam was proposed with the features as shown in Table A.4.9. The location of the dam is shown in Figure E.4.1 (Plate No.NW-00).

Table A.4.9 Features of Hulandawa and Bingamara Dam

Item	Hulandawa Dam	Bingamala Dam
River	Hulandawa River	Nilwala River
Purpose	- Flood Control (10-year flood) - Power Generation	
Dam Type	Earthfill Dam	Rockfill Dam
Dam Height	54.9 m	70.7 m
Crest Elevation	79.9 m M.S.L.	79.9 m M.S.L.
Catchment Area	62.2 km^2	308.2 km^2
Maximum Water Level	76.8 m M.S.L.	
Normal High Water Level	73.2 m M.S.L.	
Spillway Gate	Radial gate (2 nos. x 7.3m x 4.6m)	

Source: Feasibility Report on Multipurpose Development of the Nilwala Ganga, Gin Ganga, Kaku Ganga Basins, ECI, September 1968

However, due to the large extent of affected people and structures at the Hulandawa-Bingamara dam site, Siyambalagoda dam site further upstream, where less environmental impact is expected, was assumed for the Alternative Plan in the current study.

(7) Flood forecasting and early warning system

Out of the existing gauging stations, gauging facilities at the following stations shall be automated.

Table A.4.10 Gauging Stations to be Automated in Nilwala River Basin

Station	Existing	Scheme		
		Master Plan	Japanese Grand Aid	Total
Rain gauge	14	8 (2)	2	10 (2)
Hydrometric	6	6 (2)	-	6 (2)
Total	20	14 (4)	2	16 (4)

Notes: ( ) means station to be newly installed.

Source: JICA Study Team

This alternative structural measure is shown in Figure E.4.8 (Plate No. NW-07).

A.4.6 Promising Non-Structural Measures (Nilwala)

(1) Flood Forecasting and Early Warning System

It is recommended that a similar system as introduced in the Kelani and Kalu should be also extended to the Nilwala River basins in order to secure the local residents and their property in the unprotected area at downstream part of the Nilwala, where the flood bund forms the boundary.

(2) Installation of Rainwater On-site Storage and Rainfall Infiltration Facility

Urbanization will trigger an increase of flood runoff volume from land into the river channel. In parallel with it, increasing the channel capacity normally has severe limitation and difficulty of land acquisition, etc. In order to cope with this problem, installation of rainfall infiltration facilities and on-site rainwater storage tank, etc. shall become obligatory for every entity of new development including governmental agencies. Especially, in connection with the urban development in Matara and its suburban area, to legalize installation of such facilities for regulating local runoff shall be integrated in the new development plan.

(3) Promotion of Water-resistant Architecture

In principle, it is desirable to relocate the houses, which are located in the flood prone area such as low lying area and flood retarding basin, to safer zone. However, if the situation does not allow it, countermeasures such as promotion of water-resistant building construction, heightening of building foundation, construction of column-supported housing (piloti style), change to multi-storied housing and water proofing of wall/housing material, etc. shall be introduced.

(4) Promotion of Flood Fighting Activities

In the flood prone area, in particular in the unprotected area along the Kelani, the interview survey conducted in the current Study verified that self-defense flood fighting activities are already part of the usual reaction during flood. Flood fighting activities such as information dissemination in the communities, evacuation to safer area and removal of their properties in house/building, etc. shall be further propagated to mitigate flood damage. In particular, the effective linkage between early warning and monitoring system with such flood fighting activities to be installed under the current Study, is highly expected.

(5) Resettlement

In order to ensure appropriate evacuation during flood and to aim at future permanent resettlement of the people living in the unprotected area in the Gin River basins, construction of "mound dike" is proposed in the current Study. Following basic concept for mound dike construction is applied:

1) Mound dike will be constructed by earth material in the river side adjacent to the existing flood bund or low hill avoiding direct hitting by turbulent flow and hazardous reduction of flow area, etc.

2) For the time being, the filled area, which should be owned by the government, will be used as a temporary evacuation area for the affected people when they need to evacuate from their places due to inundation.

3) Evacuation center and other public structures (school, temple, community hall, day care center, etc.) can be constructed on the mound mainly by local governments with appropriate access road and proper drainage network.

4) People shall be given an incentive to own the land on the mound dike in the future with specific conditions for permanent resettlement from their original place.

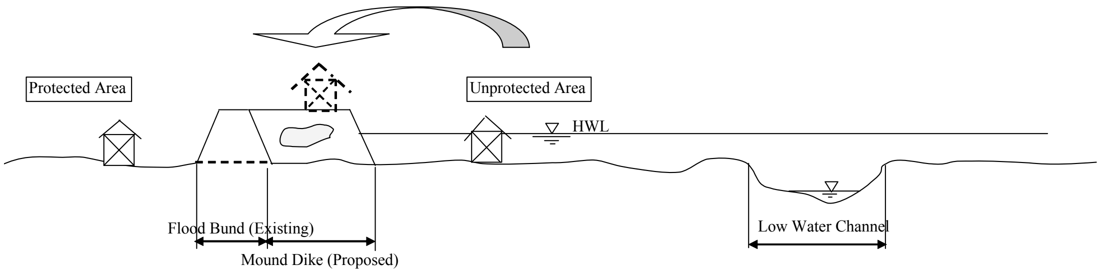


Figure A.4.6 Schematic Feature of Mound Dike

The final location and appropriate size of the mound dike shall be further examined through stakeholder meetings and/or consultations by the executing agencies during the detailed design and implementation stage in the future.

Supporting Report B

Hydrological and Hydraulic Model Studies

Supporting Report B Hydrological and Hydraulic Model Studies

B.1 Description of River Basins

B.1.1 Kelani River Basin

Kelani River is the second largest river in Sri Lanka with a basin area of 2,229 km^2 and an average annual runoff of 5,500 million cubic meters. A plan view of Kelani River and its basin is shown in Figure B.1.1. The river originates in the central hills from the confluence of two smaller streams, Kehelgamu Oya and Maskeliya Oya about 95 km from the sea and flows entirely through the wet zone to fall into sea at northern boundary of City of Colombo. The two originating streams are dammed further upstream forming Castlereigh and Maussakele reservoirs utilized for hydro power generation.

The two major tributaries of Kelani River are Gurugoda Oya connected approximately 25 km downstream of the origin and Sitawaka Ganga with its confluence further 14 km downstream. The Glencourse river gauging station is located 1.5 km downstream from the confluence with Sitakwaka Ganga. The river basin upstream of Glencourse, is characterized by steep river valleys, with a steeply sloping main river and its tributaries flowing through rocky and irregular bed. The river bed slope flattens slightly beyond Glencourse up to Pugoda but the river valley walls remain steep. Downstream of Pugoda, the river bed slope flattens considerably and river valleys open out revealing wide flood plains. The river in this are is also intersected by several small streams with flat wide valleys.

The floods in Kelani River originate in the mountainous upper reaches of the basin which constitutes about two third of the river basin. Upstream of Glencourse the major floods are in general contained within the river banks with minimal inundation. However, downstream of Glencourse, in particular Pugoda, even medium scale floods overtop the river banks inundating the adjacent low lying land. As a consequence the flood volume in the river decreases, flood peak attenuates and travel time of the flood wave propagation slows down considerably.

The low lying land adjacent to the river downstream of Pugoda is predominately used for paddy cultivation. Therefore, in order control inundation of these land during minor floods, in 1930's several Minor Flood Protection (MFP) schemes were constructed. These MFP's comprise low bunds constructed across the valleys of an intersecting stream just upstream of the intersection with the Kelani River. Automatic flap gates or manually controlled screw gates are built into these flood bunds and they remain closed during passage of minor floods preventing backflow of river water along the streams. These flood bunds afford protection against minor floods of 3-5 year return period. However, at higher return periods these flood bunds are overtopped and in order to prevent structural damage most of their MFP's are provided with bypass spillways set below the crest level.

The city of Colombo and its suburbs adjacent to the north and south banks of the river are protected by flood bunds acting as major flood protection schemes. The north bund protecting area north of Colombo lies at a level 4.5 to 6.4 m above mean sea level (MSL) and extends from Victoria Bridge 7.6 km upstream to Talwatte. This bund lies adjacent to the river bank. The City of Colombo itself is protected by the south bund or the Railway Embankment extending from just downstream of Victoria Bridge and joining with the high grounds at Kolonnawa. This bund has a crest level around 6.3 to 7.3 m MSL and is located at a distance 300 to 1900 m from the river. Gothatuwa Bund with a crest level of 7.4 m MSL carries this level between two low hills over low lying ground east of the oil storage facility at Kolonnawa, extending the area effectively protected by the south bund.

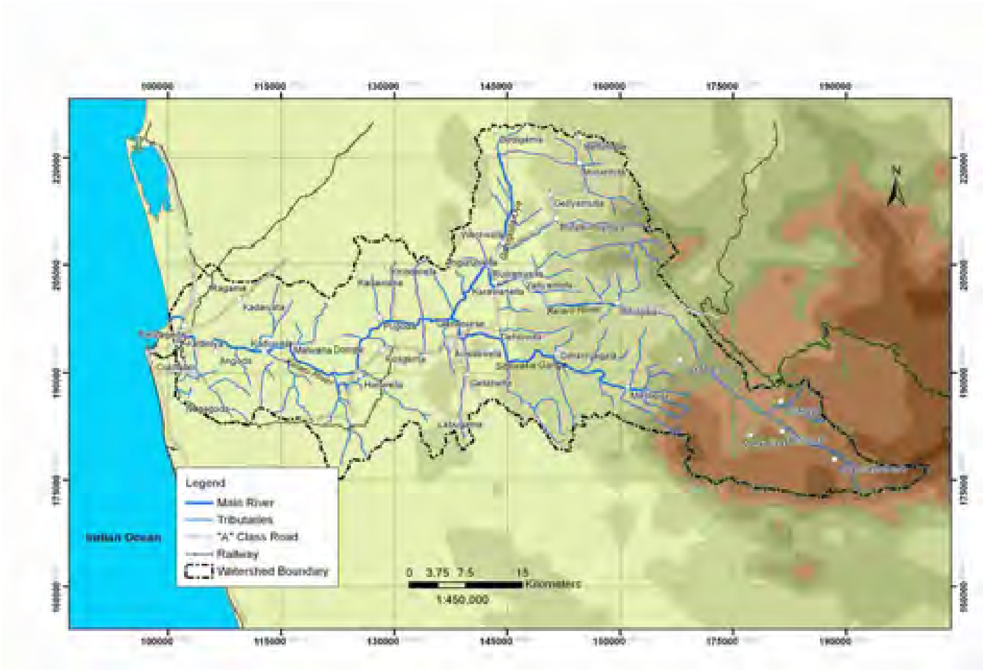
The severity of floods in the low laying areas in lower reaches of Kelani River is considered to be indicated by the gauge post reading of Nagalagam Street at Colombo by the Irrigation Department as given in Table B.1.1.

Table B.1.1 Classification of Floods in Kelani River by Irrigation Department

Flood Classification	Nagalagam Street Gauge Reading	MSL Level (m)
Minor Flood	Greater than 5 ft	1.5
Major Flood	Greater than 7 ft	2.1
Dangerous Flood	Greater than 9 ft	2.7
Critical Flood	Greater than 12 ft	3.6

Source: DOI

The most severe recent flood in Kelani River occurred in June 1989 with Nagalagam Street gauge post recording 9.2 ft, indicating it as a major flood. Since then apart from few flood events which approached minor flood level at Nagalagam Street gauging station, floods of comparable magnitude have not occurred. The 1989 flood adversely affected 25,000 families, 13,000 houses, 850 small industries and 120 commercial establishments. The extent of inundated agricultural land was about 50,000 acres. However, the increased human settlement in the flood plain between the river bank and south bund and industrial and agricultural developments in areas further upstream has created present conditions conducive for much severe flood damage in the case of a major flood.



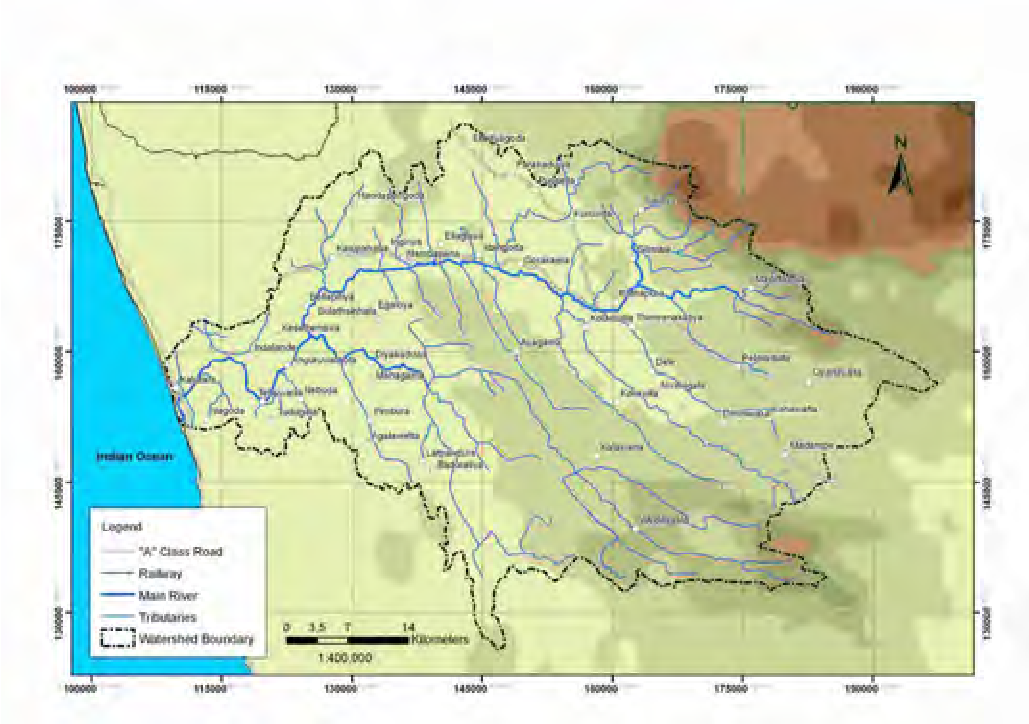
Source:JICA Study Team

Figure B.1.1 Location Map of Kelani River Basin

B.1.2 Kalu River Basin

Kalu River with a catchment area of 2,719 km^2 originates in the Adam's Peak Range on the south western side, at an altitude of about 2250m above MSL. (Figure B.1.2) A cluster of mountain streams form the Kalu River and then cascades down to Ratnapura. The Way Ganga with a catchment area of 230 km^2 also joins the Kalu River just upstream of Ratnapura. The river gradient above Ratnapura is extremely steep, while gradient below the town is remarkably flat. The river section is also restricted just below the town, especially at Ellagawa. Its course towards the western coast, the Kalu River is fed by many tributaries including Kuru Ganga and Kuda Ganga.

High rainfall in the upper reaches of steep gradient, the flat river gradient below Ratnapura and constriction of river section below the town causes regular flooding in Ratnapura. Generally, when flood starts to recede at Ratnapura, river overtops at many places in downstream due to the prevailing mild slope and low ground elevation, causing heavy inundation in a vast area. The average annual runoff to sea is around 7,000 million m^3 which is the highest among all rivers in Sri Lanka.



Source:JICA Study Team

Figure B.1.2 Location Map of Kalu River Basin

B.1.3 Gin River Basin

Gin River originates from the mountainous region in southern side of Sinharaja forest and runs through Tawalama, Neluwa and Agaliya and falls into sea at Gintota, Galle (Figure B.1.3) .The basin area of the river is 932 km^2. with an average annual runoff of 2,000 million m^3. The catchment that covers with a variety of types of vegetation has an estimated average annual rainfall of around 3,500 mm. The river provides irrigation water mainly for paddy cultivation and also for tea, rubber, subsidiary crops and vegetable plantations.

As flooding was a major hazard in lower reaches of the river, a flood protection scheme which included a levee system and some pumping stations was implemented in 1970s. In addition, the bypass canal Kepu Ela connected to main stream at Holuagoda also discharges water flow into sea at Galle. However, with the construction of levee system, most downstream area is protected; the area upstream of Agaliya experiences more flooding than earlier.

Source:JICA Study Team

Figure B.1.3 Location Map of Gin River Basin

B.1.4 Nilwala River Basin

Nilwala River that comprises a basin area of 971 km^2 originates from the mountainous region in Deniyaya and Rakwana, and runs through Deniyaya town, Morawaka, Akuressa and falls into sea at Thotamuna, Matara (Figure B.1.4). The river provides irrigation water mainly for tea, rubber and paddy cultivation and subsidiary crops such as cardamom, cinnamon and vegetable plantations. Nilwala River is characterized by excessive flows during wet season which causes flooding, but considerably drying out during dry season. The river flow is not sufficient during the dry season to meet the irrigation requirement.

Nilawala River is the main source of domestic and industrial water supply for the population that lives around Matara town. There are 3 water supply intakes in operation, namely at Nadugala, Kaddduwa and Balakawila situated 8.4 km, 16.1 km and 17.2 km upstream of the sea outfall. Increased salinity intrusion at these intake locations had made it impossible to satisfy increasing demand for drinking water during the dry season. As a result a salinity barrier was designed and is to be implemented at Nadugala through studies done in the year 2000.

North of Matara city and its suburbs often get flooded during the rainy season. To arrest this problem a flood protection scheme was initiated by the Ministry of Irrigation in 1979 with the assistance from the Government of France. This flood protection scheme included a levee system and some pumping stations. As a result of implementation of this scheme, the areas which got flooded earlier could be brought under paddy cultivation.

The Nilwala Flood Warning System was the first and only fully equipped centre in Sri Lanka country established for real time flood monitoring and warning purposes in 1980s. It was based on a computer model simulated real time flood scenario based on transmitted signals from automatic rain gauges. When forecasted probable water level went over the critical level a flood warning was issued. However, this system was severely affected due to the damage caused to transmitting equipment in late 1980s.

Source:JICA Study Team

Figure B.1.4 Location Map of Gin River Basin

B.2 Data Collection and Analysis

B.2.1 Topographical Data

The topographic maps produced by Survey Department at 1:50,000 scale covering the four river basins were collected. These maps were used to demarcate the four river basins and boundaries of sub catchments into which river basins were divided for hydrological modeling, following the land contour pattern.

In the case of Kelani River basin, available 1:10,000 topographical maps from Survey Department were also collected mainly for the purpose of identifying the extent of agricultural areas protected by Minor Flood Protection (MFP) schemes downstream of Pugoda. The extent of inundation areas due to overtopping of these MFPs and the areas protected by them were computed following the land contour pattern in these maps.

B.2.2 River Cross Sections

River cross sectional data were collected from the Hydrology Division of Irrigation Department (DOI), Regional Deputy Director of Irrigation's (RDI), Galle office and Lanka Hydraulic Institute (LHI). A brief description of data collected is presented in Table B.2.1.

Table B.2.1 Available River Cross Sections

River	Data source	Year	Coverage of cross sections (distance in km)	Number of cross sections
Kelani	DOI	2005	Kelani River (Glencorse to Colombo - 52.1 km)	10
	LHI	2003	Kelani River (Kitulgala to Colombo-90.6 km)	65
			Sitawaka Ganga (Algoda Bridge to Kelani River Confluence - 10.3 km)	3
			Gurugoda Oya (Imbulana to Kelani River Confluence - 1.9 km)	2
	LHI	1990	Kelani River (Kitulgala to Colombo – 90.6 km)	64
			Sitawaka Ganga (Algoda Bridge to Kelani River Confluence - 10.3 km)	3
			Gurugoda Oya (Imbulana to Kelani River Confluence - 1.9 km)	2
Kalu	DOI	2004	Kalu Rievr (Ratnapura to Kalutara – 76.0 km)	22
			Kuda Ganga (Millakanda to Kalu River Confluence – 10.0 km)	3
Gin	LHI	2003	Gin River (Tawalama to Gintota – 58.4 km)	40
		1999	Kepuwela (Holuagoda to Galle – 5.3 km)	4
		1999	Terun Ela (Polgahawila, 2.3 km)	3
Nilwala	DOI/RDI, Galle	2003	Nilwala River (Bopagoda to Matara - 36.3 km)	10
	LHI	1999	Nilwala River (Pitabeddara to Matara - 40.1 km)	16

Source: DOI

B.2.3 Flood Protection Schemes and Flood Prone Areas

In the case of Kelani River, the extent (locations and lengths) of major flood protection bunds were scaled out from 1:50,000 topographical maps. The flood bund levels were obtained from Kelani Ganga Flood Protection Study Report by DHI/LHI.

The details of MFP's were collected from RDI-Colombo office. The areas protected by MFP's (flood cells) with their storage capacities were obtained by following the contour pattern in 1:10,000 topographical maps. The basic details of MFPs compiled are given in Table B.2.2.

Table B.2.2 Existing Flood Management Structures in Kelani River Basin
(Minor Flood Protection Schemes)

No.	Name of Minor Flood Protection Schemes	Right or Left	No. and size	Type of Gates	Bund Top Level (EL.ft)	Protection Level (EL.ft)	Protected Area (ha)
1	Senasumgoda	R	7 nos. 4' 0" x 4' 6" (W)	Flap Gate	-	-	141.8
2	Pugoda	R	4 nos. FG 4' x 4' 6" (W) 4 nos. Lifting gates	Flap Gate Lifting gate	44.0	42.0	108.5
3	Nikawela	R	6 nos. 6' 0" x 4' 0" (W)	Flap Gate	38.0	33.0	91.1
4	Kapugoda	R	5 nos. 4' 0" x 6' 0" (W)	Flap Gate	36.5	34.0	137.7
5	Modarakada	R	2 nos. 4' 6" x 5' 0" (W)	Flap Gate	-	-	96.0
6	Yattowita	R	2 nos. 4' 9" x 5' 0" (W)	Flap Gate	-	-	87.1
7	Kadatiyawatta	R	2 no. 4' 6" x 5' 0" (W)	Flap Gate	-	30.0	93.6
8	Mora Ela	R	2 nos. 4' 6" x 6' 0" (W)	Flap Gate	-	26.5	88.3
9	Gontota Ela	R	1 no. 3' 0" dia.	Flap Gate	-	-	30.4
10	Modarakadawatta	R	2 nos. 2' 6" dia.	Flap Gate	-	-	70.9
11	Wellawata	R	2 nos. 1' 6" dia.	Flap Gate	-	-	64.8
12	Malwana Pahuruoya	R	6 nos. 4' 0" x 5' 0" (W)	Flap Gate	23.5	21.5	643.5
13	Yabaraluwa	R	3 nos. 3' 0" dia.	Flap Gate	22.0	20.0	80.2
14	Kukulawala	R	3 nos.	Lifting gate	-	-	75.3
15	Rakgahawatta	R	6 nos. opening 4' 6" x 5' 6" (W)	Flap Gate	-	-	22.1
16	Pattiwila	R	4 nos. 1' 6" dia.	Flap Gate	19.0	17.0	111.4
17	Bollegala Pelawatta	R	1 no. 3' 0" x 3' 0" (W)	Flap Gate	-	-	8.5
18	Seethawaka	R	1 no. 4' 6" x 4' 6" (W)	Flap Gate	-	-	68.9
19	Koskumbura	R	1 no. 3' 0" x 3' 0" (W)	Flap Gate	-	-	9.3
20	Nagahawattha	R	3 nos. 3' 0" dia.	Flap Gate	-	-	121.5
Total							**2,150.8**
1	Ranwela Muttetupola	L	1 no.	Lifting gate	26.0	24.0	14.2
2	Madapana	L	1 no.	Lifting gate	26.0	24.0	12.2
3	Wanahagoda	L	1 no.	Lifting gate	30.0	30.0	60.8
4	Dasawella	L	Bund only	Lifting gate	38.0	36.0	81.0
5	Koratota	L	5 nos. 5.5' x 5'	Lifting gate	17.5	15.0	126.0
6	Akkarawita	L	6 nos. 5' x 4'	Lifting gate	32.0	30.0	135.6
7	Kahatapitiya II	L	1 no. 2' 0" dia.	Flap Gate	34.0	32.5	-
8	Kahatapitiya I	L	3 nos. 3' 0" dia.	Flap Gate	34.0	32.5	16.2
9	Brandigampala II	L	4 nos. 4' 0" dia.	Flap Gate	38.0	35.0	-
10	Brandigampala I	L	2 nos. 4' 0" dia.	Flap Gate	38.0	33.5	121.5
11	Palawatta Wela	L	1 no. 4' 0" dia.	Flap Gate	32.0	30.0	12.96
12	Meegoda	L	1 no. 2' 0" dia.	Lifting gate	25.0	22.0	14.6
13	Henpita	L	8 nos. 5' x 4'	Lifting gate	28.0	25.0	50.2
14	Ranala	L	3 nos. 3' 0" dia.	Flap Gate	26.0	24.0	50.6
15	Undugoda	L	Bund only		-	-	-
16	Rada Ela	L	1 no. 12" dia.	Flap Gate	21.5	18.5	20.3
17	Bomiriya	L	8 nos. 5' x 4'	Lifting gate	20.5	18.5	1,214
18	Hewagama	L	2 nos. 5' x 4'	Lifting gate	20.0	18.5	81.0
19	Weliwita	L	2 nos. 5' x 5'	Lifting gate	19.5	17.5	232.3
20	Ambatale	L	4 nos. 5' x 4'	Lifting gate	19.0	17.0	-
21	Nirmawila	L	1 nos. 2' 0" dia.	Flap Gate	-	-	20.3
22	Kelanimulla	L	2 nos. 6' x 5.5'	Lifting gate	-	-	20.3
23	Sedawatta	L	10 nos. 5' x 4'	Lifting gate	-	7.0	20.3
24	Grand Pass	L	2 nos. 6' x 5'	Lifting gate		5.0	
Total							**2,304.1**

Source: DOI

B.2.4 Hydrological Data

(1) Rainfall

The daily rainfall data were collected from Meteorological Department in digital form for all 4 river basins. The time period 1950-2006 was selected for collection of rainfall. However, there were several stations for which rainfall data for this full duration was not available. The availability of rainfall data for the four river basins is indicated in Table B.2.3. The locations of rainfall stations are indicated in Figures under River Basin Models.

Table B.2.3 Duration of Daily Rainfall Record Collected

ver	Name	Elevation (m msl)	Period of record
Kelani	Angoda	15.2	1950-2006
	Avissawella	30.5	1950-2006
	Bogawantalawa (Campion)	-	1950-1998
	Canyon	-	1983-2006
	Castlereigh	-	1983-2006
	Chesterford	198.2	1950-2006
	Colombo	7.3	1950-2006
	Deraniyagala (Dabar)	228.7	1950-1973 & 1975 -1988
	Dehiowita (Digalla)	122.0	1950-2006
	Dehiowita (Dunedin)	122.0	1950-2006
	Dompe	22.9	1950-1999
	Elston	-	1984-2006
	Kitulgala (Ingoya)	304.9	1950-1988 & 1990
	Labugama	-	1950-2006
	Maliboda	274.4	1950-2006
	Maussakelle	-	1983-1988 & 1999-2006
	Meepe	-	1950-1966 & 1971-2006
	Norton	-	1984-1998 & 2002-2006
	Ragama	-	1950-1974,1986-1996, 1998-2000 & 2003-2004
	Watawala	-	1950-1998 & 2002-2006
	Welisara-Navy	-	1999-2006
	Undugoda (Yataderiya)	-	1950-1988, 1992-1993 & 2002-2006
Kalu	Alupolla	762.5	1950-2006
	Balangoda	527.4	1950-2006
	Clyde Estate	24.4	1952-1999
	Depdeen Group	-	1950-2006
	Frocester Estate	15.2	1952-2006
	Galatura Estate	-	1950-2006
	Gikiyanakanda	106.7	1950-2006
	Gonapenigala Estate	408.5	1950-1973 & 1975-2005
	Halwatura	137.2	1950-2006
	Hapugastenna Group	594.5	1950-2006
	Horana	30.5	1950-1995 & 1997-2006
	Kalutara	3.0	1950-1982, 1984-2004 & 2006
	Kuruwita	243.9	1950-2006
	Kumbaduwa	121.9	1950-1974 &1979-1980
	Lellopitiya Estate	-	1954-2006
	Ratnapura	34.4	1950-2006
	Rayigama	-	1950-2006
	Wadduwa	-	1952-1981,1983,1985,1990-1991
	Wellandara	-	1989-2006
Gin	Deniyaya (Anningkanda)	533.5	1950-2006
	Galle	12.5	1950-2006
	Baddegama Estate	15.2	1950-2006
	Hiniduma	-	1994-2006
	Korelegama	350.0	2001-2006

ver	Name	Elevation (m msl)	Period of record
Gin	Labuduwa	-	1950-2006
	Monrovia Group	-	1954-2006
	Panilkanda Estate	-	1950-1992
	Tawalama	-	1954-1993 &1995
Nilwala	Deniyaya (Anningkanda)	533.5	1950-2006
	Goluwawatta	-	1965-2006
	Kamburupitiya	243.9	1951-1965,1967-1968 & 1971-2003
	Kekenadura	48.8	1950-2006
	Kirama	122.0	1951-1972 &1974-2006
	Mawarella	-	1950-1994 & 1999-2006
	Telijjawila Group	-	1980-1985 & 1989-2005
	Thihagoda	-	1950-2002

Source: Meteorological Department

(2) Evaporation

The evaporation data are of less importance compared to rainfall data. Therefore, representative evaporation values for the river basins were inferred from evaporation data for selected stations at Colombo, Ratnapura, Nuwara Eliya and Sevanagala.

B.2.5 Hydrometric Data

(1) Discharge Recordings

The daily discharge records at water level gauging stations along the four rivers were obtained from Irrigation Department and encoded. The duration of discharge records collected are given in Table B.2.4.

Table B.2.4 Duration of Daily Discharge Record Collected

River	Gauging station	Available period from	Duration of record
Kelani	Kitulgala	1948	1985-2006
	Deraniyagala	1948	1985-2006
	Holombuwa	1962	1985-2006
	Glencorse	1977	1985-2006
	Hanwella	1977	1985-2006
Kalu	Millakanda	1990	1990-2005
	Putupaula	-	1969-2004
	Ratnapura	1975-1995	1985-1995
	Dela	1955	1985-2004
	Ellagawa	1956	1969-2005
	Kukule Gama	1973-2003	1985-2003
Gin	Agaliya	1992	1985-2004
	Tawalama	1973	1985-2005
Nilwala	Pitabeddara	1973	1985-2004
	Bopagoda	1939-2000	1985-2000

Source: DOI

(2) Water level records

In the calibration of hydrodynamic model for flood events, it is necessary to have observed water levels at higher temporal resolution. In this respect, hourly water level records obtained by Irrigation Department at selected gauging stations were encoded for identified flood events covered by discharge records. The duration of record encoded are given in Table B.2.5.

Table B.2.5 Duration of Hourly Rainfall Record Collected

River	Gauging Station	Flood Events Selected
Kelani	Kitulgala	May/June 1989, May 1990, Nov 2004
	Deraniyagala	May/June 1989, May 1990, Nov 2004
	Holombuwa	May/June 1989, May 1990, Nov 2004
	Glencorse	May/June 1989, May 1990, Nov 2004
	Hanwella	May/June 1989, May 1990, Nov 2004
Kalu	Millakanda	Oct 2001, May 2003, Sep 2004
	Putupaula	Oct 2001, May 2003, Sep 2004
	Ratnapura	Oct 2001, May 2003, Sep 2004
	Dela	Oct 2001, May 2003, Sep 2004
	Ellagawa	Oct 2001, May 2003, Sep 2004
	Kukule Gama	Oct 2001, May 2003
Gin	Tawalama	Oct 2000, Apr 2002, May 2003
	Agaliya	Oct 2000, Apr 2002, May 2003
Nilwala	Pitabeddara	Jan 2001, June 2002, May 2003
	Bopagoda	Jan 2001, June 2002, May 2003

Source: DOI

In addition, as for Kelani River basin, hourly water levels at manual recording gauge posts installed between Hanwella and Colombo were also obtained for the periods of significant floods as tabulated in Table B.2.6:

Table B.2.6 Duration of Hourly Water Levels at Manual Gauging Posts at Downstream of Hanwella in Kelani River

Gauge post location	Flood events selected
Artigala	Nov 2004, Nov 2005, Oct 2006
Ranala	May/June 1989, May 1990
Nawagamuwa	Nov 2004
Ihalabomiriya	May/June 1989, May 1990
Kaduwela	Nov 2004
Ambatale	May/June 1989, May 1990, Nov 2004
Kelanimulla	Nov 2004. June 2006
Wennawatte	Nov 2004
Kotuwila	May/June 1989, May 1990
Nagalagam Street	May/June 1989, May 1990, Nov 2004
Modara	May/June 1989, May 1990

Source: DOI

B.3 Study Methodology

In this study MIKE 11 mathematical modeling system developed at Danish Hydraulic Institute (DHI) was used in hydrological and hydrodynamic modeling. A brief overview of MIKE 11 model is presented below.

B.3.1 MIKE 11 Modeling System

MIKE 11 is a professional engineering software package for simulating flows, advection-dispersion processes, water quality and sediment transport in inland water bodies, where flow can be considered basically one dimensional, such as in rivers, channels, irrigation systems and estuaries. It is a very useful tool in flood inundation analysis, flood forecasting and design of flood protection measures in river basins. MIKE 11 is developed as a software tool with advanced user interfaces for fully integrated graphical and tabular editing faculties for data input. The output of the model computation can be obtained in tabular or graphical form while animated presentations of model simulations are also possible.

MIKE 11's hydrodynamic module (MIKE 11 HD) is the nucleus of its module structure with facility for selecting add-on modules for hydrology, advection-dispersion processes, water quality and sediment transport based on the particular application. In this study the hydrological module NAM for simulating rainfall-runoff process in river catchments was linked MIKE 11 HD for modeling of river basins. A brief description of these two modules is given below.

B.3.2 MIKE 11 HD Module

MIKE 11 HD is based on numerical (finite difference) solution of Saint-Venant equations for the conservation continuity and momentum. The numerical solution is obtained in a computational grid of alternating water level (h) and discharge (Q) points automatically generated on the basis of user requirements. The Q-points are placed midway between neighboring h-points and at structures, while h-points are located at cross-sections, or at equidistant intervals in between, if the distance between cross-sections is greater than a maximum user specified distance.

MIKE 11 HD provides the user with the choice of 3 alternative flow descriptions based on dynamic wave, diffusive wave and kinematic wave approximations to momentum equation. The dynamic wave approach based on full momentum equation allows the simulation of fast transients, tidal flows and backwater profiles. The most simplest kinematic wave approach based on balance between gravity force and bed friction may be used in simulating basically unattenuated flood wave propagation in steeply sloping rivers. The diffusive wave approach, where the hydrostatic gradient term is accounted for in addition to gravity and friction forces allows for accounting for backwater effects. Depending on the type of problem, the user can choose the most appropriate flow description. All three approaches simulate branched as well as looped networks.

The river bed roughness in MIKE 11 HD can be based on either Manning's or Chezy's formula. The model permits for variation of roughness coefficient longitudinally along the river network or within the cross section. This permits accounting for higher resistance to flow in flood plains compared to main river channel. External boundary conditions are required at upstream and downstream ends of all model branches which are not connected at junctions. The boundary conditions may be specified in terms of time variation of water level and/or discharge or a relationship between water level and discharge (rating curve). The computational time step and grid spacing should be selected within module's numerical stability criteria based on user requirements of spatial and temporal resolution of numerical computation. The initial water levels and discharges in the river network can be user specified or can be generated by the model through steady state backwater computation. The hydrodynamic module can also account for flow over variety of hydraulic structures including possibilities to describe structure operation.

B.3.3 NAM Module

The rainfall-runoff process within the river catchments was modeled using NAM hydrological module. NAM is a deterministic, lumped, conceptual rainfall-runoff module accounting for water content up to 4 different storages representing surface zone, root zone and ground water storages. It simulates the overland flow, inter flow and base flow components of catchment runoff based on user specified input time series of rainfall and evaporation. This module can be applied either independently to a river catchment or can be used to generate boundary or lateral inflows to a river network by linking with the hydrodynamic module. In this manner it is possible to treat a single river or a large river basin containing numerous catchments and a complex network of rivers and channels within the same modeling framework.

The user is provided with the facility to digitize the catchment boundary within a graphical display (basin view) or import externally digitized data. The model will then automatically generate the catchment on the basin view and computes the catchment area. The spatial variation in rainfall pattern within a river catchment can be accounted for by specifying time series of rainfall from several selected rainfall stations located within or outside the catchment. The weighted average rainfall for the catchment will be calculated based on Theisen Polygons generated by the model. The user will also have the option of changing weightages at rainfall stations based on his professional judgment. Additionally the isohytel map can also be automatically generated and catchment rainfall for a fixed period may be obtained from the isohytel pattern.

As default NAM model is prepared based on 9 parameters accounting for surface zone, root zone and groundwater storages. The automatic calibration of the model for a river catchment is possible through an optimization algorithm which is aimed at obtaining the best possible comparison between the model computed runoff hydrograph and observed stream flow time series at a gauging station.

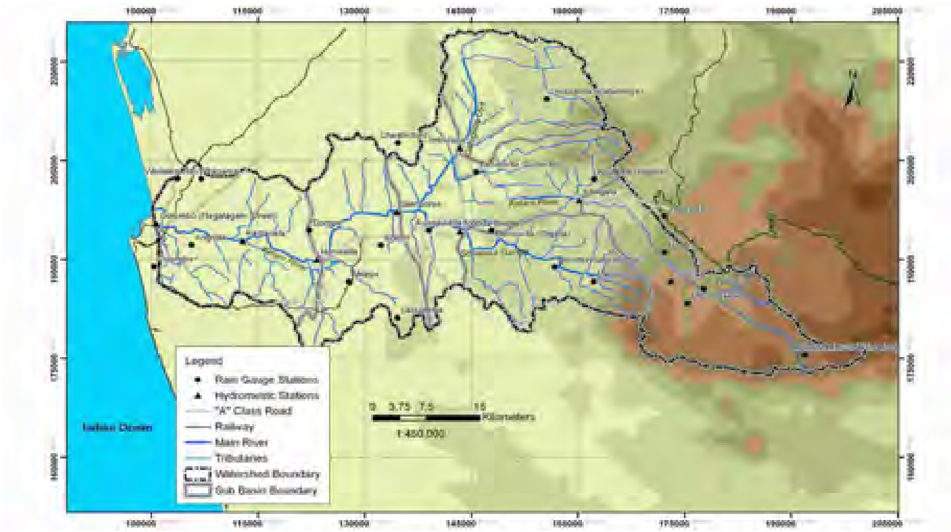
B.4 Kelani River Basin Model

Kelani River Basin Model developed basically contained the river basin together with the Kelani River between Kitulagala and Colombo with its two main tributaries Sitawaka Ganga from Algoda Bridge and Gurugoda Oya from Imbulana .

B.4.1 Hydrological Modelling

(1) Model Set-up

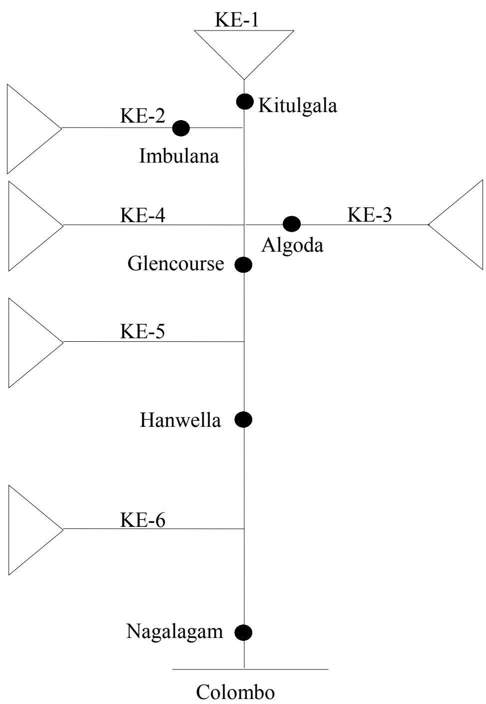
Kelani River basin was divided into 6 sub catchments (Figure B.4.1 (a) & (b)) for the purpose hydrological modeling. The boundaries of sub catchments were digitized from 1:50,000 topographical maps. The upper sub catchments (Kitulgala, Imbulana and Algoda) represented watershed areas draining into model boundaries of the main river and the two tributaries considered. The two gauging stations at Glencorse and Hanwella together with Colombo at downstream end constituted the 3 intermediate sub catchments.



Source:JICA Study Team

Figure B.4.1 (a) Location Map of Sub Catchments in Kelani Basin with Rainfall and Hydrometric Gauging Stations

Having considered the distributed network of all rainfall stations throughout the river basin, the most relevant and spatially well distributed stations for mean aerial rainfall computation in sub catchments were selected. The selection of rainfall stations was based on their presence within or just outside a sub catchment, reliability and availability of a long term rainfall record covering the model simulation period. The details of sub catchments together with rainfall stations considered are given in Table B.4.1.



Source:JICA Study Team

Figure B.4.1 (b) Schematic Diagram of Sub Catchments in Kelani Basin

Table B.4.1 Sub Catchments & Rainfall Stations for Hydrological Modelling of Kelani Basin

Sub Catchment	Type	Area (km^2)	Rainfall Stations
1. Kitulgala	Upper Kelani	425.8	Kitulgala (Ingoya), Maliboda, Watawala, Norton, Maussakelle, Castlereigh, Canyon, Campion
2. Imbulana	Upper Gurugoda Oya	325.5	Undugoda (Yataderiya), Chesterford, Dehiowita (Dunedin), Kitulgala (Ingoya)
3. Algoda	Upper Sitawaka Oya	314.4	Dehiowita (Digalla), Maliboda, Avissawella, Kitulgala (Ingoya)
4. Glencourse	Intermediate Kelani (Kitulgala to Glencorse)	456.3	Labugama, Chesterford, Avissawella, Dehiowita (Dunedin), Dehiowita (Digalla), Undugoda (Yataderiya), Kitulgala (Ingoya),
5. Hanwella	Intermediate Kelani (Glencorse to Hanwella)	369.4	Dompe, Meepe, Labugama, Elston, Avissawella, Chesterford
6. Colombo	Intermediate Kelani (Hanwella to Colombo)	422.3	Colombo, Ragama, Angoda, Dompe, Meepe

Having established the sub catchment boundaries and rainfall stations on the Basin View of the NAM Model, the Thiessen Polygons for the sub catchments were created. The model then automatically computed the Thiessen weights for mean aerial rainfall calculation. In order to account for missing rainfall records, suitably selected combinations of missing records from selected rainfall stations were specified. The Theissen weights for these combinations were also computed through the Basin View upon generating the Theissen Polygons. Based on established Theissen weight combinations mean aerial rainfall time series for each sub catchment was generated. In the case of Evaporation data a time series based representative monthly evaporation data was used as input to the NAM model.

NAM model calibration at the most upstream gauging station was made against the observed discharge for a selected period which consists of several flood events. For other sub catchements, calibration was done along with model running of hydrodynamic model linked with runoff model.

(2) Calibration and Verification

The 5-year time period from 1988-1992 was selected for model simulations. This choice was made as this time period contained the most severe recent flood occurred in Kelani River in June 1989. The selection of a long period for NAM simulations enabled model results to be compared with observed stream flow records for flood events of different magnitude. This also enabled the hydrodynamic model to be subsequently run for simulation of selected flood events with the same mean aerial rainfall time series generated.

The NAM model in its stand-alone mode could be calibrated only for the Kitulgala upper sub catchment as stream flow records were not available at Algoda Bridge or Imbulana. The calibration of the model was based on adjustment of 9 model parameters for Kitulgala subcatchment to obtain the best possible comparison between simulated runoff and obvserved streamflow at Kitulgala for the 1989 June flood event.

However, Kitulgala is a mountainous catchment which rapidly responds to heavy rain resulting in “flash floods”. With rainfall data available on a daily basis it is not possible to reproduce the flood peaks without knowing the distribution of rain in time. The stream flow at Glencourse is contributed by the runoff from the 3 upper catchments at Kitulgala, Algoda and Imbulana and Glencourse intermediate catchemnt as lateral inflow. A simple calculation based on comparison of total rainfall volume from these catchments and stream flow volume at Glencourse showed that stream flow volume exceeds the rainfall volume for 1989 flood event. The possibility of this happening due to errors in extrapolating high flows from rating curve at Glencourse could be eliminated as subsequent hydrodynamic simulations showed good comparison between computed water levels as well when computed discharge at Glencourse was matched with observed stream flow. This indicates that rainfall stations are not reliable during this high flood event.

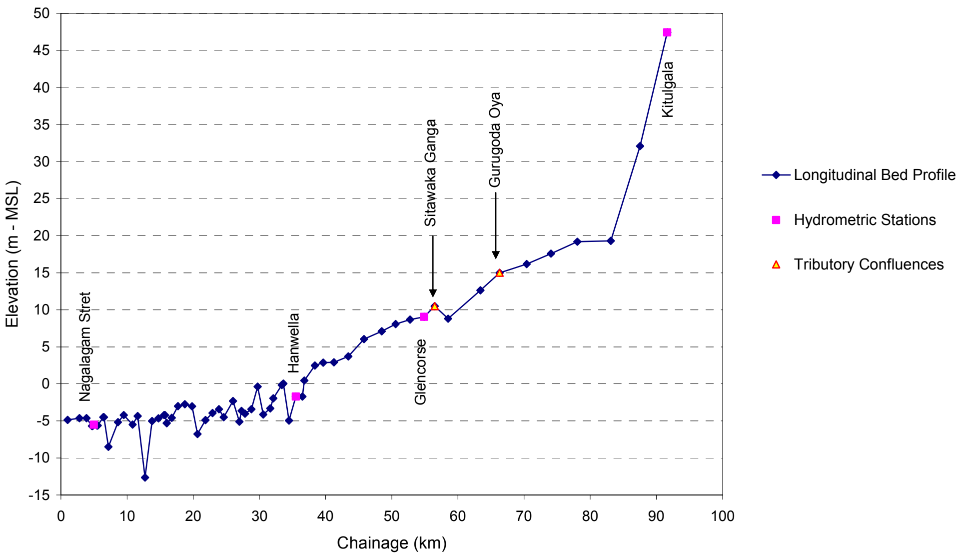
Due to these reasons, for calibration of the model, adjustment of the rainfall by a factor was required to match the stream flow at Glencourse through coupled NAM and hydrodynamic model simulations. Having established a good comparison for both computed discharge and water level at Glencourse this way hydrodynamic modeling is being proceeded to simulate overbank flooding downstream of Glencourse. In the Kelani River Flood Protection Study conducted by DHI/LHI in early 1990's the river stretch down stream of Glencourse has been calibrated using observed data at Glencourse at boundary input.

B.4.2 Hydrodynamic Modelling

(1) Model Set-up

1) River Network and Cross Sections

The hydrodynamic model of Kelani River was set up covering Kelani River between Kitulgala and Colombo linked with two main tributaries Sitawaka Ganga downstream of Algoda Bridge and Gurugoda Oya downstream of Imbulana. The river cross sections available from LHI 2003 survey data was used in setting up the model. The raw data is available in the form of (x, z) coordinates, x being the horizontal distance across the cross section and z the elevation above a selected datum (MSL). The bed resistance at river cross sections was specified in terms of Manning's roughness coefficients. The model processed these data and computed the hydraulic parameters such as cross sectional area, width, hydraulic radius, conveyance at different water levels as "processed data". The longitudinal profile of the river was also automatically generated. Figure B.4.2 shows the longitudinal profile of the main Kelani River.



Source: Hydrology Division of DOI and LHI

Figure B.4.2 Longitudinal Profile of Kelani River

2) Flood Plain Schematization

Three different schematizations were used to represent flood plains.

<u>Flood Plains</u>

Flood Plains are wide flat areas lying on both sides of the main river channel to which water will enter at high river storages. These areas were included through an extension of the cross section beyond the river banks. A typical representation of this flood plain schematization in the model was the inclusion of flood plain between Colombo South Bund and Kelani River left bank.

<u>Flood Cells</u>

Whenever a levee bank or other obstruction prevents exchange of water between the river and the flood plain this type of schematization was used. In this case, water level in the main channel will be different from that in the flood plain. Within one dimensional flow description of MIKE 11 these flood cells were included by linking them across a connecting stream to appropriate location in the river across a weir. This type of description was typically used in representing MFPs downstream of Pugoda. The connecting weir in this case corresponded to an overflow spillway which is general built into or adjacent to the flood protection structure. The functioning of flap gates which permits passage of water from the flood cells to the main river when river stage is low was represented in the model by defining a low level weir across the connecting stream which permits only one-way flow. The storage capacity of the flood cells at different elevations were computed from contour pattern and spot levels in 1:10,000 maps.

<u>Additional Flooded Areas</u>

These represent off stream storage areas directly connected to river but which do not contribute to the main river flow. These storage areas were introduced by adding flooded areas directly to the processed data of the appropriate cross sections.

3) Boundary Conditions

The boundary conditions are required at all external boundaries of the model. The boundary conditions used for Kelani River and the two main tributaries are given in Table B.4.2. Additionally boundary conditions are required for all streams connecting flood cells to the main river. In this case a nominal discharge of negligible magnitude was introduced to satisfy model requirements.

Table B.4.2 Hydrodynamic Model Boundary Conditions – Kelani River and Main Tributaries

River	Model Boundary	Type of Boundary Condition	Data Source
Kelani River	Kitulgala	Discharge	NAM model simulated runoff for Kitulgala sub catchment
	Colombo (sea)	Water Level	0.0 MSL
Sitawaka Ganga	Algoda Bridge	Discharge	NAM model simulated runoff for Algoda sub catchment
Gurugoda Oya	Imbulana	Discharge	NAM model simulated runoff for Imbulana sub catchment

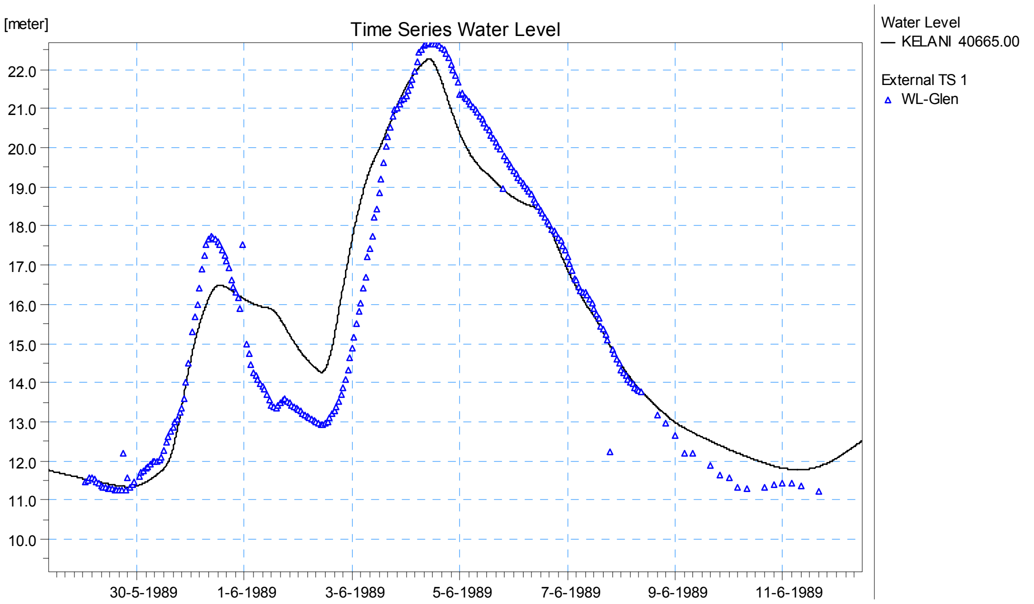
Source:JICA Study Team

4) Lateral Inflows

The NAM simulated runoff for the 3 intermediate sub catchments were linked as uniformly distributed lateral inflows between upstream and downstream stations of the catchments as defined in Table B.4.1.

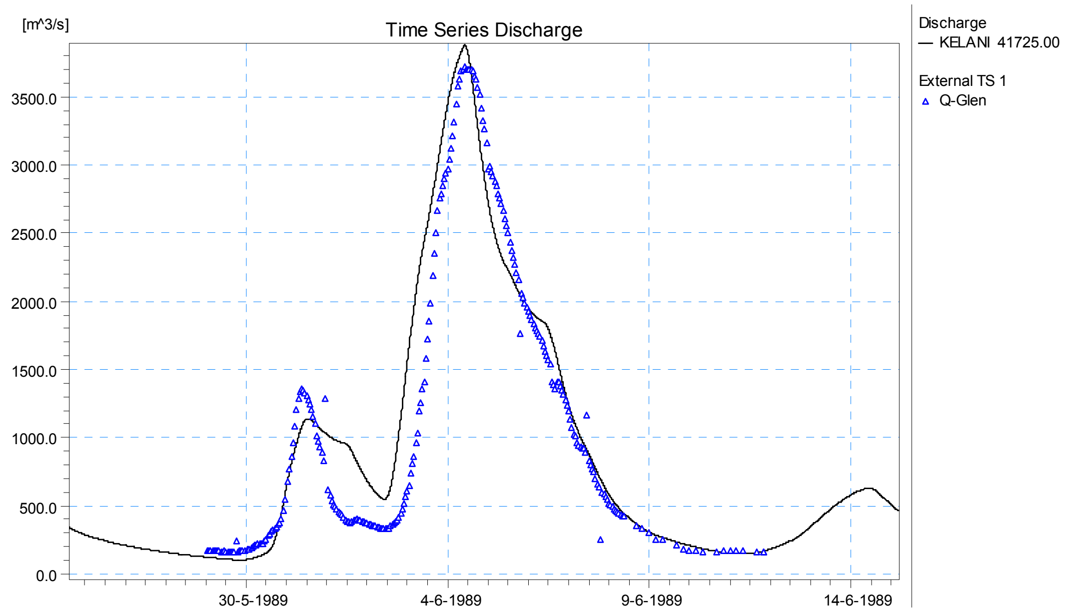
(2) Calibration and Verification

The model calibration in the first phase was based on matching the computed water level and discharge time series at Glencourse with observed data. Figures show the comparison of discharge and water levels at Glencourse for 1989 May-June flood event. It is seen that there are two flood peaks within this flood event and both peaks are reasonably matched in respect of both discharge and water level.



Source:JICA Study Team

Figure B.4.3 Simulated and Recorded Water Levels at Glencourse



Source:JICA Study Team

Figure B.4.4 Simulated and Recorded Discharge at Glencourse

(3) Model Results

As mentioned above, the model application for assessment of flood inundation downstream of Glencourse was carried out by setting up the hydrodynamic model downstream of Glencourse. The inflow boundary input for hydrodynamic modeling was obtained from recorded hourly stream flow data at Glencourse gauging station for the flood events considered. Figure B.4.5 (a), (b) & (c) show the comparison between computed and observed water levels at Glencourse, Hanwella and Nagalagam Street for the 1989 May/June flood event which is the most severe flood occurred in Kelani River during last 60 years. It is seen that very good comparison with respect to magnitude and time of occurrence of peak water level at Hanwella is obtained. Although some discrepancy is seen at Nagalagam Street, Colombo gauging station location, the simulated peak water level is within reasonable limits of observed peak water level.

Table B.4.3 compares the simulated peak water levels at several gauging posts between Hanwella and Glencourse as well as the peak water levels observed at these two stations. It is seen that reasonable comparison is obtained and therefore, model is predicting flood inundation conditions with acceptable level of accuracy, taking into consideration various complexities caused by over bank flooding within one dimensional framework of the model. It should be noted that all MFP's downstream of Pugoda were overtopped during 1989 flood and model results are predicting this situation.

Table B.4.3 Simulated and Recorded Water Levels – 1989 Flood Event

Station Name	Simulated Peak WL (m-MSL)	Recorded Peak Water Level (m-MSL)
Glencourse	23.12	22.68
Hanwella	11.76	11.55
Artigala	10.62	10.61

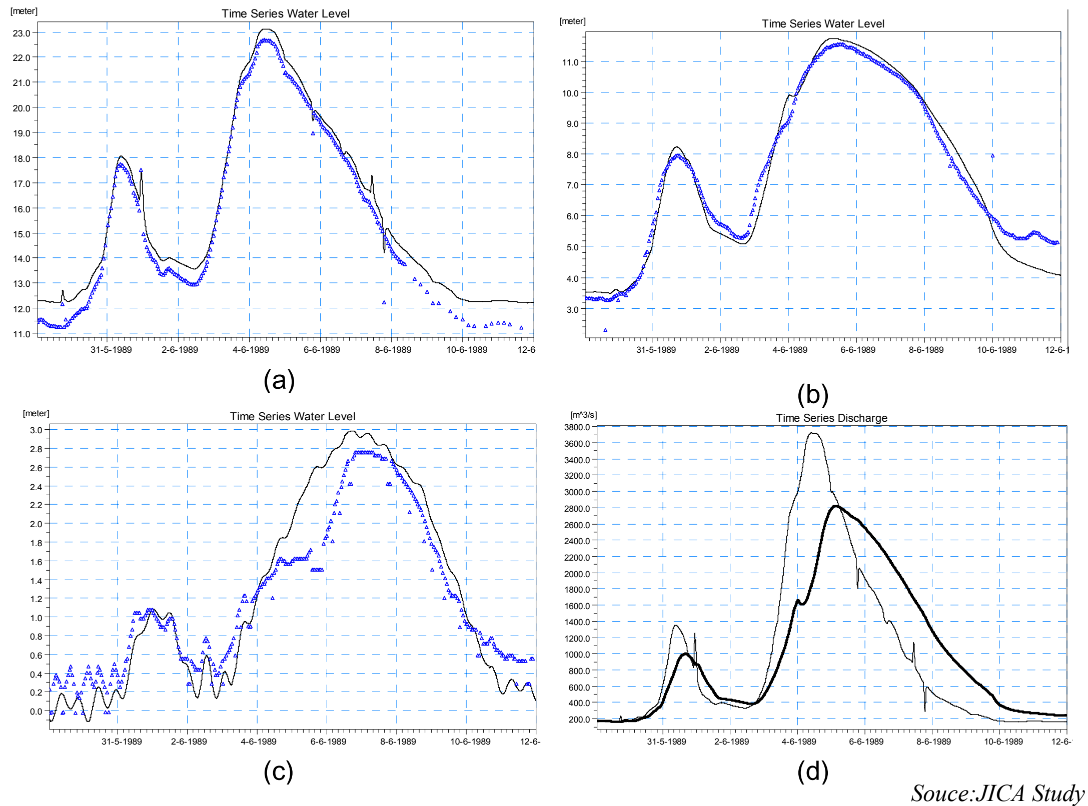
Station Name	Simulated Peak WL (m-MSL)	Recorded Peak Water Level (m-MSL)
Ranala	9.90	8.98
Nawagamuwa	9.46	8.87
Ihala Bomiriya	8.64	8.63
Kaduwella	7.88	7.82
Ambatale	6.70	7.39
Kelanimulla	5.58	5.45
Wennawatte	4.73	5.04
Kotuwila	3.94	3.56
Naglagam Street	2.98	2.65

Source: DOI

In Figure B.4.5 (d), the attenuation of flood discharge from Glencourse to Hanwela is indicated. It is seen that peak flood discharge has reduced from about 3,720m^3/s to about 2,800m^3/s, due to the storage in inundation area between these two sections.

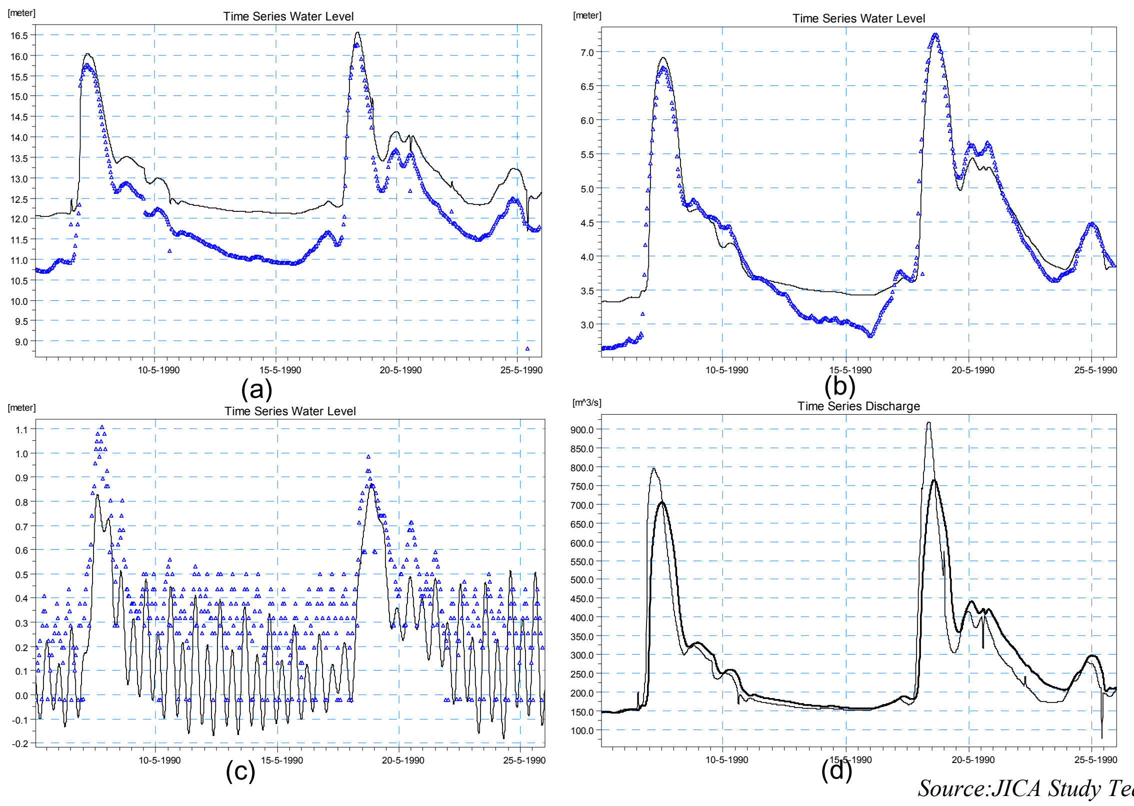
As a verification of the model a minor flood event which occurred in May 1990 was also simulated. In this event, the amount of inundation downstream of Glencourse was significantly less and the simulation of this event can be considered as an indicator of the performance of the model in reproducing the propagation of a flood wave confined within river banks. The river bed roughness coefficient was the main governing parameter in this case. Figures B.4.6 (a) & (b) show the comparison of water levels at Glencourse and Hanwella. It is seen that model is predicting the two observed flood peaks with reasonable accuracy.

In the simulation of these two flood events at the sea outlet of the model, the tidal behaviour was introduced by using predicted tide calculated based on tidal constituents for Colombo available in Admiralty Tide Table as downstream boundary condition. Pronounced tidal behaviour is observed at Nagalagam Street gauging station location (Figure B.4.6 (c)). Figure B.4.6 (d) indicates the attenuation of flood discharge from Glencourse to Hanwella and it is seen peak discharge between Glencourse and Hanwella has reduced from about 925 m^3/s to about 750 m^3/s.



Souce:JICA Study Team

Figure B.4.5 Simulated and Recorded Results – 1989 Flood (a) Water Level – Glencourse, (b) Water Level - Hanwella, (c) Water Level - Nagalagam Street (d) Discharge – Glencourse (Recorded) & Hanwella (Simulated)



Source:JICA Study Team

Figure B.4.6 Simulated and Recorded Results – 1990 Flood (a) Water Level – Glencourse, (b) Water Level – Hanwella, (c) Water Level – Nagalagam Street (d) Discharge – Glencourse (Recorded) & Hanwella (Simulated)

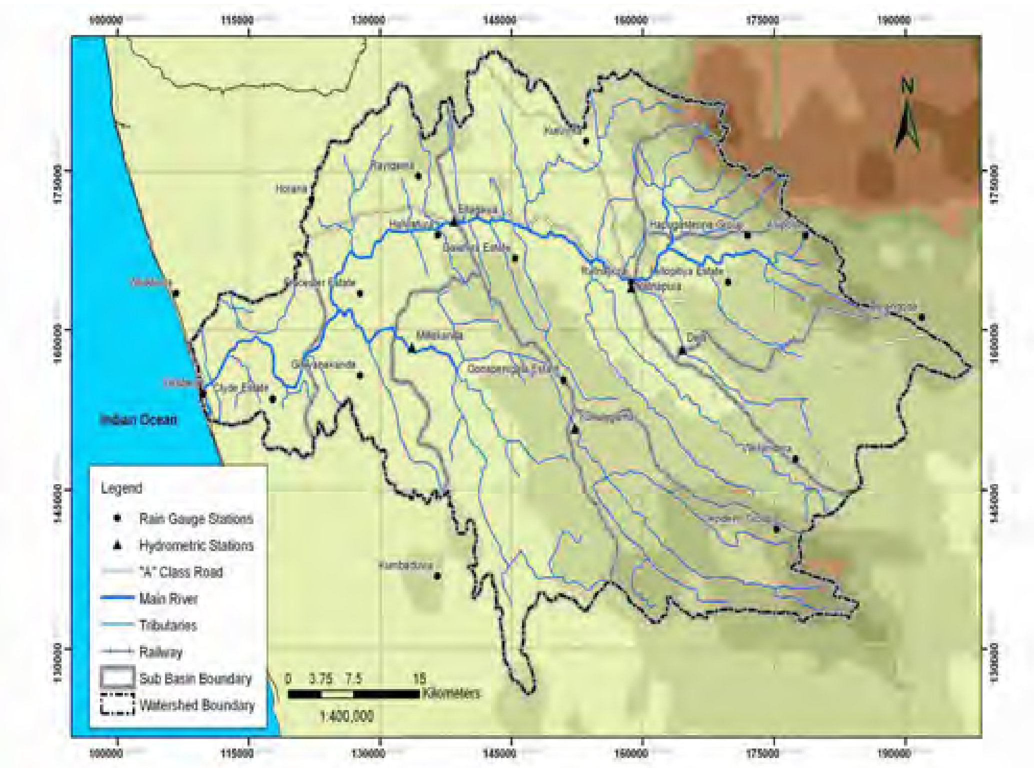
B.5 Kalu River Basin Model

Kalu River Basin Model developed basically contained the river basin together with the Kalu River between Ratnapura and Colombo and its main tributary Kuda Ganga from Millakanda.

B.5.1 Hydrological Modelling

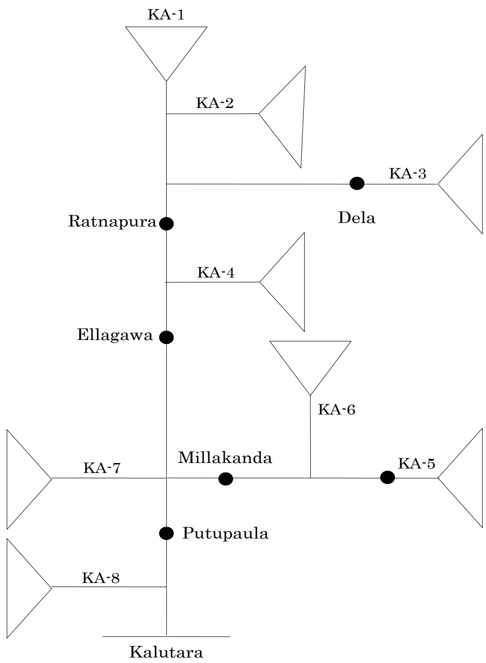
(1) Model Set-up

Kalu River basin was divided into 8 sub catchments for the purpose hydrological modeling (Figure B.5.1 (a) & (b)). Out of these, three sub catchments located upstream of Ratnapura drains flow discharge through hilly areas, in extent comprising nearly one third of total catchment area. The inflows from 3 tributaries, namely Rath Ganga, Denawak Ganga and Way Ganga were accounted for by hydrological modeling of these sub catchments and introducing computed runoff as point inflows to the hydrodynamic model. In between Ratnapura and Ellagawa was demarcated as one sub catchement to account the flow of several tributaries, being Ellagwa a hydrometric gauging station. Two sub catchment divisions were made, one at Kukulegama and the second at Millakanda to account the flow of Kuda Ganga. The remaining two sub catchments represented watershed areas draining into the river over different segments at the downstream of river.



Source:JICA Study Team

Figure B.5.1 (a) Location Map of Sub Catchments in Kalu Basin with Rainfall & Hydrometric Gauging Stations



Source:JICA Study Team

Figure B.5.1 (b) Schematic Diagram of Sub Catchments in Kalu Basin

For the purpose of mean aerial rainfall computation in sub ctachments a total 19 rainfall stations were selected. The selection of rainfall stations was based on their presence within or just outside a sub catchment, reliability and availability of a long term rainfall record covering the model simulation period.

The details of sub catchments together with rainfall stations considered are given in Table B.5.1.

Table B.5.1 Sub Catchments & Rainfall Stations for Hydrological Modelling of Kalu River Basin

Sub Catchment	Type	Area (km^2)	Rainfall Stations
1. DurageKanda	Rath Ganga	134	Hapugastenna
2. Ratnapura	Upper Denawak Ganga	246	Alupo, Balangoda,Hapugastenna, Lellopitiya, Ratnapura
3. Dela	Upper Way Ganga	266	Balangoda, Wellandura
4. Ellagawa	Intermediate Kalu (Ratnapura to Ellagawa)	767	Depdeen, Galatura, Gonapenigala, Kuruwita, Ratnapura
5. Kukulegama	Upstream of Kukule Ganga	305	Depdeen, Gonapenigala
6. Millakanda	Kuda Ganga between Kukulegama to Millakanda	477	Galatura, Geekiyanakanda, Gonapenigala, Kambaduwa
7. Putupaula	Intermediate Kalu (Ellagawa to Putupaula)	433	Frocester, Geekiyanakanda, Halwatura, Horana, Raigama
8. Kalutara	Intermediate Kalu (Pupaula to Kalutara)	173	Kalutara, Clyde, Wadduwa

Having established the sub catchment boundaries and rainfall stations on the Basin View of the NAM Model, the Thiessen Polygons for the sub catchments were created. The model then automatically computed the Thiessen weights for mean aerial rainfall calculation. In order to account for missing rainfall records, suitably selected combinations of missing records from selected rainfall stations were specified. The Theissen weights for these combinations were also computed through the Basin View upon generating the Theiseen Polygons. Based on established Theissen weight combinations mean aerial rainfall time series for each sub catchment was generated. In the case of Evaporation data a time series based representative monthly evaporation data was used as input to the NAM model.

NAM model calibration at the most upstream gauging station was made against the observed discharge for a selected period which consists of several flood events. For other sub catchements, calibration was done along with model running of hydrodynamic model linked with runoff model.

(2) Calibration and Verification

The 5-year time period from 1990-1991 and 2000-2003 was selected for model simulations. This choice was made as this time period contained the most severe recent flood occurred in Kalu River in May 2003. The selection of a long period for NAM simulations enabled model results to be compared with observed stream flow records for flood events of different magnitude. This also enabled the hydrodynamic model to be subsequently run for simulation of selected flood events with the same mean aerial rainfall time series generated.

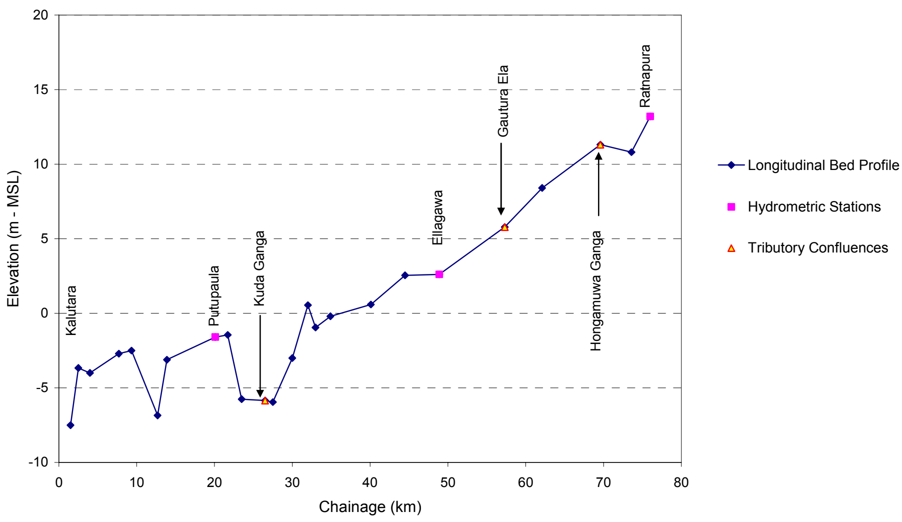
The NAM model in its stand-alone mode could be calibrated at Dela and Kukulegama as stream flow records were available at the gauging stations. At Ratnapura, daily flow records were not maintained after 1995 except for flood events and also recently gauging station has been shifted to a new place. Therefore, calibration at these stations namely Ratnapura, Ellagawa, Millakanda and Putupaula was performed linking the runoff model with hydrodynamic model.

B.5.2 Hydrodynamic Modelling

(1) Model Set-up

1) River Network and Cross Sections

The hydrodynamic model of Kalu River was set up covering Kalu River between Ratnapura and Kalutara linked with the main tributary Kuda Ganga at Millakanda. The river cross sections available from Department of Irrigation which were taken for "Pre Feasibility Study Assessment of Kalu Ganga Flood Protection with Special Reference to Ratnapura, July 2004" were used in setting up the model. The raw data is available in the form of (x, z) coordinates, x being the horizontal distance across the cross section and z the elevation above a selected datum (MSL). The bed resistance at river cross sections was specified in terms of Manning's roughness coefficients. The model processed these data and computed the hydraulic parameters such as cross sectional area, width, hydraulic radius, conveyance at different water levels as "processed data". The longitudinal profile of the river was also automatically generated. Figure B.5.2 shows the longitudinal profile of the main Kalu River.



Source:Hydrology Division, DOI

Source:JICA Study Team

Figure B.5.2 Longitudinal Bed Profile of Kalu River

2) Boundary Conditions

The boundary conditions are required at all external boundaries of the model. The boundary conditions used for Kalu River and the main tributary are given in Table B.5.2.

Table B.5.2 Hydrodynamic Model Boundary Conditions – Kalu River and Main Tributary

River	Model Boundary	Type of Boundary Condition	Data Source
Kalu River	Ratnapura	Discharge	NAM model simulated runoff for Ratnapura, Dela. Duragekanda sub catchments
	Colombo (sea)	Water Level	0.0 MSL
Kuda Ganga	Millakanda	Discharge	NAM model simulated runoff

Source:JICA Study Team

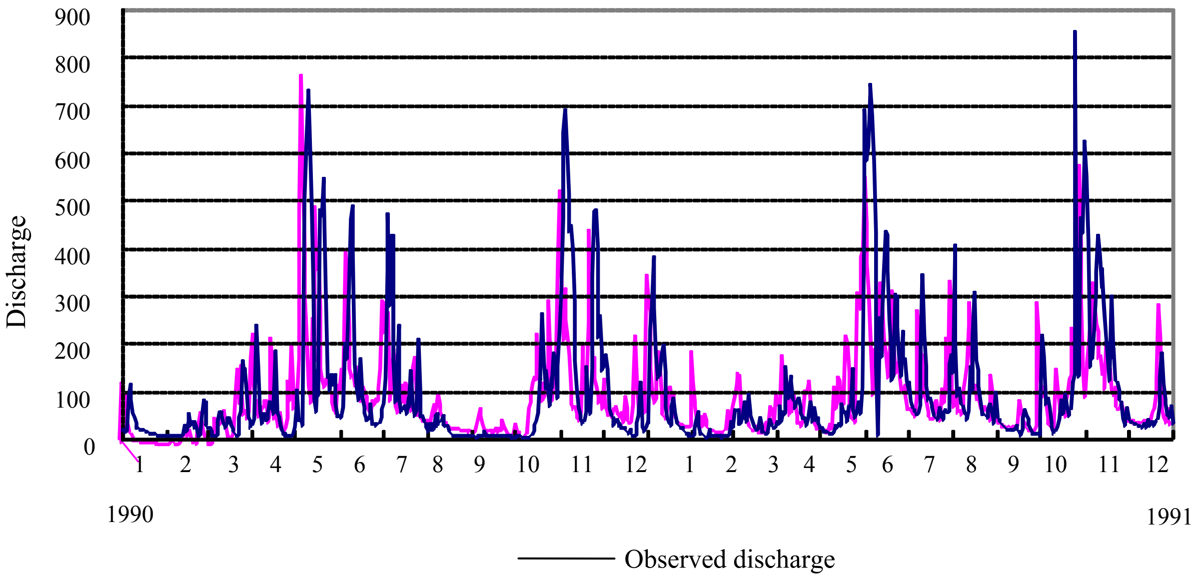
3) Lateral Inflows

The NAM simulated runoff for the 3 intermediate sub catchments were linked as uniformly distributed lateral inflows between upstream and downstream stations of the catchments as defined in above Table.

(2) Calibration and Verification

The model calibration in the first phase is based on matching the computed water level and discharge time series at Ratnapura with observed data for flood events. Discharge records at Ratnapura gauging station were not continued since 1995 as reliability of rating curve is not high. Further, available rating curve at Ratnapura is also not covered high water stages. Therefore, derived discharge and water levels in 2003 May flood were referred from “Pre Feasibility Study assessment of Kalu Ganga Flood Protection with Special Reference to Ratnapura” published by Irrigation Department in July 2004.

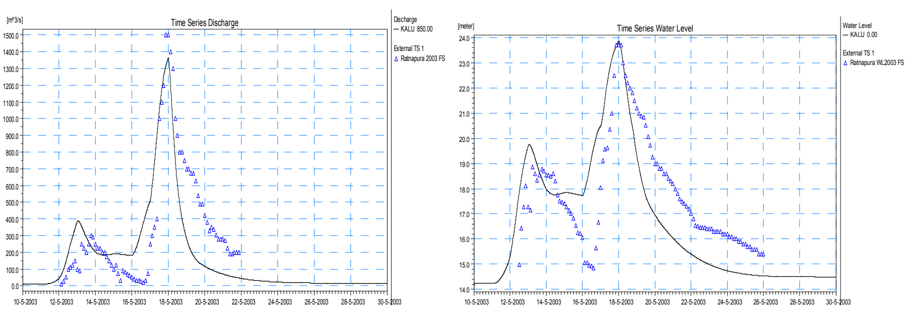
The calibration results for the period from 1990-1991 is given below:



Source:JICA Study

Figure B.5.3 Observed and Simulated Discharge during 1990 - 1991 at Ellagawa

The figure below shows the comparison of water level and discharge at Ratnapura for 2003 May flood event.



Observed and Simulated Discharge at Ratnapura

Observed and Simulated Water Level at Ratnapura

Source:JICA Study Team

Figure B.5.4 Observed and Simulated Water Level / Discharge in 2003 Flood at Ratnapura

Table B.5.3 compares observed and simulated peak water levels and discharges during 2003 May flood at main gauging stations in Kalu River.

Table B.5.3 Observed and Simulated Peak Discharges/Water Levels in May 2003 Flood

Station	Observed Discharge (m^3/s)	Simulated Discharge (m^3/s)	Observed Water Level (m MSL)	Simulated Water Level (m MSL)
Ratnapura	1500	1365	23.70	23.88
Ellagawa	2600	2627	14.04	14.93
Putupaula	NA	3188	6.09	6.22
Millakanda	1200	1166	9.00	8.97

NA: Not Available; Observed data as of DOI
Source:JICA Study Team

B.6 Gin River Basin Model

Gin River Basin Model developed contains the river basin together with the Gin River between Tawalama and Gintota (Galle) together with its looped tributary Terun Ela and the bypass canal Kepu Ela, downstream of Wakwella to Galle.

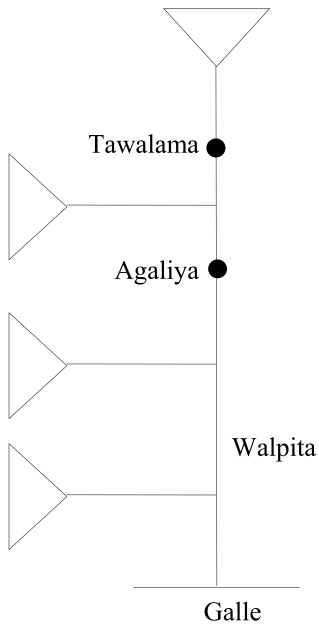
B.6.1 Hydrological Modelling

(1) Model Set-up

Gin River basin was divided into 4 sub catchments for the purpose hydrological modeling (Figure B.6.1 (a) & (b)). The sub catchment of Tawalama drains flow discharge through hilly areas, in extent comprising 376km^2 more than one third of total catchment area. In between Tawalama and Agaliya was demarcated as one sub catchement to account the flow of several small tributaries, being Agaliya a hydrometric gauging station. The remaining two sub catchments represented watershed areas draining into the river over different segments at the downstream of river.

Source:JICA Study Team

Figure B.6.1 (a) Location Map of Sub Catchments in Gin Basin with Rainfall & Hydrometric Gauging Stations



Source:JICA Study Team

Figure B.6.1 (b) Schematic Diagram of Sub Catchments in Gin Basin

Rainfall data were collected from seven rainfall stations available in sub catchments for mean aerial rainfall computation. The selection of rainfall stations was based on their presence within or just outside a sub catchment. However, spatially distribution of rainfall stations within the sub catchment is not balanced. As a result, number of rainfall stations outside the sub catchment boundaries had to be selected. The details of sub catchments together with rainfall stations considered are given in Table B.6.1.

Table B.6.1 Sub Catchments & Rainfall Stations for Hydrological Modeling ofGin River Basin

Sub Catchment	Type	Area (km^2)	Rainfall Stations
1. Tawalama	Upper Gin	376	Deniyaya, Panilkanda, Tawalama
2. Tawalama-Agaliya	Intermediate Gin (Tawalama-Agaliya)	351	Tawalama, Hiniduma, Koralegama, Baddegama
3. Agaliya-Walpita	Intermediate Gin (Agaliya-Walpita)	142	Baddegama, Labuduwa
4. Walpita-Galle	Intermediate Gin (Walpita-Galle)	64	Labuduwa, Monrovia Group, Galle

Source:JICA Study Team

Having established the sub catchment boundaries and rainfall stations on the Basin View of the NAM Model, the Thiessen Polygons for the sub catchments were created. The model then automatically computed the Thiessen weights for mean aerial rainfall calculation. In order to account for missing rainfall records, suitably selected combinations of missing records from selected rainfall stations were specified. The Theissen weights for these combinations were also computed through the Basin View upon generating the Theiseen Polygons. Based on established Theissen weight combinations mean aerial rainfall time series for each sub catchment was generated. In the case of Evaporation data a time series based representative monthly evaporation data was used as input to the NAM model.

NAM model calibration at the most upstream gauging station was made against the observed discharge for a selected period which consists of several flood events. For other sub catchements, calibration was done along with model running of hydrodynamic model linked with runoff model.

(2) Calibration and Verification

The 2-year time period from 2001-2003 was selected for model simulations. This choice was made as this time period contained the most severe recent flood occurred in Gin River in May 2003. The selection of a long period for NAM simulations enabled model results to be compared with observed stream flow records for flood events of different magnitude. This also enabled the hydrodynamic model to be subsequently run for simulation of selected flood events with the same mean aerial rainfall time series generated.

The NAM model in its stand-alone mode could be calibrated at Tawalama as stream flow records were available at this gauging station. The calibration at Agaliya was performed linking the runoff model with hydrodynamic model. However, data availability at short time intervals at these two stations for a common period is quite few.

The flood in 2003 May is rather big and most of the downstream area was inundated with high water level. As a result, recorded water levels at gauging stations were out of the rating curves. Therefore, no reliable discharge data is available. According to DOI, the peak daily discharge at Tawalama is recorded as1,273 m^3/s.

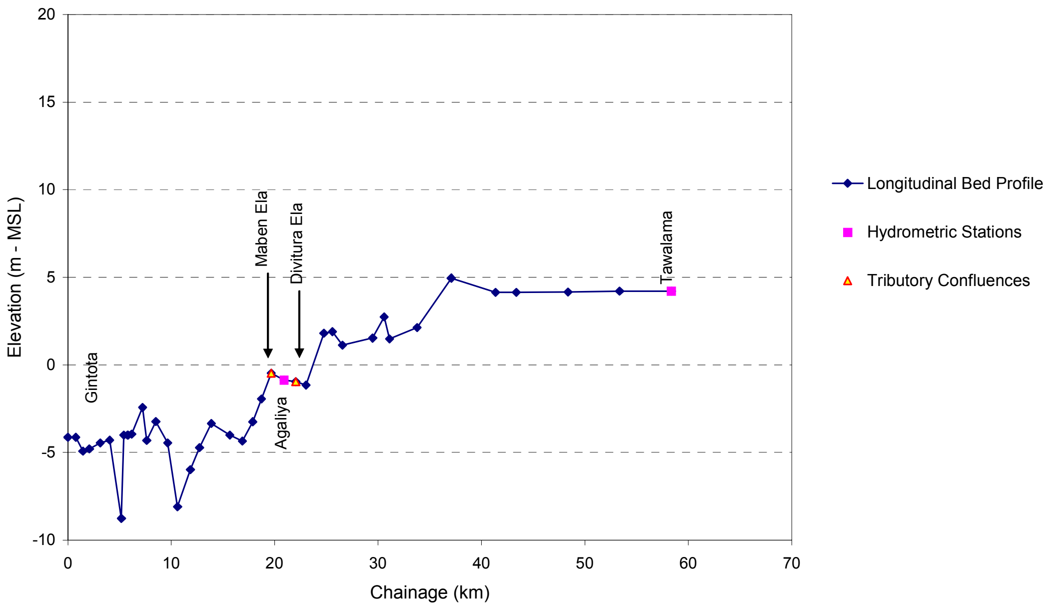
The simulation results of NAM model indicate that the peak discharge at Tawalama is 980m^3/s based on the rainfall - runoff analysis. As mentioned above, since the reliability of recorded discharge is low, validity of NAM calculated runoff discharge was checked with water levels in hydrodynamic module.

B.6.2 Hydrodynamic Modelling

(1) Model Set-up

1) River Network and Cross Sections

The Hydrodynamic model of Gin River was set up between of Tawalama and Galle. The length of river section is about 58.3km. The catchments linked to the hydrodynamic model are given in Table B.6.1. The river cross sections in main river surveyed in 2003 and Terun Ela and Kepu Ela surveyed in 1999 was used in model set up. The longitudinal profile of the river is given in Figure B.6.2.



Source: LHI

Figure B.6.2 Longitudinal Bed Profile of Gin River

2) Boundary Conditions

The boundary conditions are required at all external boundaries of the model. The boundary conditions used for Gin River and Kepu Ela are given below:

Table B.6.2 Hydrodynamic Model Boundary Conditions – Gin River and Kepu Ela

River	Model Boundary	Type of Boundary Condition	Data Source
Gin River	Tawalama	Discharge	NAM model simulated runoff
	Gintota (Galle) - sea	Water Level	0.4m MSL
Kepu Ela	Galle	Water Level	0.4m MSL

Source:JICA Study Team

At the downstream boundary, water level at sea is taken as 0.4m MSL considering the tidal height.

3) Lateral Inflows

The NAM simulated runoff for the 3 intermediate sub catchments were linked as lateral inflows to the main river as defined in above Table B.6.1.

(2) Calibration and Verification

The model calibration in the first phase is based on matching the computed water level and discharge time series at Tawalama with observed data for flood events. Discharge records at Tawalama gauging station were not reliable for high floods when compared with the possible maximum rainfall-runoff volume. Therefore, 2003 May flood was simulated based on rainfall-runoff discharge generated from NAM model and compared the water level at Tawalama running the hydrodynamic module. The simulated and observed water levels during 2003 May flood are given below.

Table B.6.3 Observed and Simulated Water Levels in May 2003 Flood

Station	Observed Water Level (m MSL)	Simulated Water Level (m MSL)
Tawalama	31.15	31.28
Agaliya	8.33	8.47

Source:JICA Study Team

It is recommended to upgrade the rating curves at the above gauging stations with new river cross sections covering the high water stages. Further, recording of temporal variation of water levels during high floods at these stations and also at some downstream points will be needed to upgrade the present hydrodynamic models.

B.7 Nilwala River Basin

Nilwala River Basin Model comprised the river catchment area together with 40.1 km long reach of main river between Pitabeddara and sea outfall at Matara.

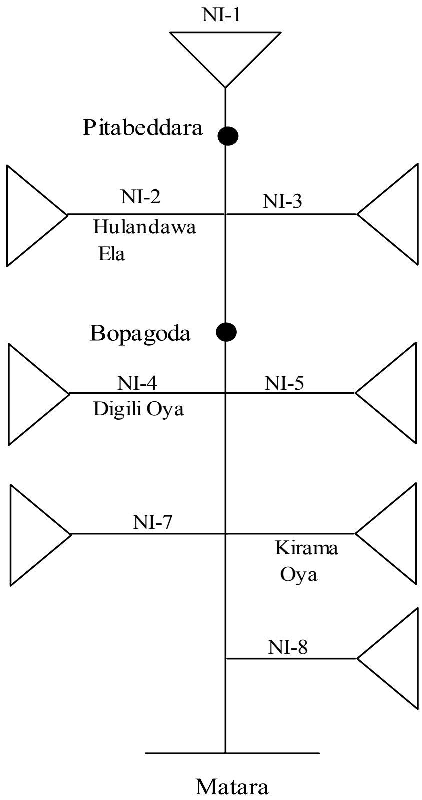
B.7.1 Hydrological Modelling

(1) Model Set-up

Nilwala River basin was divided into 8 sub catchments for the purpose hydrological modeling (Figure B.7.1 (a) & (b)). Out of these, Upper Nilwala subcatchment at Pitabeddara was the largest in extent comprising nearly one third of total catchment area. The inflows from 3 tributaries, namely Hulandawa Ganga, Digili Ella and Kirama Oya were accounted for by hydrological modeling of their sub catchments and introducing computed runoff as point inflows to the hydrodynamic model. The remaining four intermediate sub catchments represented watershed areas draining into the river over different segments.

Source:JICA Study Team

Figure B.7.1 (a) Location Map of Sub Catchments with Rainfall & Hydrometric Gauging Stations



Source:JICA Study Team

Figure B.7.1 (b) Schematic Diagram of Sub Catchments in Kalu Basin

For the purpose of mean aerial rainfall computation in sub catchments a total 8 rainfall stations were selected. The selection of rainfall stations was based on their presence within or just outside a sub catchments, reliability and availability of a long term rainfall record covering the model simulation period. However, apart from Kirama-Matara club catchments rainfall stations were found to be poorly contained within sub catchments. As a result, a significant number rainfall stations outside the sub catchment boundaries had to be selected. The details of sub catchments lings to the Nilwala River and the tributaries and rainfall stations considered are give in Table B.7.1.

Having established the sub catchment boundaries and rainfall stations on the Basin View of the NAM Model, the Thiessen Polygons for the sub catchments were created. The model then automatically computed the Thiessen weights for mean aerial rainfall calculation. In order to record for missing rainfall records, suitably selected combinations of missing records from selected rainfall stations were specified. The Theissen weights for these combinations were also computed through the Basin view upon generating the Theissen Polygons.

View on established Theissen weight combinations mean aerial rainfall time series for each sub catchment was generated. In the case of evaporation data a time series based on representative monthly evaporation data was used as input to the NAM model.

Table B.7.1 Sub Catchments & Rainfall Stations for Hydrological Modeling of Nilwala River Basin

Sub Catchment	Type	Area (km^2)	Rainfall Stations
1. Pitabeddara	Upper Nilwala	301.0	Deniyaya, Kirama, Mawarella, Goluwawatta, Kamburupitiya
2. Hulandawa	Upper Hulandawa Ela	65.1	Goluwawatta, Mawarella, Kamburupitiya
3. Pitabeddara-Bopagoda	Intermediate Nilwala (Pitabeddara to Bopagoda)	24.0	Mawarella, Goluwawatta, Kamburupitiya
4. Digili Oya	Upper Digili Oya	83.3	Goluwawatta, Mawarella, Telijjawila
5. Bopagoda-Kirama Oya	Intermediate Nilwala (Bopagoda to Kirama Oya)	79.9	Goluwawatta, Telijjawila, Kekenadura, Thihagoda, Kamburupitiya, Mawarella, Kirama
6. Kirama Oya	Upper Kirama Oya	169.1	Goluwawatta, Telijjawila, Kekenadura, Thihagoda, Kamburupitiya, Mawarella
7. Digili Oya-Matara	Intermediate Nilwala (Digili Oya to Matara)	107.9	Goluwawatta, Telijjawila, Kekenadura, Thihagoda, Kamburupitiya
8. Kirama Oya - Matara	Intermediate Nilwala (Kirama Oya to Matara)	72.0	Kekenadura, Thihagoda, Kamburupitiya, Telijjawila

Source:JICA Study Team

(2) Calibration and Verification

The 5 year period 1999-2003 was selected for hydrological model simulations, particularly because it contained the most recent severe flood occurred in this basin in mid May 2003. In the first phase, calibration runs focused on this flood. The stream flow gauging station at Pitabeddara receives the runoff from the Pitabeddara catchment. During the 2003 May flood, daily averaged discharge records indicated a maximum flow of 2910 m^3/s on 18 May 2003. The hourly records of stream flow at the same station indicated a peak discharge of 4672 m^3/s.

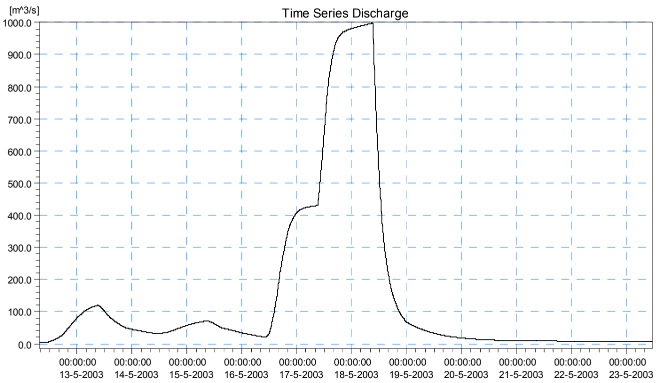
Having had discussions with Irrigation Department and having reviewed the flood situation in neighbouring Gin and Kalu catchments, it is speculated that the maximum flood recorded at Pitabeddara could not have reached that magnitude. Furthermore, the recorded flood peak at Pitabeddara is outside the range of the rating table developed by the Irrigation Department for that station.

Approximate calculations carried out for this flood event confined to the period 17 May 2003 to 20 May 2003 based on mean aerial rainfall estimated for Pitabeddara sub catchment indicated a runoff to rainfall ratio of around 4.8. Even if the highest recording rain gauge station within this sub catchment at Deniyaya recordings is used as the basis of calculations, the corresponding ratio was found to be around 3.4. However, in the case of neighboring Gin Ganga basin, the peak daily average stream flow recorded for this flood event at Tawalama was 1,273m^3/s for a catchment area of 376 km^2 (Sub catchment area of Pitabeddara is 301km^2).

The catchment areas at Tawalama in Gin Ganga basin and Pitabeddara in Nilwala Ganga basin are similar in topographic characteristics with mountainous land form and both catchments respond rapidly to high intensity rainfall events such as 2003 May flood event. During 2003 flood event, catchments of these stations received heavy rainfall and Deniyaya rain gauge station which is located bordering the two catchments can be considered to be representative of rainfall characteristics of both these catchments. Based on its location Deniyaya rainfall station can be considered as well representative for indicating rainfall pattern in both these catchments in heavy rainfall events.

Therefore with the uncertainty on high stream flow recorded at Pitabeddara, the most logical approach would be to utilize Deniyaya rainfall station as representative, for rainfall events causing heavy flood event at Pitabeddara. Additionally, the more reliability in terms of data availability for Deniyaya rain gauge station compared to other stations originally considered for mean aerial rainfall in Pitabeddara sub catchment was also noted.

The hydrological model simulations conducted for Pitabeddara sub catchment based on Deniyaya rainfall station records indicated a peak runoff around 1,000 m^3/s (Figure B.7.2), which can be considered as a reasonable estimate based on recorded stream flow at Tawlama and comparing the extent of catchment areas of the two stations. As the water levels recorded at Pitabeddara can be considered as more reliable, on the basis of this computed runoff, the hydrodynamic model calibration as described below aimed at obtaining reasonable comparison with recorded water levels at Pitabeddara for 2003 May flood event.



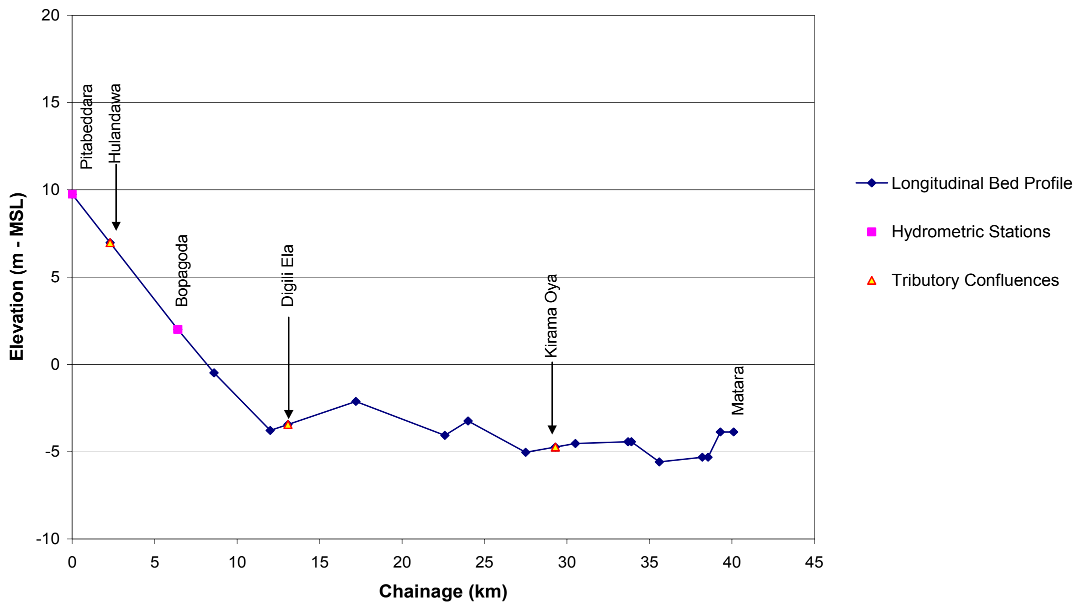
Source:JICA Study Team

Figure B.7.2 Simulated Flood Hydrograph for Pitabeddara – 2003 Flood

B.7.2 Hydrodynamic Modelling

(1) Model Set-up

The Hydrodynamic model was set up between Pitabeddara and Matara covering a total length of 40.1 km. The tributary inflows from 3 small connecting streams were taken into account as point inflows from NAM model simulations. The other catchments are linked to the hydrodynamic model as given in Table B.7.1. In the case of Pitabeddara and Bopagoda gauging station located 6.4 km downstream of Pitabeddara, DOI cross sections were used. In the case of Pitabeddara, the cross section had to be extended to cover high river stages. In the case of Bopagoda, the gauging station cross section was extrapolated by matching with DOI/RDI cross section. The longitudinal profile of the river is given in Figure B.7.3.



Source: Hydrology Division of DOI and LHI

Figure B.7.3 Longitudinal Bed Profile of Nilwala River

(2) Boundary Conditions

As Nilwala river was considered as a single entity, only two boundary conditions at upstream end at Pitabeddara and downstream end at Matara are required. The boundary conditions used are given in Table B.7.2 below.

Table B.7.2 Hydrodynamic Model Boundary Conditions – Nilwala River

Model Boundary	Type of Boundary Condition	Data Source
Pitabeddara	Discharge	NAM model simulated runoff for Pitabeddara sub catchment
Matara (sea)	Water Level	0.4m MSL

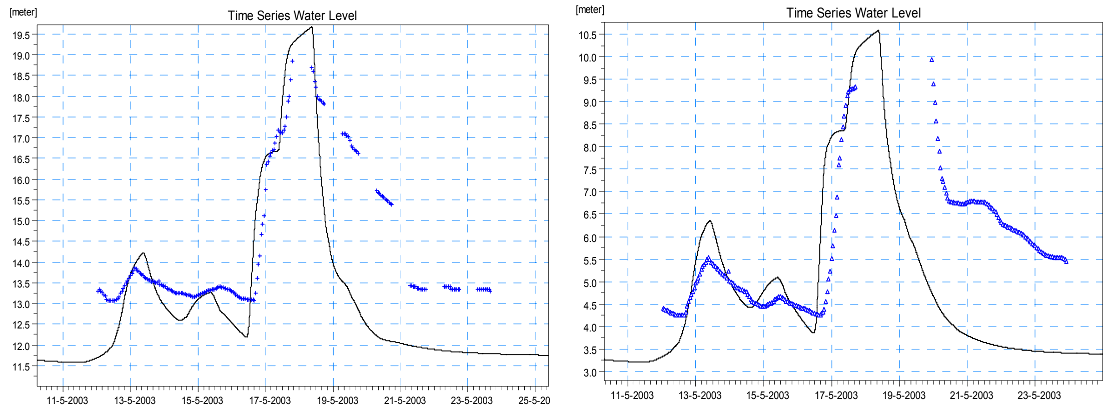
Source:JICA Study Team

(3) Lateral Inflows

The NAM model simulated lateral inflows from intermediate catchments were directed uniformly over different segments of the river as given in Table B.7.1.

(4) Calibration and Verification

The model calibration was based on comparison of simulated water levels at Pitabeddara and Bopagoda stations for the 2003 May flood event. As there was a considerable degree of uncertainty with respect to extrapolated cross sectional geometry at these two locations, coupled with boundary inflow to the model from Pitabeddara sub catchment, the best that could be achieved in the calibration is to obtain some reasonable agreement with recorded water levels at the two stations during the May 2003 flood event. The comparisons are shown in Figure B.7.4 (a) & (b), for Pitabeddara and Bopagoda, respectively. These indicate reasonable match during rising stage of flood water level at Pitabeddara. This calibration need to be considerably improved further by obtaining more reliable data on river cross sections, rainfall and stream flow records and comparing with different flood events. A verification run was carried for a flood occurred in the year 2001.



(a) Pitabeddara (b) Bopagoda

Source:JICA Study Team

Figure B.7.4 Simulated and Recorded Water Levels

B.8 Design Rainfall Hyetographs for NAM Model

B.8.1 Design Rainfall Events at Rain Gauging Stations

In order to assess the flood inundation due to occurrence of extreme flood events design flood hydrographs of different return periods need to synthesized and simulated in the river basin models developed. For this purpose, in the first phase cumulative rainfall for 1-day, 2-day up to 5-day duration was compiled for each rainfall station for all years of data availability. These rainfall values were processed on an annual basis to obtain annual maximums of 1-day, 2-day up to 5-day rainfall. The results of annual maximums (1-day) are shown in the Table together with observed maximum rainfall during the period of data available since 1950.

Table B.8.1 Daily Annual Maximum Rainfall for 10, 25, 50 and 100 year at Rainfalls Stations in Four River Basins

River	Name	Elevation (m)	Data Available Period	Annual Daily Maximum Rainfall				
				10 year	25 year	50 year	100 year	Obs. Max.
Kelani	Angoda	15.2	1950-2006	228.65	271.94	304.05	335.93	287.6
	Avissawella	30.5	1950-2006	202.54	237.78	263.93	289.88	264.2
	Bogawantalawa (Campion)		1950-1998	137.42	159.52	175.91	192.19	185.1
	Canyon	-	1983-2006	235.15	273.75	302.38	330.80	272.0
	Castlereigh	-	1983-2006	182.53	209.41	229.36	249.15	181.9
	Chesterford	198.2	1950-2006	191.08	219.46	240.52	261.42	255.5
	Colombo	7.3	1950-2006	236.66	286.23	323.00	359.50	493.7
	Deraniyagala (Dabar)	228.7	1950-1973 & 1975 -1988	220.18	257.14	284.56	311.78	343.1
	Dehiowita (Digalla)	122.0	1950-2006	191.25	221.55	244.02	266.33	227.3
	Dehiowita (Dunedin)	122.0	1950-2006	191.87	218.59	238.41	258.09	230.3

River	Name	Elevation (m)	Data Available Period	Annual Daily Maximum Rainfall				
				10 year	25 year	50 year	100 year	Obs. Max.
Kelani	Dompe	22.9	1950-1999	192.88	226.05	250.65	275.08	230.5
	Elston	-	1984-2006	240.12	283.07	314.93	346.55	362.7
	Kitulgala (Ingoya)	304.9	1950-1988 & 1990	229.29	264.79	291.13	317.27	278.9
	Labugama	-	1950-2006	214.45	247.08	271.29	295.32	304.6
	Maliboda	274.4	1950-2006	226.27	262.95	290.16	317.17	264.1
	Maussakelle	-	1983-1988 & 1999-2006	174.12	203.34	225.02	246.54	181.4
	Meepe	-	1950-1966 & 1971-2006	203.42	237.70	263.12	288.36	260.0
	Norton	-	1984-1998 & 2002-2006	296.28	343.31	378.21	412.84	285.5
	Ragama	-	1950-1974, 1986-1996, 1998-2000 & 2003-2004	217.69	265.27	300.58	335.62	431.8
	Watawala	-	1950-1998 & 2002-2006	279.42	328.65	365.16	401.41	321.8
	Welisara-Navy	-	1999-2006	219.37	263.16	295.65	327.90	277.3
	Undugoda (Yataderiya)	-	1950-1988, 1992-1993 & 2002-2006	203.02	235.34	259.31	283.11	292.1
Kalu	Alupolla	762.5	1950-2006	206.16	242.29	269.10	322.44	350.0
	Balangoda	527.4	1950-2006	144.42	166.53	182.93	199.21	168.9
	Clyde Estate	24.4	1952-1999	215.00	248.85	273.96	298.88	288.3
	Depdeen Group	-	1950-2006	176.80	205.17	226.21	247.10	232.1
	Frocester Estate	15.2	1952-2006	228.28	265.61	293.31	320.80	269.2
	Galatura Estate	-	1950-2006	227.80	265.91	294.19	322.25	246.8
	Gikiyanakanda	106.7	1950-2006	225.53	262.07	289.17	316.07	360.6
	Gonapenigala Estate	408.5	1950-1973 & 1975-2005	233.71	286.92	326.39	365.57	402.9
	Halwatura	137.2	1950-2006	205.03	237.41	261.43	285.27	280.3
	Hapugastenna Group	594.5	1950-2006	209.66	241.29	264.75	288.04	254.0
	Horana	30.5	1950-1995 & 1997-2006	203.38	234.41	257.43	280.29	244.3
	Kalutara	3.0	1950-1982, 1984-2004 & 2006	199.18	233.20	258.45	283.51	244.8
	Kuruwita	243.9	1950-2006	209.37	239.70	262.21	284.54	284.5
	Kumbaduwa	121.9	1950-1974 &1979-1980	248.68	295.48	330.20	364.67	309.8
	Lellopitiya Estate	-	1954-2006	185.04	212.36	232.63	252.74	201.4
	Ratnapura	34.4	1950-2006	231.98	279.37	314.52	349.42	392.5
	Rayigama	-	1950-2006	231.98	279.37	314.52	312.07	272.3
	Wadduwa	-	1952-1981, 1983,1985, 1990-1991	184.50	219.14	244.84	270.35	206.7
	Wellandara	-	1989-2006	194.05	236.86	268.62	300.14	266.7
	Deniyaya (Anningkanda)	533.5	1950-2006	195.15	228.19	252.71	277.04	230.8

River	Name	Elevation (m)	Data Available Period	Annual Daily Maximum Rainfall				
				10 year	25 year	50 year	100 year	Obs. Max.
Gin	Galle	12.5	1950-2006	186.46	218.60	242.44	266.11	282.6
	Baddegama Estate	15.2	1950-2006	234.79	284.46	321.32	357.90	463.5
	Hiniduma	-	1994-2006	212.05	243.91	267.55	291.01	224.2
	Korelegama	350.0	2001-2006	143.65	172.64	194.14	215.49	147.0
	Labuduwa	-	1950-2006	219.45	257.73	286.12	314.31	284.2
	Monrovia Group	-	1954-2006	187.05	221.01	246.21	271.23	232.5
	Panilkanda Estate	-	1950-1992	176.95	205.57	226.79	247.87	228.6
	Tawalama	-	1954-1993 &1995	239.49	276.74	304.37	331.79	279.4
	Goluwawatta	-	1965-2006	185.78	217.98	241.87	265.58	280.1
Nilwala	Kamburupitiya	243.9	1951-1965, 1967-1968 & 1971-2003	169.54	198.08	219.25	240.26	217.9
	Kekenadura	48.8	1950-2006	167.52	198.23	221.01	240.26	232.4
	Kirama	122.0	1951-1972 &1974-2006	165.28	194.88	216.84	238.64	207.2
	Mawarella	-	1950-1994 & 1999-2006	196.82	234.99	263.30	291.41	354.8
	Telijjawila Group	-	1980-1985 & 1989-2005	160.05	181.47	197.36	213.14	190.0
	Thihagoda	-	1950-2002	162.27	198.08	224.64	251.01	203.2
	Thihagoda	-	1950-2002	162.27	198.08	224.64	251.01	203.2

Source:JICA Study Team

The established set of annual maximum rainfall data were fitted with Gumbel extreme value probability distribution to obtain 1-day, 2-day up to 5-day design rainfall of 5, 10, 25 and 50 year return periods.

B.8.2 Synthesis of Design Rainfall Hyetographs

The 1-day, 2-day up to 5-day rainfall magnitudes of a particular return period was combined based on an alternative technique to generate rainfall hyetograph of 5-day duration for all rainfall stations. The hyetographs at several locations are presented below:

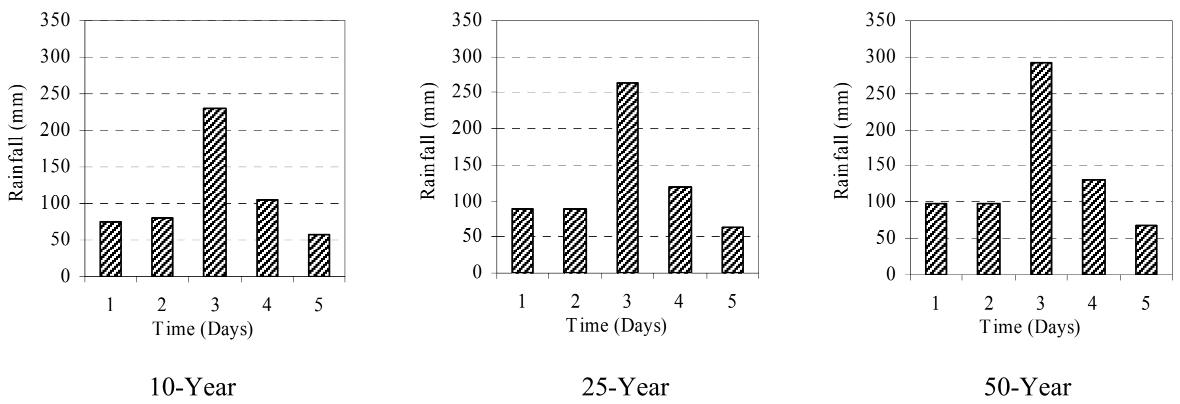
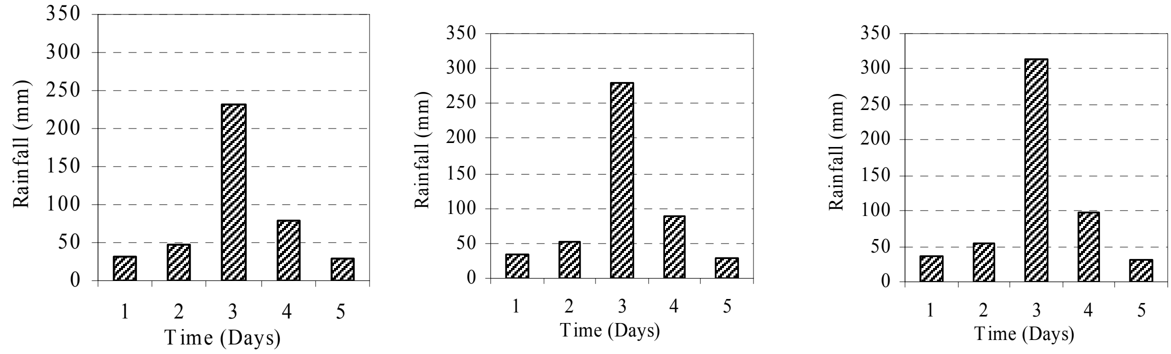
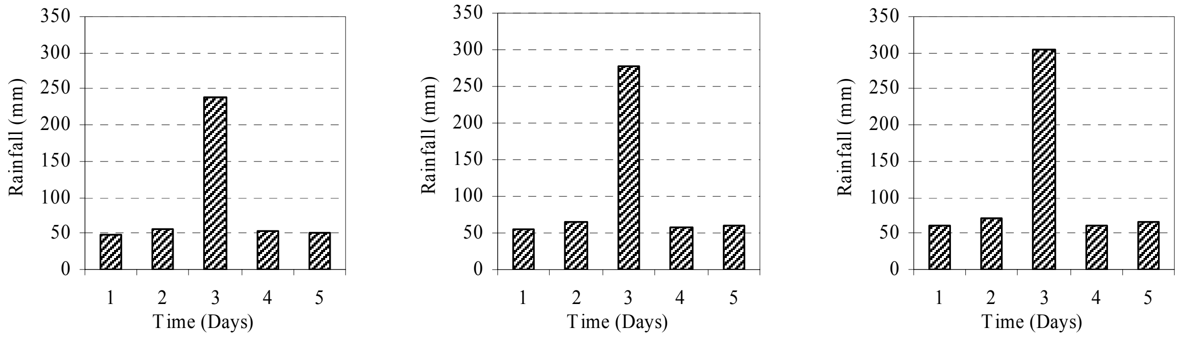


Figure B.8.1 (a) Hyetographs at Kitulgala Rainfall Station in Kelani Basin



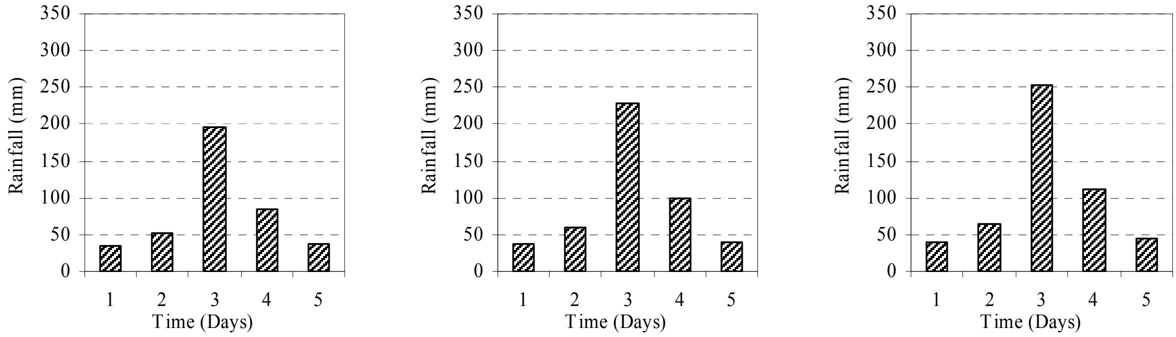
10 -year 25-Year 50-Year

Figure B.8.1 (b) Hyetographs at Ratnapura Rainfall Station in Kalu Basin



10-Year 25-Year 50-Year

Figure B.8.1 (c) Hyetographs at Tawalama Rainfall Station in Gin Basin



10-Year 25-Year 50-Year

Source:JICA Study Team

Figure B.8.1 (d) Hyetographs at Deniyaya Rainfall Station in Nilwala Basin

B.8.3 Design Rainfall Events based on Sub Basin Mean Rainfall

In Kalu River basin, peak discharge calculated from NAM simulation and peak discharge given in "Pre Feasibility Study Assessment of Kalu Ganga Flood Protection with Special Reference to Ratnapura" conducted by DOI is basically good in agreement. Hence, it was decided to carry out model simulations by NAM and HD modules for entire catchment instead of using recorded data at gauging stations, especially at upstream boundary, Ratnapura gauging station where recorded data is not continuous and accurate. For this catchment, additional analysis was also done for determining the design rainfall events based on sub basin mean rainfall.

Daily mean rainfall in each sub basin was calculated by Theissen Polygon method and then, annual maximum 1 day, 2 day, 3 day, 4 day and 5 day rainfall during 1985-2005 was obtained. It is illustrated below.

Table B.8.2 Annual Maximum Rainfall for Sub Basins in Kalu River

Year	Sub Basin 1 - Duragakanda					Sub Basin 2 - Ratnapura Part				
	1 Day	2 Day	3 Day	4 Day	5 Day	1 Day	2 Day	3 Day	4 Day	5 Day
1985	135	198	273	322	388	111	152	181	224	263
1986	117	172	209	227	239	103	168	201	219	240
1987	83	121	159	199	226	81	112	157	194	205
1988	183	312	328	345	386	116	201	260	303	322
1989	190	362	366	393	571	218	336	342	417	536
1990	201	297	344	364	382	166	238	276	307	329
1991	110	147	194	245	298	91	148	194	223	283
1992	178	228	261	297	343	131	213	224	251	269
1993	167	272	332	407	441	156	231	295	322	369
1994	88	144	184	229	288	61	119	148	206	248
1995	123	237	300	346	380	98	179	240	282	322
1996	106	146	181	218	232	166	189	213	221	247
1997	95	150	223	292	348	102	143	166	214	261
1998	113	165	208	309	319	122	160	190	273	279
1999	165	270	303	323	360	150	257	284	305	322
2000	109	162	203	211	219	82	113	138	157	170
2001	84	160	190	206	266	85	142	175	191	257
2002	123	149	185	206	248	77	104	140	179	206
2003	197	336	386	452	466	211	301	333	361	385
2004	93	121	170	228	253	72	105	135	174	200
2005	200	260	295	320	343	108	176	199	211	273

Year	Sub Basin 3 - Dela					Sub Basin 4 - Ellagawa				
	1 Day	2 Day	3 Day	4 Day	5 Day	1 Day	2 Day	3 Day	4 Day	5 Day
1985	89	113	154	194	239	117	181	201	241	292
1986	108	158	223	273	286	90	143	184	234	289
1987	147	193	252	267	284	113	145	174	190	231
1988	117	157	187	190	217	166	212	228	239	264
1989	84	136	170	194	202	175	299	352	389	414
1990	87	150	160	176	184	71	122	158	192	211
1991	63	91	134	162	171	88	122	171	210	236
1992	74	126	134	162	171	115	200	224	266	289
1993	98	137	186	211	276	155	215	280	306	384
1994	56	90	103	120	134	87	170	224	268	304
1995	86	98	130	175	193	99	162	195	228	256
1996	141	151	152	156	180	233	263	302	306	316

Year	Sub Basin 3 - Dela					Sub Basin 4 - Ellagawa				
	1 Day	2 Day	3 Day	4 Day	5 Day	1 Day	2 Day	3 Day	4 Day	5 Day
1997	157	165	168	203	217	145	179	227	271	294
1998	75	102	116	120	154	96	148	186	234	241
1999	91	111	128	142	147	153	279	324	354	395
2000	78	105	119	130	166	91	161	193	248	316
2001	77	115	146	161	174	95	156	205	252	270
2002	67	109	114	140	171	82	131	148	157	189
2003	178	248	252	259	274	287	342	382	391	404
2004	55	96	135	143	152	130	195	239	246	322
2005	70	116	133	155	179	145	159	162	186	227

Year	Sub Basin 5 - Kukulegama					Sub Basin 6 - Millakanda				
	1 Day	2 Day	3 Day	4 Day	5 Day	1 Day	2 Day	3 Day	4 Day	5 Day
1985	94	131	182	241	286	70	109	148	188	219
1986	117	149	177	187	201	46	65	76	85	95
1987	57	95	131	139	142	67	74	95	108	117
1988	123	182	222	238	268	94	104	115	121	139
1989	127	209	255	268	272	85	151	169	182	195
1990	120	132	144	161	194	31	48	68	89	110
1991	105	156	218	259	295	119	209	273	322	364
1992	136	195	213	278	312	146	248	289	325	355
1993	221	290	389	446	489	252	268	393	409	443
1994	87	117	156	194	223	68	107	132	159	198
1995	77	118	158	202	224	44	69	71	78	81
1996	101	142	192	235	258	101	178	246	307	370
1997	119	161	180	191	218	130	149	166	182	203
1998	70	98	127	147	161	54	86	111	147	182

Year	Sub Basin 7 - Putupaula					Sub Basin 8 – Kalutara				
	1 Day	2 Day	3 Day	4 Day	5 Day	1 Day	2 Day	3 Day	4 Day	5 Day
1985	132	196	243	282	309	124	219	270	331	348
1986	64	107	114	123	135	81	114	152	172	202
1987	112	202	242	299	317	128	196	212	233	289
1988	122	159	197	204	216	146	250	285	301	311
1989	121	208	299	357	401	99	148	204	223	228
1990	100	124	179	200	243	79	92	126	145	148
1991	176	263	360	440	465	129	238	270	290	325
1992	167	232	290	341	351	270	271	276	284	300
1993	98	131	199	241	281	132	170	182	221	226
1994	109	185	243	273	298	132	162	169	193	273
1995	85	143	170	206	231	160	219	259	300	308
1996	113	176	196	209	217	74	136	156	162	170
1997	107	165	187	234	260	96	141	176	222	260
1998	141	202	235	254	281	234	305	442	465	475
1999	215	256	279	291	307	154	220	265	276	300
2000	97	150	215	260	304	112	112	149	167	220
2001	81	111	132	197	214	190	226	230	230	338
2002	106	184	202	221	275	100	141	177	223	264
2003	117	156	163	166	177	142	207	218	223	229
2004	89	144	187	226	264	123	153	154	154	167
2005	181	244	260	290	341	-	-	-	-	-

Source:JICA Study Team

The set of annual maximum rainfall data were fitted with Gumbel extreme value probability distribution and obtained 1-day, 2-day up to 5-day design rainfall for various return periods as shown below:

Table B.8.3 Probable Maximum Rainfall for Sub Basins in Kalu River

Sub Basin 1-Duragakanda

Return Period	1-Day	2-Day	3-Day	4-Day	5-Day
2	129.22	197.66	240.39	279.92	318.40
3	146.84	228.92	270.37	311.36	356.10
5	166.46	263.75	303.77	346.37	398.09
10	191.12	307.51	345.73	390.37	450.86
20	214.77	349.48	385.98	432.58	501.47
25	222.27	362.80	398.74	445.96	517.52
30	228.38	373.63	409.13	456.85	530.58
50	245.39	403.81	438.08	487.20	566.98
70	256.54	423.60	457.05	507.10	590.84
100	268.33	444.53	477.12	528.14	616.07
1000	287.53	511.29	538.37	573.11	727.43
10000	325.49	596.96	625.21	646.38	849.83

Sub Bain 2-Ratnapura Part

Return Period	1-Day	2-Day	3-Day	4-Day	5-Day
2	112.29	169.90	203.51	238.22	272.09
3	130.64	196.69	229.92	266.26	305.24
5	151.07	226.52	259.34	297.49	342.17
10	176.74	264.01	296.30	336.74	388.56
20	201.37	299.97	331.75	374.38	433.07
25	209.18	311.37	343.00	386.32	447.19
30	215.54	320.65	352.15	396.04	458.67
50	233.25	346.51	377.64	423.11	490.68
70	244.86	363.46	394.36	440.86	511.66
100	257.14	381.39	412.03	459.62	533.85
1000	316.17	460.28	472.75	545.70	717.09
10000	378.91	548.76	588.30	638.93	882.90

Sub Basin 3-Dela

Return Period	1-Day	2-Day	3-Day	4-Day	5-Day
2	89.51	125.44	149.90	170.36	190.86
3	103.84	141.60	167.69	189.21	210.62
5	119.80	159.59	187.50	210.21	232.63
10	139.85	182.20	212.39	236.59	260.28
20	159.09	203.89	236.27	261.89	286.80
25	165.19	210.77	243.84	269.92	295.22
30	170.15	216.37	250.00	276.45	302.06
50	183.99	231.96	267.17	294.65	321.13
70	193.05	242.19	278.43	306.58	333.64
100	202.64	253.00	290.33	319.19	346.86

Sub Basin 4-Ellagawa

Return Period	1-Day	2-Day	3-Day	4-Day	5-Day
2	121.38	179.74	215.85	247.19	281.97
3	143.63	204.90	243.25	273.41	308.75
5	168.41	232.92	273.76	302.62	338.57
10	199.54	268.14	312.10	339.31	376.05
20	229.41	301.91	348.88	374.51	412.00
25	238.88	312.63	360.55	385.68	423.40
30	246.59	321.35	370.04	394.76	432.68
50	268.07	345.64	396.49	420.08	458.53
70	282.15	361.56	413.83	436.67	475.48
100	297.04	378.40	432.16	454.22	493.40

Sub Basin 5-Kukulegama

Return Period	1-Day	2-Day	3-Day	4-Day	5-Day
2	110.46	154.33	187.21	212.32	237.01
3	131.69	177.65	213.88	241.56	267.88
5	155.35	203.63	243.57	274.12	302.26
10	185.07	236.27	280.89	315.03	345.47
20	213.57	267.57	316.68	354.28	386.91
25	222.62	277.50	328.04	366.73	400.06
30	229.97	285.58	337.28	376.86	410.75
50	250.47	308.10	363.02	405.08	440.55
70	263.91	322.86	379.89	423.58	460.09
100	278.13	338.47	397.74	443.15	480.75

Sub Basin 6-Millakanda

Return Period	1-Day	2-Day	3-Day	4-Day	5-Day
2	103.90	147.47	179.24	205.08	233.07
3	135.29	183.96	221.85	249.51	280.81
5	170.25	224.60	269.32	299.00	333.99
10	214.18	275.67	328.96	361.19	400.81
20	256.32	324.66	386.17	420.84	464.91
25	269.69	340.20	404.31	439.76	485.24
30	280.57	352.84	419.08	455.16	501.78
50	310.87	388.06	460.22	498.05	547.87
70	330.74	411.16	487.19	526.18	578.09
100	351.74	435.58	515.71	555.91	610.04

Sub Basin 7-Putupaula

Return Period	1-Day	2-Day	3-Day	4-Day	5-Day
2	114.47	170.54	209.13	241.50	268.15
3	129.95	189.72	233.52	270.93	299.19
5	147.20	211.07	260.68	303.72	333.77
10	168.87	237.91	294.82	344.91	377.21
20	189.66	263.65	327.56	384.43	418.88
25	196.25	271.81	337.95	396.96	432.10
30	201.62	278.45	346.40	407.16	442.85
50	216.56	296.96	369.94	435.58	472.82
70	226.36	309.10	385.38	454.21	492.47
100	236.73	321.93	401.70	473.90	513.24

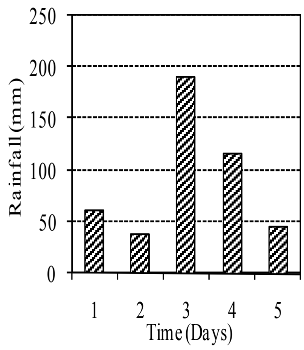
Sub Basin 8-Kalutara

Return Period	1-Day	2-Day	3-Day	4-Day	5-Day
2	127.58	178.16	209.90	233.07	262.37
3	148.86	202.67	240.44	264.35	293.27
5	172.57	229.98	274.46	299.19	327.68
10	202.35	264.29	317.20	342.97	370.93
20	230.92	297.20	358.20	384.96	412.41
25	239.98	307.64	371.21	398.28	425.57
30	247.35	316.13	381.79	409.12	436.28
50	267.89	339.80	411.28	439.32	466.11
70	281.36	355.32	430.61	459.11	485.66
100	295.60	371.72	451.05	480.05	506.34

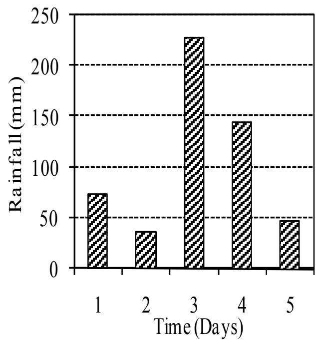
Source:JICA Study Team

The hyetographs derived by applying alternative techniques are presented below:

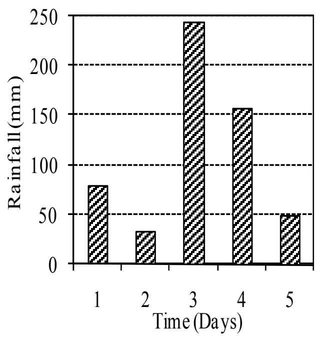
(a) Sub Basin 1-Duragakanda



10 year

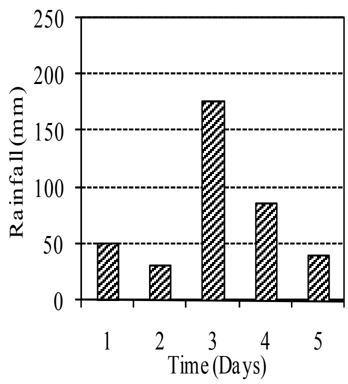


30 year

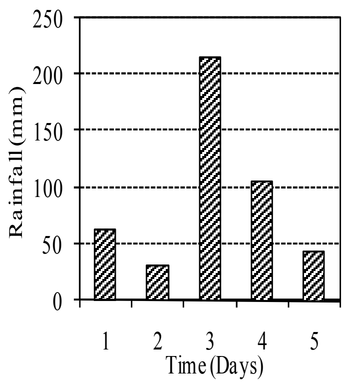


50 year

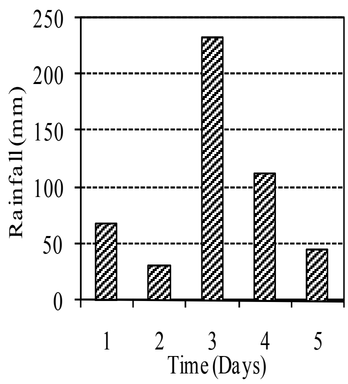
(b) Sub Bain 2-Ratnapura Part



10 year

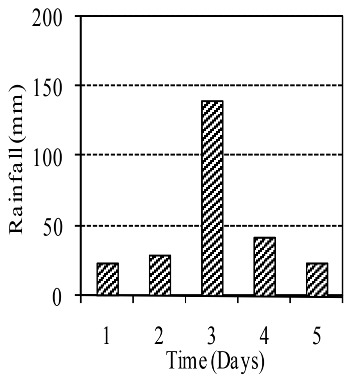


30 year

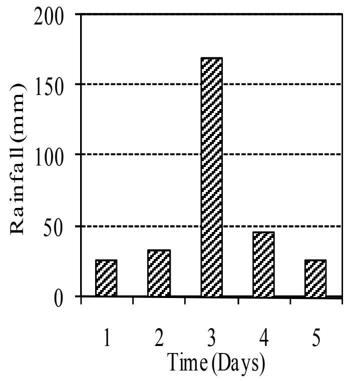


50 year

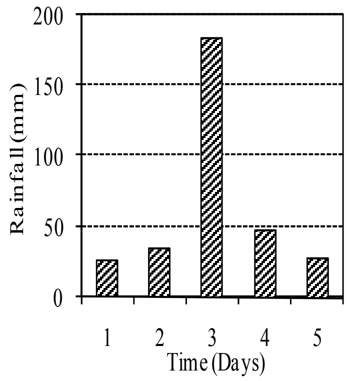
(c) Sub Basin 3-Dela



10 year

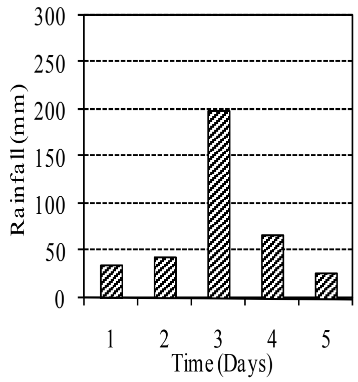


30 year

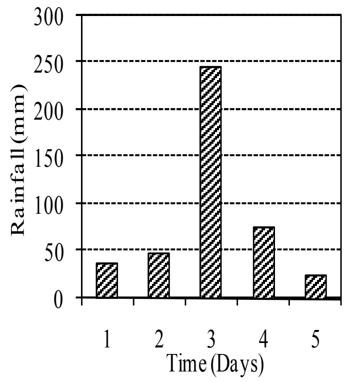


50 year

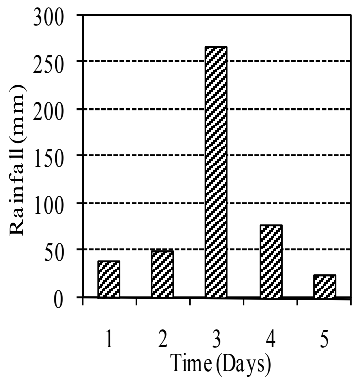
(d) Sub Basin 4-Ellagawa



10 year

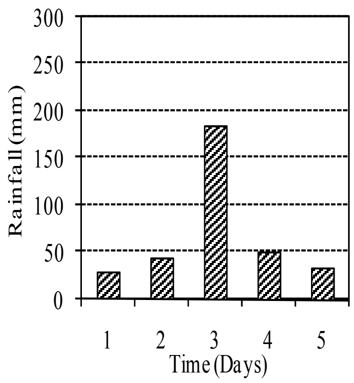


30 year

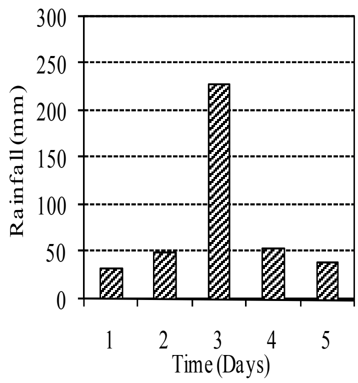


50 year

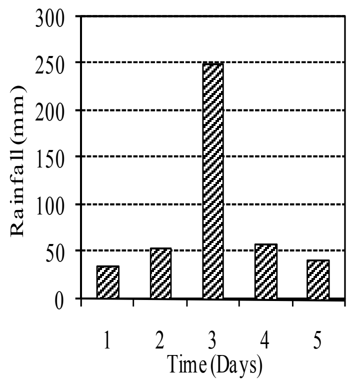
(e) Sub Basin 5-Kukulegama



10 year

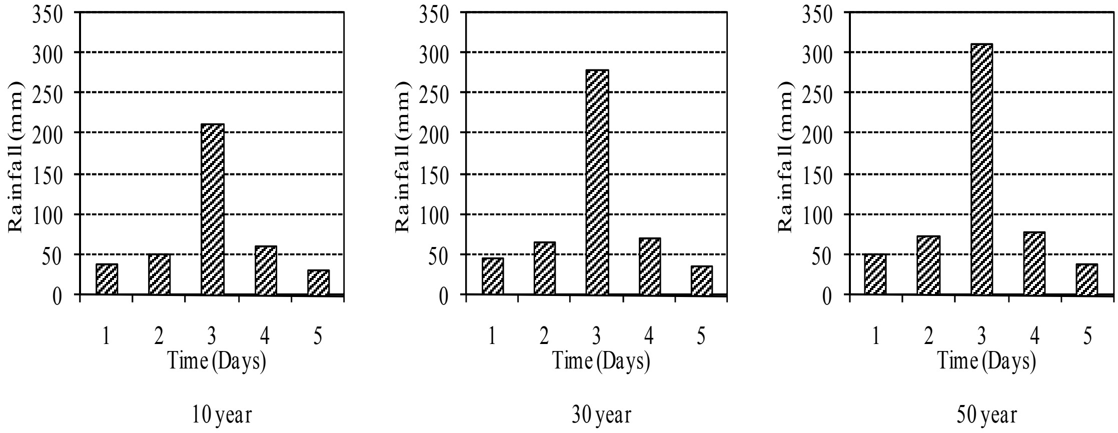


30 year

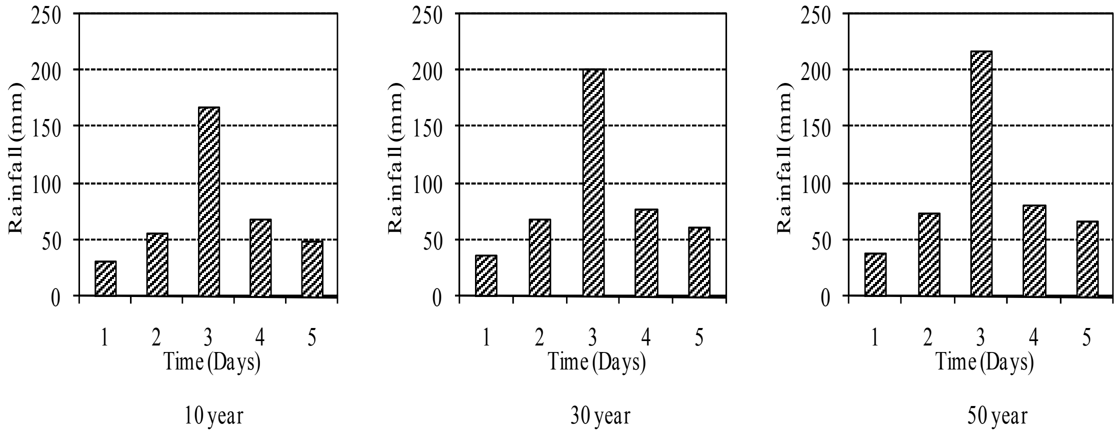


50 year

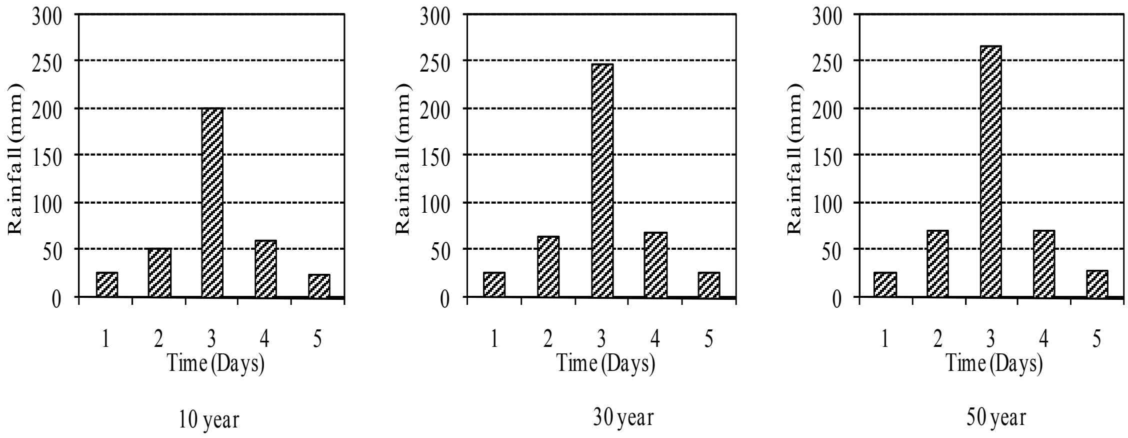
(f) Sub Basin 6-Millakanda



(g) Sub Basin 7-Putupaula



(h) Sub Basin 8-Kalutara



Source:JICA Study Team

Figure B.8.2 Hyetographs for Sub Catchments in Kalu Basin

B.9 Probable Discharges at Upstream Boundaries

For Hydrodynamic simulations of Kelani, Gin and Nilwala Rivers, upstream boundary condition was taken as known discharge at the upstream gauging station except Kalu river where NAM generated runoff discharge was linked to the HD model as upstream discharge. The probable discharges calculated at each gauging station applying frequency analysis using Gumbel extreme value probability distribution are as follows.

Table B.9.1 Probable Discharges at Upstream Boundaries of Kelani, Gin and Nilwala Rivers

Return period	Kelani	Gin	Nilwala
	Glencourse	Tawalama	Pitabeddara
2	1,431	542	500
3	1,831	694	723
5	2,277	863	972
10	2,837	1,076	1,284
20	3,374	1,279	1,584
25	3,544	1,344	1,679
30	3,683	1,397	1,756
50	4,069	1,543	1,972
70	4,322	1,639	2,113
100	4,590	1,741	2,262

Source:JICA Study Team

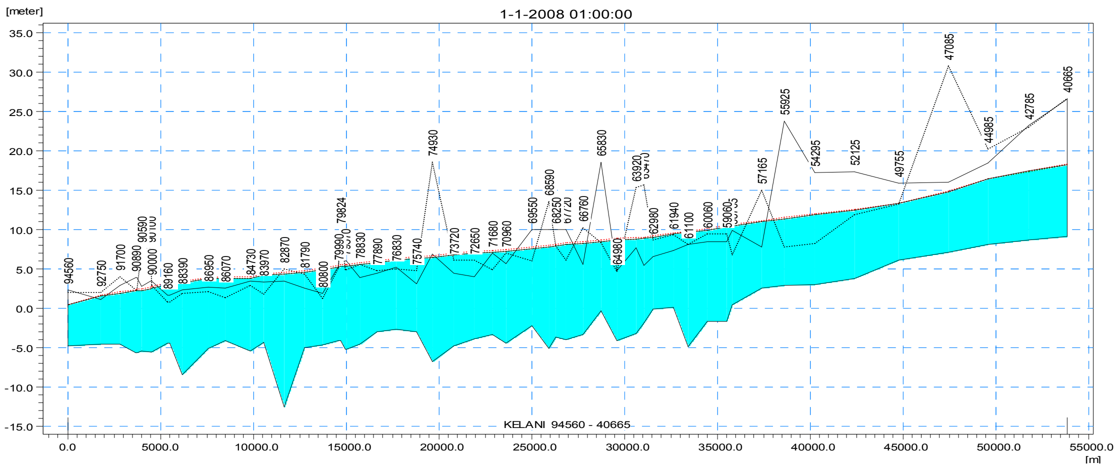
B.10 River Channel Capacity

B.10.1 Present Condition

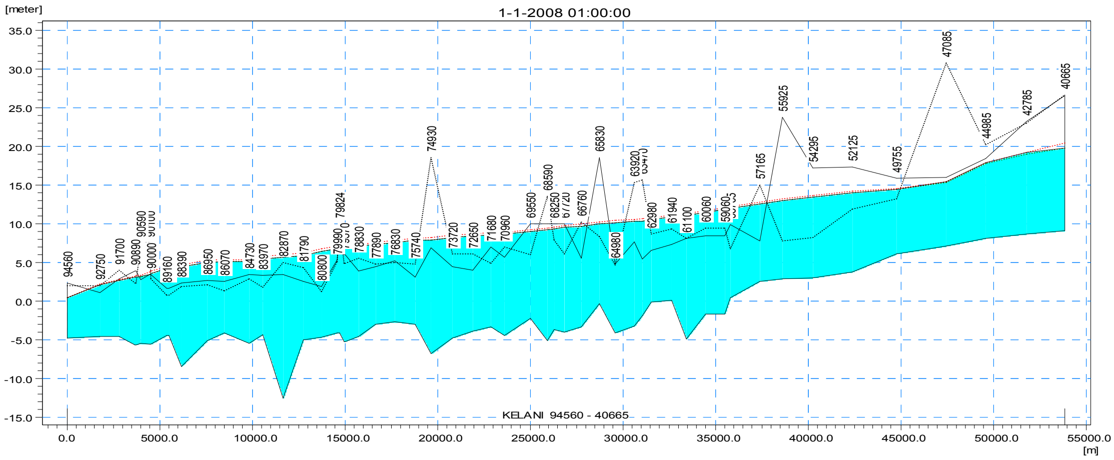
The river channel capacity in terms of water level and discharge was estimated in order to identify and decide the necessary structural measures. Hence, during this analysis, the runoff from all sub catchments are directed to main river without having any flood storage outside the main river, aiming to estimate maximum water level and discharge at the main river for various return periods. The simulated water profiles are given below.

(1) Kelani River Maximum Water Level Profiles

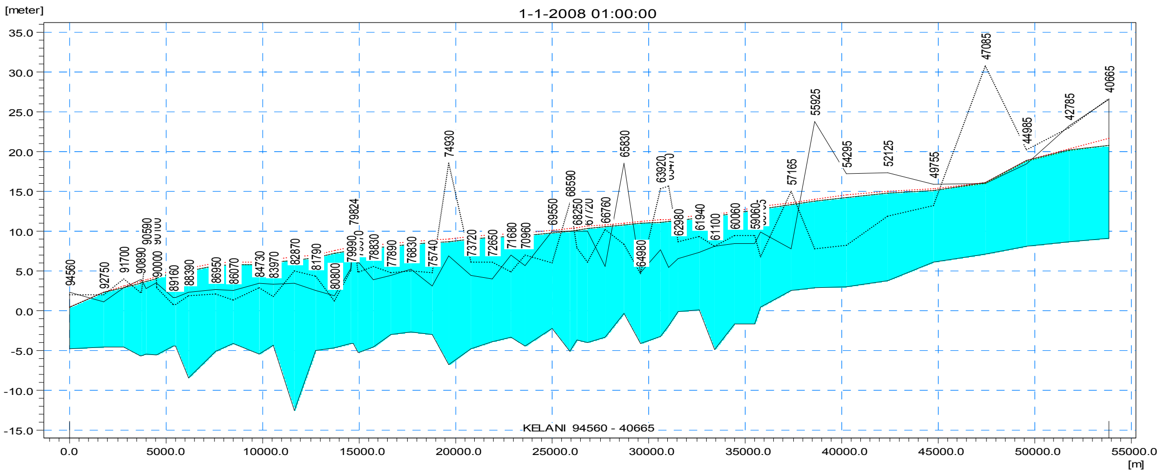
(a) Kelani River (2 year)



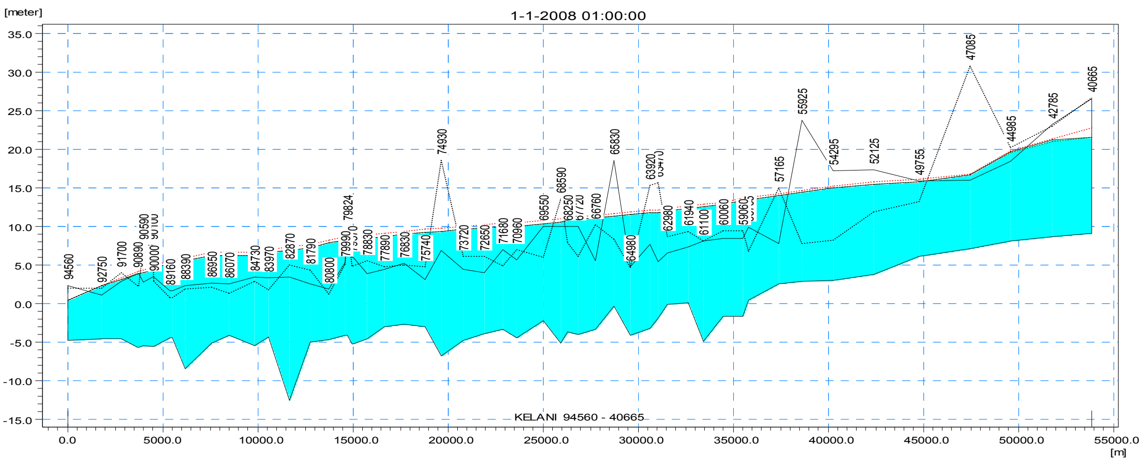
(b) Kelani River (5 year)



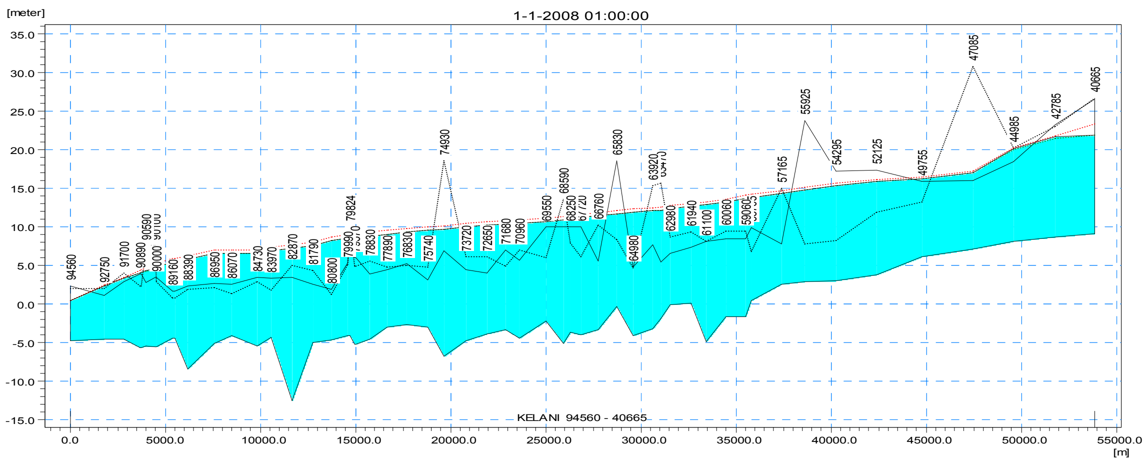
(c) Kelani River (10 year)



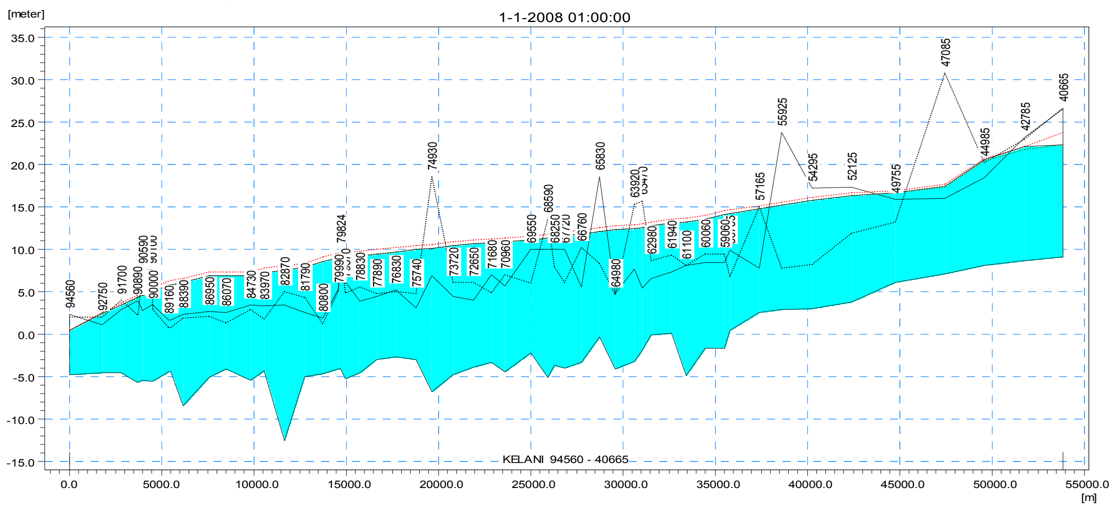
(d) Kelani River (20 Years)



(e) Kelani River (30 Year)



(f) Kelani River (50 year)

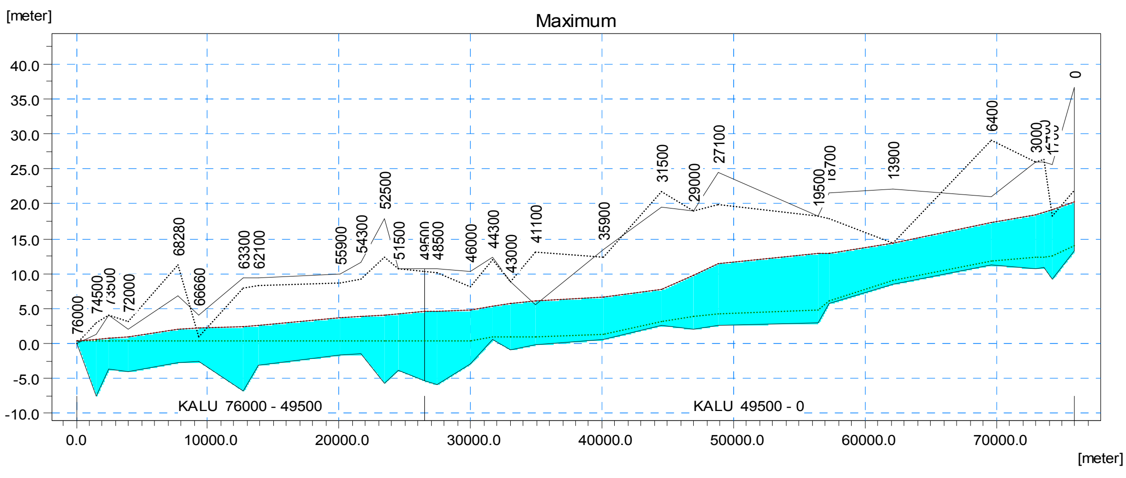


Source:JICA Study Team

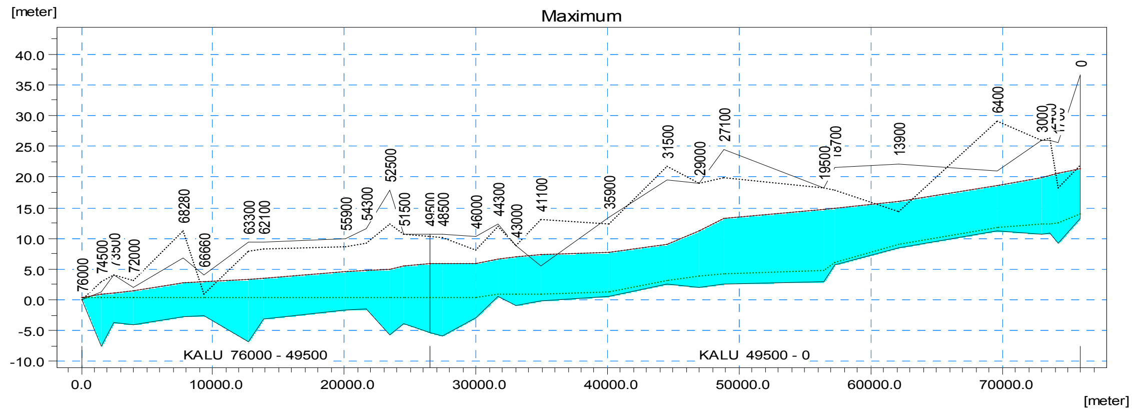
Figure B.10.1 Maximum Water Level Profile along Kelani River

(2) Kalu River Maximum Water Level Profiles

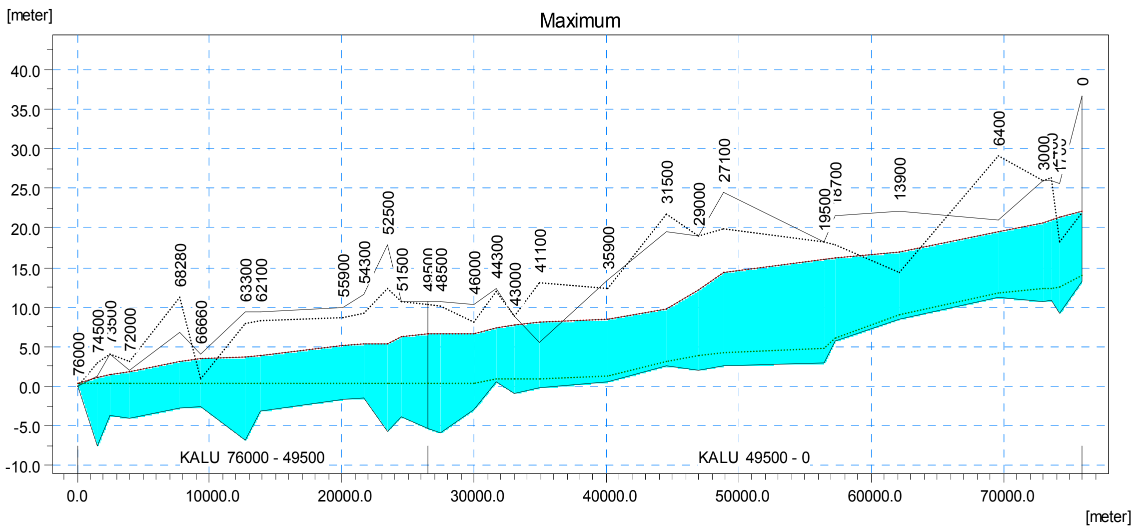
(a) Kalu River (2 year)



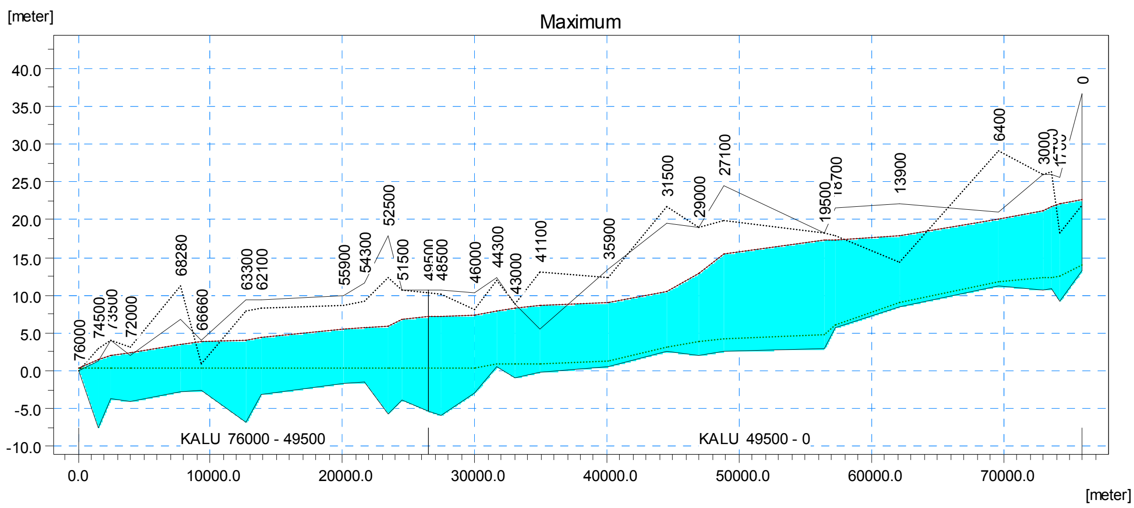
(b) Kalu River (5 year)



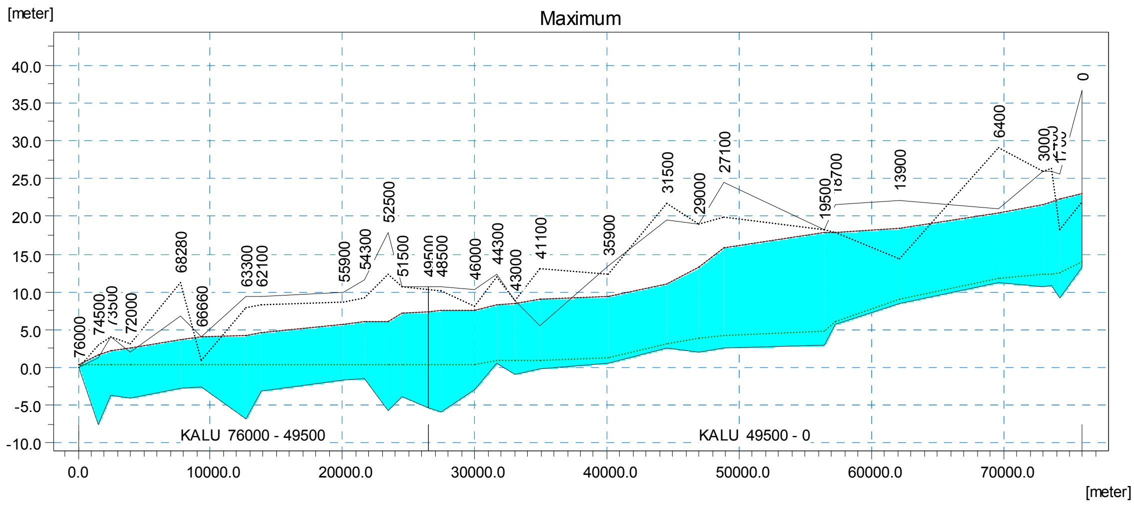
(c) Kalu River (10 year)



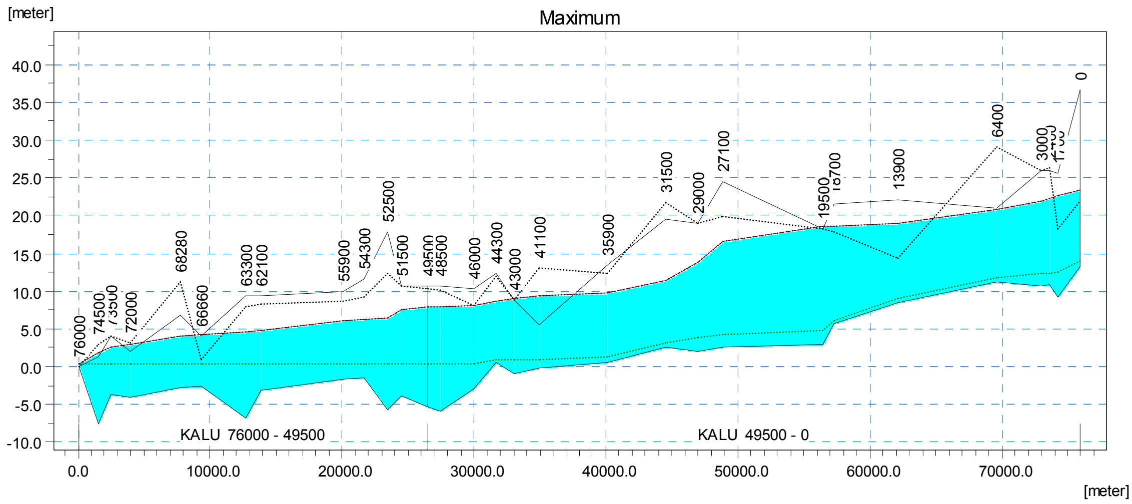
(d) Kalu River (20 year)



(e) Kalu River (30 year)



(f) Kalu River (50 year)

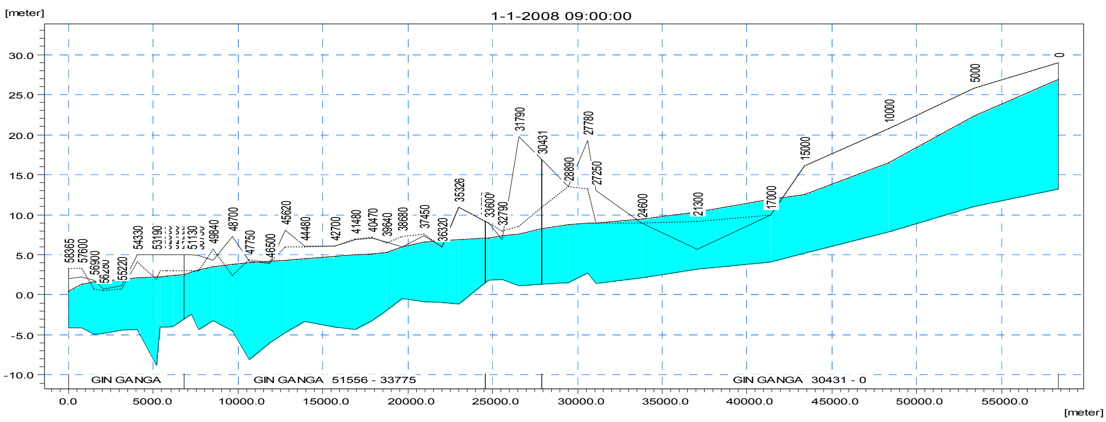


Source:JICA Study Team

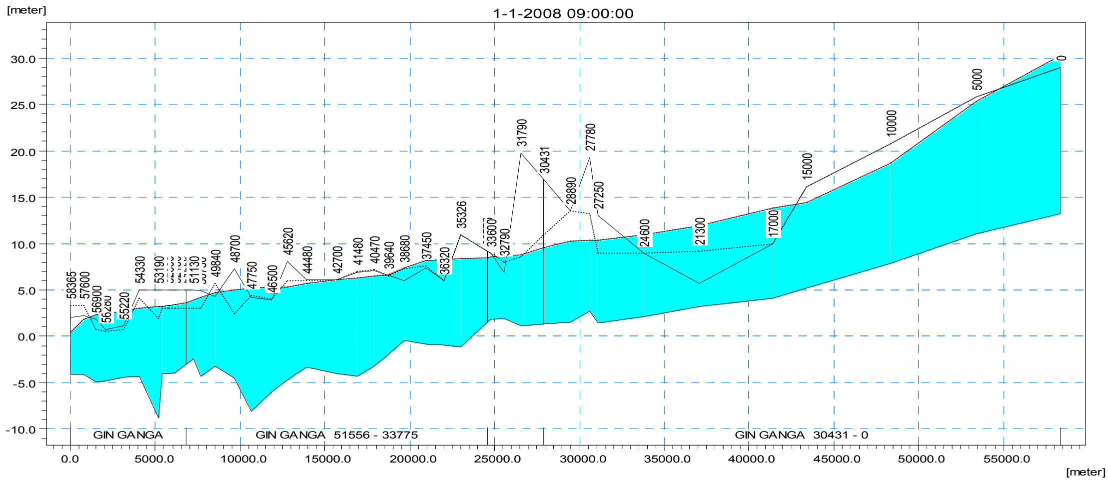
Figure B.10.2 Maximum Water Level Profile along Kalu River

(3) Gin River Maximum Water Level Profiles

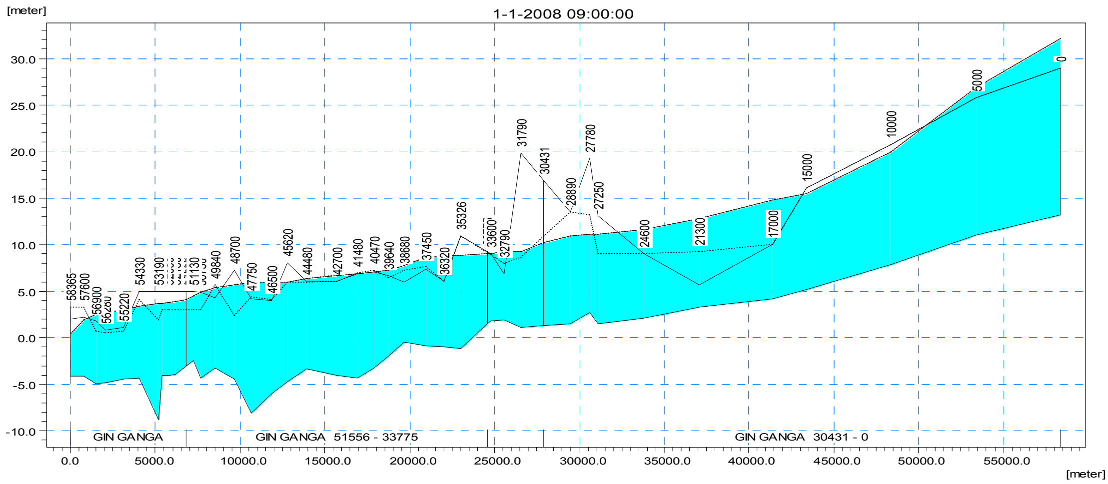
(a) Gin River (2 year)



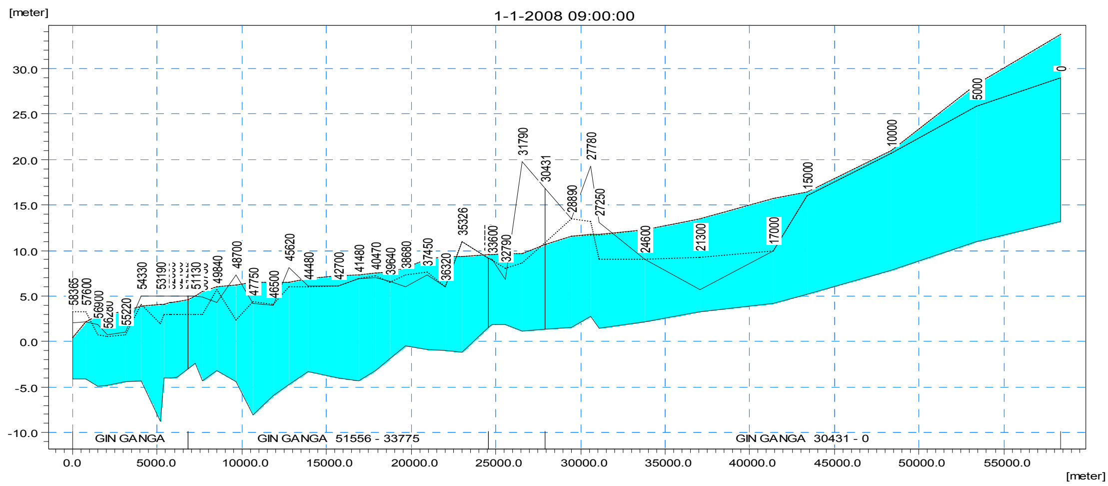
(b) Gin River (5 year)



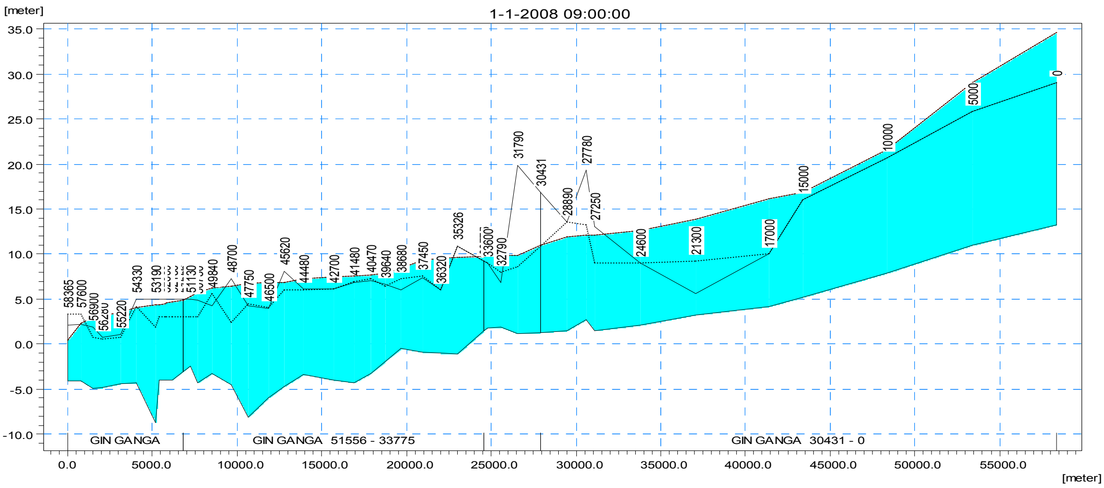
(c) Gin River (10 year)



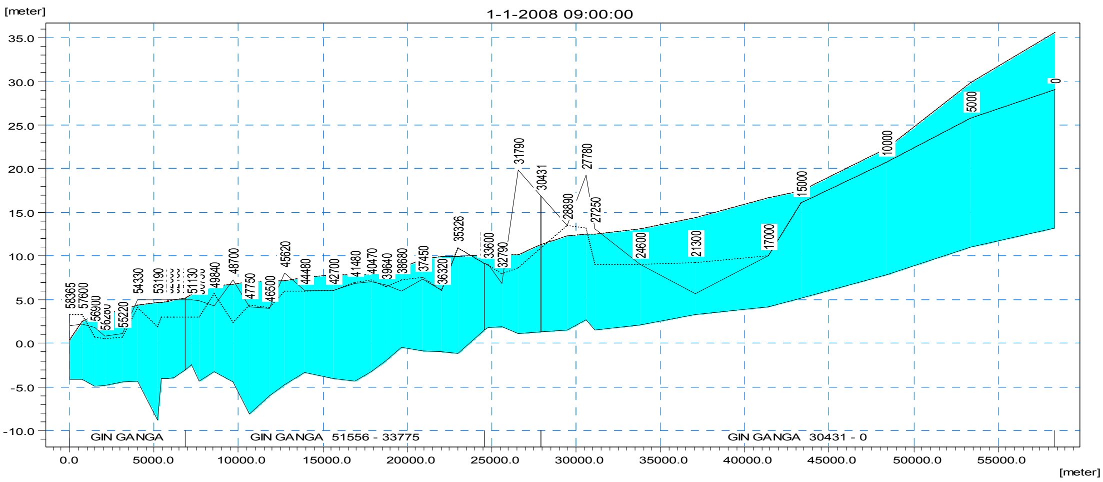
(d) Gin River (20 year)



(e) Gin River (30 year)



(f) Gin River (50 year)

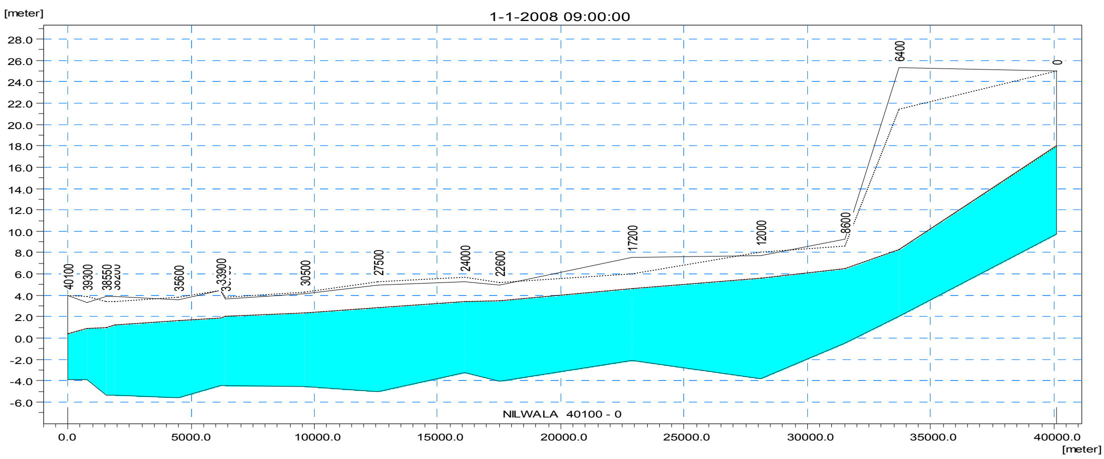


Source:JICA Study Team

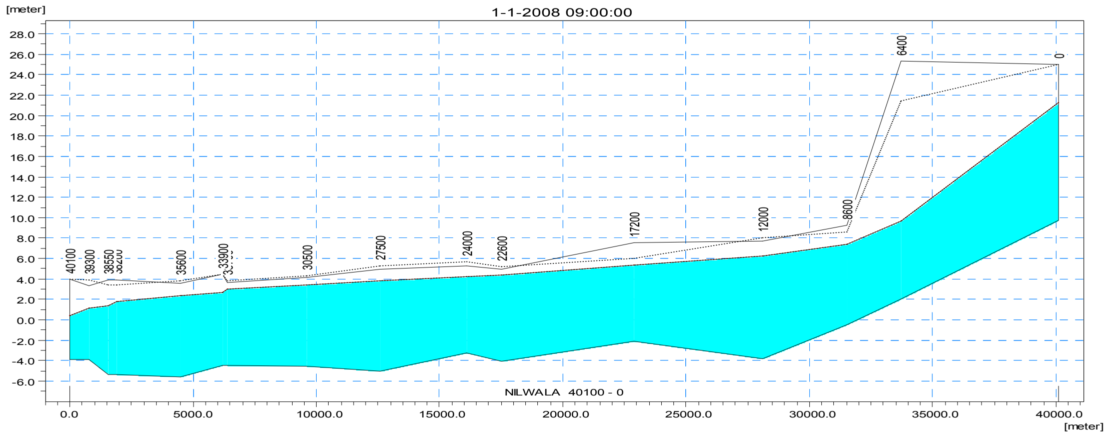
Figure B.10.3 Maximum Water Level Profile along Gin River

(4) Nilwala River Maximum Water Level Profiles

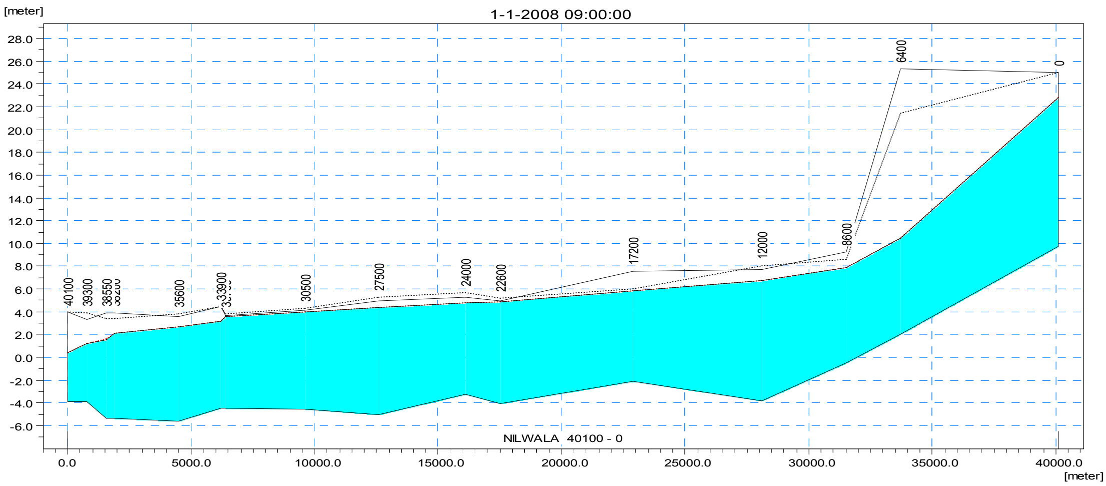
(a) Nilwala River (2 year)



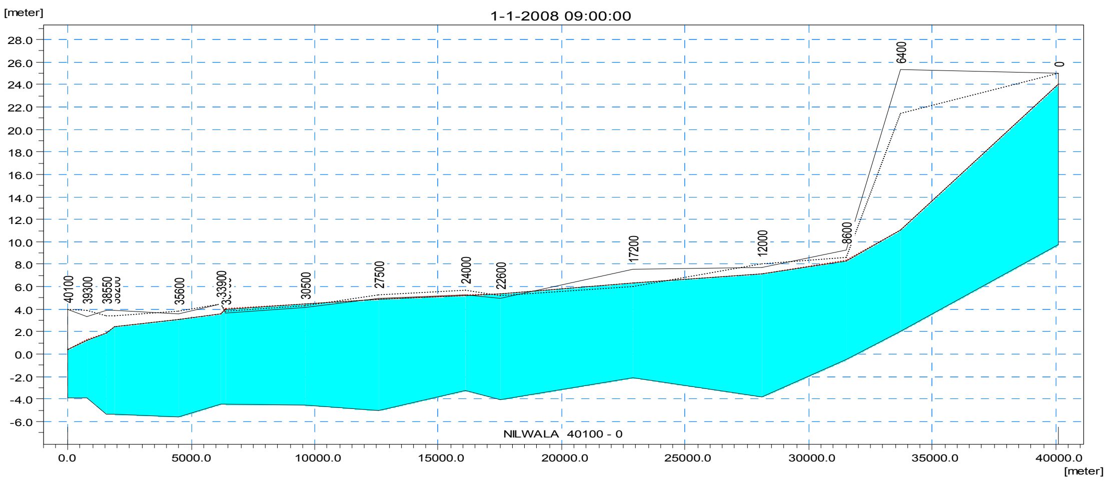
(b) Nilwala River (5 year)



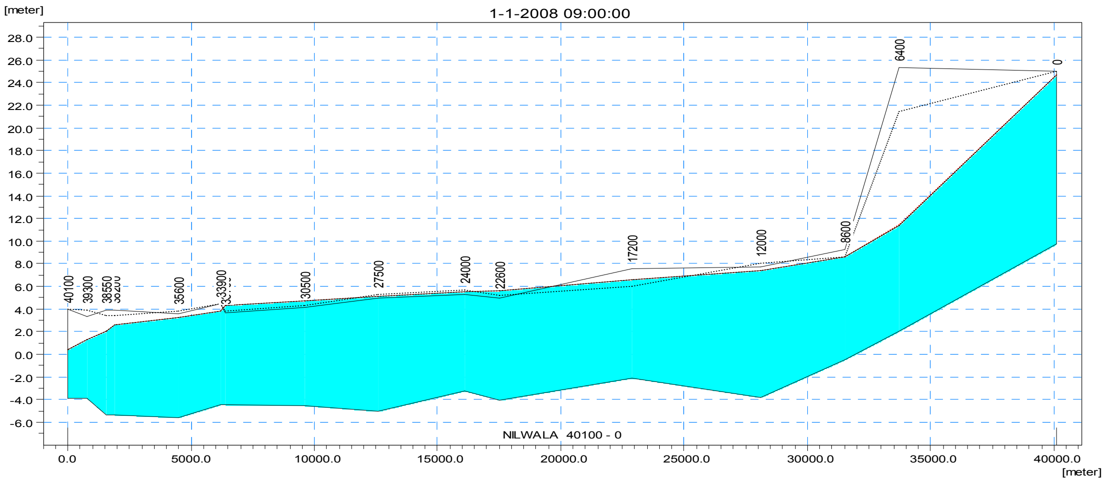
(c) Nilwala River (10 year)



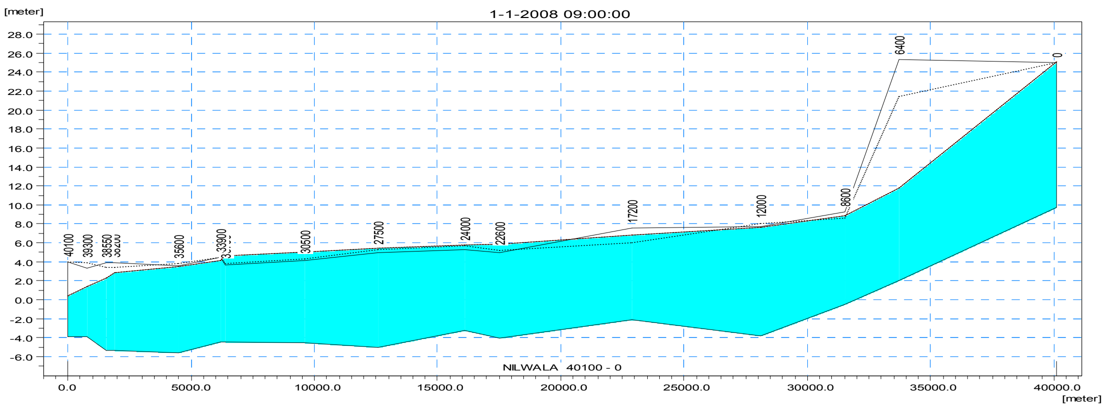
(d) Nilwala River (20 year)



(e) Nilwala River (30 year)



(f) Nilwala River (50 year)



Source:JICA Study Team

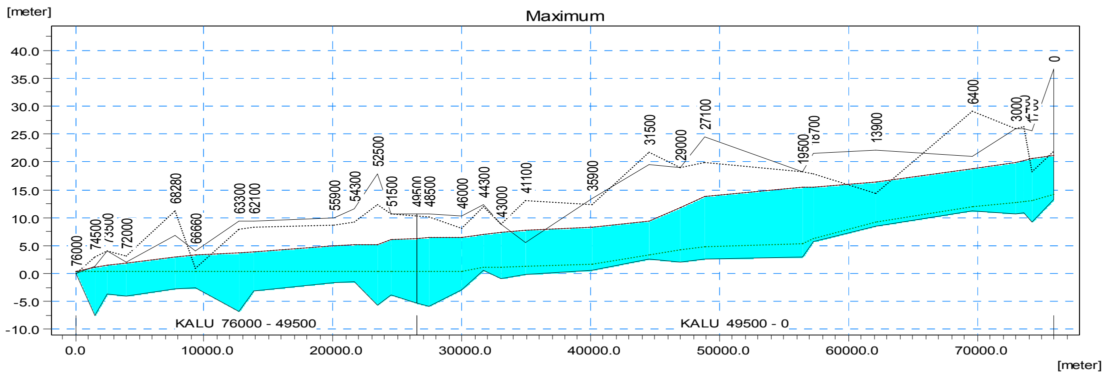
Figure B.10.4 Maximum Water Level Profile along Nilwala River

B.10.2 River channel capacity with selected upstream reservoirs

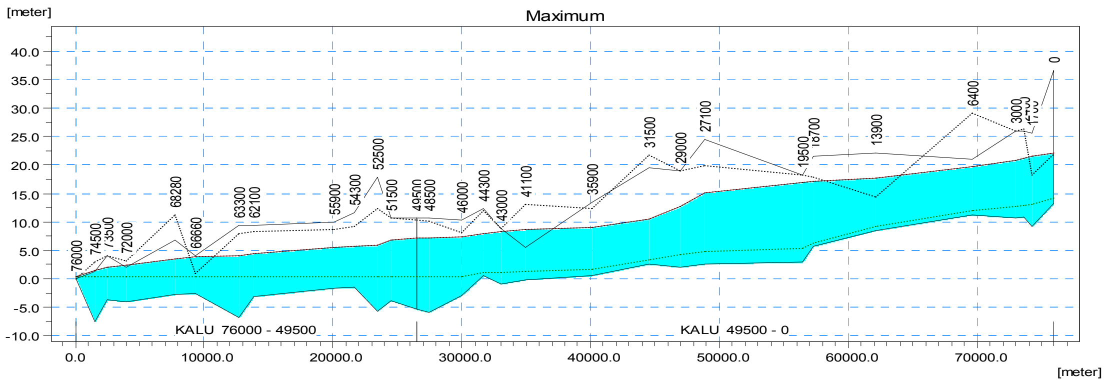
The water level and discharge in main rivers were estimated with proposed development schemes using MIKE 11 model. In case of Kalu River, retarding effect of Malwala Reservoir is taken into account whereas effect of Jasmin, Neluwa and Medìripiiya reservoirs for Gin River and effect of Atu Ela, Hulandawa and Digili Oya reservoirs for Nilwala river were taken into analysis. However, during this study, especially for Gin and Nilwala basins, a simplified method was applied with basic assumptions in determining the reservoir capacities as explained in the main report.

(1) Kalu River Maximum Water Level Profiles with Malwala Reservoir

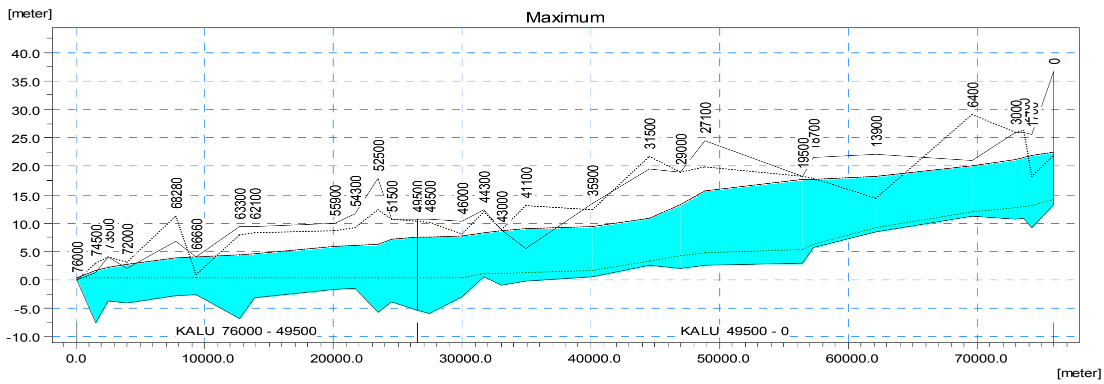
(a) Kalu River (10 year)



(b) Kalu River (30 year)



(c) Kalu River (50 year)

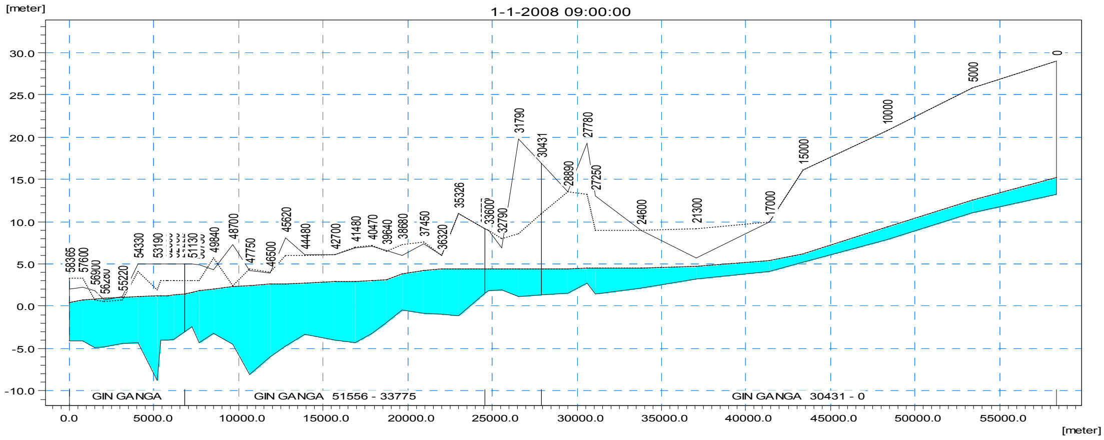


Source:JICA Study Team

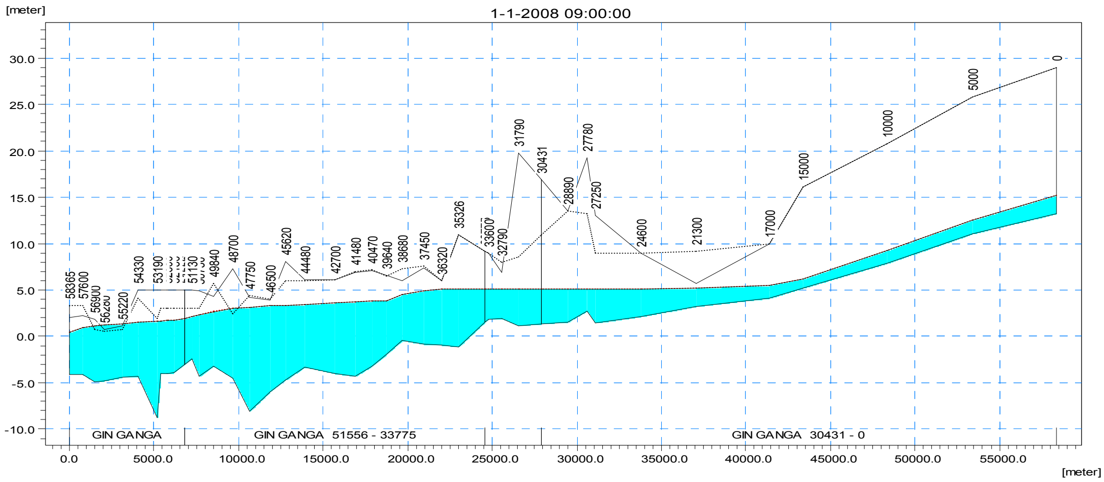
Figure B.10.5 Maximum Water Level Profile along Kalu River with Malwala Reservoir

(2) Gin River Maximum Water Level Profiles with Upstream Reservoirs

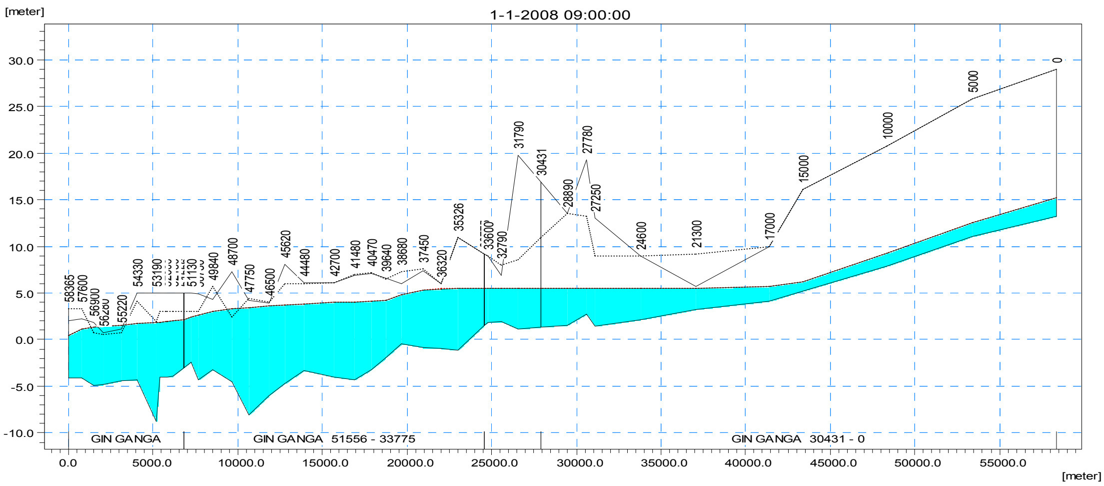
(a) Gin River (10 year)



(b) Gin River (30 year)



(c) Gin River (50 year)

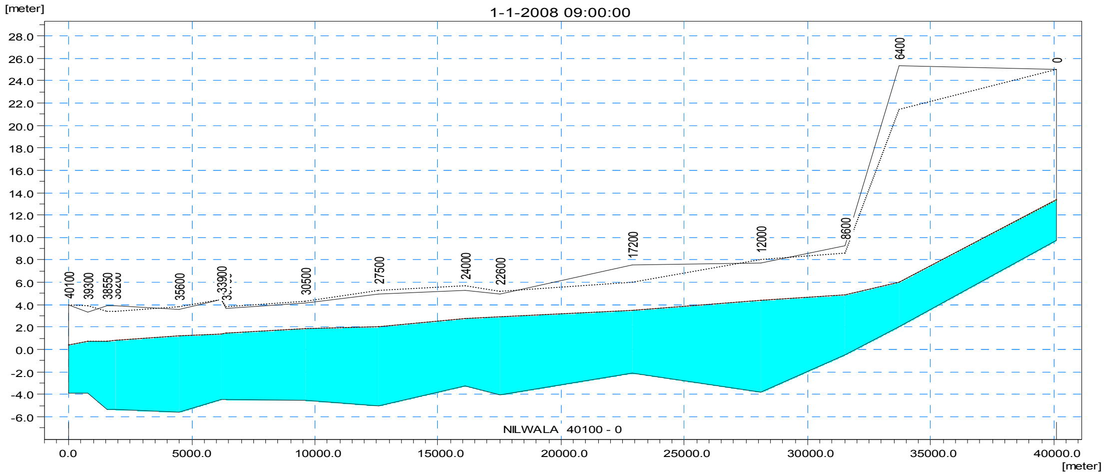


Source:JICA Study Team

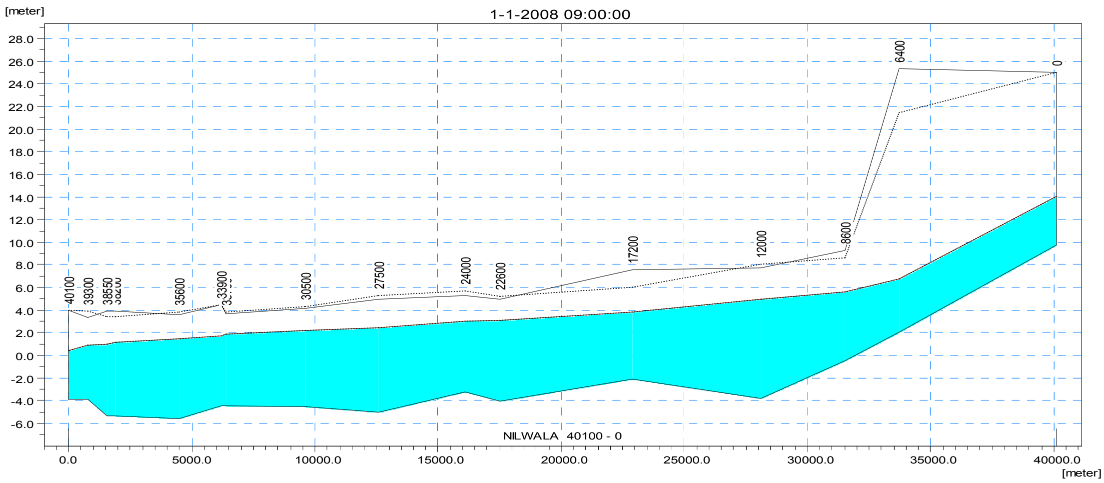
Figure B.10.6 Maximum Water Level Profile along Gin River with Upstream Reservoirs

(3) Nilwala River Maximum Water Level Profiles with Upstream Reservoirs

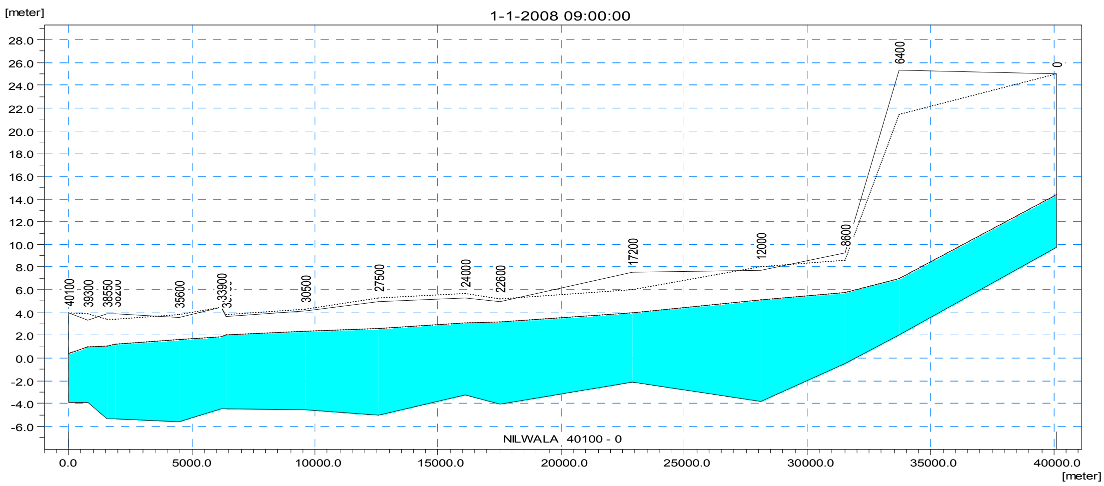
(a) Nilwala River (10 year)



(b) Nilwala River (30 year)



(c) Nilwala River (50 year)



Source:JICA Study Team

Figure B.10.7 Maximum Water Level Profile along Nilwala River with Upstream Reservoirs

B.11 Limitations and Restrictions in Model Studies

The river basin models were calibrated and verified with reasonable accuracy for the purpose of present study. In order to calibrate with high degree of accuracy, it is essential to have detailed information of river, flood plain, discharge and water level as well as rainfall data in the catchment area. However, since limitations and restrictions were observed. Throughout the study following points shall be improved in order to elaborate the river basin models, which were created by the current study.

- Inadequate distribution of rainfall stations within sub catchments
- Non reliability of rainfall records during heavy rainfall events
- Non availability of higher time resolution rainfall records (eg. hourly instead of daily) at least from few stations during heavy rainfall events (for simulation of flash floods in rapidly responding mountainous sub catchments)
- Inadequate number of river cross sections
- Inadequate coverage of flood plains in cross sections
- Lack of stream flow measurements at high flows in gauging stations (validity of extrapolated rating curves)
- Non availability of cross section geometry extending to high stages at gauging stations
- Significant mismatch between available cross sections and those obtained at gauging stations
- Lack of details of flood prone areas acting as off channel storage areas