ENVIRONMENTAL FLOW ASSESSMENT OF GORAI-MADHUMATI- KALIGANGA- BALASWAR RIVER SYSTEM

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ENVIRONMENTAL FLOW ASSESSMENT OF GORAI-MADHUMATI- KALIGANGA- BALASWAR RIVER SYSTEM

A THESIS SUBMITTED TO THE DEPARTMENT OF WATER RESOURCES ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF **MASTER OF SCIENCE IN WATER RESOURCES ENGINEERING**

SUBMITTED BY

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CERTIFICATION OF APPROVAL

We hereby recommended that the M.Sc.Engg. Research work presented by Mohammad Tofail Islam, Roll No. 1014162095(P), Session: October 2014, entitled "**Environmental Flow Assessment of Gorai-Madhumati-Kaliganga-Balaswar River System**" has been accepted as satisfactory in partial fulfilment of the requirements for the degree Master of Science in Water Resources Engineering on 14, September 2019.

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DECLARATION

This is to certify that this project work entitled **“Environmental Flow Assessment of Gorai-Madhumati-Kaliganga-Balaswar River System”** has been done by me under the supervision of Dr. Umme Kulsum Navera, Professor, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, Dhaka. I do hereby declare that this project or any part of it has not been accepted elsewhere for the award of any degree or diploma from any other institution.

Signature of the student

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n	Meaning Roughness Co-efficient
A_i	Surface area of cell i for PHABSIM
C_i	Combined suitability of cell i for PHABSIM
V_i	Suitability associated with velocity in cell i for PHABSIM
D_i	Suitability associated with depth in cell i for PHABSIM
S_i	Suitability associated with channel index in cell i for PHABSIM
V	Velocity
a	Cross sectional area
q	Lateral inflow per unit distance
S_f	Frictional slope
G	Acceleration due to gravity
Z	Elevation of the water surface
V	Volume of the water quality cell (m^3)
Φ	Water temperature (C) or concentration (kg/ m^3)
Q	Discharge (Cumec)
D	User-defined dispersion coefficient (m^2s-1)
A	Cross sectional area (m^2)
S	Sources and sinks (kg s-1)

LIST OF ABBREVIATIONS

1-D	One-Dimensional
BBM	Building Block Methodology
BTM	Bangladesh Transverse Mercator
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
CEIP	Coastal Embankment Improvement Project
CEGIS	Center for Environment and Geographic Information Services
CYM	Constant Yield Method
DoF	Department of Fisheries
DS	Down-Stream
EFA	Environmental Flow Assessment
E-flow	Environmental Flow
EFR	Environmental Flow requirement
EOL	End of Line
FDC	Flow Duration Curve
GIS	Geographic Information System
GMKB	Gorai-Madhumati-Kaliganga-Balaswar
GoB	Government of Bangladesh
GRRP	Gorai River Restoration Project
HEC-RAS	Hydrologic Engineering Centers River Analysis System
H I S	Habitat Suitability Index
IWM	Institute of Water Modelling
m^3/s	Cumec
MAF	Mean Annual Flow
MIKE 11	DHI's One Dimensional Modelling Software
MoWR	Ministry of Water Resources
PHABSIM	Physical Habitat Simulation Method
PWD	Public Works Department
SA	South Africa

SOL	Start of Line
SWMC	Surface Water Modelling Centre
UK	United Kingdom
US	UP-Stream
USA	United State of America
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WARPO	Water Resources Planning Organization
WL	Water Level
WPT	Weighted Perimeter Technique
WSL	Water Surface Level
WUA	Weighted Usable Area

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ABSTRACT

Environmental flow (e-flow) in a river describes the quantity, quality and timing of water flow required to sustain minimum flow/ fresh water, estuarine ecosystem, the livelihoods and well-being of people that depend on these ecosystems. Bangladesh is already facing problem due to upstream withdrawal on Ganges River which caused the Gorai River (main tributary of Ganges in Bangladesh) almost dried up during low flow season. As a result, the demands for irrigation, navigation, industries and habitat suitability of fish species and other water users could not get the minimum water flow during the dry low flow season. Because of the reduced flow of water, the intrusion of saline water in the upstream has progressively made the south west region of the country vulnerable to increase salinity. In view of these river functions and problem, the assessment of environmental flow is essential. This research work has been carried out to assess the e-flow requirement of Gorai-Madhumati-Kaliganga-Balaswar River System which is a dominant river system in south-west region of Bangladesh.

There are different methods have been used for determining e-flow in many countries around the world. To obtain the e-flow of Gorai-Madhumati-Kaliganga-Balaswar River System the methodology covers the hydrological methods such as Tennant Method, Flow Duration Method (FDC), Constant Yield Method (CYM), Hydraulic rating method (Weighted Perimeter Method), Habitat simulation method (PHABSIM), Holistic Method (Building Block Methodology). Fisheries such as Bacha, Ayeer, Golda, Carp Species and Salinity are the indicators for this research work. One-Dimensional mathematical model has also been set up by using HEC-RAS Modelling Tool for the condition of salinity to maintain the required e-flow through Gorai-Madhumati-Kaliganga-Balaswar River System. Historical flow data, Historical Water Level, Cross-sectional data and Salinity Data collected from Bangladesh Water Development Board (BWDB).

The e-flow of Gorai and Madhumati River has been assessed by considering hydrological approaches and dominant fish requirement. Both of the Rivers, Dominant fish requirement is higher than hydrological approaches and the mean monthly flow is less than the required e-low during low flow season. In that case Gorai and Madhumati River must be maintained the minimum computed e-flow during low flow season for keeping the sustainable ecosystem. The flow demand for considering hydrological approaches and Dominant fish requirement in Kaliganga and Balaswar River is so called satisfactory; the mean monthly flow is higher than the required e-flow in both Kaliganga and Balaswar River. The existing salinity condition of Gorai and Madhumati River (upstream of Kamarkhali Bridge) has remained below 0.20 and 0.25 ppt respectively and the salinity level based on required e-flow has been remained the near to same. But Madhumati (downstream of Kamarkhali Bridge), Kaliganga and Balaswar River existing salinity condition has been remained from January to June is 1.2-5.2 ppt, 2.1-7.5 ppt and 5.5 to 8.2 ppt respectively and July to December 0.75-4 ppt, 1.2-6 ppt and 1.2-7 ppt respectively. The salinity level based on required e-flow of Madhumati, Kaliganga and Balaswar River from January to May has been remained around 0.3-1.80 ppt, 0.75-2.0 ppt and 1-2.5 ppt respectively and also from July to December has been remained below 1ppt.

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Environmental flow (e-flow) is that flow that is essential within a stream to maintain its natural resources and dynamics at desired or specified level. Environmental flow means that water in rivers is managed in such a way that downstream users and ecosystems receive enough water for their sustainability. Environmental flow assessment (EFA) is required for balancing the use (or development) of water from aquatic ecosystems for various purposes whilst protecting (or managing) the aquatic ecosystems so that it can continue to be used by present and future generations (Akter, 2010; Ali, 2012). In simple, e-flow is the amount of water needed in a watercourse to maintain healthy ecosystems. The amount of the original river flow regime that needs to flow down the river in order to maintain specified valued features of the river ecosystem is generally referred to as the Environmental Flow Requirement (EFR). The term Environmental Flow Requirements is used as well, to emphasis the fact that it concerns water that remains within the river ecosystem and is not withdrawn to be used elsewhere outside of the river ecosystem (Bari and Marchand, 2006). Knowledge of e-flow requirements is a must in planning for new projects related to water development and evaluating the operation and management of existing projects.

1.2 Importance of the Study

Bangladesh is a riverine country. About 405 rivers including 57 common rivers (54 rivers with India and other 3 rivers with Myanmar) flow through the country constituting a waterway (all rivers, streams, creeks and channels) of total length around 24,140 km. So, the water resources development and river system is the main factor of lives and livelihoods of the People of Bangladesh. In 1975, India commissioned a barrage across the Ganges at Farakka in West Bengal to divert 40000 cumec of water into Bhagirathi-Hoogli River to improve the navigability of Calcutta Port (Akter, 2010). This has decreased considerably the discharge of Ganges and Gorai in Bangladesh part. The Gorai takes off from the Ganges at Talbaria, north of Kushtia town and 16 km downstream from Hardinge Bridge. After running about 200 km the Gorai bifurcates into Madhumati and Nabaganga River. Madhumati passes through Gopalganj and Pirojpur district and after these areas it is named as Kaliganga River. At the downstream end, the Kaliganga River and other distributaries met and are renamed as Baleshwar River which discharging into the Bay of Bengal. As effect of Farakka barrage, the offtake of Gorai River almost silted up and water from Ganges to Gorai cannot flow in the dry period. As a result, the demands for irrigation, navigation, industries and habitat suitability of fish species other water users could not mitigate the minimum water flow requirement during the dry period. Because of the reduced flow of water, the intrusion of saline water in the upstream has progressively made the south west region of the country vulnerable to increase salinity (BWDB, 2017).

FAP 4 study, 1993 study reported that the Gorai River region used to contain at least 200 of the 260 species of freshwater and enormous fish indigenous to Bangladesh. However according to recent report, many of these species are now rare or endangered (EGIS, 2000; Hanif et al., 2016) due to reduced flow of Gorai River in the dry period. A recent study (Hanif et al., 2016) on small indigenous species of Gorai River reported that among the 143 small indigenous species available in Bangladesh, they have found a total of 40 small indigenous species fishes in the study area.

After running about 200 km the Gorai bifurcates into Madhumati and Nabaganga River. Madhumati passes through Gopalganj and Pirojpur district and after these areas it is named as Kaliganga River. At the downstream end, the Kaliganga River and other distributaries met and are renamed as Balaswar River which discharging into the Bay of Bengal. To estimate e-flow at Gorai off-take, e-flow requirement of Gorai-Nabaganga-Passure-Shibsha River system and Gorai- Madhumati-Kaliganga-Balaswar River system is essential. There is research work based on Gorai-Nabaganga-Passure-Shibsha River system (BWDB, 2017). The flow requirement at Gorai offtake depends highly on the e-flow requirement for Gorai-Madhumati-Kaliganga-Balaswar River system. To maintain the habitat requirement for fish species and also maintain the salinity condition for required e-flow it is important to assess the e-flow as the Gorai-Madhumati-Kaliganga-Balaswar River system.

1.3 Scope of the Study

The scopes of this study on environmental flow assessment for Gorai-Madhumati-Kaliganga-Balaswar River system are given as below:

1. To collect historical water level and discharge data from secondary sources and perform statistical analysis of hydrological data.

2. To collect fish data from secondary sources to select dominant fish species and develop habitat suitability criteria for these dominant fish species.

3. To develop a one dimensional fish habitat model to predict optimum water requirement for dominant fish species.

4. To set up a one dimensional hydrodynamic model of the Gorai-Madhumati-Kaliganga-Balaswar River system and calibrate and validate the model.

5. To set up a one dimensional salinity model and simulate salinity condition for required e-flow

6. To assess environmental flow assessment by different hydrological approaches and habitat simulation model

1.4 Objectives of the Study

The aim of this study is to assess the e-flow requirement of selected river system in terms of their functions and problems. The objectives of this study are to be selected based on above circumstances. Objectives of the study are as follows:

1. To assess the e-flow requirement of Gorai- Madhumati-Kaliganga- Balaswar River System by hydrological approaches.

2. To assess the e-flow for dominant fish species of Gorai-Madhumati-Kaliganga-Balaswar River system by using fish habitat model.

3. To determine the salinity level for required e-flow by using one dimensional mathematical modeling HEC-RAS.

Possible outcomes of the study are as follows:

1. The minimum flow requirement from different hydrological approaches has been indicated the e-flow requirement of Gorai-Madhumati-Kaliganga-Balaswar River system.

2. The monthly average discharge requirement for dominant fish species during the dry season has been come out from this study.

3. The condition of salinity to maintain the above-mentioned e-flow through the Gorai-Madhumati-Kaliganga-Balaswar River system has been come out from the mathematical modeling.

1.5 Outlines of the thesis

The thesis has been organized under six chapters.

Chapter 1 describes the importance of the study, objectives and possible outcomes of the study.

Chapter 2 describes literatures, previous studies related to this study for finding the research gaps.

Chapter 3 describes the theoretical background for one dimensional model and a brief description of the approach and methodology of this study.

Chapter 4 describes the data collection from various sources, brief discussion of study area and describes the parameters of e-flow indicators.

Chapter 5 demonstrates the results of e-flow assessment by hydrological approaches in terms of discharge, determine the e-flow requirement for dominant fish species by using fish habitat model and also determine the salinity level to maintain the required e-flow by using one-dimension mathematical modeling HECRAS.

Finally, conclusion and recommendation for further study are outlined in Chapter 6.

CHAPTER 2
LITERATURE REVIEW

2.1 General

Available literatures have been reviewed for searching out available techniques for assessing e-flow requirements. In previous studies, the key information and recommendations of different techniques for different environmental values are described with their limitations, advantages and cost-effectiveness. It has been identified that the function, definition and rational for EFA of a river, identified the different methods and approaches in different countries, application and case studies in different river system in Bangladesh.

2.2 Definition of e-flow

Environmental flow has become a central concern for river development in many parts of the world since the middle of the 20^{th} century. The term “environmental flow requirement” is often described “minimum flow” (arbitrarily 10% of the mean annual runoff) in a river, or the “managed flood” and “river flow objective” (Acreman et al., 2000). e-flow is a key contributor to river health, economic development and poverty alleviation (Dyson et al., 2003). Several attempts have been made to define river ecosystem integrity, health, sustainability and resilience (Norris and Thoms, 1999). Sustainability of the river ecosystem was categorized at the Earth Summit in Rio de Janeiro in 1992 through “water allocation to species and ecosystems besides human needs” (Acreman and Dunbar, 2004).

2.3 Definition of e-flow assessment

EFA is required for balancing the use (or development) of water from aquatic ecosystems for various purposes whilst protecting (or managing) the aquatic ecosystems so that it can continue to be used by present and future generations (Akter and Ali 2012). Historically, and still today in many instances, the focus of e- flow assessment was entirely on the maintenance of economically important freshwater fisheries. There is no single best way for EFA. Each method, approach or framework will thus be suitable only for a set of particular circumstances. (Marchand, 2003).

Table 2.1: Three different categorizations of EFA Methodologies

Organization	Categorization of EFA	Sub-category	Examples
IUCN (Dyson et. al., 2003)	Methods	Look-up tables	Hydrological (e.g.Q95 Index)
			Ecological (e.g.Tennant Method Index)
		Desk-top Analysis	Hydrological (e.g. Richter Method)
			Hydraulic (e.g. Wetted Perimeter Method)
			Ecological
		Functional Analysis	Building Block Method (BBM), Expert Panel Assessment
			Method, Benchmarking Methodology
		Habitat Modelling	PHABSIM
	Approaches		Expert Team Approach
			Stakeholder Approach (expert and non-expert)
	Frameworks		IFIM, DRIFT
World Bank (King and Brown, 2003)	Perspective Approaches	Hydrological Index Method	Tennant Method
		Hydraulic Rating Methods	Wetted Perimeter Method
		Expert Panels	
		Holistic Approaches	BBM
	Interactive approaches		IFIM
			DRIFT
IWMI (Tharme, 2003)	Hydrological Index Method		Tennant Method
	Hydraulic Rating Methods		Wetted Perimeter Method
	Habitat Simulation methodologies		IFIM
	Holistic methodologies		BBM, DRIFT, Expert Panels, Benchmarking Methodology

(Source: Gopal, 2013)

Table 2.2: Comparison of four main types of environmental flow methodologies presently used worldwide

Methodology Type	Riverine ecosystem components addressed	Data needs	Assessments	Appropriate level of application
Hydrological Index	Whole ecosystem	Virgin/naturalized historical flow records Some use historical ecological data	Hydrological Some ecological expertise	Reconnaissance level of water resource developments, or as tool within other methodology
Hydraulic Rating	Instream habitat for target biota	Historical flow records Discharge hydraulic variables, typically from single river cross-section Hydraulic variable(s) as surrogate for habitat flow needs of biota	Hydrological Some hydraulic modeling Some ecological expertise	Water-resource developments where no or limited negotiation is involved
Habitat Simulation	Primarily instream habitat for target biota Some consider: channel form, sediment transport, water quality, riparian vegetation, wildlife	Historical flow records Many hydraulic variables – multiple cross-sections Physical habitat suitability data for target species	Hydrological Advanced computer-based hydraulic and Habitat modeling Specialist ecological expertise on physical habitat-flow needs of target species	Water resource developments, often large-scale, involving rivers of high conservation and/or strategic importance, and/or with complex, negotiated offstream/instream tradeoffs; primarily developed countries

Table 2.2: Comparison of four main types of environmental flow methodologies presently used worldwide (contd.)

Methodology Type	Riverine ecosystem components addressed	Data needs	Assessments	Appropriate level of application
Holistic	Whole ecosystem all/most individual components Some consider: groundwater, wetlands, estuary, floodplain, social dependence on ecosystem, as well as instream and riparian components	Historical flow records Many hydraulic variables - multiple cross-sections Biological data on flow- and habitat related requirements of all biota and ecological components	Hydrological Advanced computer based hydraulic modeling Habitat modeling in some cases Specialist expertise on all ecosystem components Some require social and economic expertise	Water resource developments, often large-scale, involving rivers of high conservation and/or strategic importance, and/or with complex offstream/instream tradeoffs; developing and developed countries

(Source: King. et al., 1999)

2.4 Status of e-flow Assessment of Various Countries

Just over half (52%) of the countries representing the developed world were shown to be routinely involved in e- flow initiatives, at various levels of advancement. In contrast developed countries (WRI, 2002), in the vast developing countries environmental flow assessment has received significantly but only 11% of the developing countries are recorded as applying environmental flow methods (Tharme,2002). This applies even to semi-arid and arid parts of the world, where the availability, quality and sustainability of fresh water resources play a crucial role in socio-economic development. Presently, 49 countries are formally designated 'Least Developed Countries' (LDCs) by the Economic and Social Council of the United Nations, on the basis of the criteria: low income, human resource weakness and economic vulnerability. Of these, five African countries (or 10%) have implemented some kind of environmental flow assessment methods. It is important, however, to remember that even the most successful environment flow requirement will only partially militate against the effect of a dam or diversion on a river (King. et al., 1999).

The environmental flow methodology has long enjoyed legal status in America. In Spain, 10% of the mean annual run-off of a river should be released from dams as environmental flow, which although probably insufficient to sustain the downstream environment, at least acknowledge the need for environmental flow. In Europe the enactment of environmental flow requirements varies between the countries. Often the re-licensing of dam operations provides the main framework for executing environmental flow requirements. And although the European Union Water Framework Directive has clearly defined for environmental standards. In Australia most applications thus far, especially early on, centered on the use of expert panel approaches such as the Expert Panel Assessment Method (EPAM) and more advanced Scientific Panel Assessment Method (SPAM), and the Holistic Approach. Increasingly sophisticated, diverse methodologies have emerged, including the Flow Restoration Methodology (FLOWRESM) and the Benchmarking Procedure, especially suitable for poorly studied systems (Tharme, 2002). In south Africa the National Water Act (NWA) of 1998 provides the legal framework for setting environmental flows. One of the key provisions of the NWA is the recognition that the water resources require protection. This is formalized in the 'Reserve' concept the definition of which is that quantity and quality of water required to satisfy basic human need for all people who are, or who may be, supplied from the relevant water resources and to protect aquatic ecosystems in order to secure ecologically sustainable development.

Globally, in future, the inherent capacity of holistic methodologies to absorb advanced features, like hydraulic and habitat modelling tools, as these become available, as well as their consideration of all major ecosystem components, is liable to render them increasingly suitable compared with habitat simulation approaches. At this level of application, in all instances, technical capacity will need to be developed, and users will require up-to date formal training and ongoing guidance for the successful application of either advanced holistic or habitat simulation methodologies. However, holistic methodologies, such as the Building Block Method (BBM) were specifically designed for situations where data, time and finances are scarce. The BBM can produce answers on EFRs in a few weeks or months. However, inevitably, the confidence in its outputs increases with investment in time and specialist inputs (King et al., 1999). The numbers of individual Environmental flow methods of different types and the advantage and disadvantage of different environmental flow methodologies presently used worldwide for the countries are summarized in Table 2.3.

Table 2.3: Environmental Flow Methodologies Use in Various Countries

Country	Environmental Flow Methodologies in use	Most widely used or preferred methodologies	Comments
Alaska	IFIM; Tennant Method, including modifications thereof on the basis of professional judgment and fish data	Tennant Method	Holistic methodologies do not appear to have been applied Estes (1996) provides further information
Australia	State-dependent wide array of methodologies, including Tennant Method; FDCA and various other hydrological indices; Holistic Method; BBM	RHYHABSIM, IFIM, and various holistic methodologies	Northern Territory and Australian Capital Territory do not appear to have employed any methodologies
Austria	Habitat modeling; other methods unspecified	Unspecified	A future aim is to combine IFIM with elements of holistic methodologies
Britain and Wales	Various methodologies: IFIM; hydrological tools (e.g. Micro LOW FLOWS); hydrological indices (e.g. Q95); Environmentally Prescribed Flow Method; Holistic Method	Unspecified	A future aim is to combine IFIM/PHABSIM II analyses for target species with holistic elements
Canada	Various methodologies: IFIM, including Biologically Significant Periods/Fish Rule Curve Approach; Tennant Method, including set percentages of Average Annual Flow (e.g. 25% MAF Method); Wetted Perimeter Method; correlation of fish year class to spawning flow; WSP model; water quality models; 7Q10 Method; Median Monthly Flow Method; FDCA (e. g., 90th percentile);	IFIM used in all of the 7 provinces that apply instream flow methodologies, and Tennant Method or a modification thereof often routinely applied	Northwest Territories do not employ any methodologies Holistic methodologies do not appear to apply

Table 2.3: Environmental Flow Methodologies Use in Various Countries (contd.)

Country	Environmental Flow Methodologies in use	Most widely used or preferred methodologies	Comments
Czech Republic	IFIM	IFIM	IFIM-based procedures are under development
Denmark	Hydrological methods	Median Minimum Method	It is recognized that other low flow hydrological indices are more sophisticated
Finland	EVHA (habitat simulation) and detailed approaches based on physical habitat simulation method	Unspecified	There are no standard methods
France	Habitat simulation methodologies, such as EVHA	EVHA: applied in about 70 cases	Ongoing research is taking place into continuous fish population modeling within an IFIM framework
Germany	Hydrological indices, case-specific expert opinion, and a habitat simulation methodology, CASIMIR	Mean of minimum daily flows for each year,	CASIMIR (Computer Aided Simulation Model for Instream Flow and Riparia) has been applied for benthic invertebrates
Indonesia	IFIM	First studies are in progress	None
Italy	Hydrological indices, including FDCA, daily and annual mean flows, IFIM; Tennant Method, Wetted Perimeter Method	Hydrological indices IFIM in resource-intensive applications	Relationships between fisheries standing crop and environmental variables are under development
Japan	IFIM, including multidimensional hydraulic modeling	Unspecified	Re-evaluation using various methods
Netherlands	Hydrological model, alternative approaches, including HEP, a general habitat suitability scoring model, an ecotope classification (ECLAS), a physical habitat model (MORRES), a habitat suitability model (EKOS)	Unspecified	None

Table 2.3: Environmental Flow Methodologies Use in Various Countries (contd.)

Country	Environmental Flow Methodologies in use	Most widely used or preferred methodologies	Comments
New Zealand	Various hydrological, hydraulic and habitat simulation methodologies (unspecified), IFIM, RHYHABSIM	RHYHABSIM: used on 25 Rivers, IFIM	None
Norway	Hybrid approaches based on habitat modeling,	Microhabitat modeling	None
South Africa	Various hydrological indices, including IFIM, BBM, DRIFT, some alternative approaches, e.g. River Conservation Status Model, geomorphological change flow, Biotopes Approach, hierarchical suite of methodologies for the determination of the Ecological Reserve: Planning Estimate and extended version, Preliminary Reserve Methodology, Comprehensive Reserve Methodology	BBM, DRIFT, and range of methodologies for Reserve determination	The Biotopes Approach is recommended for further investigation, Habitat and water quality modeling techniques are recommended for incorporation into the BBM
USA	State-dependent, extremely wide array of methodologies covering hydrology-based, hydraulic rating, habitat simulation, and various hybrid or alternative approaches; 7 commonly used methodologies: IFIM; Tennant Method, Wetted Perimeter Method; 7Q10 Method; Professional judgment; R-2 Cross Method; hydrological methods based on flow records/FDCA; Water Quality methods; USGS Toe- Width Method.	IFIM, Tennant method Wetted Perimeter; ABF, 7Q10	Holistic methodologies have not been formally applied Habitat modeling techniques, especially using PHABSIM II, are under continual development
China	Various methodologies: IFIM, hydrological tools (e.g., Micro LOW FLOWS), hydrological indices (e.g., Q95), Environmentally Prescribed Flow Method, Holistic Method and Ecotop method	Unspecified	None

(Source: Tharme, 2003)

2.5 e-flow Related Studies in Bangladesh

In Bangladesh, some academic studies have been carried out regarding e-flow assessment.

Rahman (1998) conducted an investigation to determine the instream flow requirement of the Ganges River, one of the mighty rivers of Bangladesh. In this study the author applied three methods of the hydrological approach. The computed instream flow requirement based on analysis of Flow Duration Curve method ranges from 1,580 cumec in dry season to 40,000 cumec in the wet season. The corresponding values for the Constant Yield method ranges from 1,990 cumec to 40,200 cumec and those for the Mean Annual Flow method varies from 1,150 cumec to 23,080 cumec. A comparison of these values with minimum discharge revealed that in the pre-Farakka period, the minimum observed discharge met the flow requirement for instream protection whereas that for the post-Farakka period falls much below the required flow. The study concluded that since the minimum flow is less than the recommended flow for instream protection, the Ganges has suffered substantial morphological and environmental degradation

Zobeyer (2004) undertook a study to determine instream flow requirement for Surma River, located in the north-east region of Bangladesh, from flow-habitat relations developed for dominant fish species. In his study PHABSIM model has been applied only for adult life stage of *Ghagot*, *Baghair* and *Bacha* fish species. Considering the Weighted Usable Area versus discharge curves and seasonal availability of these three fish species, instream flow requirement becomes 150 cumec for November to May, 500 cumec for June to September and 300 cumec for October. But considering the available median monthly flows for the months from November to April, a discharge of 150 cumec may not be set as instream flow for these months, because in these months 50% of the time flow is well below 150 cumec. So, median monthly flow of each of these months may be considered as instream flow for that month.

Saha (2007) conducted a study on Gorai River for assessment of instream flow requirement based on salinity intrusion and fish habitat consideration. For salinity consideration, the target was to assess the flow requirement for irrigation water quality, sources of drinking water and household use, and to support *Sundari* tree in the mangrove. For fish habitat consideration, two target species were selected, *Ayeer* and

Bacha. The study concluded that (i) flow requirement for the selected fish species also suffices salinity intrusion prevention, (ii) of the two selected fish species, flow requirement for *Ayeer* fish is about the same as the requirement for salinity prevention which is about 250 cumec and (iii) flow required for *Bacha* fishes is almost double the amount required for *Ayeer* fishes.

Sudip (2009) conducted a study to assess the environmental flow requirement for the Karnaphuli River. The study attempted to assess flow requirement for different species of fishes. Fishes were categorized into three categories. In group-I, Chital, Foli, Rita, Catla, Ilish and Kalbaush fishes were considered. The preferred water depth and velocity for those fishes are 0.60 m and 1.01 m/s to 1.25 m/s respectively. In group-II, Magor, Singhi, Koi, Tangra, Pabda, Gazar and Shoal fishes were considered; the preferred water depth and velocity for those fishes are 0.50 m to 0.60 m and 0.14 m/s to 1.25 m/s respectively. In group-III, Mala, Puti and Small Shrimp fishes were considered; preferred water level and velocity for these fishes are 0.15 m and 0.18 m/s to 0.47 m/s respectively. Required flows for these categories of fishes were computed considering the preferred habitat of these fishes and the required flow was compared with the presently available flow in Karnaphuli River. The computed minimum discharge required for group I, II and III categories of fishes are 179.48 cumec, 24.88 cumec and 31.99 cumec respectively. The study concluded that based on the water level requirement for fish habitat, the study reach of the river exhibits environmental flow for all three categories of fishes. But according to discharge requirement, environmental flow is satisfied for the last two categories of fishes while it does not satisfy for the first category which comprise of big fishes.

Akter (2010) conducted a study to assess the environmental flow requirement for the Ganges River. First objective of this study is to identify the appropriate methodology among the established e-flow measurement techniques for the Ganges River and the second objective is to assess the e-flow for fisheries, maintenance of Sundarbans ecosystem and morphological equilibrium condition of the river. Based on detailed review on various methodologies, the Indicator of Hydraulic Alteration (IHA) method of Range of Variability Approach of Hydrologic method is used for assessing the impact on flow regime of Ganges River after the construction of Farakka Barrage. Building Block Method (BBM) is used to estimate the fisheries demand, ecological demand, Sundarbans‘ requirement, flushing flow and morphological equilibrium. This study also identified that the observed minimum flow during the pre-Farakka period was within the range of e-flow requirements in the dry season. But in the post-Farakka period, the minimum flow falls below the dry season requirement. The dry season flow has been reduced drastically after 1975 but it was found that the average flow between the two time periods differs only by 706 cumec. This study has shown a reasonable hydrograph (here it is called e-flow hydrograph) at Hardinge Bridge. The sustainability of Ganges River itself and its selected dependents may be secured if the required amount of water can be ensured at Hardinge Bridge.

Hossain (2010) conducted a study deals with the assessment of Instream Flow Requirement (IFR) of Dudhkumar River using three methods of hydrological approach. Methods used are (i) Mean Annual Flow (MAF) method, (ii) Flow Duration Curve (FDC) method and (iii) Constant Yield (CY) method. Dudhkumar River is located in the north-east corner of north-west region of Bangladesh. It is an international river shared by Bhutan, India and Bangladesh. The present study is a preliminary level desk-top analysis using historical river flow data.

IUCN (2005) has carried a study on Bakkhali River and developed a protocol to adopt a holistic method to assess e-flow in Bangladesh. The protocol has been piloted at the Bakkhali River Rubber Dam, where there was a need to establish a balance between water for irrigation and dry season flows for fish movement to increase fish production. The protocol is mainly based on the expert assessment considering the dearth of data regarding e-flow. The protocol was tested in case of Bakkhali rubber dam in Cox‘s Bazar district. Those efforts were mainly based on fisheries component. E-flow was assessed for Golda and Hilsa species at the rubber dam site of the Bakkhali River in Cox‘s Bazar. An overall flow release requirement was also assessed for all fish movement. These requirements are found to be comparable to the surplus volumes and may be negotiated for release through the dam.

Bari and Marchand (2006) has carried out a research with a focus on suitability of methods to assess e-flows in Bangladesh and inclusion of socio-economic aspects in e-flow assessments under BUET-DUT Linkage Project, Phase III. The suitability of different e-flow assessment methods is tested in three rivers: the Surma-Kushiyara, the Teesta and the Gorai. The study so far has made progress in collection and analysis of hydrological data for the above three rivers and made use of several hydrology-based methods of e-flow assessment (including Tennant, Constant Yield, Flow Duration Curve and the Range of Variability Approach – RVA). Physical Habitat Simulation Model has been applied for Surma, Teesta and Gorai River. Ghagot, Baghair and Bacha have been taken as dominant fish species for Surma River, Boirali for Teesta River and, Ayeer and Bacha for Gorai River. Karen Mayer, a Ph.D student of Delft Hydraulics, Technical University of Delft and IUCN, Bangladesh, has carried out a Ph.D research on a part of Surma River under this project.

Mullick et al. (2010) has carried out another study on river Teesta. The analysis is based on the observed flow data at Kaunia which is about 70km downstream of the TIP barrage at Dalia. The analyses show that considerable amount of flow reduction has taken place especially in the recent past from the year 2001. Environmental flow requirements have been calculated using three methods and the results are consistent between the methods. The results suggest that flow about 90 to 120 cumec for the dry season in particular for January and February is essentially required for the sustenance of the river itself. However, in the period of 2001 – 2006 (post-barrage-2), the dry season (December – March) mean flow is observed only 80 cumec whereas mean January, February and March flow is observed only 40, 24 and 57 cumec respectively; all these values are quite below from the Environmental flow requirement.

Moly et al. (2015) studied the environmental flow characteristics of the Gorai River, Bangladesh. The estimated environmental flow for the Gorai River is 233.8 cumec which is the average of calculated environmental flow determined by Tennant method (229.6 cumec), flow duration curve method (230.5 cumec) and constant yield method (241.2 cumec). High flow season June and November of intermediate flow season meet the environmental flow requirement i.e. from December to May the river does not have the environmental flow. Again, the Goari suffers from significant flow reduction in recent time. Mean annual flow decreases by about 21.8% from the year 1976-1990 to 1991-2007 for all year where mean monthly in high flow season decreases by about 23% and mean monthly minimum flow decreases by about 83%. August and April are the highest and lowest flowing months respectively for both the periods. The low flow seasons suffers in severe water shortage where April mean flow is 52.9 cumec and 56.1 cumec for 1976-1990 and 1991-2007 periods, respectively. However during that period, very high reduction in flow occurs at July and high reduction in January, October and December which are the months of high flow and intermediate flow seasons.

Akter and Ali (2012) have carried out another study on river Halda. In this study, the log-Pearson Type III distribution was selected to estimate the Halda River flow with different return periods/probabilities and the Building Block Method (BBM) was employed to reduce/mitigate the environmental problems in the Halda River. The expected extreme and satisfactory fish habitat (i.e. 30% of mean flow) flows at Panchpukuria station for different return periods were estimated based on the yearly maximum discharge using the log-Pearson Type III distribution. Similarly, the expected extreme water levels at Panchpukuria, Narayanhat, Telpari and Enayethat stations for different return periods were estimated based on the yearly maximum water level using the log-Pearson Type III distribution, which might also be helpful to obtain necessary action against flood. Environmental flow requirements and conservation of fish resources in the Halda River may be achieved by integrating a range of suggested tasks in conjunction with the popular building block method.

BWDB (2017) has carried out a research to assess e-flows of Gorai River in Bangladesh and inclusion of socio-economic aspects in e-flow assessments under GRRP Project, Phase II. Due to EFA of Gorai River has been considered of Gorai- Nabaganga- Passure river system. The study so far has made progress in collection and analysis of hydrological data for the above rivers and made use of several hydrology-based methods of e-flow assessment (including Tennant, Constant Yield and Flow Duration Curve) Physical Habitat Simulation Model has been applied for Gorai River. Ghagot, Baghair and Bacha have been taken as dominant fish species for Gorai River. E-flow assessed based on hydrological methods claim the minimum flow 160 cumec for fair habitat quality during dry period. To keep the river water salinity level to 1ppt at Khulna on Rupsha River, the minimum flow needed to be conveyed by Gorai River at Gorai Railway Bridge is 400 cumec.

2.6 Benefit of e-flow assessment

The e-flow assessment is often defined as how much of the original flow regime of a river should continue to flow down it in order to maintain the riverine ecosystem in a prescribed state- like pristine, good or satisfactory. The issue of environmental flow requirements is receiving considerable attention world-wide because increasing pressure from water and catchments development has led to the decline in the condition of many water dependent ecosystems. The understanding that flows are critical for maintaining ecosystems should lead to describe the links between flow and ecosystems functioning, so that environmental flow can be specified to help overcome or at least minimize the of valued ecosystem features. In river of Bangladesh are highly dynamic exhibiting high season flow variability and cause extensive inundation flood plain in monsoon and severe low flow condition in dry season. Historically, river was the sole source of irrigation water, fisheries and the only economic transport route. Also, water levels above a threshold are necessary to limit the salinity intrusion in estuary in south west region of Bangladesh and decreasing flow has caused the salinity level to rise causing adverse impact to the corresponding area. In view of these river functions and problem, the assessment of environmental flow is essential. The environmental flow requirements set forth in different management plan until now are based on judgement. However, the effective planning and utilization of water resources knowledge of environmental flow assessment is essential.

2.7 Summary

Based on literature review, it is found that few studies of e-flow have been carried out in Bangladesh. Among them, BWDB, 2017 has carried out the study on Gorai River that was mainly on Gorai-Nabaganga-Passur River System. To estimate e-flow at Gorai off-take, e-flow requirement of Gorai-Nabaganga-Passure-Shibsha River system and Gorai-Madhumati-Kaliganga-Balaswar River system is essential. The flow requirement at Gorai offtake depends highly on the e-flow requirement for Gorai- Madhumati-Kaliganga-Balaswar River system which will be assessed in this study.

CHAPTER 3

E-FLOW ASSESSMENT METHODS AND THEORITICAL BASIS FOR SALINITY MODEL

3.1 General

Minimum flows in rivers and streams aim to provide a certain level of protection for the aquatic environment. The level of protection is described by a measure such as a prescribed proportion of historic flows, wetted perimeter or suitable habitat. Flow and hydraulic methods assume that lower than natural flows will degrade the stream ecosystem, whereas habitat methods accept the possibility that aspects of the natural ecosystem can be enhanced by other than naturally occurring flows. Application of hydraulic and habitat methods suggests that the environmental response to flow is not linear; the relative change in width and habitat with flow is greater for small rivers than for large. Small rivers are more ‘at risk’ than large rivers and require a higher proportion of the average flow to maintain similar levels of environmental protection. Habitat methods are focused on target species or specific instream uses, and are useful where there are clear management objectives and an understanding of ecosystem requirements. Flow and hydraulic methods are useful in cases where there is a poor understanding of the ecosystem or where a high level of protection for an existing ecosystem is required. Several environmental flow methods have been developed; however, in contrast to developed countries; only 11% of developing countries are applying environmental flow methods (Jowett, 1998; Tharme, 2002).

Environmental flow indicator will be selected depending on data availability. Fisheries and salinity indicator are selected for this research work. The parameters for the selected indicator are discharge, depth, velocity, critical velocity and cross section of the river. The criteria for site selection will be mainly based on data availability. The total requirements of each indicator will be calculated which are quantified in terms of discharge for the sustainability of the selected indicators. Finally, the monthly flow requirements for the sustainability of river are calculated for each indicator. This study also determine the salinity level for required e-flow by using one dimensional mathematical modeling HEC-RAS.

3.2 Environmental Flow Assessment Methods

The Environmental flow (e-flow) requirement for a river is the minimum flow required to enhance or maintain aquatic and riparian life. The relatively most accepted methodologies for determining environmental flow requirements based on analysis of historic flow. Some methodologies were developed for broader ecosystem protection. These techniques have reportedly been applied in over 25 countries, resulting in a considerable body of experience in developed countries, but only limited experience in the application of these methods in developing countries (World Bank, 2003).

More than 200 approaches have been used for determining e-flows in many different countries around the world, these methods can be classified in one or other way (Akter,2010). Following the classification schemes proposed by Jowett, 1997; Gordon et al.,1992 and King et al., 2000, different approaches used worldwide for quantifying environmental flows and can be grouped into four categories which are used for the study for assessment of e-flow (Stalnakers et al., 1995). These are:

1) Hydrological Method

2) Hydraulic Rating Method

3) Habitat Simulation Method

4) Holistic Method

3.2.1 Hydrological Methods

Hydrological Method was developed first and still continue to be developed further and used widely. Hydrological method utilizes long-term series data on the river flows measured at several points along the stream. Because of the reliance past flow data it is also called Historical Flow Methods (Tennant, 1976; Poff et al., 1997, Richter et al., 1996; 1997). The data may be average daily, weekly, 10-daily and monthly. Hydrological methods are the simplest and least data intense methods for estimating the e-flow. The most commonly used hydrological method includes:

1) The Tennant Method
2) Flow Duration Curve Method (FDC)
3) Constant Yield Method (CYM)

Hydrological methods correspond to standard setting problems related to fisheries (Stalnaker et al., 1995), the easiest to use and require data on the historic flow records of a stream. These consist of approaches where historical flow records are used to develop environmental flow recommendation. The techniques are considered suitable for long-range planning of environmental flows for fisheries in a low intensity situation when not much detail is required and where a quick, reconnaissance-level, office-type may be used. Hydrological Methods are described below:

(i) The Tennant Method: Also known as Montana Method is one of the oldest methods developed specially for the needs of fish. The Tennant Method is simple as it requires no field work and it based on a single hydrological statistics. The Tennant Method was developed to specify minimum flows for watercourses in the mid-western USA. The minimum flow requirements for a water course express as a percentage of the mean annual naturalized flow at a specified flow at a specified site. Eight classes of flow classifications were established by Tennant analyzing a series of field measurement and observations to correlate habitat quality with various percentage of mean annual flow. Table 3.1 shows Tennant‘s recommendations for e-flow to support varying qualities of fish habitats based on his observations of how to best mimic nature‘s hydrology (Stalnakers et al., 1995; Reiser et al., 1989; Jowett et al., 1997; Bari and Marchand, 2006). There have been several modifications to the Tennant Method by various practitioners since it was first used in the USA in 1976. Tennant assume that a portion of mean flow is needed to maintain a healthy stream environment.

Table 3.1 Percentage of mean annual flow required to achieve different objectives based on the Tennant method

Habitat Quality	% of Mean Annual Flow	
	Low Flow Season	High Flow Season
Flushing or Maximum	200	200
Optimum	60-100	60-100
Outstanding	40	60
Excellent	30	50
Good	20	40
Fair	10	30
Poor	10	10
Severe degradation	<10	<10

(Source:Tennant, 1976)

The method never produces a zero-flow recommendation. The method is not applicable to semi-arid regions. The relationship between flow and the state of the aquatic ecosystem is poorly established and this method is site specific.

(ii) Flow Duration Curve Analysis: The flow-duration curve (FDC) is a cumulative frequency curve representing the percent of time during which the average discharge equaled or exceeded a particular value at a given location. The FDC may be based on daily, weekly or monthly values of discharge. The flow duration curve is a plot that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest. The basic time unit used in preparing a flow-duration curve will greatly affect its appearance. For most studies, mean daily discharges are used. These will give a steep curve. When the mean flow over a long period is used (such as mean monthly flow), the resulting curve will be flatter due to averaging of short-term peaks with intervening smaller flows during a month. Extreme values are averaged out more and more, as the time period gets larger (Richard et al., 1993).

Flow Duration Curve (FDC) are used to derive specific flow percentiles (percentage exceedance values) associated with required suitable river conditions, often in combination with professional judgment, to produce e-flow recommendations. For instance, the Q95 Method is based on the 95% exceedance value on a seasonal FDC (Dunbar et al., 1998). In FDC, naturalized or present-day historical flow records are analyzed over specific durations to produce curves displaying the relationship between the range of discharges and the percentage of time each of them is equaled or exceeded. Usually, 90^{th} percentile flow (Q_{90}) has been set as the minimum e-flow. This is the flow that is exceeded 90% of the time. The 50^{th} percentile usually has been set as high flow month. However, to apply such a FDC technique, hydrological flow data are required.

(iii) Constant Yield Method: This method has been developed in the U.S.A. It uses a combination of median monthly flow and constant yield statistic to represent the watershed hydrology. This method is suitable for unregulated streams having catchment area greater than 130 km^2 and historic flow records of more than 25 years. In this method, the median monthly flow serves as the datum for evaluating the environmental flow requirement and 100% of the median monthly flow is set as the environmental flow requirement. In Bangladesh, this procedure has been used for assessment of environmental flow requirement for Surma, Kushiyara, Teesta and Gorai River (Bari and

Marchand., 2006) and for the Ganges River (Rahman, 1998) and for the Gorai-Madhumati-Nabaganga-Passur River system (BWDB, 2017). In this study the same procedure has been used.

3.2.2 Hydraulic Rating Method

Hydraulic rating methodologies use changes in simple hydraulic variables, such as wetted perimeter or maximum depth, usually measured across single, flow limited river cross-sections (commonly riffles), as a surrogate for habitat factors known or assumed to be limiting to target biota. These are stated to be a little more than basic standard-setting techniques but not quite incremental. Environmental flows are determined from a plot of the hydraulic variable(s) against discharge, commonly by identifying curve breakpoints where significant percentage reductions in habitat quality occur with decreases in discharge. It is assumed that ensuring some threshold value of the selected hydraulic parameter at a particular level of altered flow will maintain aquatic biota and thus, ecosystem integrity. One of the most commonly used hydraulic methods considers the variation in wetted perimeter with discharge (Reiser and Wesche, 1989) is described below:

(i) Weighted Perimeter Method: The relationships are constructed from measuring the length of the wetted perimeter at different discharges in the river of interest. The resulting recommended discharges are based on inflection points on the wetted-perimeter/discharge curve, which are assumed to represent the maximum habitat for minimum flow before the next inflection point. The wetted perimeter-discharge relationship is shown in Figure 3.1 and 3.2 (Gopal, 2013). The method is based on the assumption that fish rearing is related to food production, which in turn is related to how much is river bed is wet. It uses relationship between wetted perimeter and discharge, depth and velocity to set minimum discharges for fish food production, and rearing (spawning). The wetted perimeter technique selects the narrowest wetted bottom of the stream cross section that is estimated to protect the minimum habitat needs. The analyst selects an area assumed to be critical for the streams functioning (typically riffle). When a riffle is used in the analysis, the assumption is that minimum flow satisfies the needs for food production, fish passage and spawning. Once this level of flow is estimated, other habitat areas, such as pools and runs are also assumed to be satisfactorily protected.

The usual procedure is to choose the break or point of diminishing returns in the stream's wetted perimeter versus discharge relation as a surrogate for minimally accepted habitat. This inflection point represents that flow above which the rates of wetted perimeter gains begin to slow. Because the shape of the channel can influence the results of the analysis, the technique is usually applied to streams with cross-sections that are wide, shallow and relatively rectangular.

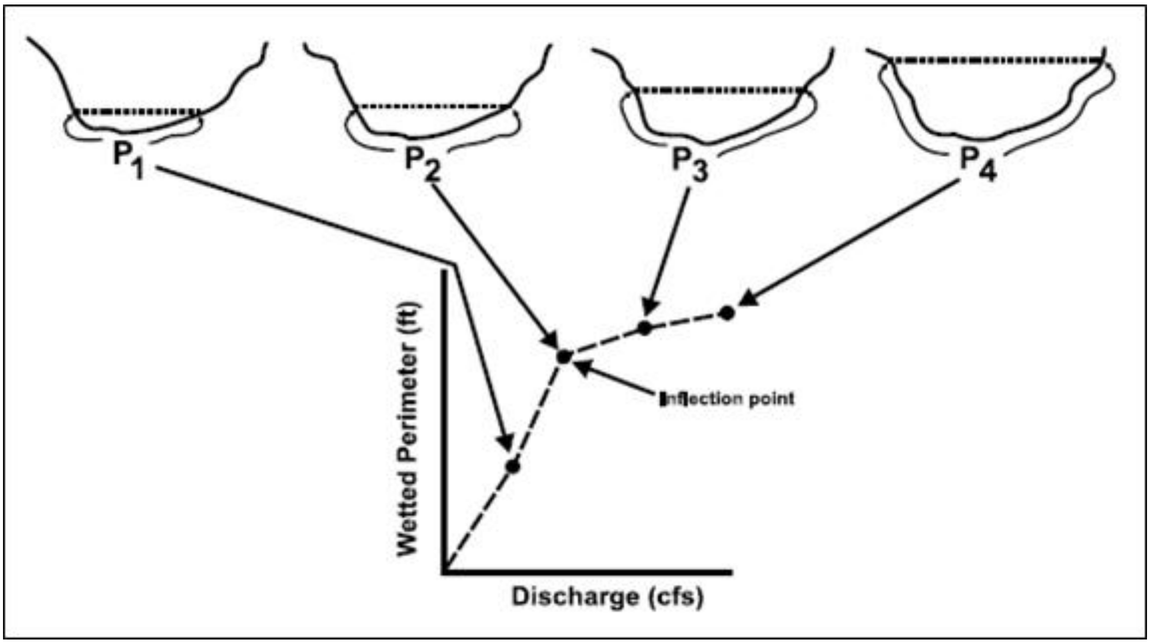


Figure 3.1: Wetted Perimeter method (Source: Gopal, 2013)

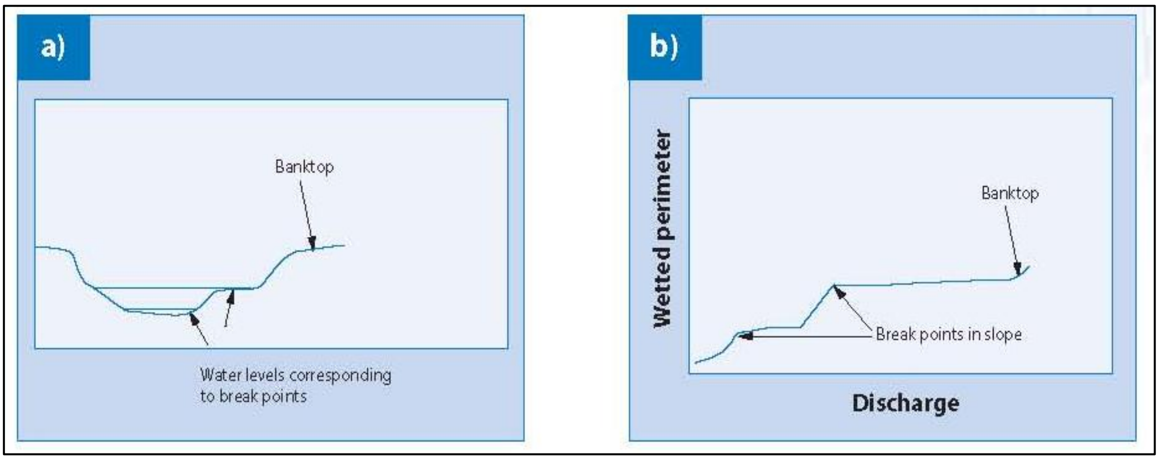


Figure 3.2: Wetted-perimeter method: (a) hypothetical channel cross-section and (b) graph of wetted perimeter versus Discharge (Source: World Bank, 2003)

It should be noted that compound cross-sections with multiple benches will produce an irregular relationship between wetted perimeters and there may be more than one breakpoint where the slope is unity. The lowest breakpoint is probably the most relevant to minimum flow determination. The main advantage of the wetted perimeter method is that it is relatively simple to use and it requires relatively little data. It recommends only a minimum environmental base flow and the method is site specific.

The disadvantage of the method is that the observed relationships between wetted-perimeter and discharge used to recommend suitable habitat for fish are based on general principles, and are not proven to be relevant to the fish of a particular river. To remedy this, detailed studies have to be undertaken on the relationship between wetted perimeter and the survival and reproduction of particular fish species. Although these studies increase the reliability of the results, they also add considerably to the time required and the costs of the method.

3.2.3 Habitat Simulation Method

The Habitat Simulation Method aim to conserve specific and pre-selected target species for which the habitat requirements can be reasonably estimated in the study area or are believed to be known from previous studies elsewhere. As mentioned above, the theory is based on the belief that there is an underlying relationship between the level of flow and "optimum" physical habitat conditions for the target species. By using simulations of the discharge conditions, the method, in its typical and simplest form, aims to find this optimum and set a target flow (a typical recommendation includes a static minimum flow level) such that the amount of physical habitat for the selected group of target species does not decline beyond a subjectively determined conservation level (USGS, 2001). One of the most commonly used habitat simulation methods which are the Physical Habitat Simulation System (PHABSIM), as first presented by Bovee and Milhous, 1978, and discussed by Bovee, 1982 and Milhous. et al., 1984. Description of PHABSIM method is described below:

(i) Physical Habitat Simulation Method (PHABSIM): In a PHABSIM analysis, the needed hydraulic model has been applied to determine characteristics of the stream in terms of depth and velocity as a function of discharge for the full range of discharges to be considered for the study. In the habitat modeling process, this information is integrated with habitat suitability criteria (HSC) to produce a measure of available physical habitat as a function of discharge. The general theory behind the habitat modeling programs within PHABSIM is based on the assumption that aquatic species will react to changes in the hydraulic environment. These changes are simulated for each cell in a defined stream reach. The stream reach simulation takes the form of a multi-dimensional matrix of the calculated surface areas of a stream having different combinations of hydraulic parameters (i.e., depth, velocity, and channel index) as illustrated in Figure 3.3. The depth and velocity for each cell is the average of the simulated depth and velocity values obtained from the hydraulic simulation phase of PHABSIM. Depth and velocity attributes vary with simulated changes in discharge, causing changes in the amount and quality of available habitat. The end product of the habitat modeling is a description of habitat area as a function of discharge as illustrated in Figure 3.4 (USGS, 2001). Figure 3.4 shows a generalized representation of a river segment for a series of transects that define a matrix of habitat cells with their associated attributes of depth, velocity and channel index (i.e., substrate and cover). These habitat cells represent the basic computational cells used by the various habitat programs to derive relevant indices of available habitat. The hydraulic models define a cell as one-half the distance to the next vertical in each direction. Thus, the hydraulic models simulate depths and velocities (shown as d_1, d_2, v_1 and v_2 in Figure 3.4) at the verticals used in the habitat models (USGS, 2001).

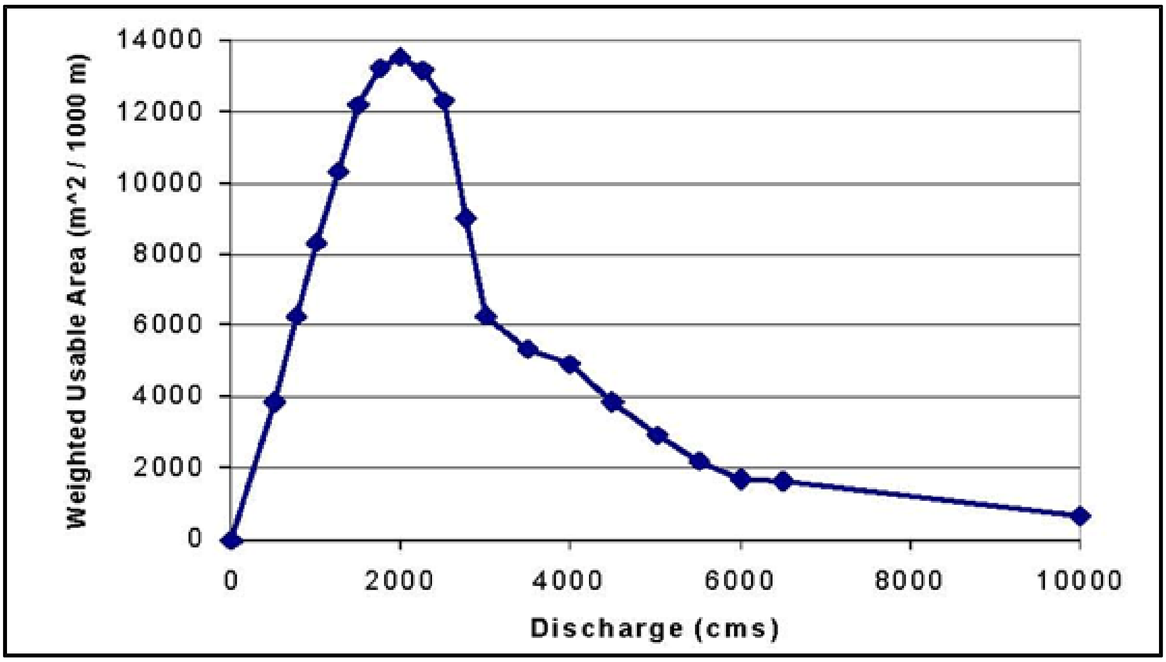


Figure 3.3: Habitat-flow relation for one Species/life stages derived from a PHABSIM Analysis (Source: USGS, 2001)

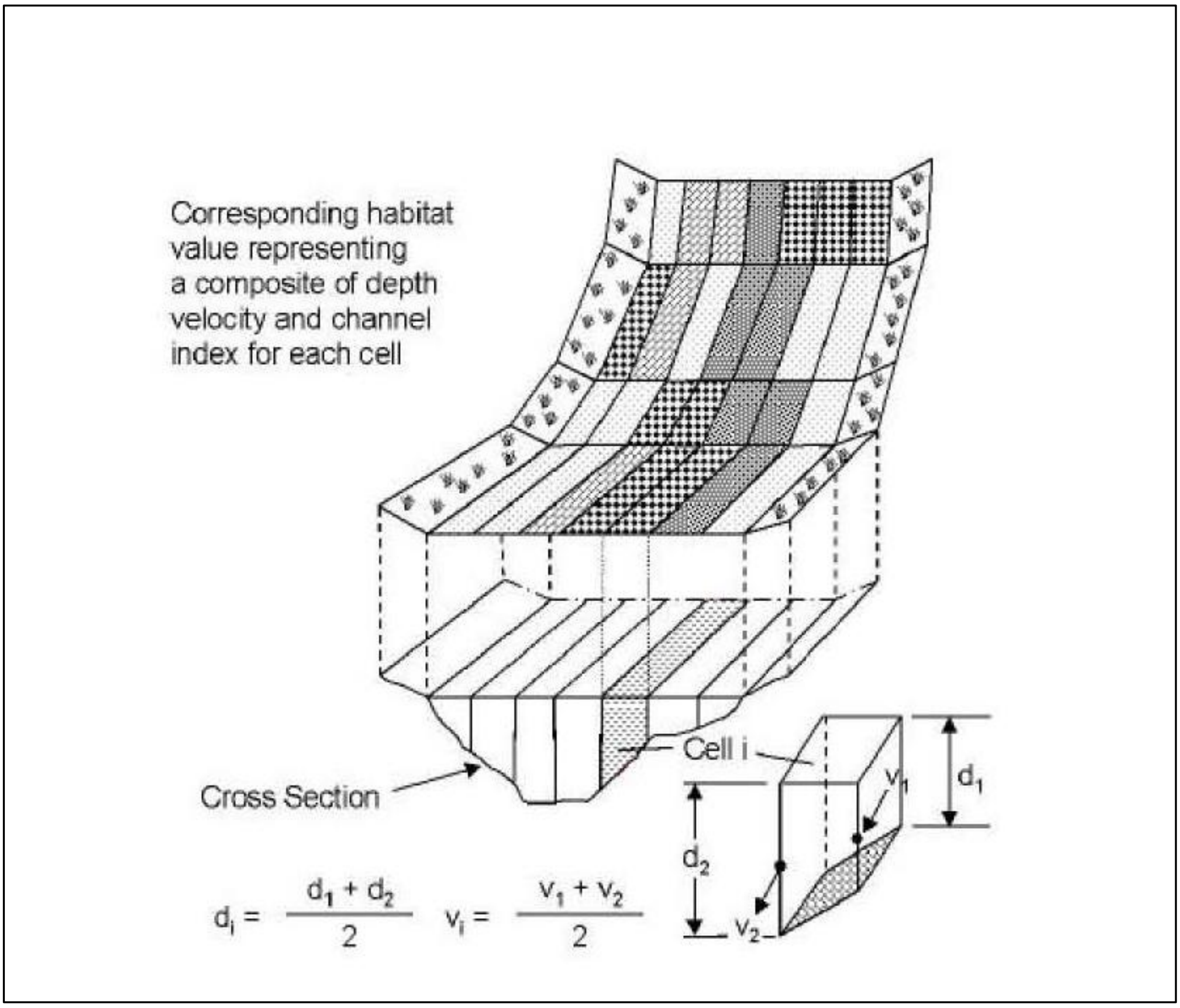


Figure 3.4: Matrix of habitat cell attributes in a PHABSIM (Source: USGS, 2001)

The habitat models rely on habitat suitability criteria relating hydraulic and channel characteristics to the habitat requirements of fish, other aquatic species, or even recreational activities. These HSC are used to describe the adequacy of various combinations of depth, velocity, and channel index conditions in each (or the adjacent) habitat computational cell to produce an estimate of the quantity and or quality of habitat in terms of surface area, bed area, or volume. As noted earlier, this metric is referred to as Weighted Usable Area (WUA) and has units of square feet per 1,000 linear feet of stream length (regardless of stream width). WUA is computed within the reach at a specific discharge from (Bari and Marchand, 2006):

$$\text{WUA} = \frac{\sum_{i=1}^{n} Ai * Ci}{\text{Reach length (1000 feet)}} \quad (3.1)$$

Where: A_i = surface area of cell i

C_i = combined suitability of cell i (i.e., composite of depth, velocity and channel index individual suitabilities)

The combined suitability of the cell is derived from the component attributes of each cell shown in Figure 3.4 which are evaluated against the species and life stage habitat suitability curve coordinates for each attribute to derive the component suitabilities as shown in Figure 3.5. Once the individual component suitabilities have been determined, the user has the option to select several different ways of aggregating them for a cell into single composite cell suitability.

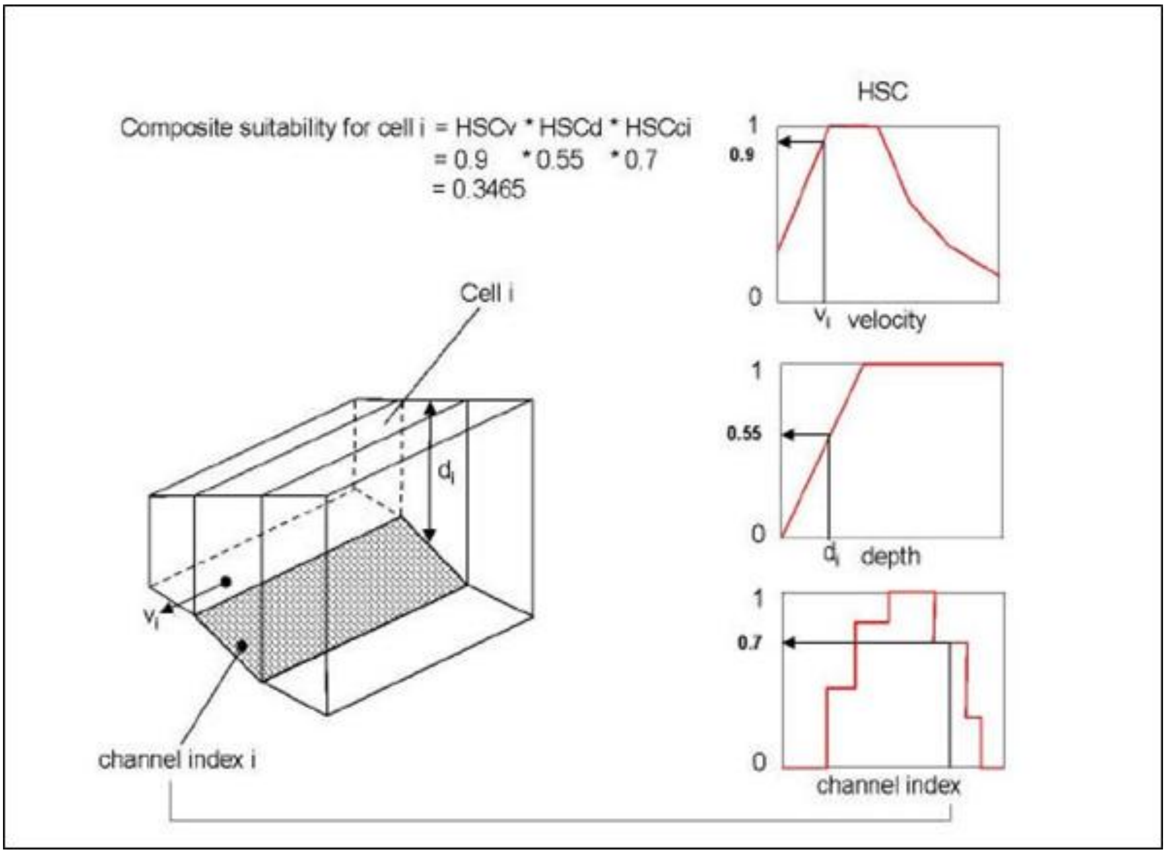


Figure-3.5: Habitat Suitability Criteria attributes for a Habitat Cells, showing multiplicative aggregation option (Source: USGS, 2001).

The most common method is a multiplicative aggregation given by (Bari and Marchand, 2006):

$C_i = V_i * D_i * S_i$ ……………………………......………………...…..……… (3.2)

Where: C_i = composite suitability of cell i

V_i = suitability associated with velocity in cell i

D_i = suitability associated with depth in cell i

S_i = suitability associated with channel index in cell I

The geometric mean can be used. This implies a compensation effect between the component suitability values. If two of three individual composite suitabilities are within the optimum range and the third is very low, the third individual composite suitability has a reduced effect on the computation of the composite suitability. The geometric mean is calculated as:

$$C_i = \sqrt[3]{Vi * Di * Si} \qquad (3.3)$$

The most locally limiting individual suitability factor can be selected by setting the composite suitability for the cell based on the minimum of the individual cell factors according to:

$$C_i = \text{Min}\,(V_i, D_i, S_i) \qquad (3.4)$$

Once the composite suitability Ci has been determined, then the amount of WUA using all cells at this specific discharge is computed according to the following equation:

$$WUA = \sum_{i=1}^{n} Ai * Ci \qquad (3.5)$$

Where:

WUA = total Weighted Usable area in stream at specific discharge

Ai = Vertical view area of cell i

C_i = combined suitability of cell i

This process is then repeated for all discharges simulated and the functional relationship between habitat and discharge as illustrated in Figure 3.4 is obtained a WUA versus discharge function. WUA is expressed as square meter of habitat area estimated to be available per 1000 linear meter of stream reach at a given flow.

3.2.4 Holistic Method

The most widely used holistic method in southern Africa is the Building Block Method (BBM). This methodology for determining e-flow requirements is outlined below.

(i) Building Block Method

The BBM is introduced in (King and Tharme, 1994; King, 1996). The BBM originated in two major South African specialist workshops on EFAs, where parts of it began evolving in the form of the “Cape Town” and “Skukuza” approaches (King and O‘Keeffe, 1989; Bruwer, 1991). The BBM was developed in South Africa by the Department of Water

Affairs and Forestry and various academic institutions (Hughes and Münster, 1999; Akter, 2010). This method requires the following:

a) The total flow volume of the following four building blocks components:

1) Low flows;
2) Habitat maintenance floods;
3) Channel maintenance/Flushing floods;
4) Spawning migration flows;

b) Monthly distribution of the four building block components;

The major objective of the method is to estimate the values of the four building block components as a percentage of the mean annual runoff of the natural flow regime. A building block e-flow study would be carried out as follows:

i. The monthly naturalized flow series for the site of interested must be established.

ii. The ecological management of the site is established.

iii. The flow variability has to be established to summaries the variability within the wet and dry seasons. This is based on the average coefficient of variation (i.e. standard deviation/mean) for the three main wet season months and the three main dry season months (excluding those that have zero mean monthly flows). The actual coefficient of variation (CV) is the sum of these two means. The assumption is that rivers with a high degree of variability in their flow regime will require a lower proportion of their natural mean annual runoff because they are used to experiencing such conditions. Rivers with more reliable flows and less flow variation are assumed to be ecological less well adjusted to frequent extremes in the flow regime.

iv. The base flow is calculated. The base flow index (BFI) is the proportion of the total flow occurring as the base flow.

v. A combined variability index is calculated by dividing the coefficient of variation by the base flow index.

vi. For particular sub-catchments, curves can be constructed for maintenance low flow estimation and maintenance high flows versus the variability index (CV/BFI) for the four future ecological management classes.

vii. The drought low and drought high flows are established. A hypothetical e-flow requirement created using the Building Block Methodology is shown in Figure 3.6

viii. The monthly distribution of flows is then produced. It should be noted that one of the basic principles of the approach is that a higher proportion of the natural monthly flow is required during the dry months than during the wet months.

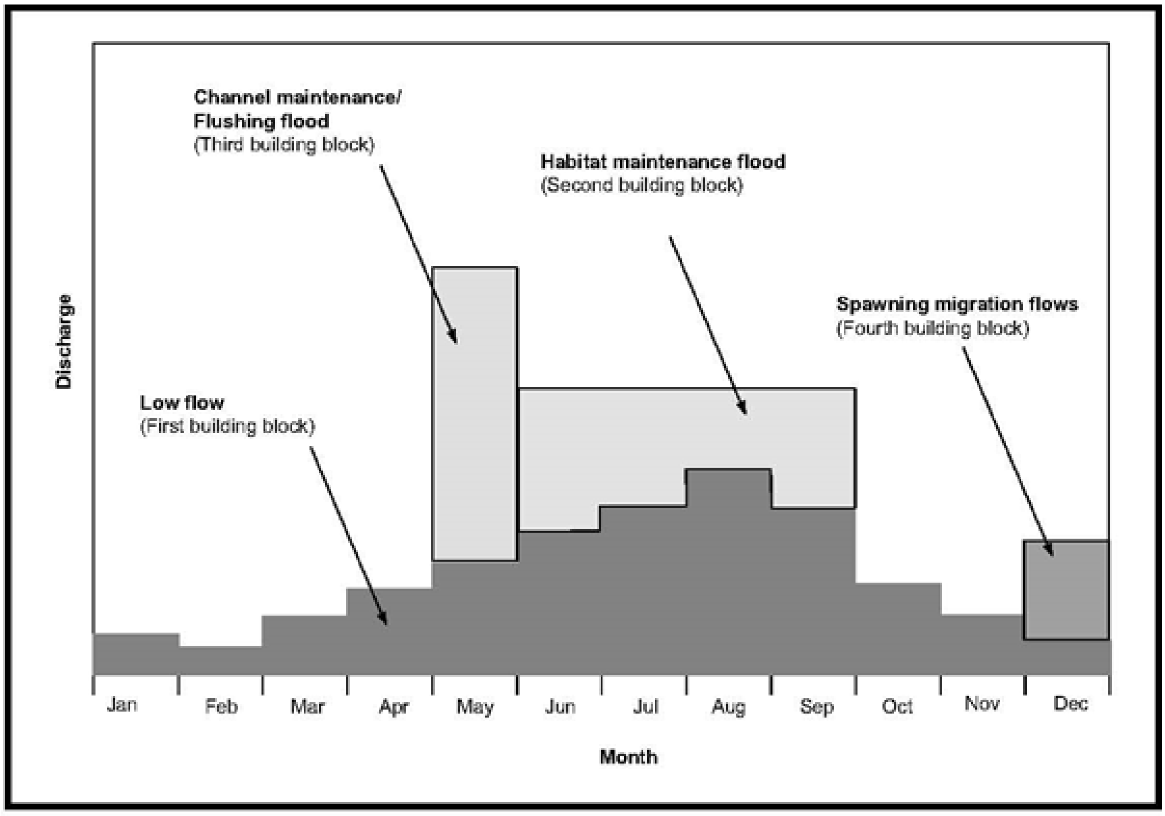


Figure 3.6: Example of the flow building block used in BBM (Source: DFID, 2003)

The main advantage of this method is that it takes into account the monthly flow variability for both high and low flows. The low flow building block can be used to assess preliminary e-flow requirements.

3.3 Comparison Among Different e-flow Assessment Methods

Historical and hydraulic techniques such as the Tennant Method and wetted perimeter technique are applicable for establishing minimum environmental demands for high level water resources management. It should be noted that these techniques provide an initial “low confidence” estimate. These techniques can be applied rapidly at a large number of sites to provide a first estimate of the likely quantities of water required to maintain the ecology in a given condition. The BBM can also be used for rapid assessments (Akter, 2010). In conclusion there is no one methodology that should be used for establishing the e-flow demand. Table 3.2 indicates that the major differences between historic flow, hydraulic and habitat flow assessment methods (Jowett et al., 1997).

Table 3.2. Summary of major differences between historic flow, hydraulic and habitat flow assessment methods

Method	Historic flow	Hydraulic	Habitat
Data requirement	Flow record	Cross-section survey	Cross-section survey Habitat Suitability criteria % Habitat retention
Method of assessing flow requirement	% of average annual or monthly flow % exceedance	% habitat retention	% habitat retention Inflection point Optimum Minimum habitat (exceedance or percentage)
Stream hydraulics	Effect on width, depth and velocity dependent on morphology Maintains ‘character	Effect on depth and velocity dependent on morphology Maintains ‘character’ only in terms of variable considered (e.g. wetted perimeter)	Prescribed depth and Velocity Potential loss of ‘character’
Ecological assumption	Close relationship between natural flows and existing ecology	Biological productivity related to wetted area	Close relationship between habitat and ecology
Advantages and disadvantages	‘Cook-book’ flow Assessment Trade-off considerations not possible Flow always less than, but related to natural Precludes enhancement	Trade-off considerations not possible Flow dependent on channel Shape Levels of protection difficult to relate to ecological goals	Allows trade-offs Flow assessment independent of natural flow Enhancement Potential recognized

(Source: Jowett et al., 1997)

3.4 Theoretical Basis for One-Dimensional Flow Calculations for Salinity Model

In this study, the hydrological methods such as Tennant Method, Flow Duration Method (FDC), Constant Yield Method (CYM), hydraulic rating method, Physical habitat simulation method (PHABSIM), Holistic Method (Building Block Methodology) will be analyzed and also determine the Salinity level for required e-flow by using modeling tools HEC-RAS for the Gorai-Madhumati-Kaliganga-Balaswar River system.

In HEC-RAS the one dimensional hydrodynamic is solved using a system of one-dimensional unsteady continuity and momentum equation with implicit scheme of finite difference method. The tidal and non-tidal hydrodynamic are calibrated by varying the Mannings roughness co-efficient and also stage-discharge relationship has been used for the calibration of hydrodynamic model. For the analysis of salinity intrusion at a certain reach Dispersion coefficient value is given in the model. This value indicates measure of the spread of data about the mean value, or with reference to some other theoretically important threshold or spatial location, e.g. the standard deviation. The theoretical background for 1D hydrodynamic model and water quality analysis is described below:

(i) Unsteady flow routing

A flow in which quantity of liquid flowing per second is not constant is called unsteady flow.

The physical laws which govern the flow of water in a stream are: (1) the principle of conservation of mass (continuity), and (2) the principle of conservation of momentum. These laws are expressed mathematically in the form of partial differential equations known as Saint Venant equation, which will hereafter be referred to as the continuity and momentum equations.

Continuity equation:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q = 0 \qquad (3.6)$$

Momentum equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + ga\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \qquad (3.7)$$

Here,

A = Total flow area

Q = Discharge

V = Velocity

a = Cross sectional area

q = Lateral inflow per unit distance

S_f = Frictional slope

G = Acceleration due to gravity

Z = Elevation of the water surface

(ii) Boundary Conditions

For a reach of river there are N computational nodes which bound N-1 finite difference cells. From these cells 2N-2 finite difference equations can be developed. Because there are 2N unknowns (ΔQ and Δz for each node), two additional equations are needed. These equations are provided by the boundary conditions for each reach, which for subcritical flow, are required at the upstream and downstream ends. For supercritical flow, boundary conditions are only required at the upstream end. There are several different types of boundary conditions available to the user. The following is a short discussion of each type:

(a) Flow Hydrograph: A flow hydrograph of discharge versus time can be used as either an upstream boundary or downstream boundary condition, but it is most commonly used as an upstream boundary condition.

(b) Stage Hydrograph: A stage hydrograph of water surface elevation versus time can be used as either an upstream or downstream boundary condition.

(c) Stage and Flow Hydrograph: The stage and flow hydrograph option can be used together as either an upstream or downstream boundary condition. The upstream stage and flow hydrograph is a mixed boundary condition where the stage hydrograph is inserted as the upstream boundary until the stage hydrograph runs out of data; at this point the program automatically switches to using the flow hydrograph as the boundary condition. This type of boundary condition is primarily used for forecast models where the stage is observed data up to the time of forecast, and the flow data is a forecasted hydrograph.

(d) Rating Curve: Rating curve is a graph of discharge versus stage. The rating curve option can be used as a downstream boundary condition.

(e) Normal Depth: The normal depth option can only be used as downstream boundary conditions for an open-ended reach. Use of Manning' equation with a user entered friction slope produces a stage considered to be normal depth if uniform flow conditions existed.

(iii) Water Quality Analysis

Those water personal satisfaction module employments those QUICKEST-ULTIMATE express numerical plan. There are three sets of water quality menus. The water quality data entry menu manages input data and calibration parameters; the water quality analysis menu manages simulation options and controls, and finally output tools manage model output files to facilitate viewing and exporting model results.

(a) Water Quality Data Entry: Water quality boundary data, meteorological data and source and sink parameters are entered in the Water Quality Data Window. This window is accessed from the main water quality input either through the menu bar by selecting edits. Water Quality Data or by selecting the Water Quality Data Icon.

(b) Water Quality Analysis: All water quality data simulations are performed by first opening the Water Quality Analysis Window. This window is accessed from the main water quality input either through the menu bar by selecting Run. Water Quality Analysis or by selecting the Water Quality Analysis Icon.

The advection dispersion equation:

$$\frac{\partial}{\partial t}(V\emptyset) = -\frac{\partial}{\partial x}(Q\emptyset)\Delta x + \frac{\partial}{\partial x}(DA\frac{\partial\emptyset}{\partial x})\Delta x \pm S \quad (3.8)$$

Here,

V = volume of the water quality cell (m^3)
Φ= water temperature (C) or concentration (kg m^{-3})
Q = flow (cumec)
D= user-defined dispersion coefficient (m^2s^{-1})

A = cross sectional area (m^2)
S = sources and sinks (kg s^{-1})

Sources and Sinks will not be considered on this working model. The value of dispersion coefficient and Flow of the river will be given.

(c) Water Quality Results: Water Quality results are available in either spatial or time series format. Plots and tables are accessed from the main HEC-RAS window.

3.5 Summary

Environmental flow decisions may include license for water withdrawal, an operating schedule for a water storage project, negotiation on river water sharing with riparian countries or an element of national water management plan (Bari and Marchand, 2006). Since no one method will provide for all needs and required flow assessment should be reevaluated with changing demands and amount of data should be appropriate (Saha, 2007). However, all other hydrologic, hydraulic method physical habitat simulation method and Building Block Methodology will be analyzed and will be compared and also determine the Salinity level for required e-flow by using modeling tools HEC-RAS for the Gorai-Madhumati-Kaliganga-Balaswar River system.

CHAPTER 4
STUDY AREA AND METHODOLOGY

4.1 General

River in Bangladesh are highly dynamic exhibiting high seasonal flow variability and cause extensive inundation of flood plains in monsoon and severe low flow conditions in dry season. This phenomenon has further been exacerbated by human interferences, such as deforestation and land use changes as well as impoundments and abstraction of water in the upper catchments by dam and barrage. Historically, rivers were the sole source of irrigation water, fisheries and the only economic transport route. In the present context rivers still hold the major source of fisheries and provide an economic way of travel in rural areas and river flow is vital for maintaining navigable waterways and the spawning of different fish and other aquatic species. Also, water levels above a threshold are necessary to limit the salinity intrusion in estuaries in the south west region of Bangladesh and decreasing flow has cause the salinity intrusion level to rise causing adverse impacts to corresponding areas. In view of south west region rivers functions and problems, the assessment of environmental is essential. In this context the purpose of this research is to assess the e-flow requirement of Gorai- Madhumati-Kaliganga-Balaswar River System (Figure-4.1) based on dominant fish species requirement and salinity intrusion.

4.2 Gorai-Madhumati-Kaliganga-Balaswar River System

Considering the function and problems of rivers, this river system has been selected for this study. This river system contains four rivers. These are Gorai, Madhumati, Kaliganga and Balaswar River. The four river lies in the southwest region. After running about 200 km the Gorai bifurcates into Madhumati and Nabaganga River. Madhumati passes through Gopalganj and Pirojpur district and after these areas it is named as Kaliganga River. At the downstream end, the Kaliganga River and other distributaries met and are renamed as Baleshwar River which discharges into the Bay of Bengal. The Gorai-Madhumati-Kaliganga-Balaswar River system is shown in Figure 4.1.

The Gorai is a right bank distributary of the Ganges and was a major source of water for the south-west region of Bangladesh. The course of the Gorai is wide, long and meandering. It is navigable by boat in the monsoon, but in the dry season it becomes non-navigable. In the downstream it is navigable throughout the year. In recent years, the Gorai River is fast losing its conveyance and carry discharges from the Ganges only in the wet months from June to October. The sediment deposition at the Gorai mouth has been risen the bed levels and in the recent years the Gorai river was hydraulically disconnected from the Ganges in the dry season. The catchment area of Gorai River is 15160 Km^2 and a length of 200 km. It is located between 21^o 30 N to 24^o 0' N latitude and 89^o 0' E to 90^o 0' E longitude, covering partly or fully of Kushtia, Rajbari, Faridpur, Jhenaidah, Magura, Norail districts of south western region of Bangladesh. Gorai River influenced by estuarine phenomena, such as tides and salinity intrusion, navigation fishery, mangrove forest, pollution abatement, agriculture, etc. since the offtake of Gorai River almost dried up condition prevailed in the dry season until 1998 when capital dredging on a pilot scale was started. The dredging was done from 1998 to 2001 over a reach at the river intake and Gorai started to flow in dry season. Maintenance dredging or some permanent structure will be necessary to keep the channel flowing; otherwise it will be silted up quickly. Knowledge of environmental flow is necessary for undertaking any river restoration and resuscitation work. The index Map of Gorai River is shown in Figure 4.2

The river has different names at different parts of its course. Towards the upstream part above kamarkhali ghat, it is known as the Gorai, down stream of kamarkhali ghat is flows by the name Madhumati. After running about 200 km the Gorai bifurcates into Madhumati and Nabaganga River. Madhumati passes through Gopalganj and Pirojpur district and after these areas it is named as Kaliganga River. Length of the Madhumati River is about 170 km and average width of the Madhumati River is 408m. From its originating point to Kamarkhali, it is navigable by boat in the monsoon, but in the dry season it becomes non-navigable. In the downstream it is navigable throughout the year. The index Map of Madhumati River is given below Figure 4.3.

Kalignaga River is taken off from the Madhumati River under Kalikhali Union of Pirojpur district and discharging into the Kocha River. The name of the tributary of Kaliganga River is Belua and Shaldha River. The name of the distributary of Kaliganga River is Balaswar. Kaliganga River passes through the Nesarbad (Sorupkhati) Upazilla. Length of the Kaliganga River is about 32 km and average width of Kaliganga River are 330m. The index Map of Kaliganga River is shown in Figure 4.4.

Balaswar River is taken off from the Kaliganga River under Pirojpur district under Nazirpur Upazilla and discharging into the Bay of Bengal. The name of the tributary of

Balaswar River is Bhoghi, Bhola, Khasiakhali and Kocha River. The name of the distributary of Balaswar River is Panghuchi. Balaswar River passes through the Pirojpur, Bhagerhat and Borguna district. Length of the Balaswar River is about 146 Km and average width of Balaswar River are 1644m. The index Map of Balaswar River is shown in Figure 4.5.

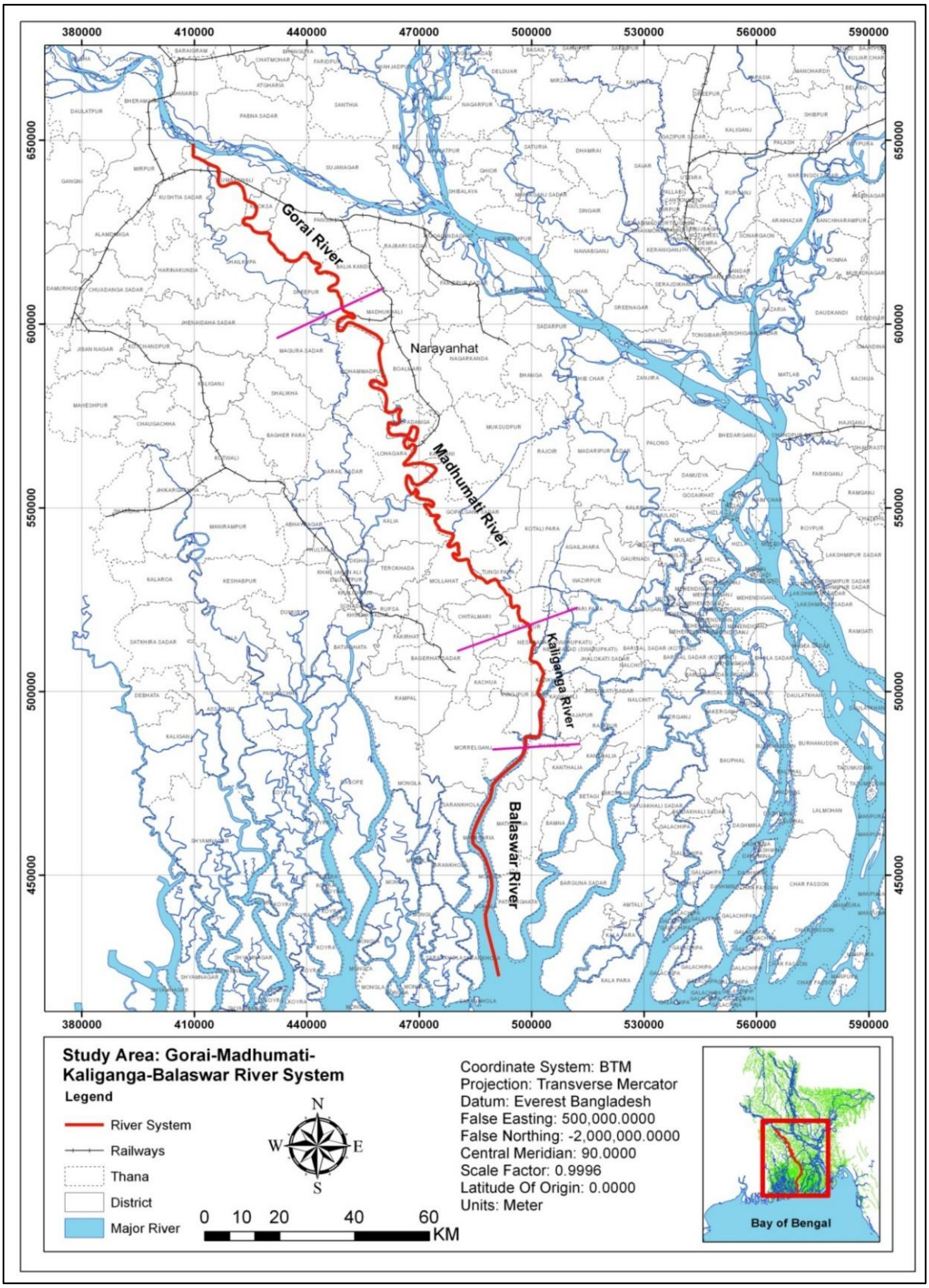


Figure 4.1: Gorai-Madhumati-Kaliganga-Balaswar River System

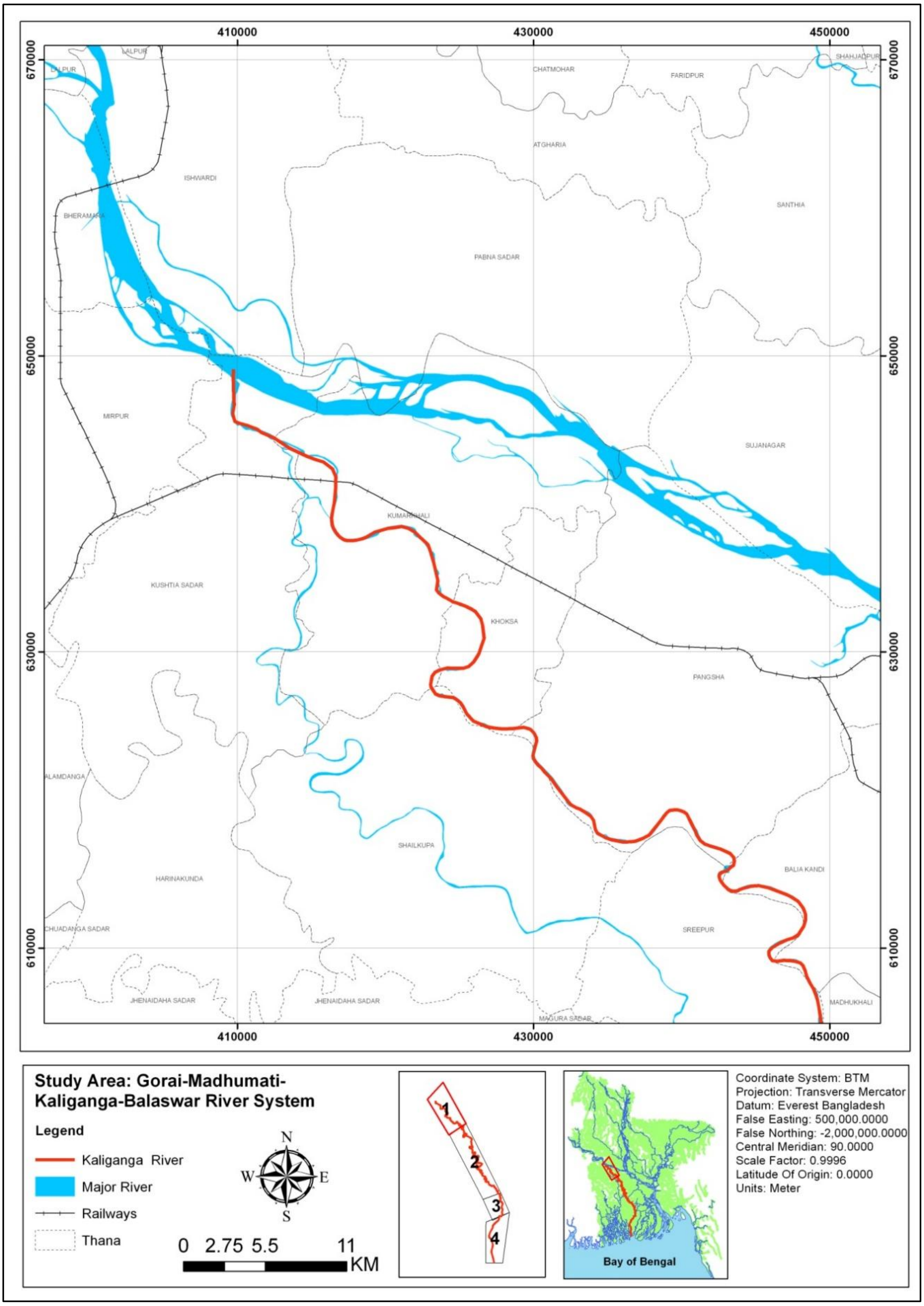


Figure 4.2: Index Map of Gorai River

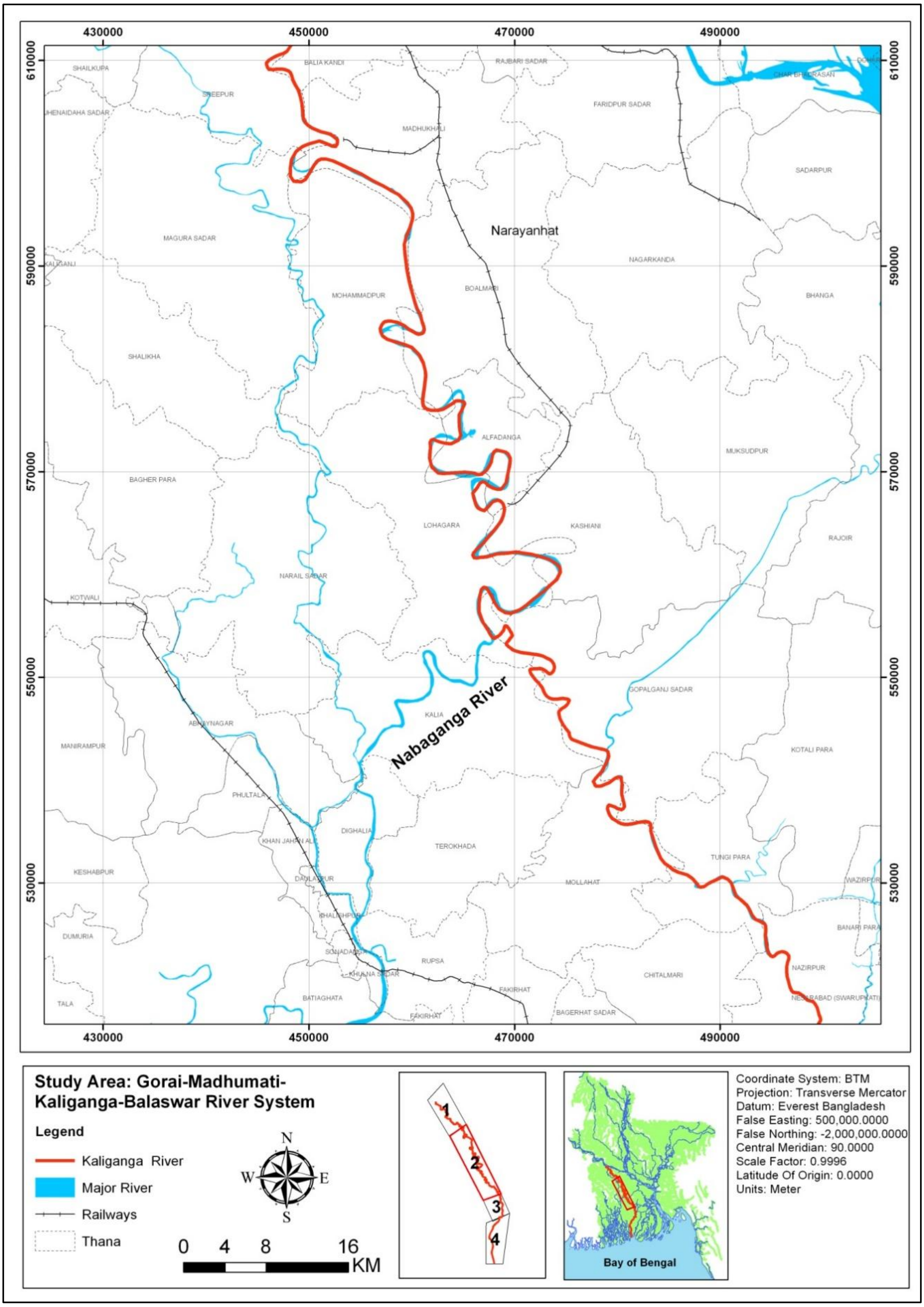


Figure 4.3: Index Map of Madhumati River

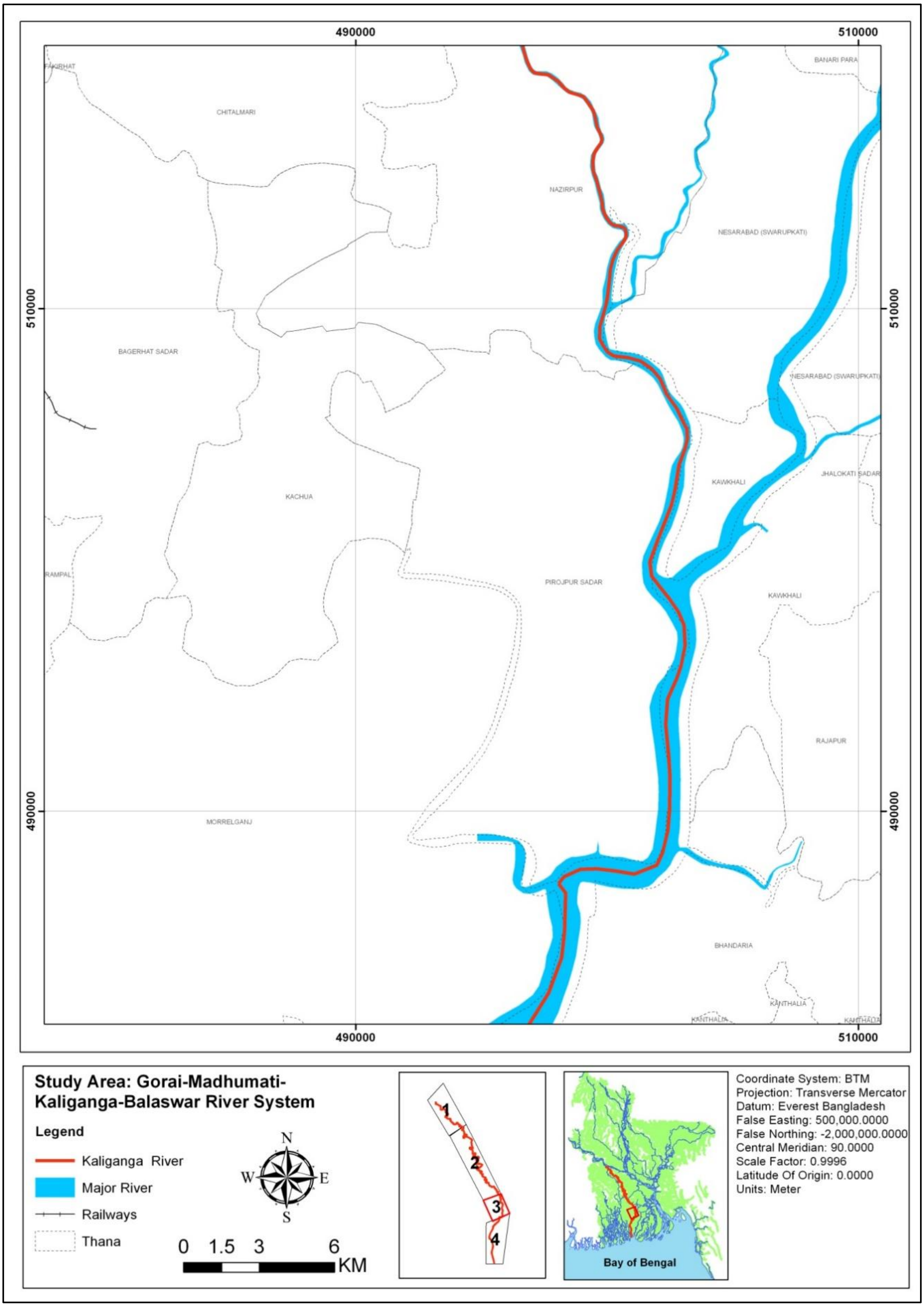


Figure 4.4: Index Map of Kaliganga River

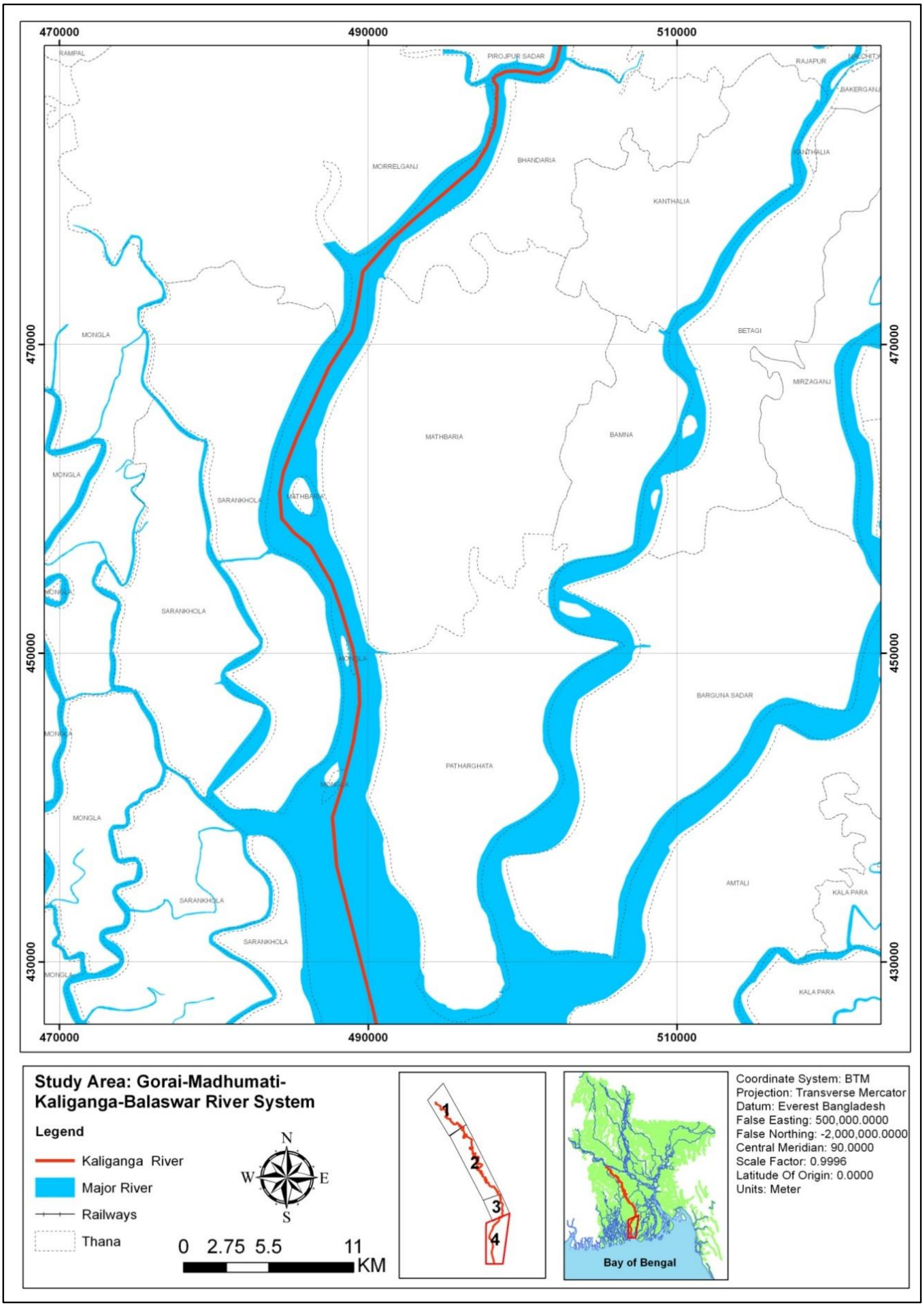


Figure 4.5: Index Map of Balaswar River

4.3 Methodology of the Study

The minimum flow requirement from different hydrological approaches will be assessed the e-flow requirement of Gorai-Madhumati-Kaliganga-Balaswar River system. The monthly average discharge requirement for dominant fish species during the dry season will come out from Physical Habitat Simulation Method (PHABSIM) model. Hydrological approaches and indicator-based e-flow requirement of Gorai-Madhumati-Kaliganga-Balaswar River system will be come out by hydrological and PHABSIM methods. Finally, the total requirement will be assessed in terms of discharge for the sustainability of the selected indicators. The condition of salinity to maintain the above-mentioned e-flow through the Gorai-Madhumati-Kaliganga-Balaswar river system will come out from the mathematical modeling. Three different approaches are being applied in order to provide a means of identifying whether a common standard could be established for evaluating results generated by different methods. The flow chart of the methodology is shown in Figure 4.6.

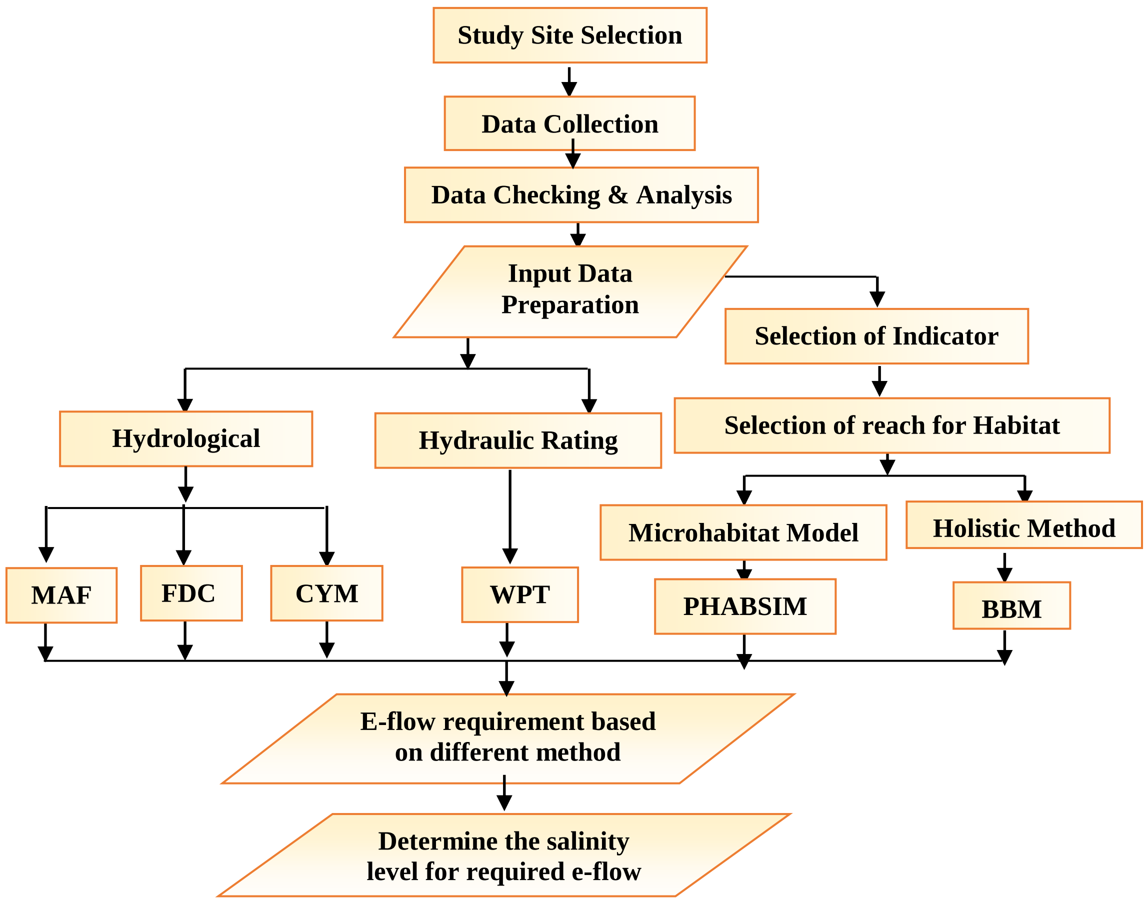


Figure 4.6: Flow Chart of the Methodology

4.4 Selection of Study Site

The location of the Gorai Rail Bridge (GRB) is chosen as the study site for Gorai River based on some specific reasons. There is only another discharge measuring station at Kamarkhali Transit other than Gorai Rail Bridge in this study river. But Gorai Railway Bridge station has more significance than the Kamarkahli Transit station. Gorai River is being fed from the Ganges; Gorai Railway Bridge is almost 5 km downstream from the Gorai offtake. The Gorai River which is the main source of fresh water to the southern part of Bangladesh; this location has been selected for this study.

The location of the Bordia is chosen as the study site for Madhumati River based on some specific reasons. In dry season, Madhumati River at Bordia station has some tidal effect but in high flood season, it is a non-tidal river. Also, Madhumati River is bifurcate into Nabaganga and Madhumati at Bordia location. Width of the Nabaganga River is higher than Madhumati River at the Bordia Location. Considering the above criteria, this location has been selected for this study.

The location of the Pirojpur Sadar is chosen as the study site for Kaliganga River based on some specific reasons. In dry and high flood season, Kaliganga at Pirojpur Sadar station have tidal effect all over the year. The Kaliganga River is taken off from the Madhumati River under Pirojpur district under Kalikhali Union. The location is chosen for this study after the tributary river location. The name of the tributary of Kaliganga River is Belua and Shaldha River. The combined flow of Madhumati and Tributary River is used for e-flow assessment of this river. Considering the above criteria, this location has been selected for this study.

The location of the Charduani is chosen as the study site for Balaswar River based on some specific reasons. In dry and high flood season, Balaswar at Charduani station have tidal effect all over the year. The tidal fluctuation range is almost 1m to 1.5m. In this river mean annual flow is lower than dry season flow. The name of the tributary of Balaswar River is Bhoghi, Bhola, Khasiakhali and Kocha River. The name of the distributary of Balaswar River is Panghuchi. The combined flow of Kaliganga and Tributary River is used for e-flow assessment of this river system. Considering the above criteria, this location has been selected for this study. The location of the station for e-flow assessment of Gorai-Madhumati-Kaliganga-Balaswar River System is shown in Figure 4.7.

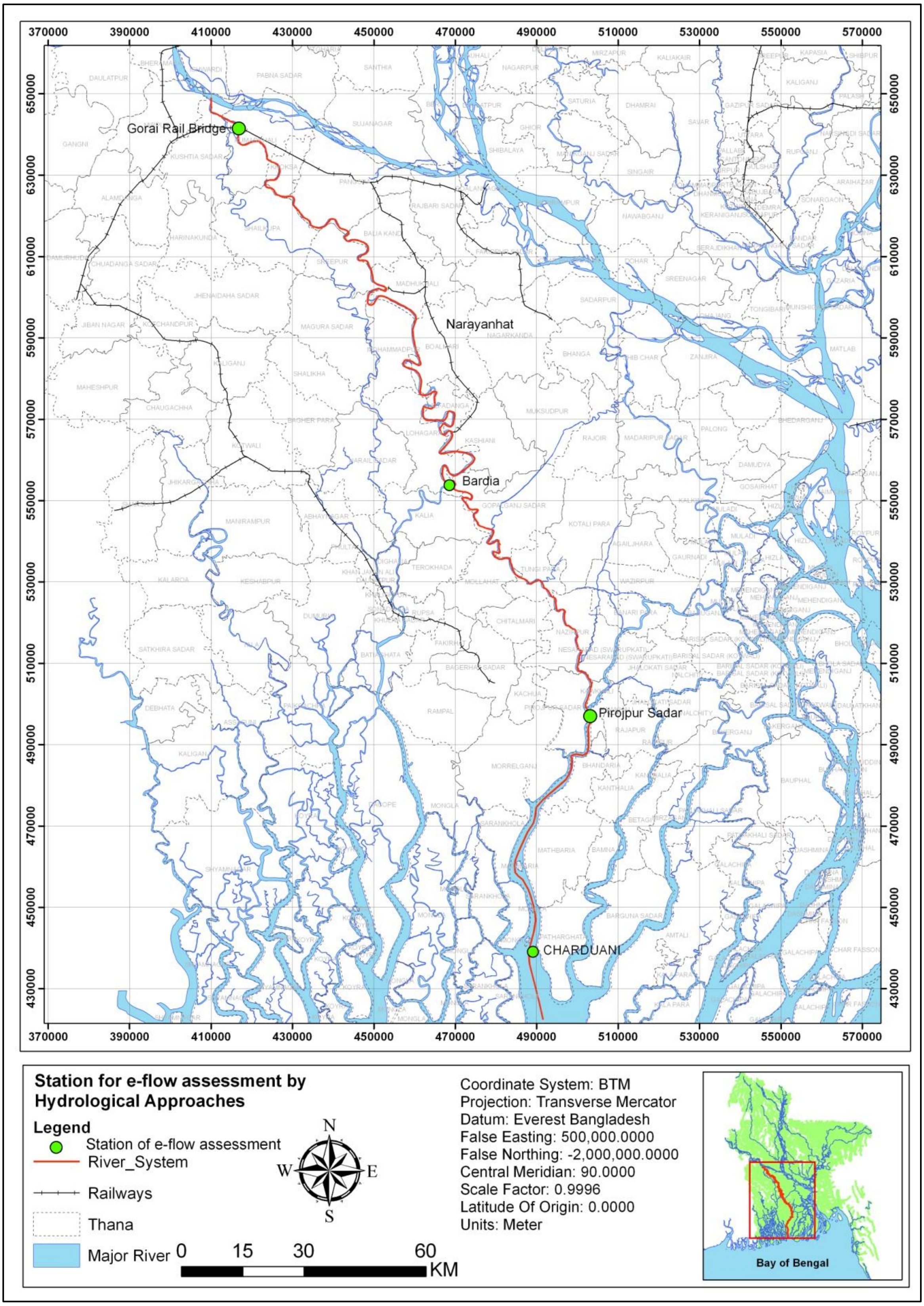


Figure 4.7: Station of e-flow assessment by Hydrological approaches

4.5 Data Collection from Secondary Sources

In order to assess the environmental flow requirement for Gorai-Madhumati-Kaliganga-Balaswar River various types of data have been collected from secondary sources such as BWDB. The collected data include historical water level, historical discharge, historical cross-sections and salinity data at various locations extending from Gorai Railway Bridge on the Gorai River to the Charduani point on the Balaswar River. Brief discussions of the data type are given below:

4.5.1 Discharge Data

Historical discharge data are crucial for hydrological analysis and mathematical model study. In order to assess the e-flow requirement for Gorai-Madhumati-Kaliganga-Balaswar River system by hydrological approaches and to determine the salinity level for required e-flow by mathematical 1D Model, historical discharge data is mandatory. To perform these analyses, historical discharge data have been collected for BWDB station ID SW99 near Gorai Railway Bridge of the Gorai River and SW 103 near Bordia Bazar of the Madhumati River. Kaliganga River at the location of Pirojpur Sadar and Balaswar River at the location of Charduani historical discharge data has been collected from Coastal Embankment Improvement Project (CEIP), BWDB. Figure 4.8 shows the locations of discharge measuring stations.

4.5.2 Bathymetric data

Historical bathymetry data of Gorai River, Madhumati River, Kaliganga River and Balaswar River have been collected from BWDB for the period of 2010. A detailed bathymetry survey of the Gorai River starting from Gorai-offtake to the downstream of Balaswar River has been conducted in December to March 2010. These bathymetry data are being used for set up of hydrodynamic and fish habitat model. Figure 4.9 shows the locations of cross-sections and Figure 4.9 shows the station of e-flow assessment by Hydrological approaches.

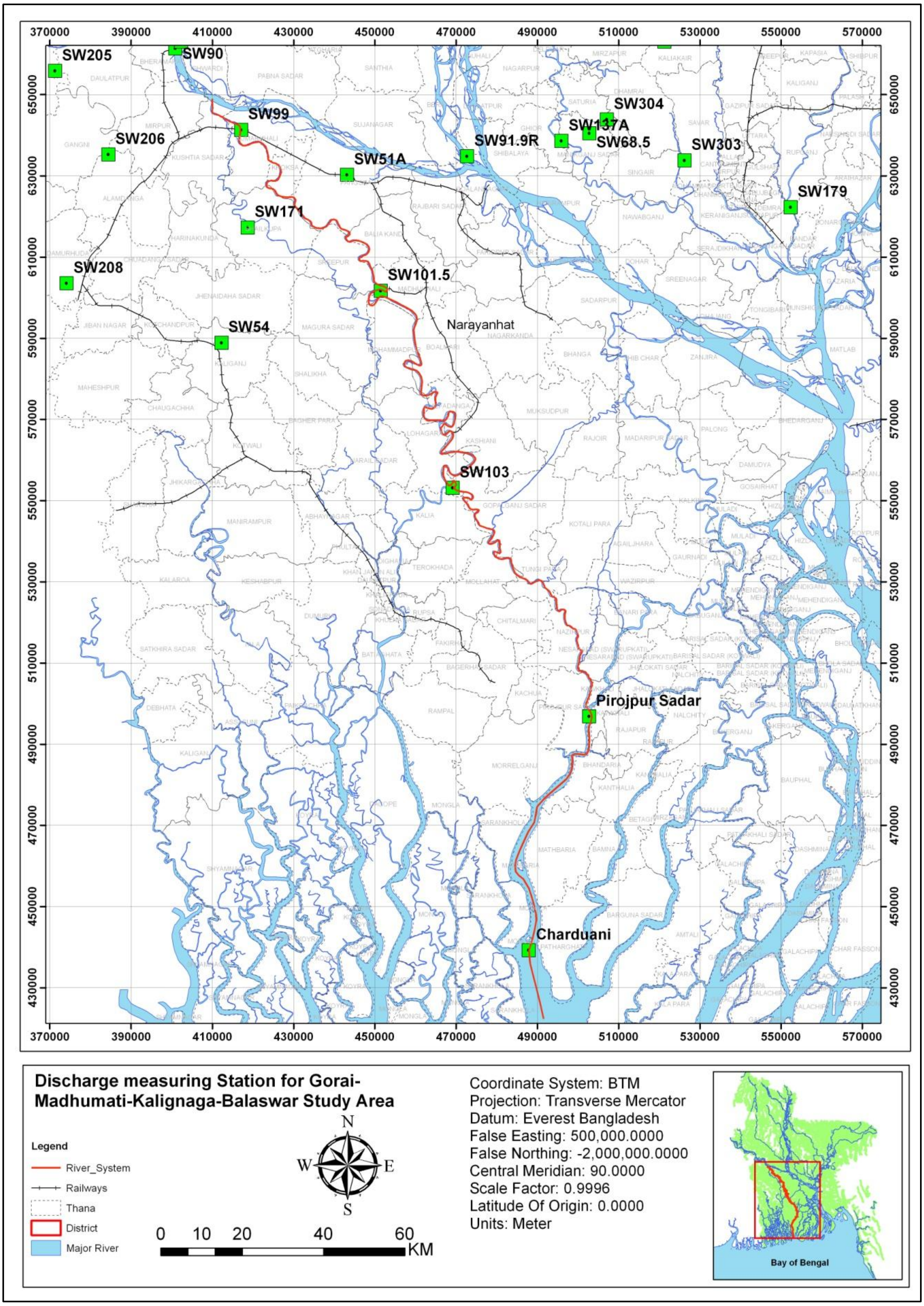


Figure 4.8: Discharge measuring station for Gorai-Madhumati-Kaliganga-Balaswar River System

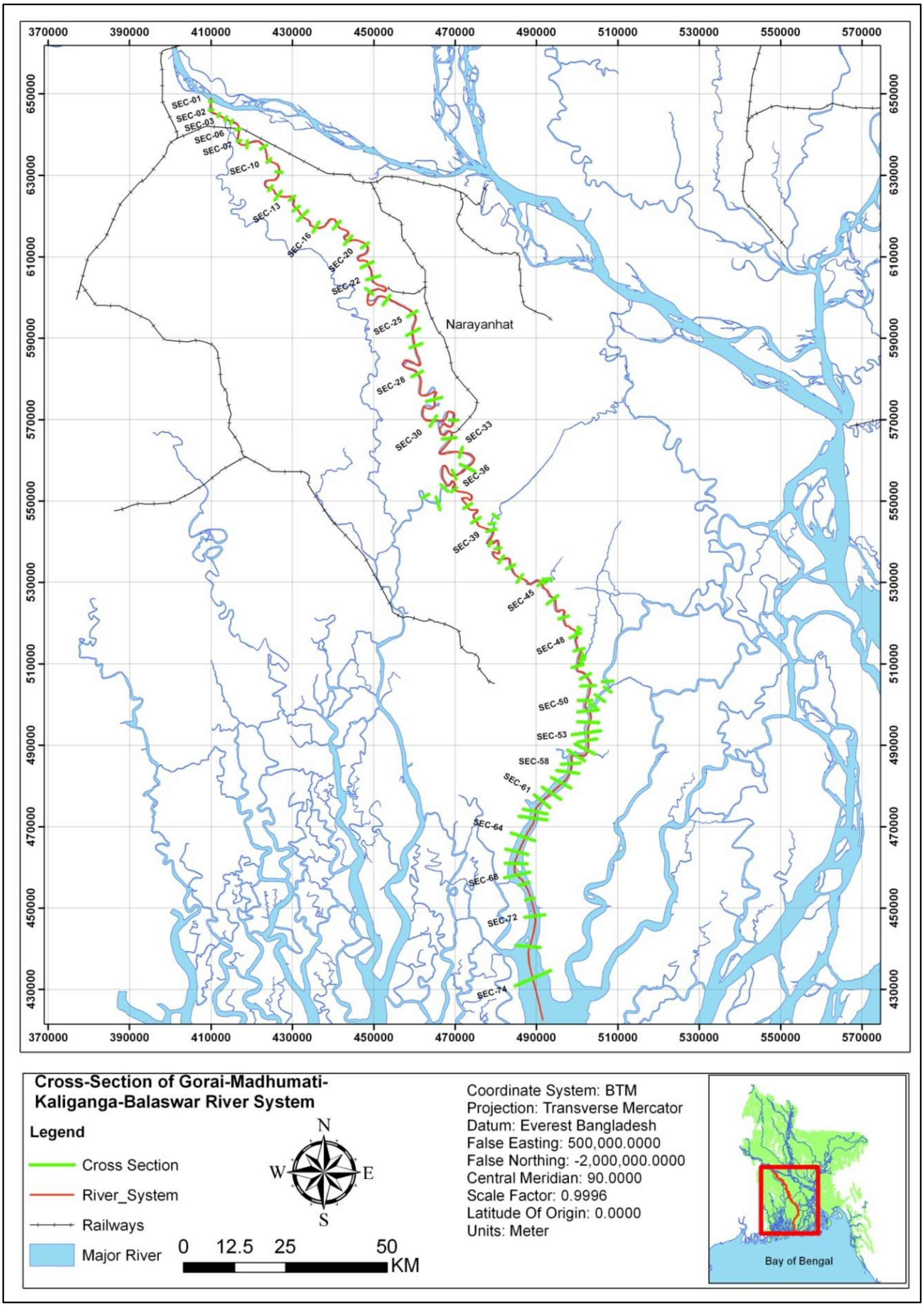


Figure 4.9: Location of Cross sections uses of Gorai-Madhumati-Kaliganga-Balaswar River System

4.5.3 Water Level Data

Water level data which include both tidal and non-tidal water level at different locations on Gorai River, Madhumati River, Kaliganga River and Balaswar River has already been collected based on data availability for historical data analysis. Water level data will also be used as boundary condition for hydrodynamic, morphological and fish habitat studies. Water level data have been collected for BWDB stations SW 99 Gorai Railway Bridge, SW 101 (Kamarkhali transit) on Gorai River and Station ID SW 102 (Batiapara), SW 103 (Bardia), SW 105 (Offtake of Atharba), SW 106 (Patghati) on the Madhumati River, station ID SW 107 (Pirojpur), SW 136.10 (Umedpur) on the Kaliganga River and Station ID SW 107.20 (Rayenda) and SW 108 (Charduani) on the Balaswar River. Table 4.1 shows a summary of BWDB tidal and non-tidal water level data collection locations and Figure 4.10 shows the locations of water level station of the study area.

Table 4.1: Summary of BWDB water level data collection locations

Type of Data	River Name	Station ID	Station Name	Data Periods
Water Level	Gorai	SW 99 (NT)	Gorai Railway Bridge	1946-2018
	Gorai	SW 101 (NT)	Kamarkhali	1997-2018
	Gorai	SW 101.50 (NT)	Kamarkhali Transit	1997-2018
	Madhumati	SW 102 (NT)	Batiapara	1997-2018
	Madhumati	SW 103 (T)	Bordia	1941-2018
	Madhumati	SW 105 (T)	Offtake of Atharba	1997-2018
	Madhumati	SW 106 (T)	Patghati	1953-2018
	Kaliganga	SW 107 (T)	Pirojpur	1952-2018
	Kalignga	SW 136.10	Umedpur	1997-2018
	Balaswar	SW 107.20	Rayenda	1997-2016
	Balaswar	SW 108	Charduani	1959-1986

4.5.4 Fish Data

The available fish data of Gorai, Madhumati, Kaliganga and Balaswar River have been collected from Department of Fisheries (DoF), different reports (BWDB, 2017; Bari and Marchand, 2006; Akter, 2010 and Chowdhury et al., 2005) and other relevant sources. The fish data will be used to select dominant fish species and their different life stages. The habitat Suitability criteria (HSC) for dominant fish spices for their different stages will be developed after collecting fish data. These fish data are being used to develop a one-dimensional fish habitat model named PHABSIM to predict optimum water requirement for dominant fish species at different life stages over the entire study area.

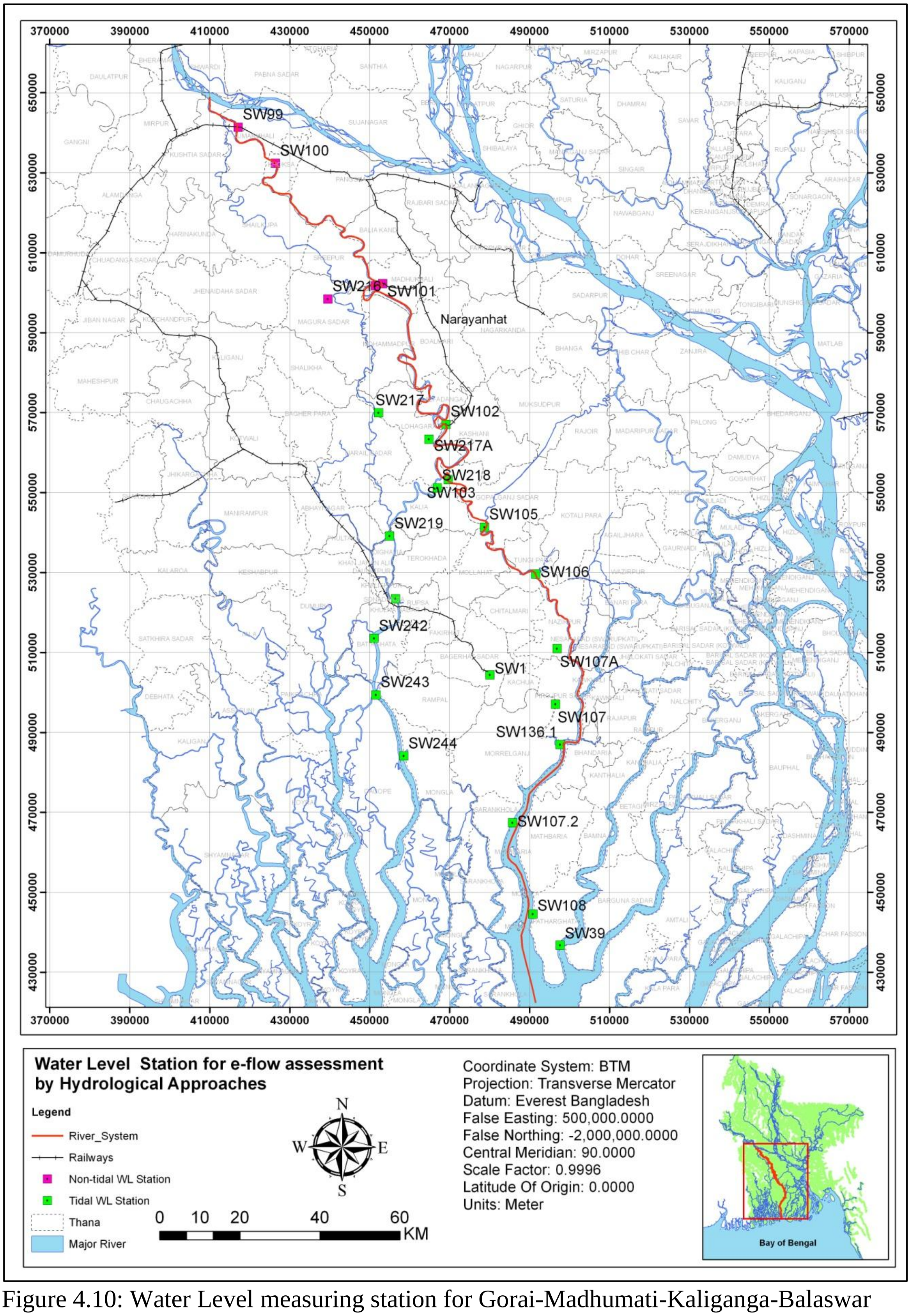


Figure 4.10: Water Level measuring station for Gorai-Madhumati-Kaliganga-Balaswar River System

4.5.5 Salinity Data

Salinity data will be used to set up a one-dimensional salinity model and simulate salinity under different flow conditions. BWDB has a very few number of salinity measuring stations on the Gorai, Madhumati, Kaliganga and Balaswar River. The available salinity data at these measuring stations have been collected from BWDB. Table 4.2 shows a summary of BWDB salinity data measuring locations.

Table 4.2: Summary of BWDB salinity data collection locations

Types of data	River Name	Station ID	Station Name	Data Periods
Salinity	Gorai	SW 101.50	Kamarkhali Transit	1997-2018
	Madhumati	SW 102	Batiapara	1997-2018
	Madhumati	SW 103	Bordia	2001-2017
	Madhumati	SW 105	Offtake of Athatba	2000-2018
	Nabaganga	SW 218	Bardia	2002-2018
	Madhumati	SW 107	Bardia	1997-2018
	Kaliganga	SW 136.1	Umedpur	2000-2018
	Balaswar	SW 107.20	Rayenda	2001-2017
	Balaswar	SW 108	Charduani	2000-2018

4.6 Selection of e-flow indicator and Parameterization

There are two indicators are selected for this study. Fisheries and Salinity indicators is selected for this research work. Environmental flow indicator has been selected depending on data availability. The parameters for the selected indicator are discharge, depth, velocity, critical velocity and cross section of the river. The criterion for site selection has been mainly based on data availability.

4.6.1 Fisheries

A very little information on the swimming and migration pattern of the fish and shrimp species of Bangladesh is available. Considering all the limitations, a detail study is carried out on the species life cycle and habitat, their migration pattern, responses to the water velocity, spawning season, seasonal occurrence and abundance, tidal condition, water depth, hydrological parameters, etc. According to Study report (BWDB, 2017), the common fish of Study River system in a Kushtia region are Kalabous, bain, ayre, boyal, pangash, rui, bacha, ghaira, shrimp, teltupi, kaski, piyeli and bash pata. The common fish of this study river system in a Jhenidah region are bele, ayre, boyal, bacha, ghaira, telupi, kaski, piyeli, bash pata and few ilish. In Magura and Narail region the common fish are found such as ayre, boyal, rui, katla, bacha, ghaira, shrimp, teltupi, kaski, bele, piyali, bash pata and few ilish. The dominant fish species has been selected for this study reach by the fisheries statistical Report 2014-2015 prepared by the department of fisheries and consultation with local fisheries department. The Fish Data as sustainable velocity, sustainable depth, and cross section for different life stages like larvae, fry, juvenile, adult and spawning etc. will be collected from the available study reports (BWDB, 2017; Bari and Marchand, 2006; Akter, 2010 and Chowdhury et al., 2005) and Department of fisheries Report (DoF) reports for the study reach.

Selection of Dominant Fish Species:

The dominant fish species for the study area is selected by discussing with local department of fisheries office. Through suggestion of local DoF officials, the following fish Species were selected. The dominant fish species habitat criteria are selected by different study reports (BWDB, 2017; Bari and Marchand, 2006; Akter, 2010 and Chowdhury et al., 2005) and Department of fisheries reports etc. The selected fish species is given in Table 4.3.

Table 4.3: Selected fish species in the study reaches of the selected rivers

River Name	Sl. No.	Species Name	Local Name	Habitat
Gorai	1	*Aorichthy aor*	Ayeer	River, Depth range: 3-10m, Salinity range: 0 ppt; Water transparency: Clean water; Bottom condition: clay
	2	*Eutropiichthys Vacha*	Bacha	River, Depth range: 3-6m, Salinity range: 0 ppt; Water transparency: Clean water; Bottom condition: No specific preference.
Madhumati River	3	*Labeo ruhita*	Rui/ Carp	River, Depth range: 1-10m, Salinity range: 0 ppt; Water transparency: Clean water; Bottom condition: Sandy or sandy-mud.
Madhumati, Kaliganga and Balaswar River	4	*Macrobrachium rosenbergii*	Golda chingri	River and estuaries, Depth range: 1-20m, Salinity range: 0-15ppt (Adult: 0-2ppt; PL or juvenile: 8-15 ppt), Water transparency: Clean water, Bottom condition: Sandy or sandy-mud.

(Source: Bari and Marchand, 2006)

Development of Habitat Suitability Criteria:

There are many important factors to develop of habitat suitability criteria whether a given species will be present in a river or not. First, food must be available for a species to survive in a particular area. Water depth and streambed width are important factors as these define available physical space, important part of physical habitat. Other factors include water depth and streambed width, water velocity, streambed substrate, temperature and water quality. Different species prefer different depth ranges. Again, different life stages of a species may require different depth ranges.

Many of the important factors are interdependent and influenced by more than flow, there are common responses to changes in flow. An increase in flow at a particular site will usually increase water velocity, depth and width, sediment movement, decrease temperature and increase oxygen content. Water velocity is important for the transport of resources to the organisms, be it dissolved nutrient to algae or prey item to animals. Minimum velocity is also important to initiate the movement of fish migration for food or spawning or both. However, velocity is also a stress factor since animal must be energy to withstand the forces of the flowing water. Velocity even has potential hazard; when water velocity exceeds specific level, the current may sweep the biota away, destroy them or limit their growth. The threshold at which this believed to strongly influence the adaptation of biota in terms of distribution, shape, and behavior (BWDB, 2017). For example, some species are found in fast flowing water, while the others are found only in slow flowing water.

Depth suitability Criteria:

Due to data availability only, adult life stage of each fish species was considered. Depth data as gathered through literature review, Study reports, Department of fisheries report and expert consultation as given in Table 4.5. Chowdhury. et al., 2005; Akter, 2010; BWDB, 2017 used some minimum depth requirement for Ayeer, Bacha, Carp and Golda fishes which are 3-10m, 3-6m, 1-15m and 1-20m respectively for fish migration. It was found from the study report BWDB (2017) that large fishes (Carp and Ayeer etc.) are generally not available below 2-3 m of depth and the small fishes (Piyeli, Bacha, Kajuli) are not available below 1-2 m depth unless they are trapped on shallow waters or come for search of food. The response on depth requirement showed that 5-10m. Based on these criteria depth preference curves for the large fish and small fish have been developed are shown in Figure 4.11 to 4.14. The binary criterion has been used to develop habitat suitability curves for depth. The index zero means that this depth is completely unsuitable and 1 means completely suitable. For river substrate data, it was observed that the bed material of pool and deep pool area are clay and that of riffle is sand. The preferred depth ranges and substrate of the dominant fish species are listed in Table 4.4.

Table 4.4: Selected fish species in the study reaches of the selected rivers

River Name	Sl. No.	Species Name	Local Name	Sources	Life stage	Preferred depth
Gorai	1	*Aorichthy aor*	Ayeer	River	Adult	3-10m
	2	*Eutropiichthys Vacha*	Bacha	River	Adult	3-6m
Madhumati River	3	*Labeo ruhita*	Rui/ Carp	River	Adult	1-15m
	4	*Macrobrachium rosenbergii*	Golda chingri	River and estuaries	Adult	1-20m

(Source: Bari and Marchand, 2006)

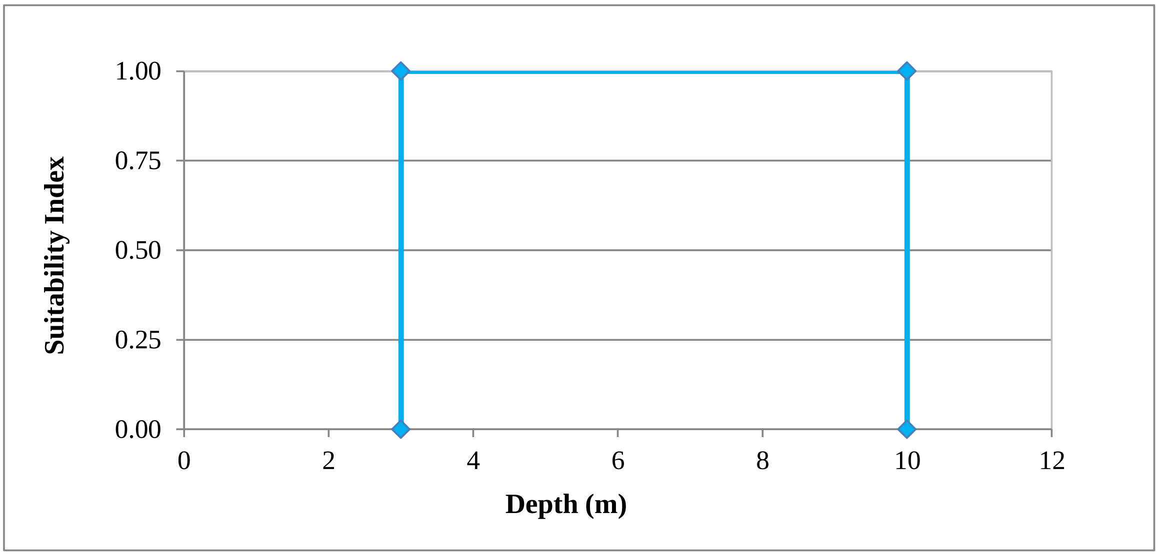


Figure 4.11: Depth Suitability Curves of Gorai River reach for Ayeer Fish (source: Bari and Marchand, 2006)

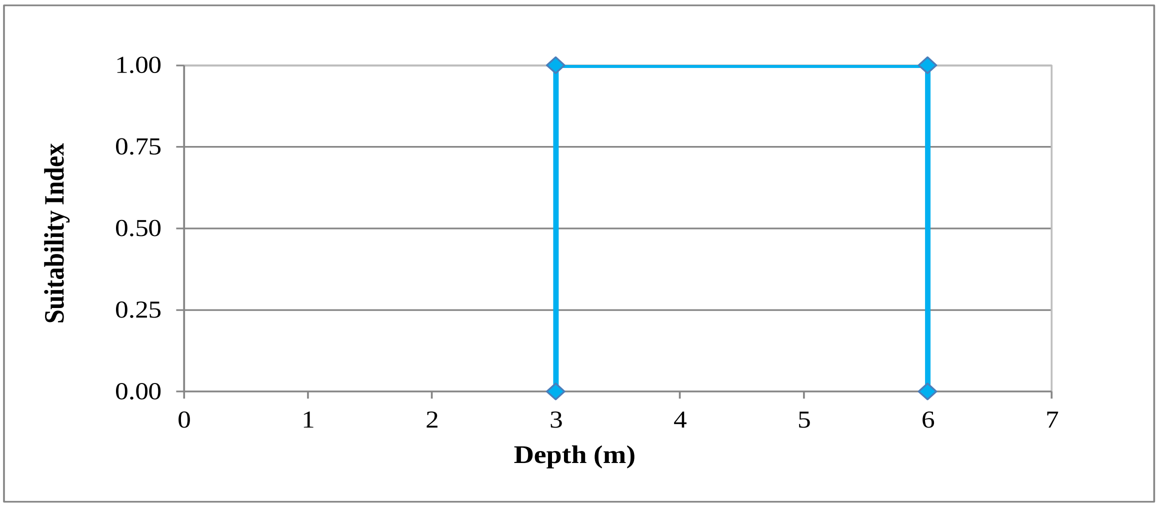


Figure 4.12: Depth Suitability Curves of Gorai River reach for Bacha Fish (Source: Bari and Marchand, 2006)

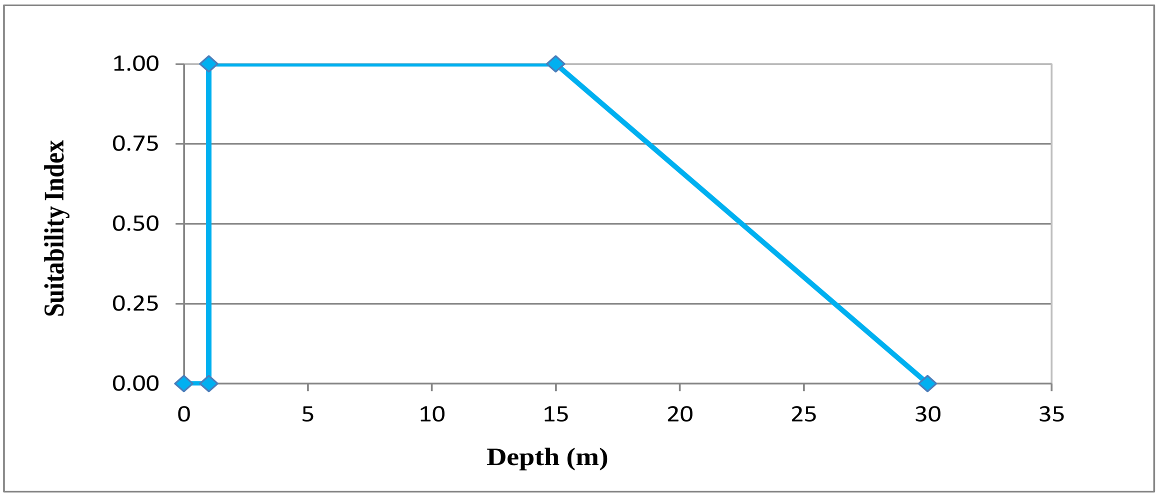


Figure 4.13: Depth Suitability Curves of Madhumati River reach for Carp Fish (Source: Bari and Marchand, 2006)

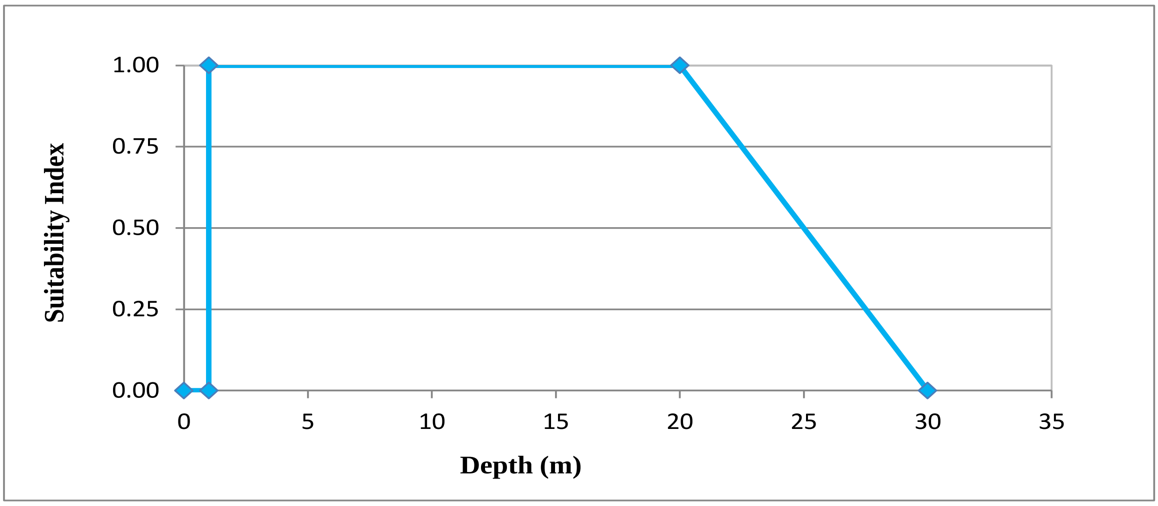


Figure 4.14: Depth Suitability Curves of Madhumati River reach for Golda Fish (Source: Bari and Marchand, 2006)

Selected Velocity Parameters for different fish species:

Velocity suitability criteria were developed in consultation with fisheries experts. Due to data availability, only adult life stage of each fish species was considered. Velocity and substrate preference data as gathered through literature review, study reports (BWDB, 2017; Bari and Marchand, 2006; Akter, 2010 and Chowdhury et al., 2005), Department of fisheries report and expert consultation are assembled in Table 4.5.

Table 4.5: Fish species their average size, cruising swimming speed and maximum swimming speed.

Species	Life stage	Average Size (cm)	Cruising Swimming Speed (m/s)	Maximum swimming speed (m/s)
Ayeer	Adult	130	0.975	1.950
Bacha	Adult	21	0.75	1.50
Carp Fish	Adult	100	0.30	0.60
Golda	Adult	14-22	0.45	0.90

(Source: Bari and Marchand, 2006)

Chowdhury et al., 2005; Akter, 2010; BWDB, 2017 used the suitable velocity limits for carp and Golda as 0.1 to 0.6 m/s and 0.2 to 0.6 m/s respectively. The values of velocity limits seem to be consistent with the other species. For the Ayeer and Bacha, the cursing swimming speed is 0.98 and 0.75 m/s respectively and swimming speed is 1.95 m/s and 1.50 m/s respectively. For the Carp and Golda, the velocity suitability index on one has been assigned for velocity of 0.1 to 0.6 m/s and 0.2 to 0.6 m/s respectively. Outside of this range, velocity suitability index is taken as Zero.

Although for adult life stage, there is no lower velocity limit, however a zero-velocity suitability index would hinder the supply of food and the amount of Oxygen may also be degraded. For velocity suitability criteria the fishes living in the river have a suitability value of 0.0 at less than 0.1 m/s. The suitability increases linearly up to 1.00 at velocity half the cruising swimming velocity and remains the same up to cruising swimming velocity. For velocity preference of fish, data on cruising swimming speed and maximum swimming speed for each of the fish species were collected from literature. Velocity suitability curves have been developed for these species as shown in figure 4.15 to 4.18.

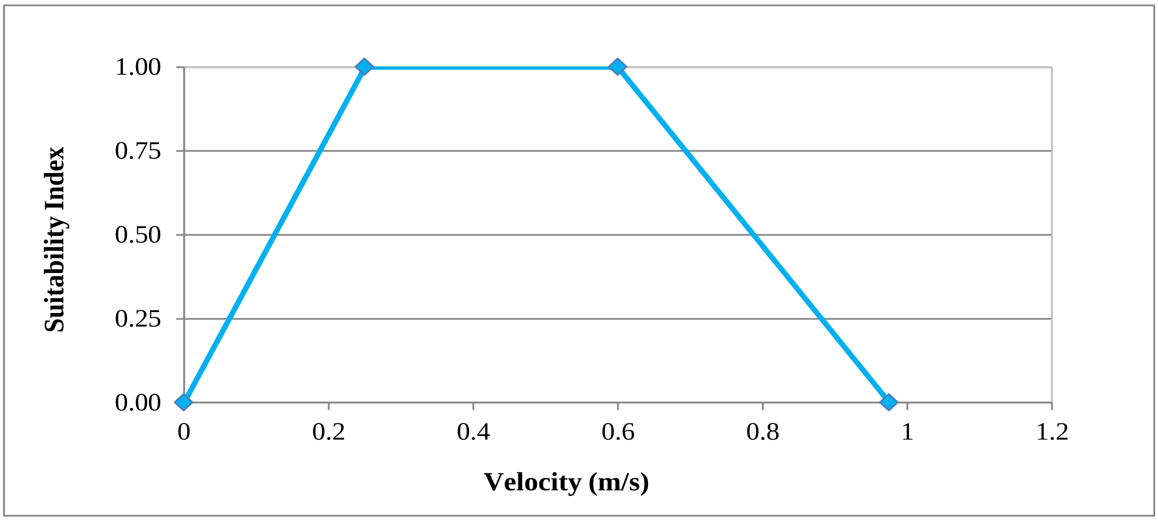


Figure 4.15: Velocity Suitability Curves of Gorai River reach for Ayeer Fish (Source: Bari and Marchand, 2006)

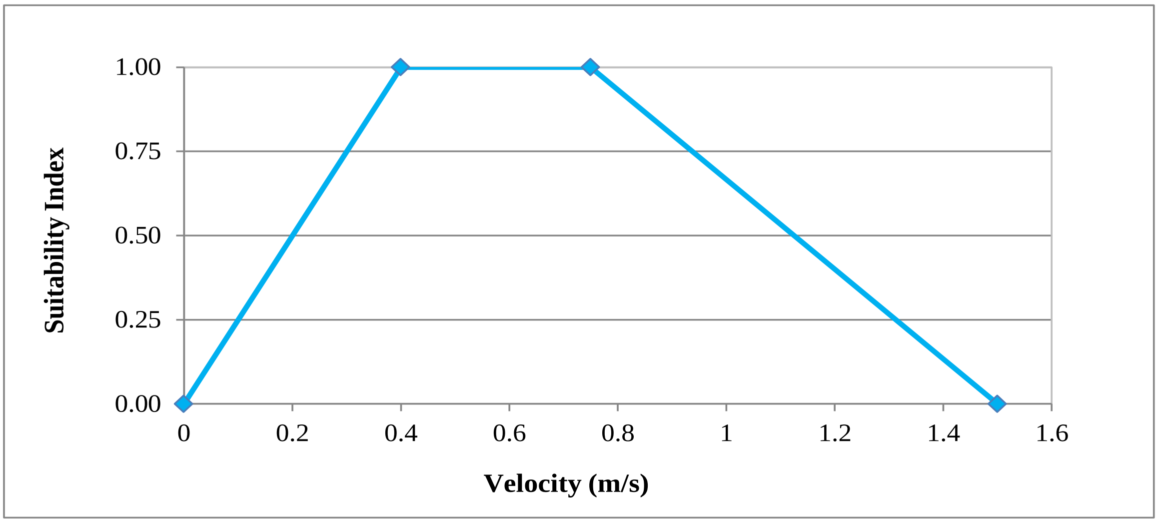


Figure 4.16: Velocity Suitability Curves of Gorai River reach for Bacha Fish (Source: Bari and Marchand, 2006)

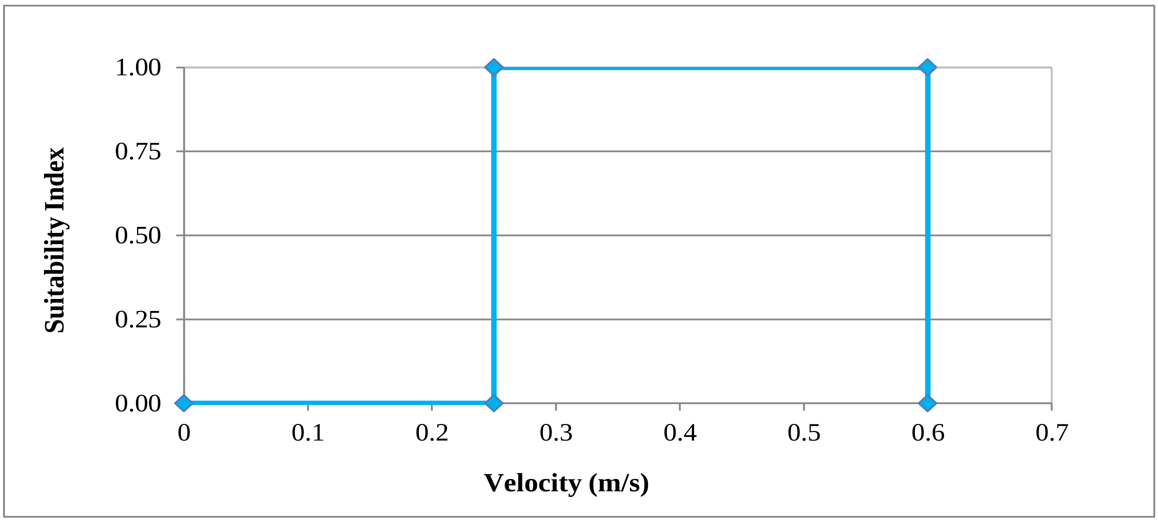


Figure 4.17: Velocity Suitability Curves of Madhumati River reach for Carp Fish (Source: Bari and Marchand, 2006)

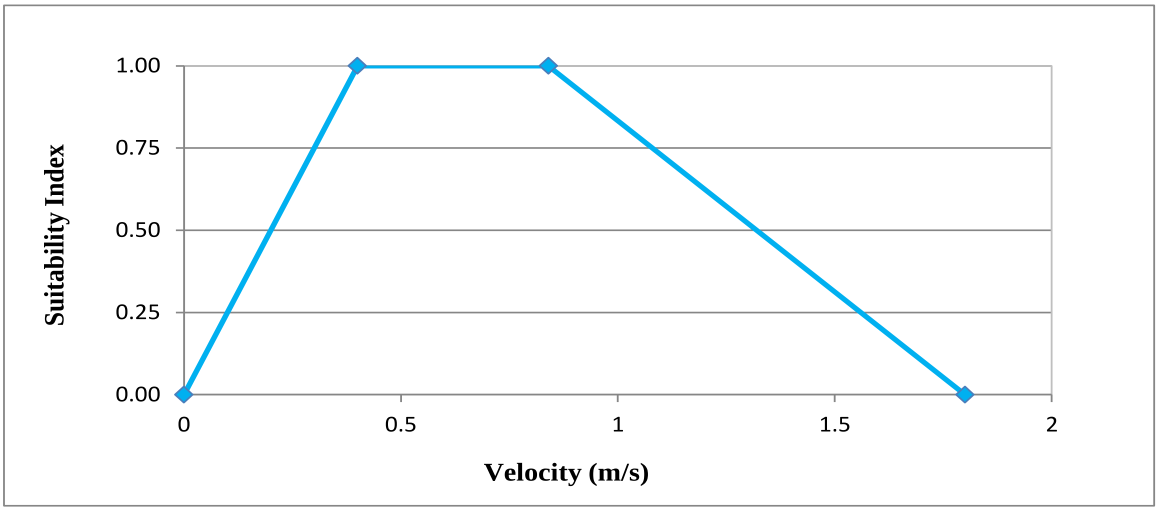


Figure 4.18: Velocity Suitability Curves of Madhumati River reach for Golda Fish
(Source: Bari and Marchand, 2006)

Fish migration Pattern:

The migratory behavior of catfishes of Bangladesh is unknown. However, it appears that by far greatest number of migratory species in Bangladesh exhibit category those with limited longitudinal migrations followed by lateral migrations onto the floodplain or feeding habitat e.g., Catla, Labeo rohita, Cirrhinus mrigala all show only local movements upstream, and primarily migrate laterally onto the floodplain after spawning along the margin adjoining the river. Euryhaline fishes are able to adapt to a wide range of salinities. Some euryhaline species show both way migrations for long distance from estuary to fresh water. River discharge provides the essential directional signal to physiologically prepared fishes to move upstream, and also offers increased resistance to progress. Some fishes tend to follow their migratory pathways against the resistance of the current in one of two ways (Akter, 2010).

(i) Carp Species

The natural pattern of fish migration during the pre-monsoon period is for adult fish, mainly Carp and Cat fish. The migration pattern during the post-monsoon is a reversal condition at pre-monsoon. Older nature adult and young new adult fish move from breeding ground to over wintering areas. The fish year can be divided into the following seasons:

February to March, Broodstock and Juveniles approaching recruitment size are concentrated in river duars and beels. No migratory movement takes place during this period of these species. The flood plain dries out and only water left is in rivers and beels, where entire fish population is lodged.

Spawing migration season (April to June) usually begins during the pre-monsoon flood phase and continue into the first part of full monsoon flood phase.

Grow-out season (June-september) of rapid fish growth. Fingerlings of those fish which bred on the flood plain are on the nursery ground so they do not have an access problem but the fingerlings hatched from the river breeding species need to get up to the flood plain. Habitat area and food availability increase enormously during this season.

Flood recession season (September to January). Flood water starts receding. As water area shrinks fish move into deeper water navigating along khals and river channel, majority to deeper water during flood recession except a few species. Migration pattern of shrimp and prawn depends on its physiological process and hydrological system of river. Anadromous fishes spend most of their adult lives at sea, but return to fresh water to spawn (Akter, 2010).

(ii) Golda Chingri

In the natural environment, mating of Golda takes place all year round, although, due to environmental reasons, peak mating takes place only during certain periods of the year. It lives in turbid freshwater, but their larval stages require brackish water to survive. Golda is popular for its rapid growth, with the males growing faster than the females. The adults are omnivorous, eat greedily and frequently on both plants and animal materials. It is usually quiet during the day and stays at the bottom without much activity tending to avoid strong illumination. At night they become active and search for food. The number of moults and the durations of inter-moults are not fixed, and depend on the environment, particularly temperature and the availability of food. The larvae are attracted by light; it avoids direct light and other strong lights area. Golda can easily tolerate different salinities of water from fresh to saltwater; therefore, this species is considered euryhaline.

Abdominal appendages movement generally occurs during the downstream spawning migration of prawn towards optimum salinity of 8-15 ppt. Even if larvae hatch in freshwater, they will not survive if they are not put into brackish water within two or three days. Larvae in the wild generally eat zooplankton, small insects and larvae of other aquatic invertebrates. larvae generally take a minimum of 26 days to metamorphose into Post-larvae (PL).

Post larvae can tolerate a wide range of salinity, but freshwater is their normal habitat. And so, two to three weeks after metamorphosis, the PL move against the current and head towards freshwater canal and rivers. They abandon the planktonic habit at this stage and become omnivorous, feeding on aquatic insects and their larvae, phytoplankton, seeds of cereals, fruit, small molluscs and crustacean, fish flesh, slaughterhouse waste and animal remains. It can move by crawling and generally swim with its dorsal side uppermost. It can swim rapidly. It takes almost 6-7 months to become sexually matured and able to reproduction of egg for a female Golda (Akter, 2010). Migration of adult Golda towards estuary for spawning usually occurs from February to April (MPO, 1985). There are four stages in the life of a freshwater prawn, viz. larvae, juvenile and adult is shown in Figure 4.19.

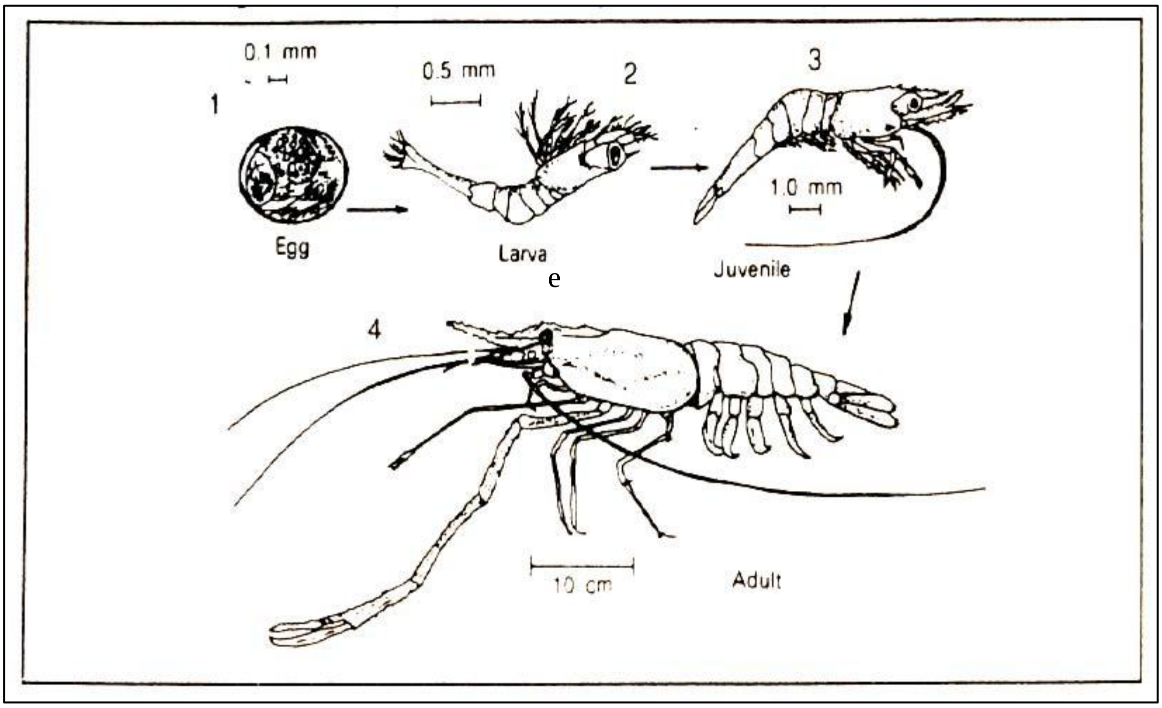


Figure 4.19: Life cycle of Golda (Source: Adopted from Akter, 2010)

(iii) Bacha Fish

Bacha breed in brackish water but mature in fresh water. Migration of Bacha for spawning usually occurs from March to October (Saha, 2007).

4.6.2 Salinity

Increased salinities and vertical stratification of water column and penetration of the salt-wedge farther upstream are attributable to reduced inflows (Peirsoon. et al., 2002). Salinity not only degrades the water quality to use it as a source of drinking and irrigation water but also hampers the suitability of the aquatic environment. The US EPA recognizes salinity as a common habitat indicator (abiotic condition indicator) for use in estuaries. Salinity is well-defined and measurable, and has ecological significance encompassing a number of estuarine properties and processes (Saha, 2007).

Saha, 2007 noted the use of an indicator species (Vallisneria Americana) to determine the overall health of the River estuary in Florida. The species was found to be especially sensitive to salinity and its growth steadily declines with increasing salinity until approximately 8-9 ppt. It will survive in waters with 11- 13 ppt, but its density declines when salinity is over 10ppt. It was determined that fresh water flows between 400-600 cubic feet per second from upstream keep the salinity near healthy levels for this species of sea grass at a designated point.

4.7 Summary

Environmental Flow Assessment is required for balancing the use (or development) of water from aquatic ecosystems for various purposes whilst protecting (or managing) the aquatic ecosystems so that it can continue to be used by present and future generations. In the study river system, Gorai and Madhumati are almost dried up in dry period but there are navigable in the monsoon period. Kaliganga and Balaswar River has been maintained the sustainable flow both dry and monsoon period. Fisheries and Salinity indicators have been selected in this chapter. Those selected indicators have been parameterized in terms of depth, velocity and discharge for their sustainability. Required data have been collected to present all requirements in terms of discharge. The details analysis and results are shown in the next chapter.

CHAPTER 5
RESULTS AND DISCUSSIONS

5.1 General

This chapter describes all results and analyses. More than 200 approaches have been developed to determine environmental flow requirement in the rivers. There is no universally accepted method for all rivers. Some methods have been used to define a minimum flow, below which no human influence should take place. The Environmental flow (e-flow) requirement for a river is the minimum flow required to enhance or maintain aquatic and riparian life. After impact analysis, e-flow assessments have been done by Hydrologic (Tennant Method, Flow Duration Curve Analysis and Constant Yield Method), Hydraulic (Wetted Perimeter Technique), Physical Habitat Simulation Method (PHABSIM) and Holistic Approaches (Building Block Method). The total requirements have been assessed in terms of discharge for the sustainability of the selected indicators and also determine the salinity level for required e-flow of the Gorai-Madhumati-Kaliganga-Balaswar River system.

5.2 Hydrological Assessment

5.2.1 Analysis of Historical Discharge and Water Level of Gorai River

In the hydrological analysis for e-flow assessment for Gorai-Madhumati-Kaliganga-Balaswar river system, the historical discharge and water level of the Gorai River at Gorai Railway Bridge is plotted against the time to show the variation of maximum and minimum discharge and water levels. The minimum discharges are shown in a separate figure for better visualization of the data range. Figure 5.1 show the maximum discharges of Gorai River , the figure shows two peaks of discharge in the year 1969 (7560 cumec) and 1974 (8460 cumec) in the pre Farakka period and two peaks in the year 1988 (8490 cumec) and 1993 (8880 cumec) in the post Farakka period. In case of the minimum discharge of Gorai River (Figure 5.2) it is found that, from the year 1988 to 1998 and 2009 to 2018 the discharge of Gorai River almost 0 cumec except the year 1993 (37.4 cumec), 1994 (10.9 cumec), 2012 (108 cumec), 2013 (100 cumec) and 2017 (20 cumec). But in recent years (2014-2018) the minimum discharge came down to around 10 cumec except the year 2017. In the Figure 5.3, the maximum, minimum and average water levels of Gorai River are found to be 11.51 to 13.65 m PWD, 2.75 to 5.89 m PWD and 5.89 m PWD to 8.90 m PWD, respectively.

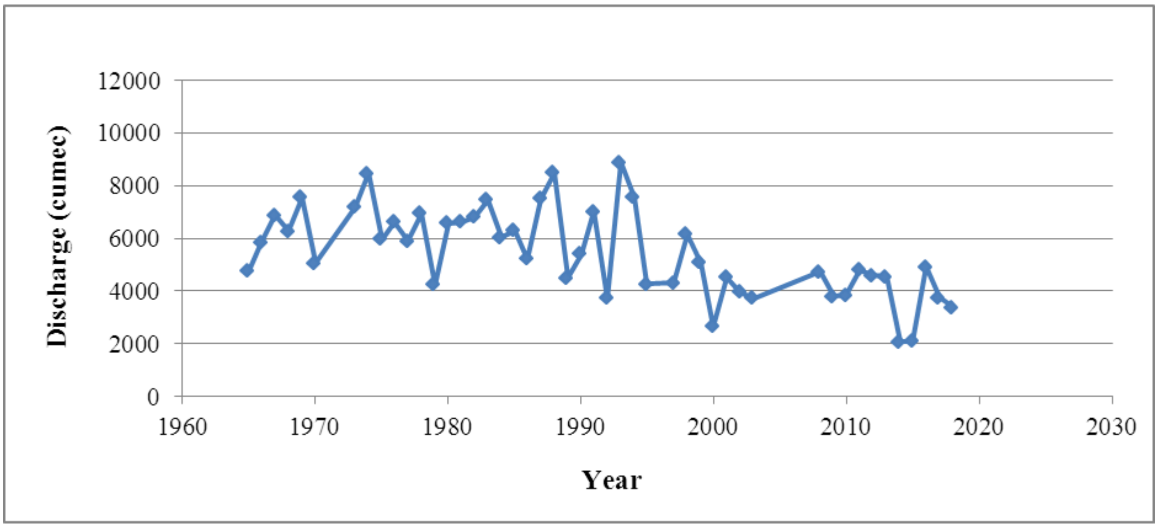


Figure 5.1: Maximum discharges of Gorai River

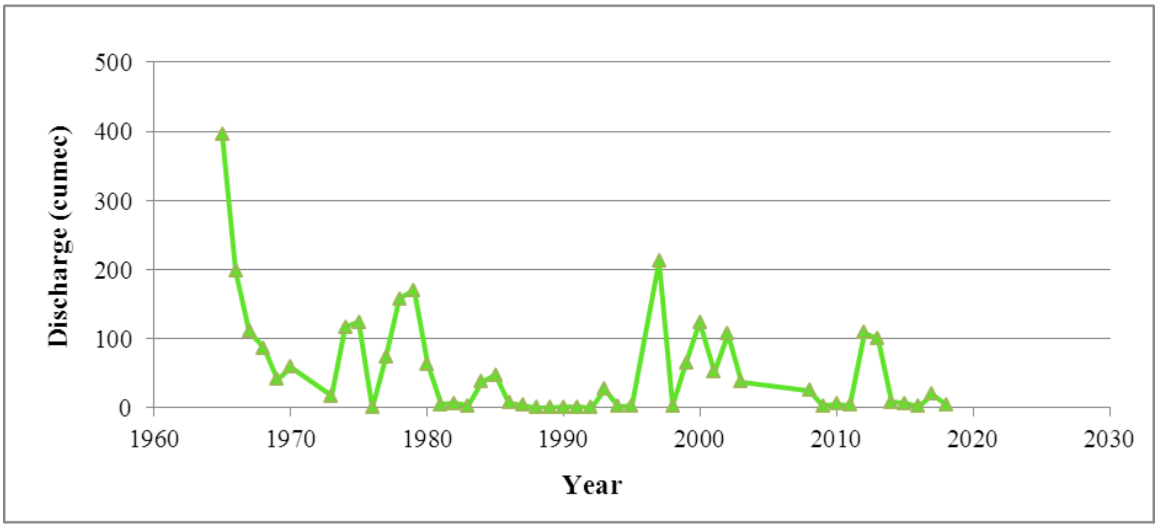


Figure 5.2: Minimum discharges of Gorai River

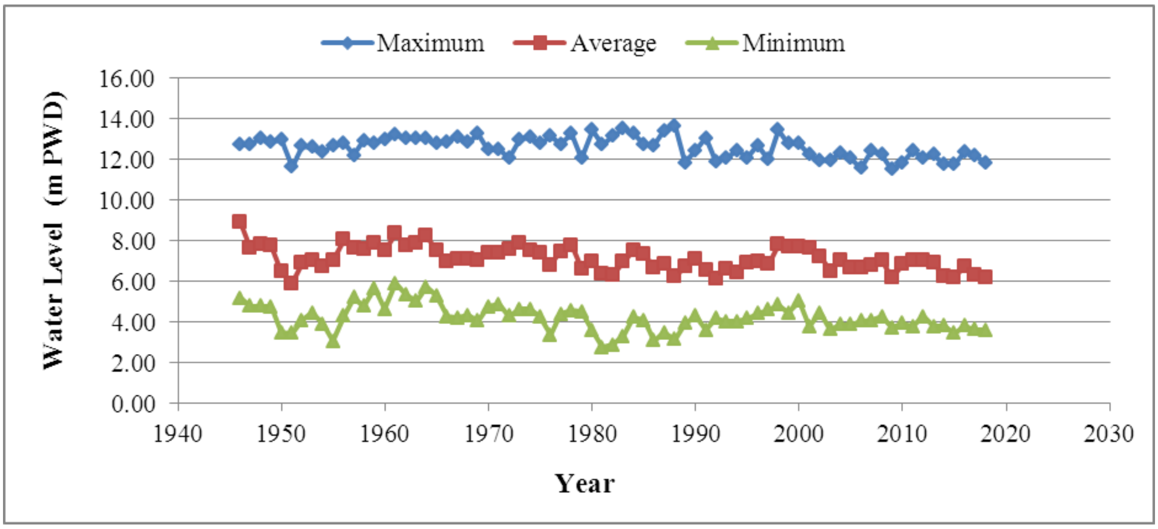


Figure 5.3: Variation of water levels of Gorai River

5.2.2 Analysis of Historical Discharge and Water Level of Madhumati River

In the hydrological analysis for e-flow assessment for Gorai-Madhumati-Kaliganga-Balaswar river system, the historical discharge and water level of the Madhumati River at Bordia location is plotted against the time to show the variation of maximum and minimum discharge and water levels. The minimum discharges are shown in a separate figure for better visualization of the data range. Figure 5.4 show the maximum discharges of Madhumati River. The Figure shows the maximum discharge it is found to be 321 cumec (1999) to 280 cumec (2005) within the year 1985 to 2012. In case of the minimum discharge of Madhumati River (Figure 5.5) it is found to be 51 cumec (1993) to 30 cumec (2003) within the year 1985 to 2012. Figure 5.6 demonstrate the maximum, minimum and average water levels for the tidal situations. In this figure, the high tide peak, low tide peak and average peak water levels in Madhumati River are found to be 4.00 to 4.93 m PWD, - 0.76 to - 1.19 m PWD and 0.21 m PWD to 0.78 m PWD respectively.

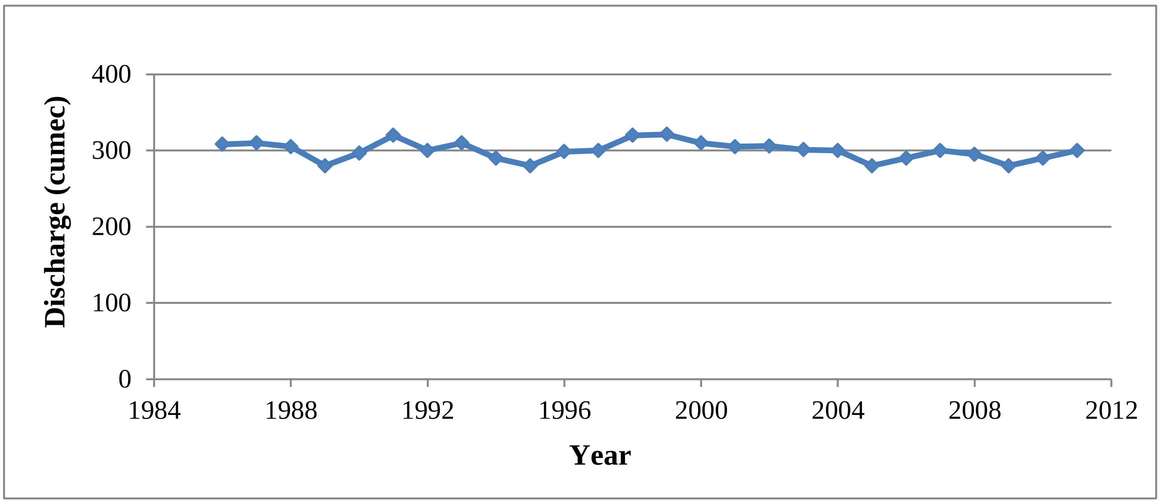


Figure 5.4: Maximum discharges of Madhumati River

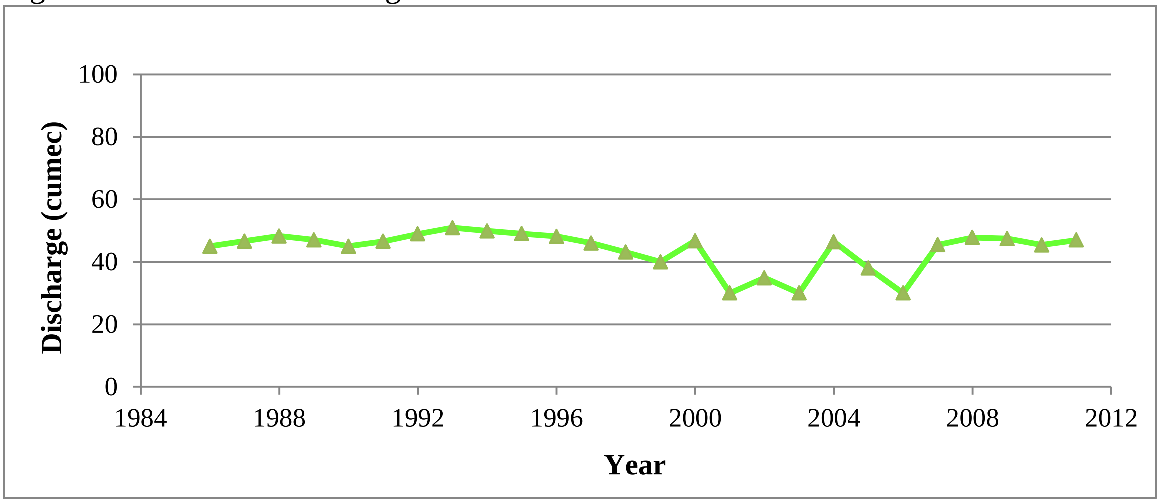


Figure 5.5: Minimum discharge of Madhumati River

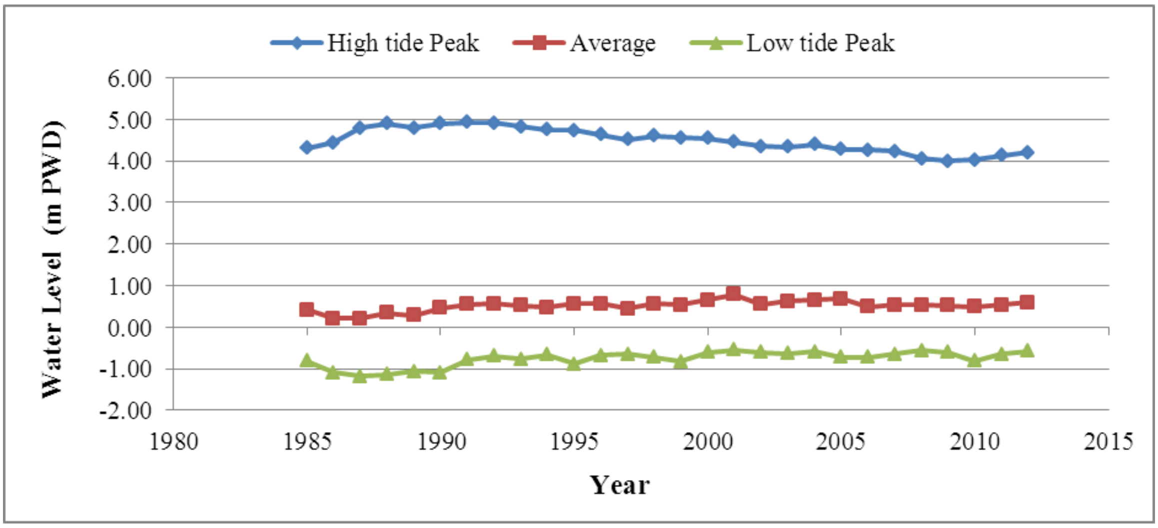


Figure 5.6: Variation of water level of Madhumati River

5.2.3 Analysis of Historical Discharge and Water Level of Kaliganga River

In the hydrological analysis for e-flow assessment for Gorai-Madhumati-Kaliganga-Balaswar River system, the historical discharge and water level of the Kaliganga River at Pirojpur Sadar is plotted against the time to show the variation of maximum and average discharge and water levels. The average discharges are shown in a separate figure for better visualization of the data range. Figure 5.7 show the maximum discharges of Kaliganga River. The figure shows the maximum discharge it is found to be 4895 cumec (2004) within the year 1985 to 2012. In case of the average discharge of Kaliganga River (Figure 5.8) it is found that, average discharge it is found to be 1450.96 cumec (1989) to 1863.234 cumec (2004) within the year 1985 to 2012. Figure 5.9 demonstrate the maximum, minimum and average water levels for the tidal situations. In this figure, the high tide peak, low tide peak and average peak water levels in Kaliganga River are found to be 1.83 to 2.44 m PWD, - 0.51 to - 1.06 m PWD and 0.36 m PWD to 0.88 m PWD respectively.

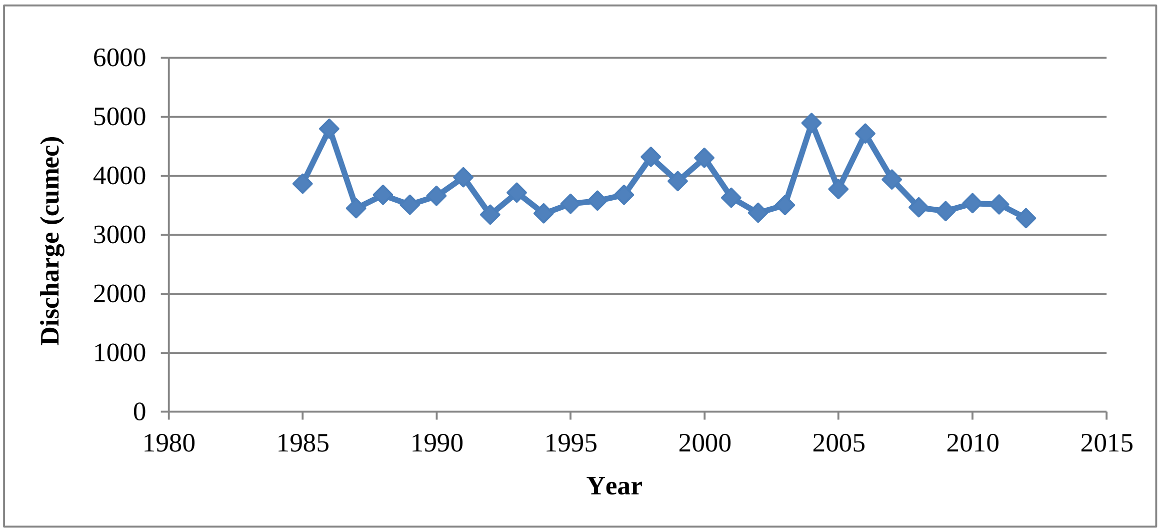


Figure 5.7: Maximum discharges of Kaliganga River

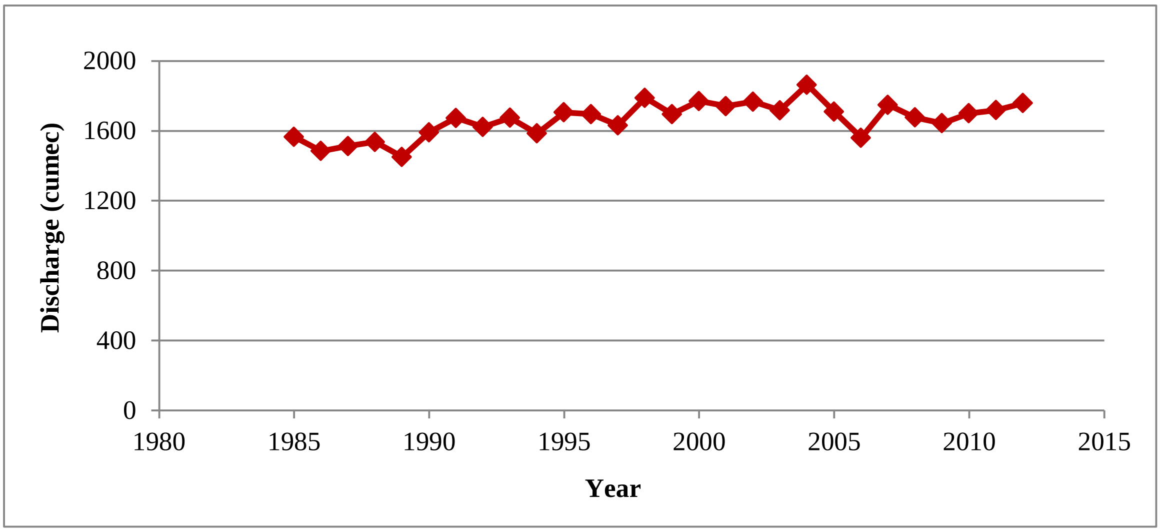


Figure 5.8: Average discharges of Kaliganga River

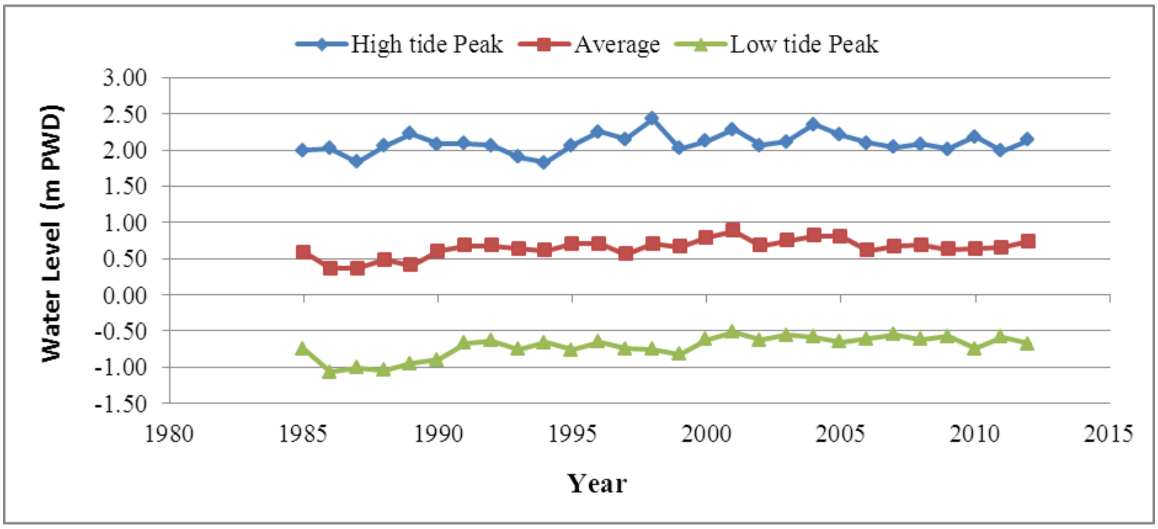


Figure 5.9: Variation of water level of Kaliganga River

5.2.4 Analysis of Historical Discharge and Water Level of Balaswar River

In the hydrological analysis for e-flow assessment for Gorai-Madhumati-Kaliganga-Balaswar river system, the historical discharge and water level of the Balaswar River at Charduani is plotted against the time to show the variation of maximum and average discharge and water levels. The average discharges are shown in a separate figure for better visualization of the data range. Figure 5.10 show the maximum discharges of Balaswar River. The figure shows the maximum discharge it is found to be 34533 cumec (2000) to 24615 cumec (2009) within the year 1985 to 2012. In case of the maximum average discharge of Balaswar River (Figure 5.11) it is found to be 12731 cumec (2012) within the year 1985 to 2012. Figure 5.12 demonstrate the maximum, minimum and average water levels for the tidal situations. In this figure, the high tide peak, low tide peak and average peak water levels in Balaswar River are found to be 2.06 to 2.62 m PWD, - 0.75 to - 1.28 m PWD and 0.21 m PWD to 0.78 m PWD respectively.

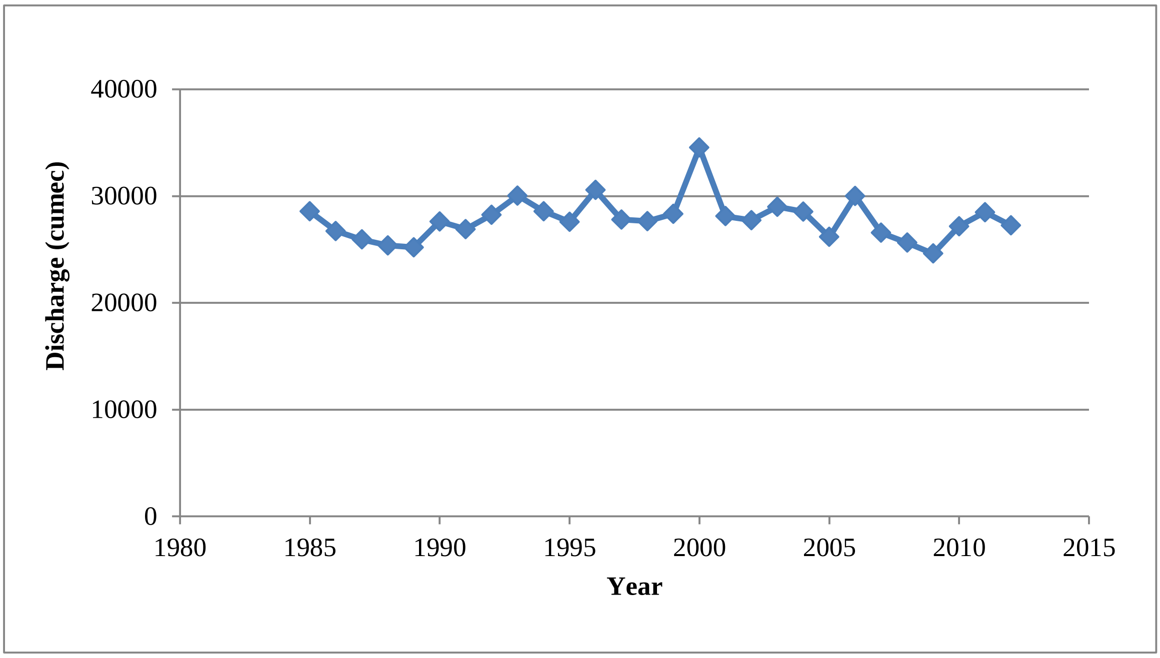


Figure 5.10: Maximum discharges of Balaswar River

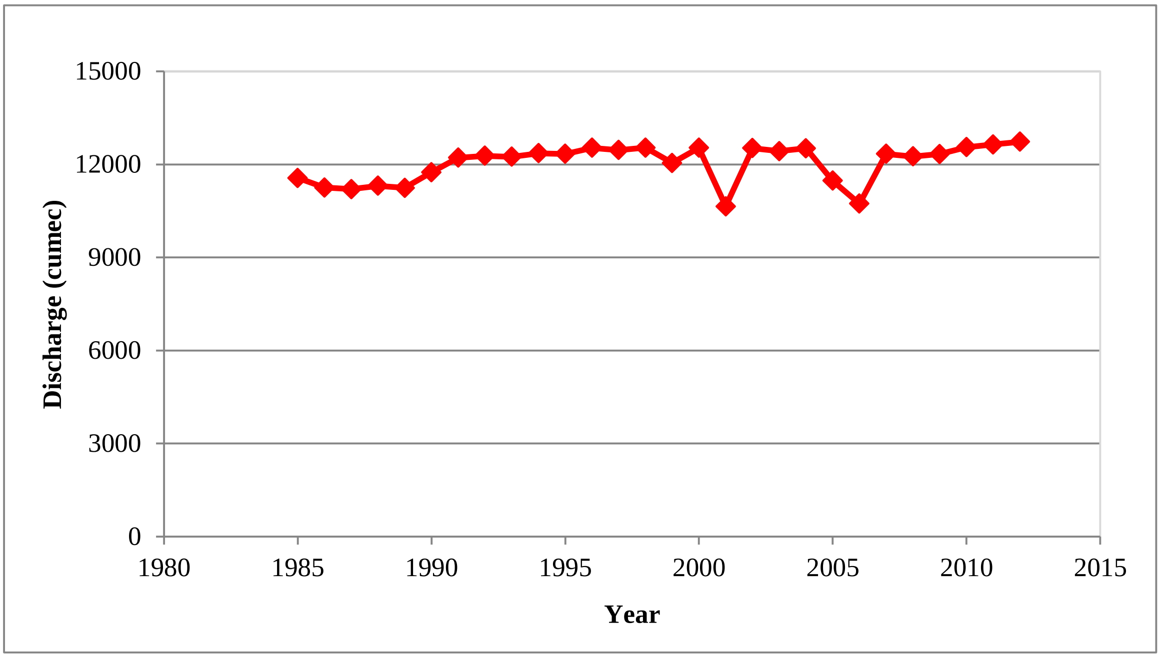


Figure 5.11: Average discharges of Balaswar River

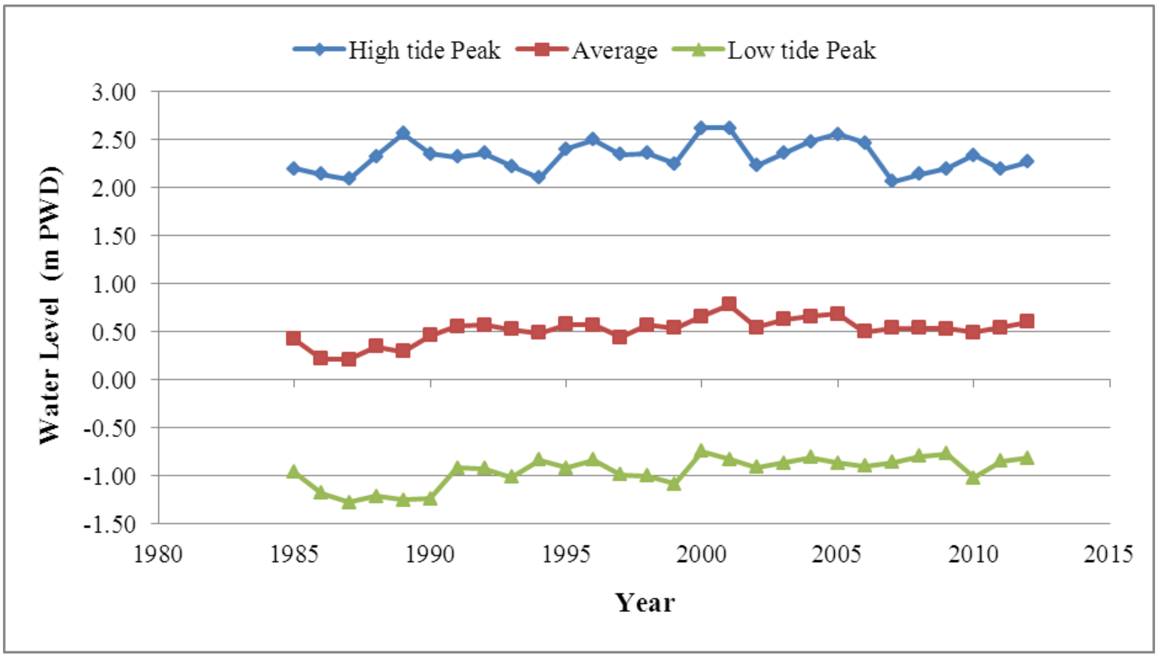


Figure 5.12: Variation of water level of Balaswar River

5.3 Hydrological Method

Environmental flow requirement for Gorai-Madhumati-Kaliganga-Balaswar River System has been assessed applying three methods of hydrological approach, using historical daily discharge data of the river. After due consistency checking of the collected data, Environmental flow requirement has been assessed using (i) Tennant Method (MAF), (ii) Flow Duration Curve (FDC) Analysis (iii) Constant Yield Method (CYM). The methods used are reiterated here in brief and the results obtained from analysis are presented in the following sections.

5.3.1 The Tennant Method

Tennant 1976 established eight classes of flow by analyzing a series of field data and measurements and observations to correlate habitat quality with various percentage of Mean Annual Flow (MAF). Seven of these classifications characterize habitat quality for fish and wild life and the eighth provides flushing flow. The Tennant method requires that MAF can be calculated from an historic flow record. A flow recommendation is established by selecting the desired classifications and multiplying MAF by the corresponding percentage or percentage range.

(i) Application of Tenant Method for Gorai River

Data analysis with the two time period (Pre-Farakka and Post Farakka) show scenarios for different condition as stated by Tennant. The average of flow data is specified to maintain the riparian habitat in a particular state. The mean annual flows at Gorai Rail Bridge of Gorai River are found as 1,511 cumec and 1,238 cumec in pre-Farakka and post-Farakka situations respectively. It shows that MAF has decreased after constructing Farakka Barrage. March is the driest month in the long time series. December to May, six months are considered as dry months for Gorai River; rest six months are considered as wet months. Mean monthly values of Gorai River are shown in Table 5.1 and variation of mean annual flow on Pre-Farakka Period shown in Figure 5.13. Table 5.2 shows the percentage of flows of Gorai River in different condition according to Tennant. It is seen that flows in the month of March less that the poor condition (10% of MAF) of Pre-Farakka Period and month of February, March ,April and May are much less that the poor condition (10% of MAF) of Post-Farakka Period of the river system. Flows of January, February and May are nearly poor condition of Pre-Farakka Period and Flows of January is nearly poor condition of Post-Farakka Period. Flow in June and November maintains 30% of MAF both Pre-Farakka and Post-Farakka period. Therefore flows in January to May in Gorai River are highly vulnerable for its ecosystem according to Tennant. Flows in December are less than good condition; which is less than 40% of mean annual flow. July, August, September and October are the months when river flushes, especially in August and September.

Table 5.1: Mean monthly flow of Gorai River

Month	Pre-Farakka	Post-Farakka
	cumec	
Jan	276	130
Feb	200	84
Mar	134	54
Apr	149	56
May	215	96
Jun	691	449
Jul	2714	2463
Aug	5238	4288
Sep	4645	4272
Oct	2275	1894
Nov	858	601
Dec	453	242

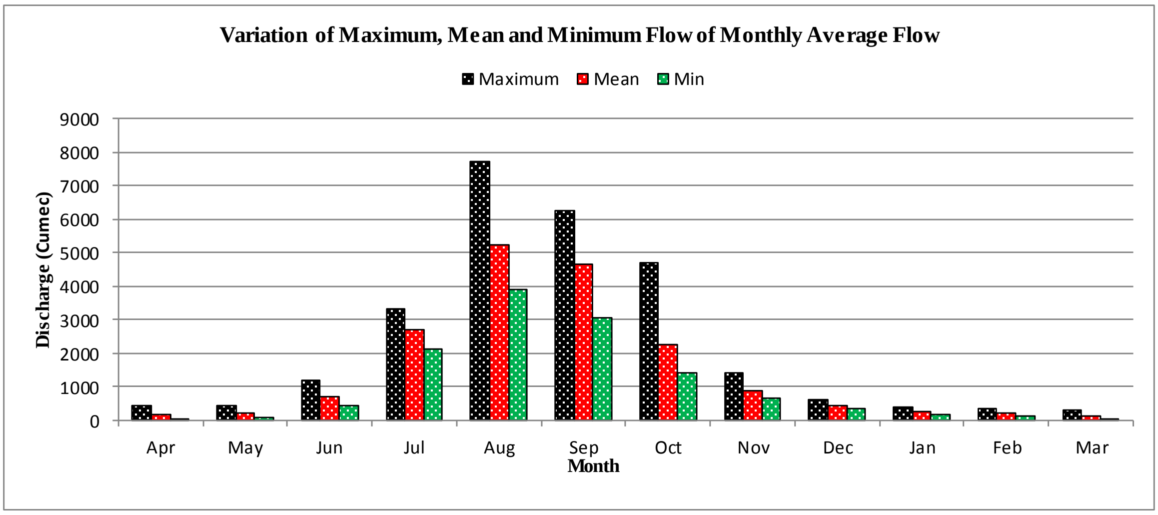


Figure 5.13: Variation of Maximum, Mean and Minimum Flow of Gorai River

Table 5.2: Percentage of Mean Annual flow of Gorai River

Percentage of MAF	Pre-Farakka	Post-Farakka
	cumec	
200% (flushing flow)	3022	2476
60-100% (optimum range)	907-1511	743-1238
60% (outstanding)	907	743
50% (excellent)	756	619
40% (good)	604	475
30% (fair or degrading)	453	371
10% (poor)	151	124
<10% (Severe degradation)	<151	<124

So, according to given tables, more than 40% of MAF should be available during the month of June to November. This method has severe limitation and should be restricted to reconnaissance level planning (Mosley, 1983). Considering January, February, March and April as the critical months and August and September as flood peaks, Table 5.3 shows corresponding e-flow of Gorai River. Therefore, the e-flow requirement for January to May becomes 151 cumec and for August and September as 3022 cumec.

Table 5.3: Environmental flow demand based on Tennant Method of Gorai River

Months	Environmental flow (cumec)		Remarks
January	10% of MAF	151	Dry month (Severely degraded condition)
February		151	
March		151	
April		151	
May		151	
August	200 % of MAF	3022	Wet months (flushing flow)
September		3022	

(ii) Application of Tenant Method for Madhumati River

For determination of e-flow by using the MAF method, the historic flow data has been used from 1985 to 2012 at Bordia of Madhumati River based on availability. Mean monthly values are shown in Table 5.4 and variation of maximum, mean and minimum flow shown in Figure 5.14. Table 5.5 shows the percentage of flows of Madhumati River in different condition according to Tennant. It is seen flows of January to June are and November to December maintain outstanding condition (60% of MAF) of this River. Therefore, flows in December to February in Madhumati River should be maintained required e-flow for its ecosystem according to Tennant. Flows in December are maintaining optimum range. July, August, September and October are the months when river flushes, especially in August and September.

Table 5.4: Mean monthly flow at of Madhumati River

Month	Mean Annual Flow cumec
Jan	59
Feb	58
Mar	62
Apr	64
May	67
Jun	67
Jul	123
Aug	198
Sep	200
Oct	107
Nov	59
Dec	55

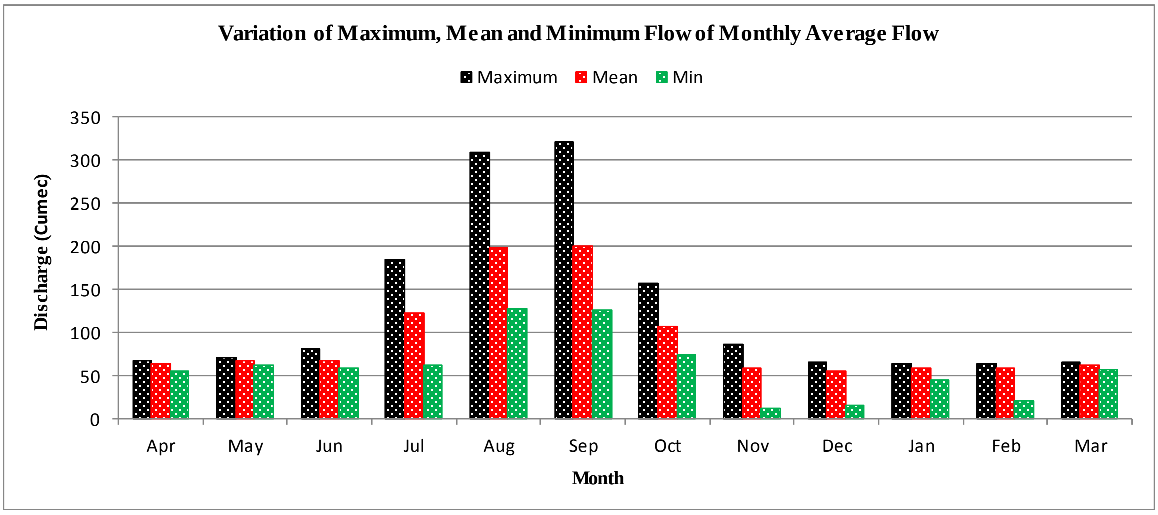


Figure 5.14: Variation of Maximum, Mean and Minimum Flow of Madhumati River

Table 5.5: Percentage of Mean Annual flow of Madhumati River

Percentage of MAF	Percentage of Flow
	cumec
200% (flushing flow)	186
60-100% (optimum range)	55-93
60% (outstanding)	55
50% (excellent)	47
40% (good)	37
30% (fair or degrading)	28
10% (poor)	9
<10% (Severe degradation)	<9

This method has severe limitation and should be restricted to reconnaissance level planning (Mosley, 1983). March, April, May and June maintain outstanding range and August and September as flood peaks of this river. Table 5.6 shows corresponding e-flow. According to above given Table 5.5, more than 60% of Mean Annual flow (around 55 cumec) should be available during the month of March to June. Therefore, the e-flow requirement for December to February becomes 55 cumec and for July to September as 186 cumec.

Table 5.6: Environmental flow demand based on Tennant Method of Madhumati River

Months	Environmental flow (cumec)		
December	60% of MAF	55	Dry month (Severely degraded condition)
January		55	
February		55	
July	200 % of MAF	186	
August		186	Wet months (flushing flow)
September		186	

(iii) Application of Tenant Method for Kaliganga River

For determination of e-flow by using the MAF method, the historic flow data has been used from 1985 to 2012 based on availability. Mean monthly values at Pirojpur Sadar of Kaliganga River are shown in Table 5.7 and variation of maximum, mean and minimum of discharge Figure 5.15. Table 5.8 shows the percentage of flows of Kaliganga River in different condition according to Tennant. It is seen that flows in the month of January to May and November to December is high that the poor condition (10% of MAF) of the river system. Flow in June to October maintains 60% of MAF. Therefore flows in January to May in Kaliganga River are not vulnerable for its ecosystem according to Tennant. River is not flushes during the month of September and October.

Table 5.7: Mean monthly flow of Kaliganga River

Month	Mean Annual Flow
	cumec
Jan	1191
Feb	1164
Mar	1257
Apr	1316
May	1448
Jun	1550
Jul	1719
Aug	1770
Sep	1718
Oct	1563
Nov	1357
Dec	1197

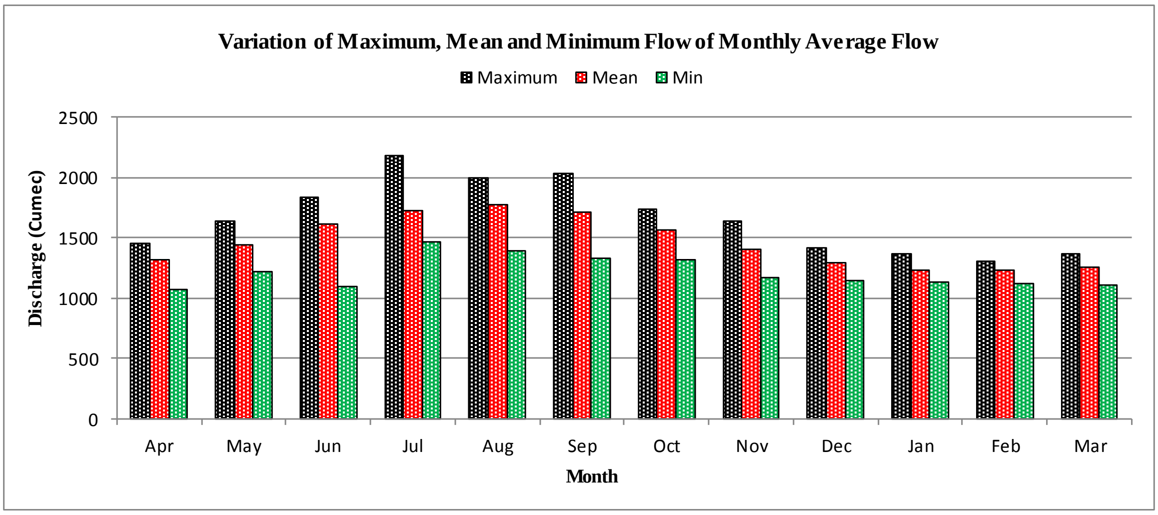


Figure 5.15: Variation of Maximum, Mean and Minimum Flow of Kaliganga River

Table 5.8: Percentage of Mean Annual flow of Kaliganga River

Percentage of MAF	MAF cumec
200% (flushing flow)	2636
60-100% (optimum range)	791-1318
60% (outstanding)	791
50% (excellent)	659
40% (good)	527
30% (fair or degrading)	395
10% (poor)	132
<10% (Severe degradation)	<132

It is seen that flows are not in the poor condition (10% of Mean Annual Flow) of the river system. So, according to given tables, optimum range of MAF should be available during the month of January to April and November to December. This method has severe limitation and should be restricted to reconnaissance level planning (Mosley, 1983). Considering March, April and May as the good for maintaining eco-system of this river. Table 5.9 shows corresponding e-flow. Therefore, the e-flow requirement for December to February becomes 1164 cumec.

Table 5.9: Environmental flow demand based on Tennant Method of Kaliganga River

Months	Environmental flow (cumec)		
December	60-100 % of MAF	1164	Dry month
January		1164	
February		1164	
August	200 % of MAF	2,636	Wet months (River are not flushing flow)
September		2,636	

(iv) Application of Tenant Method for Balaswar River

For determination of e-flow by using the MAF method, the historic flow data has been used from 1985 to 2012 based on availability. Mean monthly values at Charduani of Balaswar River are shown in Table 5.10 and variation of maximum, mean and minimum of discharge is shown in Figure 5.16. Table 5.11 shows the percentage of flows of Balaswar River in different condition according to Tennant. It is seen that flows in the month of January to May and November to December is high that the poor condition (10% of MAF) of the river system. Flow in June to October maintains 60-100% of MAF. Therefore flows in January to May in Balaswar River are not vulnerable for its ecosystem according to Tennant. River is not flushes during the month of September and October.

Table 5.10: Mean monthly flow of Balaswar River

Month	Mean Annual Flow
	cumec
Jan	11117
Feb	10971
Mar	11872
Apr	12166
May	12938
Jun	13218
Jul	13068
Aug	13213
Sep	13006
Oct	12923
Nov	11732
Dec	12417

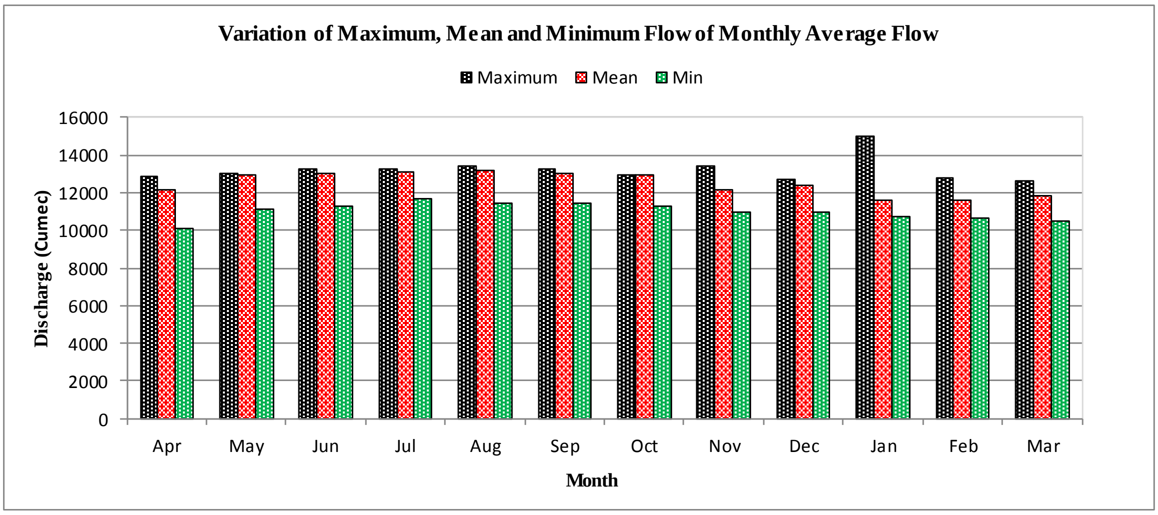


Figure 5.16: Variation of Maximum, Mean and Minimum of Balaswar River

Table 5.11: Percentage of Mean Annual flow Balaswar River

Percentage of MAF	Percentage of Flow cumec
200% (flushing flow)	23994
60-100% (optimum range)	7198-11997
60% (outstanding)	7198
50% (excellent)	5999
40% (good)	4799
30% (fair or degrading)	3599
10% (poor)	1200
<10% (Severe degradation)	<1200

It is seen that flows are not in the poor condition (10% of Mean Annual Flow) of the river system. So, according to given tables, more than 60% (Outstanding) of MAF should be available during the month of January to April and November to December. This method has severe limitation and should be restricted to reconnaissance level planning (Mosley, 1983). Table 5.12 shows corresponding e-flow. Therefore, the e-flow requirement for January to April becomes 10971 cumec.

Table 5.12: Environmental flow demand based on Tennant Method of Balaswar River

Months	Environmental flow (cumec)		
February	60-100 % of MAF	10971	Dry months
July	200 % of MAF	23994	Wet months (River are not flushing flow)
August		23994	
September		23994	

5.3.2 Flow Duration Curve (FDC) Analysis

For assessment of the Environmental flow requirement using the Flow Duration Curve method, the 90th and 50th percentile flow of the flow duration curve has been taken as the EFR for the low flow and high flow season respectively.

(i) Application of Flow Duration Curve Method for Gorai River

The flow duration curve (FDC) Method utilizes historic records to construct flow duration curves for each month to provide cumulative probabilities of exceedance for various flows. Based on at least 25 years of daily flow records, flow duration curves are obtained for all months and an environmental flow requirement (EFR) is computed for each month. The flow duration curve of each month is shown in Appendix- A. Flow duration curves for each month for the pre-Farakka period (1934-1975) have been constructed from daily mean discharge. Table 5.13 and 5.14 shows the results at Gorai Railway Bridge of Gorai River from the flow duration Curve Method.

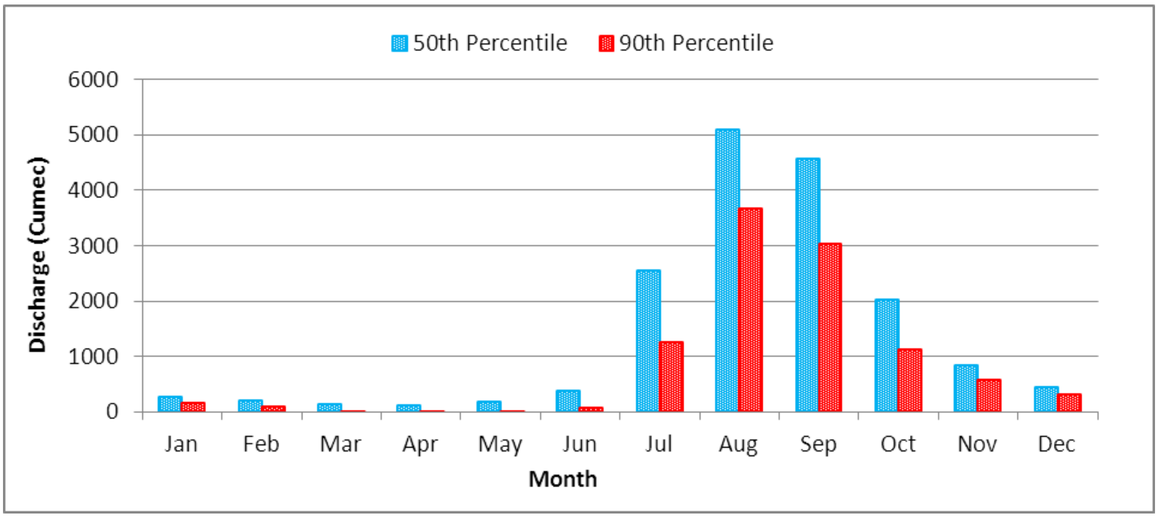


Figure 5.17: Percentile of flow duration curve of Gorai River

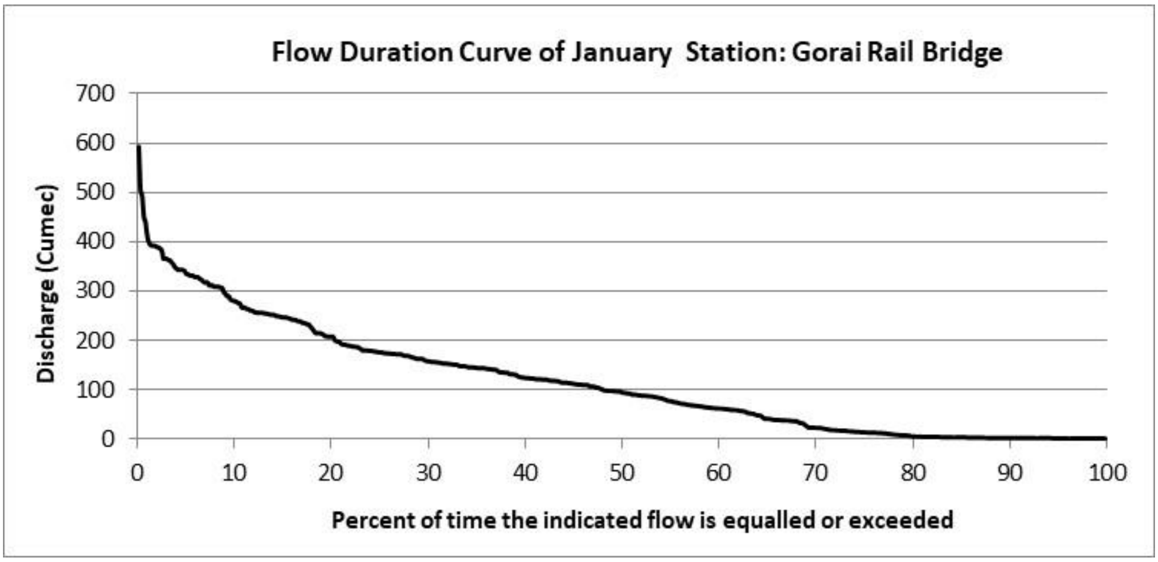


Figure 5.18: Discharge from flow duration curve of Gorai River

Table 5.13: Environmental flow demand as indicated by Flow Duration Curve Analysis of Gorai River

Month	Environmental flow		Remarks
	Percentile	cumec	
Jan	90th Percentile	152	Normal Month
Feb		106	
Mar		51	
Apr		25	
May		56	
Jun	50th Percentile	389	High Flow Month
Jul		2552	
Aug		5090	
Sep		4577	
Oct		2022	
Nov	90th Percentile	584	Normal Month
Dec		308	

Table 5.14: Environmental Flow Requirement (cumec) according to FDC Method of Gorai River

Flow Percentile	Monthly Environment Flow Requirement (cumec)											
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Flow at 50th Percentile	122	195	389	2552	5090	4577	2022	849	450	268	200	136
Flow at 90th Percentile	25	56	66	1270	3680	3043	1127	584	308	152	106	51
Flow Season	Low Flow Season90		High Flow Season 50					Low Flow Season 90				
Suggested EFR	25	56	389	2552	5090	4577	2022	584	308	152	106	51

(ii) Application of Flow Duration Curve Method for Madhumati River

For assessment of the Environmental flow requirement using the Flow Duration Curve method, the 90th and 50th percentile flow of the flow duration curve has been taken as the EFR for the low flow and high flow season respectively. The flow duration curve (FDC) Method utilizes historic records to construct flow duration curves for each month to provide cumulative probabilities of exceedance for various flows. Based on at least 25 years of daily flow records, flow duration curves are obtained for all months and an environmental flow requirement (EFR) is computed for each month. The flow duration curve of each month is shown in Appendix- A. Flow duration curves for each month for the period (1985-2012) at Bordia of Madhumati River have been constructed from daily mean discharge. Table 5.15 and 5.16 shows the results from the flow duration Curve Method.

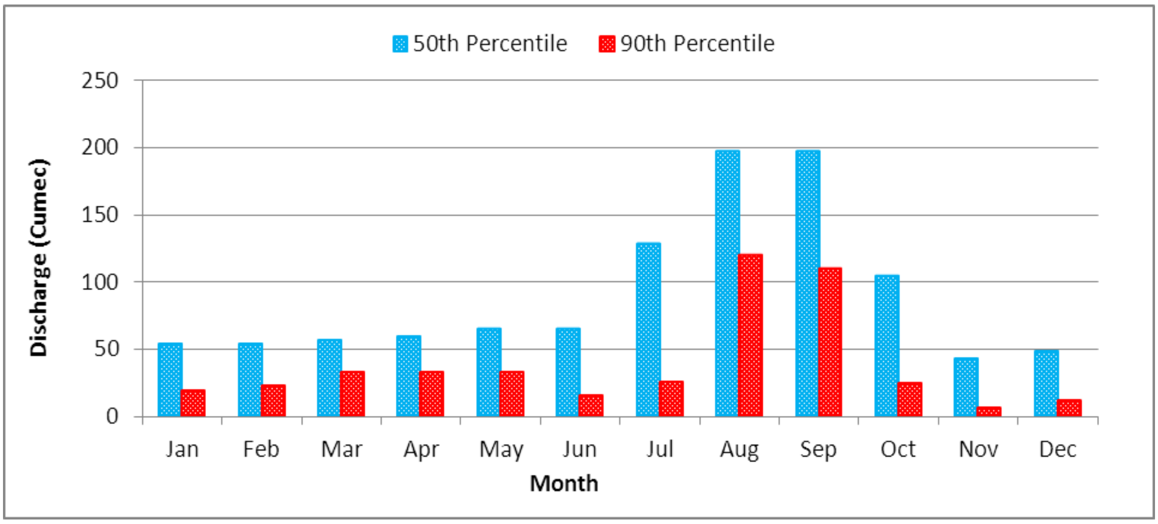


Figure 5.19: Percentile of flow duration curve of Madhumati River

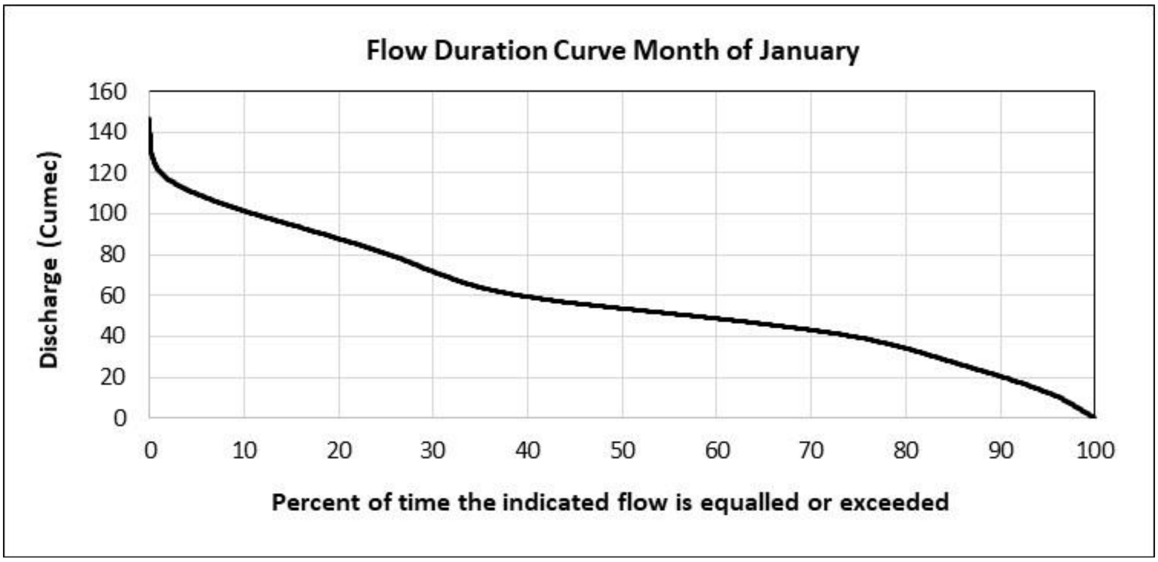


Figure 5.20: Discharge from flow duration curve of Madhumati River

Table 5.15: Environmental flow requirement as indicated by Flow Duration Curve Analysis of Madhumati River

Flow Percentile	Monthly Environment Flow Requirement (cumec)											
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Flow at 50^{th} Percentile	60	65	65	128	197	197	105	43	49	54	54	57
Flow at 90^{th} Percentile	33	33	16	26	120	110	25	7	12	20	23	33
Flow Season	**Low Flow Season90**		**High Flow Season 50**					**Low Flow Season 90**				
Suggested EFR	33	33	65	128	197	197	105	7	12	20	23	33

Table 5.16: Environmental flow demand as indicated by Flow Duration Curve Analysis of Madhumati River

Month	Environmental flow		Remarks
	Percentile	cumec	
Jan	90^{th} Percentile	20	Normal Month
Feb		23	
Mar		33	
Apr		33	
May		33	
Jun	50^{th} Percentile	65	High Flow Month
Jul		128	
Aug		197	
Sep		197	
Oct		105	
Nov	90^{th} Percentile	7	Normal Month
Dec		12	

(iii) Application of Flow Duration Curve Method for Kaliganga River

For assessment of the Environmental flow requirement using the Flow Duration Curve method, the 90^{th} and 50^{th} percentile flow of the flow duration curve has been taken as the EFR for the low flow and high flow season respectively. The flow duration curve (FDC) Method utilizes historic records to construct flow duration curves for each month to provide cumulative probabilities of exceedance for various flows. Based on at least 25 years of daily flow records, flow duration curves are obtained for all months and an environmental flow requirement (EFR) is computed for each month. The flow duration curve each month is shown in Appendix-A. Flow duration curves for each month for the period (1985-2012) at Pirojpur Sadar have been constructed from daily mean discharge. Table 5.18 shows the results from the flow duration Curve Method.

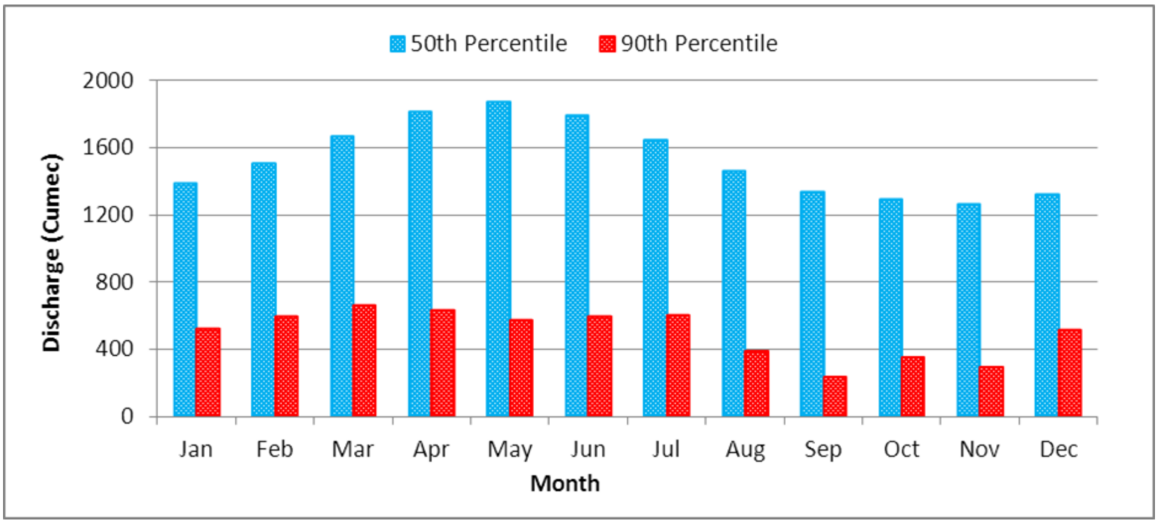


Figure 5.21: Percentile of flow duration curve of Kaliganga River

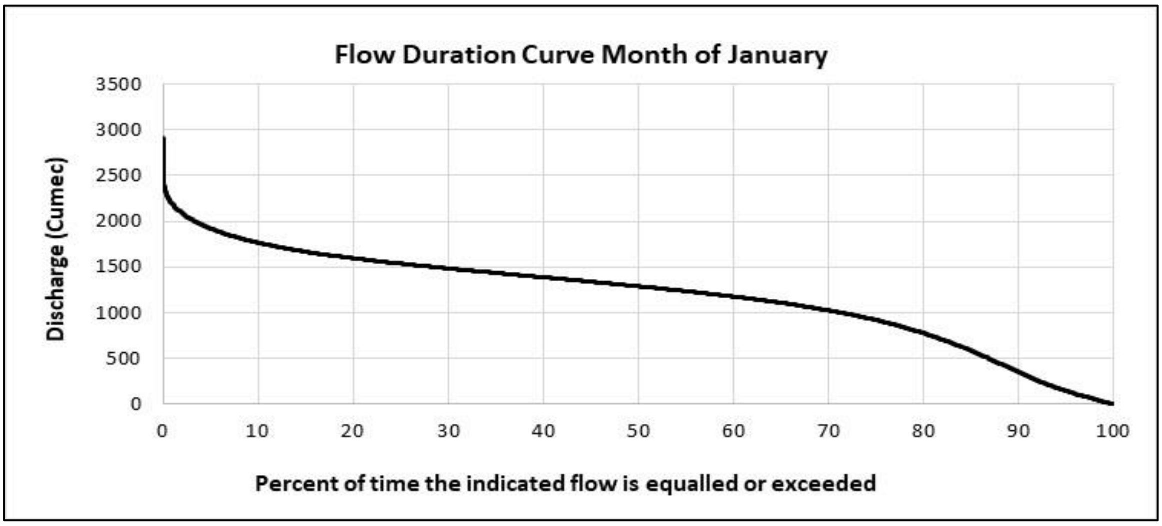


Figure 5.22: Discharge from flow duration curve of Kaliganga River

Table 5.17: Environmental flow requirement as indicated by Flow Duration Curve Analysis of Kaliganga River

Flow Percentile	Monthly Environment Flow Requirement (cumec)											
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Flow at 50^{th} Percentile	1388	1405	1464	1610	1671	1591	1439	1360	1332	1290	1263	1319
Flow at 90^{th} Percentile	524	598	661	633	577	594	599	389	234	354	294	517
Flow Season	Low Flow Season90		High Flow Season 50					Low Flow Season 90				
Suggested EFR	524	598	1464	1610	1671	1591	1439	389	234	354	294	517

Table 5.18: Environmental flow demand as indicated by Flow Duration Curve Analysis of Kaliganga River

Month	Environmental flow		Remarks
	Percentile	cumec	
Jan	90^{th} Percentile	354	Normal Month
Feb		294	
Mar		517	
Apr		524	
May		598	
Jun	50^{th} Percentile	1464	High Flow Month
Jul		1610	
Aug		1671	
Sep		1591	
Oct		1439	
Nov	90^{th} Percentile	389	Normal Month
Dec		234	

(iv) Application of Flow Duration Curve Method for Balaswar River

For assessment of the Environmental flow requirement using the Flow Duration Curve method, the 90^{th} and 50^{th} percentile flow of the flow duration curve has been taken as the EFR for the low flow and high flow season respectively. The flow duration curve (FDC) Method utilizes historic records to construct flow duration curves for each month to provide cumulative probabilities of exceedance for various flows. Based on at least 25 years of daily flow records, flow duration curves are obtained for all months and an environmental flow requirement (EFR) is computed for each month. The flow duration curve of each month is shown in Appendix- A. Flow duration curves for each month for the period (1985-2012) have been constructed from daily mean discharge. Table 5.20 shows the results from the flow duration Curve Method.

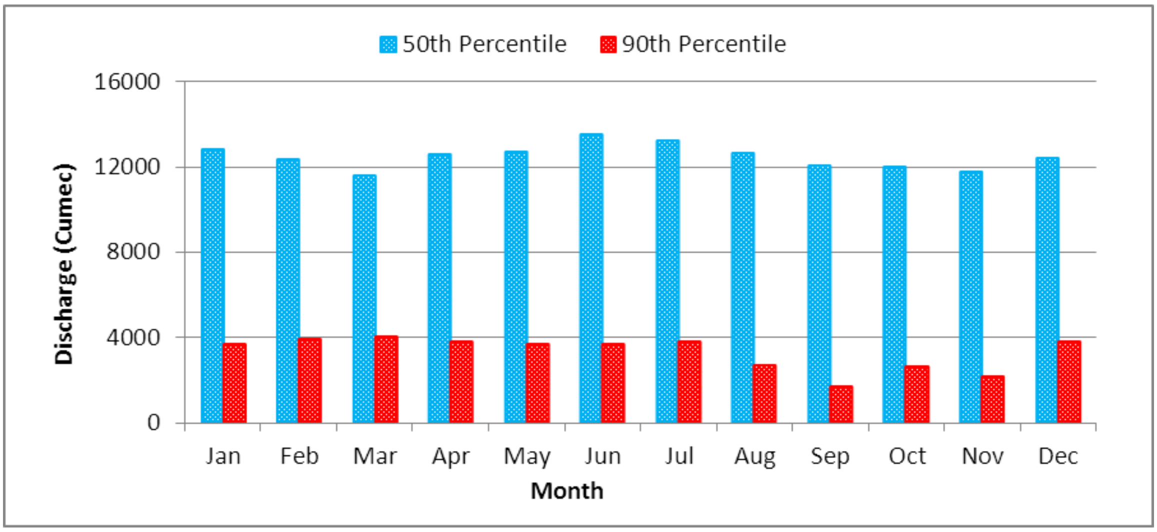


Figure 5.23: Percentile of flow duration curve of Balaswar River

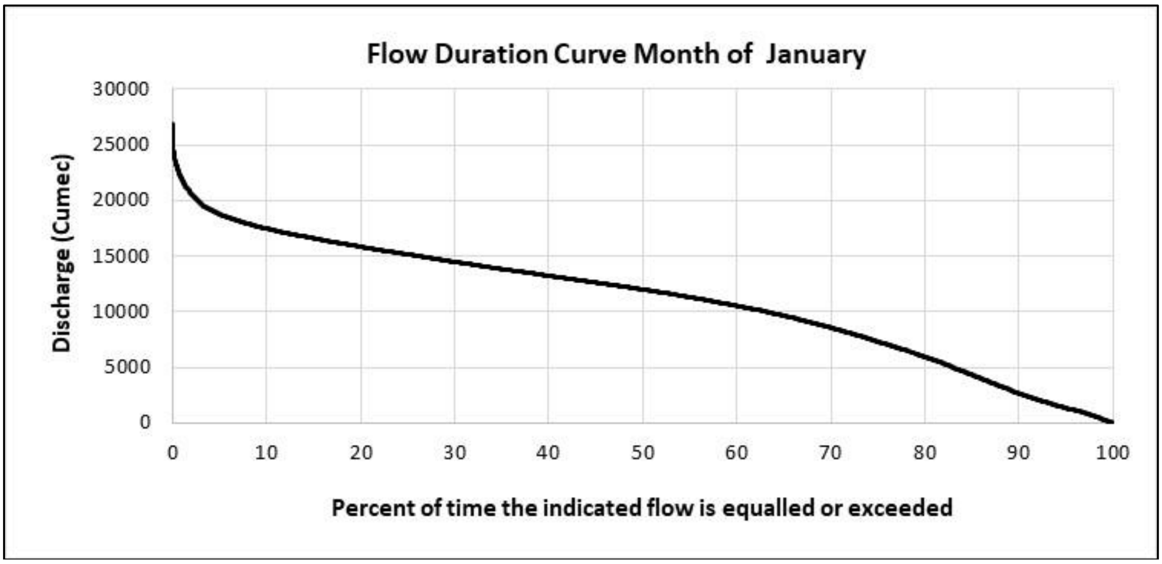


Figure 5.24: Discharge from flow duration curve of Balaswar River

Table 5.19: Environmental flow demand as indicated by Flow Duration Curve Analysis of Balaswar River

Month	Environmental flow		Remarks
	Percentile	cumec	
Jan	90th Percentile	2647	Normal Month
Feb		2202	
Mar		3814	
Apr		3720	
May		3967	
Jun	50th Percentile	11614	High Flow Month
Jul		12632	
Aug		12694	
Sep		13532	
Oct		13232	
Nov	90th Percentile	2723	Normal Month
Dec		1705	

Table 5.20: Environmental flow demand as indicated by Flow Duration Curve Analysis of Balaswar River

Flow Percentile	Monthly Environment Flow Requirement (cumec)											
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Flow at 50th Percentile	12857	12343	11614	12632	12694	13532	13232	12662	12054	11992	11811	12444
Flow at 90th Percentile	3720	3967	4063	3839	3712	3724	3824	2723	1705	2647	2202	3814
Flow Season	Low Flow Season 90		High Flow Season 50					Low Flow Season 90				
Suggested EFR	3720	3967	11614	12632	12694	13532	13232	2723	1705	2647	2202	3814

5.3.3 Constant Yield Method (CYM) Analysis

According to the constant yield method, Environmental flow requirement for the river system has been set at 100% of the median flows for each month. For this purpose, median monthly flow for each month has been computed in two different ways

(i) Application of Constant Yield Method for Gorai River

According to the 1st method, the median flow of each month has been computed considering the full data availability period (1949-1974) at Gorai Railway Bridge. In the 2nd method, median monthly flow for each month of each year has been computed separately. Thus several median values are obtained for each month, and then the median of these values has been taken as the median for the given month over entire period of record. The computed e-flow Requirement (cumec) at Gorai Railway Bridge of Gorai River according to Constant Yield Method is shown in Table 5.21.

Table 5.21: Environmental flow Requirement (cumec) according to Constant Yield Method of Gorai River

Monthly Median Flow (cumec)												
Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1st Method	119	186	538	2555	5235	4295	1845	813	442	272	205	139
2nd Method	122	196	580	2550	5090	4580	2030	849	450	268	200	134
Highest Value	122	196	580	2555	5235	4580	2030	849	450	272	205	139
Flow Season	Low Flow Season		High Flow Season					Low Flow Season				

(ii) Application of Constant Yield Method for Madhumati River

In the constant yield method, Environmental flow requirement for the Madhumati River at Bordia has been set at 100% of the median flows for each month. For this purpose, median monthly flow for each month has been computed in two different ways.

According to the 1st method, the median flow of each month has been computed considering the full data availability period (1985-2012). In the 2nd method, median monthly flow for each month of each year has been computed separately. Thus several median values are obtained for each month, and then the median of these values has been taken as the median for the given month over entire period of record. The computed e-flow Requirement (cumec) at Bordia of Madhumati River according to Constant Yield Method is shown in Table 5.22

Table 5.22: Environmental flow Requirement (cumec) according to Constant Yield Method

Monthly Median Flow (cumec)												
Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1st Method	66	68	68	115	182	183	91	57	58	61	62	63
2nd Method	69	72	78	105	195	190	98	59	62	66	68	67
Highest Value	69	72	78	115	195	190	98	59	62	66	68	67
Flow Season	Low Flow Season		High Flow Season					Low Flow Season				

(iii) Application of Constant Yield Method for Kaliganga River

Based on the constant yield method, Environmental flow requirement for the Kaliganga River at Pirojpur Sadar has been set at 100% of the median flows for each month. For this purpose, median monthly flow for each month has been computed in two different ways. According to the 1st method, the median flow of each month has been computed considering the full data availability period (1985-2012). In the 2nd method, median monthly flow for each month of each year has been computed separately. Thus several median values are obtained for each month, and then the median of these values has been taken as the median for the given month over entire period of record. The computed e-flow Requirement (cumec) of Kaliganga River at Pirojpur Sadar according to Constant Yield Method is shown in Table 5.23

Table 5.23: Environmental flow Requirement (cumec) according to Constant Yield Method

Monthly Median Flow (cumec)												
Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1st Method	1013	1101	1480	1525	1612	1598	1423	1237	1102	1022	1032	1042
2nd Method	1018	1090	1450	1550	1652	1550	1415	1257	1152	1098	1078	1058
Highest Value	1018	1101	1480	1550	1652	1598	1423	1257	1152	1098	1078	1058
Flow Season	Low Flow Season		High Flow Season					Low Flow Season				

(iv) Application of Constant Yield Method for Balaswar River

On the basis of the constant yield method, Environmental flow requirement for the Balaswar River at Charduani has been set at 100% of the median flows for each month. For this purpose, median monthly flow for each month has been computed in two different ways. According to the 1st method, the median flow of each month has been computed considering the full data availability period (1985-2012) .In the 2nd method, median monthly flow for each month of each year has been computed separately. Thus several median values are obtained for each month, and then the median of these values has been taken as the median for the given month over entire period of record. The computed median monthly flow of Kaliganga River at Charduani from this period is shown in Table 5.24.

Table 5.24: Environmental flow Requirement (cumec) according to Constant Yield Method

Monthly Median Flow (cumec)												
Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1st Method	10421	10525	11930	12130	12527	13500	13061	12358	11933	9768	10071	10592
2nd Method	10450	10625	11652	12005	12628	13700	13215	12125	11950	9668	10052	10425
Highest Value	10450	10625	11930	12130	12628	13700	13215	12358	11950	9768	10071	10592
Flow Season	Low Flow Season		High Flow Season					Low Flow Season				

5.4 Hydraulic Rating Method

The wetted perimeter method looks at the general relationship between the stream discharge and the wetted perimeter (Gillilan and Brown, 1997). Measurement of hydraulic data as wetted perimeter, width or depth from one or several cross sections in the stream can be used as hydraulic parameters.

(i) Application of Hydraulic Rating Method for Gorai River

In the Gorai River, the point of inflection is determined at various levels of flow (including extremely low and high flows) and several cross sections along the river course. At first the wetted perimeter vs discharge was plotted at the Sec-06, Sec-13 and Sec-16 (Figure 4.9) by using MIKE 11, the cross section has been analyzed and MIKE 11 also gives a relation between water level and cross section area. MIKE 11 also gives hydraulic radius at different water level. Hence, wetted perimeter has been calculated by dividing the cross section area by hydraulic radius. Then the Figure 5.25 has been shown the relation between Discharge and wetted perimeter at Section -06 (Figure 4.9) and the other sections discharge and wetted perimeter relation is given as Appendix-B. The breakpoint is found at the second point of Curvature while the incipient asymptote is found at the second point of maximum curvature. These points were identified by visual observation or by determining where the tangent to the curve is 45 degree. Discharge corresponding to the break-point represents the minimum discharge below which the condition is unfavorable.

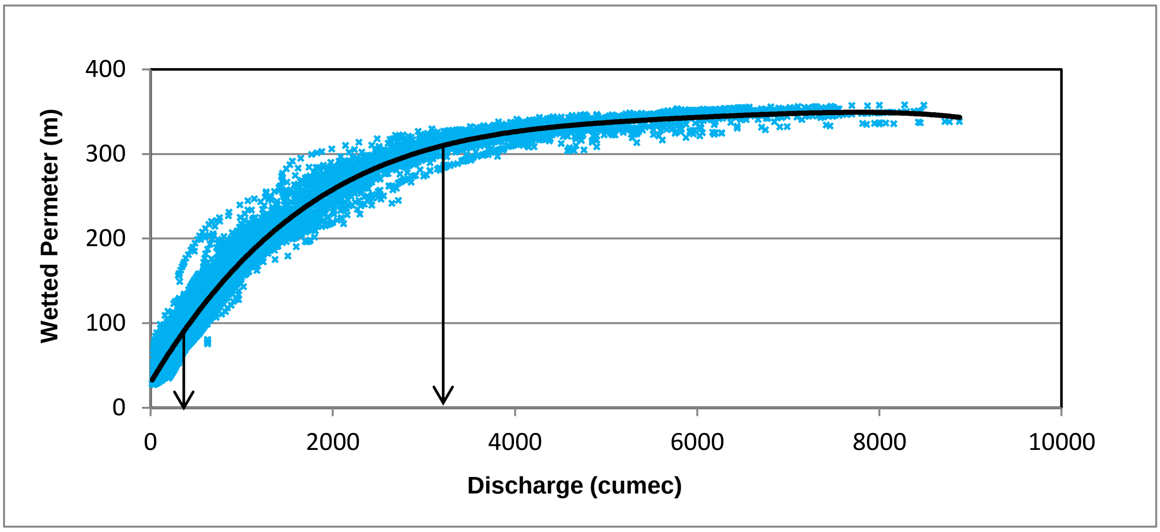


Figure 5.25: Relation between Discharge and Wetted Perimeter of Gorai River

The breakpoint is estimated as 42 cumec, 45 cumec and 48 cumec and incipient asymptote 3500 cumec, 3532 cumec and 3530 cumec respectively. So the average breakpoint discharge is 45 cumec and incipient asymptote is 3521 cumec. These results indicate that flows between 45 to 3521 cumec are critically important for keeping condition favorable for habitat.

(ii) Application of Hydraulic Rating Method for Madhumati River

In the Madhumati River, the point of inflection is determined at various levels of flow (including extremely low and high flows) and several cross sections along the river course. At first the wetted perimeter vs discharge was plotted at the Sec-28, Sec-30, Sec-33 and Sec-36 (Figure 4.9) by using MIKE 11, the cross section has been analyzed and MIKE 11 also gives a relation between water level and cross section area. MIKE 11 gives hydraulic radius at different water level. Hence, wetted perimeter has been calculated by dividing the cross section area by hydraulic radius. Then the Figure 5.26 has been shown the relation between Discharge and wetted perimeter at Section 28 and the other sections discharge and wetted perimeter relation is given as Appendix-B. The breakpoint is found at the second point of Curvature while the incipient asymptote is found at the second point of maximum curvature. These points were identified by visual observation or by determining where the tangent to the curve is 45 degree. Discharge corresponding to the break-point represents the minimum discharge below which the condition is unfavorable. The form the breakpoint discharges of different section, the average breakpoint discharge was computed.

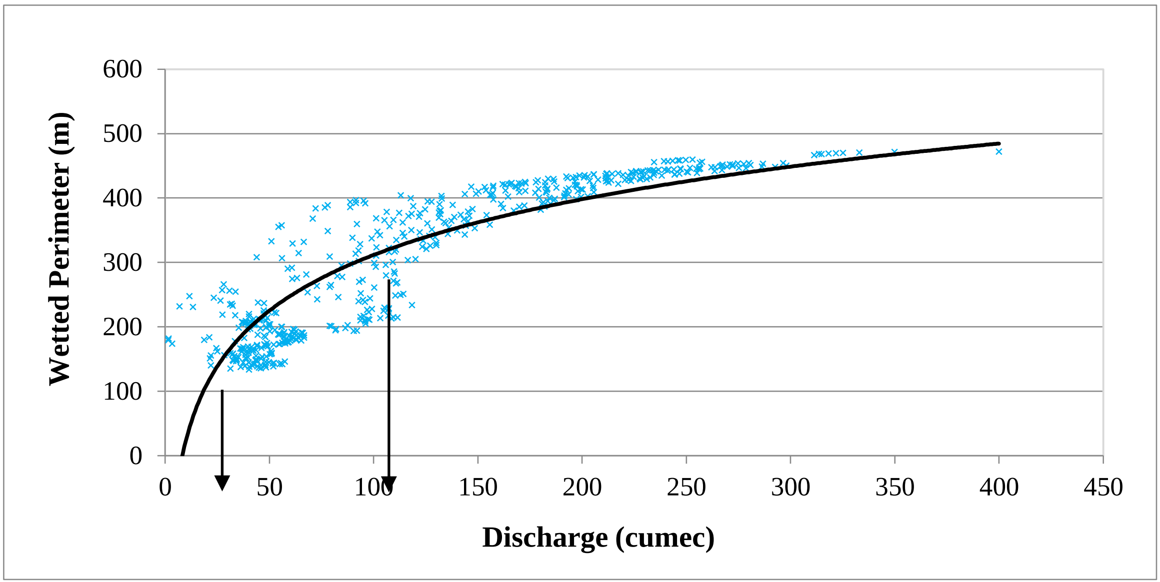


Figure 5.26: Relation between Discharge and Wetted Perimeter of Madhumati River

The breakpoint is estimated as 21 cumec, 25 cumec and 22 cumec and incipient asymptote 105 cumec, 106 cumec and 102 cumec respectively. So the average breakpoint discharge is 23 cumec and incipient asymptote is 104 cumec. These results indicate that flows between 23 to 104 cumec are critically important for keeping condition favorable for habitat.

(iii) Application of Hydraulic Rating Method for Kaliganga River

In the Kaliganga River, the point of inflection is determined at various levels of flow (including extremely low and high flows) and several cross sections along the river course. At first the wetted perimeter vs discharge was plotted at the Sec-50, Sec-54, Sec-58 and Sec-60 (Figure 4.9) by using MIKE 11, the cross section has been analyzed and MIKE 11 also gives a relation between water level and cross section area. MIKE 11 also gives hydraulic radius at different water level. Hence, wetted perimeter has been calculated by dividing the cross section area by hydraulic radius. Then the Figure 5.27 has been shown the relation between Discharge and wetted perimeter at Section-50 and the other sections discharge and wetted perimeter relation is given as Appendix-B. The breakpoint is found at the second point of Curvature while the incipient asymptote is found at the second point of maximum curvature. These points were identified by visual observation or by determining where the tangent to the curve is 45 degree. Discharge corresponding to the break-point represents the minimum discharge below which the condition is unfavorable. The form the breakpoint discharge of different section, the average breakpoint discharge was computed.

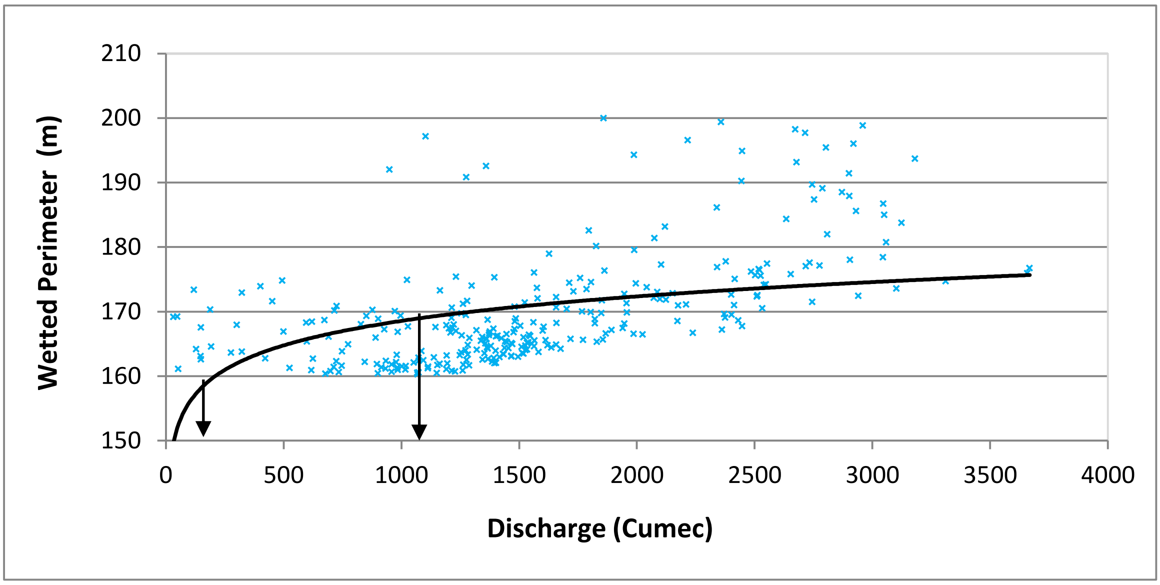


Figure 5.27: Relation between Discharge and Wetted Perimeter of Kaliganga River

The breakpoint is estimated as 112 cumec, 110 cumec, 115 cumec and 117 cumec and incipient asymptote 1021 cumec, 1022 cumec, 1023 cumec and 1024 cumec respectively. So the average breakpoint discharge is 114 cumec and incipient asymptote is 1023 cumec. These results indicate that flows between 114 to 1023 cumec are critically important for keeping condition favorable for habitat.

(iv) Application of Hydraulic Rating Method for Balaswar River

In the Balaswar River, the point of inflection is determined at various levels of flow (including extremely low and high flows) and several cross sections along the river course. At first the wetted perimeter vs discharge was plotted at the Sec-64, Sec-66, Sec-68, Sec-69, Sec-70, Sec-71 and Sec-72 (Figure 4.9) by using MIKE 11, the cross section has been analyzed and MIKE 11 also gives a relation between water level and cross section area. MIKE 11 also gives hydraulic radius at different water level. Hence, wetted perimeter has been calculated by dividing the cross section area by hydraulic radius. Then the Figure 5.28 has been shown the relation between Discharge and wetted perimeter at Section 72 and the other sections discharge and wetted perimeter relation is given as Appendix-B. The breakpoint is found at the second point of Curvature while the incipient asymptote is found at the second point of maximum curvature. These points were identified by visual observation or by determining where the tangent to the curve is 45 degree. Discharge corresponding to the break-point represents the minimum discharge below which the condition is unfavorable. The form the breakpoint discharges of different section, the average breakpoint discharge was computed.

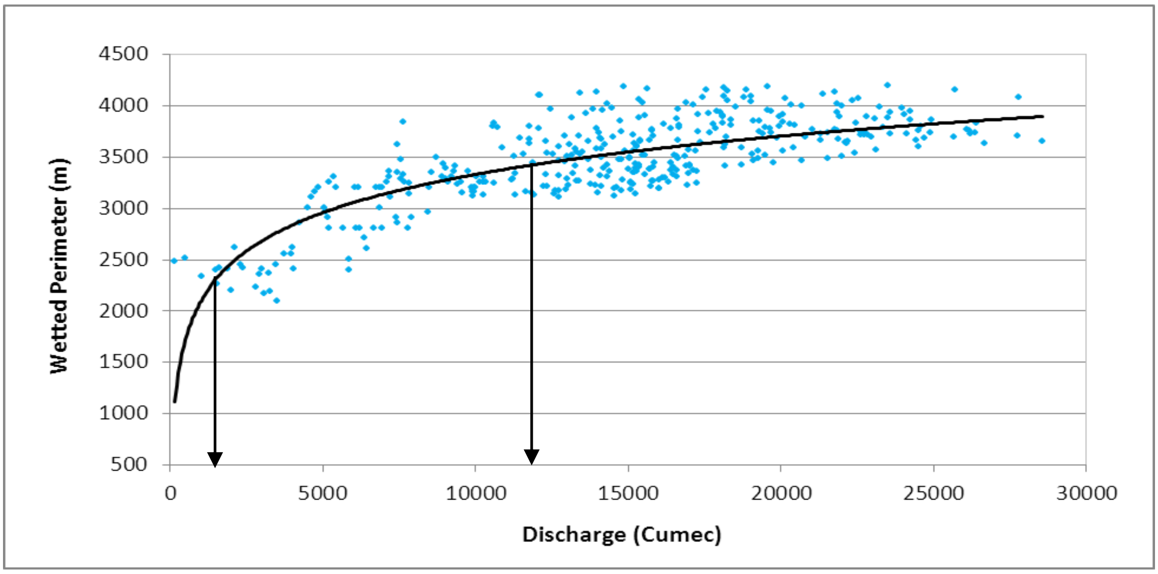


Figure 5.28: Relation between Discharge and Wetted Perimeter of Balaswar River

The breakpoint is estimated as 1200 cumec, 1230 cumec, 1210 cumec , 1218 cumec, 1215 cumec 1222 and 1224 and incipient asymptote 12020 cumec, 12025 cumec, 12028 cumec, 12032 cumec, 12045 cumec, 12035 and 12028 cumec respectively. So the average breakpoint discharge is 1217 cumec and incipient asymptote is 12031 cumec. These results indicate that flows between 1215 to 12031 cumec are critically important for keeping condition favorable for habitat.

5.5 Physical Habitat Simulation Method (PHABSIM)

Habitat modeling in a river relates the habitat availability of any living species with the flow of the river. Habitat modeling involves four basic steps to be completed: Study site selection, Selection of dominant species and development of habitat suitability criteria, Hydraulic simulation and Habitat simulation

The widely used habitat model is the Physical Habitat Simulation PHABSIM Model. In its basic form, PHABSIM comprise two sets of procedures, hydraulic simulation and habitat simulation. The result of the simulation procedures is linked to produce an output of weighted Usable Area (WUA) versus Discharge. Breakpoint on the WUA-Discharge Curves is used to recommended environmental flow.

5.5.1 Study Site Selection

The criteria that have taken into account in selecting the study site include: (i) availability of a discharge measuring station, cross-section and other hydraulic data and (ii) a stream segment having fish potential. The study reaches selected for two rivers are shown in Figure 5.29 to Figure 5.30 and described below:

Gorai River: Starting just upstream of the railway bridge, the selected reach of Gorai River is about 26 km along in the downstream direction. Since Gorai is fed by flow from the Ganges which is regulated by a barrage in India, the Pre-barrage period (1964-1974) data was considered.

Madhumati River: Starting just downstream of the Kamarkhali Bridge, the selected reach of Madhumati River is about 17 km along in the downstream direction. Since Madhumati is fed by flow from the Gorai, Period (1985-2012) data was considered.

5.5.2 Study Site Representation

Study site representation for this study was based on mesohabitat type approaches. The procedure for Gorai River here and for Madhumati River similar process was followed. Based on frequency of observed depth of riffle, pool and depth pool areas, as well as discussion with local Dof officials the following classification scheme was adopted. It was also observed that these three mesohabitat tend to occur in the same proportion.

Mesohabitat type	**Depth range (m)**
Riffle	0-2
Pool	2-4
Deep Pool	>4

Figure 5.29: Site selection Map for PHABSIM model of Gorai River

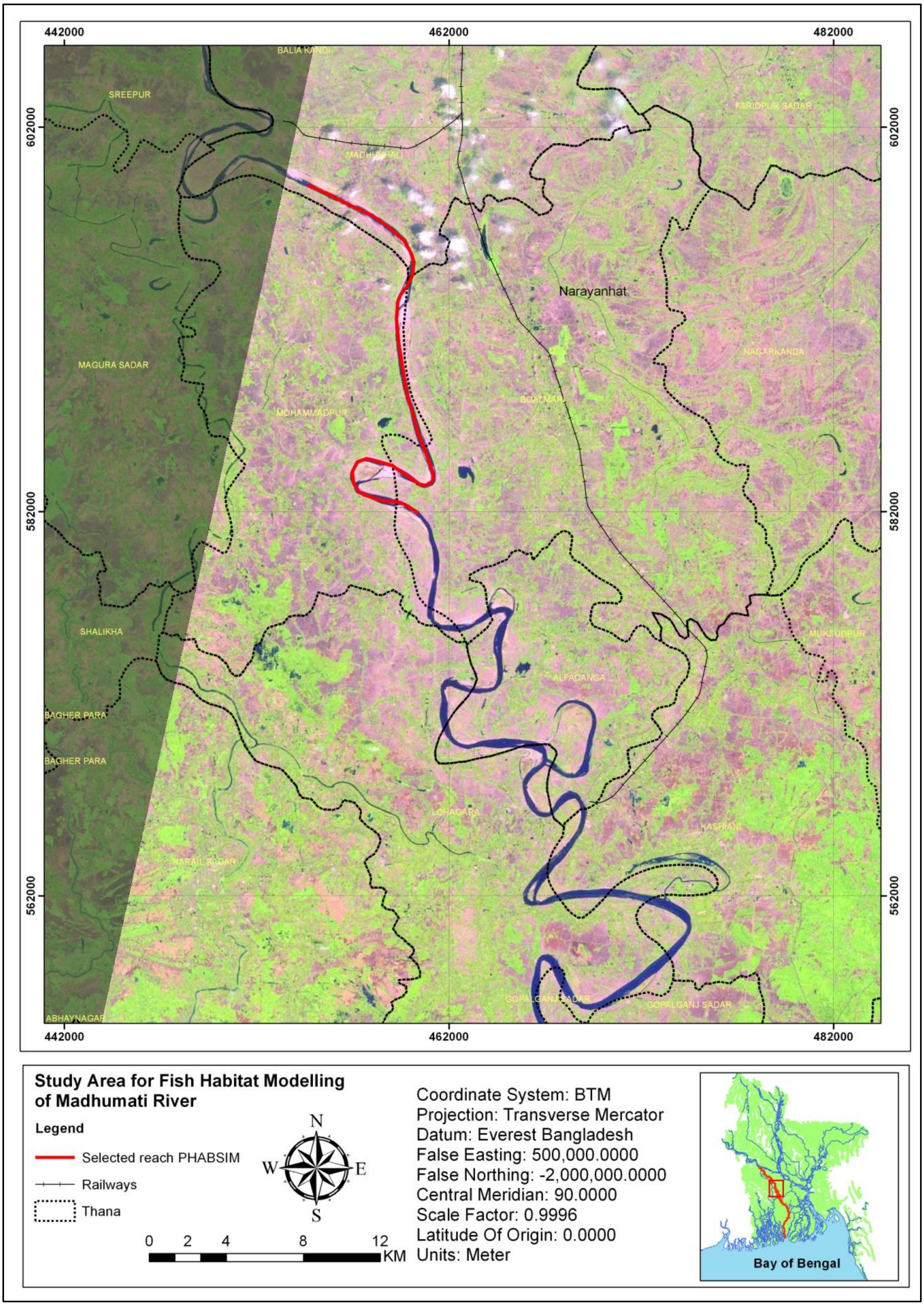


Figure 5.30: Site selection Map for PHABSIM model of Madhumati River

5.5.3 Data collection and Organization

Data required for this study include a number of cross sections over the selected reaches, stage-discharge relationship at each cross section, depth, velocity and substrate preference of dominant fish species and discharge time series at selected gauging stations.

5.5.4 Cross Section used in PHABSIM Model

For Gorai River and Madhumati River nine cross sectional profile within the selected reach were collected from Bangladesh Water Development Board (BWDB). The location of the cross sections in term of Chainage, X and Y co-ordinate (UTM 45N) with mesohabitat types are given in Table 5.25. For Gorai River pre-barrage period cross-sections were collected. Five cross-sections were used for the Gorai river study reach and four cross sections for the Madhumati River reach.

Table 5.25: Cross-Section ID and location in the selected reaches of the river

River Name	Cross Section ID	SOL Easting (m)	SOL Northing (m)	EOL Easting (m)	EOL Northing (m)	Mesohabitat type
Gorai River	1	721816	2643080	722265	2643148	Riffle
	2	723764	2639209	723722	2639640	Pool
	3	728087	2638534	728758	2638797	Riffle
	4	731074	2634854	731278	2635137	Pool
	5	731492	2631599	731907	2631344	Riffle
Madhumati River	1	760441	2601568	760434	2601924	Pool
	2	765174	2599008	76545684	2599428	Pool
	3	765804	2593639	766072	2593649	Deep pool
	4	767375	2587262	767819	2587700	Deep pool

5.5.5 Water level and Discharge Data

For Gorai River, pre-barrage historic flow and water level data are used. For Gorai River the Pre-barrage period (1964-1974) data for Gorai Railway Bridge were collected. For Madhumati River the time series period (1985-2012) data for Bordia Station were collected. For these two rivers, water level and discharge at selected Cross-sections were obtained by interpolation based on discharge and water level values at Upstream and downstream gauging stations.

5.5.6 PHABSIM Simulation Results for Gorai River

PHABSIM simulations have been performed to generate estimate of weighted usable area for the range of calibration flows for adult life stage of each target fish species for the study areas. Simulated outputs are presented in following ways: Weighted Usable area against discharge functions, temporal variation of habitat availability; and weighted usable Area duration curves for each month.

(i) Gorai River (WUA vs Discharge)

Values of total usable area and weighted usable area (WUA) per 1000m length of river reach were computed for each of the two selected fish species- Ayeer and Bacha and plotted in Figure 5.31, respectively for discharge range of 5 to 5000 cumec to represent the range flow experienced in Gorai River. The total usable area curve shows a sharp rise at discharge of 1200 cumec for Ayeer fish species and 1500 cumec for Bacha fish species. It indicates that as flood flow spreads on flood plain a rapid increase of habitat takes place. But weighted usable area does not exhibit such an increase with discharge as habitat suitability for a given species may not necessary increase with discharge. Figure 5.31 shows that the weighted usable area (WUA) for Ayeer fish species increase sharply for discharge values from 1200 cumec and the point of inflection is found to be at 250 cumec of discharge. In case of Bacha fish species increase sharply for discharge values from 1500 cumec and inflection point at 350 cumec. The information about discharge corresponding to point of inflection of WUA versus discharge curve is useful in setting increase flow requirement.

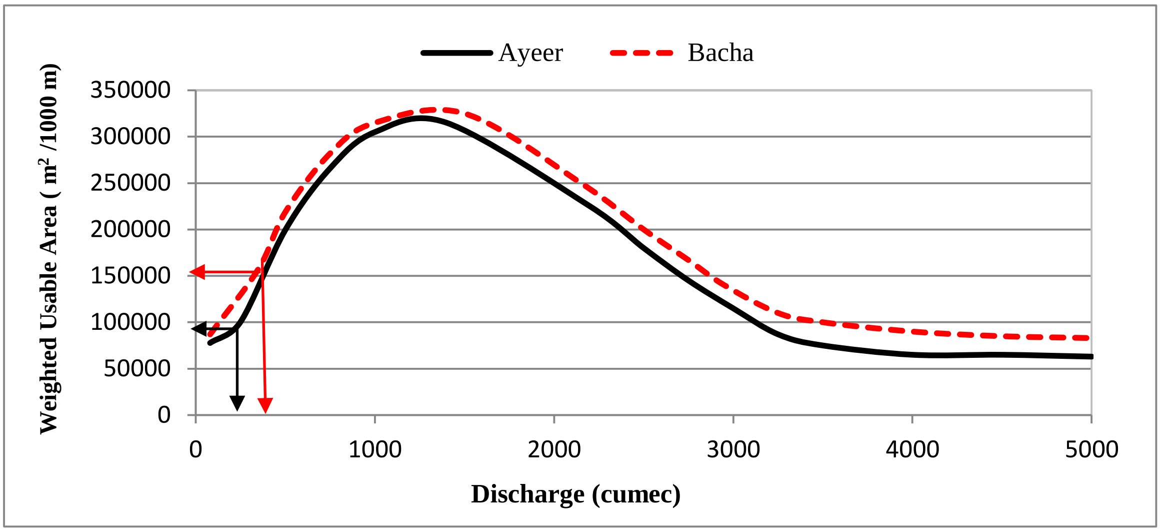


Figure 5.31: Weighted usable area vs discharge functions for Ayeer and Bacha Fish

(ii) Habitat time series analysis for Gorai River

The daily time series of discharge of Gorai at Gorai rail bridge station from 1 January 1965 to 31 December 2018 and the WUA values for each of the selected species were combined to calculate habitat time series. From the habitat time series, mean monthly habitat values for each of 12 months for two selected fish species were calculated and given in Figure 5.32.

For Ayeer maximum habitat is available in the month of October and November, which are the medium flow month. In the very high and low flow months available habitat is relatively low. For Bacha maximum habitat occurs in November. It has good amount of habitat in the medium flow season but in the low flow season available habitat is considerably low.

Comparing the mean monthly habitats of the species with their seasonal availability in the river it is revealed that although Bacha fish is not available in high flow season, it seems to have some amount of habitat in the high flow season as in the low flow season. For Bacha considerable amount of habitat is available in the high flow months but this fish is not available in this period. The reason behind this may be that fisherman cannot catch these species in high flow month due to high velocity and size of the species. Also the species may use other site in this season for other purposes, such as spawning.

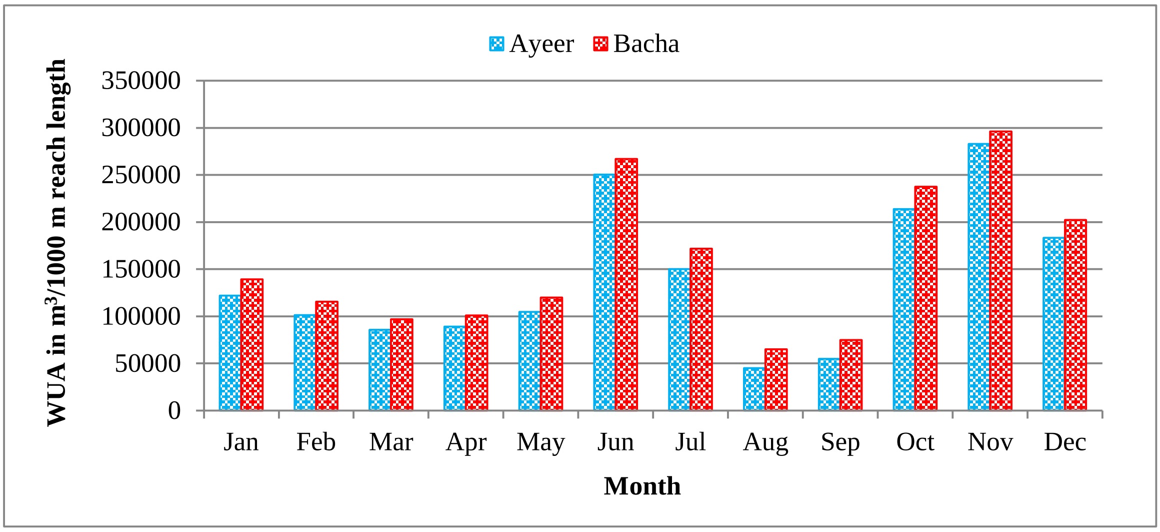


Figure 5.32: Mean monthly habitat for Ayeer and Bacha Fish

Figure 5.32 reveals that from consideration of available habitat, the month of August and September appears to be critical for each of two selected fish species: Ayeer and Bacha.

(iii) Habitat Duration Analysis for Gorai River

Based on habitat time series data, habitat duration curves for each month and each fish species were constructed. Habitat duration curves of Ayeer and Bacha fish for average historic flow from 1965 to 2018 are given in Figure 5.33 and those for other each month are given in Appendix C. Habitat duration curve is helpful in answering questions such as what amount of habitat is available in 75% of the time. What is the median habitat value? What would happen to the available habitat if the flow could be increased by 20% in low flow month? The information makes it possible to analyze the effects of changes in flow on each life stage of every species for which habitat suitability data are available.

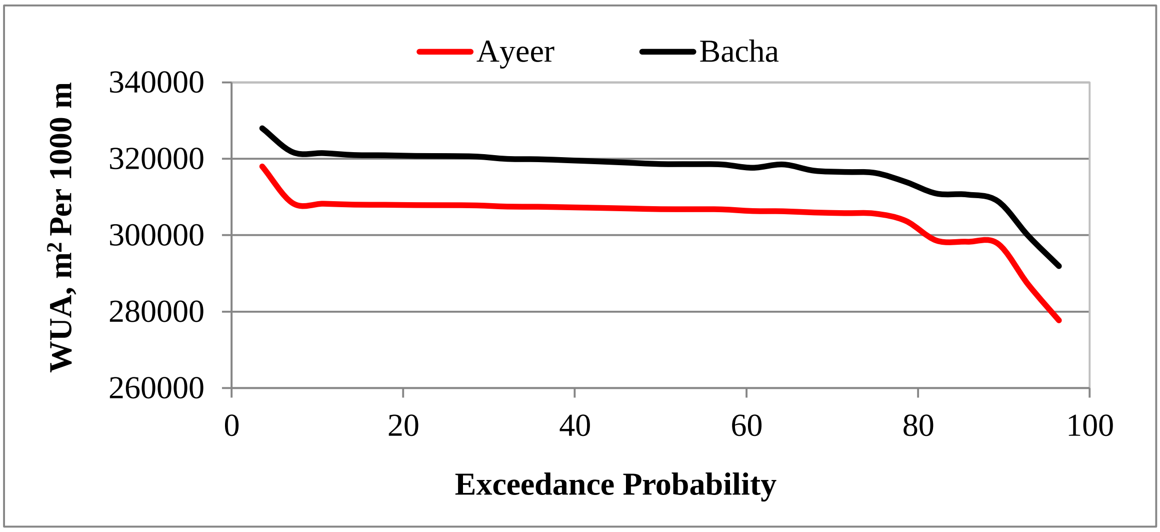


Figure 5.33: Habitat duration curve for Ayeer and Bacha fish

(iv) Spatial Variation of Habitat availability with flow

Figure 5.34 shows the suitable habitat locations for Ayeer fish in Cross-sections at different flows. From the figures it is clear that at very low flows suitable habitat for Ayeer is confined in the central portion of the deep pool areas. As discharge increases suitable habitat spreads over the pool areas as well. At discharge of 250 cumec the entire deep pool and pool areas become highly suitable for Ayeer. Suitable habitat shifts towards bank both in pool and deep pool habitat with further increase in discharge, because with high flow velocity and depth increase in the central part of the cross-sections and velocity suitability decreases. For Ayeer fish there appears to be no suitable habitat in the riffle zone throughout the discharge range, because bed material of riffle areas is mainly sand and sand is an unsuitable substrate for Ayeer.

For Bacha, the variation in habitat availability in the cross-sections, shown in Figures 5.35. At low flow, the suitable habitat in the deep pool areas is near the bank due to its shallow depth preference. With increase in discharge, suitable habitat spreads over pool and riffle areas. At a discharge of 250 cumec central parts of some riffle and pool habitat become very suitable for Bacha. At discharge 750 cumec, when maximum habitat occurs, most parts of riffle and pool habitat become highly suitable as shown in Appendix-C.

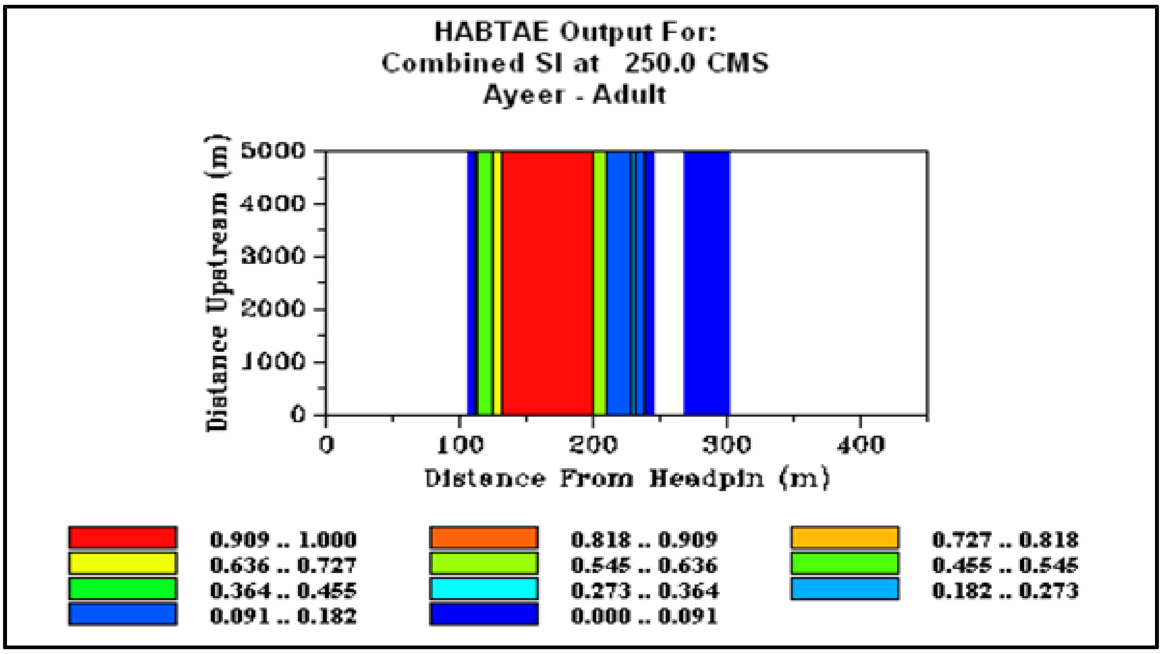


Figure 5.34: Variation of habitat suitability Ayeer in cross section at discharge 250 cumec

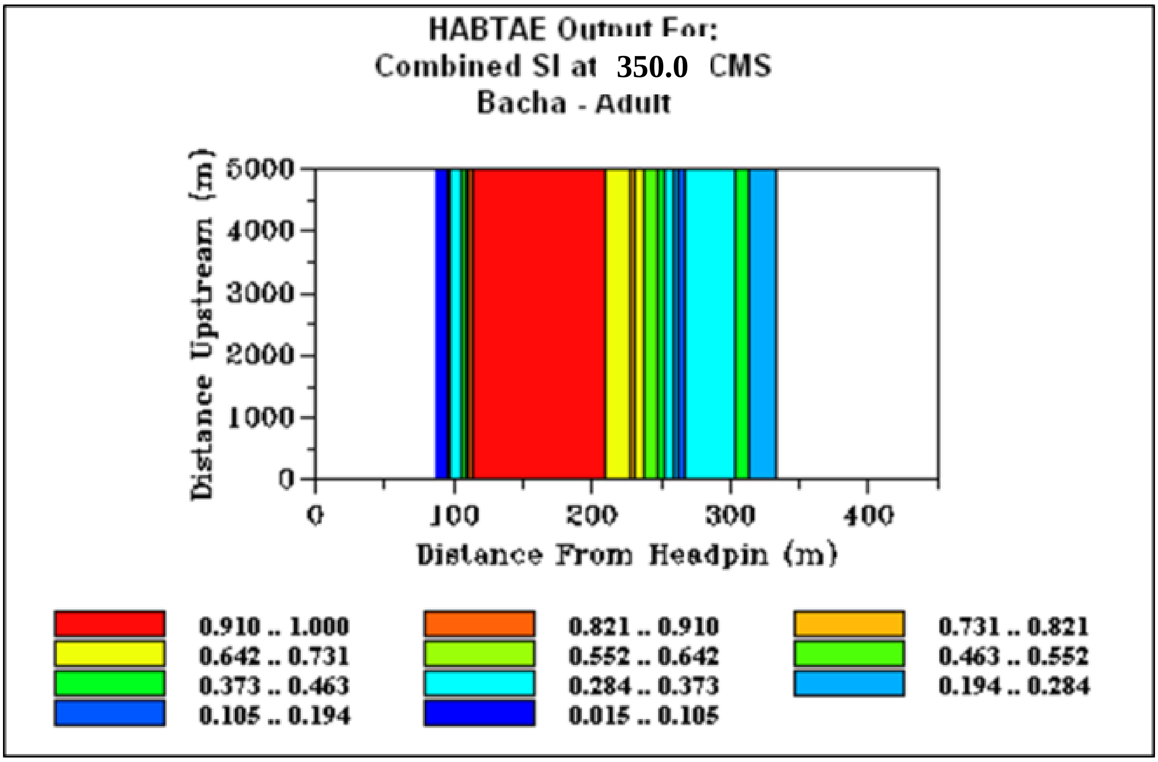


Figure 5.35: Variation of habitat suitability Ayeer in cross section at discharge 350 cumec

5.5.7 PHABSIM Simulation Result for Madhumati River

PHABSIM simulations have been performed to generate estimate of weighted usable area for the range of calibration flows for adult life stage of each target fish species for the study areas. Simulated outputs are presented in following ways such as weighted Usable area against discharge functions, temporal variation of habitat availability; and weighted usable Area duration curves for each month

(i) Madhumati River (WUA vs Discharge)

Values of total usable area and weighted usable area (WUA) per 1000m length of river reach were computed for each of the two selected fish species- Golda and Carp and plotted in Figure 5.36 , respectively for discharge range of 5 to 3000 cumec to represent the range flow experienced in Madhumati River. The total usable area curve shows a sharp rise for Golda and Carp Species at discharge of 500 cumec and 650 cumec respectively. It indicates that as flood flow spreads on flood plain a rapid increase of habitat takes place. But weighted usable area does not exhibit such an increase with discharge as habitat suitability for a given species may not necessary increase with discharge. In case of Golda fish, the peak value of WUA reached at a discharge of 500 cumec and point of inflection at 300 cumec, and for Carp Species peak of WUA occurred at a discharge of 700 cumec and inflection point at 400 cumec. Weighted usable area vs discharge functions for Golda and Carp Fish are given in Figure 5.36.

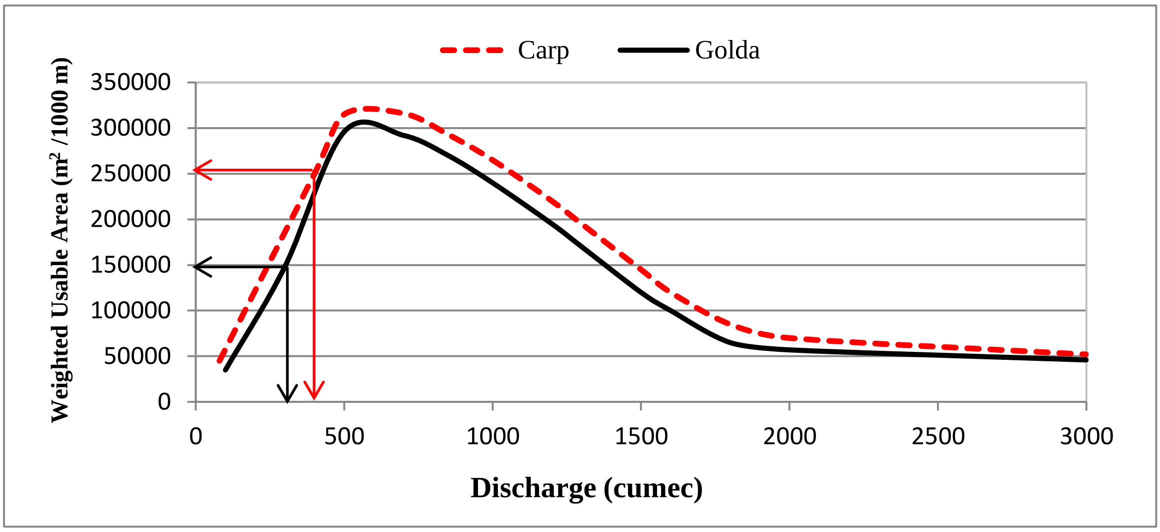


Figure 5.36: Weighted usable area vs discharge functions for Golda and Carp Fish

(ii) Habitat time series analysis

The daily time series of discharge of Madhumati at near Bardia Bazar station from 1 January 1985 to 31 December 2012 and the WUA values for each of the selected species were combined to calculate habitat time series. From the habitat time series, mean monthly habitat values for each of 12 months for two selected fish species were calculated and given in Figure 5.37.

For Golda maximum habitat is available in the month of July, August and September, which are the high flow month. In the medium high and low flow months available habitat is relatively low. For Carp species maximum habitat occurs in July to September, which is a very high flow month. It has also considerable habitat in May to October. In the low flow months, available habitat for Carp Species is much higher than Golda species.

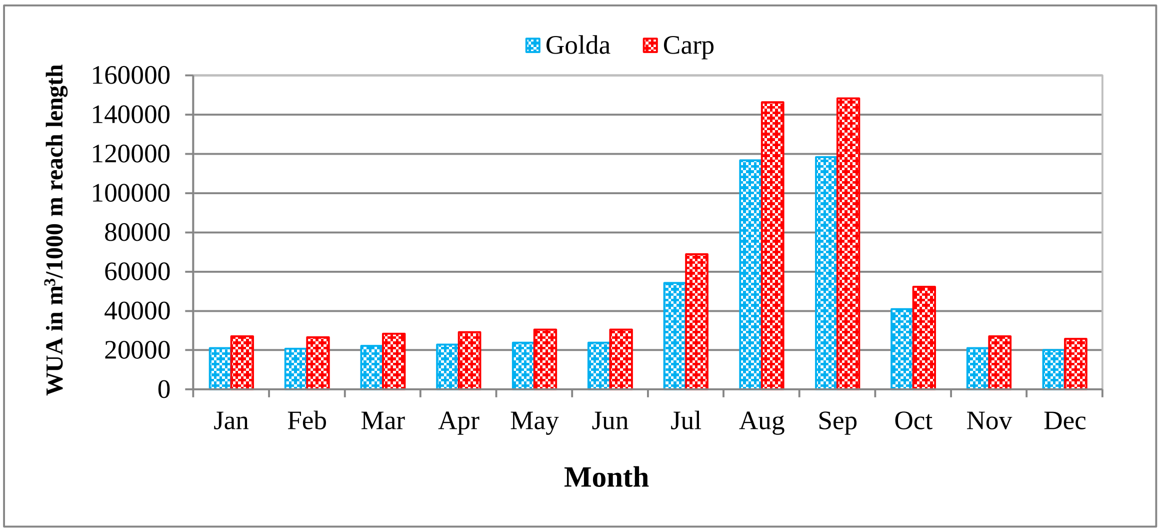


Figure 5.37: Mean monthly habitat for Golda and Carp Fish

As inspection Figure 5.41 reveals that from consideration of available habitat, the month of January and February appears to be critical for each of two selected fish species: Golda and Carp Species.

(iii) Habitat Duration Analysis

Based on habitat time series data, habitat duration curves for each month and each fish species were constructed. Habitat duration curves of Golda and Carp Species for average historical flow from 1985 to 2012 are given in Figure 5.38 and those for other each month are given in Appendix D. Habitat duration curve is helpful in answering questions such as what amount of habitat is available in 75% of the time? What is the median habitat value?

What would happen to the available habitat if the flow could be increased by 20% in low flow month? The information makes it possible to analyze the effects of changes in flow on each life stage of every species for which habitat suitability data are available.

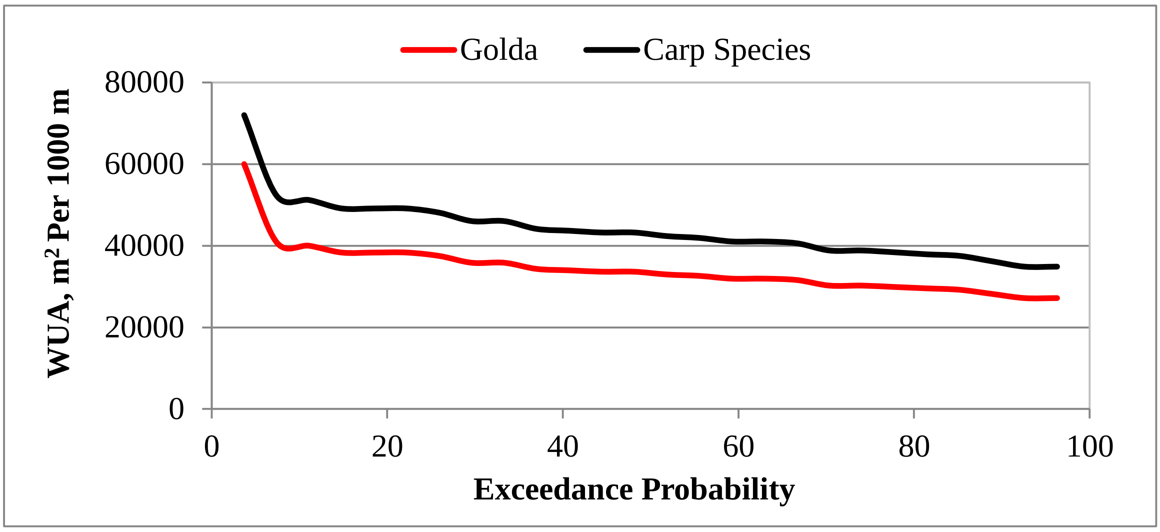


Figure 5.38: Habitat duration curve for Golda and Carp Species

(iv) Spatial Variation of Habitat availability with flow

Figure 5.39 shows the suitable habitat locations for Carp fish in Cross-sections at different flows. From the figures it is clear that at very low flows suitable habitat for Carp Species is confined in the central portion of the deep pool areas. As discharge increases suitable habitat spreads over the pool areas as well. At discharge of 250 cumec the entire deep pool and pool areas become highly suitable for Carp Species. Suitable habitat shifts towards bank both in pool and deep pool habitat with further increase in discharge, because with high flow velocity and depth increase in the central part of the cross-sections and velocity suitability decreases. For Carp fish there appears to be no suitable habitat in the riffle zone throughout the discharge range, because bed material of riffle areas is mainly sand and sand is an unsuitable substrate for Carp fish.

It is seen from Figures 5.40 that habitat for Golda is concentrated in the middle of the deep pool habitat up to discharge 500 cumec due its high depth preference. As discharge increases, suitable habitat spreads over the pool zone. At discharge 500 cumec all deep pool and pool areas appears to be highly suitable for Golda. With further increase in discharge, suitable habitat in the deep pool shifts towards the bank, but it remains in the central portion of pool habitat, similar to Carp species, Golda does not have suitable habitat in riffles as shown in Appendix-D.

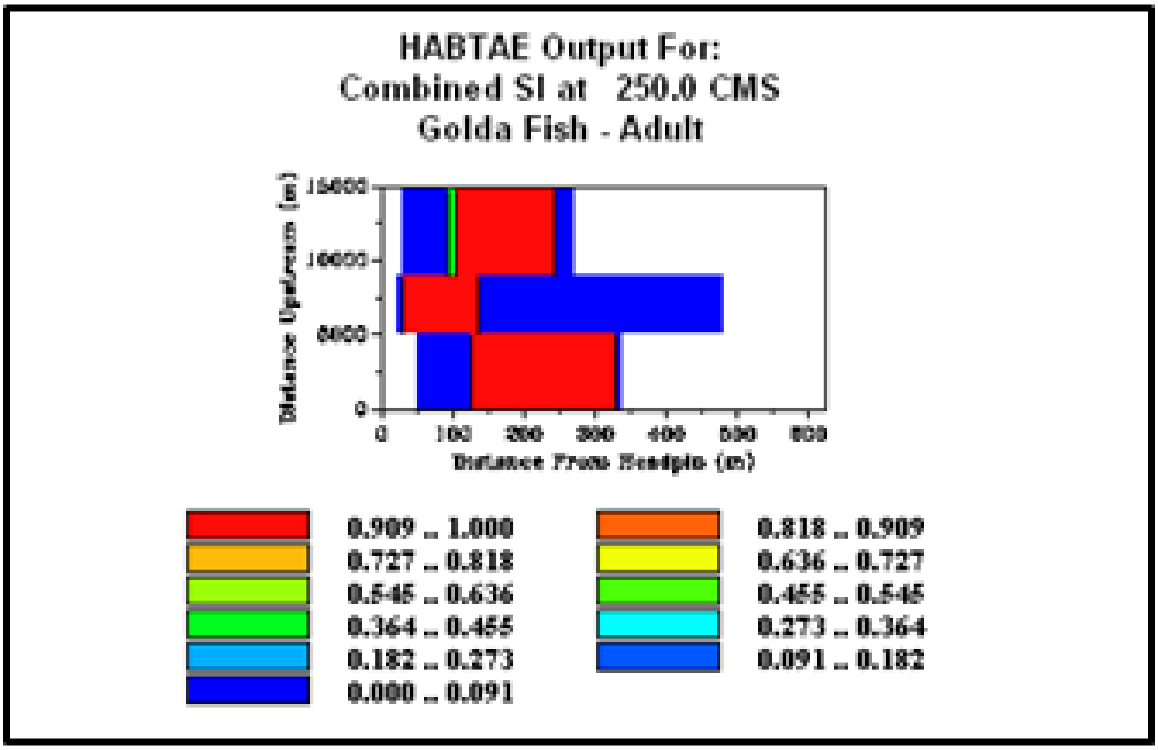


Figure 5.39: Variation of habitat suitability Carp in cross section at discharge 250 cumec

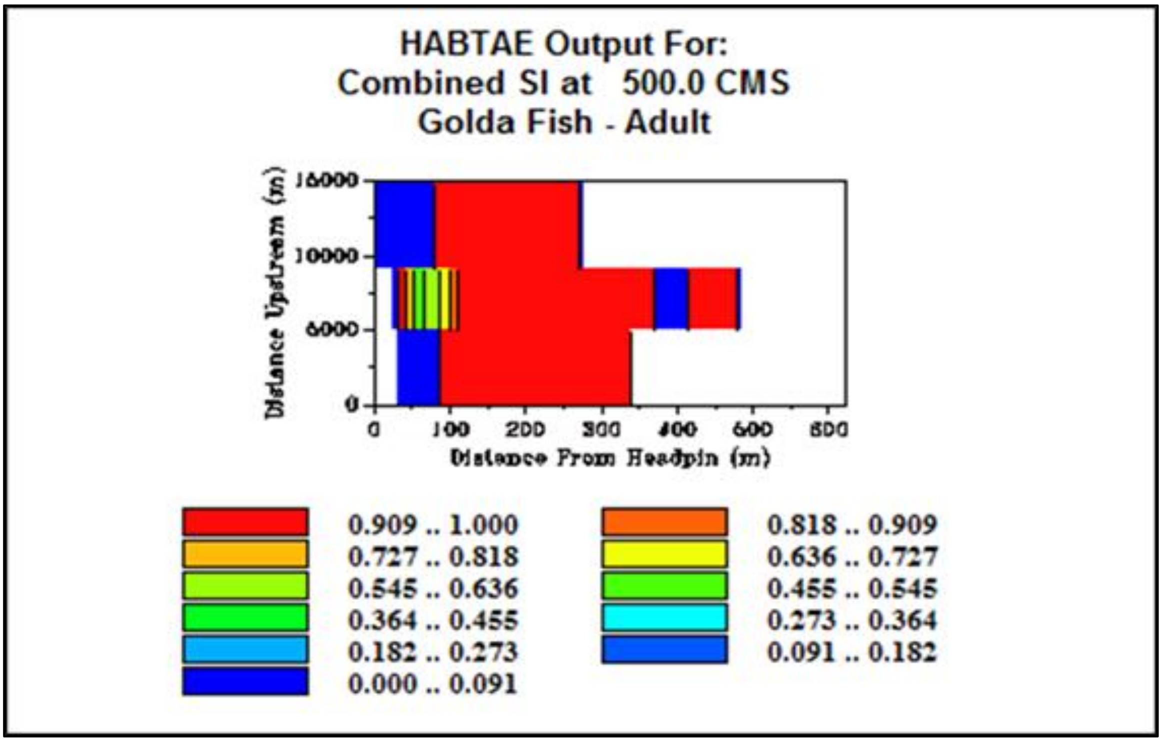


Figure 5.40: Variation of habitat suitability Golda in cross section at discharge 500 cumec

5.5.8 Setting Environmental Flows by PHABSIM

When using PHABSIM method, there are more ways of determining flow requirements than for historic flow methods, but there is no universal rule for setting Environmental flow requirements from the habitat (WUA) versus discharge curves in a river. The relationship between flow and WUA is usually nonlinear. Alternatives approaches that have been used to set flow values using WUA versus discharge function in Conjunction with fish periodicity chart are as follows:

(i) Optimal flows can be extracted from the habitat-flow relationships, and it is seemingly more logical to argue for the peak of the function threshold or inflections (Bullock et al,1991)

(ii) Other suggest that flows can be set so that they maintain optimum levels of fish habitat, retain percentage of habitat at average or median flow (Jowett, 1997) or as a percentage of exceedance value on the habitat duration curve (Beecher, 1990; Johnson et al., 1992). In Canada one approach is to select the flow giving 80% habitat exceedance percentile (Locke,1996; Dunbar. et. al.,1998) and

(iii) MESC, 2001 observes if the monthly median flow falls below the flow at which maximum habitat occurs, then the magnitude of habitat or percentage reductions would potentially represent any level of adverse conditions.

Point of inflection approach

Bullock. et al., 1991 cites a case study of willow creek, Idaho, USA (Pruitt and Nadeau, 1978) as an example of application of the habitat-flow functions to recommend the low flow regime corresponding to point of inflections on the WUA-discharge function for each month to be released through controlled releases from upstream dams for the spawning, incubation and rearing stages of selected fish species.

Approach based on comparison of flow at optimum habitat median flow

As an illustration of the application of the use of habitat functions to recommended seasonal flow requirements, Zobeyer (2004) computed flow values corresponding to optimum habitat or inflection point for the adult life stages of four fish species- Ayeer and Bacha in Gorai River and Golda and Carp Species in Madhumati River as shown in Table 5.26 and 5.28. Median monthly flows are also tabulated in the bottom row.

Table 5.26: Monthly flows corresponding to optimal habitat or inflection point flows (cumec) in Gorai River at Selected reach

Species	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Ayeer	250	250	250	250	250	250	250	250	250	250	250	250
Bacha	-	-	-	-	-	350	350	350	350	350	350	-

An inspection of the above tabular values reveals that a discharge corresponding to optimal habitat or point of inflection is 250 cumec from January to December for Ayeer species and point of inflection is 350 cumec from March to October for Bacha fish. Using habitat-flow relationship in combination with fish periodicity charts, month-wise minimum flow requirement was recommended as follows.

Table: 5.27: Minimum flow (cumec) requirement for fish species of Gorai River

Species	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Minimum flow	250	250	250	250	250	350	350	350	350	350	350	250

Table 5.28: Monthly flows corresponding to optimal habitat or inflection point flows (cumec) in Madhumati River at Selected reach

Species	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Golda	-	-	-	-	-	-	-	-	-	300	300	300
Carp	400	400	400	400	400	400	400	400	400	-	-	400

An inspection of the above tabular values reveals that a discharge corresponding to optimal habitat or point of inflection is 300 cumec from February to April for Golda species and point of inflection is 400 cumec from January to December except December to March for Carp species. Using habitat-flow relationship in combination with fish periodicity charts, month-wise minimum flow requirement was recommended as follows.

Table: 5.29: Minimum flow (cumec) requirement for fish species of Madhumati River

Species	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Minimum flow	400	400	400	400	400	400	400	400	400	300	300	400

Flow corresponding to selected habitat exceedance percentile

In the present study, using WUA-Discharge curve in conjunction with habitat duration curves, flows were computed for each month for WUA values corresponding to arbitrarily chosen 50% and 75% exceedance probabilities for illustration and the values are presented in Table 5.30 and Table 5.31 for Gorai and Madhumati Rivers respectively. Flow values corresponding to optimum weighted usable areas are also shown in the bottom row of each table. In case of practical application, the choice of exceedance percentile will depend on management strategy to be adopted by decision makers considering how much water left in the river for target species. It should be noted that the results of this study, as presented below, are of a preliminary largely due to the approximately nature of the fish habitat related input data and should not be used as an indication of fish habitat availability for design purposes. Results presented only illustrate the possible application and use of habitat-flow functions to assess seasonal flow needs.

Gorai River

The 50^{th} and 75^{th} percentile values also presented for high flow, intermediate flow and low flow months for both Ayeer and Bacha fish (Table 5.30). The bottom row of Table 5.30 shows that the maximum amount WUAs are obtained at discharge values of 250 cumec and 350 cumec, respectively for Ayeer and Bacha fish. For Ayeer fish the 75^{th} percentile value for high flow month higher than the flushing flow obtained by the Tennant Method (Table 5.2), for the intermediate flow months it covers all the condition except flushing flow and for low flow month it covers poor to degradation. For Ayeer fish the 50^{th} percentile value for high flow month higher than the flushing flow obtained by the Tennant Method (Table 5.2), for the intermediate flow months it covers all the condition except flushing flow and for low flow month it covers severe degradation to good condition.

For Bacha fish the 75^{th} percentile value for high flow month higher than the flushing flow obtained by the Tennant Method (Table 5.2), for the intermediate flow months it covers all the condition except flushing flow and for low flow month it covers severe degradation to good condition. For Bacha fish the 50^{th} percentile value for high flow month higher than the flushing flow obtained by the Tennant Method (Table 5.2), for the intermediate flow months it covers all the condition except flushing flow and for low flow month it covers severe degradation to good condition.

Table 5.30: Flow (cumec) for indicated species for various values of WUA in different seasons of the year in the Gorai River

Season	WUA (m^2/1000m reach length)	Flow (cumec) for indicated fish species	
		Ayeer	Bacha
High flow (Jun, Jul, Aug, Sep)	50th percentile 75th percentile	590-4554 480-3904	650-4427 565-3803
Intermediate flow (May, Oct)	50th percentile 75th percentile	160-1890 85-1760	175-1965 104-1866
Low flow (Apr, Nov, Dec, Jan, Feb, Mar)	50th percentile 75th percentile	90-680 35-540	103-739 44-696
	Optimum	250	350

Madhumati River

The ranges of the computed flows are summarized in Table 5.31 for high flow, intermediate flow and low flow months. The bottom row of Table 5.31 shows that the maximum amount WUAs are obtained at discharge values of 400 cumec and 300 cumec, respectively for Carp Species and Golda fish. It should be noted that the results of this study, as presented below, are of a preliminary largely due to the approximately nature of the fish habitat related input data and should not be used as an indication of fish habitat availability for design purposes. Results presented only illustrate the possible application and use of habitat-flow functions to assess seasonal flow needs. For Carp Species the 75th percentile value for high flow month falls below the flushing flow obtained by the Tennant Method (Table 5.5), for the intermediate flow months it covers all the condition except flushing flow and for low flow month it covers severe degradation to outstanding. For Carp Species the 50th percentile value for high flow month higher than the flushing flow obtained by the Tennant Method (Table 5.5), for the intermediate flow months it covers all the condition except flushing flow and for low flow month it covers severe degradation to outstanding. For Golda fish the 75th percentile value for high flow month falls below the flushing flow obtained by the Tennant Method (Table 5.5), for the intermediate flow months it covers all the condition except flushing flow and for low flow month it covers severe degradation to outstanding. For Golda fish the 50th percentile value for high flow month higher than the flushing flow obtained by the Tennant Method

(Table 5.5), for the intermediate flow months it covers all the condition except flushing flow and for low flow month it covers severe degradation to outstanding.

Table 5.31: Flow (cumec) for indicated species for various values of WUA in different seasons of the year in the Madhumati River

Season	WUA (m^2/1000m reach length)	Flow (cumec) for indicated fish species	
		Carp Species	Golda
High flow (Jun, Jul, Aug, Sep)	50th percentile 75th percentile	75-196 71-172	67-188 64-162
Intermediate flow (May, Oct)	50th percentile 75th percentile	70-120 68-99	67-102 64-93
Low flow (Apr, Nov, Dec, Jan, Feb, Mar)	50th percentile 75th percentile	65-74 62-71	59-65 55-62
	Optimum	400	300

5.6 Holistic Method for dominant fish Species

5.6.1 Holistic Method for dominant fish Species of Kaliganga River

The most popular method of holistic approaches is Building Block Method. Selected indicators for this study are fisheries. In this regards, e-flow requirements for Golda fish are calculated by using this method. In the Kaliganga River, the relations between water level and cross sectional area of Kaliganga River are derived from MIKE 11 for Sec-50, Sec-54, Sec-58, Sec-60 and Sec-61 (Figure 4.9) along the river course. Required water levels are found by adding the required depth with the minimum level of the cross section of the respective river. Cross sectional areas for that specific water level are calculated following the generated equations. Relation between water level and cross-sectional area at Sec-50 (Figure 4.9) is shown in Figure 5.41.

Golda fish requires a critical velocity 0.20 m/s during May to October with maintaining 2 m depth in the main channel. For maintaining 2m depth at Kaliganga River required level is found -2.64m PWD to 1.92m PWD. The required cross section area is found from the relation between Water level and Cross-Sectional area. In addition, there is required velocity for this species. The required discharge is found by multiplying the velocity with the calculated cross section, as Q=AV; where Q= discharge, A= cross-sectional area and V= velocity. The detail calculation of flow requirements and relation between water level and Cross sectional area is given as Appendix-E. Flow requirement of Golda fishes at different section 50 to Section 61 (Figure 4.9) is shown in Figure 5.42 and Flow requirement for Golda fishes of Kaliganga River on the basis of Building block methodology is shown in Figure 5.43.

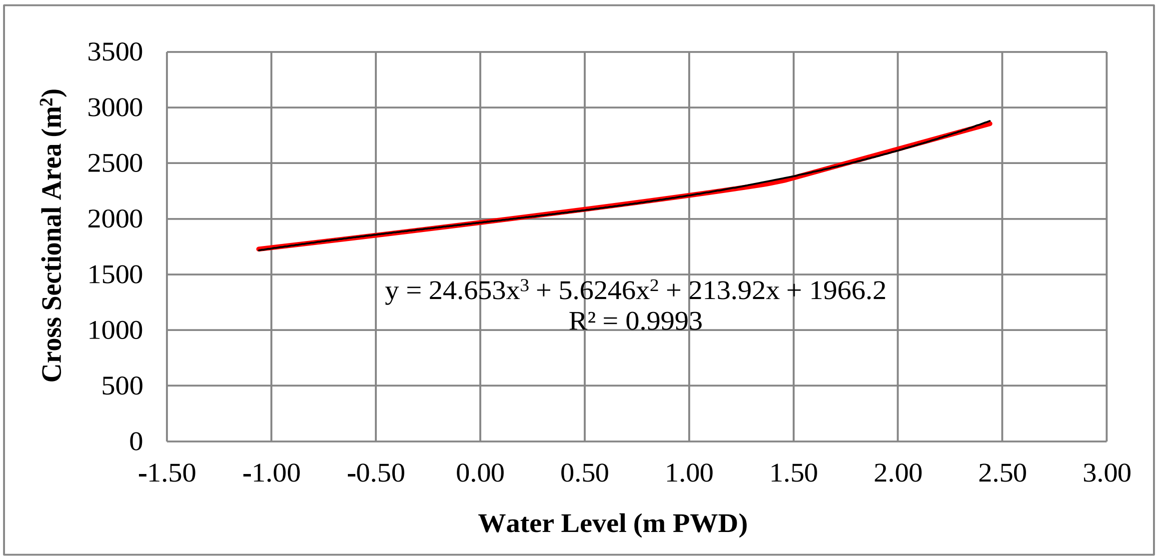


Figure 5.41: Relation between Water Level and Cross-Section Area of Kaliganga River

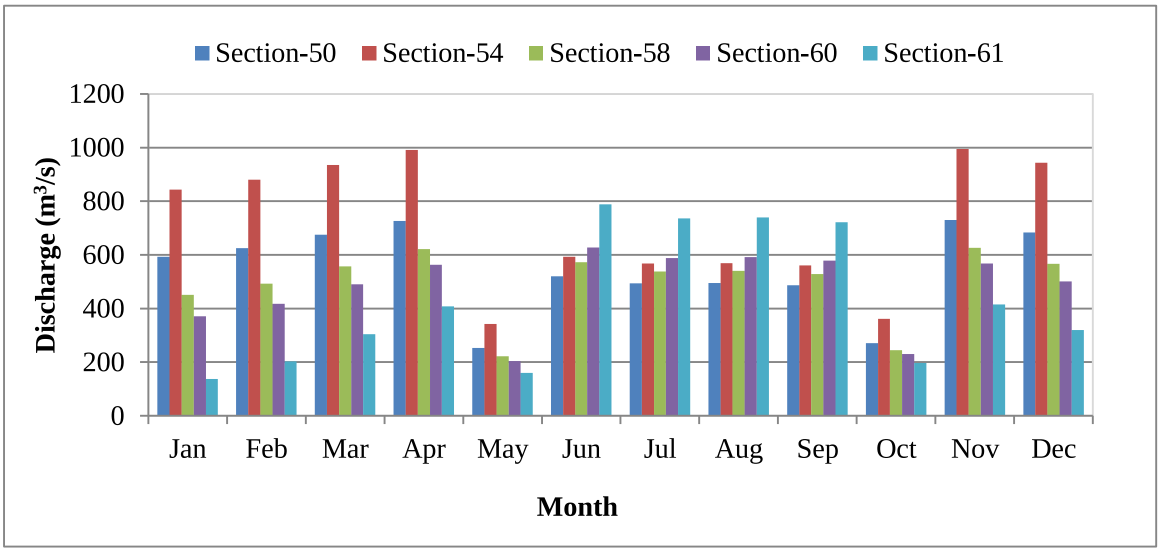


Figure 5.42: Flow requirement for Golda fishes at different Sections of Kaliganga River

The results of fisheries demand show that for Golda, maximum flow (994 cumec in November) is less than of mean annual flow requirement. Golda requires is 880 to 991 cumec during February to April.

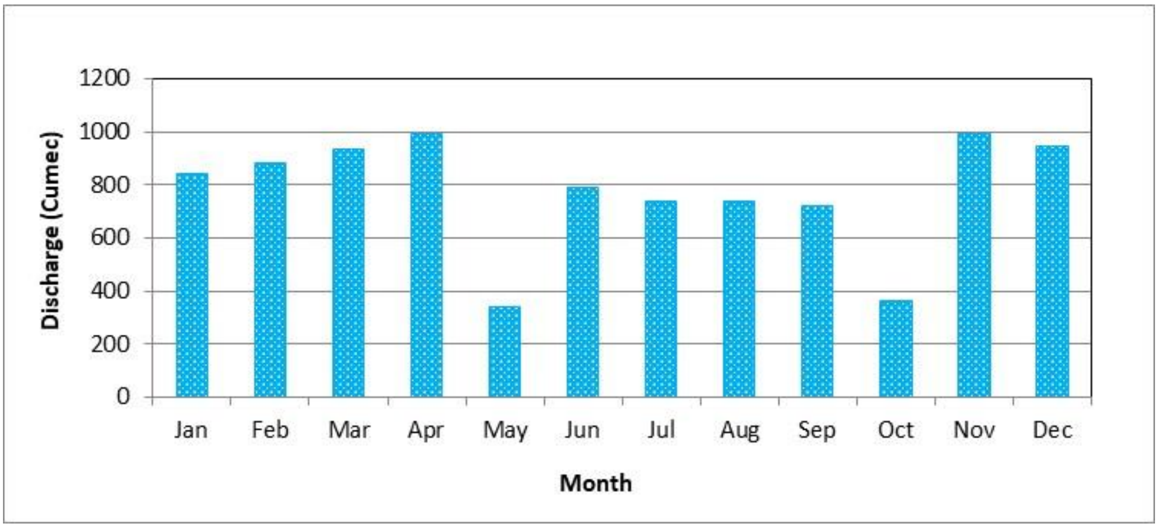


Figure 5.43: Flow requirement for Golda fishes of Kaliganga River

5.6.2 Holistic Method for Dominant fish Species of Balaswar River

The most popular method of holistic approaches is Building Block Method. Selected indicators for this study are fisheries. In this regards, e-flow requirements for Golda fish are calculated by using this method.

In the Balaswar River, the relations between water level and cross-sectional area of Balaswar River are derived from MIKE 11 Sec-64, Sec-68, Sec-70 and Sec-72 (Figure 4.9) along the river course. Required water levels are found by adding the required depth with the minimum level of the cross section of the respective river. Cross sectional areas for that specific water level are calculated following the generated equations. Relation between water level and cross-sectional area at Section 72 (Figure 4.9) is shown in Figure 5.44.

Golda fish requires a critical velocity 0.20 m/s during May to October with maintaining 2 m depth in the main channel. For maintaining 2m depth at Kaliganga River required level is found -2.21m PWD to -2.28m PWD. The required cross section area is found from the relation between Water level and Cross-Sectional area. In addition, there is required velocity for this species. The required discharge is found by multiplying the velocity with the calculated cross section, as Q=AV; where Q= discharge, A= cross-sectional area and V= velocity. The detail calculation of flow requirements and relation between water level and Cross-sectional area is given as Appendix-E. Flow requirement for Golda fishes of Kaliganga River on the basis of Building block methodology is shown in Figure 5.45.

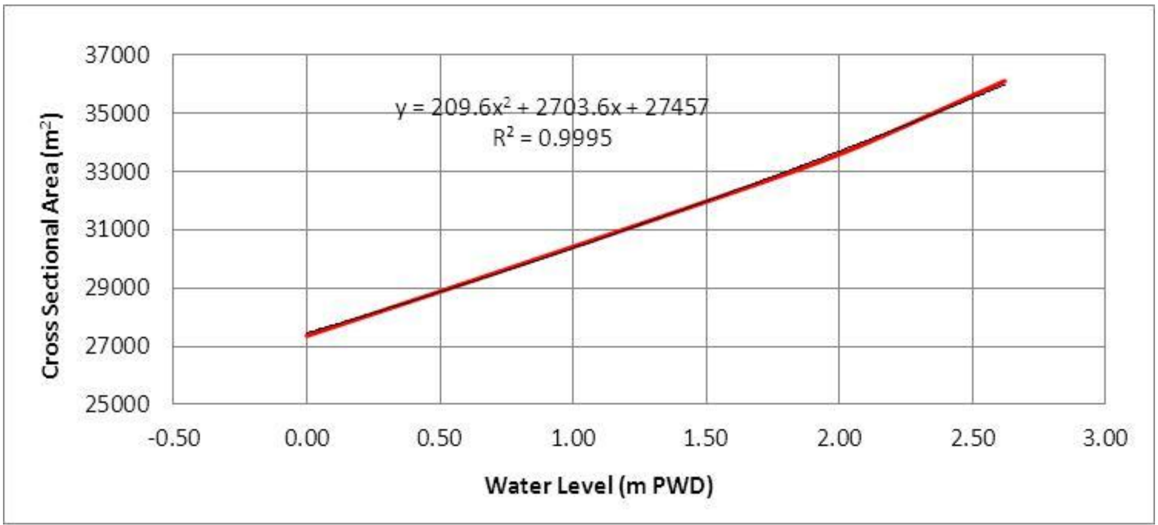


Figure 5.44: Relation between Water Level and Cross-Section Area of Balaswar River

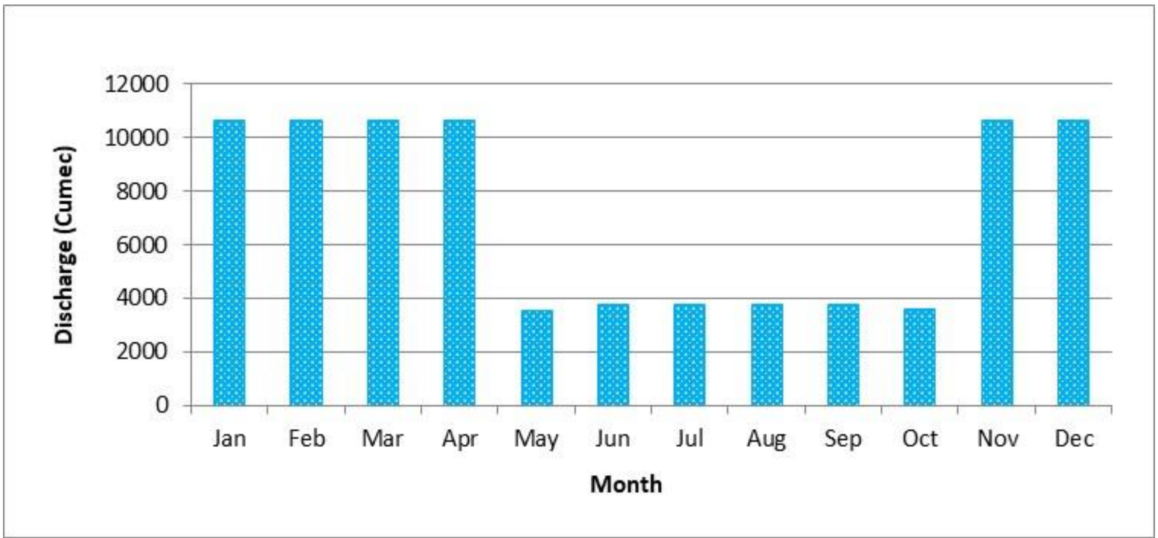


Figure 5.45: Flow requirement for Golda fishes of Balaswar River

The results of fisheries demand show that for Golda, maximum flow (10678 cumec in November) is less than mean annual flow requirement. Golda requires is 10669 to 10678 cumec during February to April.

5.7 Assessment of e-flow requirement for Gorai River

Environmental flow (e-flow) requirement of Gorai River has been assessed by Tennant, Flow Duration Curve (FDC), Constant Yield Method (CYM) and Monthly average e-flow requirement for dominant fish species of the Gorai River has been assessed by Physical Habitat Simulation Method (PHABSIM) method. The total requirement has been assessed in terms of discharge for the sustainability of the selected indicators. The comparison of computed e-flow requirements of Gorai River given in Table 5.32 below:

Table 5.32: Computed e-flow (cumec) requirements of Gorai River

Month / Method	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Tennant Method	151	151	-	-	3022	3022	-	-	-	151	151	151
Flow Duration Curve	25	56	389	2522	5090	4577	2022	584	308	152	106	51
Constant Yield Method	122	196	580	2555	5235	4580	2030	849	450	272	205	139
Wetted Perimeter Method	The flow between 45 cum to 3521 cum are favorable for habitat											
PHABSIM(Ayeer)	250	250	250	250	250	250	250	250	250	250	250	250
PHABSIM (Bacha)	-	-	-	-	-	-	350	350	350	350	350	350
e-flow (cumec)	250	250	580	2555	5235	4580	2030	849	450	350	350	350

Environmental flow assessed based on Tennant method is 151 cumec during low flow season (November to May) and flushing flow 3022 cumec. Based on Flow duration curve method, e- flow is 25 to 584 cumec during low flow season and 389 to 5090 cumec during high flow season. According to Constant yield method, the e-flow is 122 to 849 cumec during low flow season and 580 to 5235 cumec during high flow season. On the basis of wetted perimeter method the flow between 45 cumec to 3521 cumec are keeping conditions favorable for habitat. Discharge requirement for fair habitat quality of dominant fish species Ayeer claims 250 cumec from January to December and Bacha fish claims 350 cumec October to March. In that case, Gorai River must be maintained the minimum computed e-flow during low flow season (November to May) for keeping the sustainable ecosystem. The Environmental flow requirement for Gorai River considering hydrological aspects and dominant fish requirement is given in Figure 5.46 and 5.47.

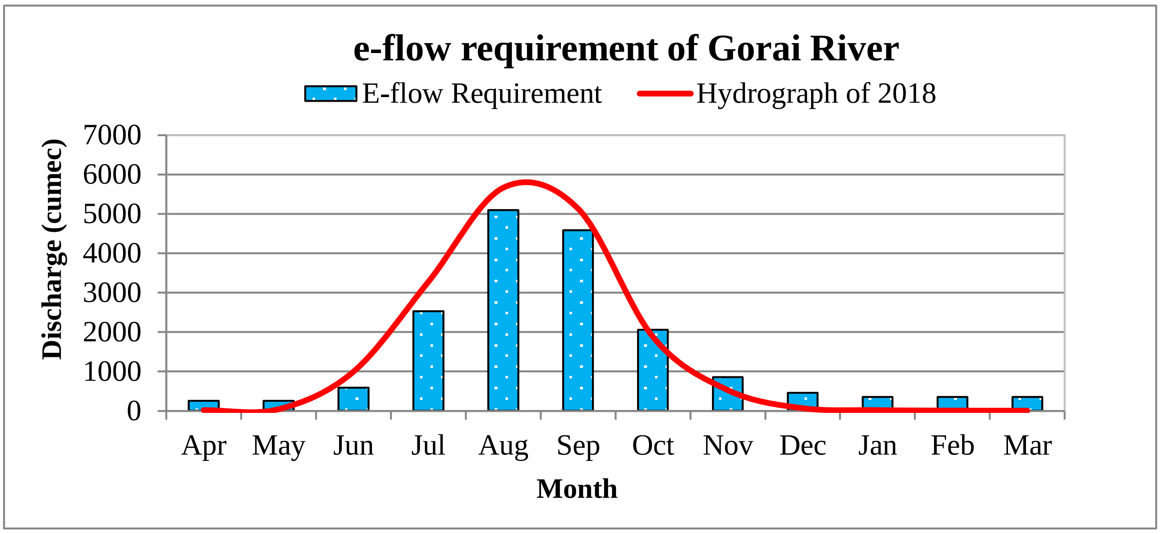


Figure 5.46: Environmental flow Requirement for Gorai River from different methods

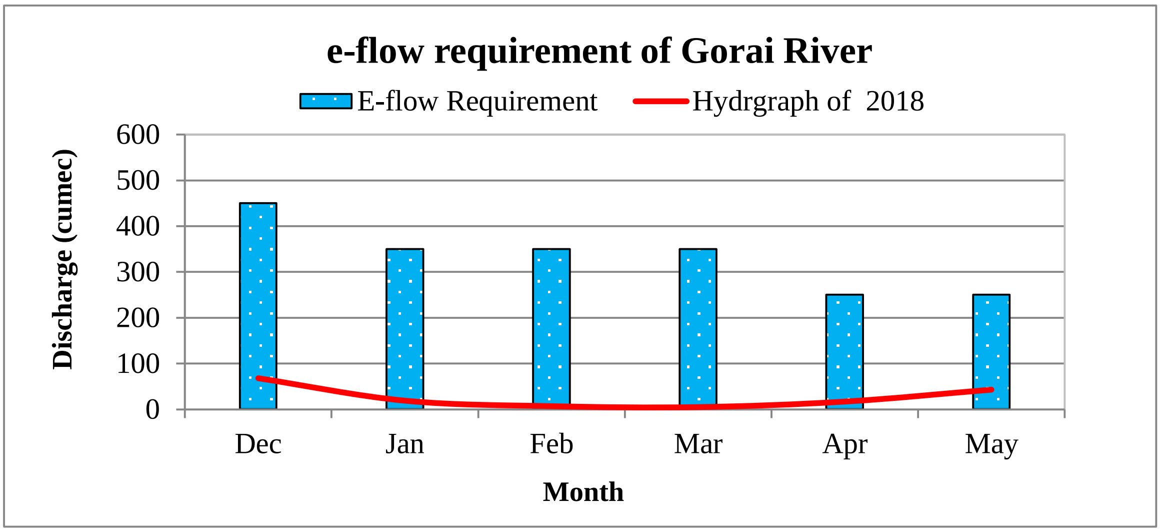


Figure 5.47: Environmental flow Requirement of Gorai River from different methods during dry season

5.8 Assessment of e-flow requirement for Madhumati River

Environmental flow (e-flow) requirement of Madhumati River has been assessed by Tennant, Flow Duration Curve (FDC), Constant Yield Method (CYM) and Monthly average e-flow requirement for dominant fish species of the Madhumati River has been assessed by Physical Habitat Simulation Method (PHABSIM) method. The total requirement has been assessed in terms of discharge for the sustainability of the selected indicators. The comparison of computed e-flow requirements of Madhumati River given in Table 5.33 below:

Table 5.33: Computed e-flow (cumec) requirements of Madhumati River

Month / Method	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Tennant Method	-	-	-	186	186	186	-	-	55	55	55	-
Flow Duration Curve	33	33	65	128	197	197	105	7	12	20	23	33
Constant Yield Method	69	72	78	115	195	190	98	59	62	66	68	67
Wetted Perimeter Method	The flow between 23 cum to 104 cumec are favorable for habitat											
PHABSIM(Golda)	300	-	-	-	-	-	-	-	-	-	300	300
PHABSIM (Carp)	400	400	400	400	400	400	400	400	400	400	-	-
e-flow (cumec)	400	400	400	400	400	400	400	400	400	400	300	300

Environmental flow assessed based on Tennant method is 55 cumec during December to February and flushing flow 186 cumec. Based on Flow duration curve method, E- flow is 7 to 33 cumec during low flow season and 65 to 197 cumec during high flow season. According to Constant yield method, the e-flow is 59 to 72 cumec during low flow season and 78 to 195 cumec during high flow season. On the basis of wetted perimeter method the flow between 23 cumec to 104 cumec are keeping conditions favorable for habitat. Discharge requirement for fair habitat quality of dominant fish species Golda claims 300 cumec from February to April and Carp fishes claims 400 cumec from January to December except February to March. In that case, Madhumati River must be maintained the minimum computed e-flow during January to December for keeping the sustainable ecosystem. The Environmental flow requirement for Madhumati River considering hydrological aspects and dominant fish requirement is given in Figure 5.48 and 5.49.

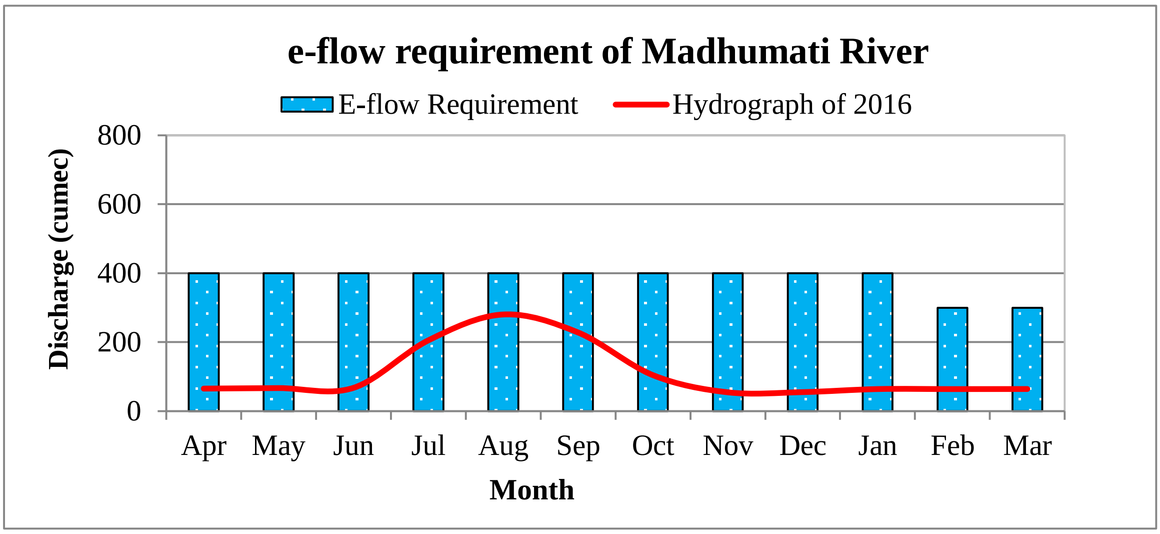


Figure 5.48: Environmental flow Requirement for Madhumati River from different methods

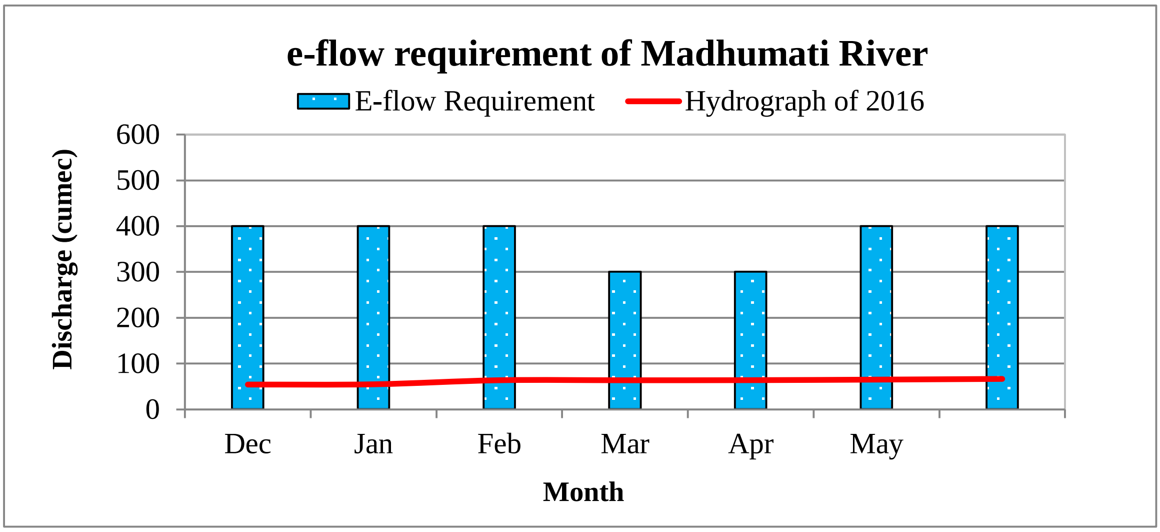


Figure 5.49: Environmental flow Requirement for Madhumati River from different methods during dry season

5.9 Assessment of e-flow requirement for Kaliganga River

Environmental flow (e-flow) requirement of Kaliganga River has been assessed by Tennant, Flow Duration Curve (FDC), Constant Yield Method (CYM) and Monthly average e-flow requirement for dominant fish species of the Kaliganga River has been assessed by Holistic method. The total requirement has been assessed in terms of discharge for the sustainability of the selected indicators. The comparison of computed e-flow requirements of Kaliganga River given in Table 5.34 below:

Table 5.34: Computed e-flow (cumec) requirements of Kaliganga River

Month / Method	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Tennant Method	-	-	-	-	-	-	-	-	1164	1164	1164	-
Flow Duration Curve	524	598	1464	1610	1671	1591	1439	389	234	354	294	517
Constant Yield Method	1018	1101	1480	1550	1652	1598	1423	1257	1152	1098	1078	1058
Wetted Perimeter Method	The flow between 114 cum to 1023 cum are favorable for habitat											
Holistic Method	991	-	-	-	-	-	-	-	-	-	880	935
e-flow (cumec)	1018	1101	1480	1610	1671	1598	1439	1257	1164	1164	1164	1058

Environmental flow assessed based on Tennant method is 1164 cumec during December to February. Based on Flow duration curve method, e-flow is 234 to 598 cumec during low season flow and 1439 to 1671 cumec during high flow season. According to Constant yield method, the e-flow is 1018 to 1257 cumec during low season flow and 1423 to 1652 cumec during high season flow. On the basis of wetted perimeter method the flow between 114 cumec to 1023 cumec are keeping conditions favorable for habitat. Minimum discharge requirement for fair habitat quality of dominant fish species Golda claims 991 cumec on April, 880 cumec on February and 935 cumec on March. It is observed that even though the flow demand for considering hydrological approaches and dominant fish requirement in Kaliganga River is so called satisfactory. The Environmental flow requirement for Kaliganga River considering hydrological aspects and dominant fish requirement is given in Figure 5.50.

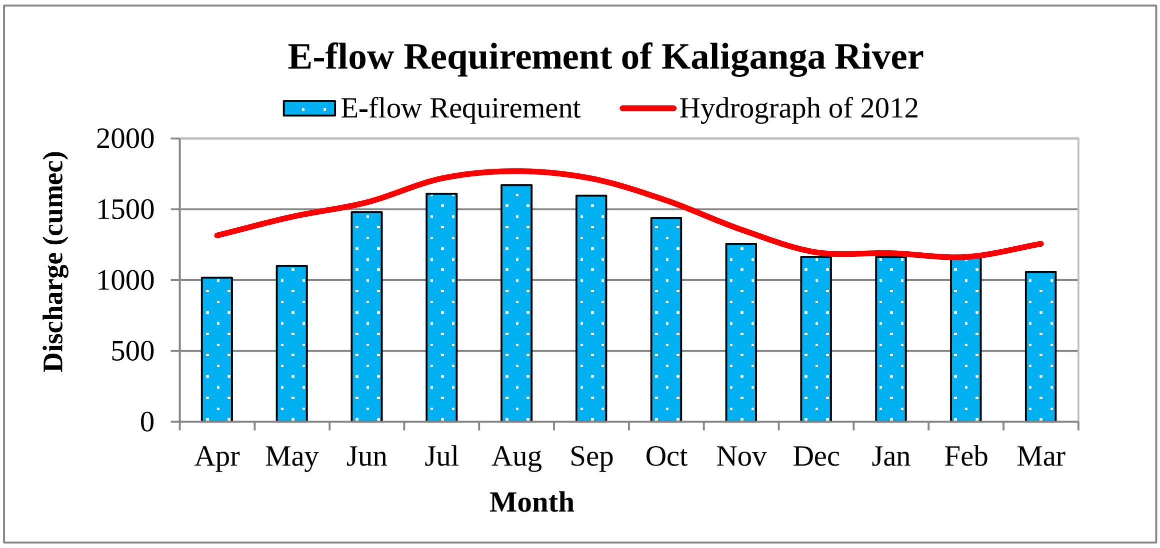


Figure 5.50: Environmental flow Requirement for Kaliganga River from different methods

5.10 Assessment of e-flow requirement for Balaswar River

Environmental flow (e-flow) requirement of Balaswar River has been assessed by Tennant, Flow Duration Curve (FDC), Constant Yield Method (CYM) and Monthly average e-flow requirement for dominant fish species of the Balaswar River has been assessed by Holistic method. The total requirement has been assessed in terms of discharge for the sustainability of the selected indicators. The comparison of computed e-flow requirements of Balaswar River given in Table 5.35 below:

Table 5.35: Computed e-flow (cumec) requirements of Balaswar River

Month / Method	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Tennant Method	-	-	-	-	-	-	-	-	-	-	10971	
Flow Duration Curve	3720	3967	11614	12132	12694	13532	13232	2723	1705	2647	2202	3814
Constant Yield Method	10450	10625	11930	12130	12628	13700	13215	12358	11950	9768	10071	10592
Wetted Perimeter Method	The flow between 1215 cum to 12031 cum are favorable for habitat											
Holistic Method	10671	-	-	-	-	-	-	-	-	-	10678	10669
e-flow (cumec)	10671	10625	11930	12132	12694	13532	13232	12358	11950	9767	10971	10669

Environmental flow assessed based on Tennant method is 10971 cumec during February. Based on Flow duration curve method, e- flow is 1705 to 3967 cumec during low season flow and 11614 to 13532 cumec during high season flow. According to Constant yield method, the e-flow is 9768 to 12358 cumec during low season flow and 11930 to 13700 cumec during high season flow. On the basis of wetted perimeter method the flow between 1215 cumec to 12031 cumec are keeping conditions favorable for habitat. Minimum discharge requirement for fair habitat quality of dominant fish species Golda claims 10671 cumec on April, 10678 cumec on February and 10669 cumec on March. It is observed that even though the flow demand for considering hydrological approaches and dominant fish requirement in Balaswar River is so called satisfactory. The Environmental flow requirement for Balaswar River considering hydrological aspects and dominant fish requirement is given in Figure 5.51.

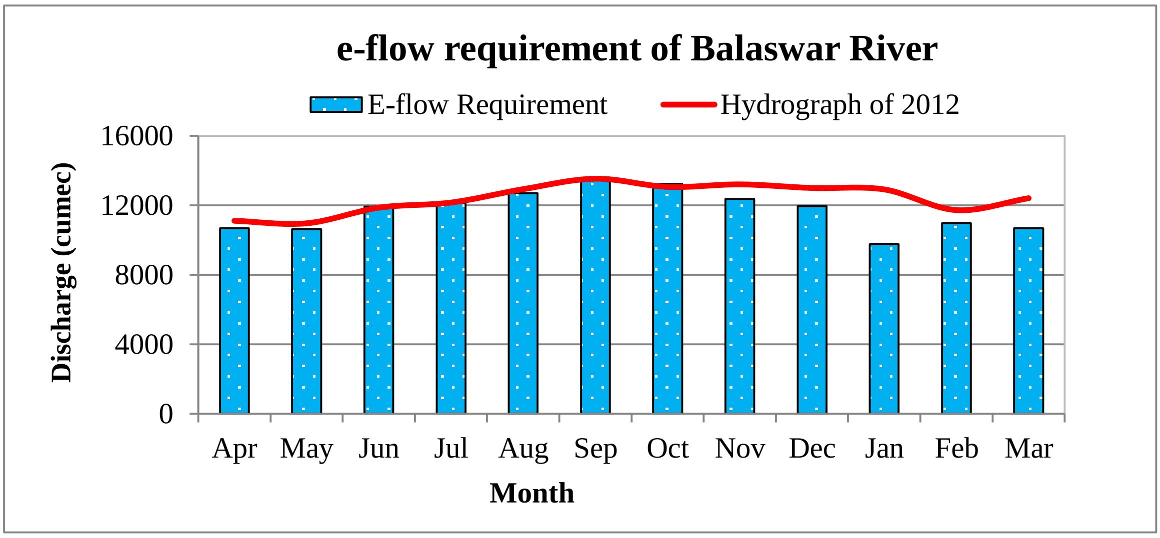


Figure 5.51: Environmental flow Requirement for Balaswar River from different methods

5.11 Assessment of decadal flow with the present e-flow

The Environmental flow (e-flow) required of Gorai River as 250 cumec to 5235 cumec considering hydrological aspects and dominant fish requirement. The mean annual flow (MAF) of Gorai River at Gorai Railway Bridge from January to December is found 5 cumec to 5664 cumec. As a result, in the dry period from October to June mean annual flow is lower than e-flow requirement but in the monsoon period (August and September, 2011-2018) mean annual flow is higher than required e-flow. In that case, Gorai River must be maintained the minimum computed e-flow (given in Table 5.32) from October to June for keeping the sustainable ecosystem. The Comparison of Mean annual flow and e-flow requirements of Gorai River is shown in Figure 5.52.

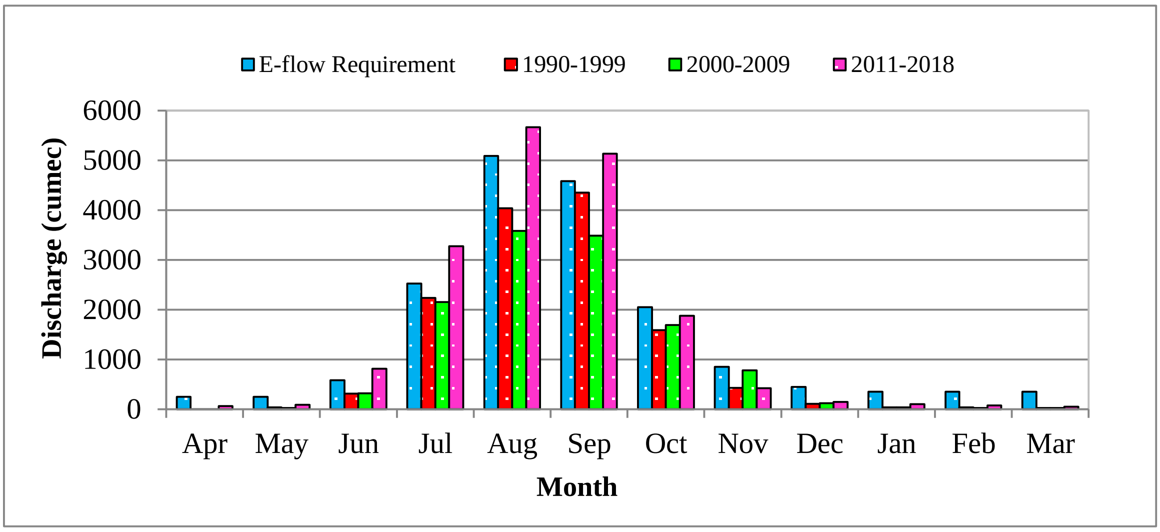


Figure 5.52: Comparison with e-flow requirement and Mean Annual Flow of Gorai River

The Environmental flow required of Madhumati River as 300 cumec to 400 cumec considering hydrological aspects and dominant fish requirement. The mean annual flow (MAF) of Madhumati River at Bordia from January to December is found 55 cumec to 210 cumec. As a result, in the period from October to June mean annual flow is lower than e-flow requirement but in the monsoon (August and September) mean annual flow is also lower than required e-flow. In that case, Madhumati River must be maintained the minimum computed e-flow (given in Table 5.31) during both dry and monsoon period (January to December) for keeping the sustainable ecosystem. The Comparison of Mean annual flow and e-flow requirements of Madhumati River is shown in Figure 5.53.

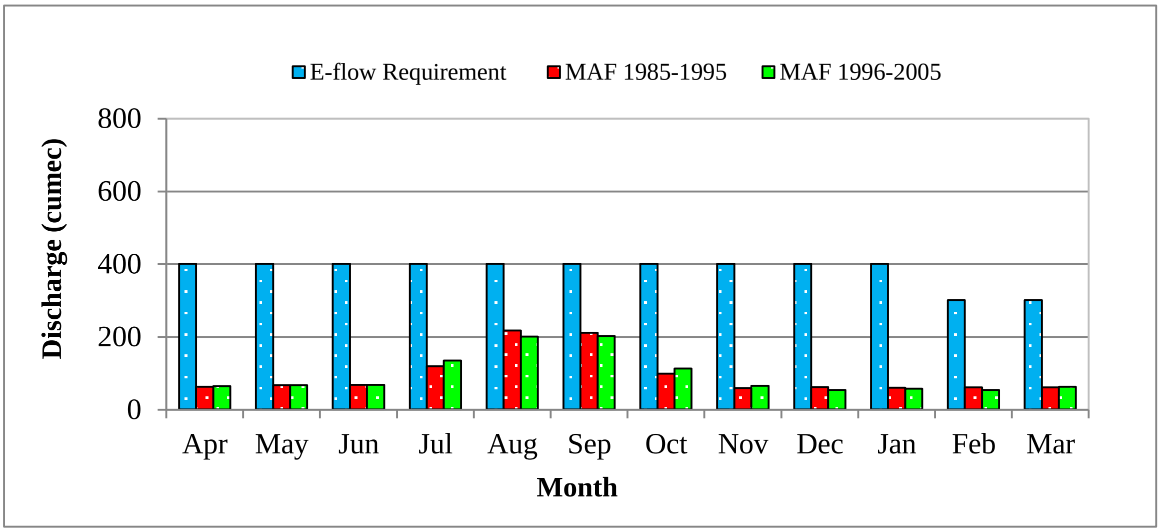


Figure 5.53: Comparison with e-flow requirement and Mean Annual Flow of Madhumati River

5.12 Salinity Model for required e-flow

A 1D hydrodynamic model and salinity analysis has been developed for the Gorai-Madhumati-Kaliganga-Balaswar River by using HEC-RAS.In HEC-RAS the one dimensional hydrodynamic is solved using a system of one-dimensional unsteady continuity and momentum equation with implicit scheme of finite difference method. The tidal and non-tidal hydrodynamic are calibrated by varying the Manning's roughness co-efficient and also stage-discharge relationship has been used for the calibration of hydrodynamic model. For the analysis of salinity intrusion at a certain reach Dispersion coefficient value is given in the model. This value indicates measure of the spread of data about the mean value, or with reference to some other theoretically important threshold or spatial location, e.g. the standard deviation.

5.12.1 Data Collection

For the development of 1D hydrodynamic mathematical model on flow and salinity analysis for Gorai-Madhumati-Kaliganga-Balaswar River system the following data such as Bathymetric data, Discharge data, and Stage hydrograph and salinity concentration has been required at various locations in the study reach. The available data at various measuring stations has been collected from BWDB.

5.12.2 Bathymetry Data

Total 89 cross sections data of Gorai-Madhumati-Kaliganga-Balaswar river system were collected from BWDB hydrology department and the project of GRRP Phase II, BWDB. Among them 22 cross sections of Gorai River, 23 cross sections of Madhumati River, 19 cross sections of Kaliganga River, 10 cross sections of Balaswar River and other sections is used for tributary channel. The distributary of Gorai through Nabaganga River has been considered here with 3 cross sections. There number of tributaries have also considered for the model setup. Madaripur Beel Route is having 3 Cross sections, Ghagar River is with 3 Cross sections, Belua River is with 3 Cross Sections, Shaynda River is with 3 Cross Sections and Ghasiakhali is with 3 Cross sections. Figure 5.49 presents the schematic diagram of the Stations of the Cross sections of Gorai-Madhumati-Kaliganga-Balaswar River system in HEC-RAS Model. The total study reaches starts from Gorai River and ends at Balaswar River.

5.12.3 Discharge Data

Discharge data were collected at Gorai Railway Bridge (SW 99). At Bordia discharges are divided into two parts, one part enters into Madhumati River and another enters into Nabaganga River. Data for January 2016 to December 2016 and January 2015 to December 2015 have been collected from BWDB hydrology department.

5.12.4 Stage Hydrograph

Stage hydrograph at the upstream of the river Gorai Railway Bridge (SW 99) and at the downstream of the Balaswar River near Charduani (SW 108) were collected from BWDB hydrology department. This hydrograph contains stage data for the year 2016 and 2015. Another stage hydrograph is collected of Kamarkhali transit (SW 101.5) and Bhatiapara (SW 102). This data was collected for calibration and validation for the year 2016 and 2015.

5.12.5 Salinity Concentration Data

For simulation of salinity condition, data required include discharge, water level, cross sections and salinity concentration at various locations for different tidal conditions. Salinity data were collected from BWDB and has been analyzed for comparing with the simulated values from model in Gorai-Madhumati-Kaliganga-Balaswar River system. Salinity data are available at station ID 101.5 (Kamarkhali Transit) on the Gorai River, ID 218 (Bordia) and ID 105 (Off take at Atharobanka) on Madhumati River, ID 107 (Pirojpur) on Kaliganga River and at station ID 107.2 (Rayenda), ID 108 (Charduani) on Balaswar River. To determine the salinity level for required e-flow of Gorai-Madhumati-Kaliganga-Balaswar River System has been established. The data set was analyzed and prepared to take care of the model simulated output.

5.12.6 Model Setup

After creating river reach and river geometry, the boundary conditions at upstream (Gorai Railway Bridge) and downstream Balaswar River (Charduani), out flow to Nabaganga river from Gorai, inflow from Madaripur Beel Route and Ghagor River to Madhumati River, an inflow branch of Belua River and Shaynda River into the Kaliganga River and inflow branch of Ghasiakhali River into the Balaswar River have been considered in HEC-RAS model. Figure 5.55 presents model reach of Gorai-Madhumati-Kaliganga-Balaswar (GMKB) River system with distributary and tributaries showing locations of boundary conditions in HEC-RAS. The developed calibrated and validated model for hydrodynamic simulation has been used for the assessment of salinity condition in Gorai-Madhumati-Kaliganga-Balaswar (GMKB) River system. But this model needs to be calibrated for water quality modelling system which has been carried out and documented in the following sections.

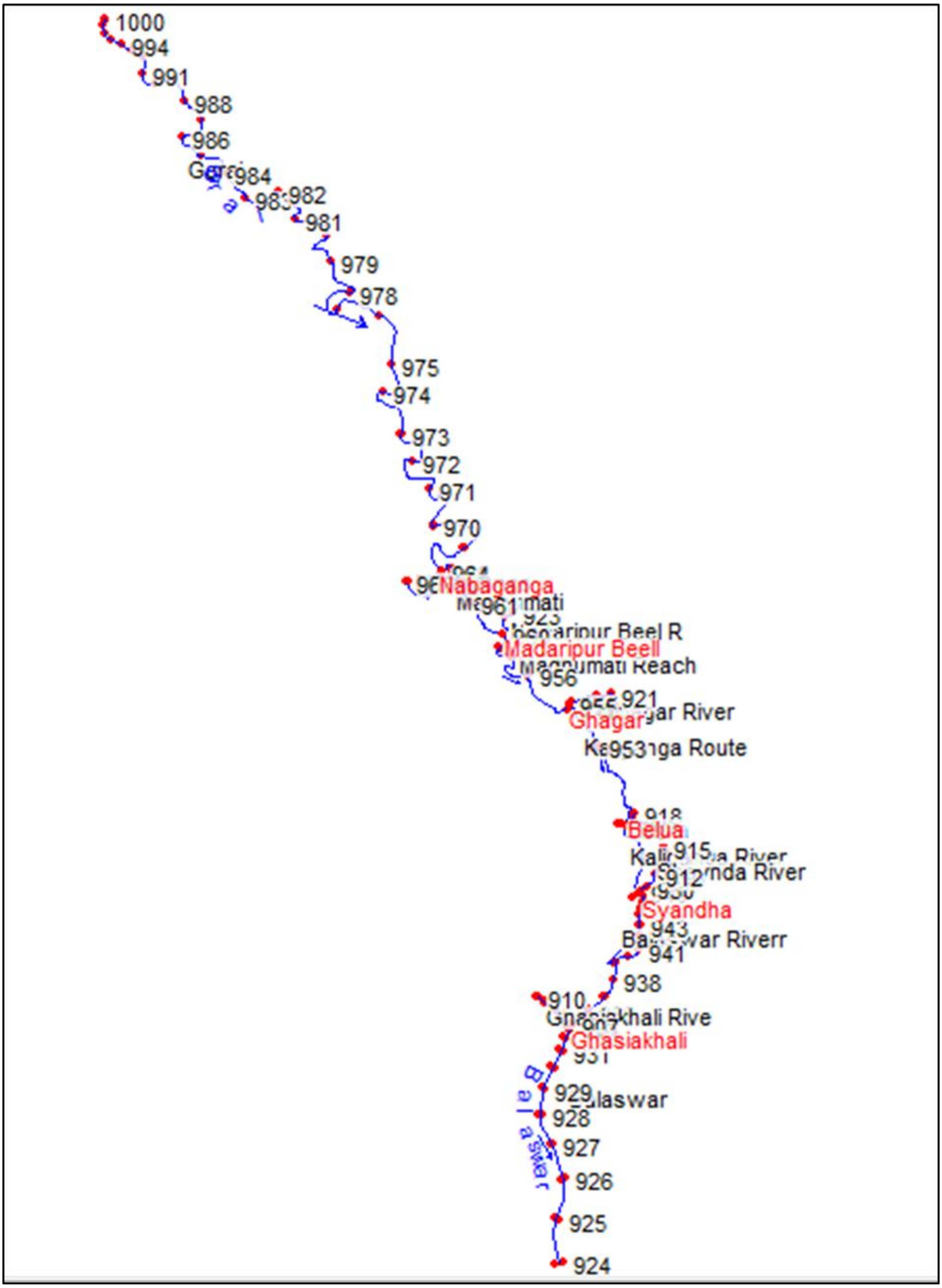


Figure 5.54: Schematic diagram of the Stations of the Cross sections of Gorai-Madhumati-Kaliganga-Balaswar (GMKB) River System in HEC-RAS

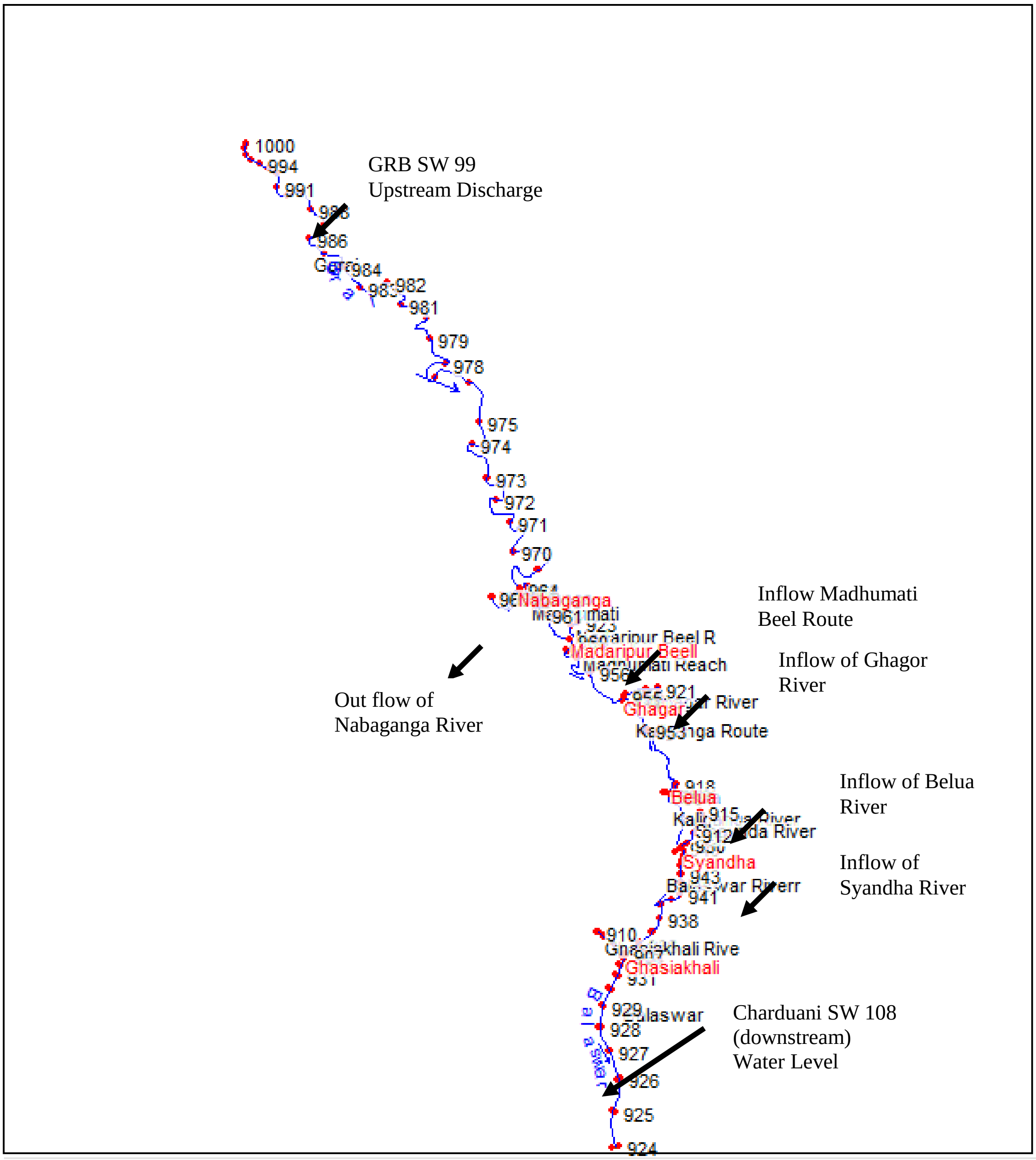


Figure 5.55: Gorai-Madhumati-Kaliganga-Balaswar River System (GMKB) showing locations of Boundary Conditions in HEC-RAS

5.12.7 Boundary Condition for Hydrodynamic Model

For the upstream boundary, the discharge data at Gorai Railway Bridge (SW-99) and for the downstream boundary the water level data at Charduani (SW-108) have been considered. Out flow to Nabaganga River from Gorai-Madhumati, inflow from Madaripur Beel Route and Ghagor River into Madhumati River, an inflow branch of Belua River and Shaynda River into the Kaliganga River and inflow branch of Ghasiakhali River into the Balaswar River have been considered as well. Figure 5.56 to Figure 5.57 show the upstream, downstream hydrograph as boundary conditions for the hydrodynamic model simulation of Gorai-Madhumati-Kaliganga-Balaswar River system. The lateral inflow and outflow hydrograph as boundary condition are shown in Appendix-F

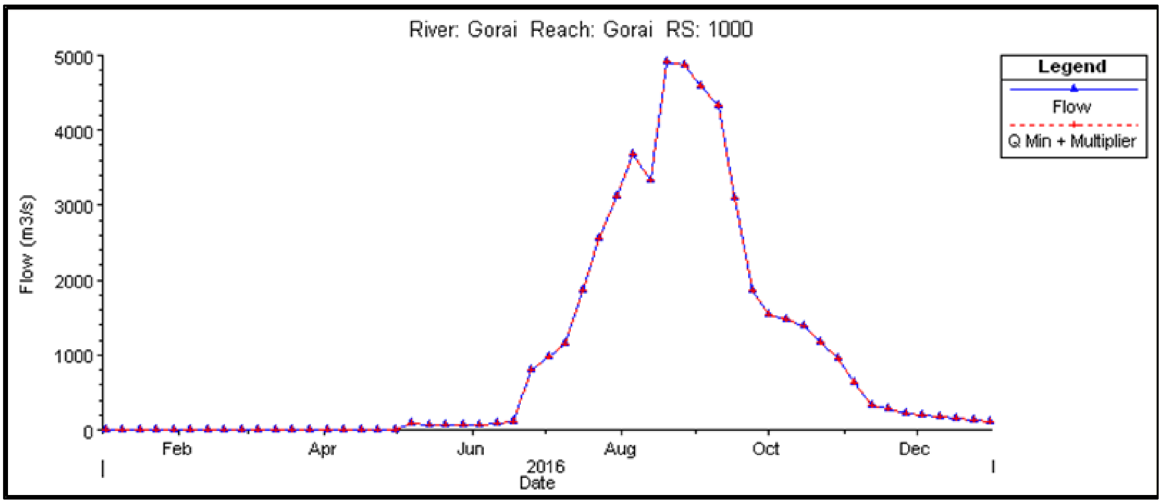


Figure 5.56: Flow Hydrograph for the year 2016 of Gorai River

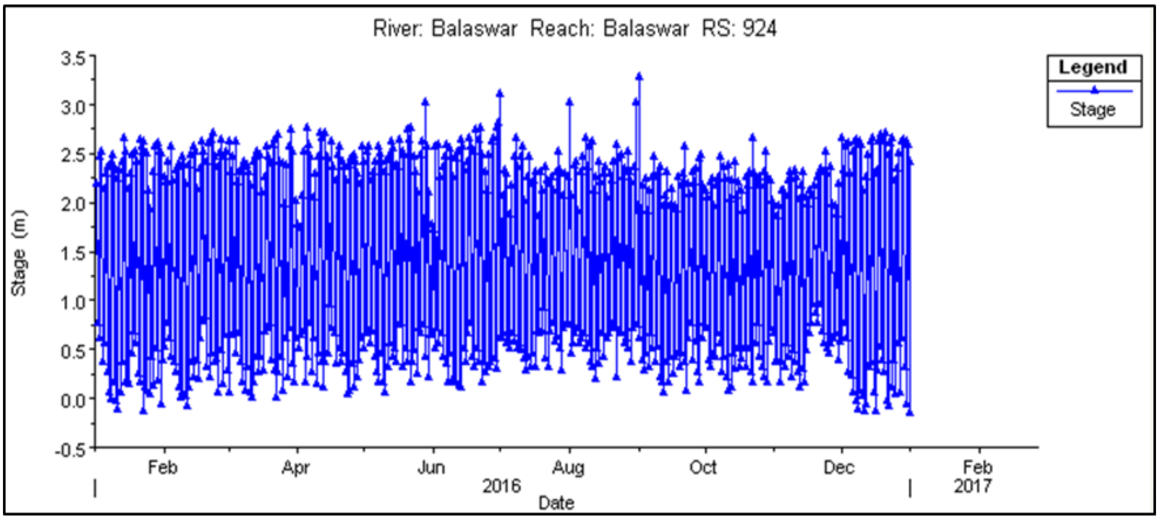


Figure 5.57: Stage Hydrograph for the year 2016 of Balaswar River

5.12.8 Calibration and Validation for Hydrodynamic Model

For hydrodynamic calibration, simulated water surface elevation has been compared with the observed water surface elevation at three different stations along the Gorai-Madhumati-Kaliganga-Balaswar River system. The locations name are Kamarkhali with station 1D SW 101.5 , Bhatiapara having station ID SW 102 and Rayenda having stations ID SW 107.2. Roughness and eddy viscosity are the parameters that have been used for fine tuning to obtain an adequate match with the observed field conditions in the present study. To calibrate the hydrodynamic model, the setup model has been simulated for 1 month at the beginning from March 2015 to 31 March 2015. Model Showed satisfactory level of matching of simulated and observed water surface for the value of n=0.020 in bank and n=0.016 in main channels, except at some different time periods, where simulated water surface elevation is somewhere lower than that of the observed water surface elevation. This mainly occurs due to use of a single n value in the cross-section of the main channel for whole reach. If roughness could be varied with time, then these phenomena could be minimized. Figure 5.58, 5.59 and 5.60 show the water level calibration results of the model at the Kamarkhali, Bhatiapara and Rayenda respectively stated above. The model has been validated at three different locations similar to the locations used for calibration for the month of March 2016. The validation result at Kamarkahli, Bhatiapara and Rayenda, show good agreement with the observed data. The result indicates that the model predicted the water level well for both increasing and decreasing trend and along the whole reach. Figure 5.61, 5.62 and 5.63 show the validation results at Kamarkhali, Bhatiapara and Pirojpur respectively.

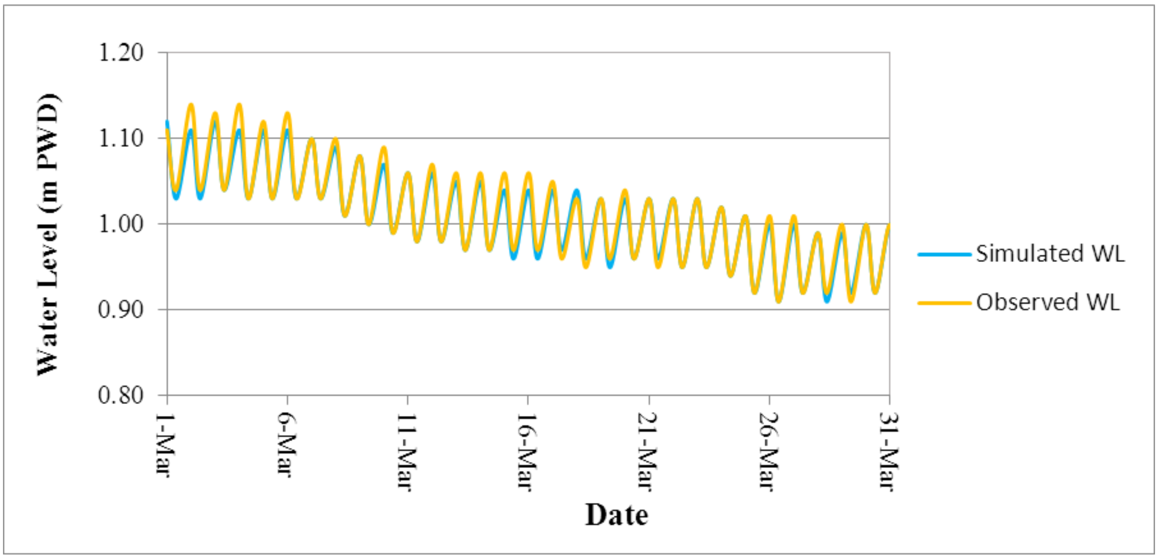


Figure 5.58: Calibration results at Kamarkhali of Gorai River

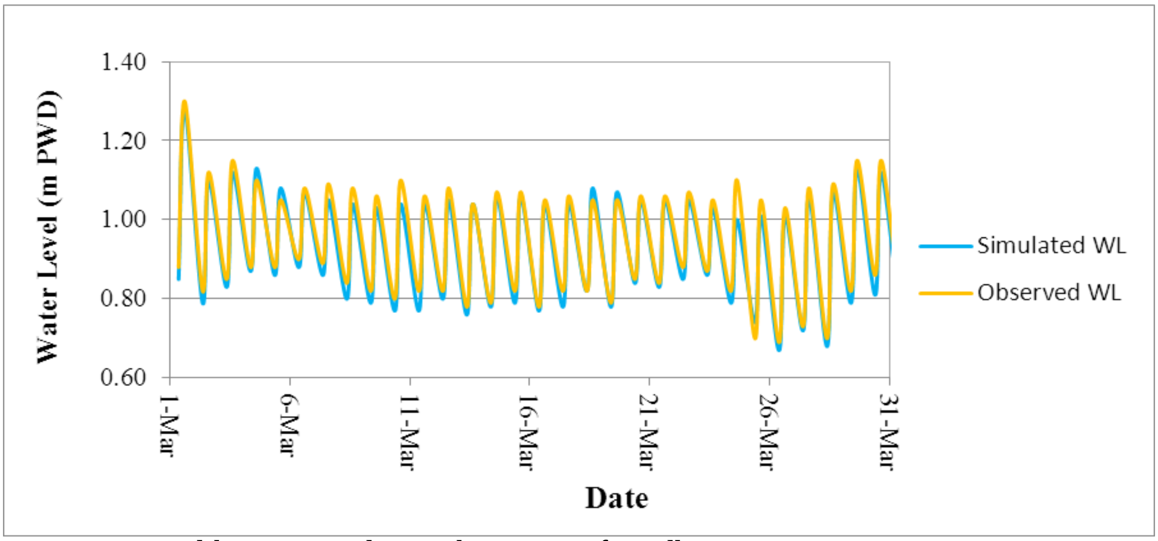


Figure 5.59: Calibration results at Bhatiapara of Madhumati River

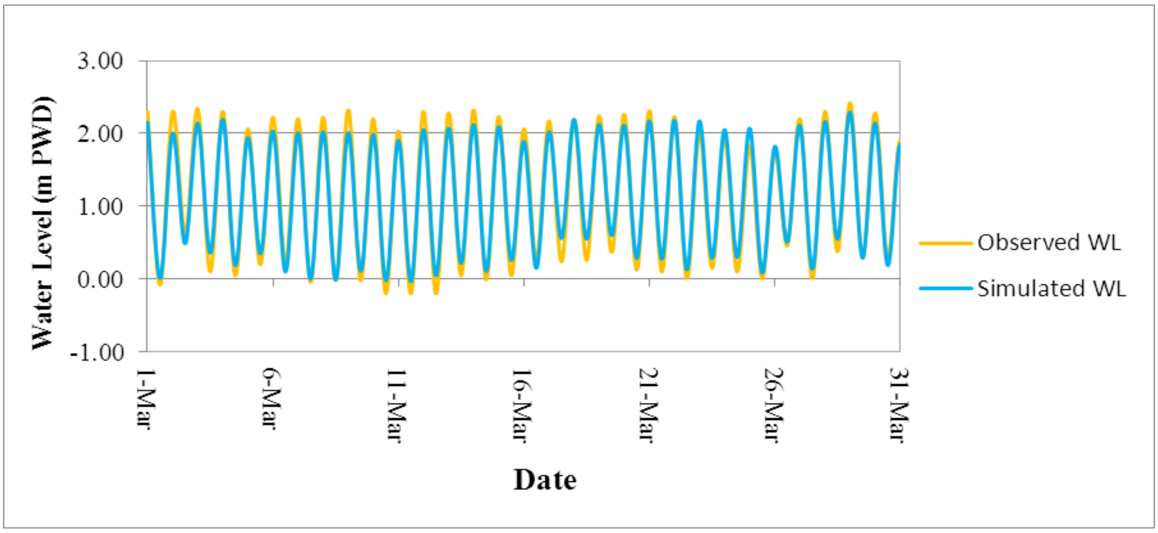


Figure 5.60: Calibration results at Rayenda of Balaswar River

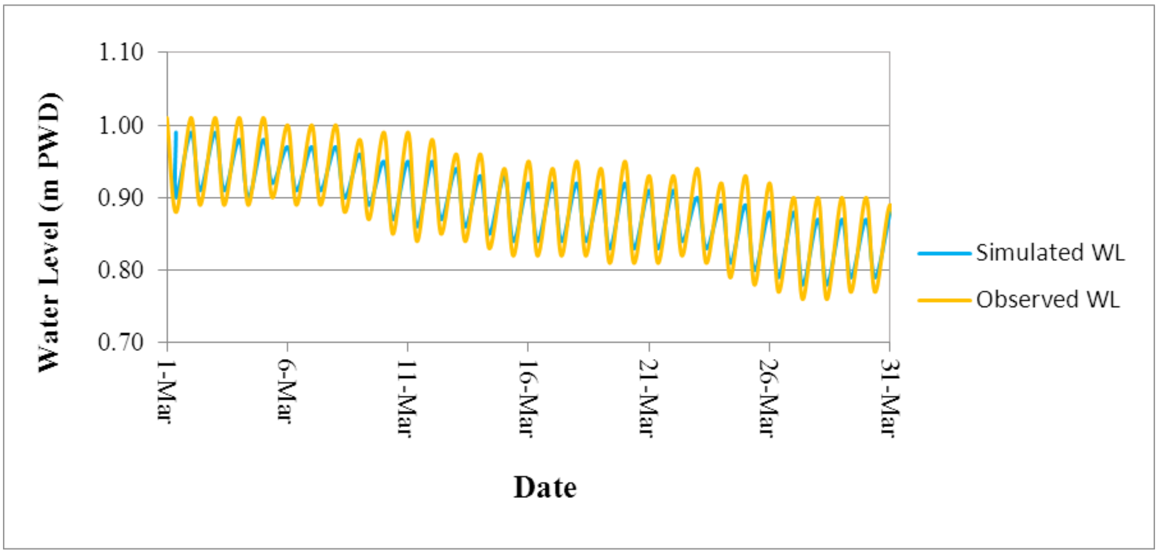


Figure 5.61: Validation results at Kamarkhali of Gorai River

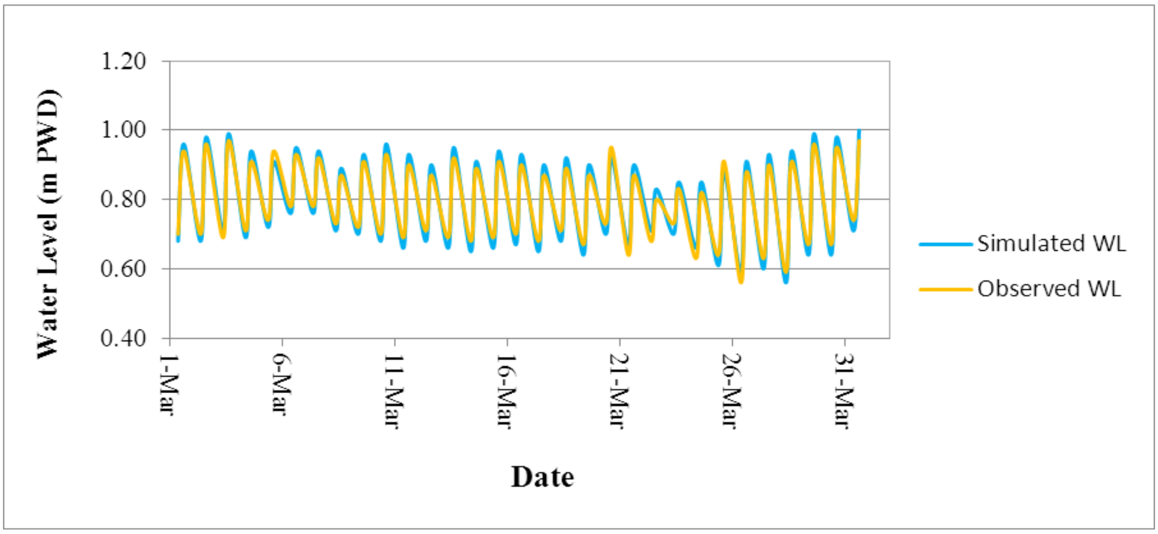


Figure 5.62: Validation results at Bhatiapara of Madhumati River

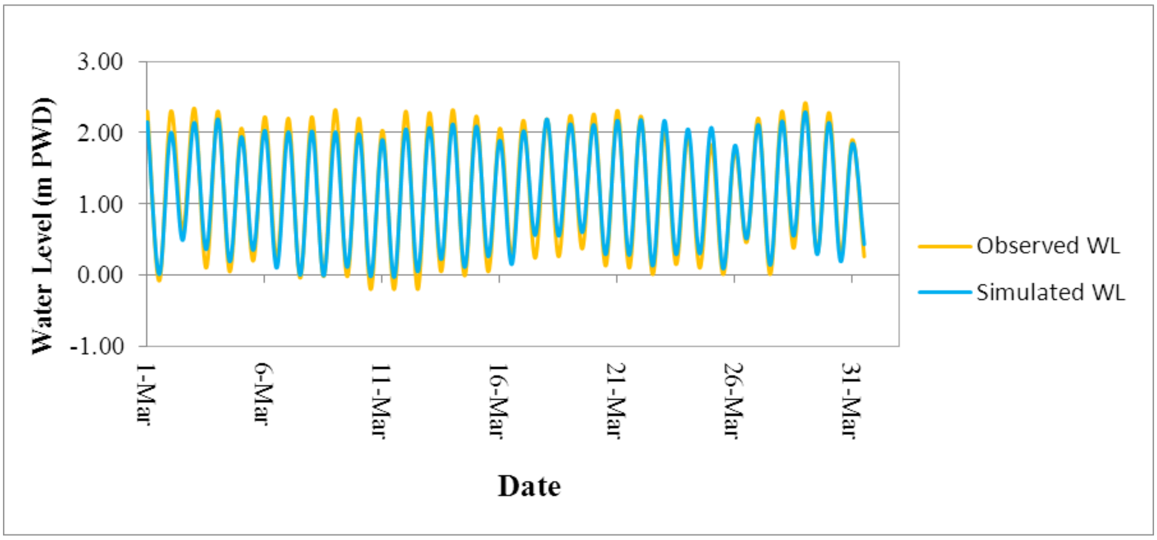


Figure 5.63: Validation results at Rayenda of Balaswar River

5.12.9 Water Quality Analysis

(i) Model Boundaries

Gorai Railway Bridge is taken as the upstream boundary and the downstream boundary has been selected at the point Charduani (SW-108) on Balaswar River. The model reach is shown in Figure 5.61. The study reach (Gorai-Madhumati-Kaliganga-Balaswar River system) is same as for the hydrodynamic Modelling.

(ii) Model Development

The developed calibrated and validated model for hydrodynamic simulation has been used for the assessment of salinity condition in Gorai-Madhumati-Kaliganga-Balaswar

(GMKB) River system. But this model needs to be calibrated for water quality modelling system which has been carried out and documented in the following sections.

(iii) Calibration of Salinity Model

Figure 5.55 presents model reach of Gorai-Madhumati-Kaliganga-Balaswar (GMKB) River System shows the locations of calibration and validation in HEC-RAS for the water quality (salinity in the case) modelling. For water quality modelling, unsteady flow model has been simulated. The model has been simulated for 3 months, which is at the beginning from 01 January 2015 to March 2015 for calibration of the model. For the upstream boundary, the discharge data of Gorai Railway Bridge (SW-99) and for the downstream boundary the water level data of Charduani (SW-108) have been considered. The salinity data at (SW-108) Charduani is considered as the boundary condition in the downstream side. Figure 5.64 shows the Calibration of water quality (salinity) at Rayenda in Balaswar River for 2015.

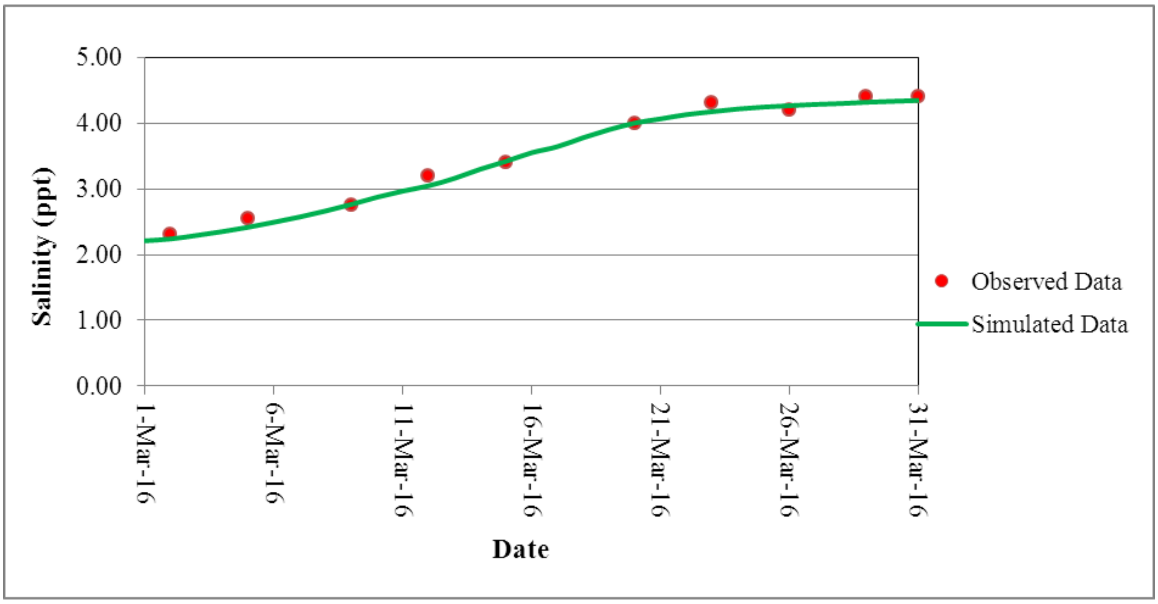


Figure 5.64: Calibration result of salinity at Rayenda in Balaswar River

In salinity simulation, the calibration parameter is the dispersion coefficient, D. The value of D varies from 1-1000 m^2/s at different location of the channel. The higher the value of D, it signifies that there is a significant amount of dispersion in the area. In this model simulation, the value of D has been adjusted through several trials. And after calibration, the values used at different locations have been kept unchanged for validation of the model for different locations. The value of D used to calibrate the model varies from $1m^2/s$ to $400m^2/s$.

(iv) Validation of the Salinity Model

The validation of the water quality (Salinity) model has been performed in same calibration location. The results are shown in Figure 5.65 provides a level of confidence of the established Gorai-Madhumati-Kaliganga-Balaswar River system.

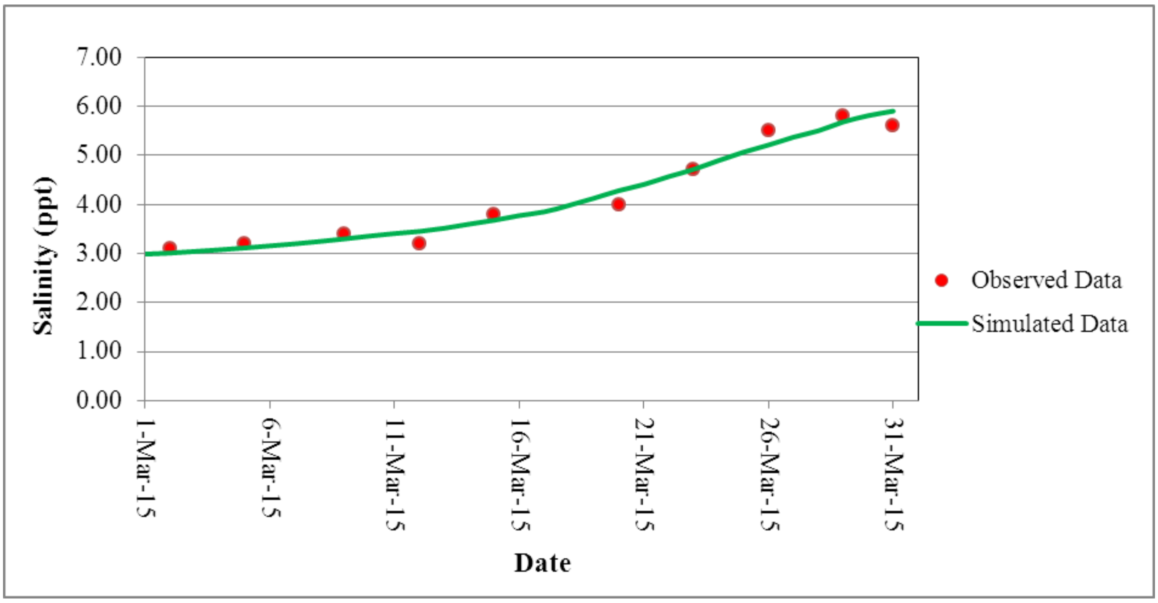


Figure 5.65: Validation of result of salinity at Rayenda in Balaswar River

5.12.10 Salinity Distribution based on the required e-flow

The salinity concentration obtained from the Salinity Modelling has been used to the required e-flow obtained from various methods. It is found that the salinity level of Gorai River based on required e-flow has been remained below around 0.20 ppt. The salinity level at downstream of Bordia location of Madhumati River from January to July based on required e-flow has been remained 0.3-1.80 ppt and from July to December has been remained below 1ppt but in the locations of Kamarkhali transit of the Madhumati River, Salinity level has been remained both dry and monsoon period has been remained below 0.25 ppt. The salinity level of Kaliganga River based on required e-flow from January to May based on required e-flow has been remained 0.75-2.0 ppt and from July to December has been remained below 1ppt. The salinity level of Balaswar River based on required e-flow from January to May based on required e-flow has been remained 1-2.5 ppt and from July to December has been remained below 1ppt. The daily salinity concentration graph of the Balaswar, Kaliganga, Madhumati and Gorai River at Section 72, 54, 44, 30, and 22 (Figure-4.9) is given in Figure 5.66 to 5.70 respectively.

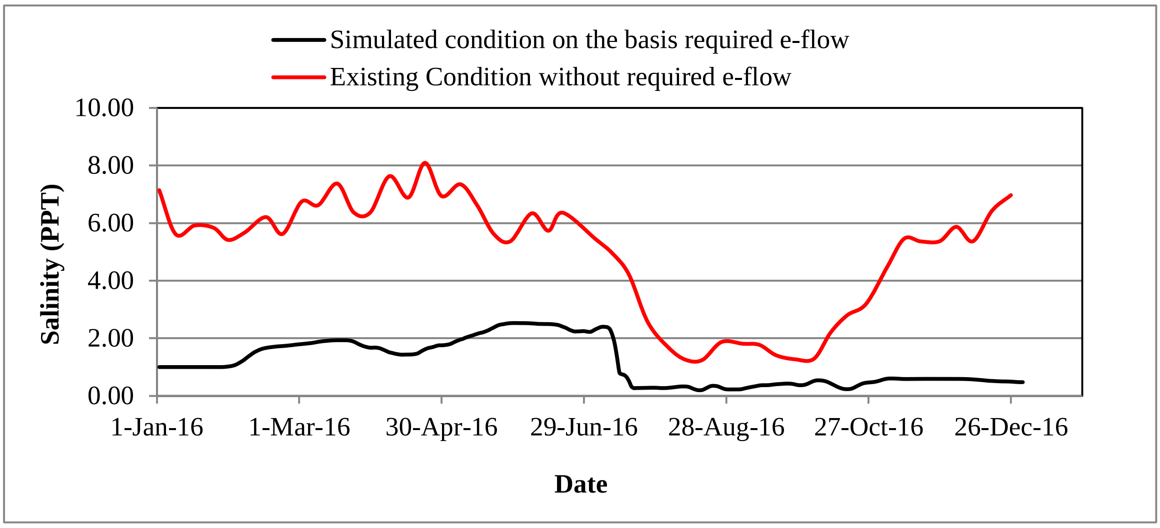


Figure 5.66: The daily Salinity concentration of Balaswar River based on required e-flow

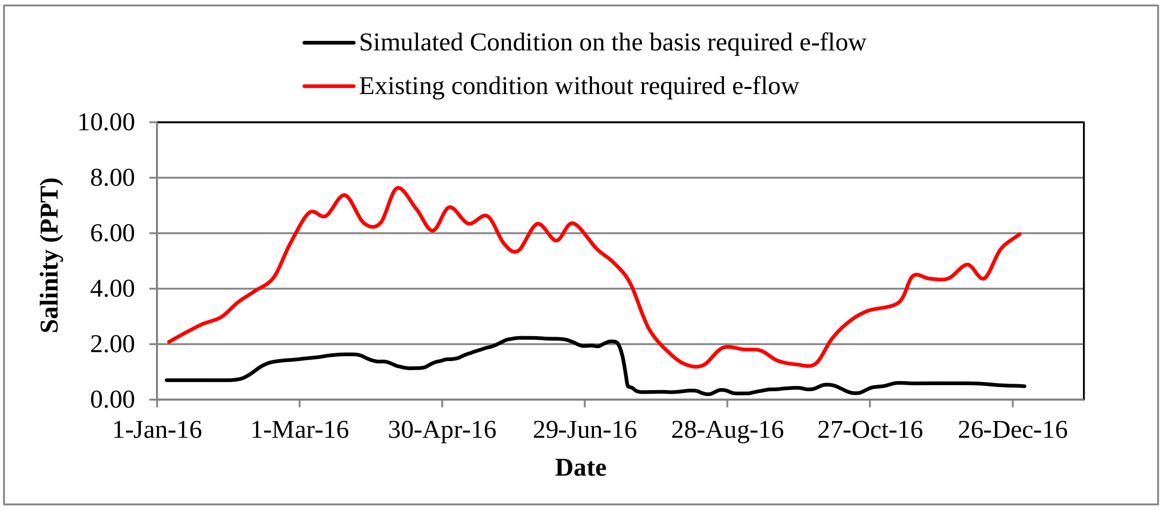


Figure 5.67: The daily Salinity concentration of Kaliganga River based on required e-flow

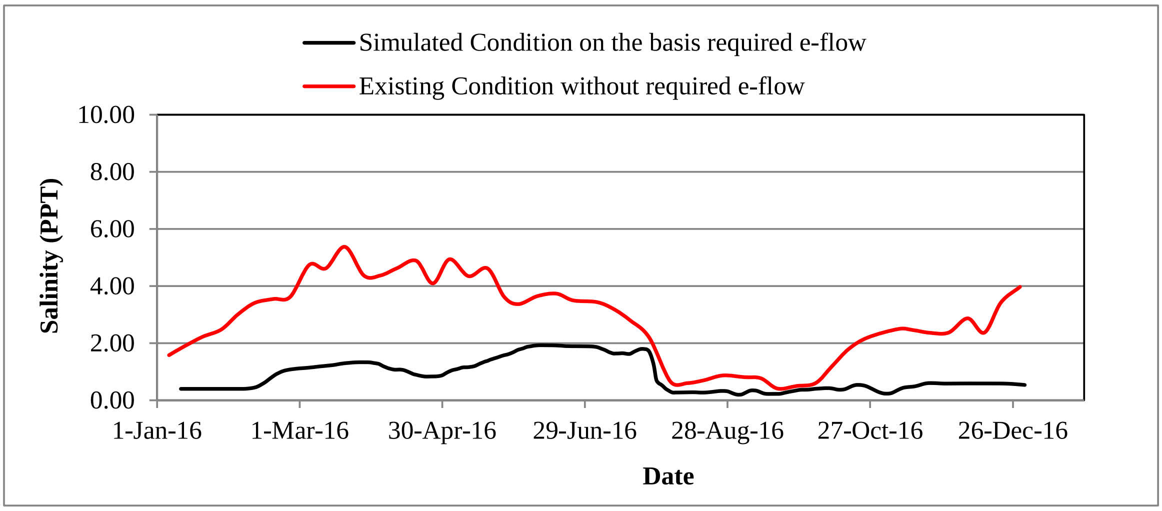


Figure 5.68: The daily Salinity concentration of Madhumati River based on required e-flow

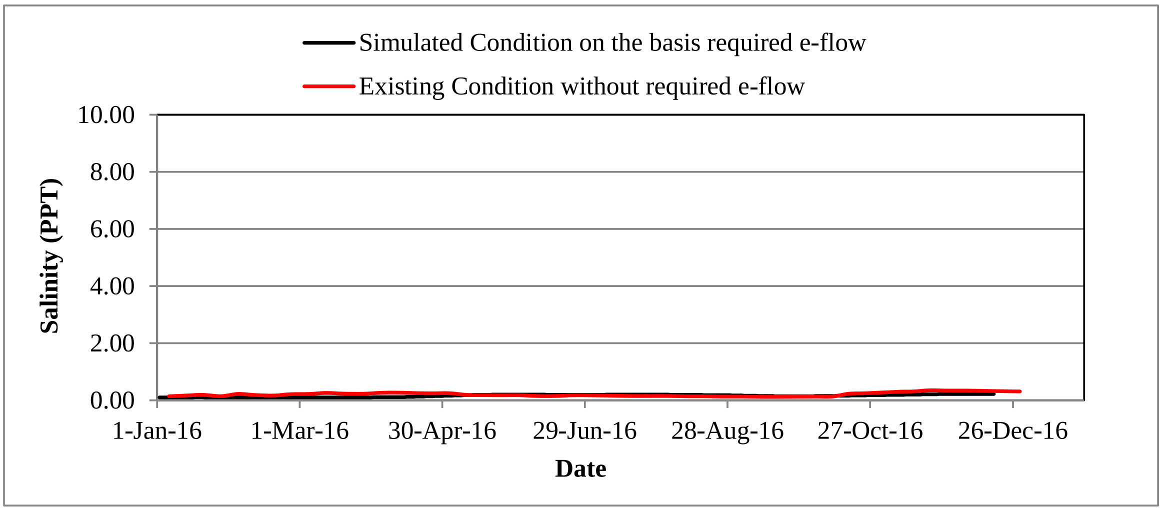


Figure 5.69: The daily Salinity concentration of Madhumati River based on required e-flow

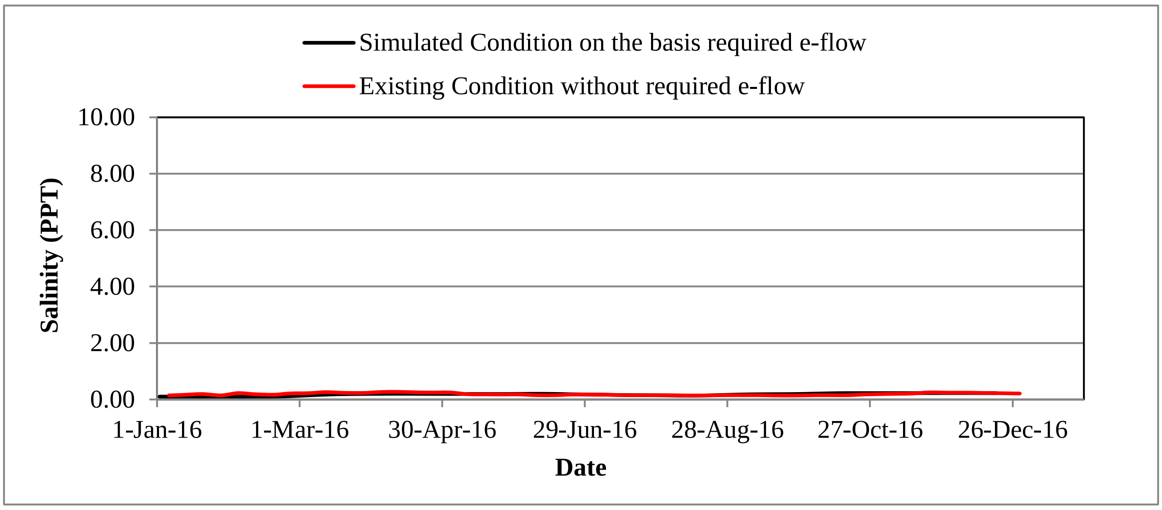


Figure 5.70: The daily Salinity concentration of Gorai River based on required e-flow

5.12.11 Comparison of Tolerate Salinity level for Fish Species with the Salinity level based on required e-flow

The observed salinity concentration of the Balaswar River is 5.5 to 8.2 ppt during dry period and simulated salinity concentration based on required e-flow has been remained 1.05 to 2.0 ppt. In that case the salinity tolerate limit of Golda is 2 ppt. It is observed that even though the salinity tolerate limit for Golda fish of Balaswar River based on required e-flow is satisfactory. The comparison of salinity concentration in between with simulated, observed and tolerate limit of Golda fish is shown in Figure 5.71.

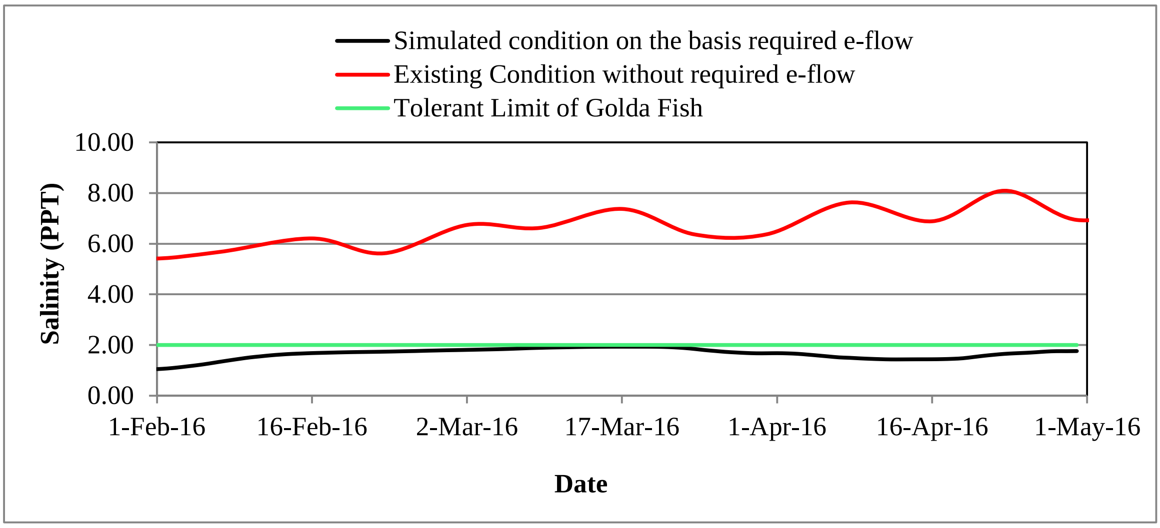


Figure 5.71: Comparison of Salinity concentration of Balaswar River for Golda fish

The existing salinity concentration of the Kaliganga River is 2.1 to 7.5 ppt during dry period and simulated salinity concentration based on required e-flow has been remained 0.70-1.63 ppt. In that case the salinity tolerate limit of Golda is 2 ppt. It is observed that even though the salinity tolerate limit for Golda fish of Kaliganga River based on required e-flow is satisfactory. The comparison of salinity concentration in between with simulated, observed and tolerate limit of Golda fish is shown in Figure 5.72.

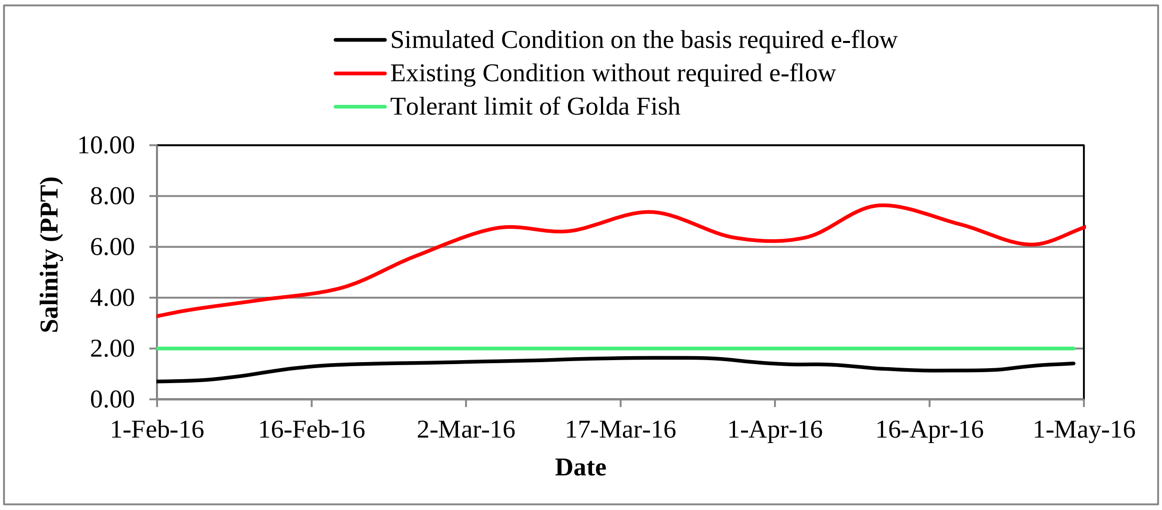


Figure 5.72: Comparison of salinity concentration of Kaliganga River for Golda fish

The existing and simulated salinity concentration of the Madhumati River is less than 0.25 ppt and otherwise tolerate limit of Golda and Carp fish is 2 and 0 ppt respectively. It is observed that even though the salinity tolerate limit for Golda and Carp fish of Madhumati River is so called satisfactory. The comparison of salinity concentration in between with simulated, observed and tolerate limit of Golda fish is shown in Figure 5.73 to 5.74.

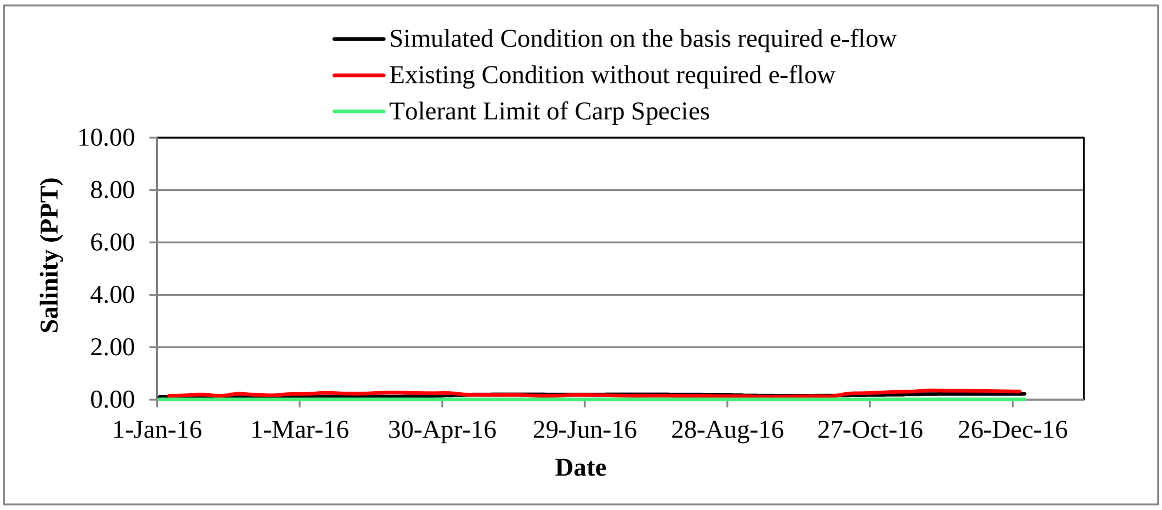


Figure 5.73: Comparison of salinity concentration of Madhumati River for Carp fish

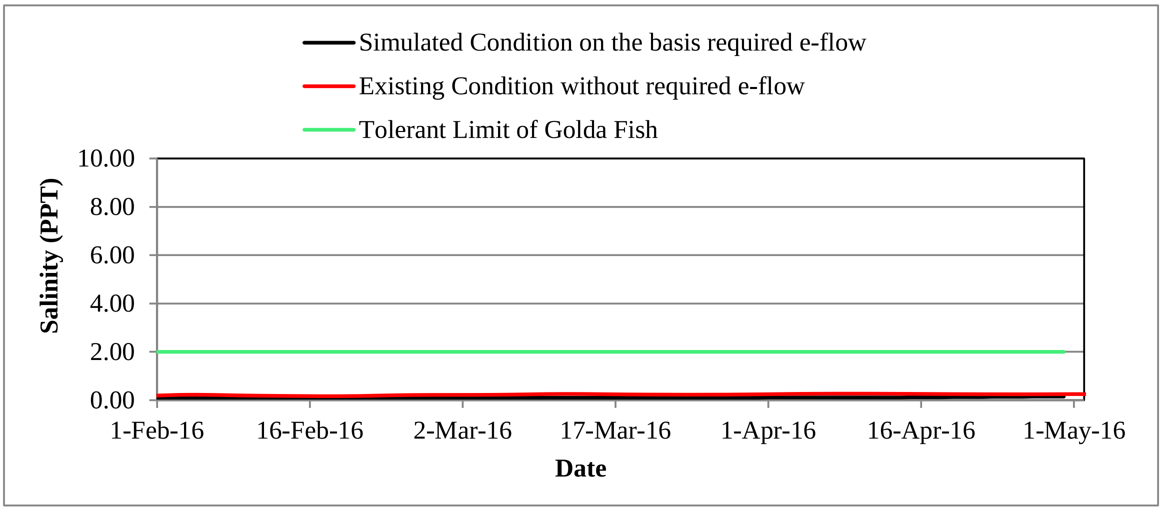


Figure 5.74: Comparison of salinity concentration of Madhumati River for Golda fish

The existing and simulated salinity concentration of the Gorai River is less than 0.20 ppt and otherwise tolerate limit of Bacha and Ayeer fish is 0 ppt. It is observed that even though the salinity tolerate limit for Ayeer and Bacha fish of Gorai River is so called satisfactory. The comparison of salinity concentration in between with simulated, observed and tolerate limit of Golda fish is shown in Figure 5.75 to 5.76.

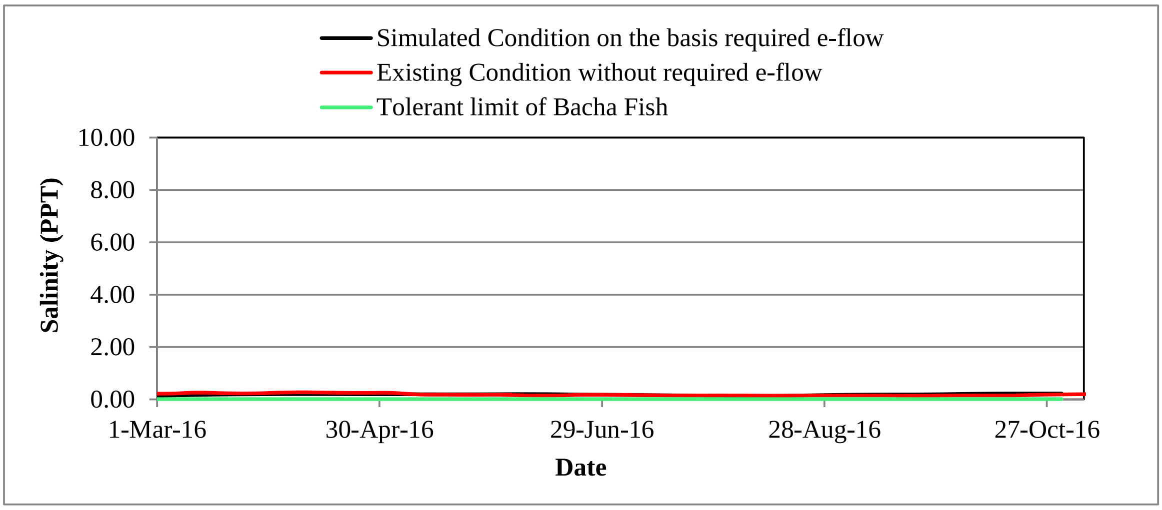


Figure 5.75: Comparison of salinity concentration of Gorai River for Bacha fish

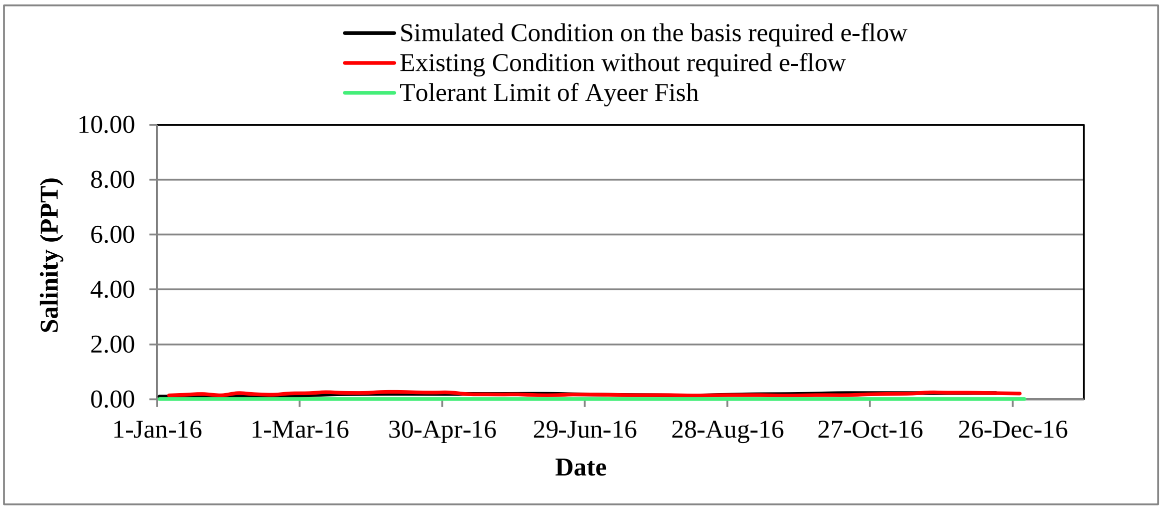


Figure 5.76: Comparison of salinity concentration of Gorai River for Ayeer fish

5.13 Summary

The e-flow assessment of Gorai-Madhumati-Kaliganga-Balaswar River System has been assessed by using the hydrological methods such as Tennant Method, Flow Duration Method (FDC), Constant Yield Method (CYM), Hydraulic rating method (Weighted Perimeter Method), Habitat simulation method (PHABSIM), Holistic Method (Building Block Methodology). As a result, Gorai and Madhumati River must be maintained the minimum computed e-flow during low flow season for keeping the sustainable ecosystem and Kaliganga and Balaswar River is so called satisfactory. The summary table of e-flow assessment by considering hydrological approaches and dominant fish requirement for Gorai, Madhumati, Kaliganga and Balaswar River is given below:

Table 5.36: Summary of e-flow (cumec) assessment of Gorai-Madhumati-Kaliganga-Balaswar River System

Month / River	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Gorai River	250	250	580	2555	5235	4580	2030	849	450	350	350	350
Madhumati River	400	400	400	400	400	400	400	400	400	400	300	300
Kaliganga River	1018	1101	1480	1610	1671	1598	1439	1257	1164	1164	1164	1058
Balaswar River	10671	10625	11930	12132	12694	13532	13232	12358	11950	9767	10971	10669

Moreover, undisturbed/ unregulated natural historical flow data have been required for the e-flow assessment of a river. Pre-Farakka historical flow data is not available of Madhumati, Kaliganga and Balaswar River. In this regards, Post Farakka historical flow data has been used for e-flow assessment of these river in this study.

CHAPTER 6
CONCLUSIONS AND RECOMENDATIONS

6.1 General

Environmental flow (e-flow) has become a central concern for river management in many parts of the world including Bangladesh since the middle of the 20th century. The term “environmental flow requirement” is often described as “minimum flow” in a river, or the “managed flood” and “river flow objective. Owing to the geographical location, rivers in Bangladesh have carried high discharge in monsoon and low discharge in dry season. Bangladesh is already facing problem due to construction of Farakka barrage on Ganges River which caused the Gorai River (main tributary of Ganges in Bangladesh) almost dried up during dry period. To maintain the aquatic life and salinity of river system it is important to analyze the e-flow as the Gorai River is only source of fresh water for south-west reason of Bangladesh. The purpose of this research is to assess the e-flow requirement of Gorai- Madhumati-Kaliganga-Balaswar River System for estimate actual e-flow requirement at Gorai offtake.

6.2 Conclusions of the Study

The methodology covers the hydrological methods such as Tennant Method, Flow Duration Method (FDC), Constant Yield Method (CYM), hydraulic rating method, Physical habitat simulation method (PHABSIM), Holistic Method (Building Block Methodology) and Salinity Modelling of the Gorai-Madhumati-Kaliganga-Balaswar River system. From the results of this study following conclusions are provided.

1. According to hydrological approaches, e-flow for Gorai at Gorai Railway Bridge for different method varies from 151 to 849 cumec for low flow season (November to May) and 580 to 5235cumec for high flow season. Considering the dominant fish species of Bacha and Ayeer in the Gorai River, physical habitat model simulates minimum requirement as 250 cumec during the month of January to December Cumec for Ayeer fish and March to October as 350 cumec for Bacha fish. In that case, Gorai River must be maintained the minimum computed e-flow during low flow season for keeping the sustainable ecosystem.

2. According to hydrological approaches, e-flow for Madhumati at Bordia for different method varies from 59 to 72 cumec for low flow season and 78 to 197 cumec for high flow season. Considering the dominant fish species of Golda and Carp in the Madhumati River, physical habitat model simulates minimum requirement as 300 cumec during the month of February to April for Golda fish and for Carp species minimum requirement as 400 cumec during of January to December except February to March. In that case, Madhumati River must be maintained the minimum computed e-flow during January to December for keeping the sustainable ecosystem.

3. According to hydrological approaches, e-flow for Kaliganga at Pirojpur Sadar for different method varies from 1018 to 1257 cumec for low flow season and 1439 to 1671 cumec for high flow season. Considering the dominant fish species of Golda in the Kaliganga River, Holistic Method (BBM) minimum requirement as 880 to 991 cumec during the month of February to April cumec for Golda fish. It is observed that even though the flow demand for considering hydrological approaches and dominant fish requirement in Kaliganga River is so called satisfactory.

4. According to hydrological approaches, e-flow for Balaswar at Charduani for different method varies from 9768 to 12358 cumec for low flow season and 11930 to 13700 cumec for high flow season. Considering the dominant fish species of Golda in the Balaswar River, Holistic method (BBM) minimum requirement as 10669 to 10678 cumec during the month of February to April cumec for Golda fish. It is observed that even though the flow demand for considering hydrological approaches and dominant fish requirement in Balaswar River is so called satisfactory.

5. The existing salinity condition of Gorai and Madhumati River (up to Kamarkhali Bridge) has remained below 0.20 and 0.25 ppt respectively and our salinity level based on required flow has been remaining the near to same. But Madhumati (downstream to Kamarkhali Bridge), Kaliganga and Balaswar River existing salinity condition has been from January to June remained 1.2-5.2 ppt, 2.1-7.5 ppt

and 5.5 to 8.2 ppt respectively and July to December 0.75-4 ppt, 1.2-6 ppt and 1.2-7 ppt. The salinity level based on required e-flow of Madhumati, Kaliganga and Balaswar River from January to May has been remained around 0.3-1.80 ppt, 0.75-2.0 ppt and 1-2.5 ppt respectively and also from July to December has been remained below 1ppt.

6.3 Recommendations for future studies

Some recommendations for future study can be made after this study. The recommendations are as below:

1. Only few indicators have been considered for this study. Steps may be made to consider other dependent indicator in future studies.

2. Offtake management is very important to divert the flow from Ganges to Gorai River. Based on present river condition, this study recommends further detailed study on offtake management to determine the best possible management option of Gorai offtake. In addition, a Silt trap or a hydraulic structure could be constructed for reducing the siltation at the Gorai offtake during dry period.

3. Availability of sufficient/more field/measured data enhances the confidence level of any investigation. As such it is suggested to develop and follow a systematic data collection program.

4. Depth and velocity of habitat suitability criteria have an enormous influence on e-flow assessment, so extensive research plan may be useful in developing the criteria.

REFERENCES

1 Acreman, M. and Dunbar, M. J. (2004). Defining environmental river flow requirements–a review. Hydrology and Earth System Sciences, 8 (5), 861–876.

2 Acreman, M. C. et al. (2000). Managed flood released from reservoirs: issues and guidance. Wallingford, UK: Centre for Ecology and Hydrology, Report to DFID and the World Commission on Dams.

3 Akter, A. and Ali, M. H. (2012). Environmental flow requirements assessment in the Halda River, Bangladesh, Hydrological Sciences Journal, Vol: 57:2, PP. 326-343.

4 Akter, J. (2010). Environmental Flow Assessment for the Ganges River. M Sc Engg. Thesis, Dept. of water Resources Engineering, BUET.

5 Bari, M. F. and Marchand, M. (2006). Introducing Environmental Flow Assessment in Bangladesh: Multidisciplinary Collaborative Research, BUET-DUT linkage project, Phase-III. pp. 127.

6 Beecher, H. A. (1990). Standards for instream flow, River, 1, 97-109.

7 Bovee, K.D., and Milhous., R. T., 1978. Hydraulic simulation in instream flow studies: Theory and Techniques. Instream Flow Information Paper 5. U.S Fish and Wildlife Service FWS/OBS-78/33. 130 pp.

8 Bovee, K. D. (1982). A guide to stream habitat analysis using the Instream Flow incremental Methodology. Instream Flow Information Paper 12. FWS/OBS-82/26. U.S.D.I. Fish. Wildl. Serv., Office of Biol. Serv. pp. 248.

9 Bovee, K. D. (1982). A guide to stream habitat analysis using the IFIM. – US Fish and Wildlife Service Report FWS/OBS-82/26. Fort Collins.

10 Bruwer, C. (1991). Flow Requirements of Kruger National Park Rivers. Department of Water Affairs and Forestry, Technical Report TR149. Department of Water Affairs and Forestry.

11 Bullock, A., Gustard, A. and Grainger, E. S. (1991). Instream flow requirements of aquatic ecology in two British rivers. Application and assessment of the Instream Flow Incremental Methodology using the PHABSIM system. Report No. 115. Institute of Hydrology, Wallingford.

12 BUET (2017). Environmental Flow (E-flow) Assessment of Gorai River, Gorai Restoration Project (Phase II), Final Report, Bangladesh Water Development Board, Government of Bangladesh.

13 Chowdhury, M. S. M., Khan, G., Nishat, A., Rahman, R. and Amin, R. (2005). Assessment of the minimum environmental flow in Bakkhali river, Cox'sBazar, IUCN/UNEP, Report of Dept. of DOE.

14 DFID (2003). Handbook for the Assessment of Catchment Water Demand and Use, Department for International Development (DFID) of the UK Government under the Knowledge and Research (KAR) programme pp. 29-38.

15 Dunbar, M. J., Gustard, A., Acreman, M. C. and Elliott, C. R. N. (1998). Review of overseas approaches to setting river flow objectives. Environment Agency RandD Technical Report W6B (96)4. Institute of Hydrology, Wallingford, United Kingdom. pp. 61.

16 Dyson, M., Bergkamp, G. and Scanlon, J. (2003). Flow: Essentials of environmental flow. Gland, Switzerland and Cambridge, UK: IUCN – the International Union for Conservation of Nature.

17 EGIS (2000). Environmental baseline of Gorai river restoration Project, EGIS II, Bangladesh water development board, Ministry of water resources, Government of Bangladesh, Delft, the Netherlands.

18 FAP 4 (1993a). Southwest area water resources management project, vol.3, Morphological studies. Sir William Halcrow and Partners Ltd., Dhaka, 104pp.

19 FAP 4 (1993b). Southwest area water resources management project, vol.9, Impact studies. Sir William Halcrow and Partners Ltd., Dhaka, 1-41pp.

20 Gordon, N. D., McMahon, T. A., and Finlayson, B. L. (1992). Stream Hydrology, An introduction for Ecologists, John Wiley & Sons, Ltd., Chichester.

21 Gopal, B. (2013). Methodologies for the assessment of environmental flows, Chapter 06, pp. 129-182

22 Hanif M. A., Siddik, M. A. B., Nahar A., Chaklader, M. R., Rumpa R. J., and Mahmud, S. (2016). The current status of small indigenous fish species (SIS) of river Gorai, a distributary of the river Ganges, Bangladesh. Journal of Biodiversity and Endangered species, volume 4, issue 2.

23 Hossain, M. M. and Hossain, M. J. (2011). Instream Flow Requirement of Dudhkumar River in Bangladesh. Asian Transactions on Engineering Vol: 01, pp. 2221-4267.

24 Hughes, D. A. (1999). Towards the incorporation of magnitude-frequency concepts into the Building Block Methodology used for quantifying ecological flow requirements of South African rivers. Water SA 25(3).pp. 279-284.

25 Chowdhury, M. S. M., Khan. G., Nishat, A., Rahman, R. and Amin, R. (2005). Assessment of the minimum environmental flow in Bakkhali river, Cox‘sBazar, IUCN/UNEP.

26 Johnson, I.W., Elliot, C.R.N., Gustard, A., and Newman, A.T. (1992). River Allen instream flow requirements, proc. Of British hydrological Society Fourth National Hydrological Symposium, BHS, Cardiff, 5.15-5.21.

27 Jowett, I. G. (1997). Instream flow methods: a comparison of approaches regulated rivers: research & management, VOL. 13, pp. 115–127.

28 Jowett, I. G. (1998). Hydraulic geometry of New Zealand Rivers and its use as a preliminary method of habitat assessment. Regulated Rivers: Research and Management, 14, pp. 451–466.

29 Brown, C. and King, J. (2003). Environmental Flow Assessment: Concepts and Methods. Water Resources and Environment, Technical Note C.1., World Bank, Washington D.C.

30 King, J.M. and O'keeffe, J.H. (1989). Looking to the future - South Africa's requirements. In: Ferrar, A.A. (ed.). Ecological Flow Requirements for South African Rivers. S. Afr. Nat. Sci. Prog. Rep. No. 162. Foundation for Research Development, CSIR, Pretoria. pp. 118.

31 King, J. M. and Tharme, R. E. (1994). Assessment of the Instream Flow Incremental Methodology and initial development of alternative instream flow methodologies for South Africa. Water Research Commission Report No. 295/1/94. Water Research Commission, Pretoria pp. 590.

32 King, J. M. (1996). Quantifying the amount of water required for aquatic ecosystems. Water law review. Discussion document for policy development. Report for the Department of Water Affairs and Forestry. August 1996. Freshwater Research Unit, University of Cape Town, Cape Town, pp.31.

33 King, J., Tharme, R., and Brown, C. (1999) Definition and Implementation of Instream Flows Cape Town. World Commission on Dams WCD Thematic Report Environmental Issues II.1

34 King, J M., Tharme, R.E., and de Villiers, D.E. (2000). Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology, Freshwater Research Univ, University of Cape Town, WRE Report No. TT 131/00, 339 pp.

35 Locke, A. G. H. (1996). Recommending variable flow values for fish.

36 MESC (2001). PHABSIM for Windows, User's Manual and Exercises, Open File Report 01-340.

37 Milhous, R. T., M. A. Updike, and D. M. Schneider, (1989). Physical Habitat Simulation System Reference Manual – Version II. Instream Flow Information Paper No. 26. U.S. Fish and Wildlife Service Biological Report 89(16). v.p.

38 Moly, S. H, Rahman, M.A.T.M.T and Sadat, A. H. M. (2015). Environmental flow characteristics of the Gorai River, Bangladesh. International Journal of Scientific Research in Environmental Sciences, 3(6), pp. 0208-0218.

39 Mosley, M. P., 1983, Flow requirements for recreation and wildlife in New Zealand rivers - a review. Journal of Hydrology (N.Z.) 22(2) 152-174.

40 MPO, (1991). National Water Plan Project Ph-II, National Water Plan, Vol-I, Ministry of Irrigation, Water Development and Flood Control, GoB, June.

41 Mullick, R. A., Babel, M. S., and Perret, S. R. (2010). Flow characteristics and environmental flow requirements for the Teesta River, Bangladesh. Proc. of International Conference on Environmental Aspects of Bangladesh (ICEAB10), Japan

42 Norris, R.H. and Thoms, M.C. (1999). What is river health? Freshwater Biology, 41 (2), 197–209.

43 Peirson, W L, Bishop, K, Van Senden, D, Horton, P Rand Adamantidis, C A. (2002). Technical Report Number 3, Environment Australia.

44 Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., Sparks, R. E. and Stromberg, J. C. (1997). The natural flow regime. Bioscience 47, pp. 769-784.

45 Rahman, M. A. (1998). A hydrologic determination of instream flow requirement of the Ganges River, M.Sc. thesis, Department Water Resources Engineering, Bangladesh University of Engineering and Technology

46 Reiser, D. W., Wesche, T. A. and Estes, C. (1989b). Status of instream flow legislation and practise in North America. Fisheries 14(2).pp. 22-29.

47 Reiser, D. W., Wesche, T. A. (1989). Status of instream flow legislation and practise in North America. Fisheries 14, 22-29.

48 Richter, B. D., Baumgartner, J. V., Wigington, R. and Braun, D. P. (1997). How much water does a river need? Freshwater Biology 37, 1, pp. 231-249

49 Richter, B. D., Baumgartner, J. V., Powell, J. and Braun, D. P. (1996). A method for assessing hydrological alteration within ecosystems. Conservation Biology 10(4), pp. 1163-1174

50 Saha, P. P. (2007). An Assessment of Instream Flow Requirement of Gorai River Considering Salinity Intrusion and Fish Habitat. M Sc Engg. Thesis, Dept. of water Resources Engineering, BUET.

51 Stalnaker, C., Lamb, B. L., Henriksen, J., Bovee, K., and Bartholow, J. (1995). The Instream Flow Incremental methodology, A Prime for IFIM, Boilogical Report 29, Natinal Biological Services, U.S. Department of Interior, Washington, D.C. March, pp 46

52 Pal, S. K., Hoque, A. and Tarannum, I. (2009). Approach to Assess Environmental Flow for the Karnaphuli River of Bangladesh. 2nd International Conference on Water and Flood Management, Vol-I, Dhaka, Bangladesh. March.

53 Tennant, D. L. (1976). Instream Flow Regimes for fish, wildlife, recreation and related environmental resources. Fisheries, 1, pp. 6-10.

54 Tharme, R. (2002). A global perspective on environmental flow assessment:emerging trends in the development and application of environmental flow methodologies for rivers. In: Conference Proceedings 4th Ecohydraulics Conference 'Enviro Flows 2002. March 3-8, 2002, Cape Town, South Africa.

55 Tharme, R. E. (2003). A Global Perspective on Environmental Flow Assessment:Emerging Trends in the Development and Application of Environmental Flow Methodologies for Rivers. River Research and Applications 19, pp. 397-441.

56 USGS (2001). PHABSIM software user manual and exercise midcontinent ecological science center, pp. 1-340.

57 WRI (2002). World Resources Institute. http://www.wri.org/

58 Wesche, T. A., Hasfurther, V.R., Hubert, W.A. and Skinner, Q.D. (1987). Assessment of flushing flow recommendations in a steep, rough, regulated tributary. In: Craig, J.F. and Kemper, J.B. (eds). Regulated streams: advances in ecology. Plenum Press, New York and London.

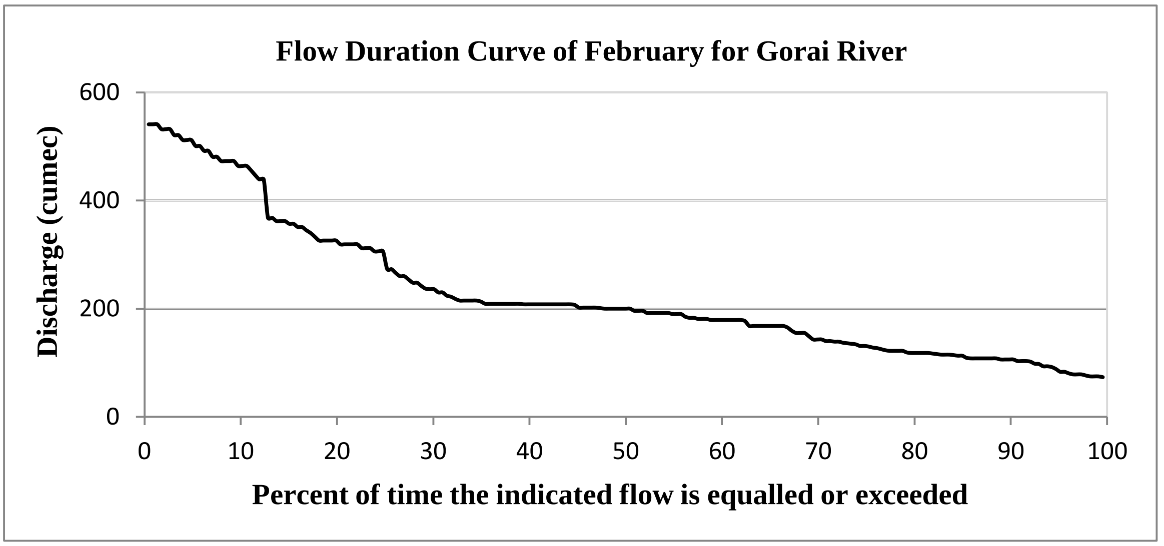
59 World Bank. (2003). Environmental Flows: Case studies, Water resources and Environment, technical note c.2.

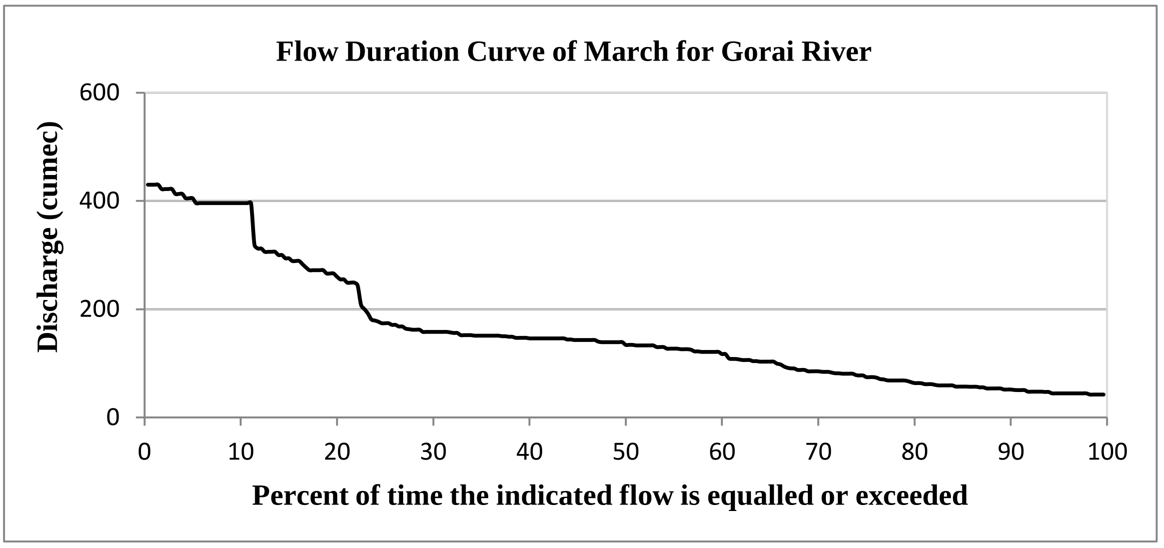
60 Zobayer, H. (2004). Application of Physical Habitat simulation approach for instream flow requirement in the Surma River, M.Sc. Thesis, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology

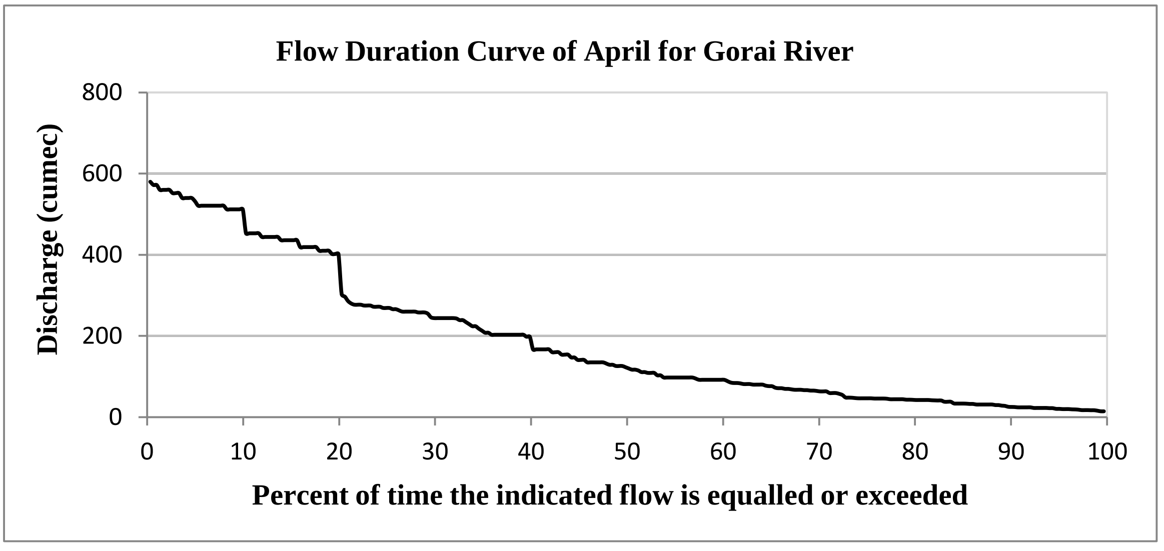
APPENDIX-A

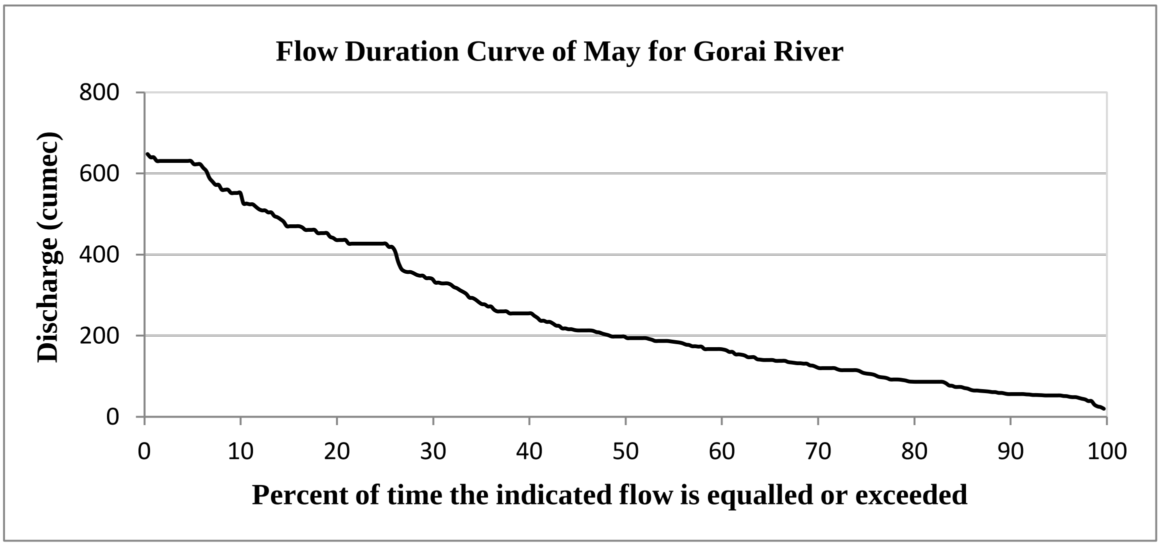
Monthly Flow Duration Curve of Gorai, Madhumati, Kaliganga and Balaswar River

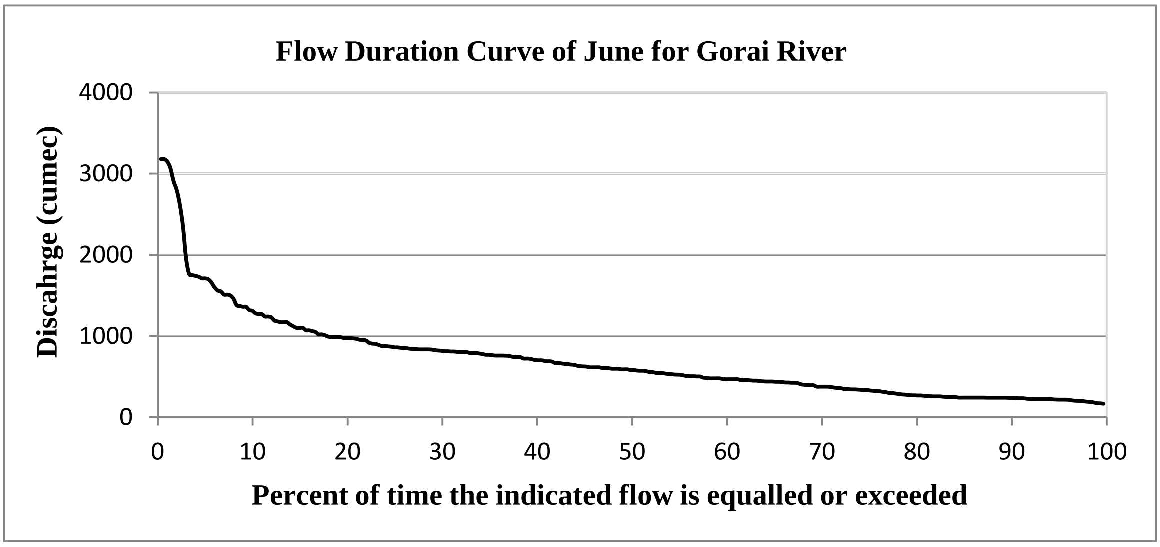
APPENDIX-A

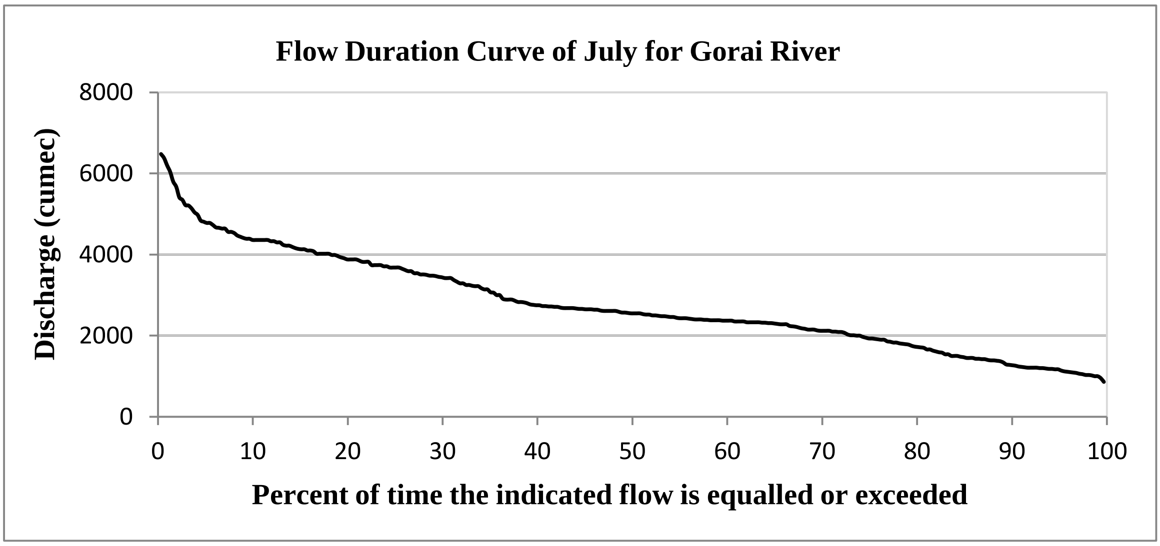

Flow Duration Curve of February for Gorai River
600
400
200
0
Discharge (cumec)
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

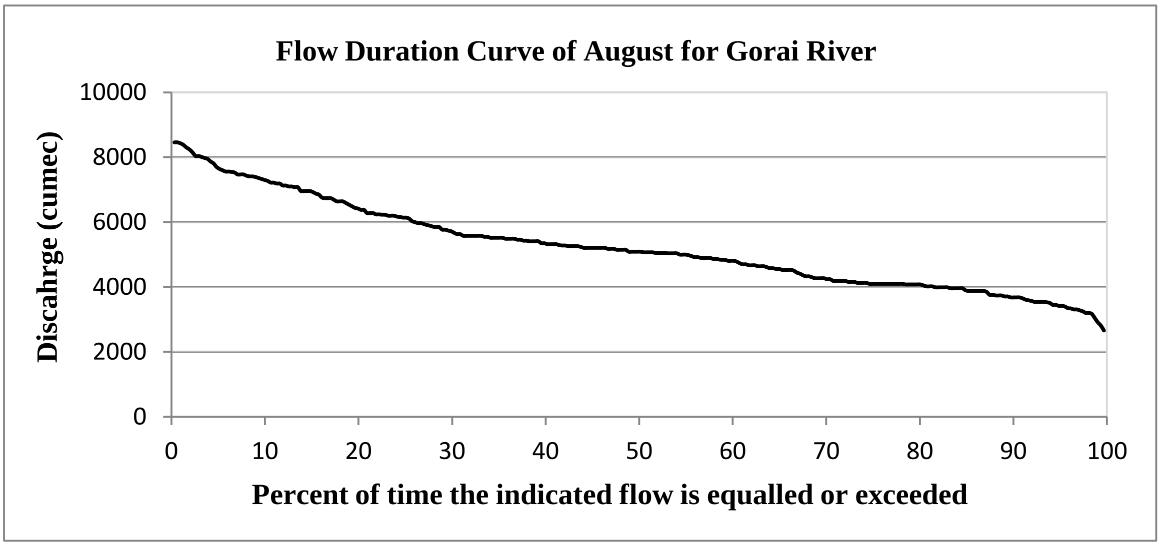

Flow Duration Curve of March for Gorai River
600
400
200
0
Discharge (cumec)
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

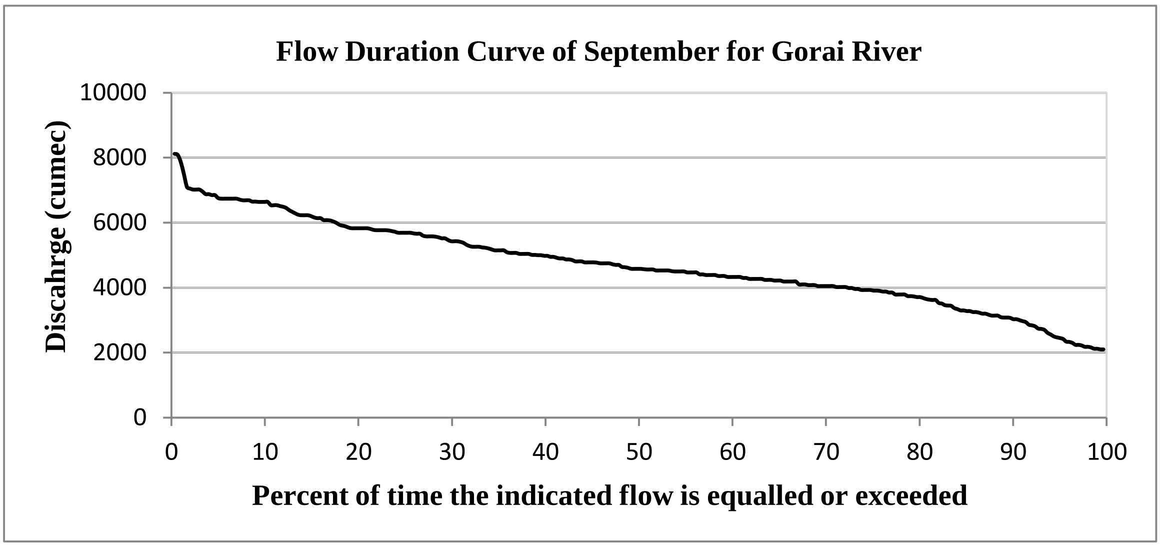

Flow Duration Curve of April for Gorai River
800
600
400
200
0
Discharge (cumec)
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

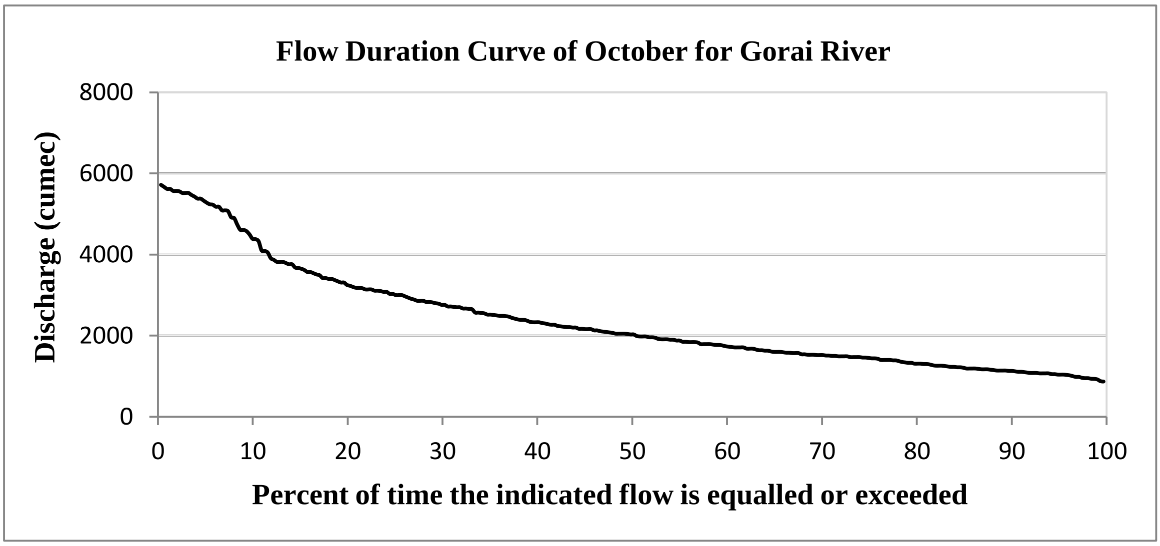

Flow Duration Curve of May for Gorai River
Discharge (cumec)
800
600
400
200
0
0 10 20 30 40 50 60 70 80 90 100
Percent of time the indicated flow is equalled or exceeded

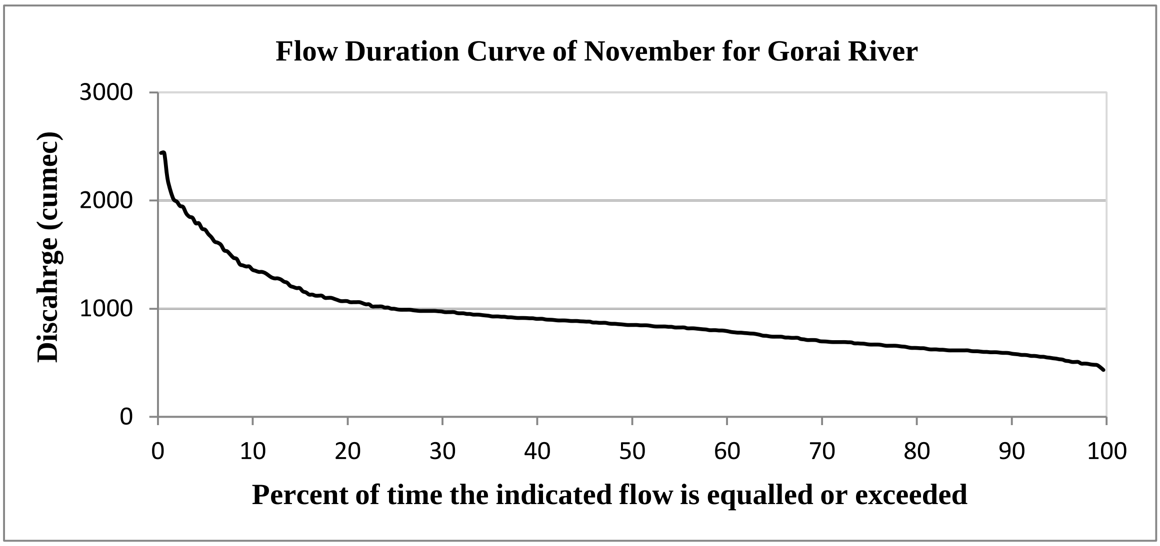

Flow Duration Curve of June for Gorai River
Discahrge (cumec)
4000
3000
2000
1000
0
0 10 20 30 40 50 60 70 80 90 100
Percent of time the indicated flow is equalled or exceeded

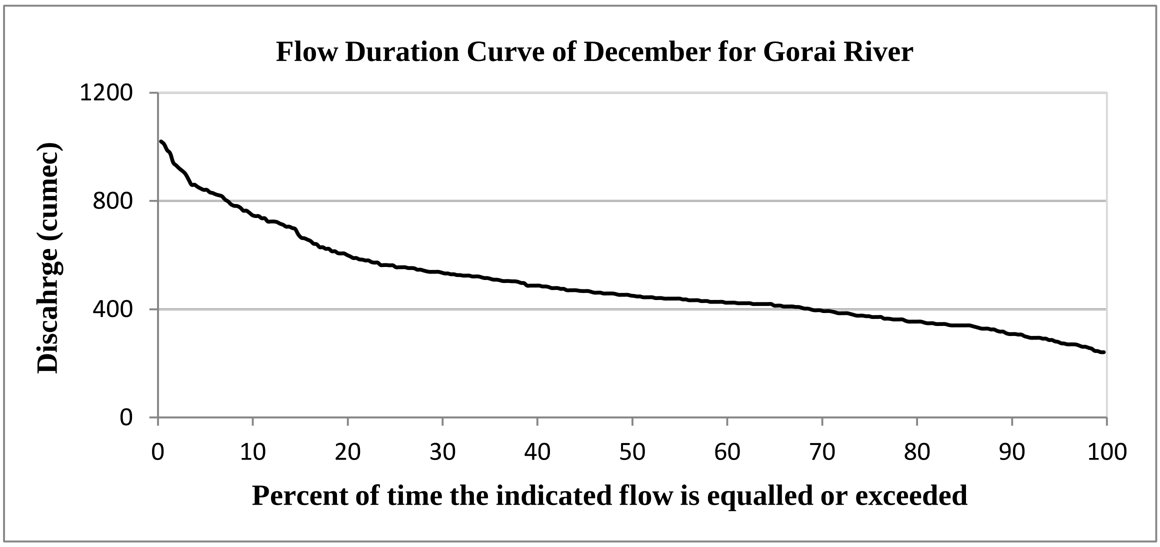

Flow Duration Curve of July for Gorai River
Discharge (cumec)
8000
6000
4000
2000
0
0 10 20 30 40 50 60 70 80 90 100
Percent of time the indicated flow is equalled or exceeded

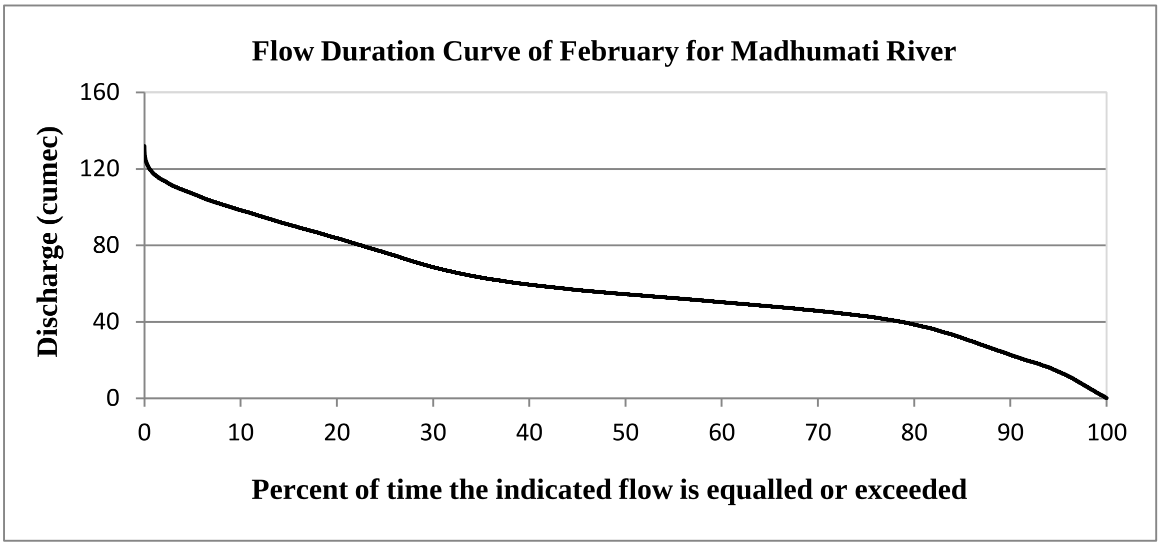

Flow Duration Curve of August for Gorai River
Discahrge (cumec)
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

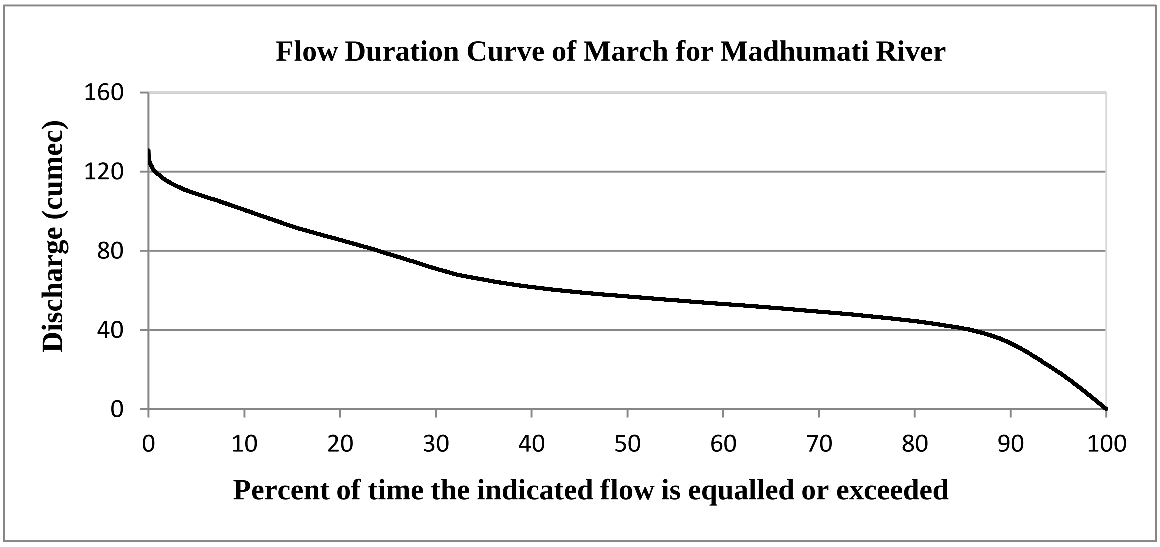

Flow Duration Curve of September for Gorai River
Discahrge (cumec)
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

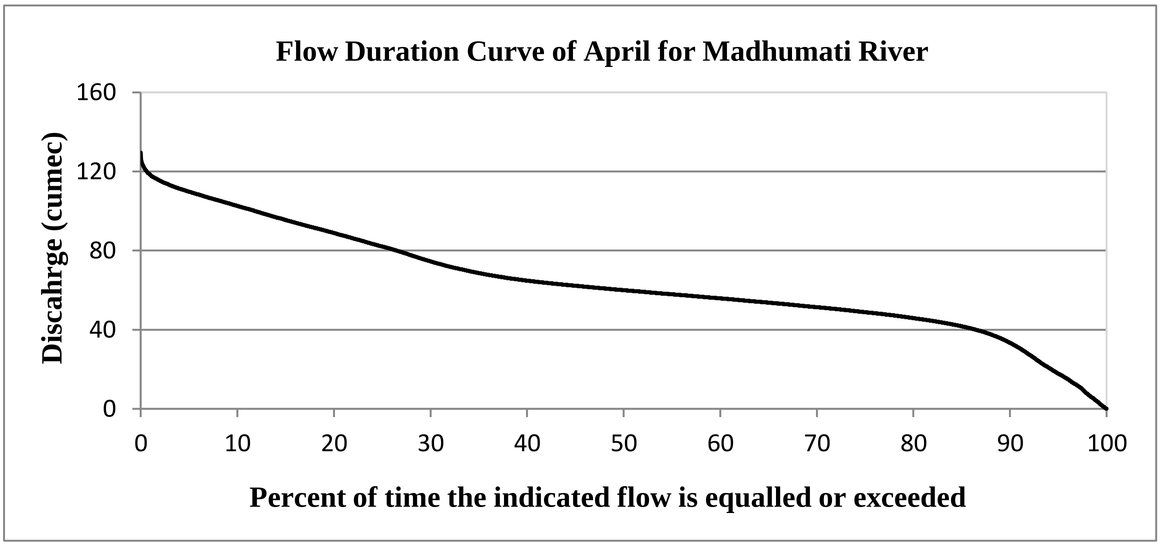

Flow Duration Curve of October for Gorai River
Discharge (cumec)
8000
6000
4000
2000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

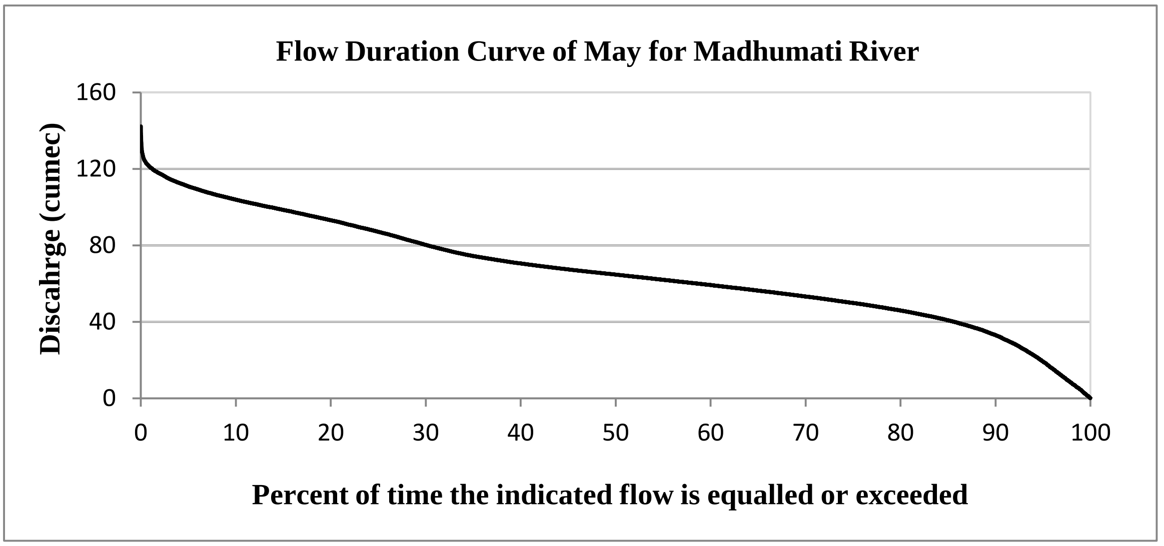

Flow Duration Curve of November for Gorai River
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
100
Discahrge (cumec)
Percent of time the indicated flow is equalled or exceeded

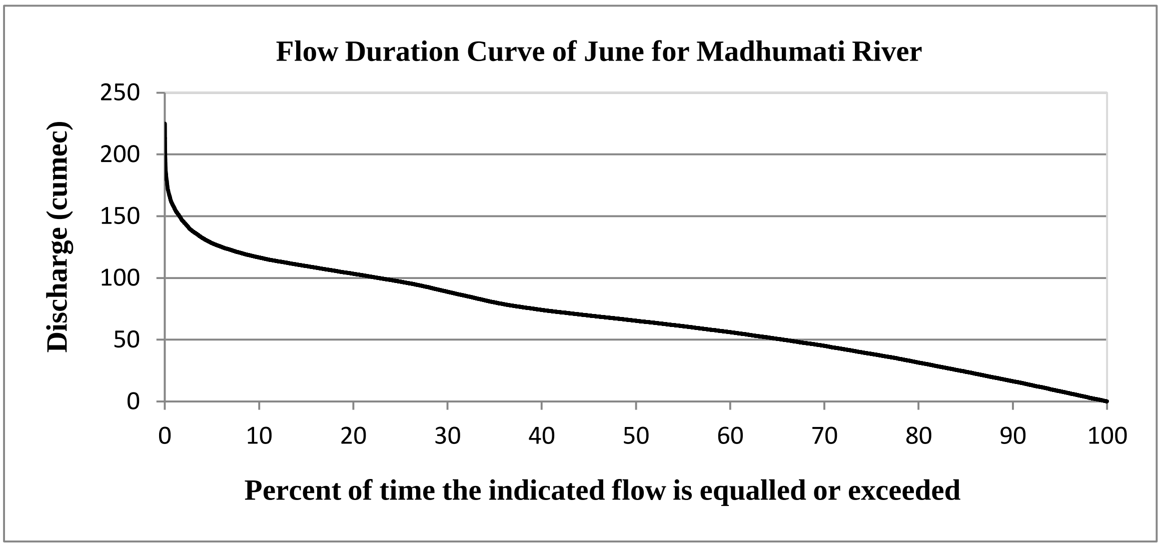

Flow Duration Curve of December for Gorai River
1200
800
400
0
0
10
20
30
40
50
60
70
80
90
100
Discahrge (cumec)
Percent of time the indicated flow is equalled or exceeded

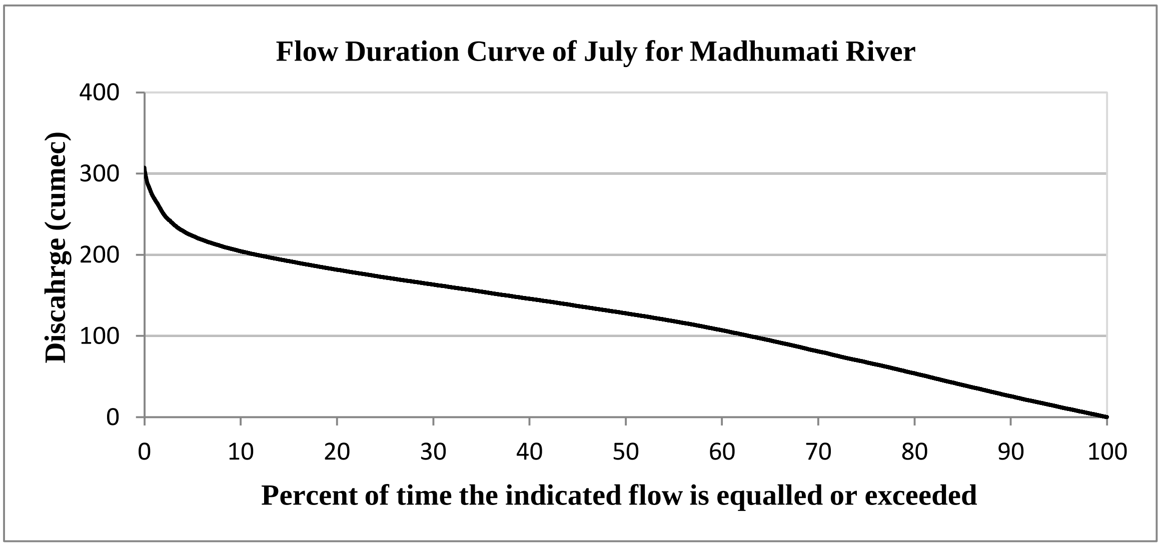

Flow Duration Curve of February for Madhumati River
Discharge (cumec)
160
120
80
40
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

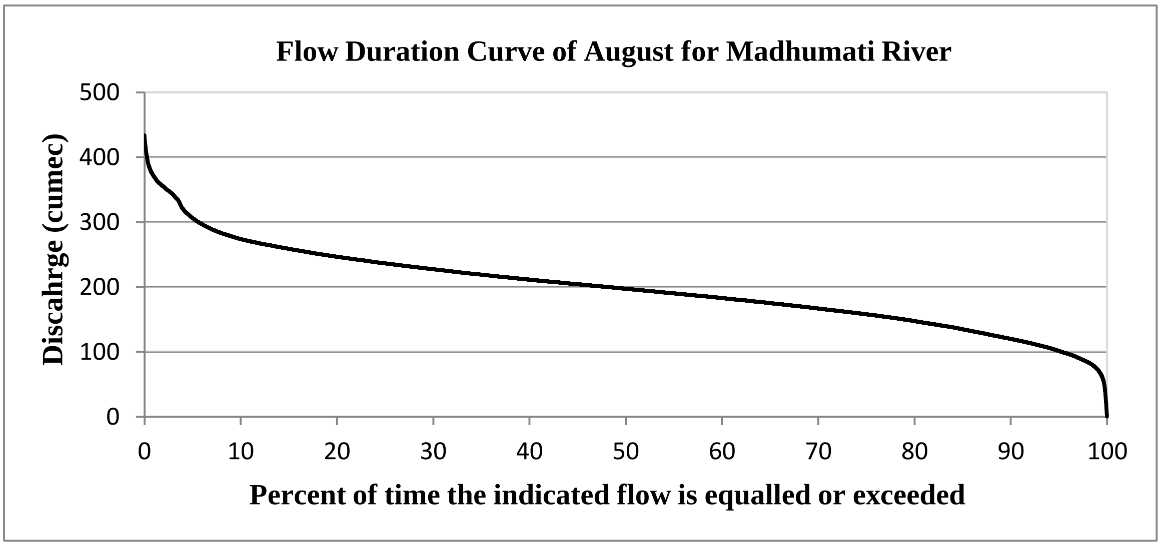

Flow Duration Curve of March for Madhumati River
Discharge (cumec)
160
120
80
40
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

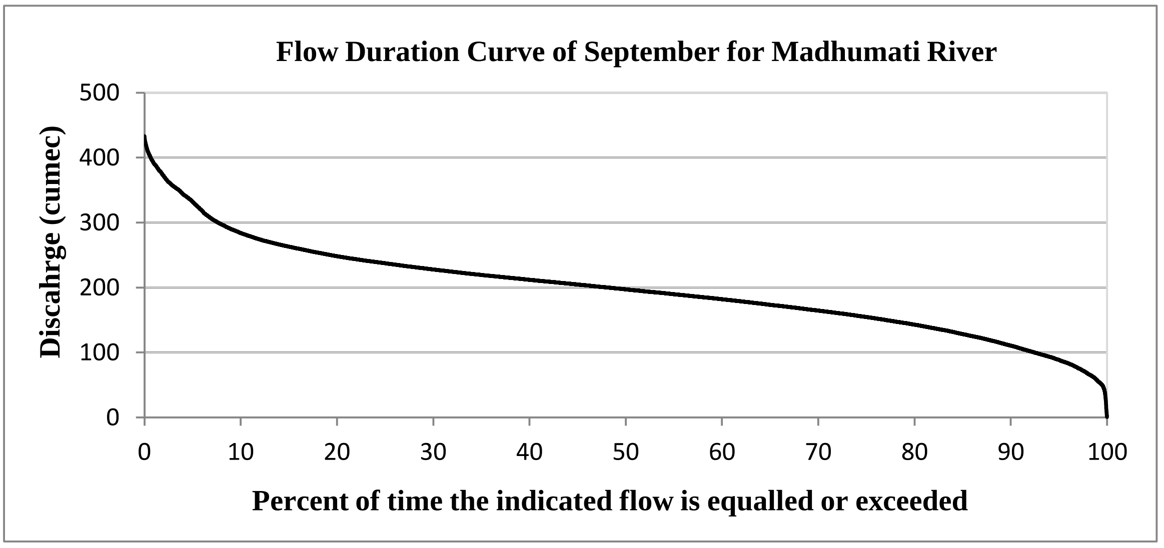

Flow Duration Curve of April for Madhumati River
Discahrge (cumec)
160
120
80
40
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

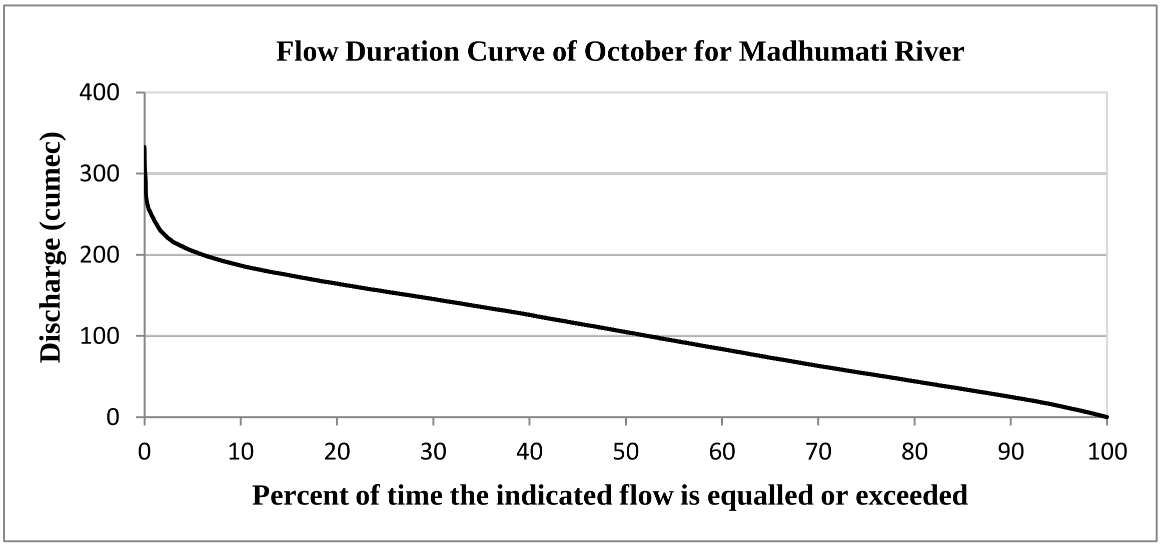

Flow Duration Curve of May for Madhumati River
Discahrge (cumec)
0
40
80
120
160
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

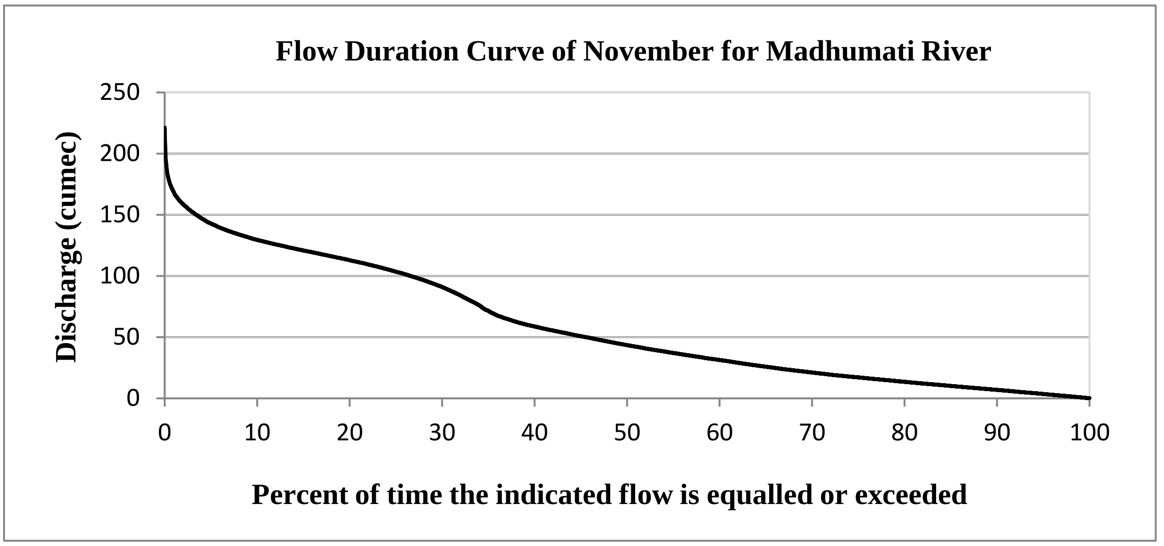

Flow Duration Curve of June for Madhumati River
Discharge (cumec)
0
50
100
150
200
250
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

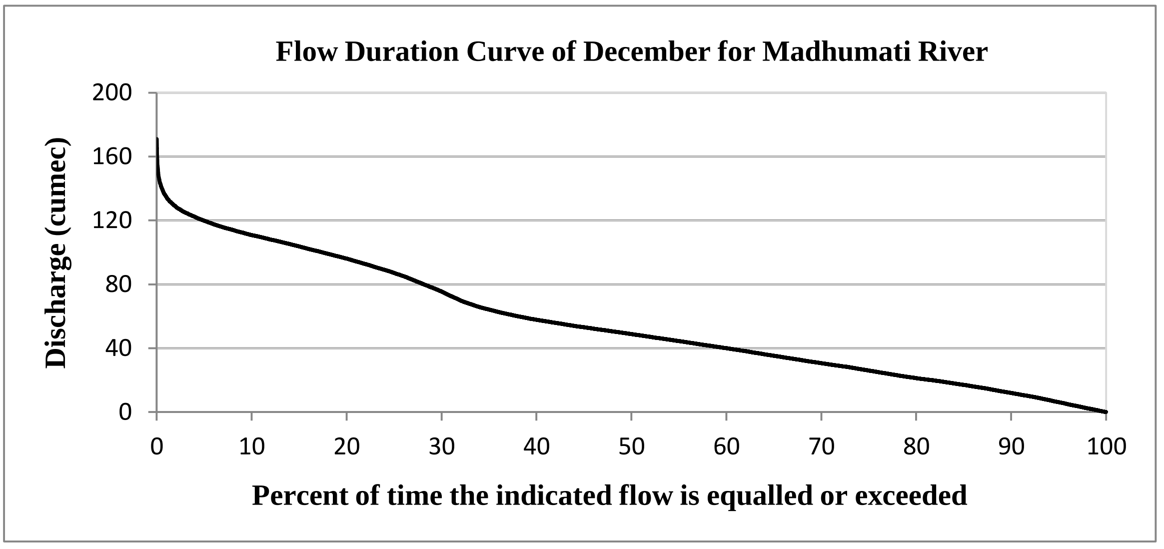

Flow Duration Curve of July for Madhumati River
Discahrge (cumec)
0
100
200
300
400
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

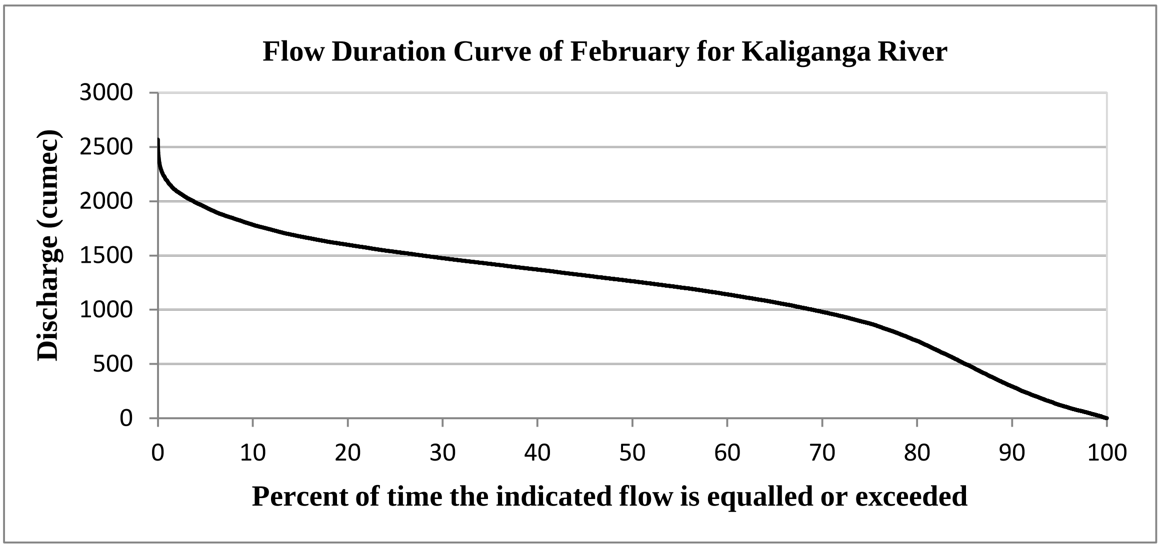

Flow Duration Curve of August for Madhumati River
Discahrge (cumec)
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

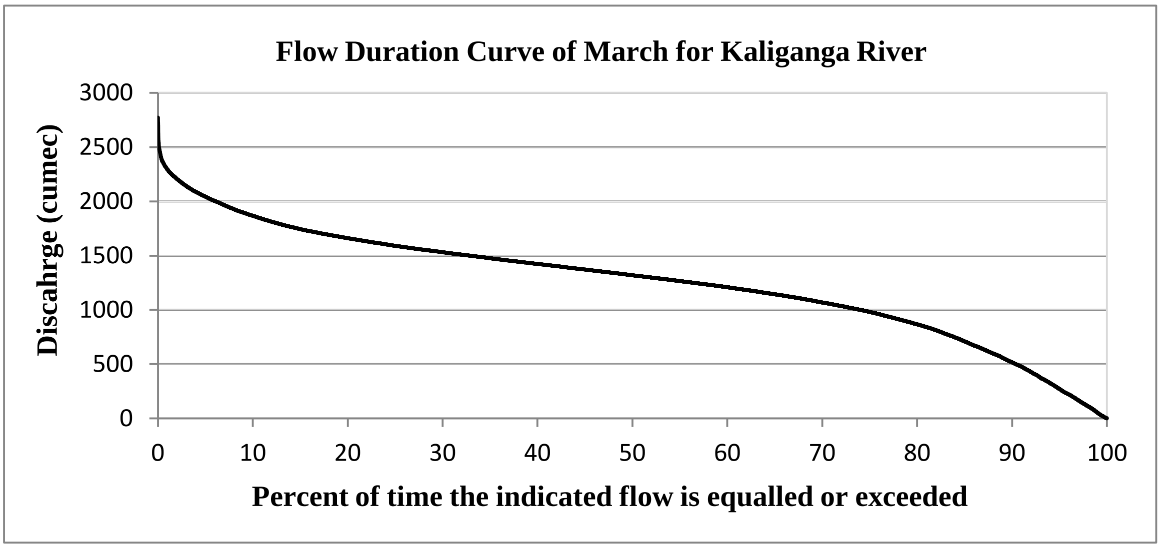

Flow Duration Curve of September for Madhumati River
Discahrge (cumec)
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

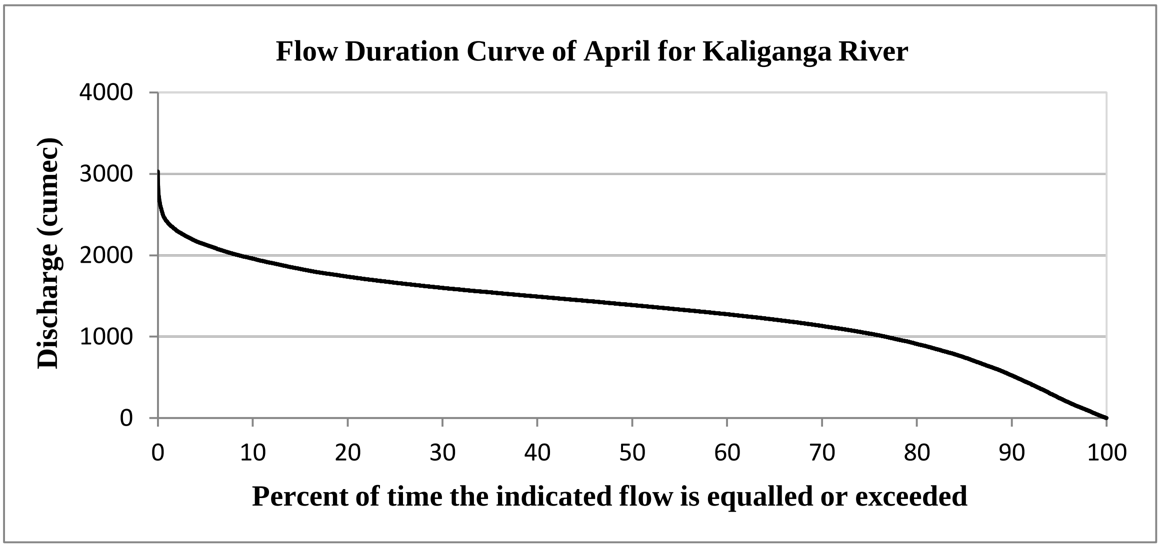

Flow Duration Curve of October for Madhumati River
Discharge (cumec)
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

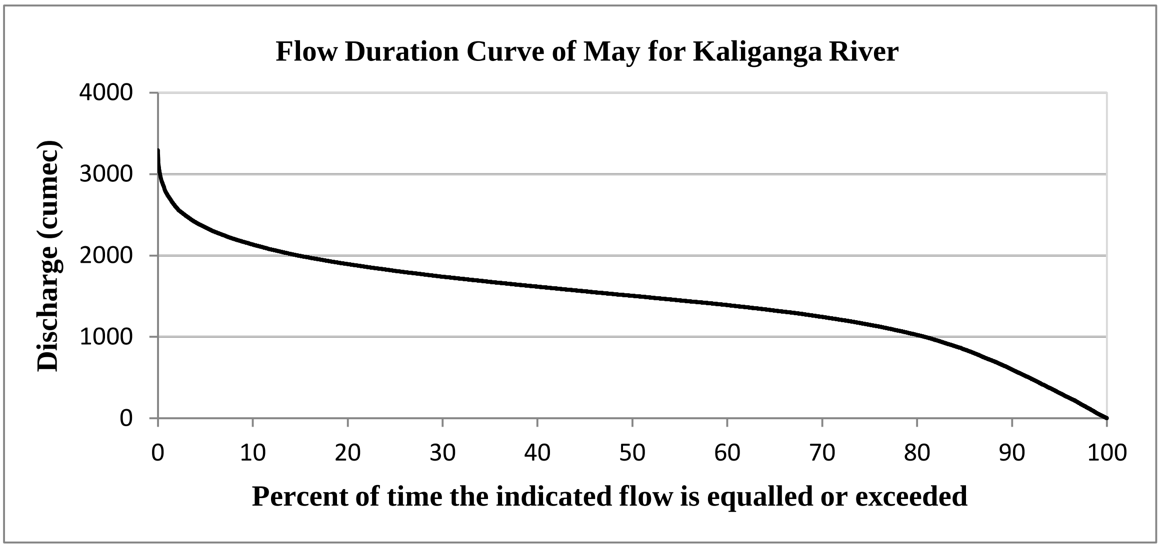

Flow Duration Curve of November for Madhumati River
250
200
150
100
50
0
Discharge (cumec)
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

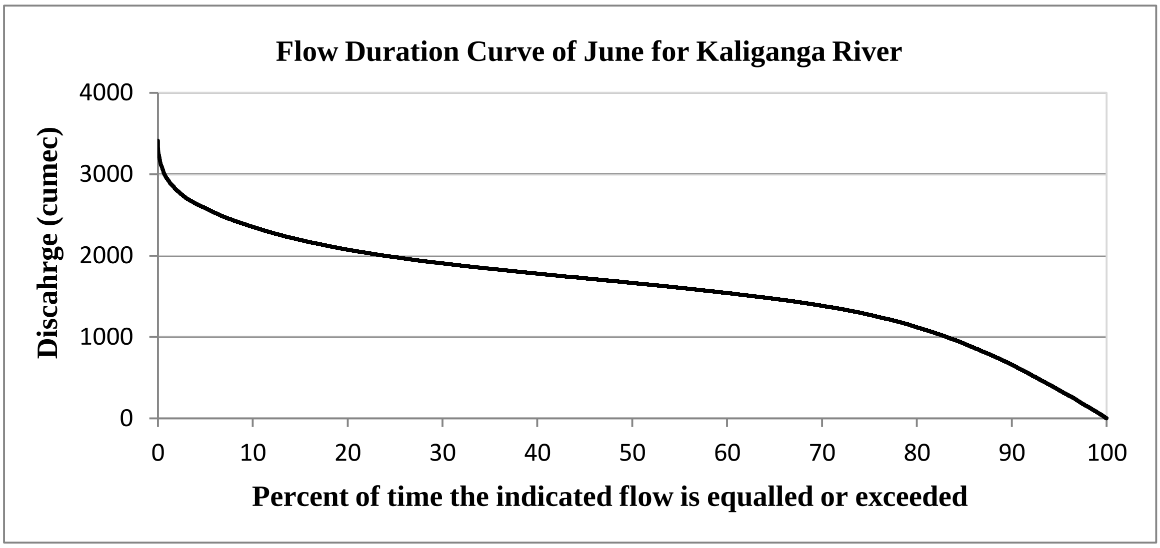

Flow Duration Curve of December for Madhumati River
200
160
120
80
40
0
Discharge (cumec)
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

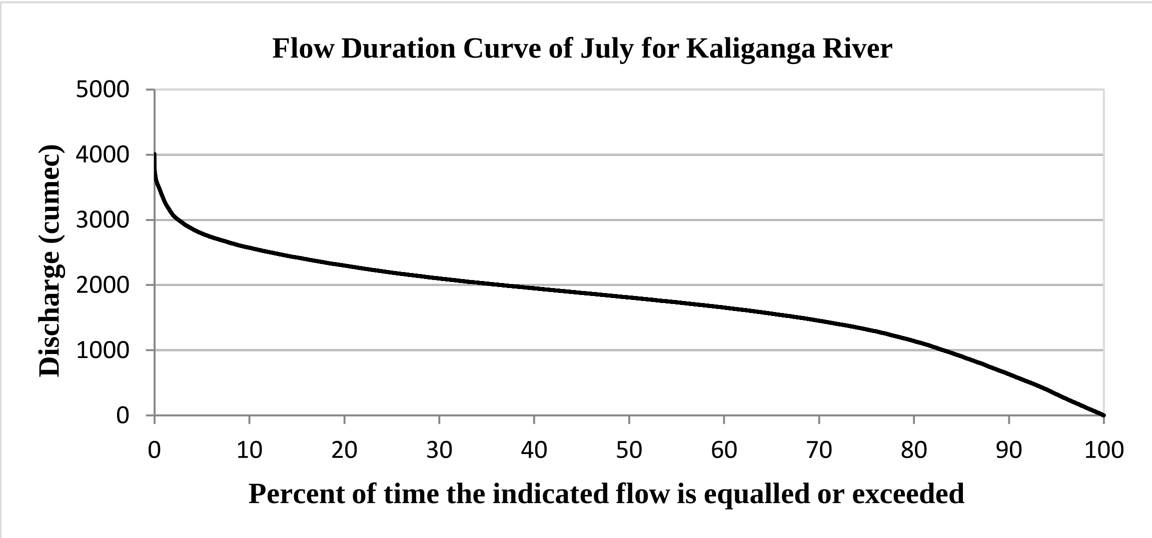

Flow Duration Curve of February for Kaliganga River
Discharge (cumec)
3000
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

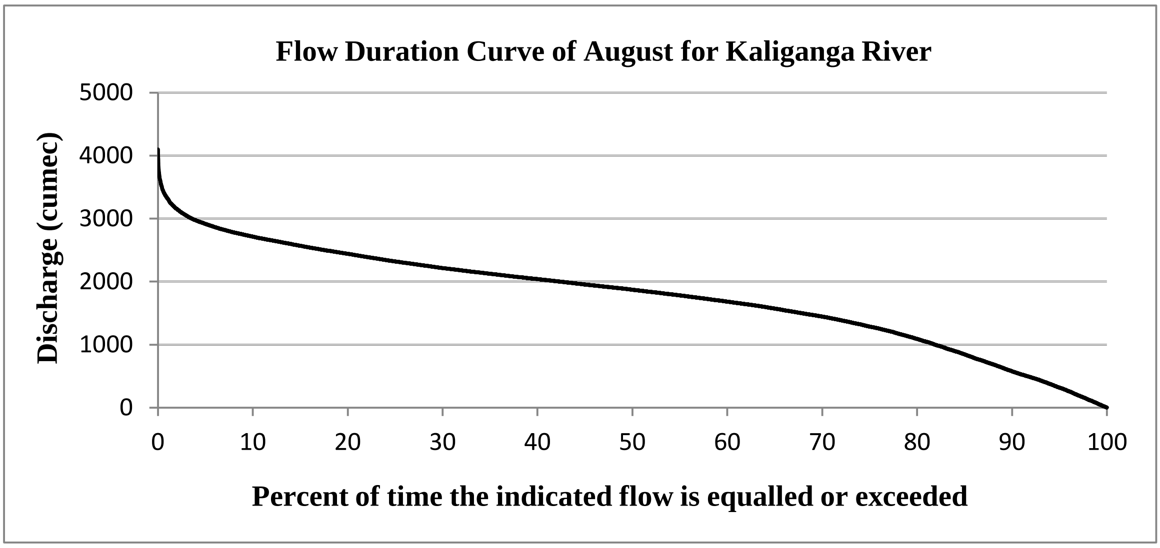

Flow Duration Curve of March for Kaliganga River
Discahrge (cumec)
3000
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

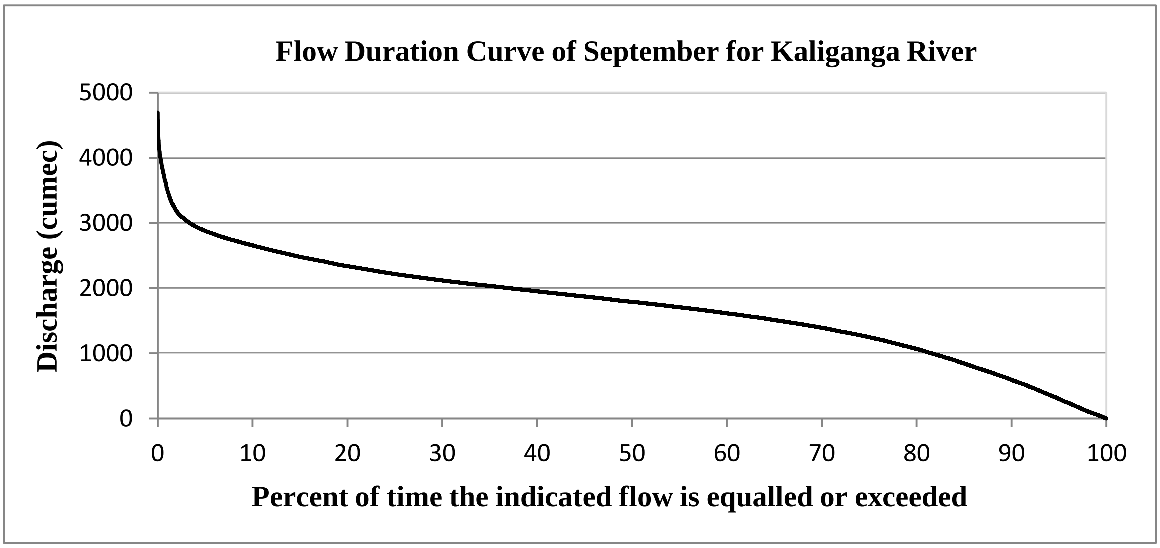

Flow Duration Curve of April for Kaliganga River
Discharge (cumec)
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

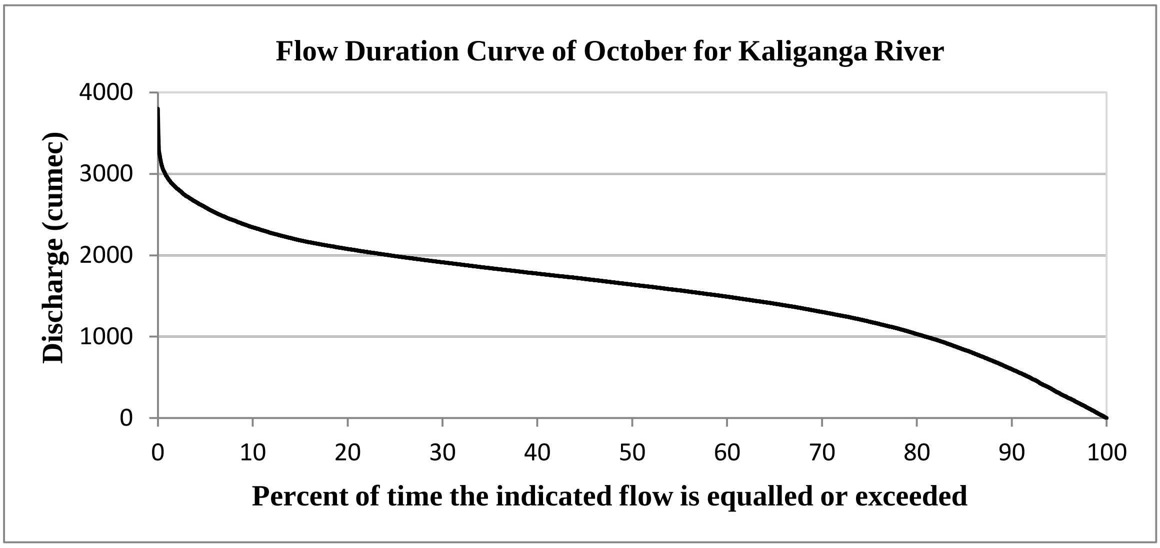

Flow Duration Curve of May for Kaliganga River
Discharge (cumec)
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

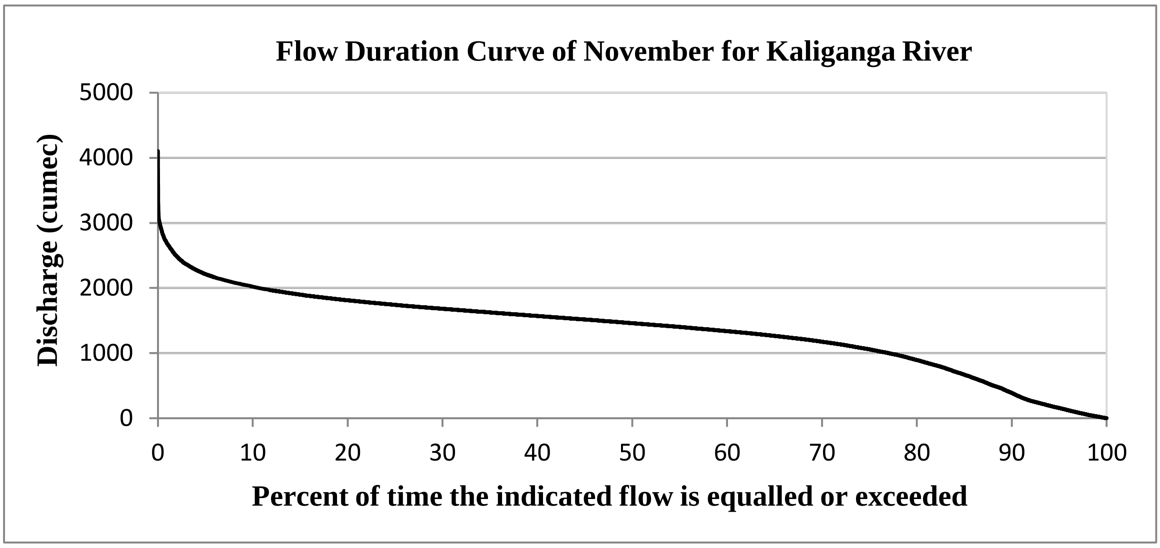

Flow Duration Curve of June for Kaliganga River
Discahrge (cumec)
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

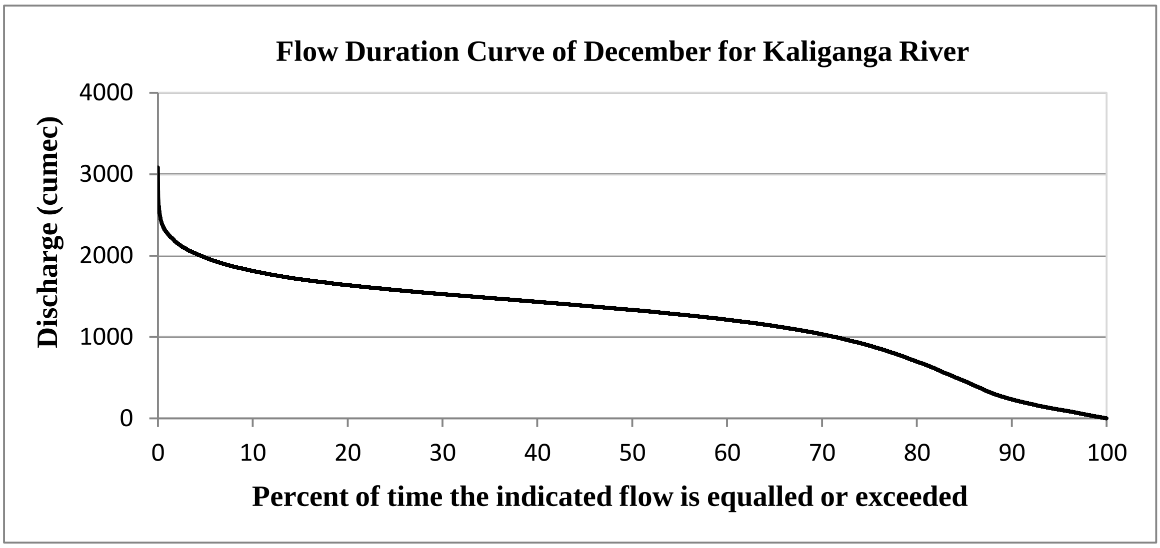

Flow Duration Curve of July for Kaliganga River
Discharge (cumec)
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

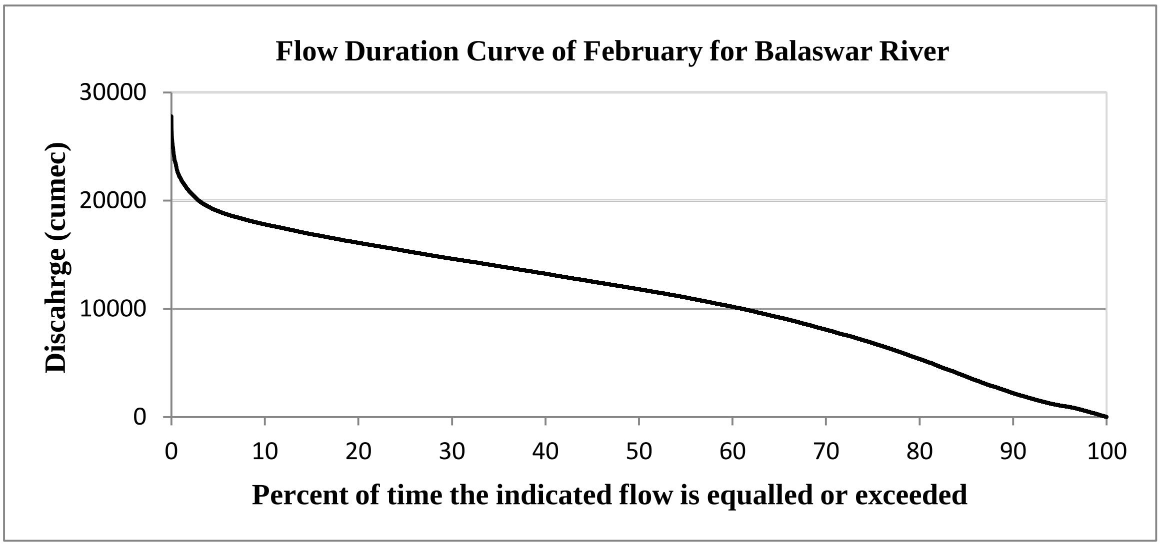

Flow Duration Curve of August for Kaliganga River
Discharge (cumec)
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

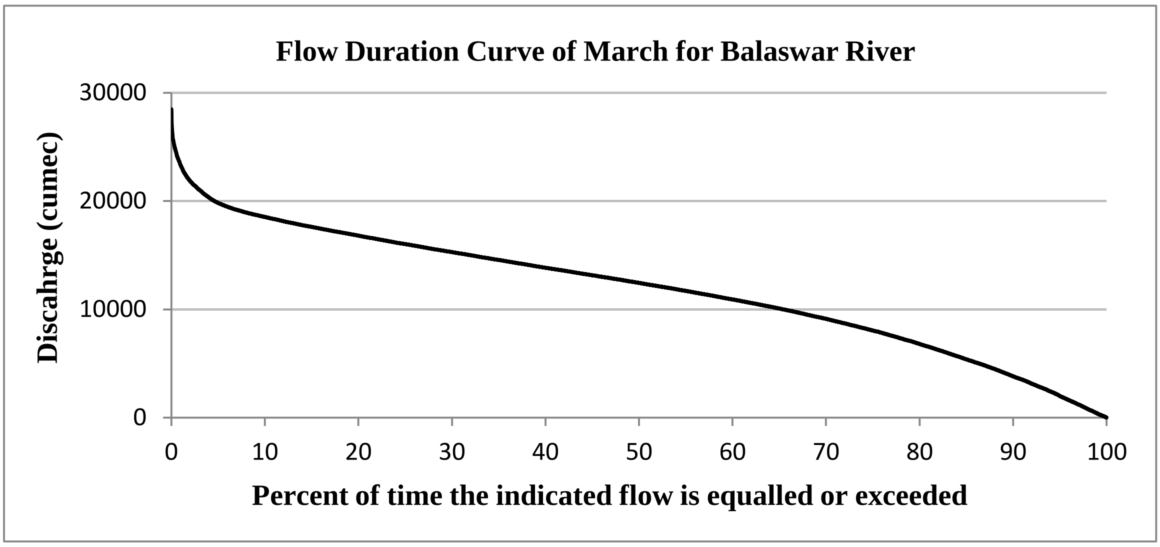

Flow Duration Curve of September for Kaliganga River
Discharge (cumec)
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

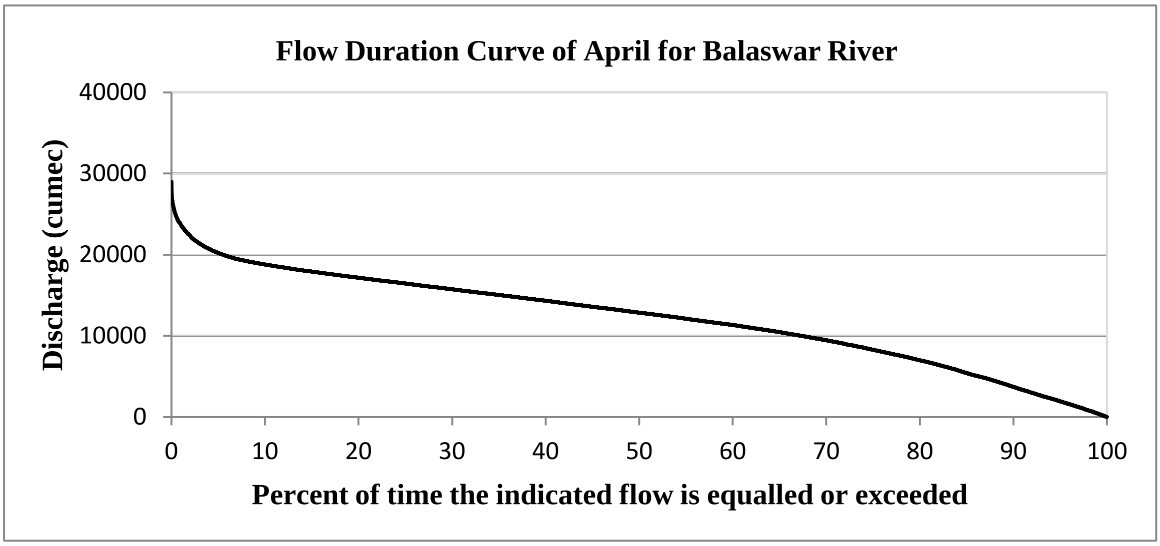

Flow Duration Curve of October for Kaliganga River
Discharge (cumec)
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

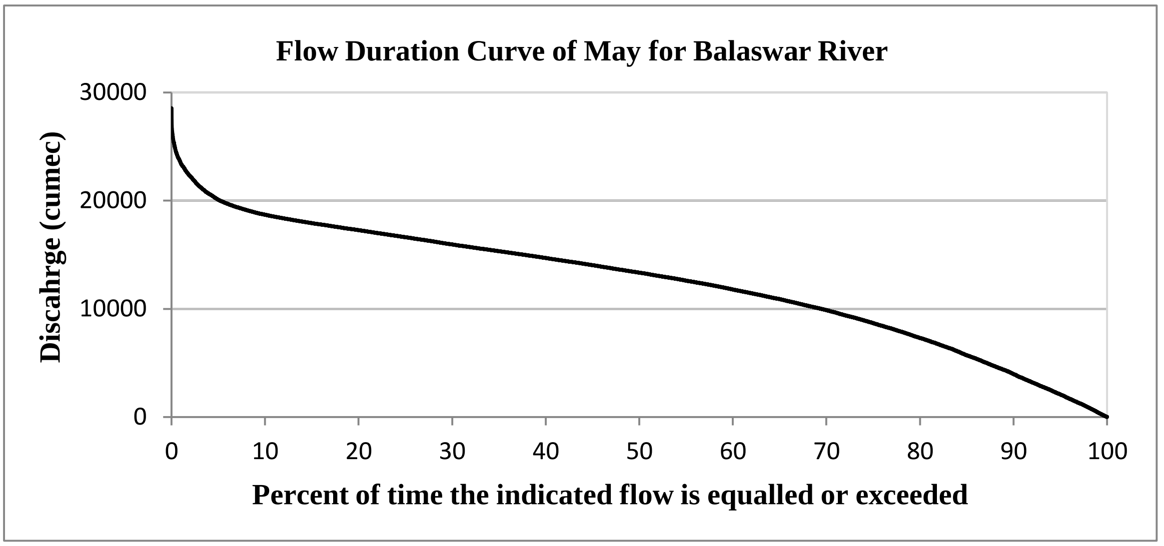

Flow Duration Curve of November for Kaliganga River
Discharge (cumec)
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

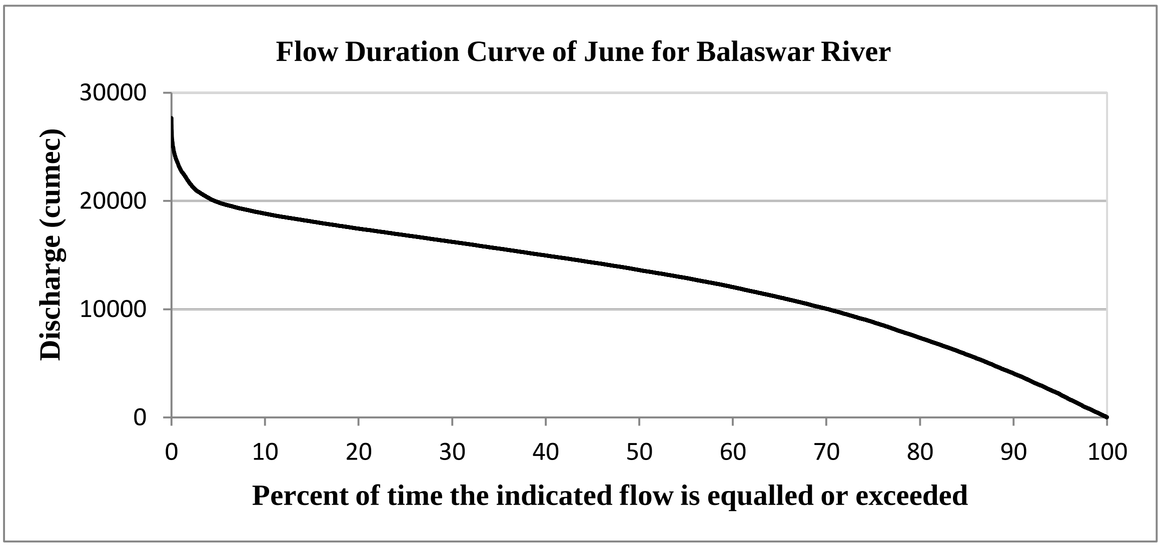

Flow Duration Curve of December for Kaliganga River
Discharge (cumec)
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

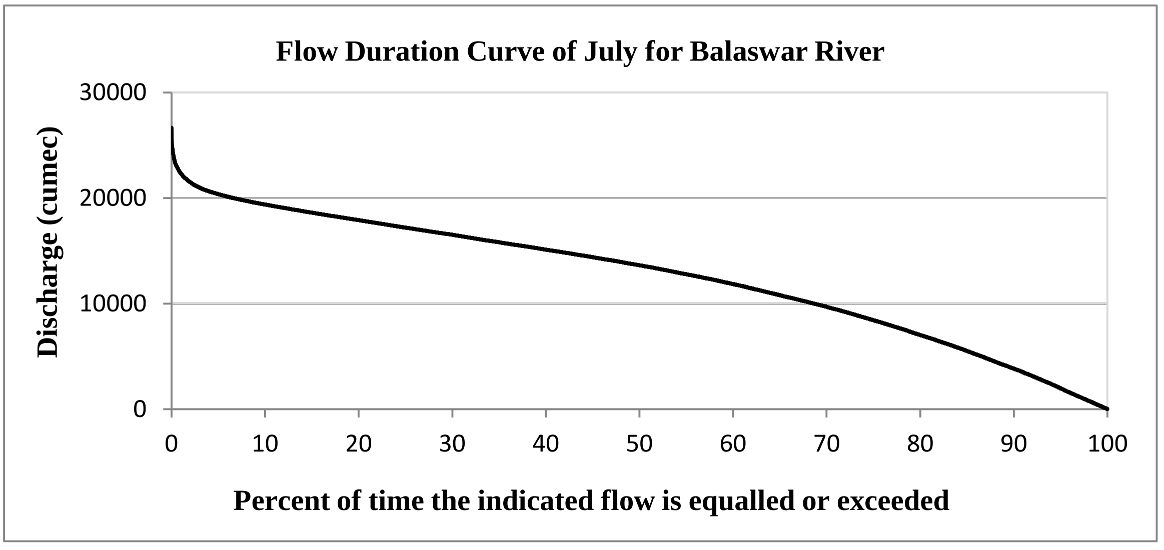

Flow Duration Curve of February for Balaswar River
30000
20000
10000
0
Discahrge (cumec)
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

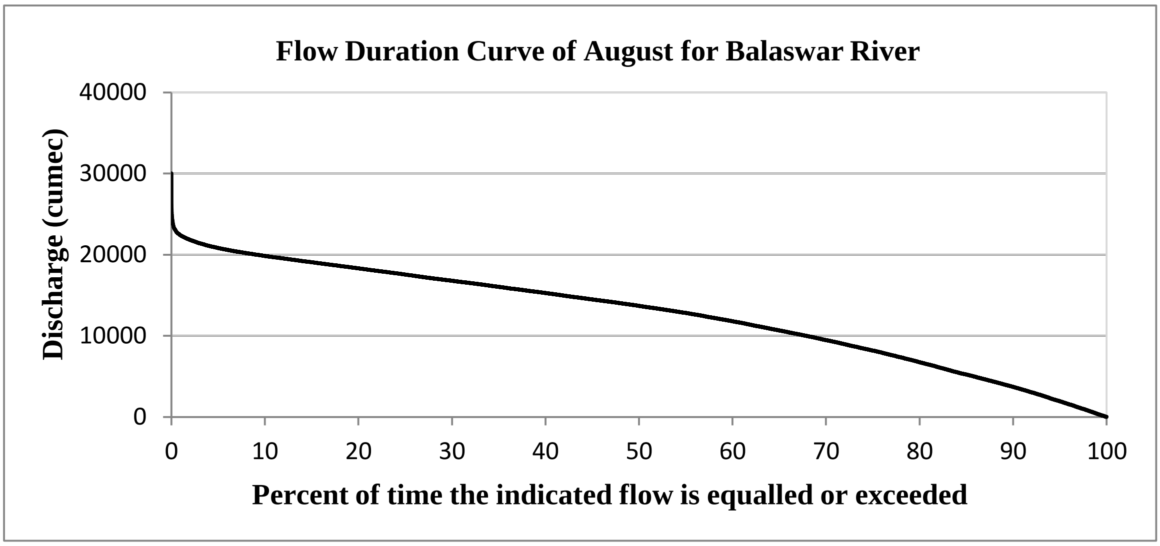

Flow Duration Curve of March for Balaswar River
30000
20000
10000
0
Discahrge (cumec)
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

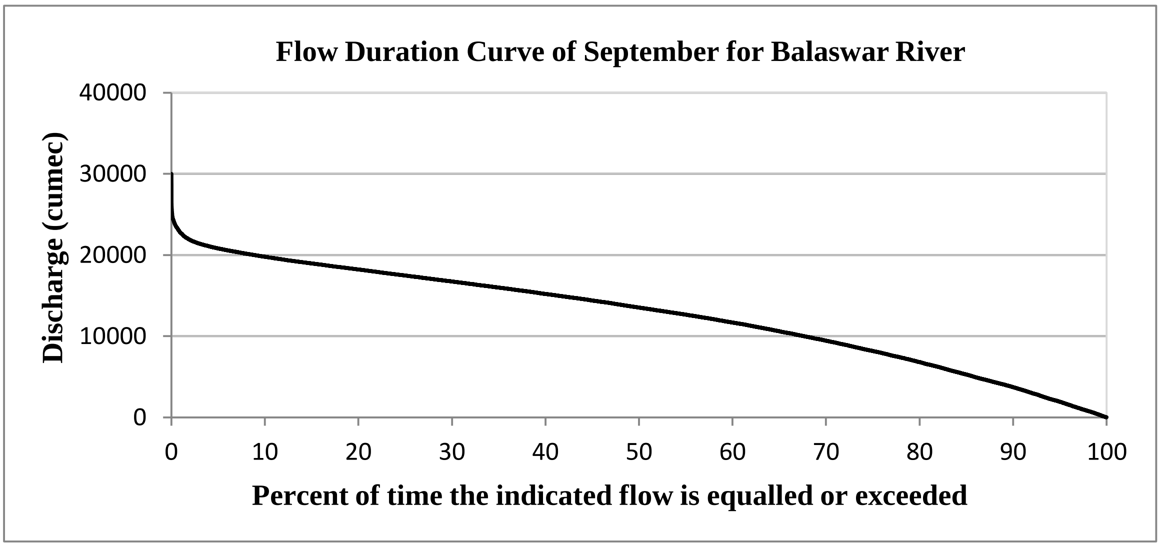

Flow Duration Curve of April for Balaswar River
40000
30000
20000
10000
0
Discharge (cumec)
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

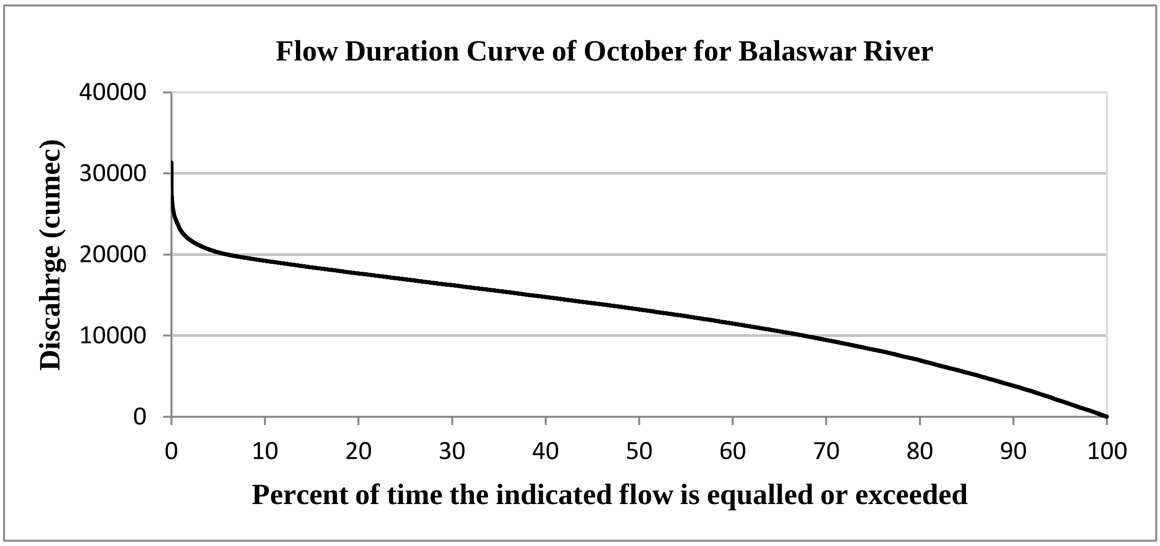

Flow Duration Curve of May for Balaswar River
30000
20000
10000
0
0
10
20
30
40
50
60
70
80
90
100
Discahrge (cumec)
Percent of time the indicated flow is equalled or exceeded

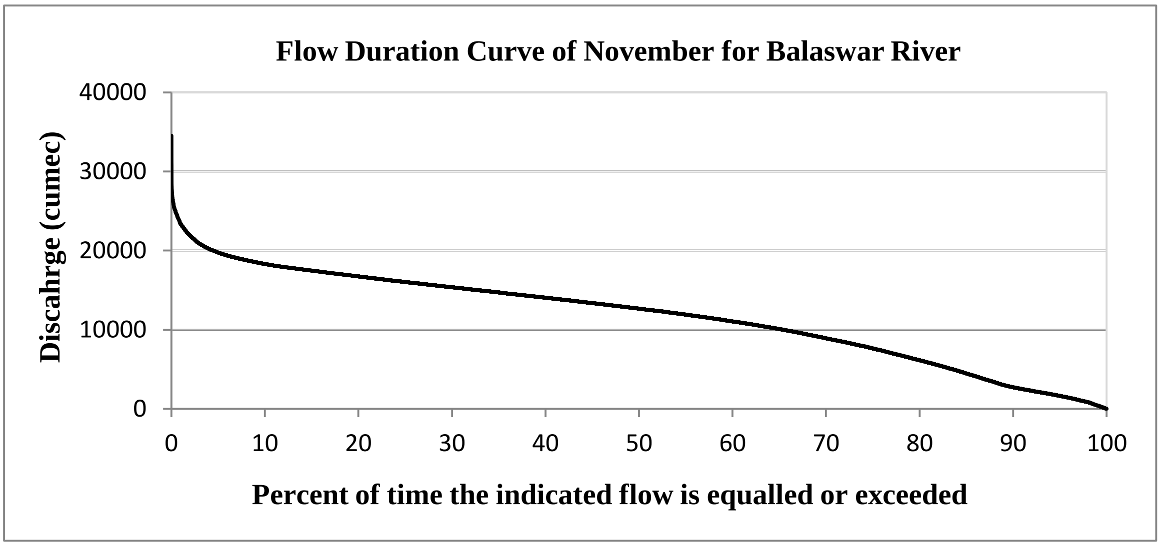

Flow Duration Curve of June for Balaswar River
30000
20000
10000
0
0
10
20
30
40
50
60
70
80
90
100
Discharge (cumec)
Percent of time the indicated flow is equalled or exceeded

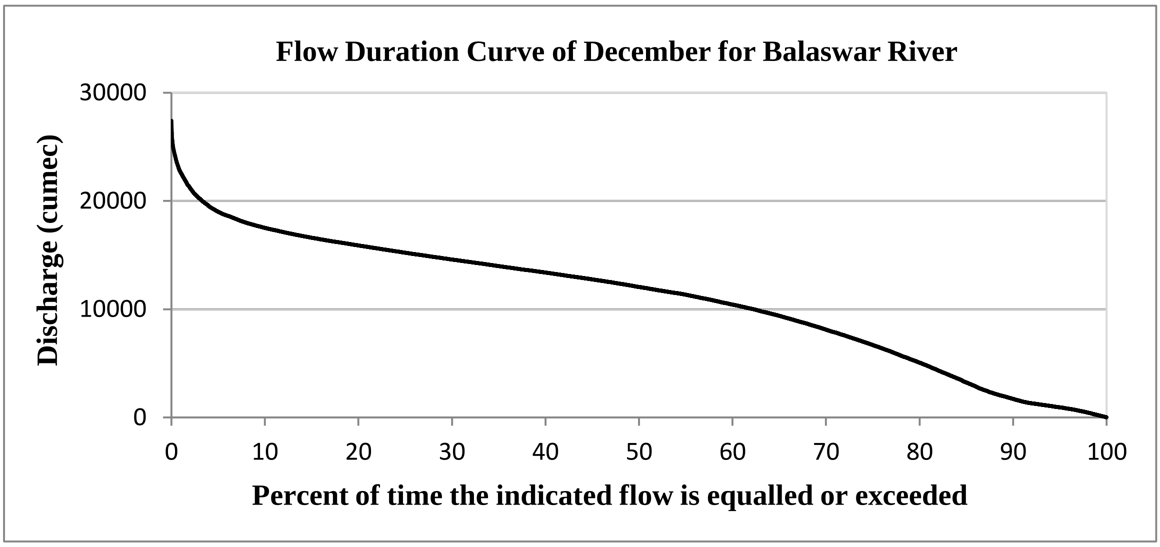

Flow Duration Curve of July for Balaswar River
30000
20000
10000
0
0
10
20
30
40
50
60
70
80
90
100
Discharge (cumec)
Percent of time the indicated flow is equalled or exceeded


Flow Duration Curve of August for Balaswar River
Discharge (cumec)
40000
30000
20000
10000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded


Flow Duration Curve of September for Balaswar River
Discharge (cumec)
40000
30000
20000
10000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded


Flow Duration Curve of October for Balaswar River
Discahrge (cumec)
40000
30000
20000
10000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded


Flow Duration Curve of November for Balaswar River
Discahrge (cumec)
40000
30000
20000
10000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded


Flow Duration Curve of December for Balaswar River
Discharge (cumec)
30000
20000
10000
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time the indicated flow is equalled or exceeded

APPENDIX-B

Discharge and Wetted Perimeter relation of Gorai, Madhumati, Kaliganga and Balaswar River

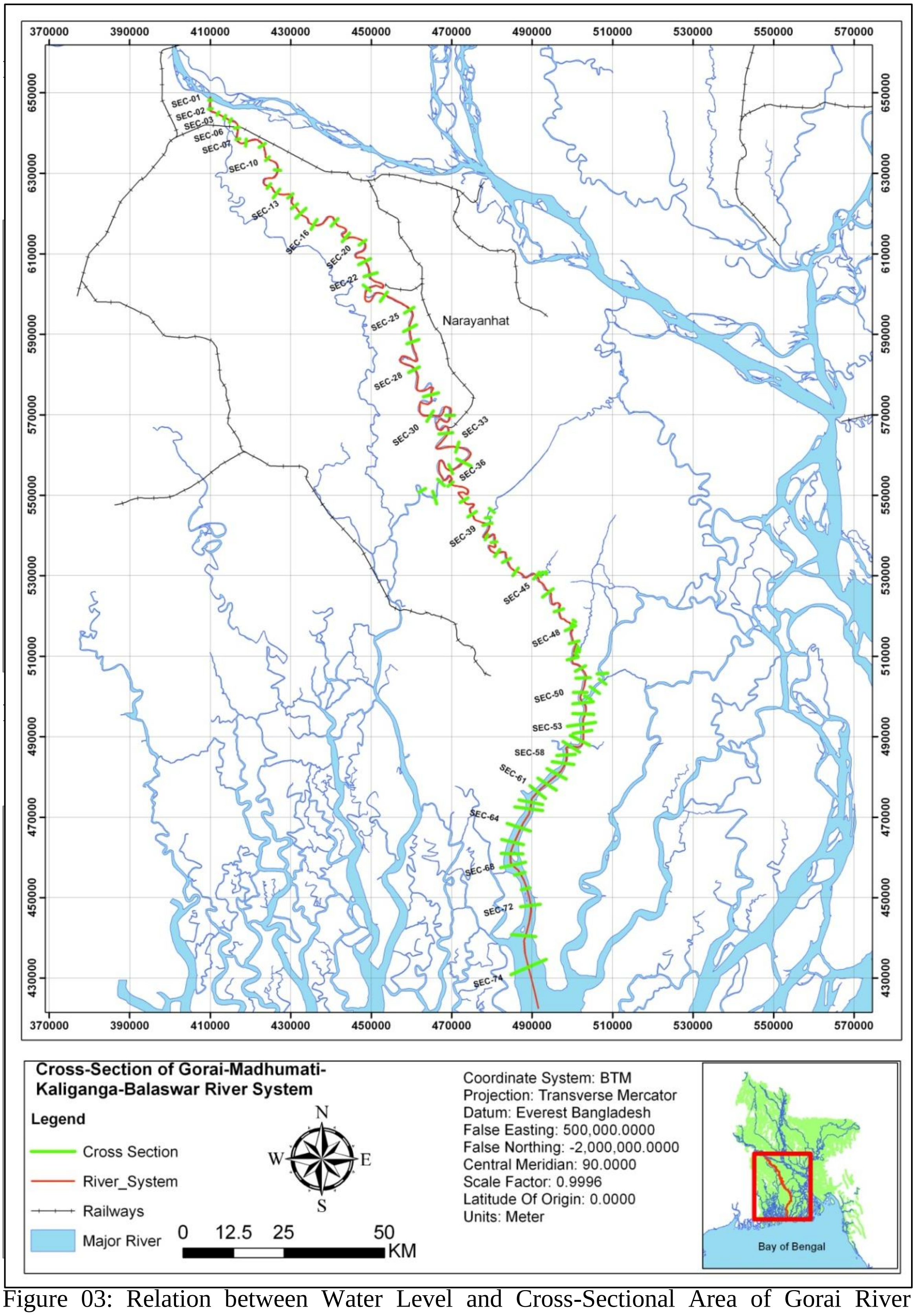


Figure 03: Relation between Water Level and Cross-Sectional Area of Gorai River (Section-13)

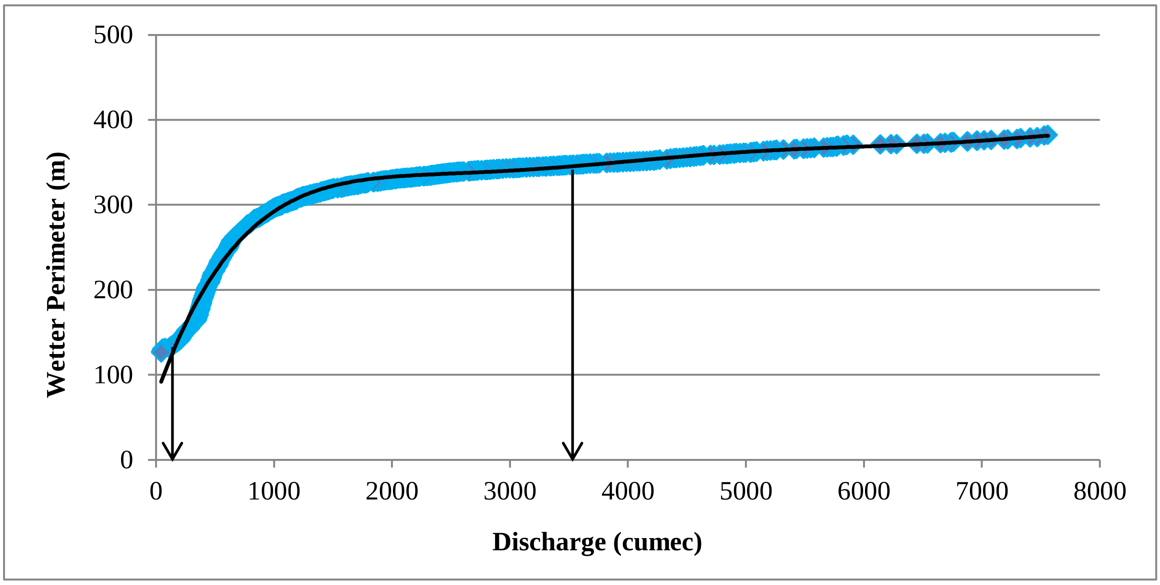


Figure 04: Relation between Discharge and Wetted Perimeter of Gorai River (Section-16)

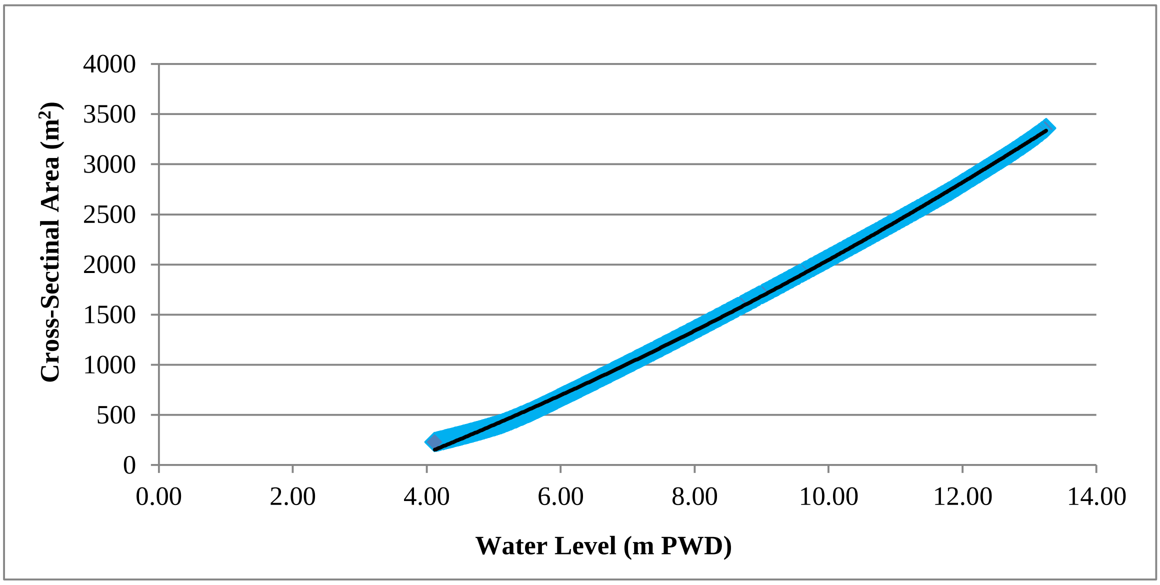


Figure 05: Relation between Water Level and Cross-Sectional Area of Gorai River (Section-16)

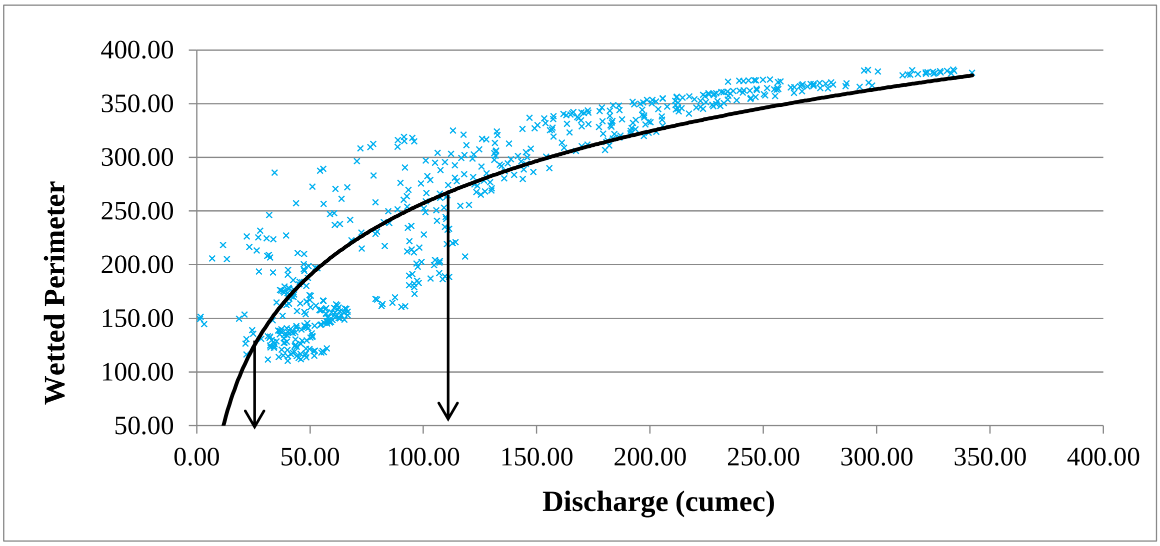


Figure 06: Relation between Discharge and Wetted Perimeter of Madhumati River (Section-33)

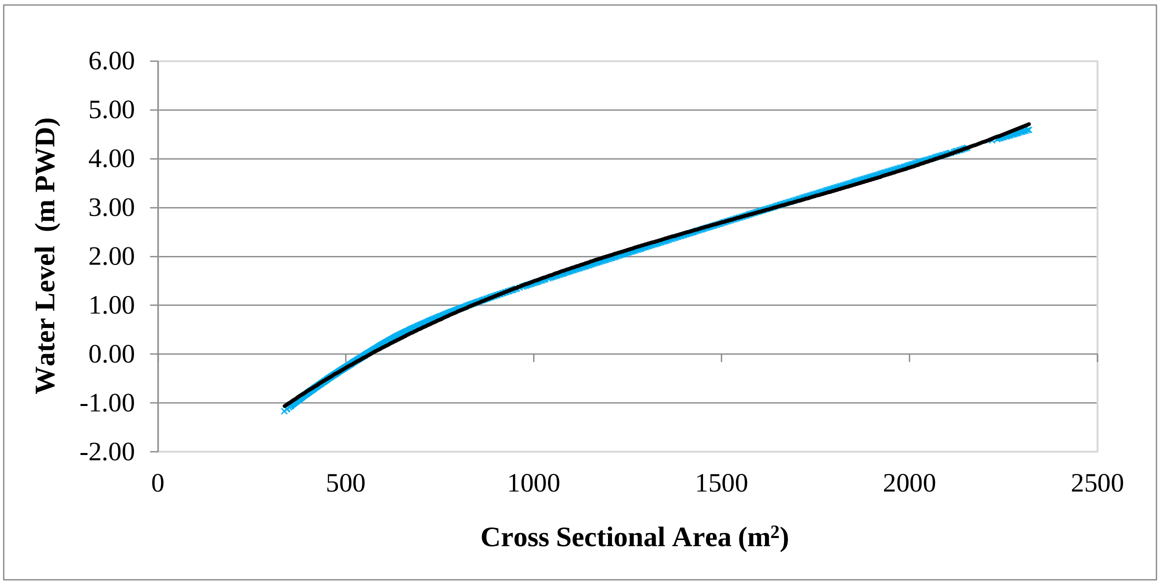


Figure 07: Relation between Water Level and Cross-Sectional Area of Madhumati River (Section-33)

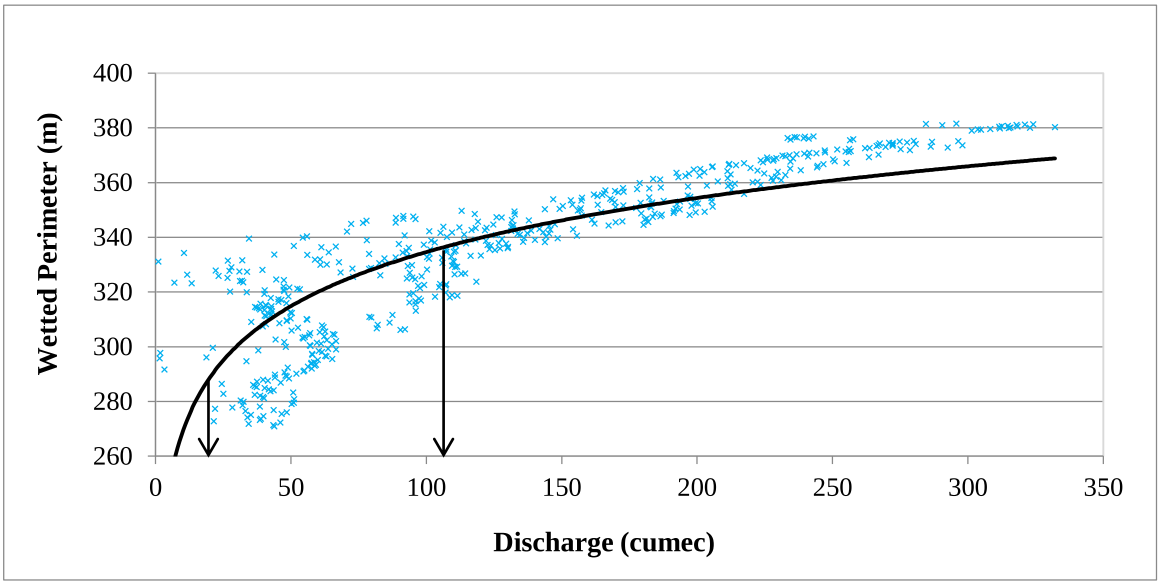


Figure 08: Relation between Discharge and Wetted Perimeter of Madhumati River (Section-36)

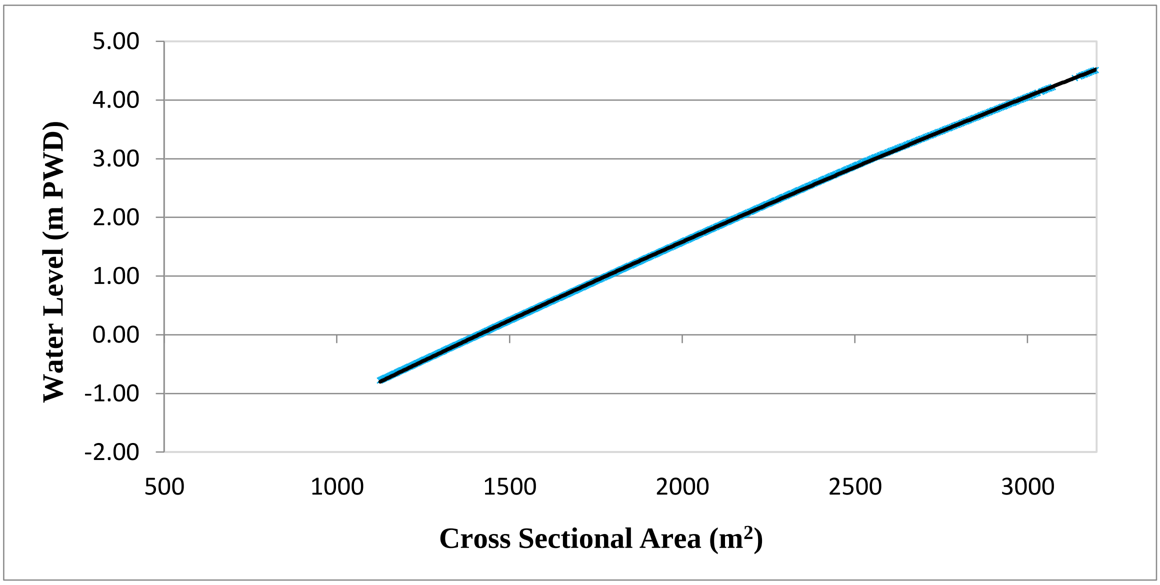


Figure 09: Relation between Water Level and Cross-Sectional Area of Madhumati River (Section-36)

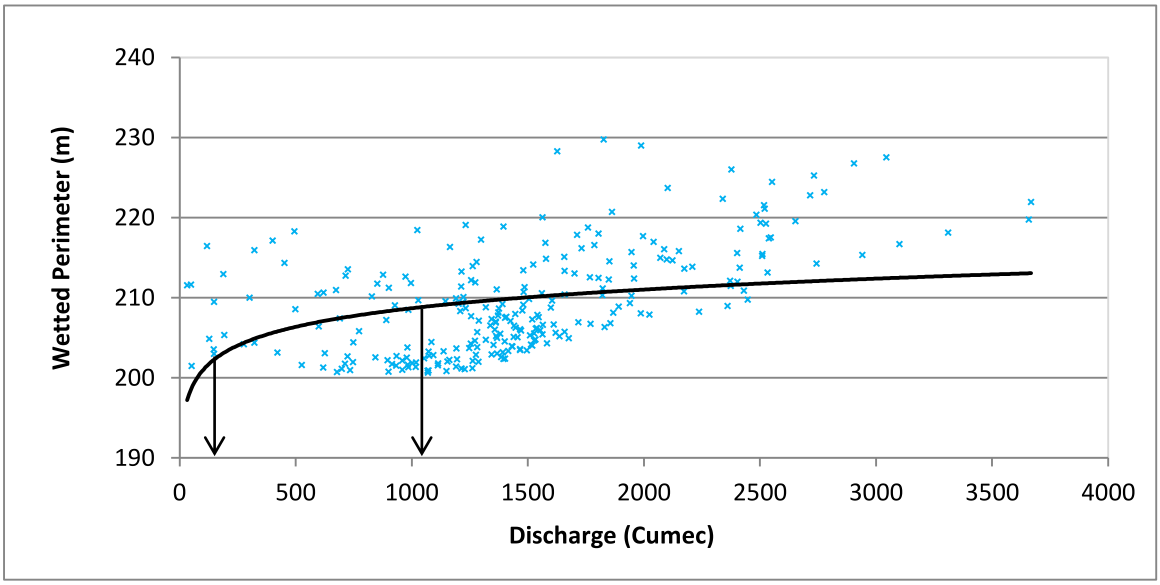


Figure 10: Relation between Discharge and Wetted Perimeter of Kaliganga River (Section-54)

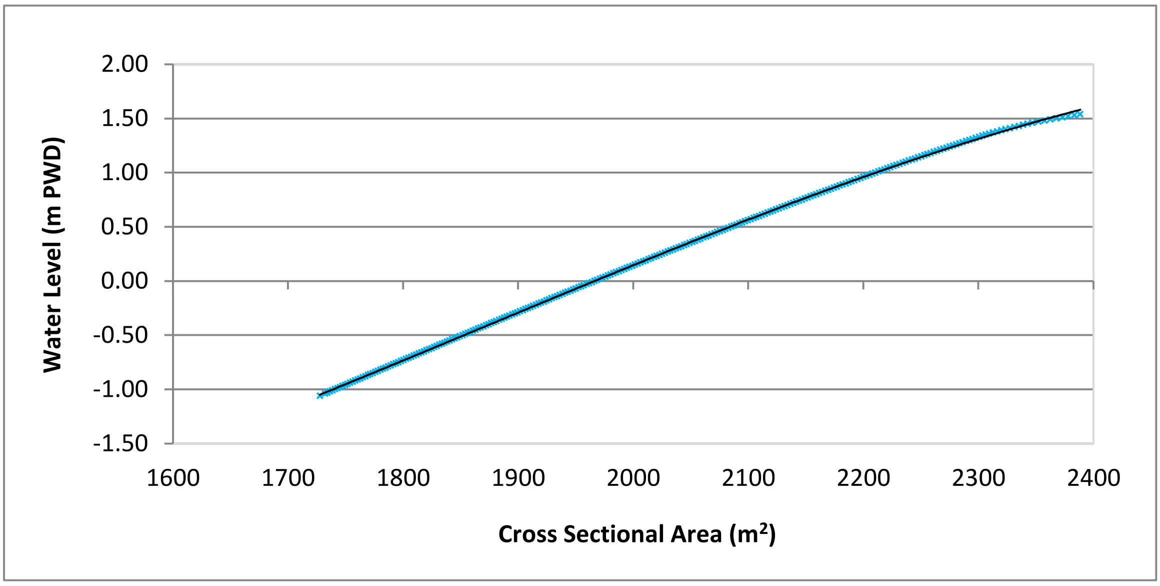


Figure 11: Relation between Water Level and Cross-Sectional Area of Kaliganga River (Section-54)

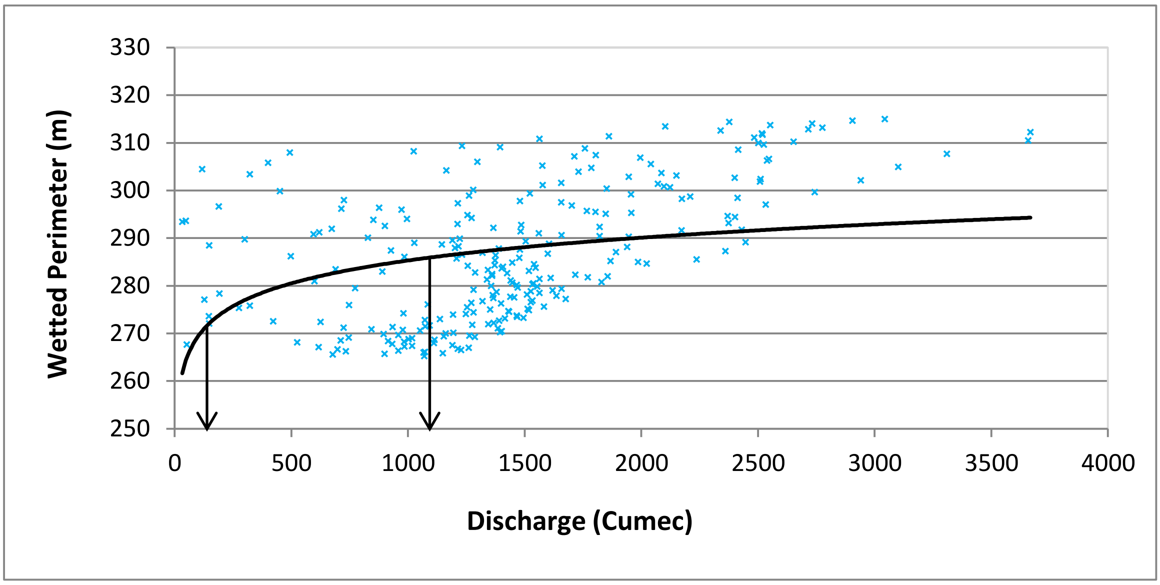


Figure 12: Relation between Discharge and Wetted Perimeter of Kaliganga River (Section-58)

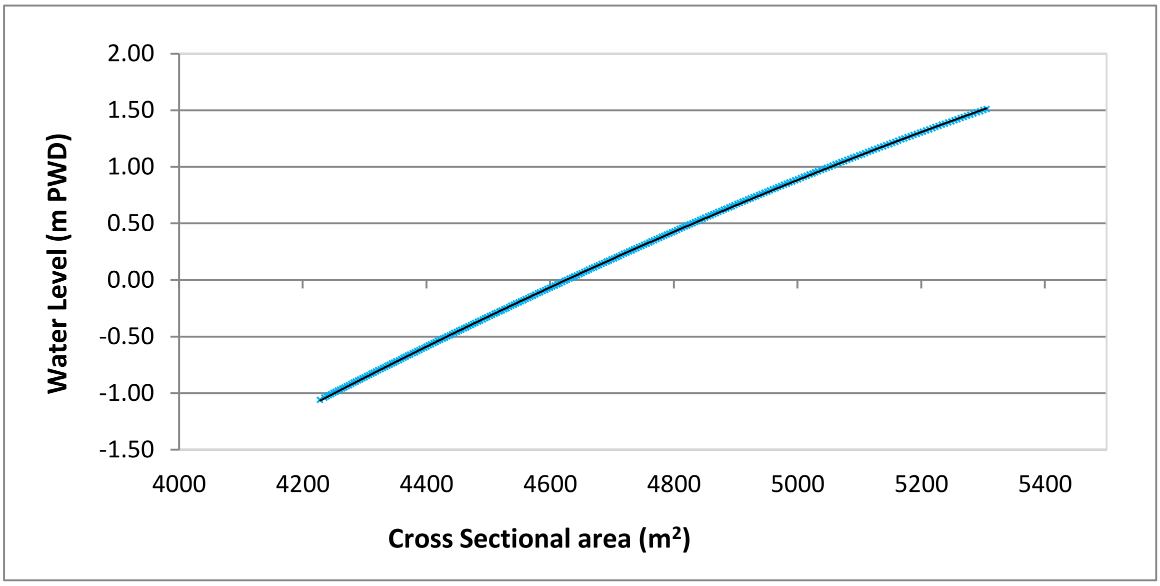


Figure 13: Relation between Water Level and Cross-Sectional Area of Kaliganga River (Section-58)

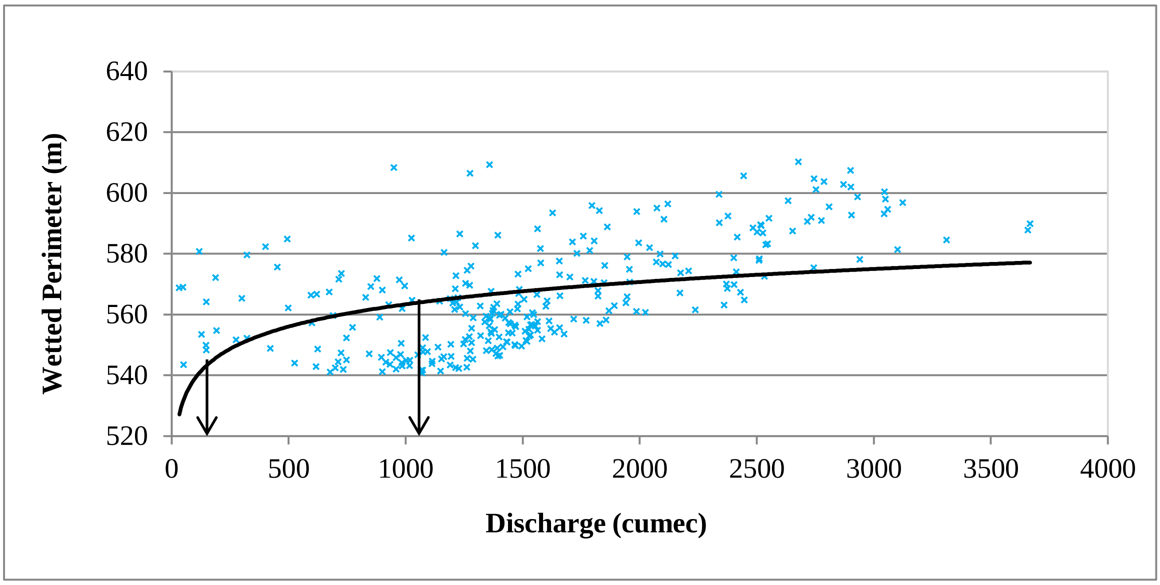


Figure 14: Relation between Discharge and Wetted Perimeter of Kaliganga River (Section-60)

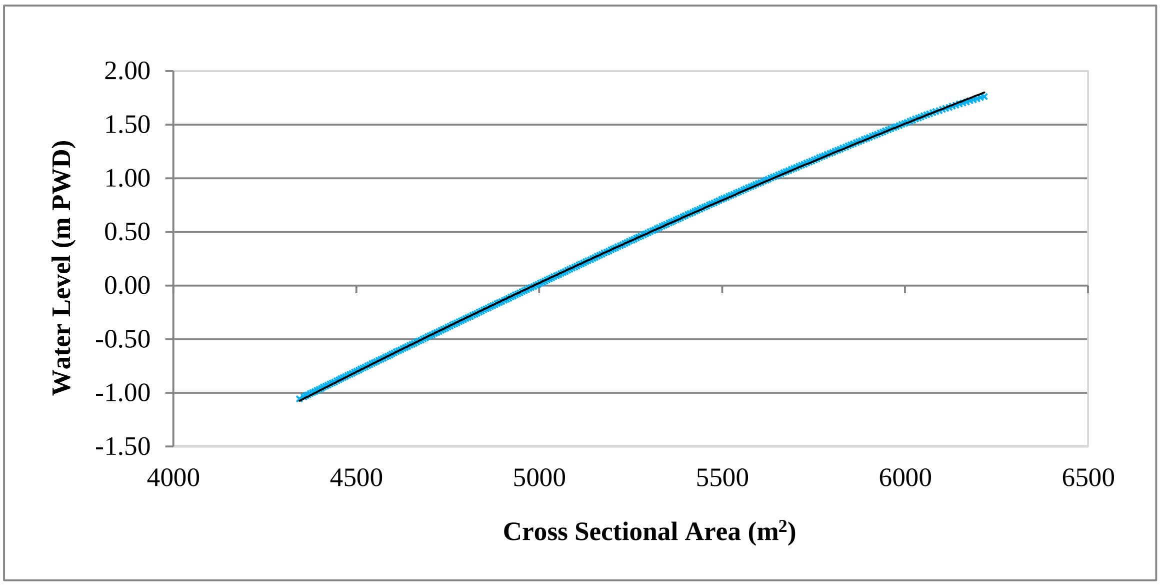


Figure 15: Relation between Water Level and Cross-Sectional Area of Kaliganga River (Section-60)

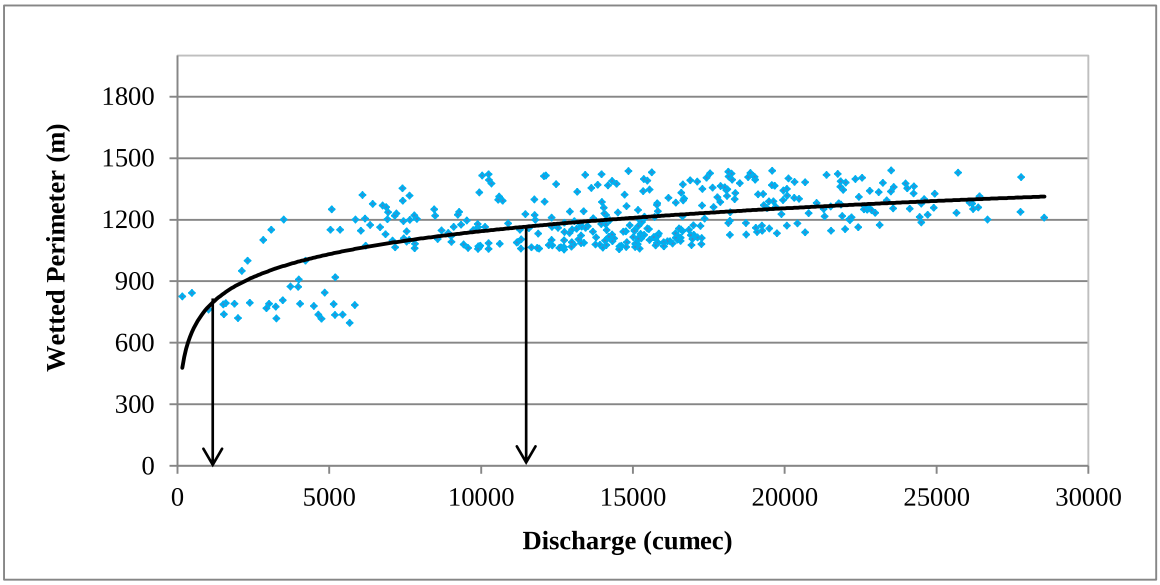


Figure 16: Relation between Discharge and Wetted Perimeter of Balaswar River (Section-64)

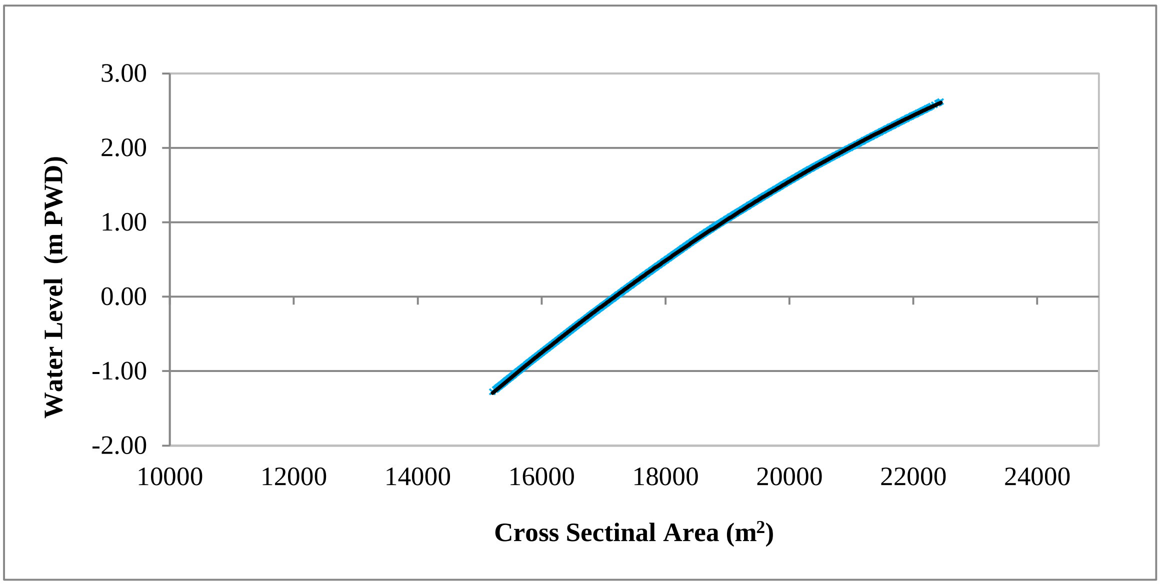


Figure 17: Relation between Water Level and Cross-Sectional Area of Balaswar River (Section-64)

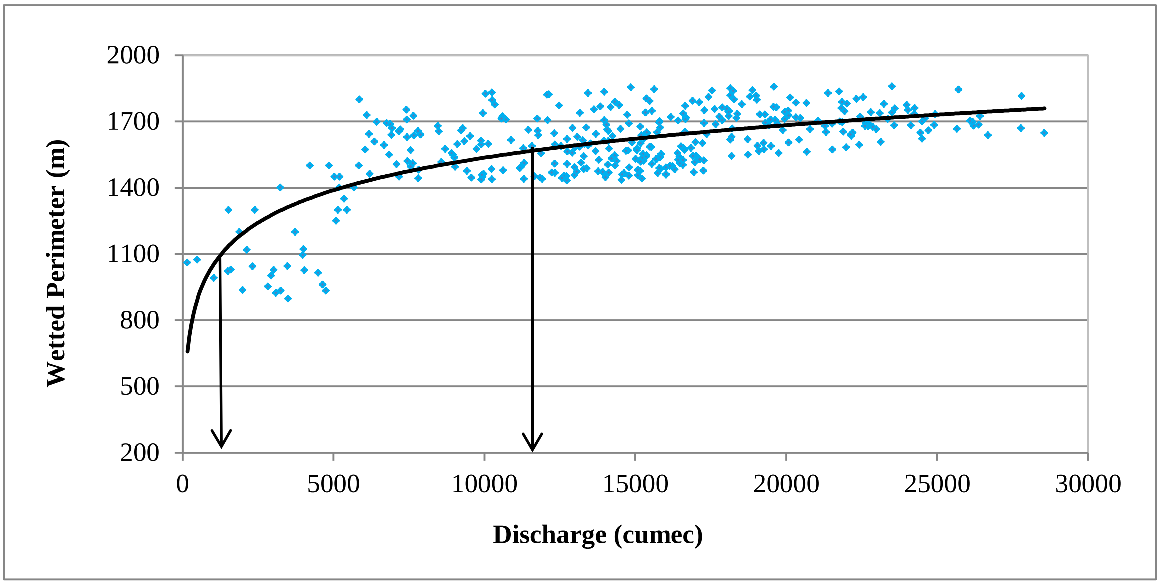


Figure 18: Relation between Discharge and Wetted Perimeter of Balaswar River (Section-66)

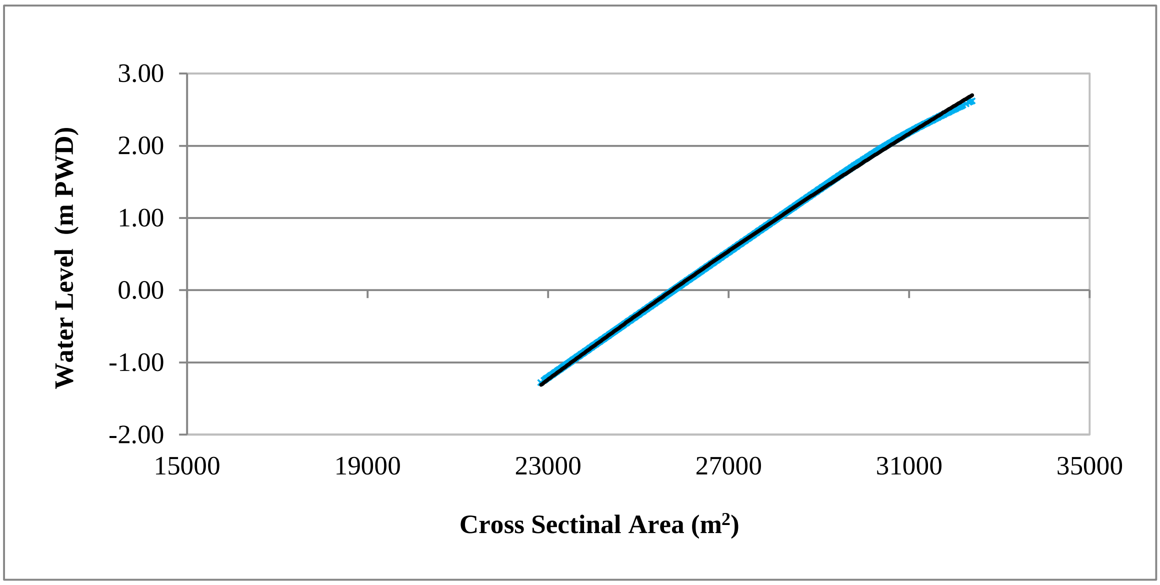


Figure 19: Relation between Water Level and Cross-Sectional Area of Balaswar River (Section-66)

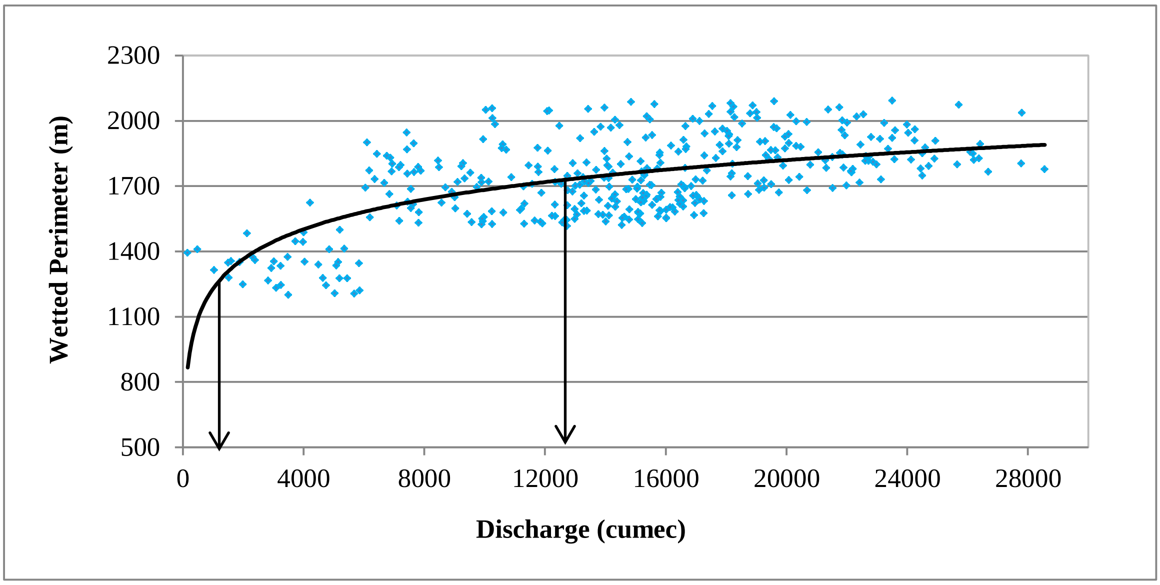


Figure 20: Relation between Discharge and Wetted Perimeter of Balaswar River (Section-68)

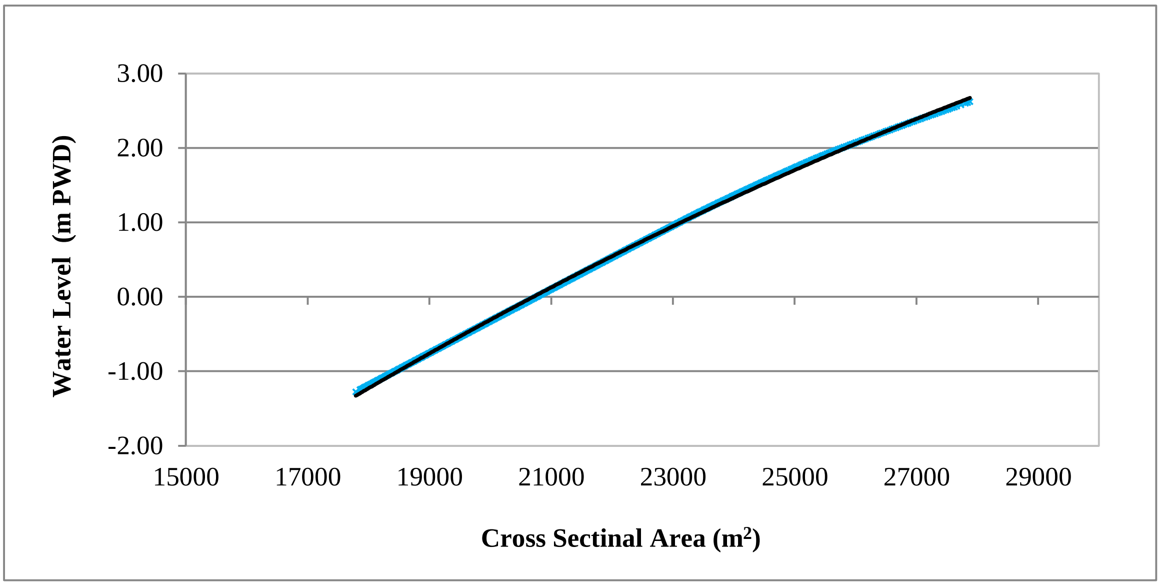


Figure 21: Relation between Water Level and Cross-Sectional Area of Balaswar River (Section-68)

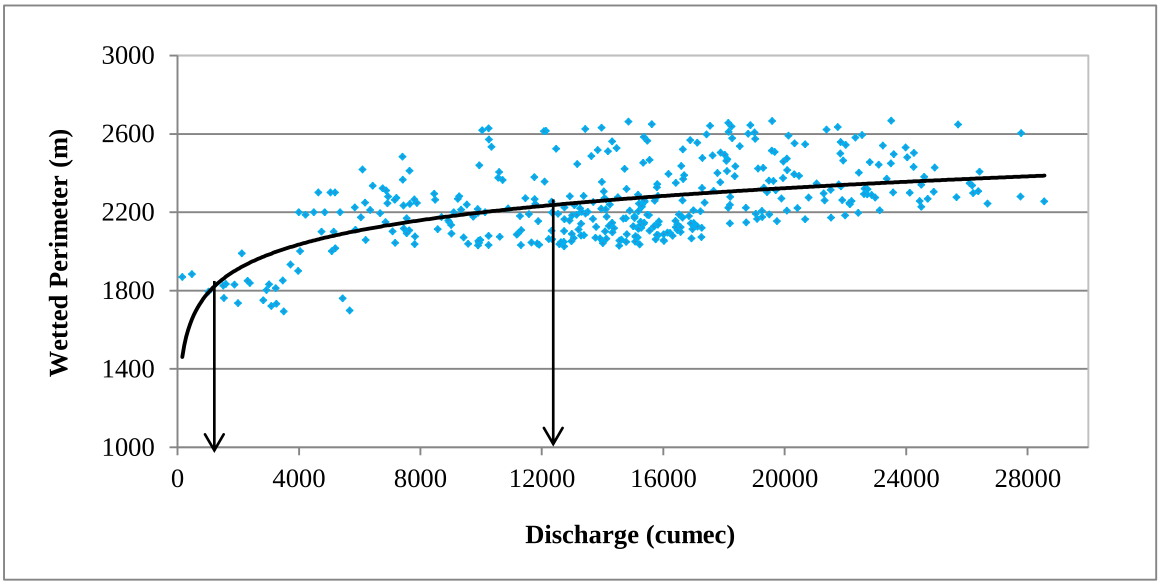


Figure 22: Relation between Discharge and Wetted Perimeter of Balaswar River (Section-69)

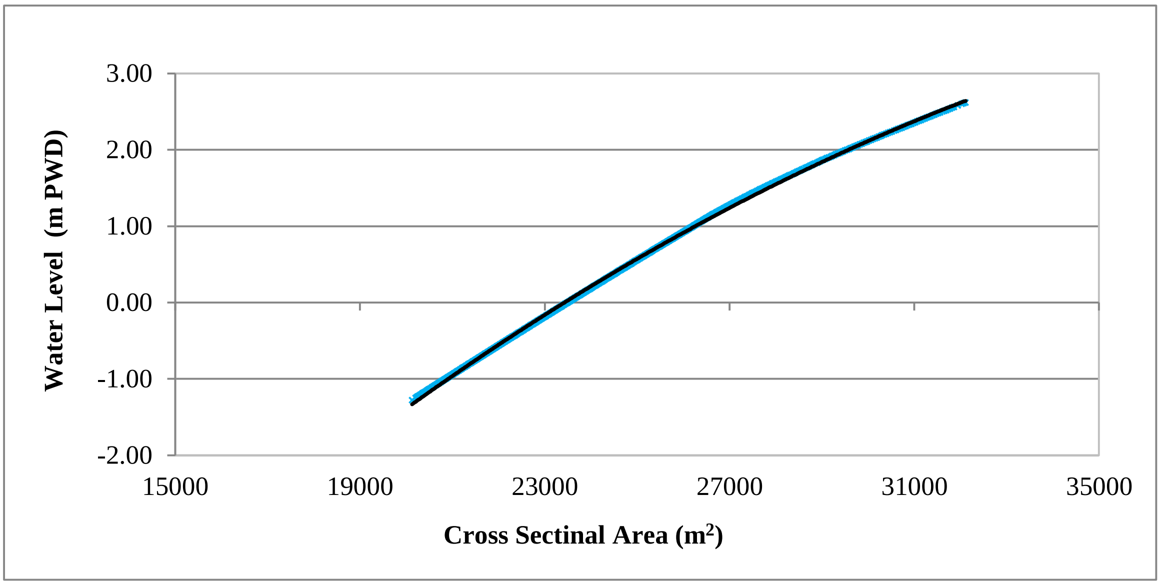


Figure 23: Relation between Water Level and Cross-Sectional Area of Balaswar River (Section-69)

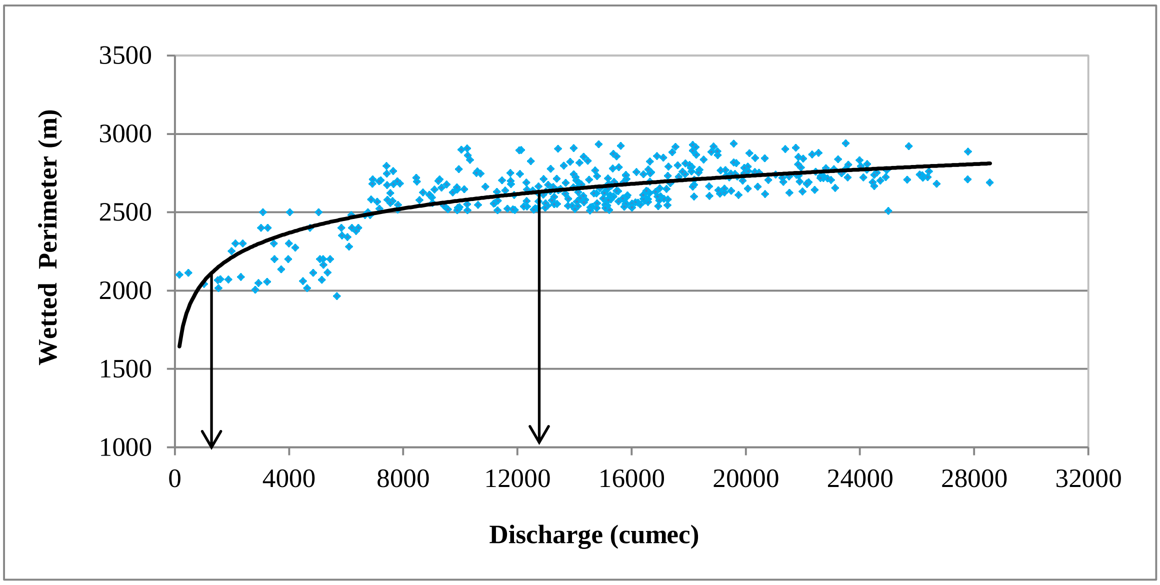


Figure 24: Relation between Discharge and Wetted Perimeter of Balaswar River (Section-70)

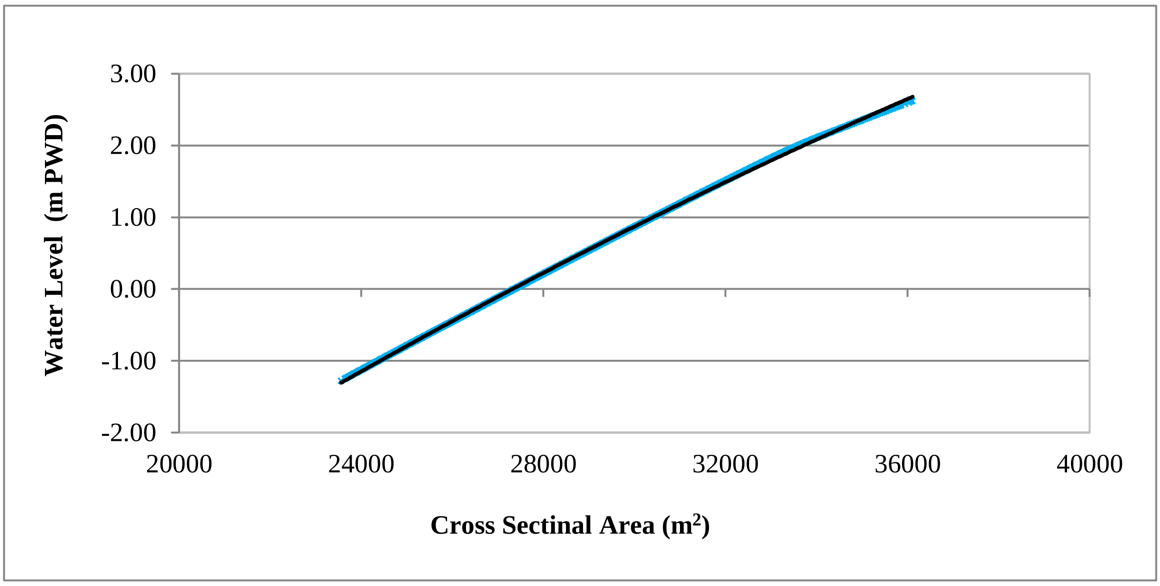


Figure 25: Relation between Water Level and Cross-Sectional Area of Balaswar River (Section-70)

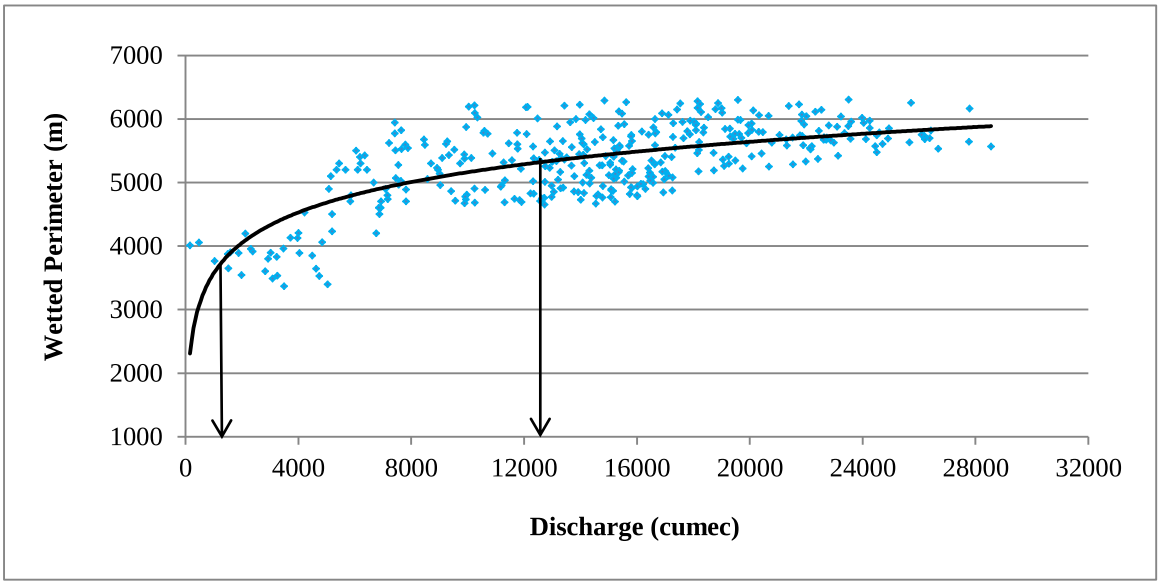


Figure 26: Relation between Discharge and Wetted Perimeter of Balaswar River (Section-71)

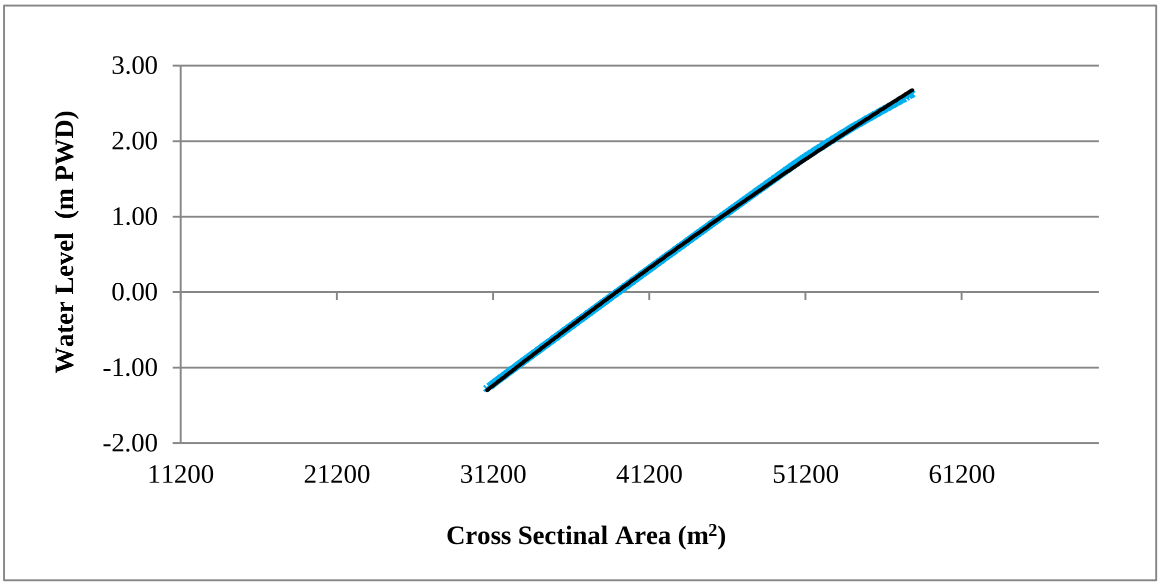


Figure 27: Relation between Water Level and Cross-Sectional Area of Balaswar River (Section-71)

APPENDIX-C

Monthly Habitat Duration Curve and variation of Habitat Suitability of Gorai River

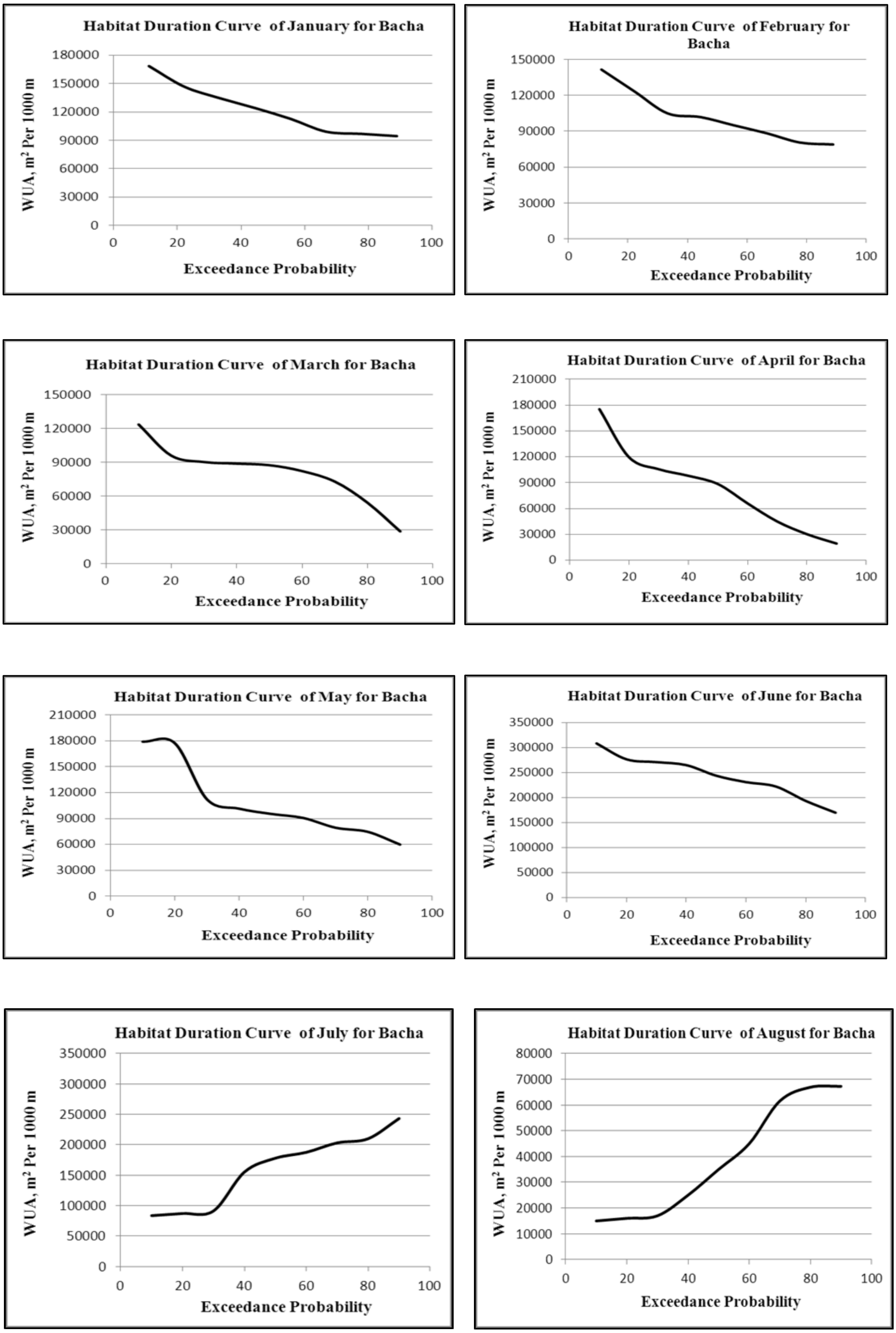


Figure 01: Habitat duration curve for Bacha fish of Gorai River in January to August

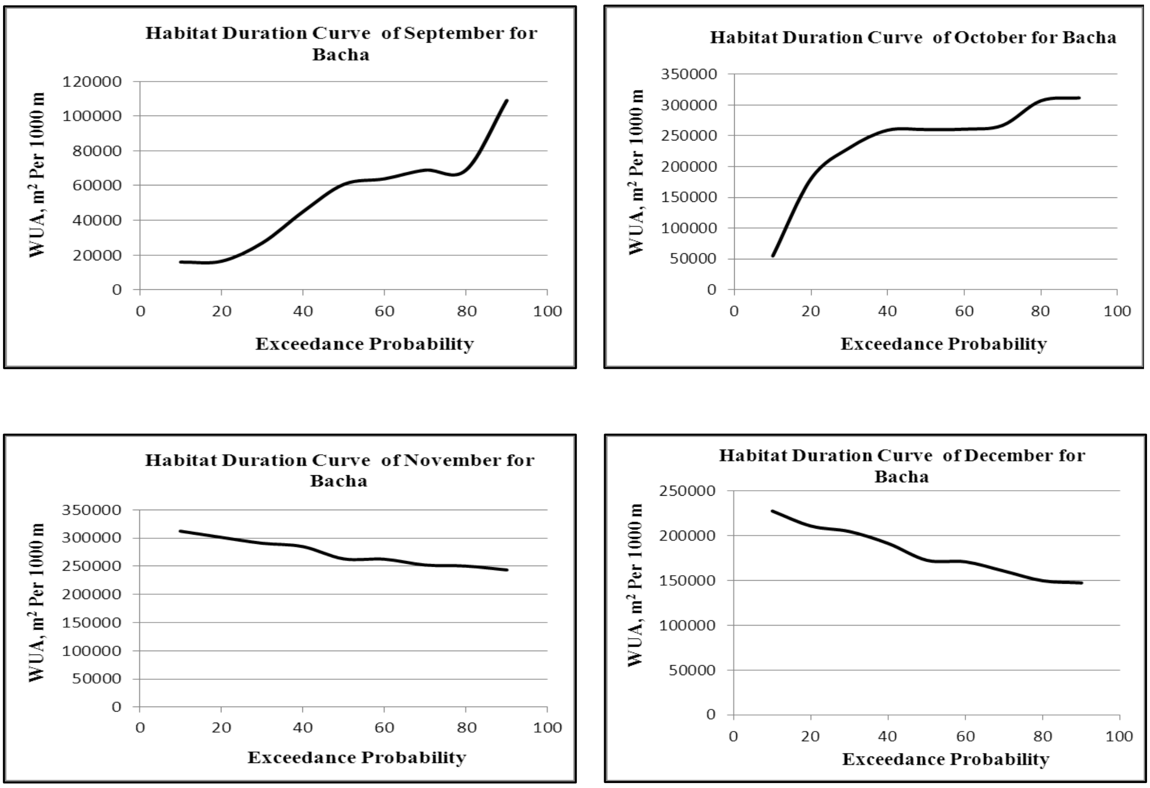


Figure 02: Habitat duration curve for Bacha fish of Gorai River in September to December

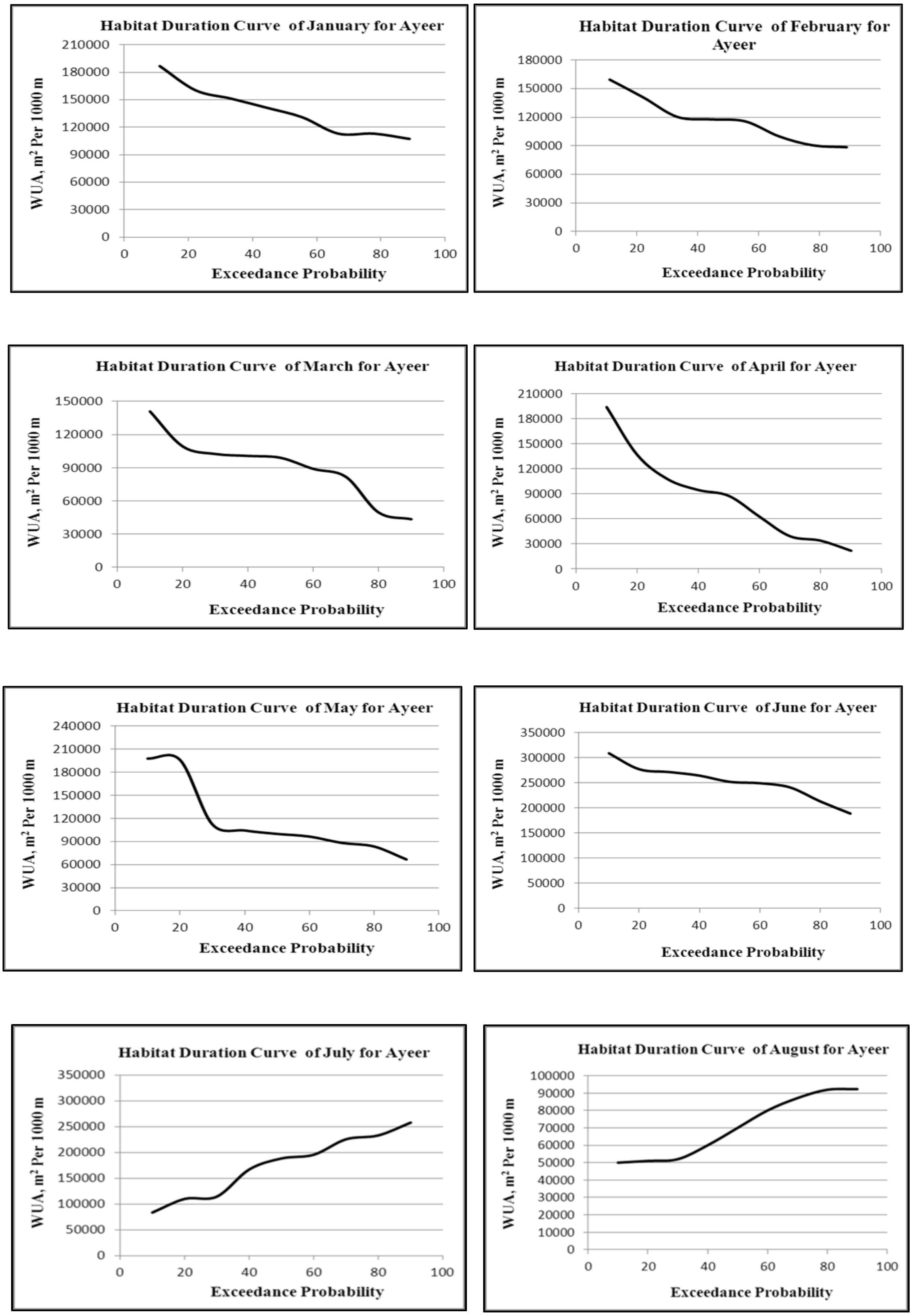


Figure 03: Habitat duration curve for Ayeer fish of Gorai River in January to August

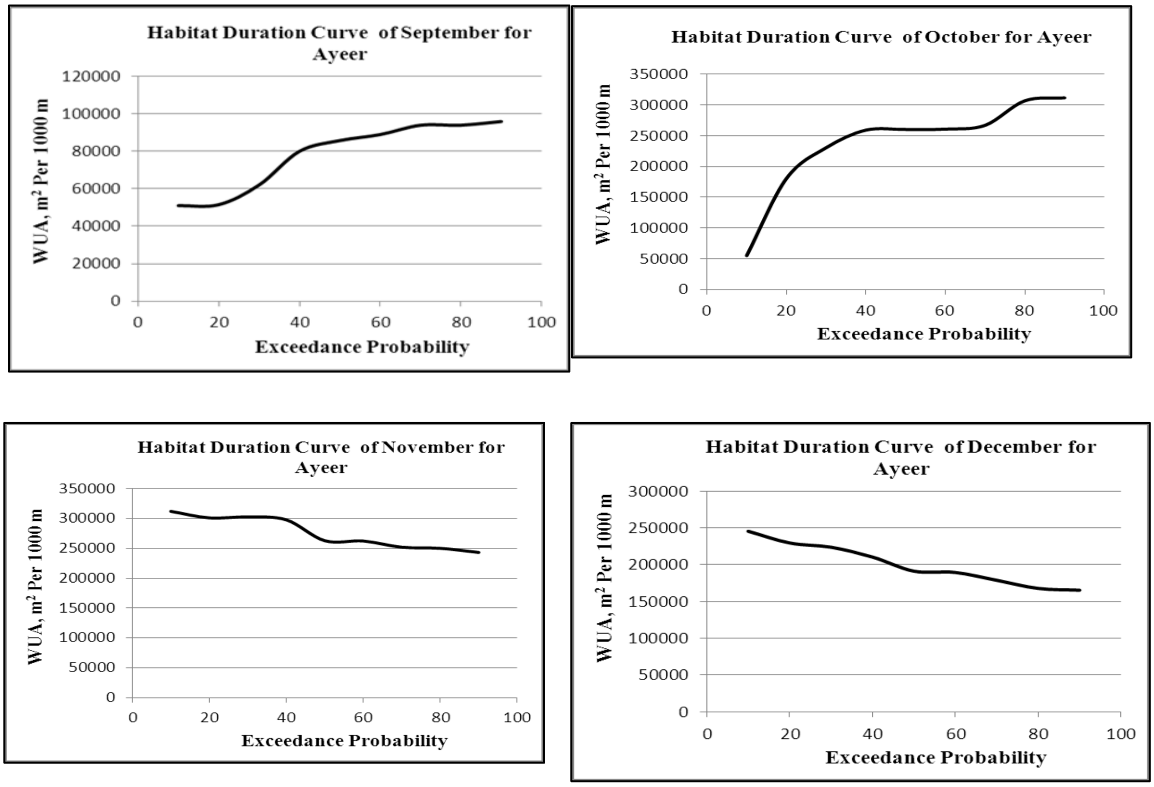


Figure 04: Habitat duration curve for Ayeer of Gorai River in September to December

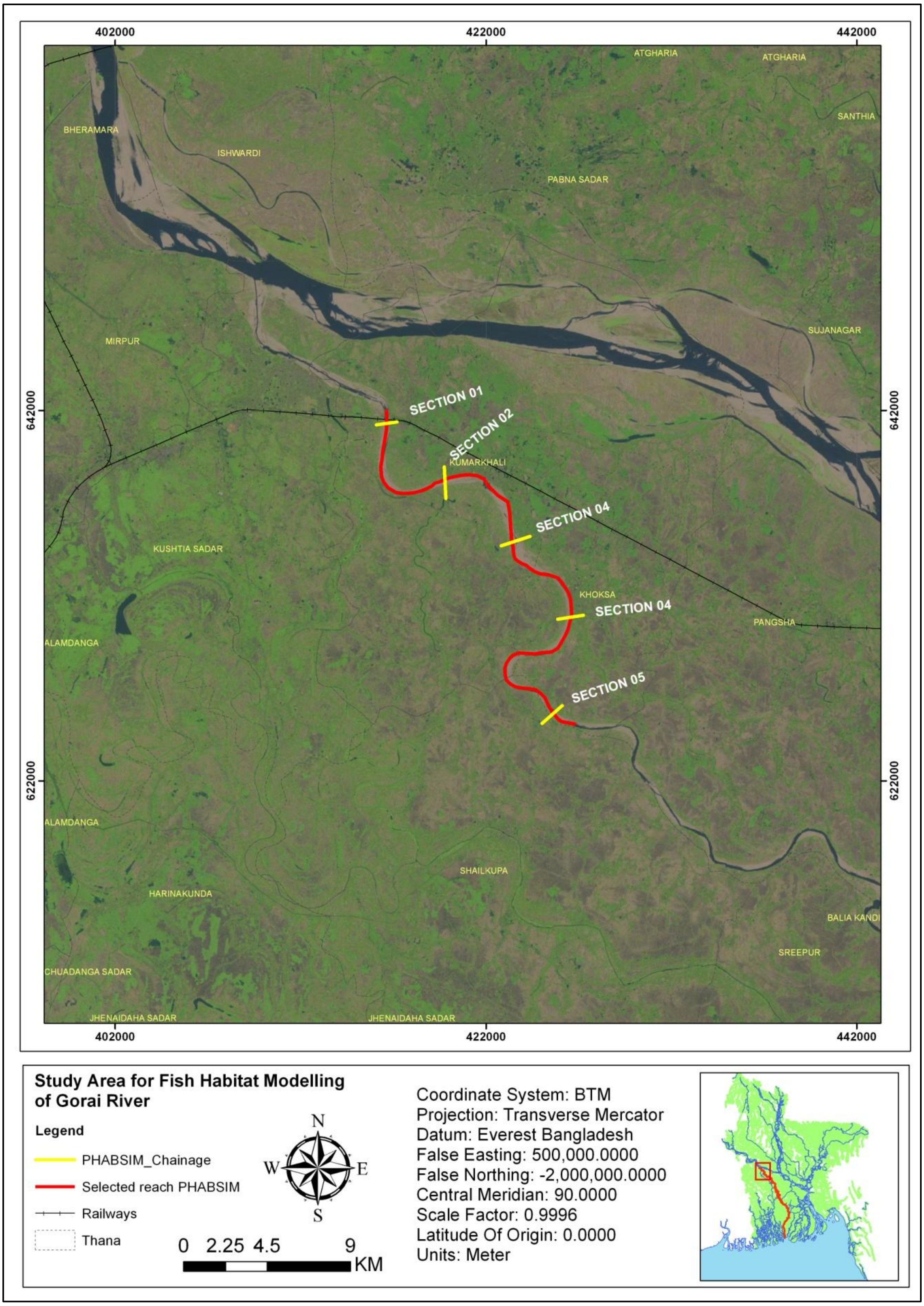


Figure 05: Site selection Map for PHABSIM model of Gorai River

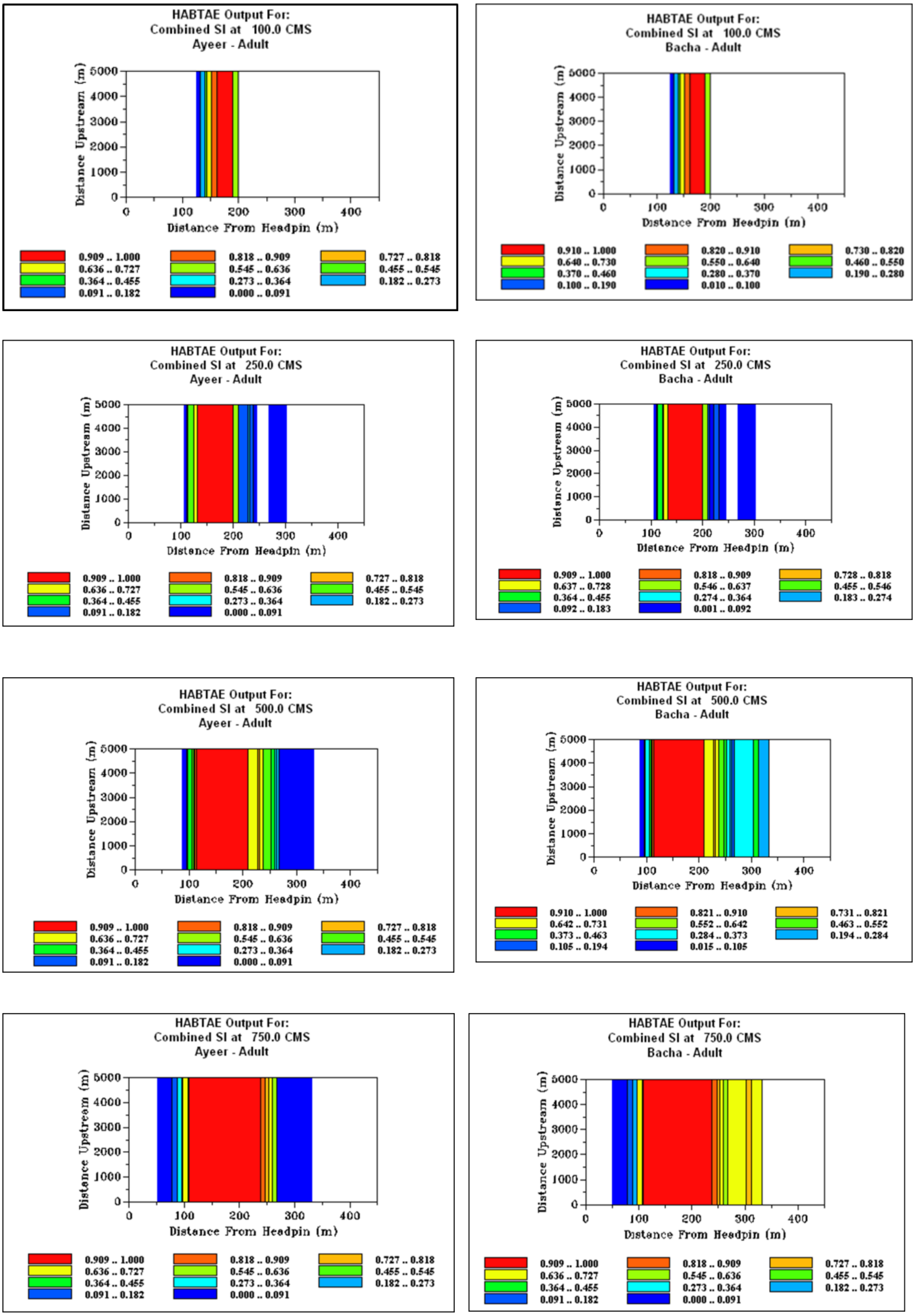


Figure 06: Variation of habitat suitability Ayeer and Bacha at Section-01 for discharge 100 to 750 m^3/s of Gorai River

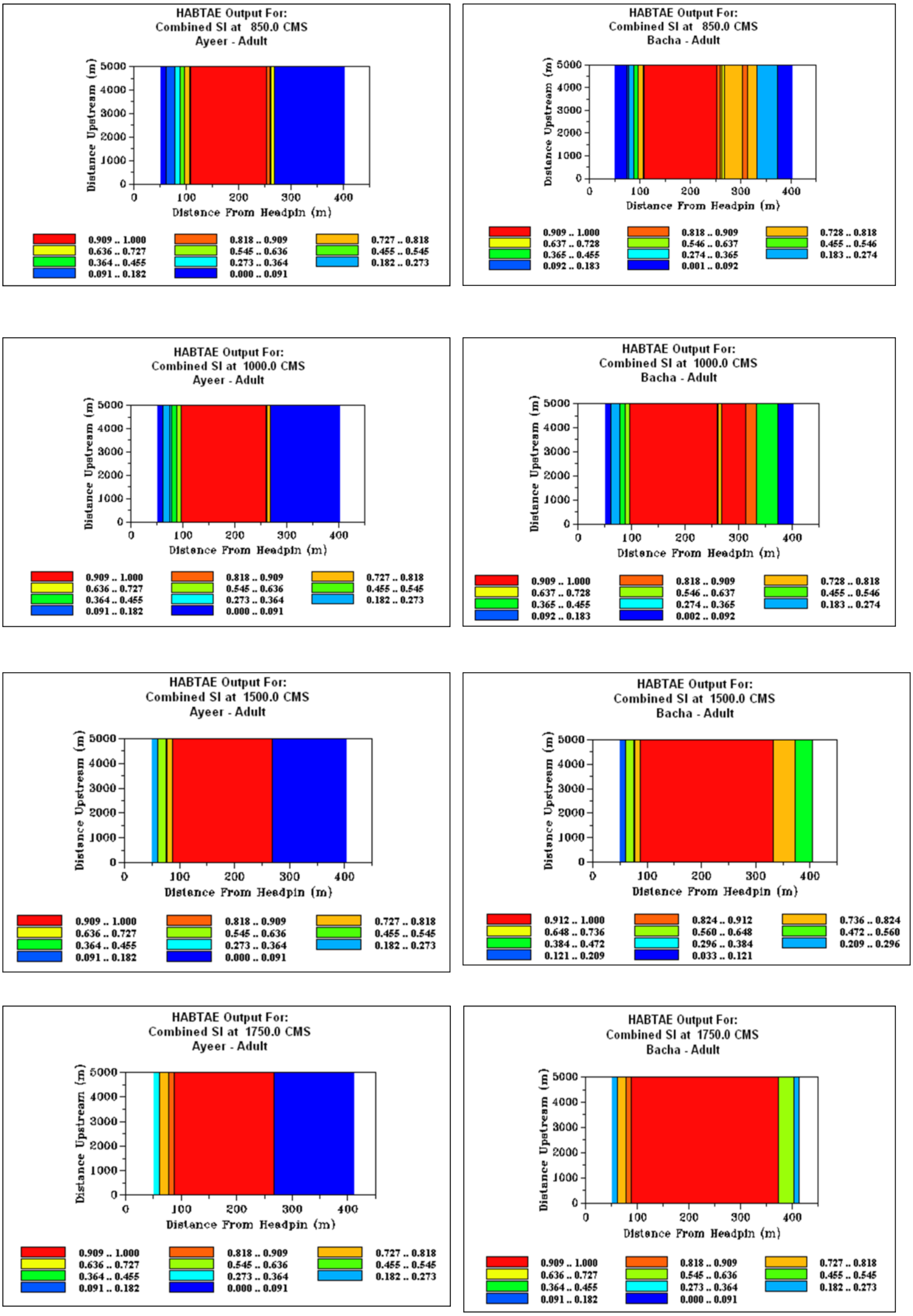


Figure 07: Variation of habitat suitability Ayeer and Bacha at Section-01 for discharge 850 to 1750 m^3/s of Gorai River

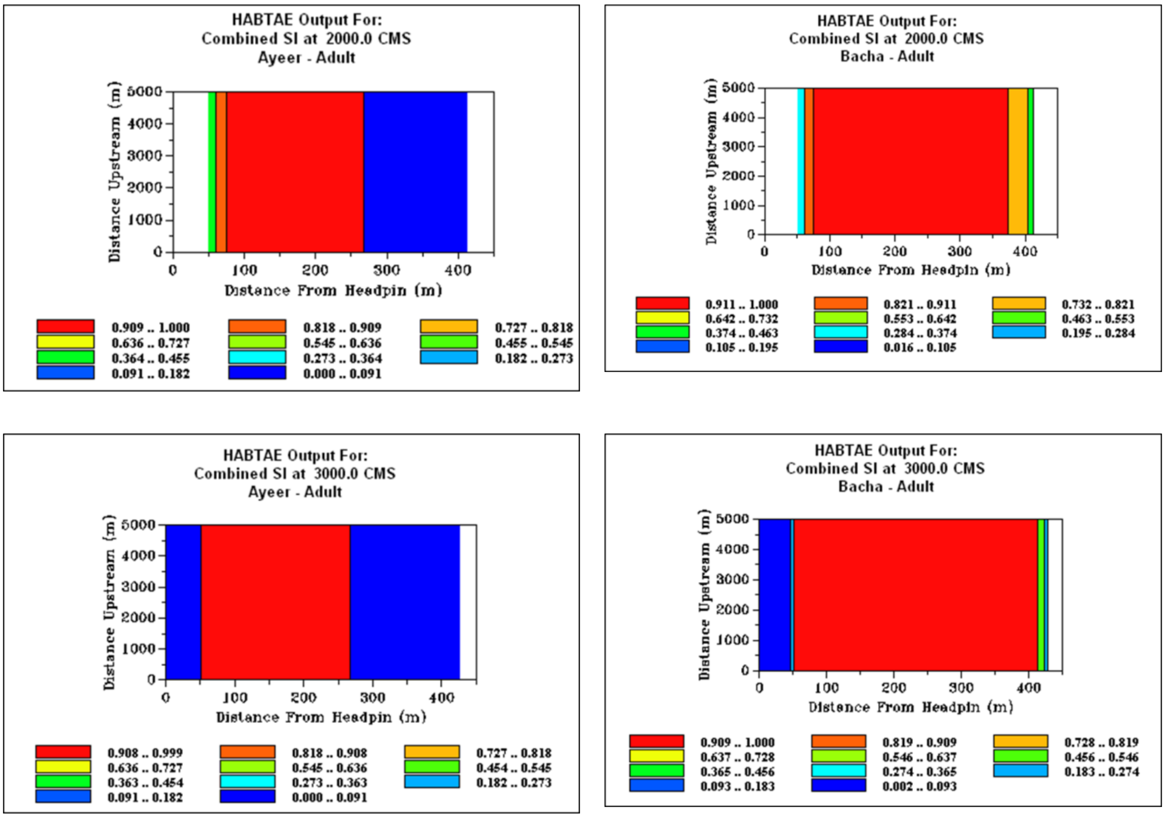
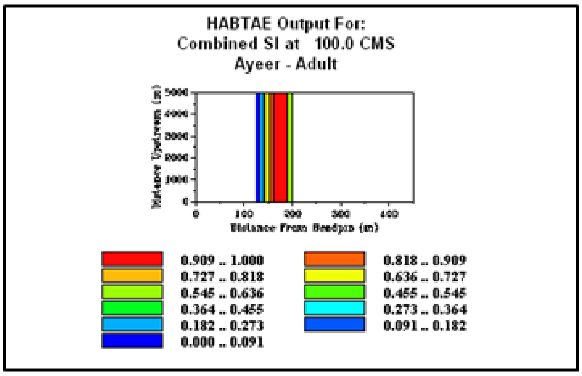
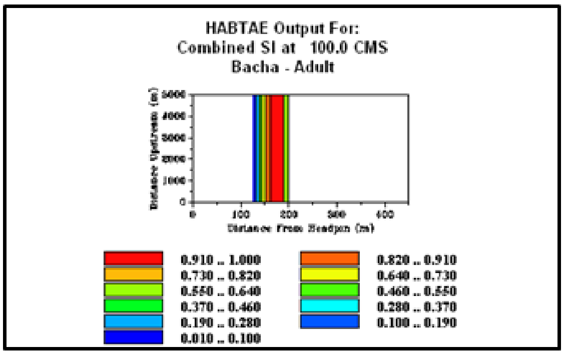
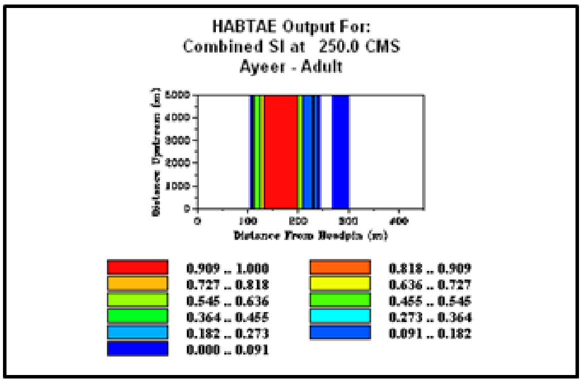
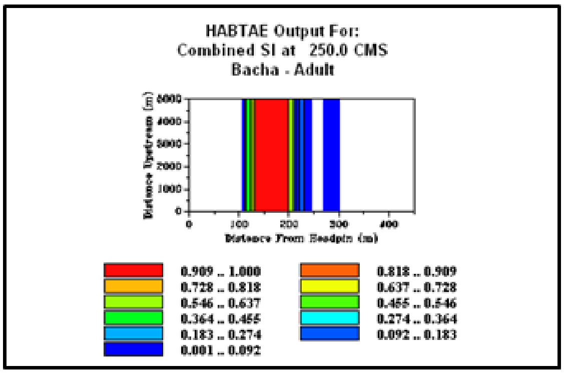


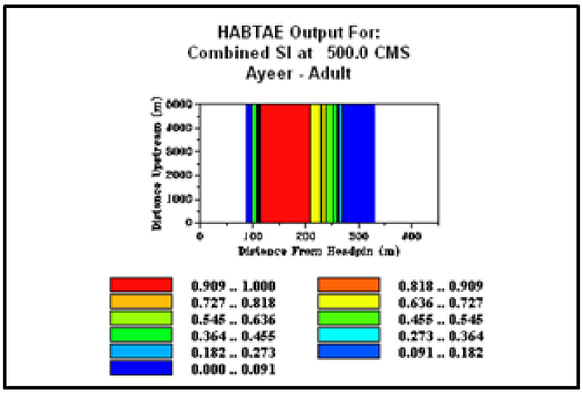
Figure 08: Variation of habitat suitability Ayeer and Bacha at Section-01 for discharge 2000 to 3000 m^3/s of Gorai River

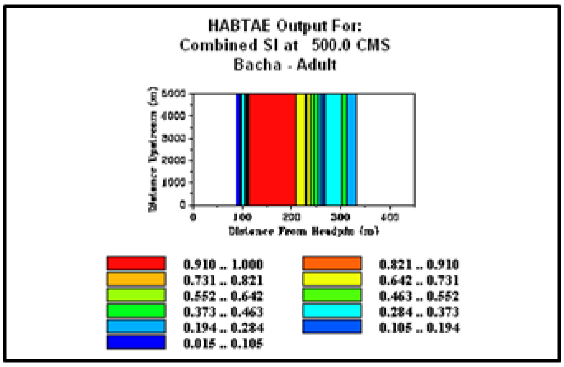


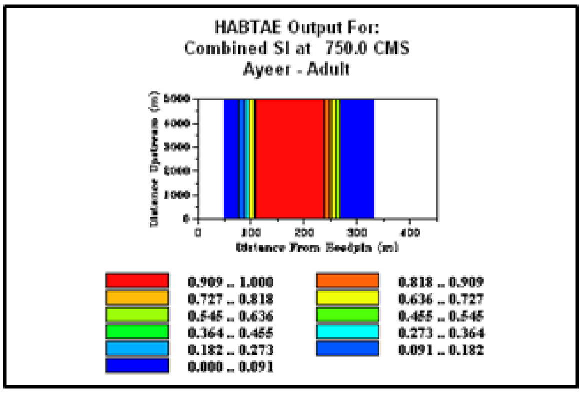












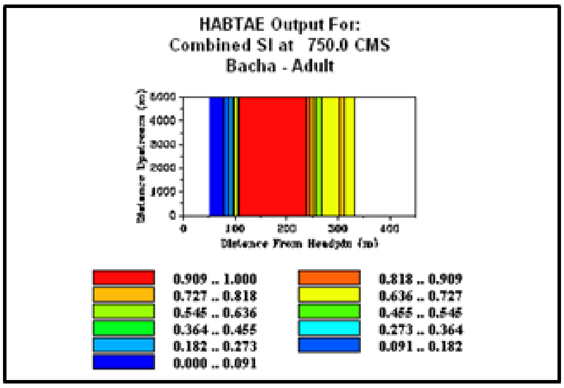


Figure 09: Variation of habitat suitability Ayeer and Bacha at Section-02 for discharge 100 to 750 m^3/s of Gorai River

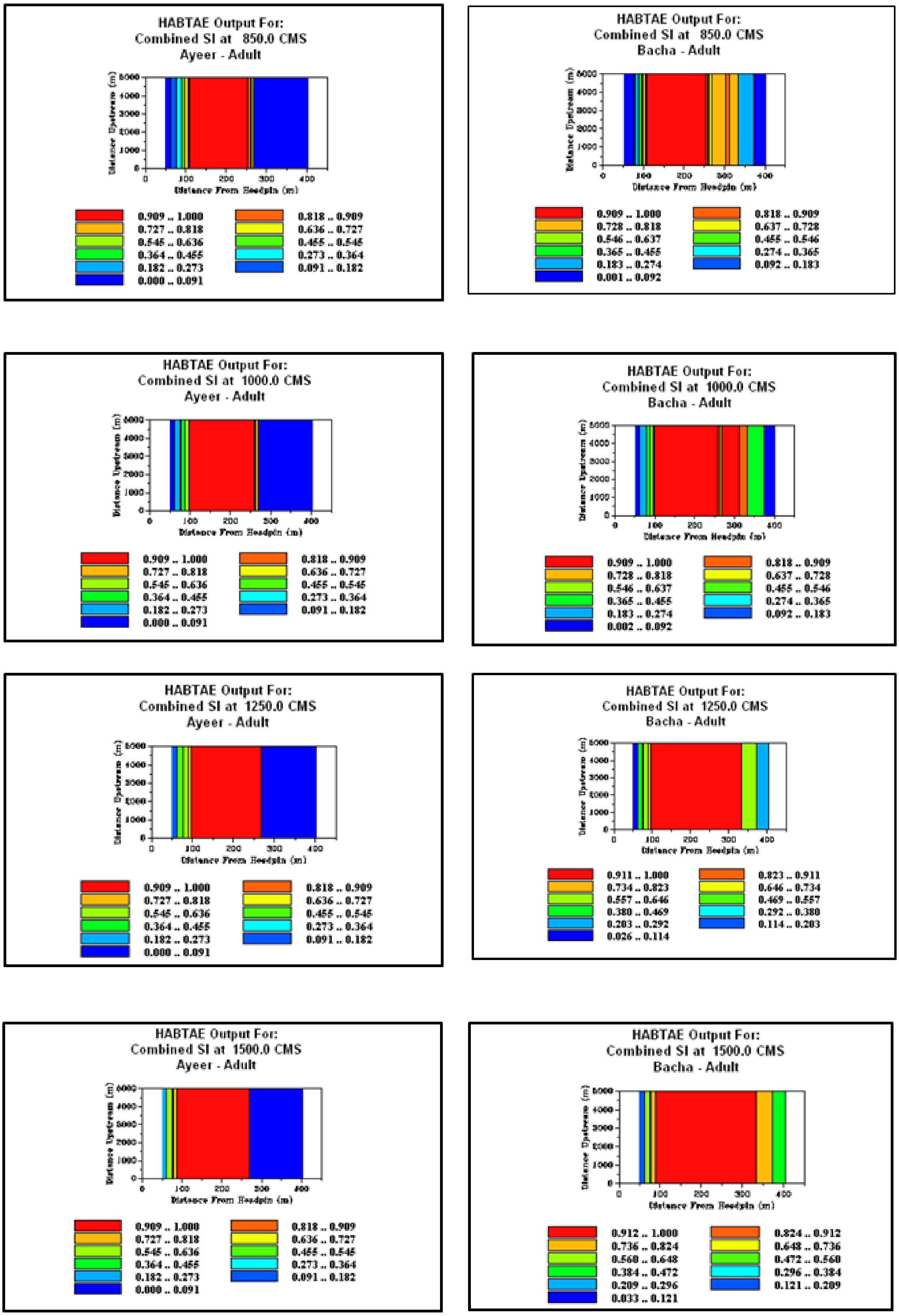


Figure 10: Variation of habitat suitability Ayeer and Bacha at Section-02 for discharge 850 to 1500 m^3/s of Gorai River

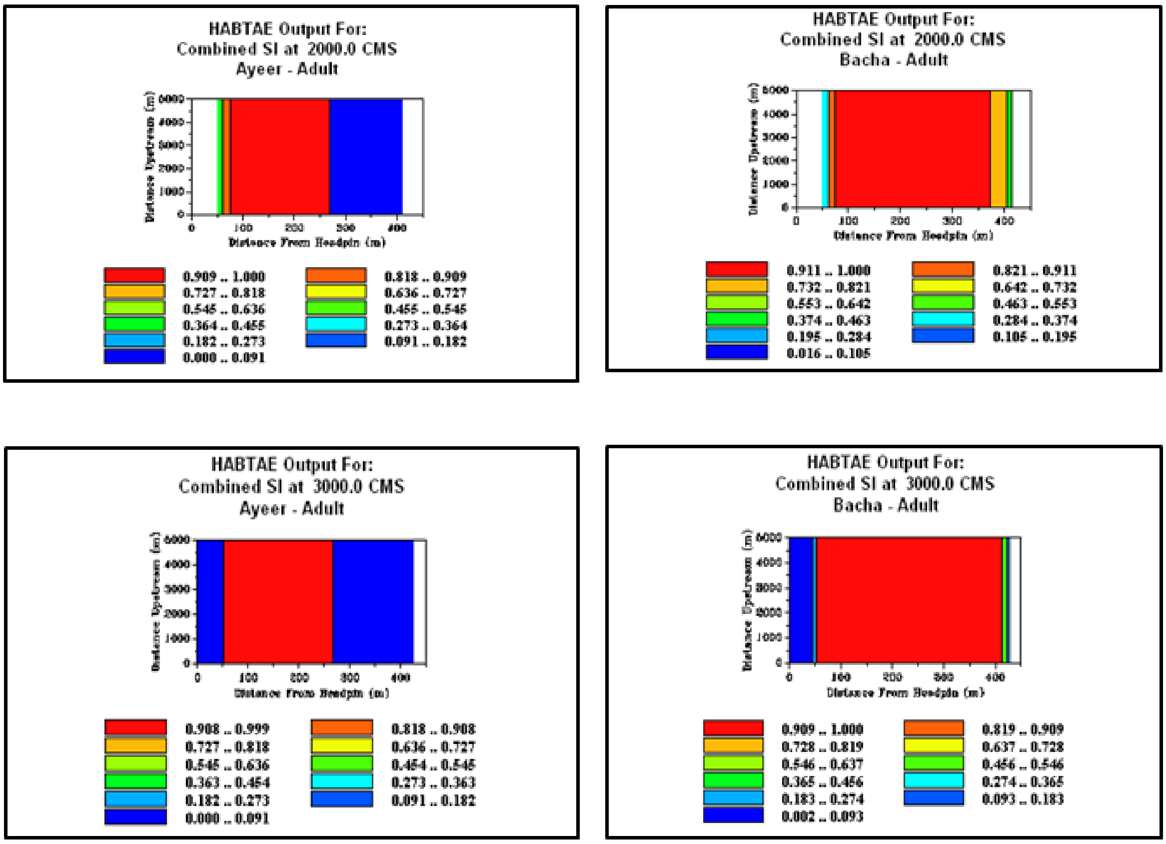


Figure 11: Variation of habitat suitability Ayeer and Bacha at Section-02 for discharge 2000 to 3000 m^3/s of Gorai River

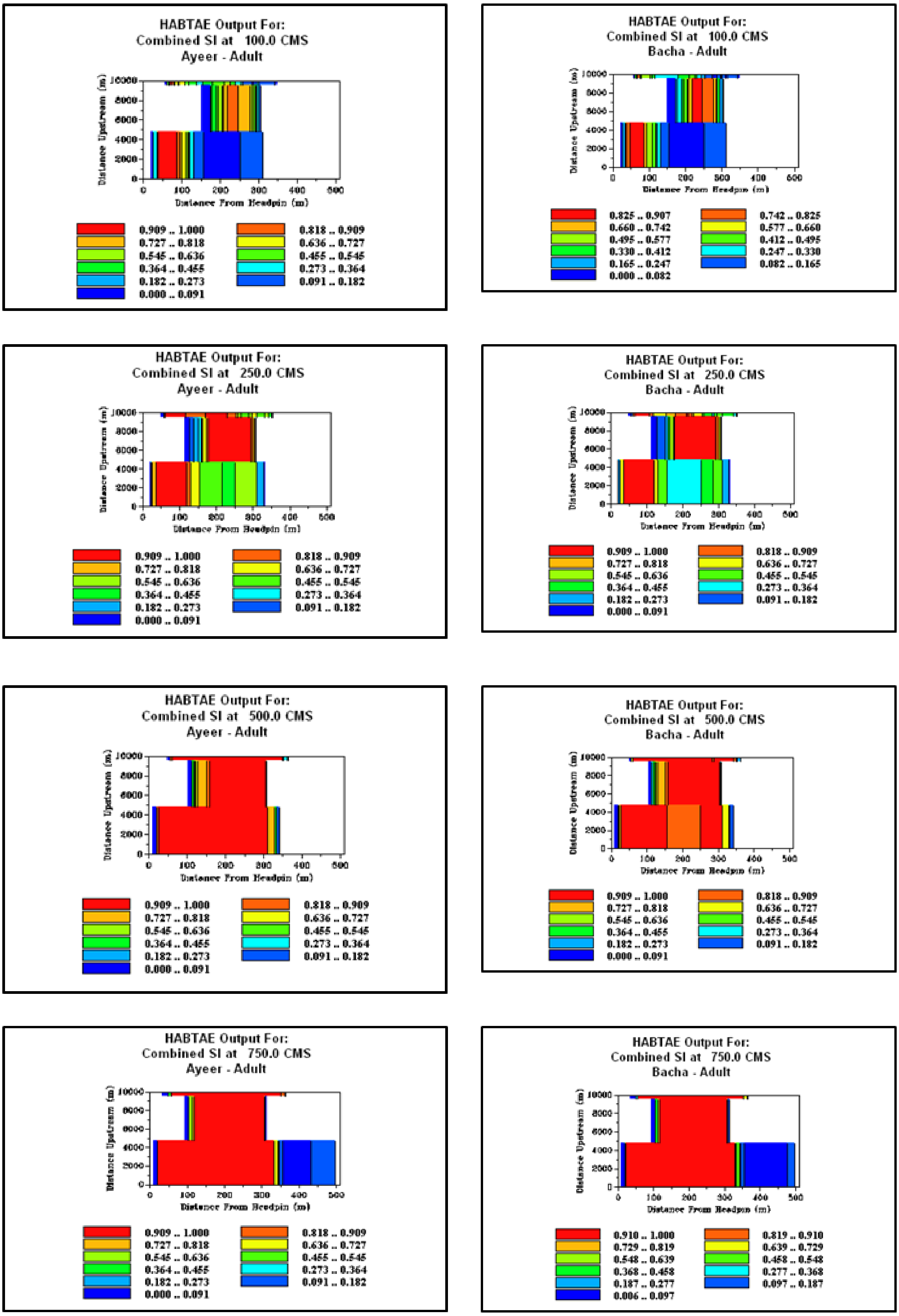


Figure 12: Variation of habitat suitability Ayeer and Bacha at Section-03 for discharge 100 to 750 m^3/s of Gorai River

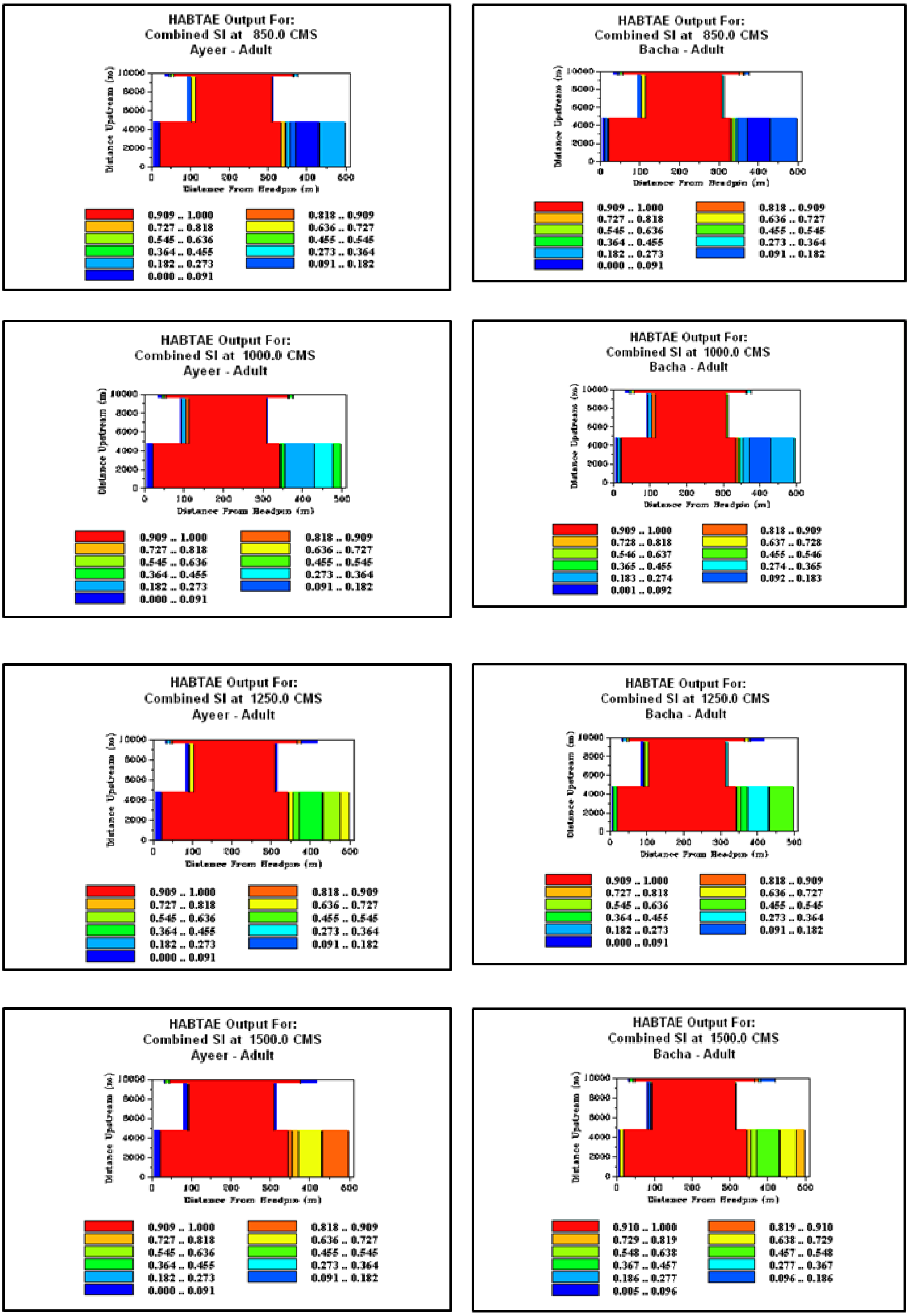


Figure 13: Variation of habitat suitability Ayeer and Bacha at Section-03 for discharge 850 to 1500 m^3/s of Gorai River

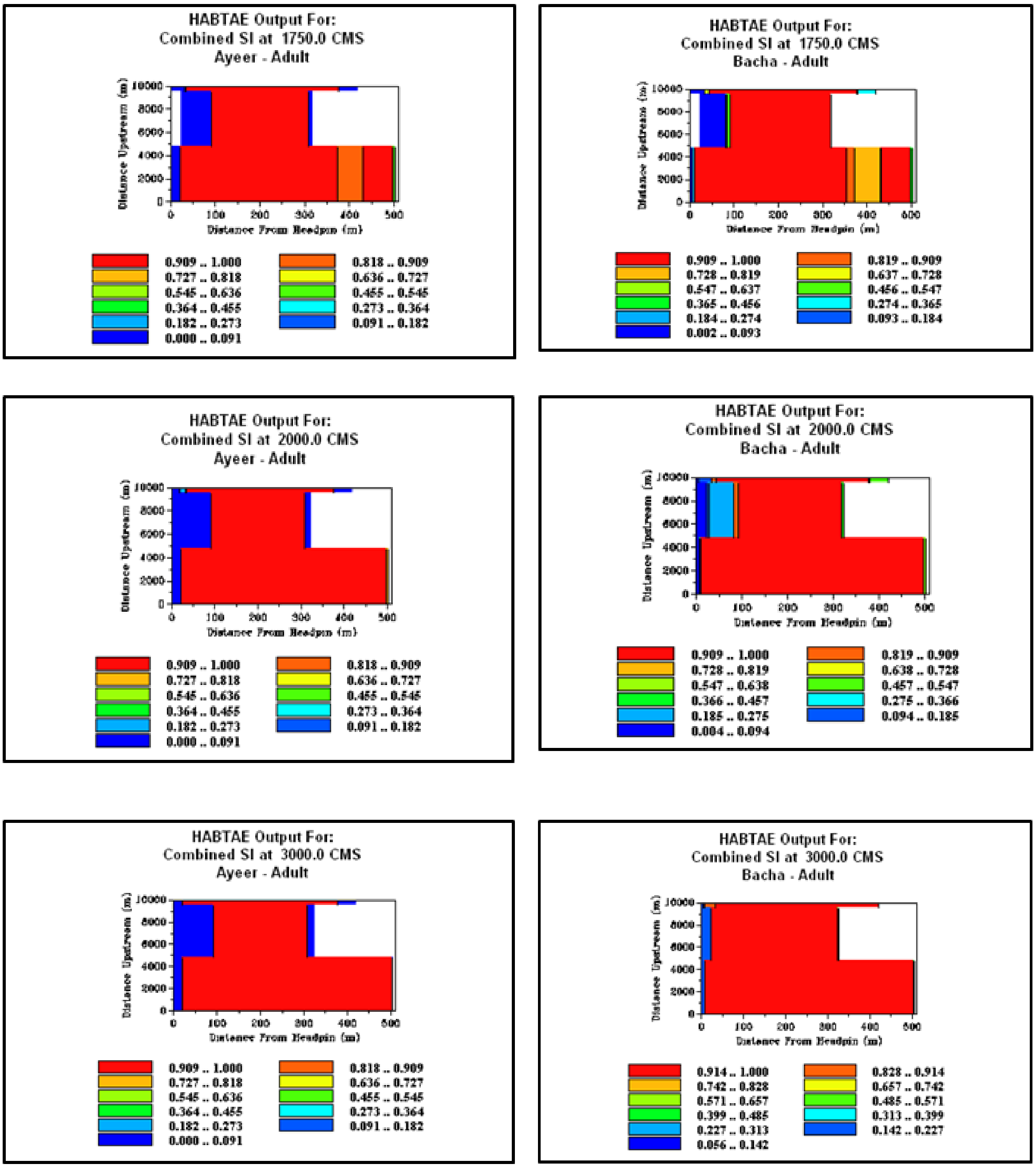


Figure 14: Variation of habitat suitability Ayeer and Bacha at Section-03 for discharge 1750 to 3000 m^3/s of Gorai River

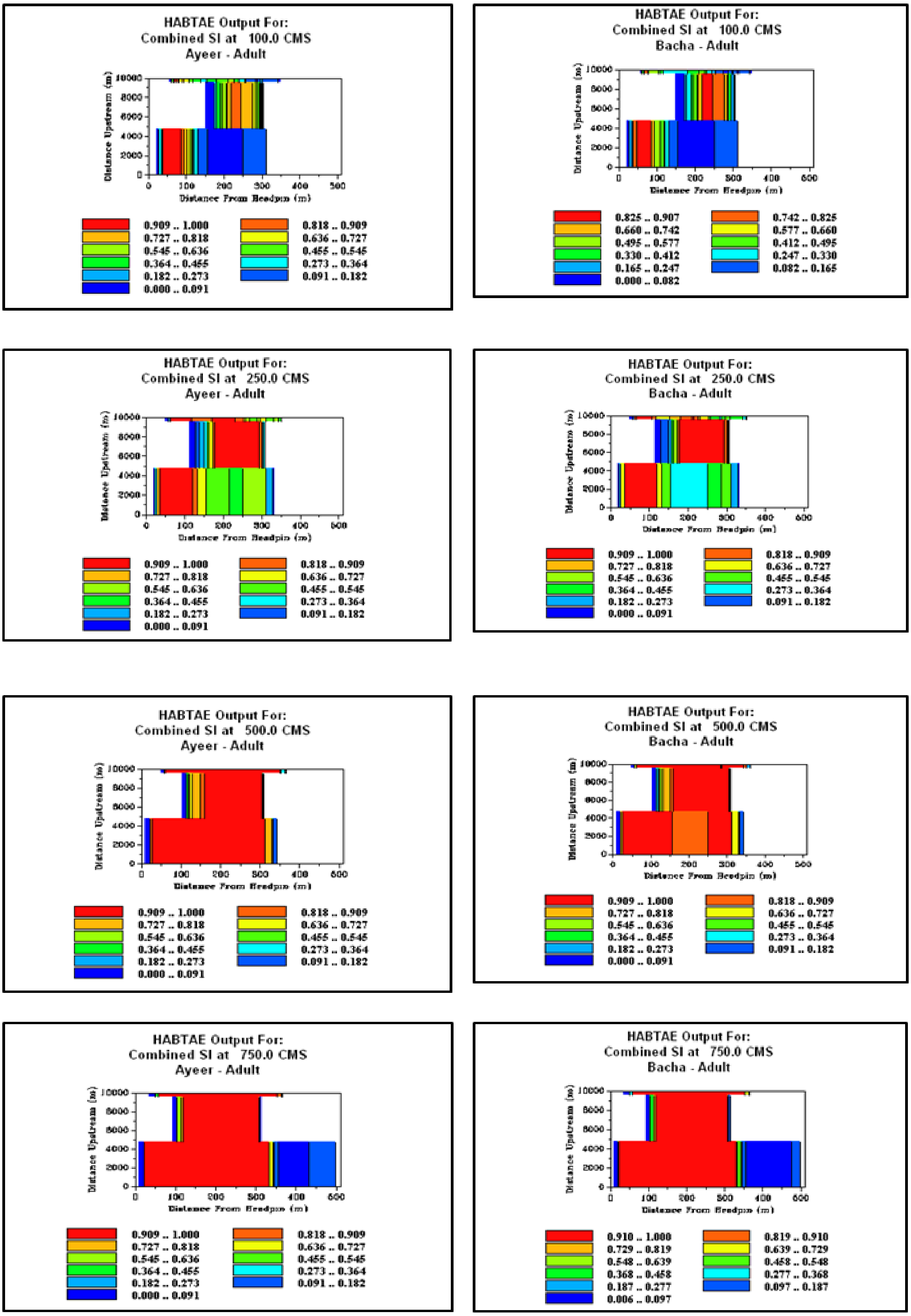


Figure 15: Variation of habitat suitability Ayeer and Bacha at Section-04 for discharge 100 to 750 m^3/s of Gorai River

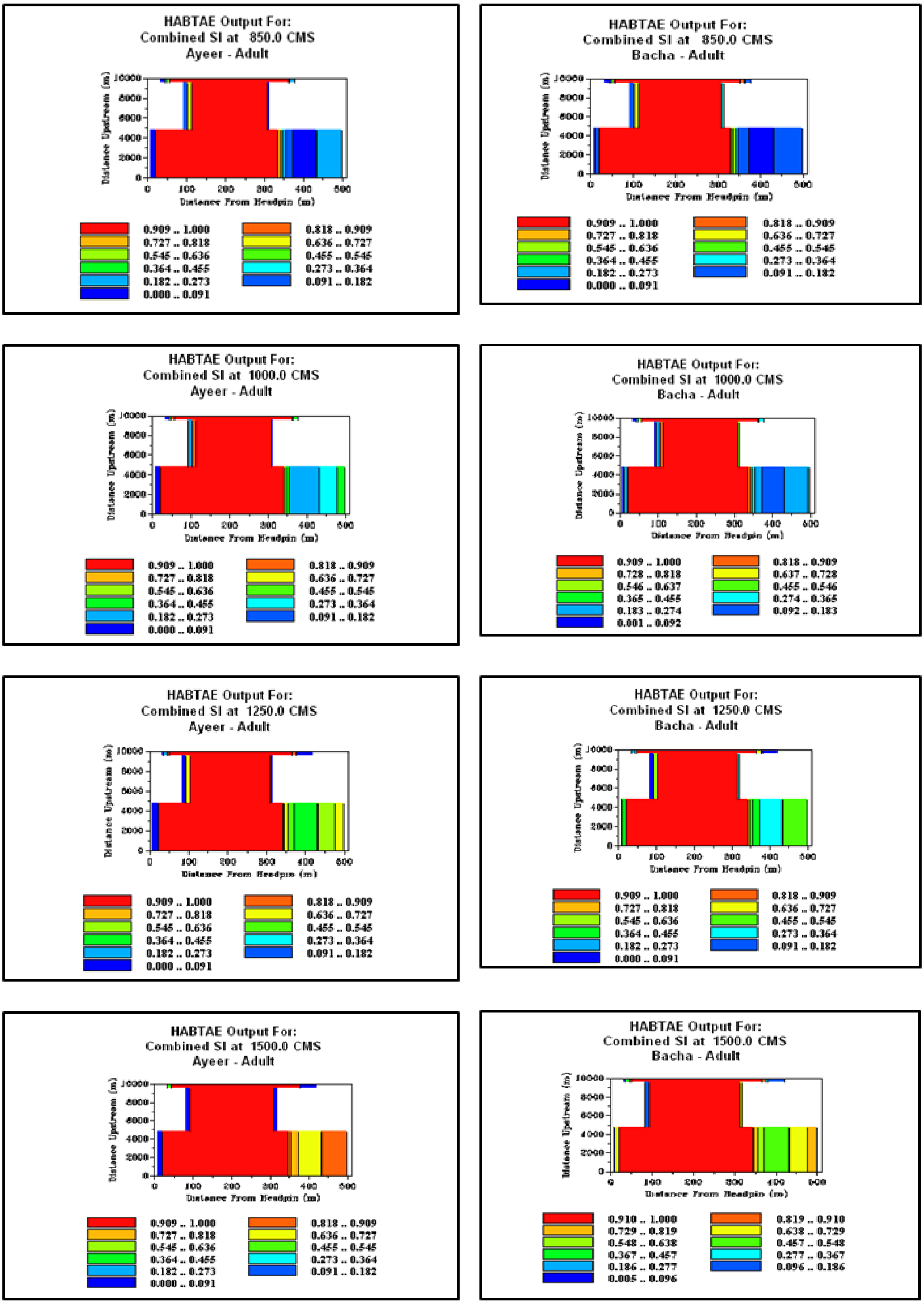


Figure 16: Variation of habitat suitability Ayeer and Bacha at Section-04 for discharge 850 to 1500 m^3/s of Gorai River

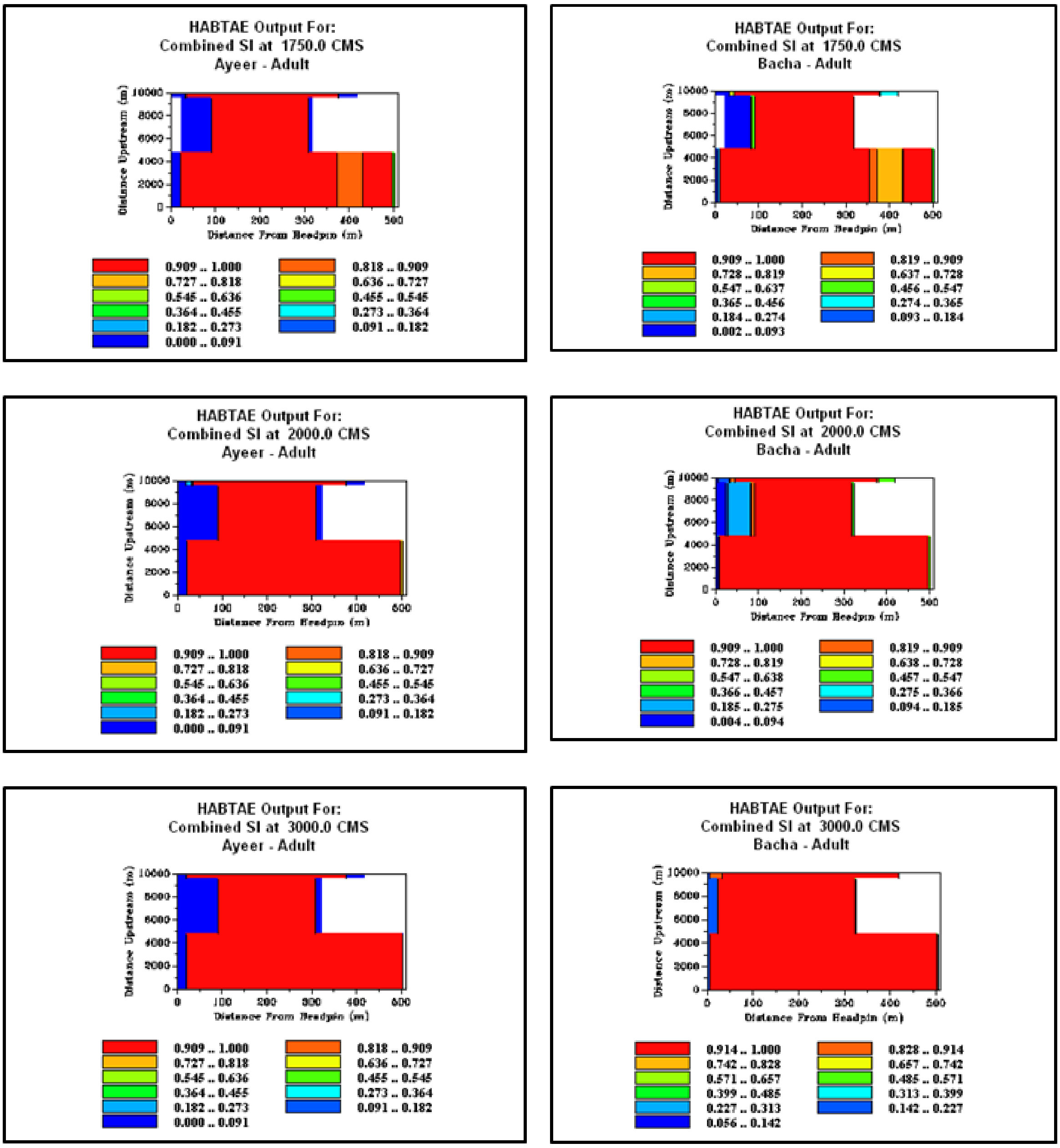


Figure 17: Variation of habitat suitability Ayeer and Bacha at Section-04 for discharge 1750 to 3000 m^3/s of Gorai River

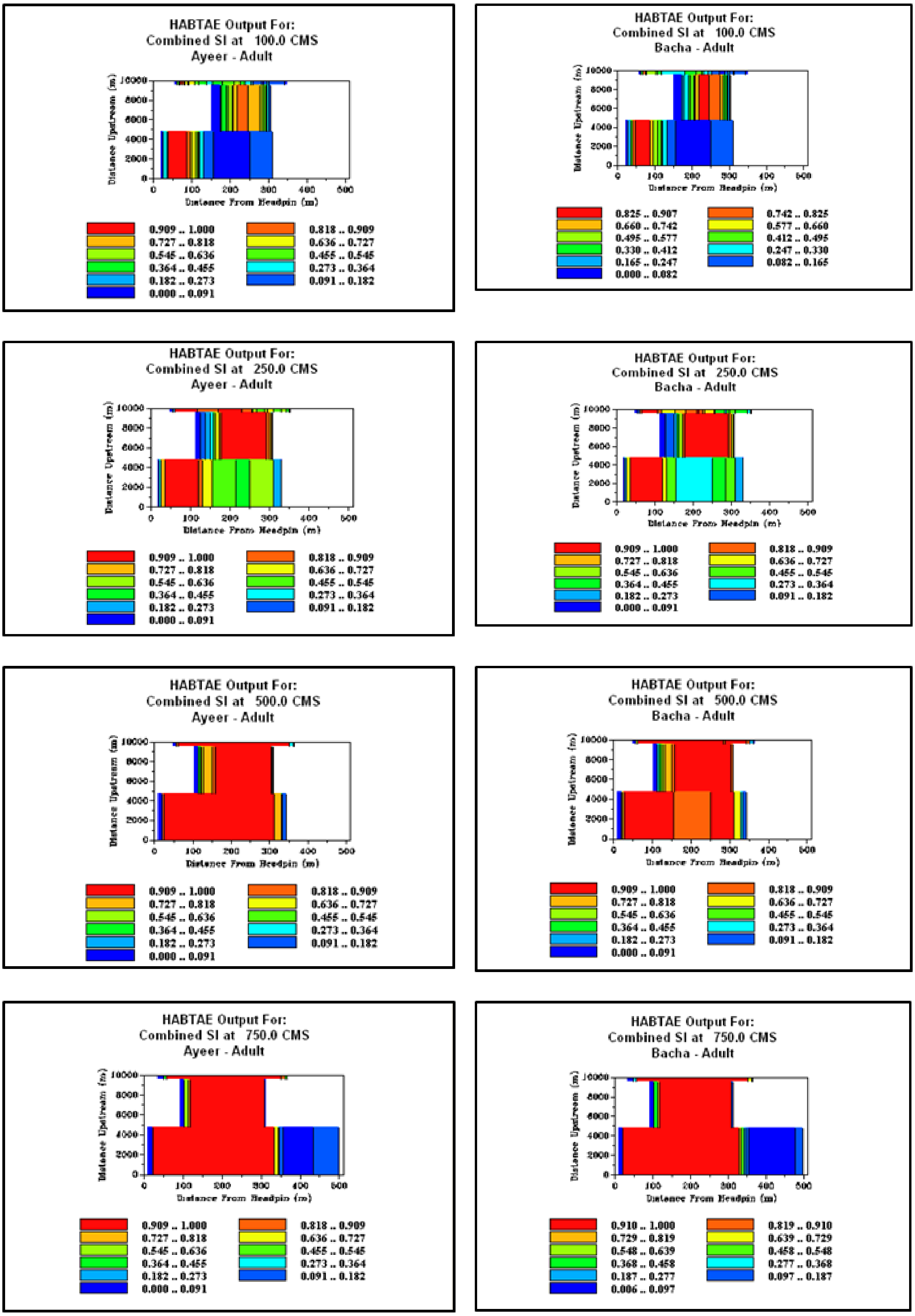


Figure 18: Variation of habitat suitability Ayeer and Bacha at Section-05 for discharge 100 to 750 m^3/s of Gorai River

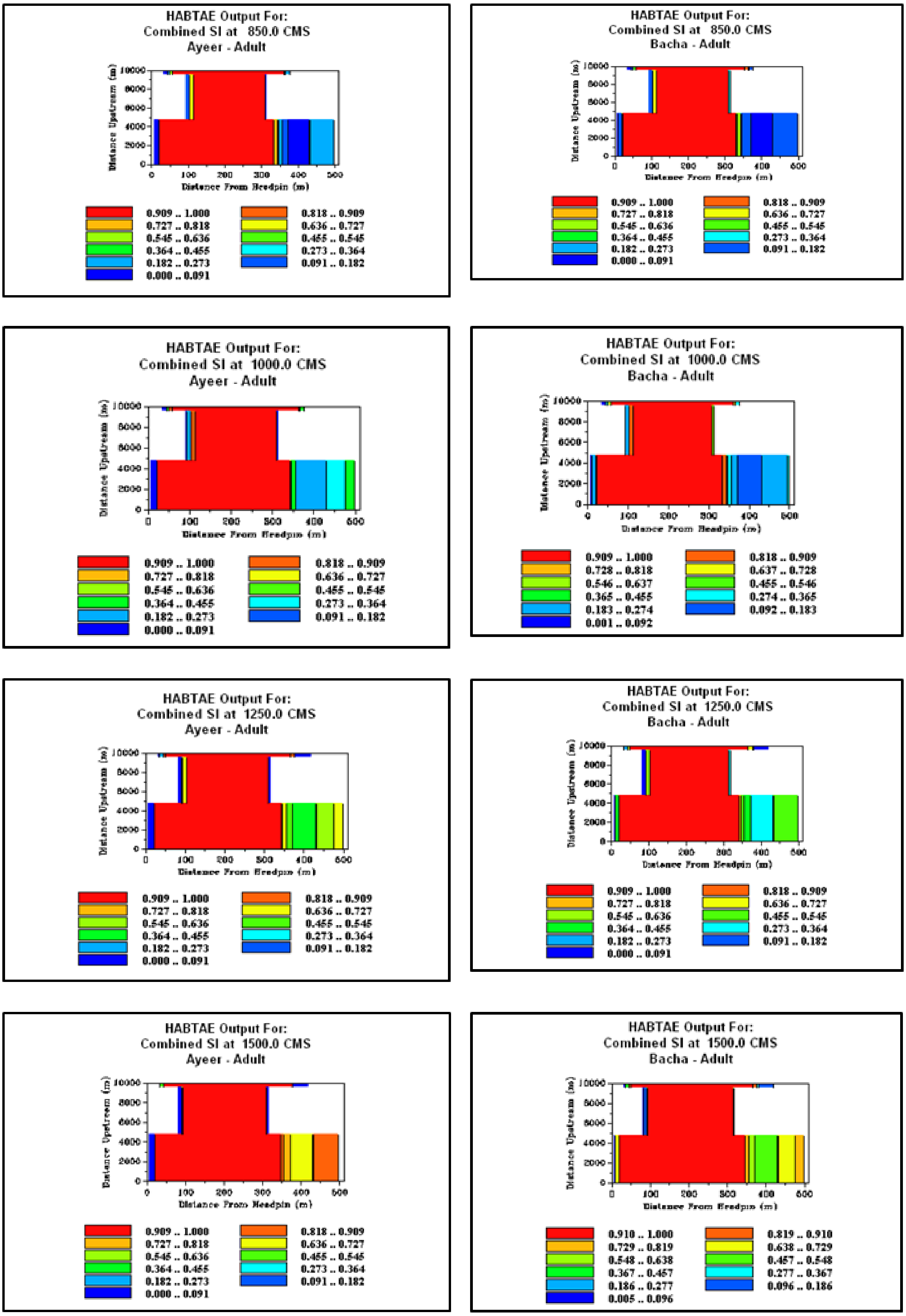


Figure 19: Variation of habitat suitability Ayeer and Bacha at Section-05 for discharge 850 to 1500 m^3/s of Gorai River

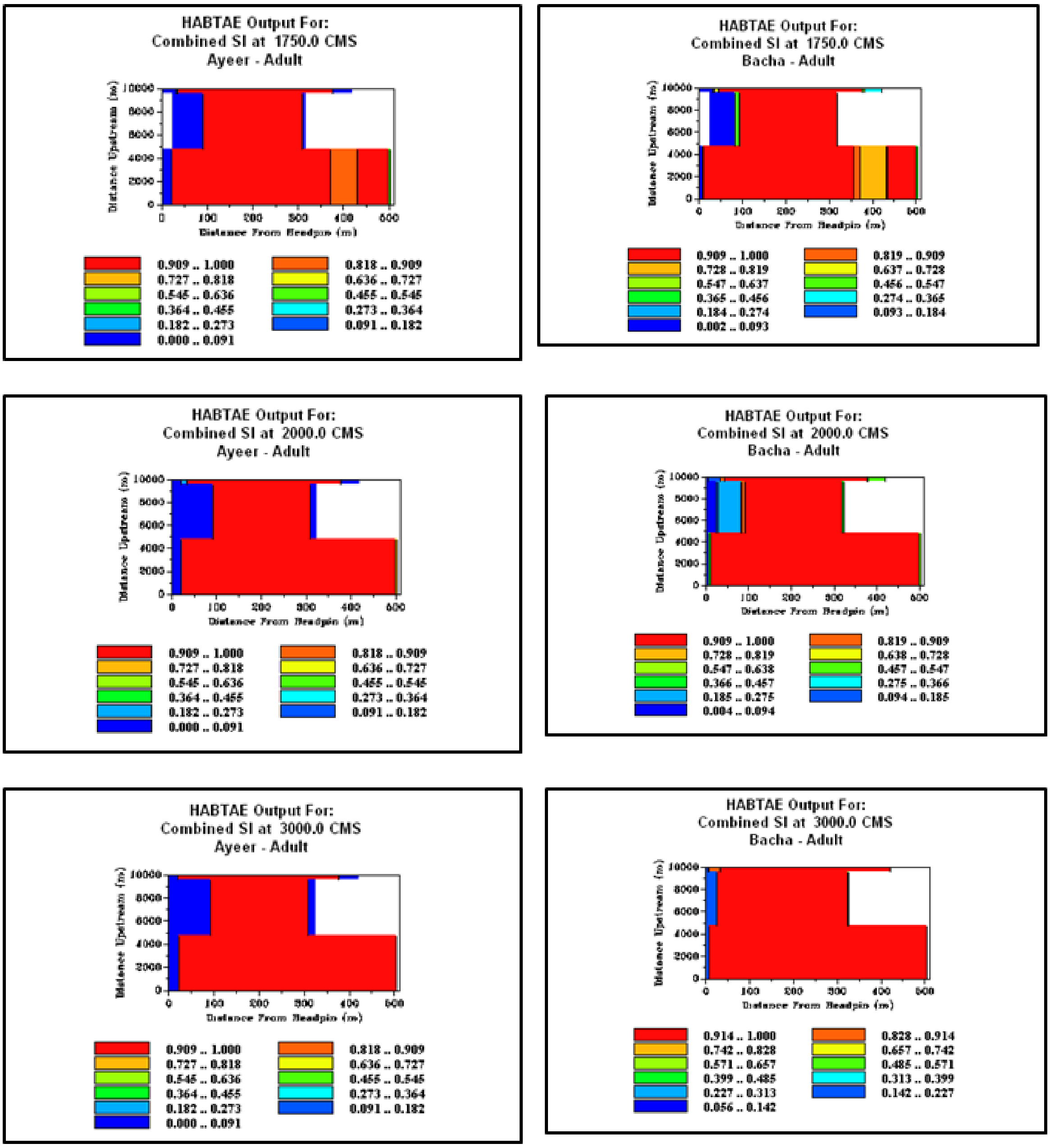


Figure 20: Variation of habitat suitability Ayeer and Bacha at Section-05 for discharge 1750 to 3000 m^3/s of Gorai River

APPENDIX-D

Monthly Habitat Duration Curve and variation of Habitat Suitability of Madhumati River

APPENDIX-D

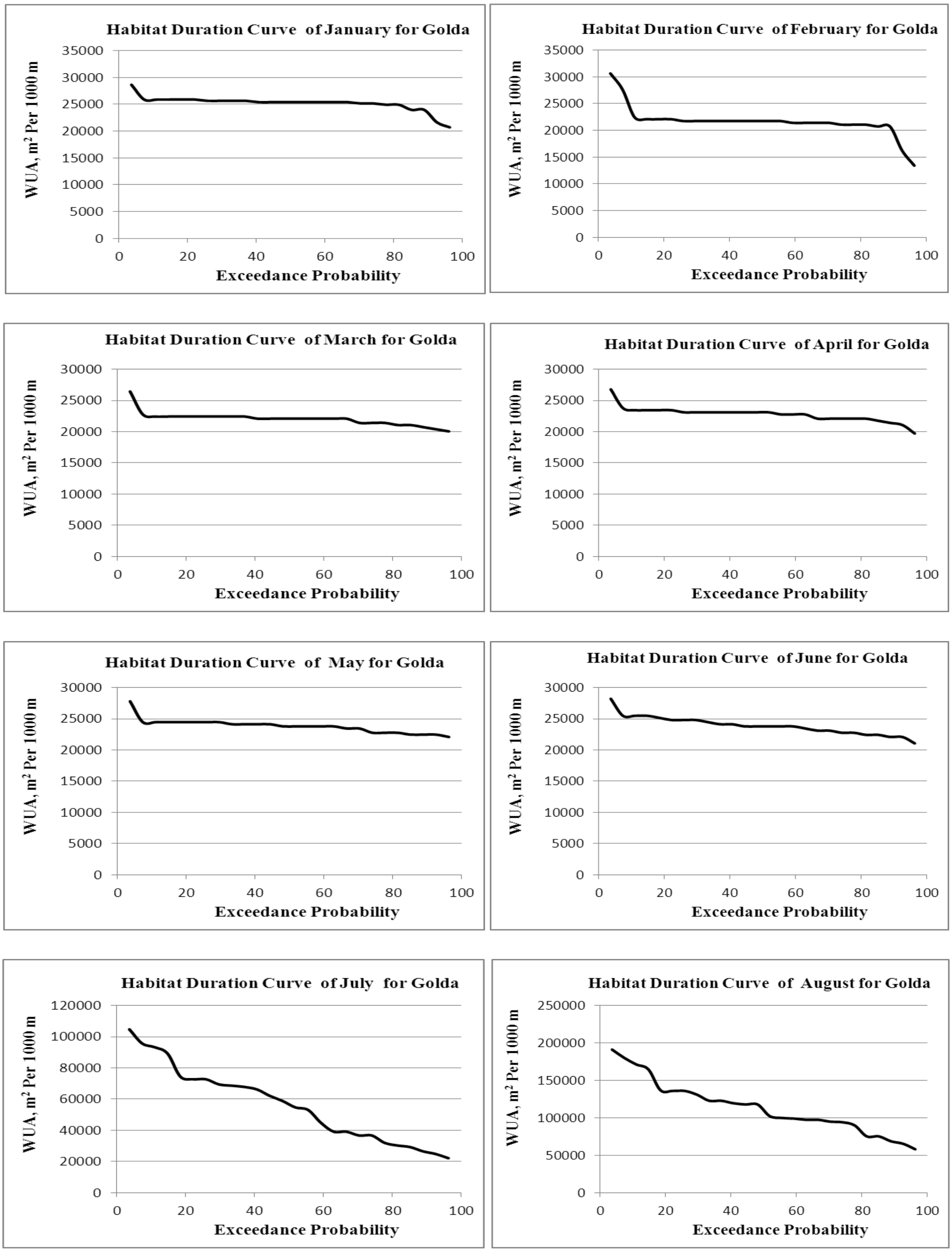


Figure 01: Habitat duration curve for Golda fish of Madhumati River in January to August

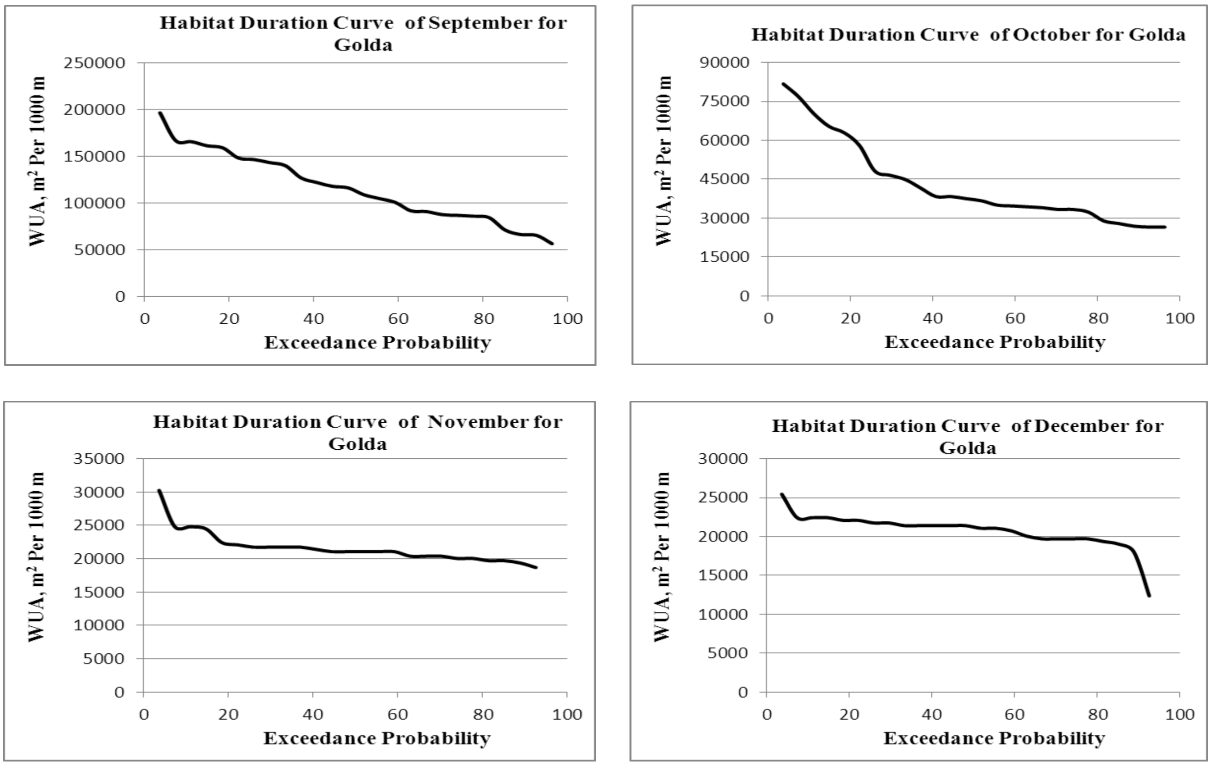


Figure 02: Habitat duration curve for Golda fish of Madhumati River in September to December

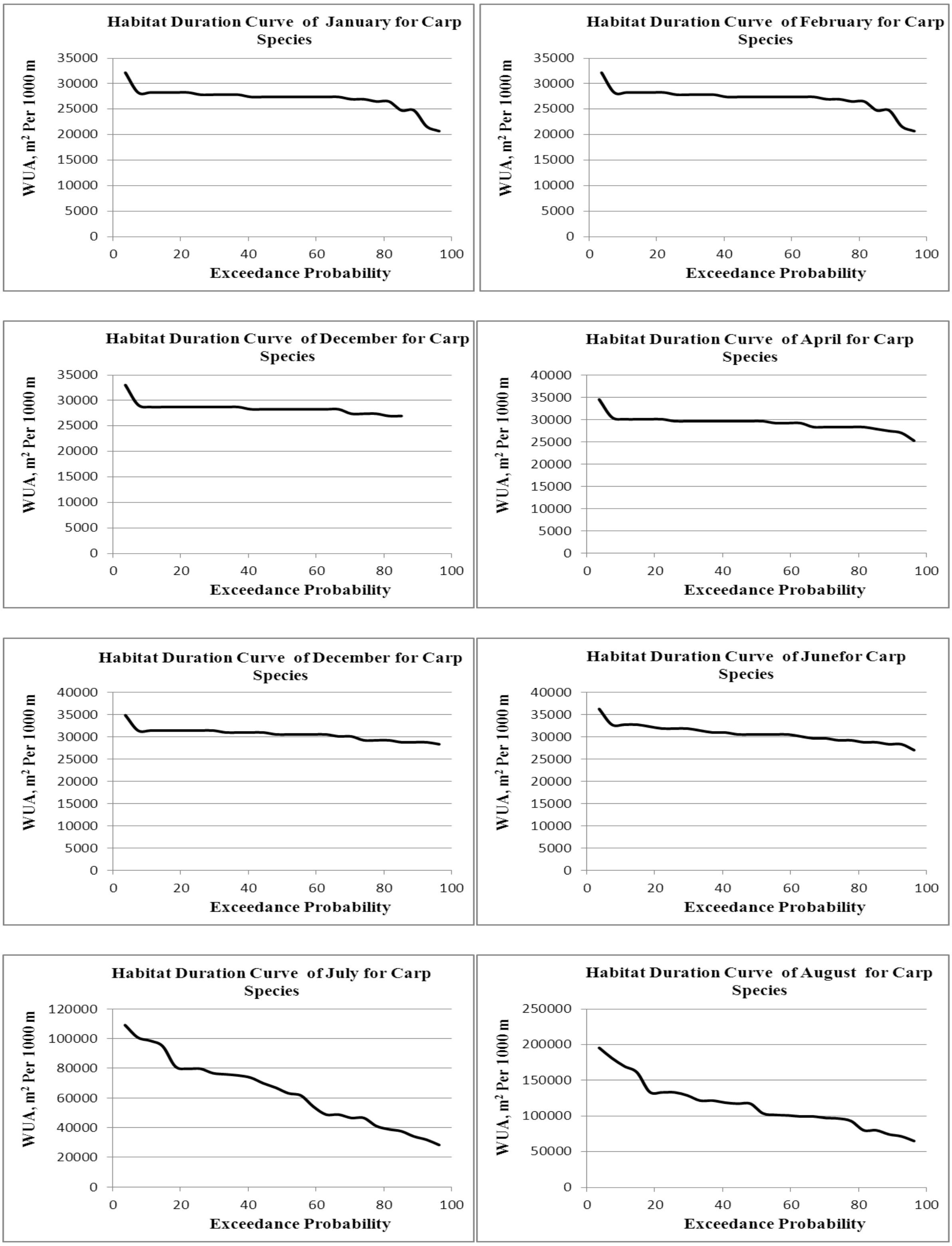


Figure 03: Habitat duration curve for Carp fish Species of Madhumati River in January to August

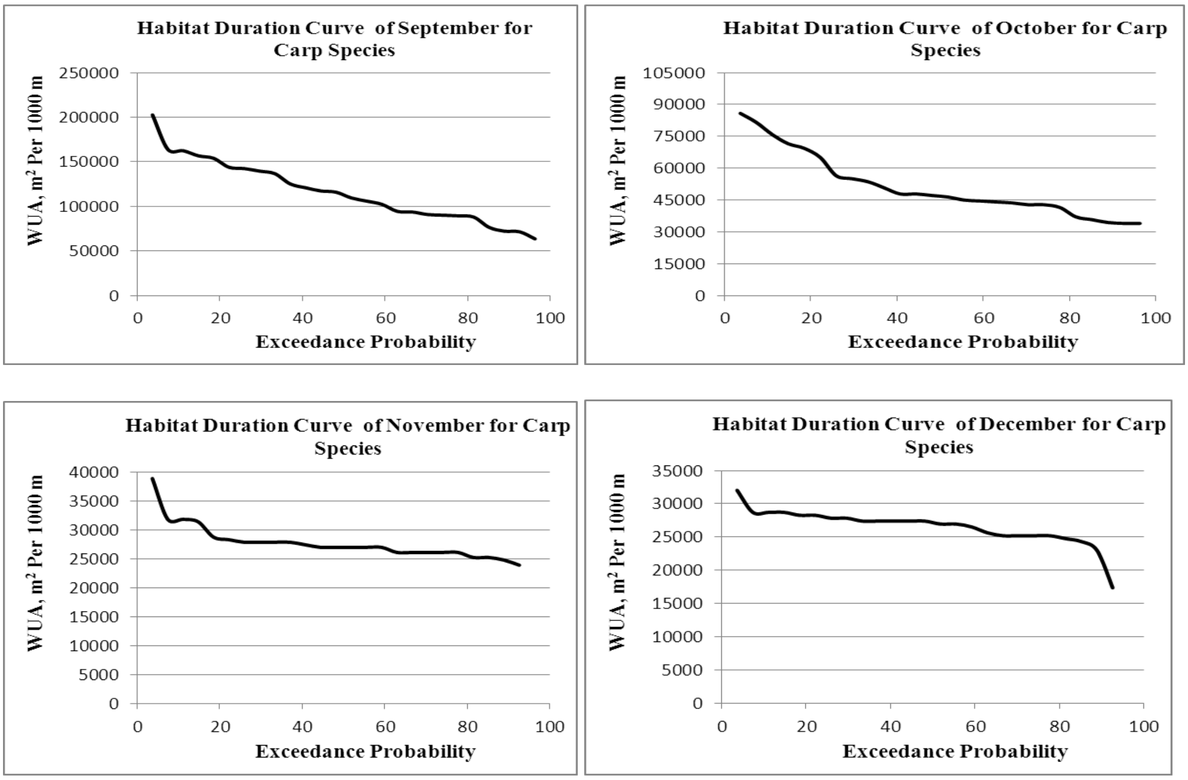


Figure 04: Habitat duration curve for Carp Species of Madhumati River in September to December

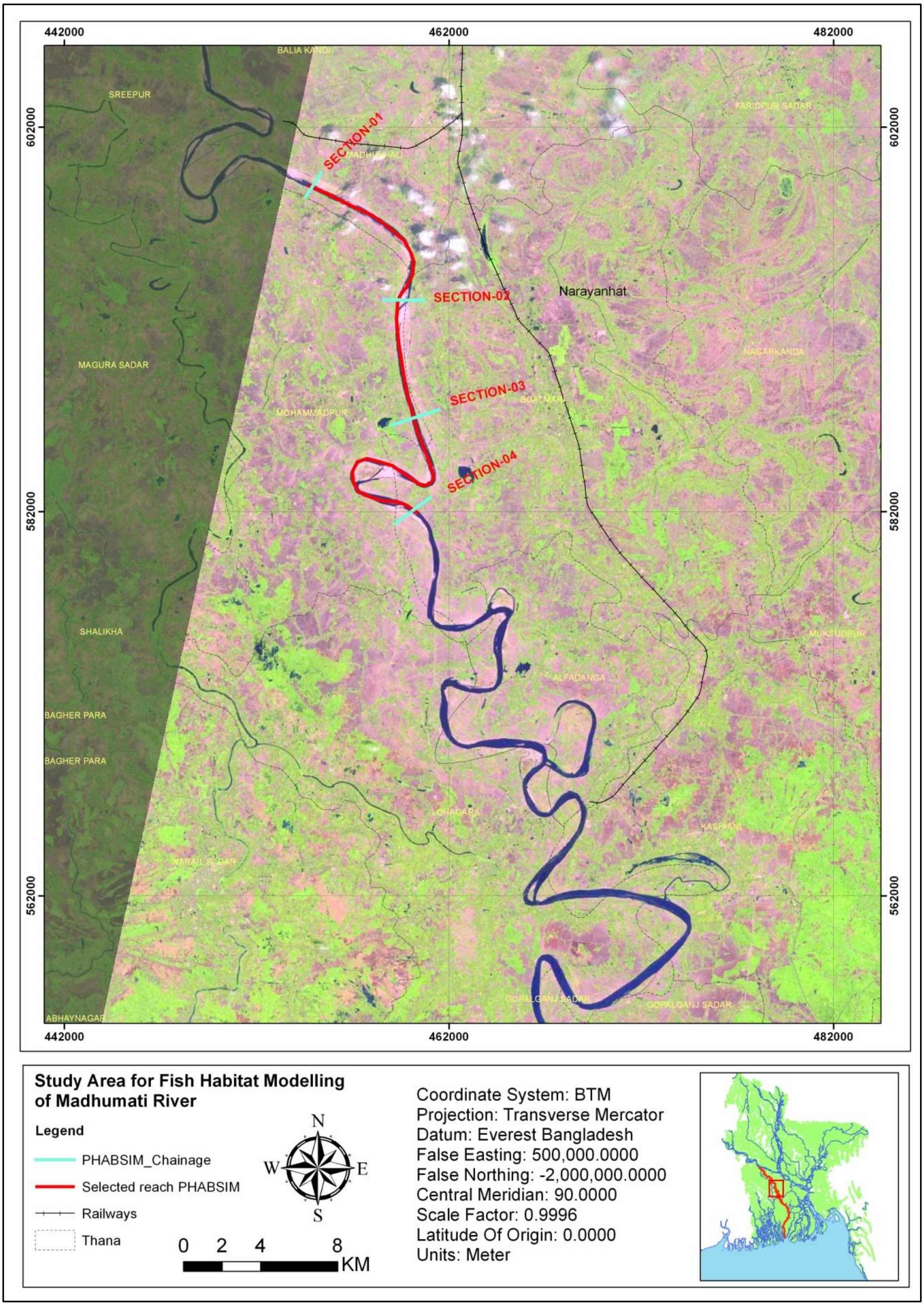


Figure 05: Site selection Map for PHABSIM model of Madhumati River

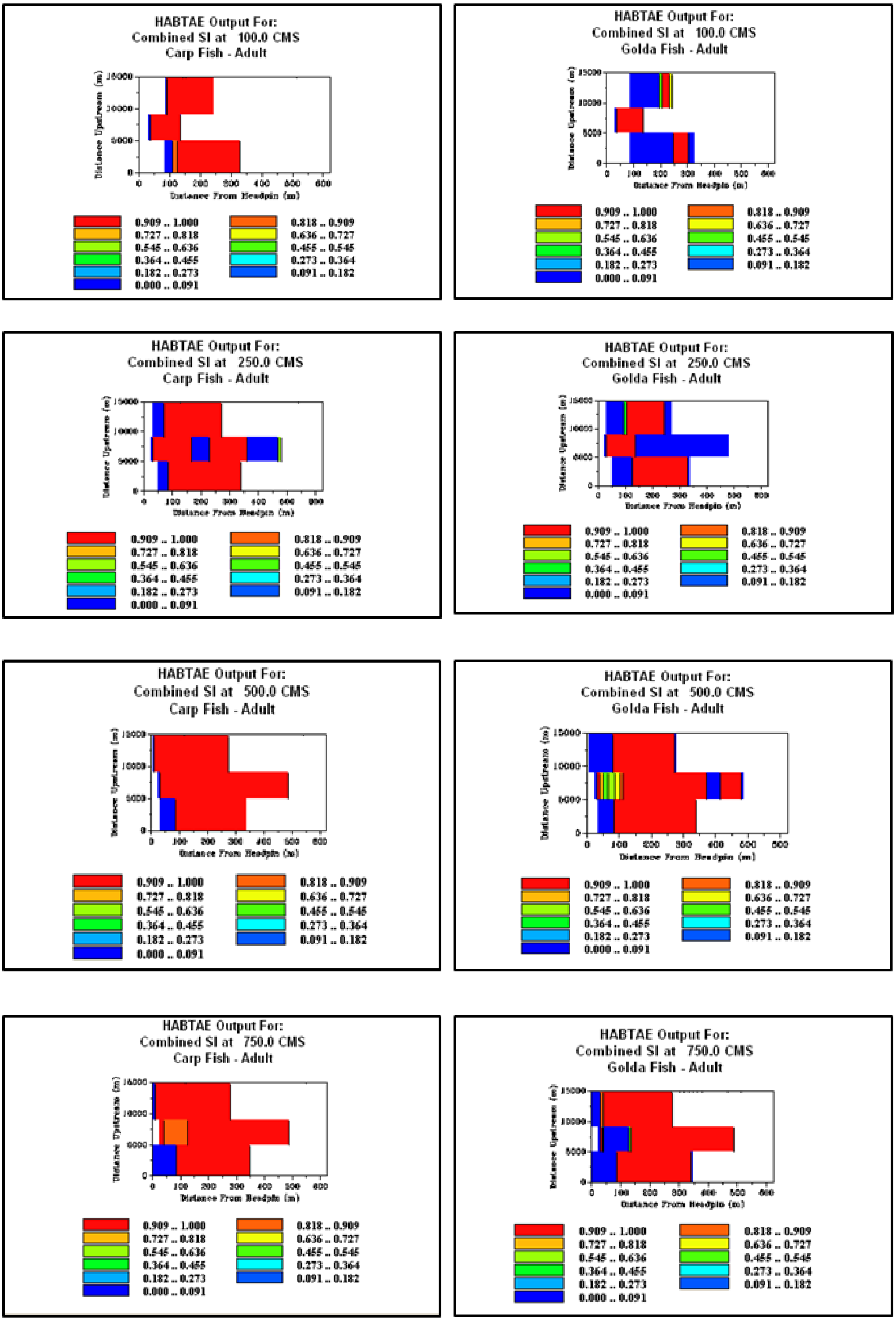


Figure 06: Variation of habitat suitability Carp Species and Golda at Section-01 for discharge 100 to 750 m^3/s of Madhumati River

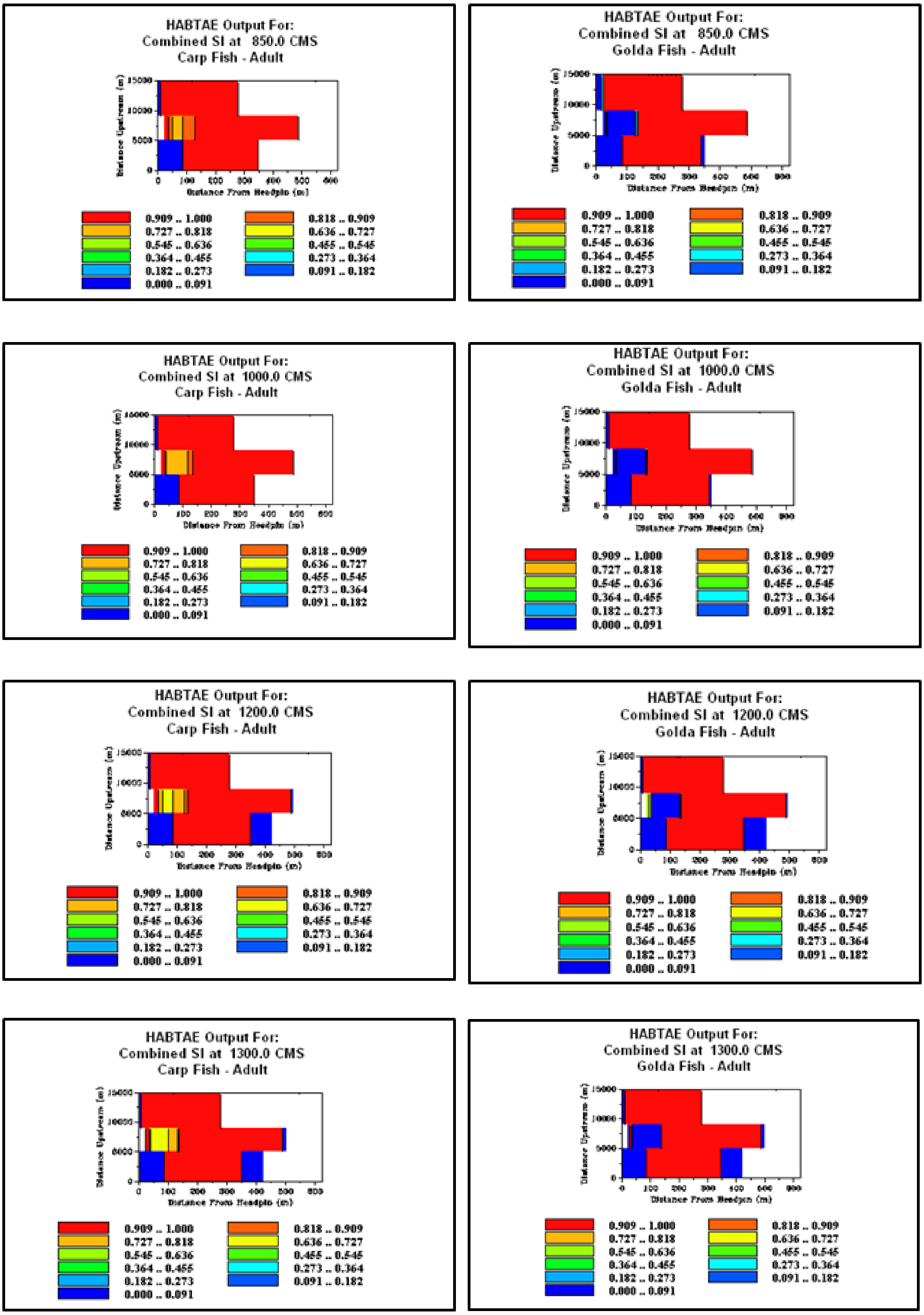


Figure 07: Variation of habitat suitability Carp Species and Golda at Section-01 for discharge 850 to 1300 m^3/s of Madhumati River

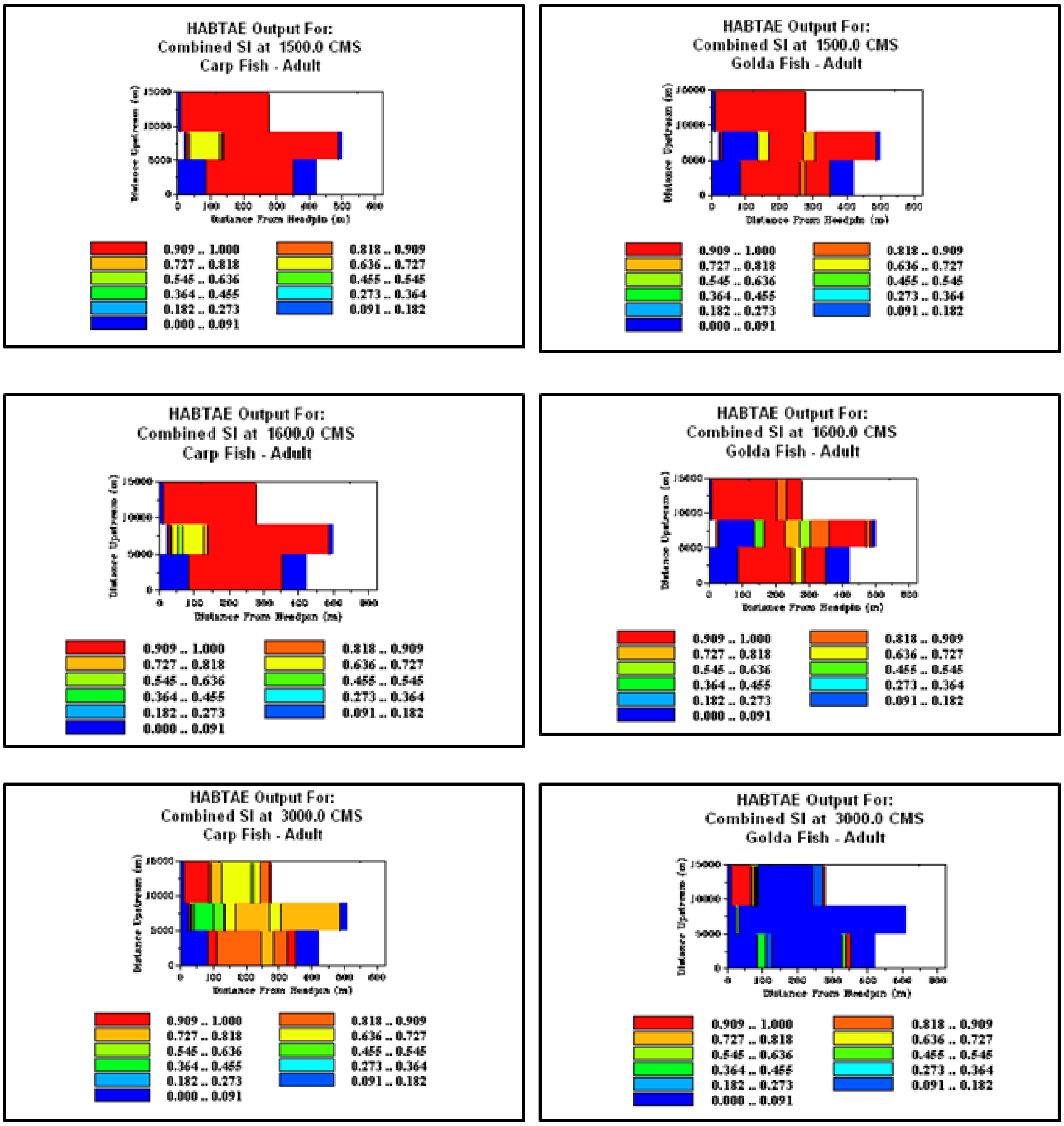


Figure 08: Variation of habitat suitability Carp Species and Golda at Section-01 for discharge 1500 to 3000 m^3/s of Madhumati River

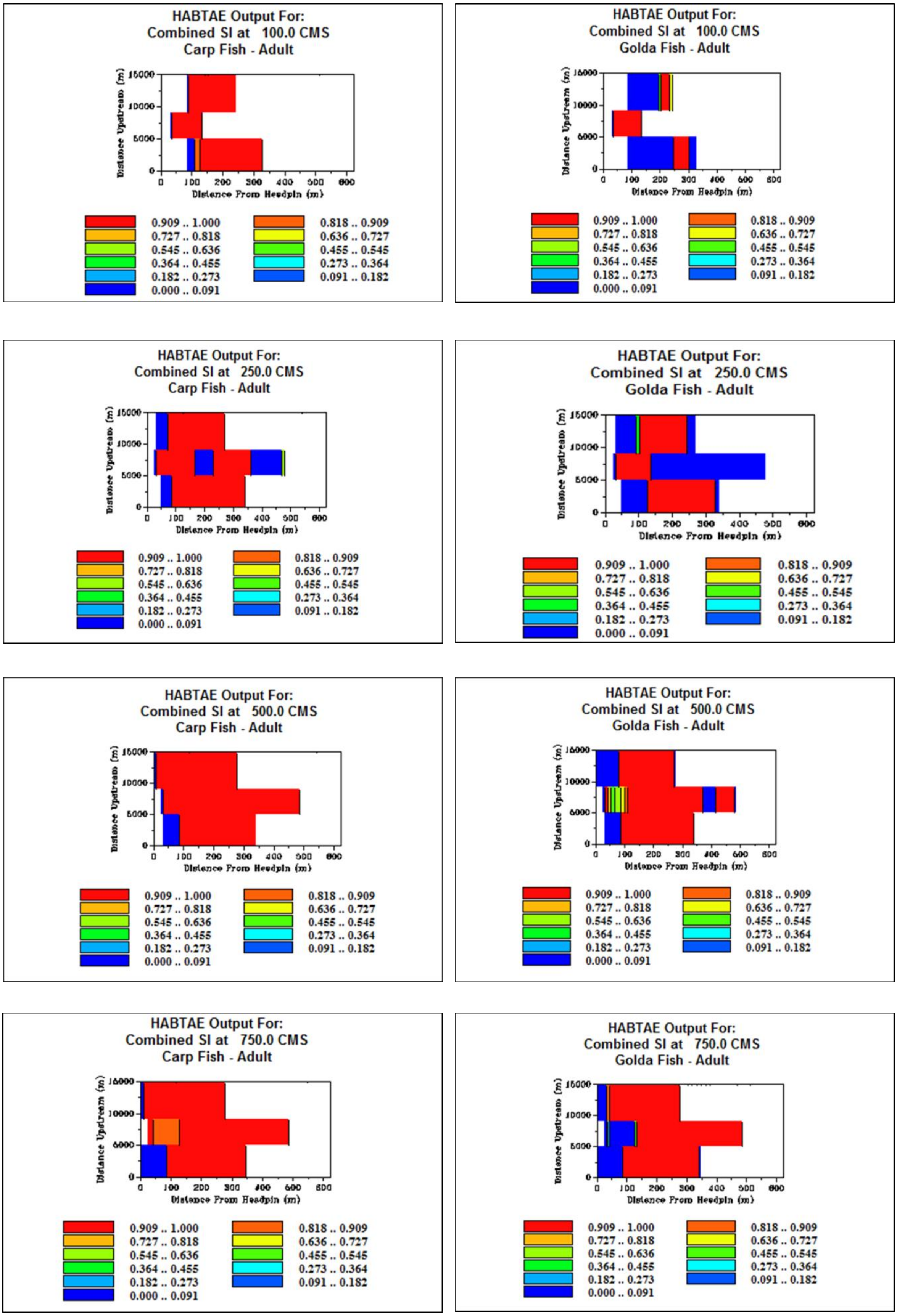


Figure 09: Variation of habitat suitability Carp Species and Golda at Section-02 for discharge 100 to 750 m^3/s of Madhumati River

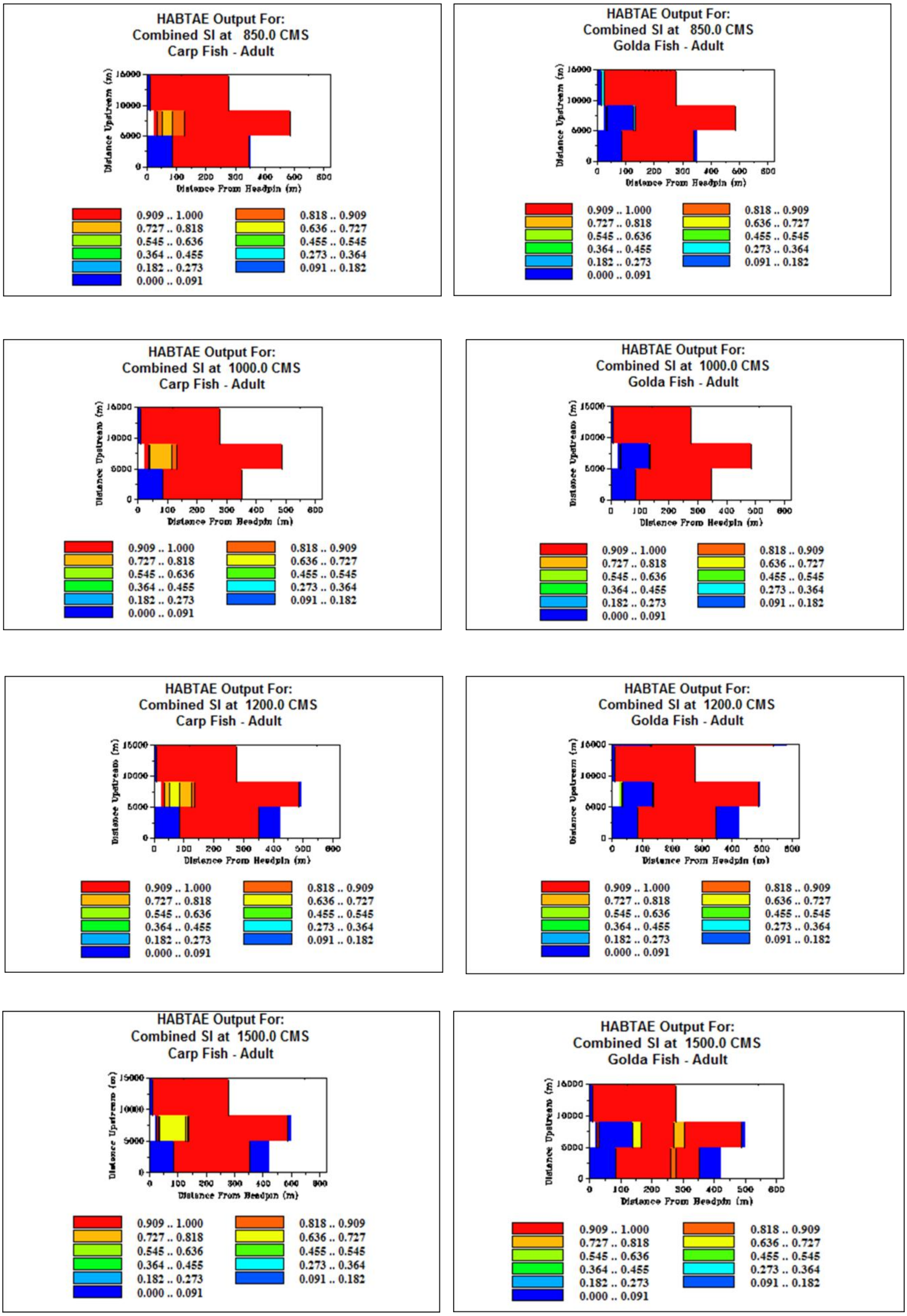


Figure 10: Variation of habitat suitability Carp Species and Golda at Section-02 for discharge 850 to 1500 m^3/s of Madhumati River

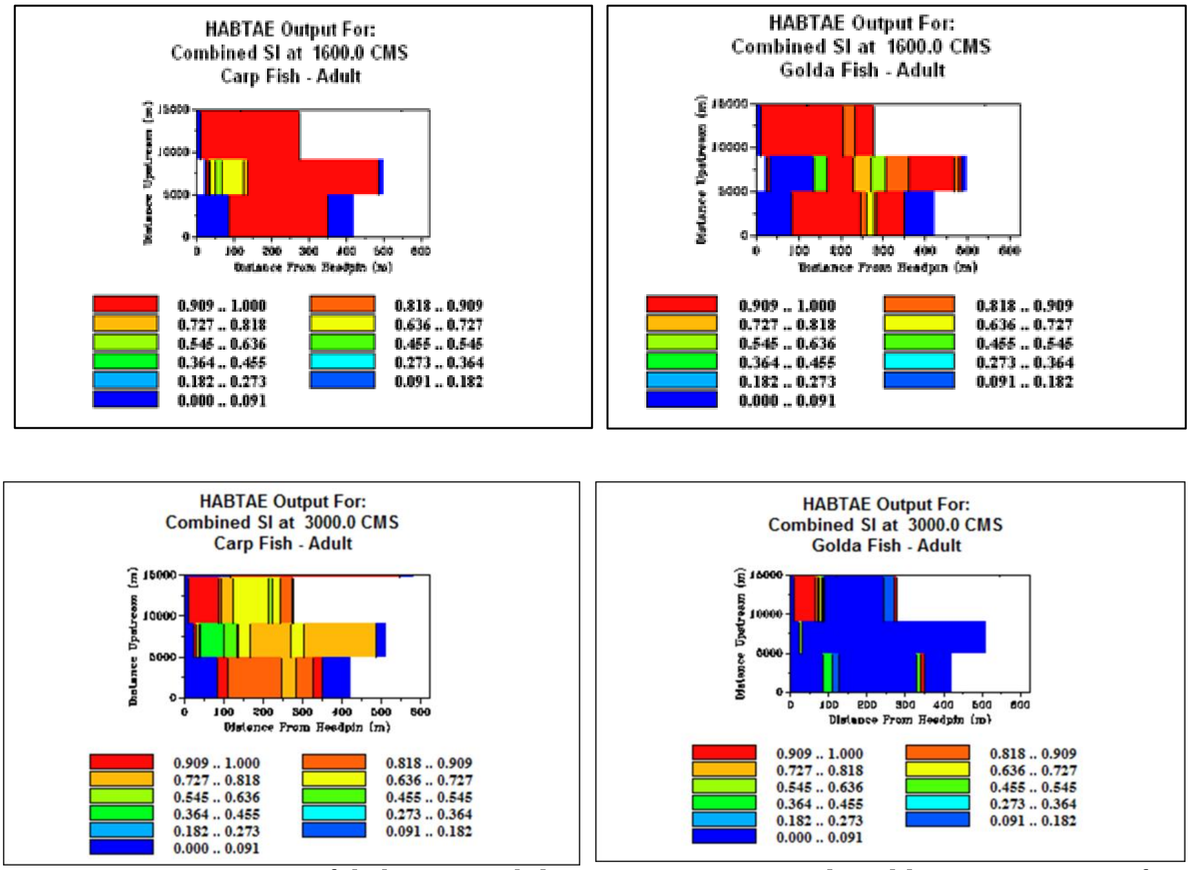


Figure 11: Variation of habitat suitability Carp Species and Golda at Section-02 for discharge 1600 to 3000 m^3/s of Madhumati River

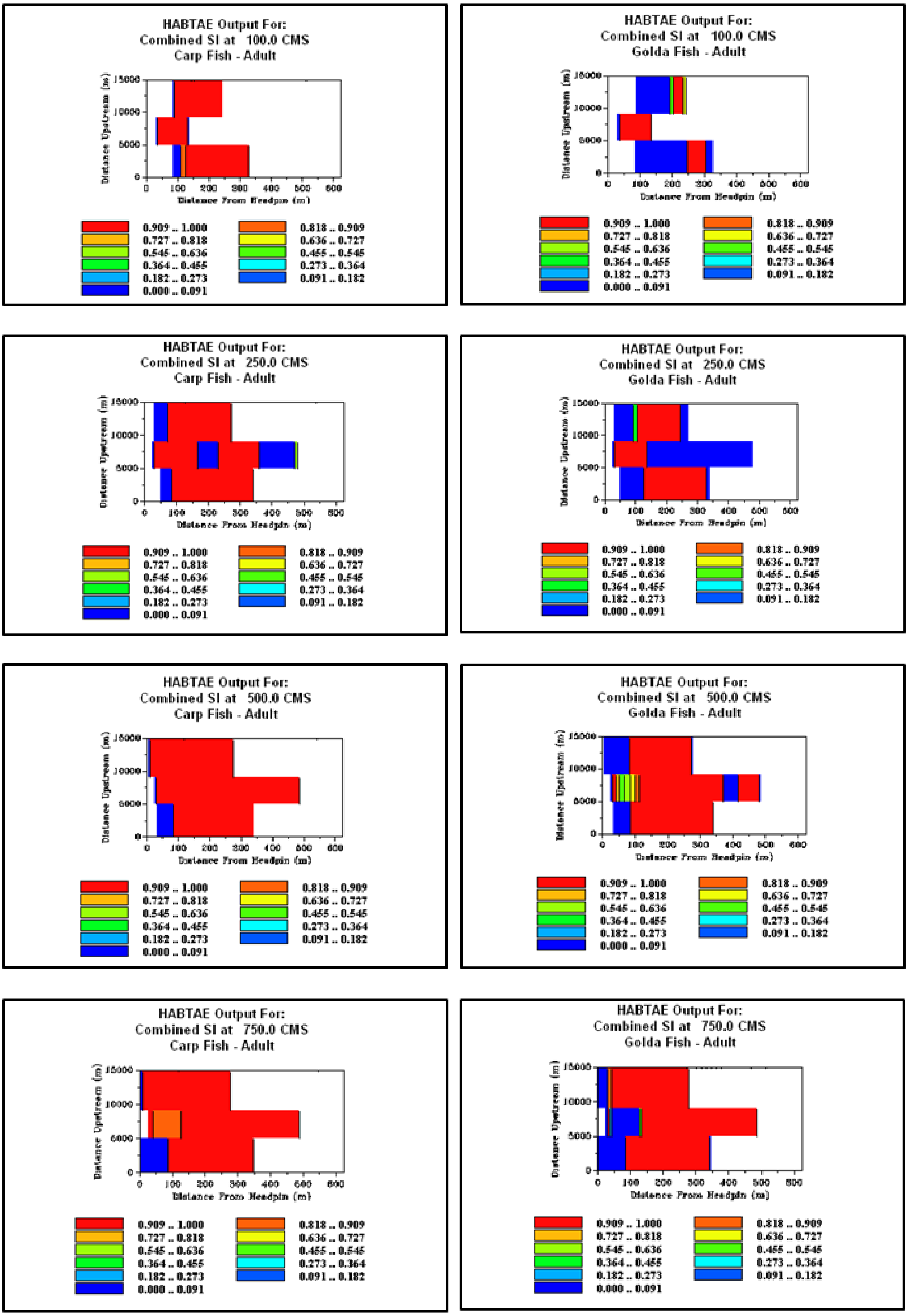


Figure 12: Variation of habitat suitability Carp Species and Golda at Section-03 for discharge 100 to 750 m^3/s of Madhumati River

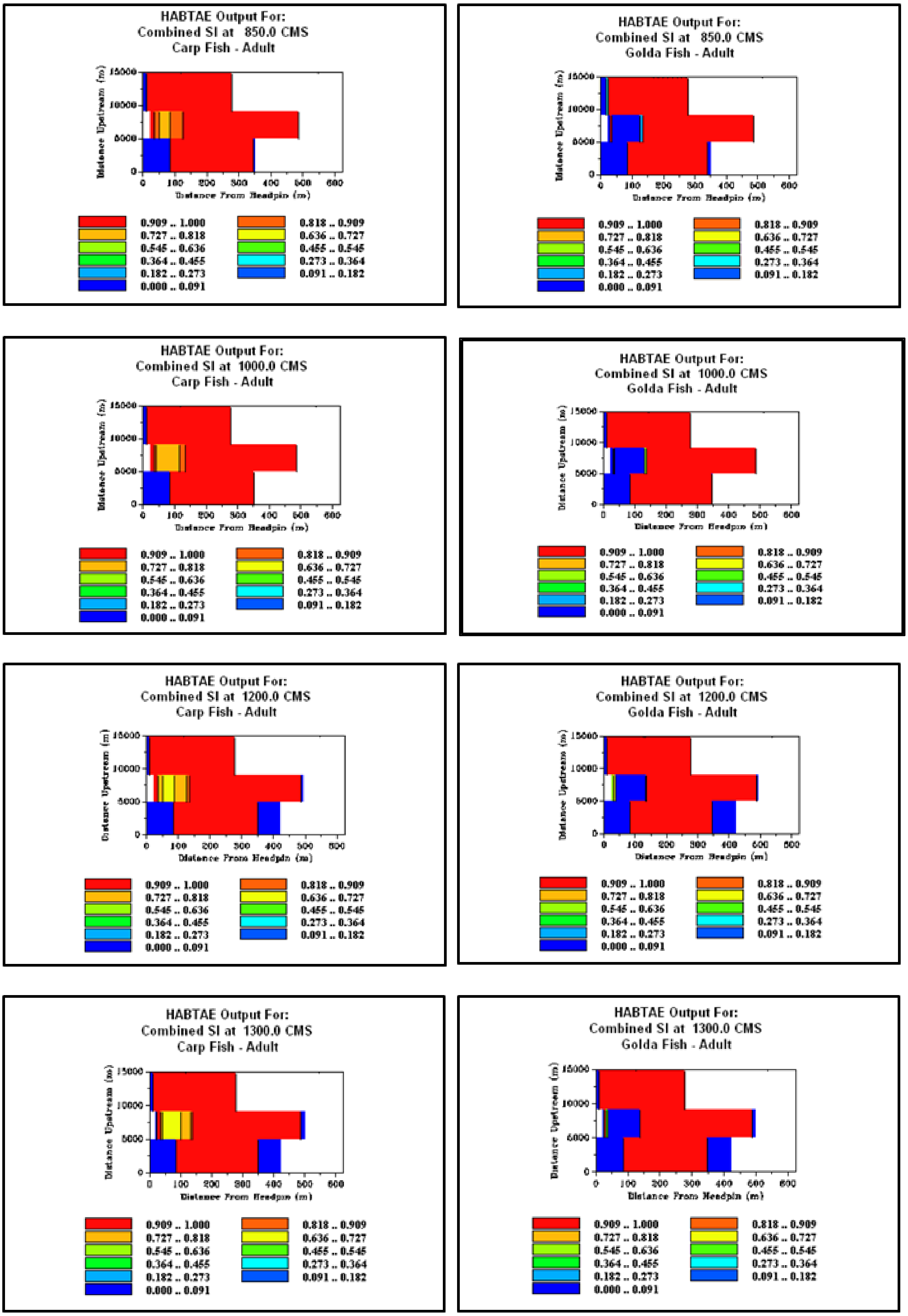


Figure 13: Variation of habitat suitability Carp Species and Golda at Section-03 for discharge 850 to 1300 m^3/s of Madhumati River

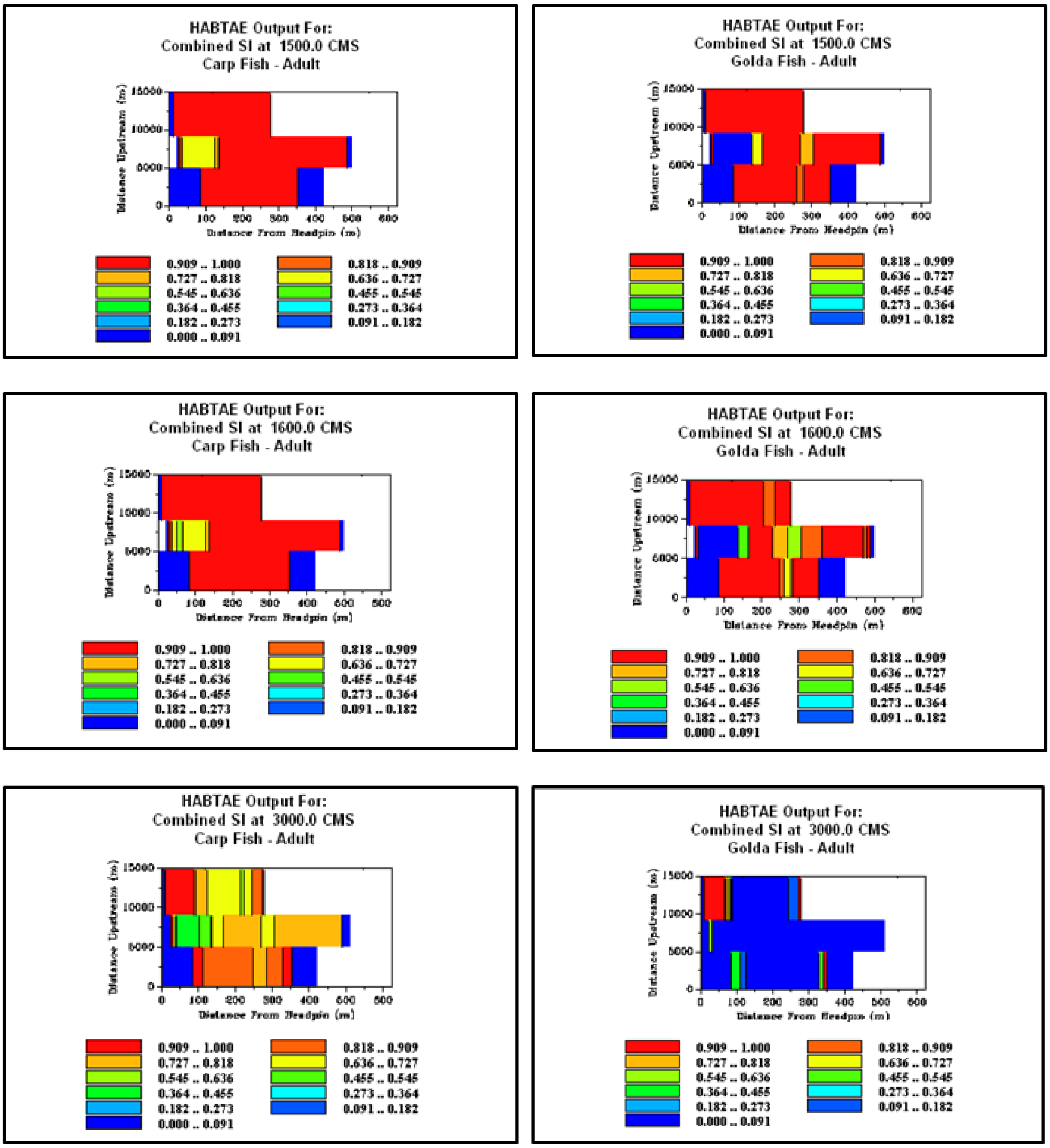


Figure 14: Variation of habitat suitability Carp Species and Golda at Section-03 for discharge 1500 to 3000 m^3/s of Madhumati River

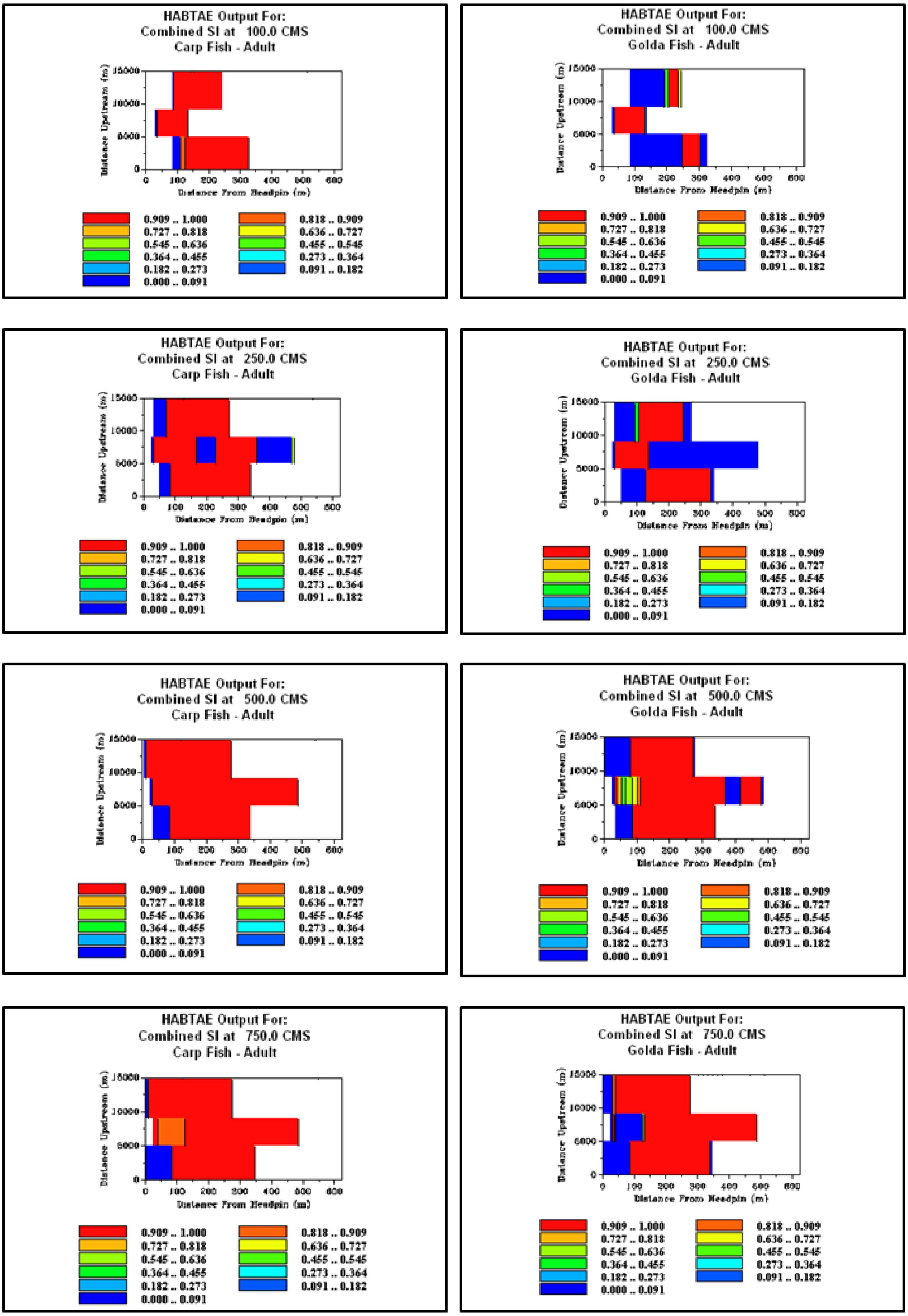


Figure 15: Variation of habitat suitability Carp Species and Golda at Section-04 for discharge 100 to 750 m^3/s of Madhumati River

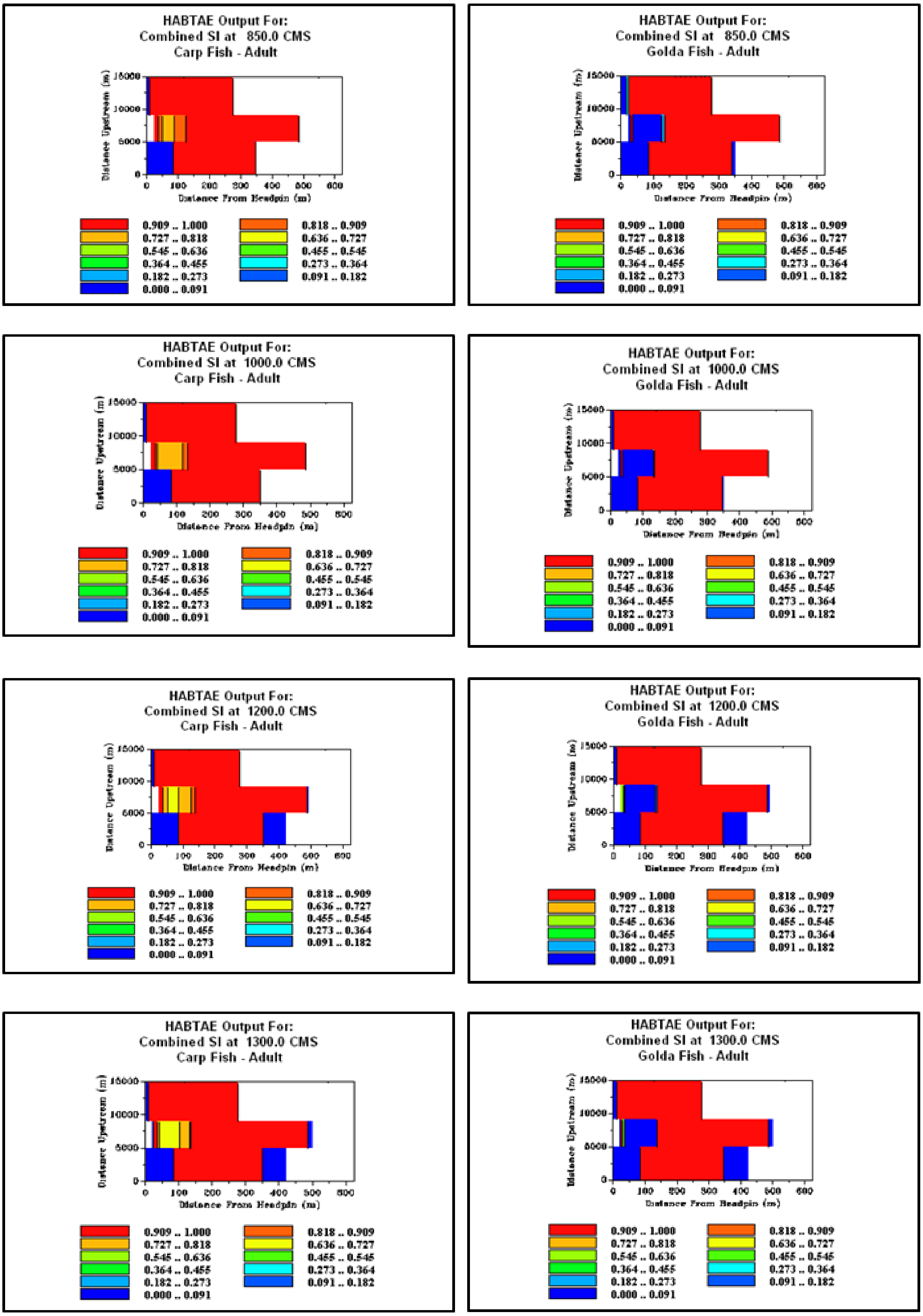


Figure 16: Variation of habitat suitability Carp Species and Golda at Section-04 for discharge 850 to 1300 m^3/s of Madhumati River

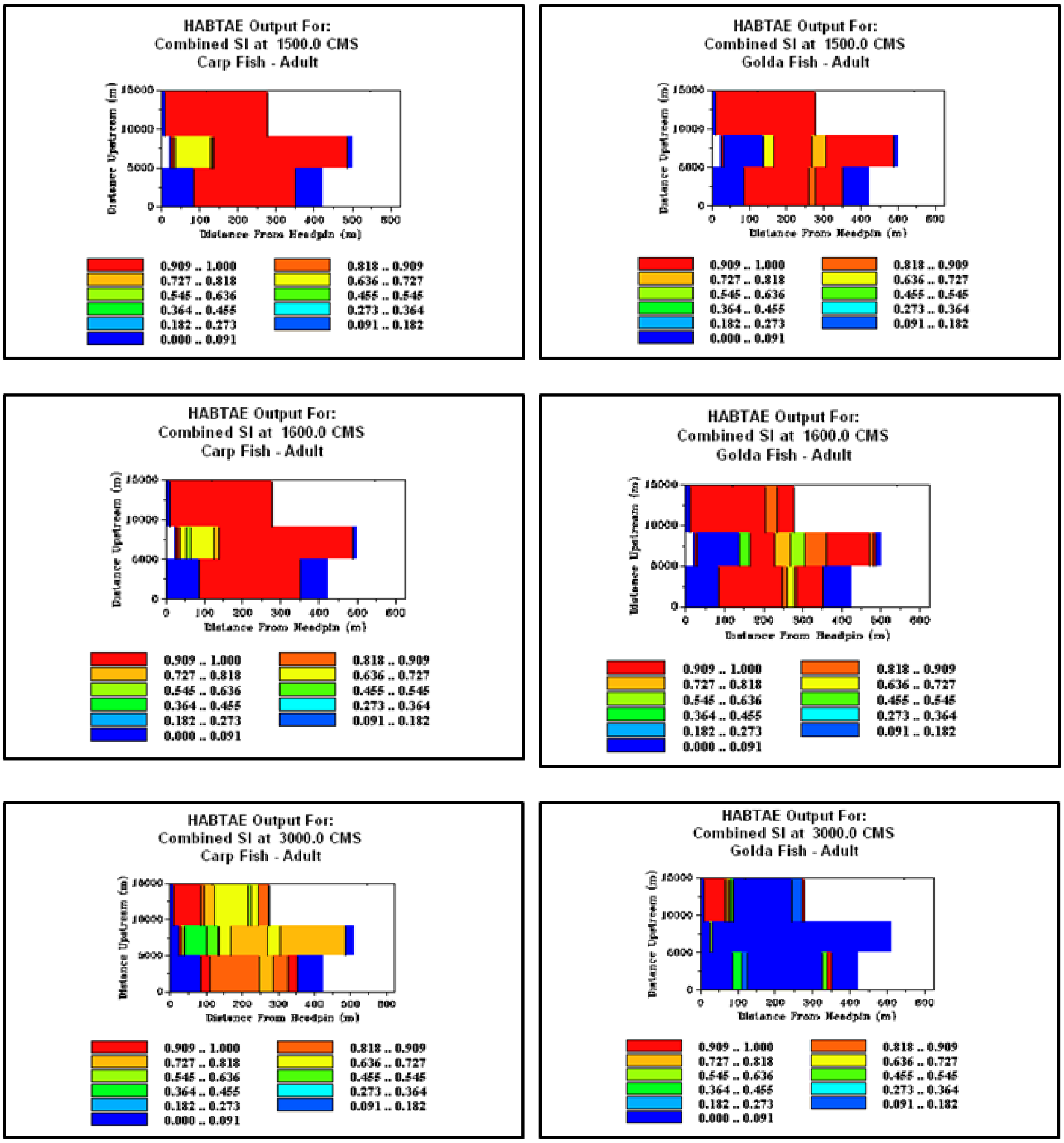


Figure 17: Variation of habitat suitability Carp Species and Golda at Section-04 for discharge 1500 to 3000 m^3/s of Madhumati River

APPENDIX-E

Detail calculation of flow requirements and relation between water level and Cross-sectional area of Kaliganga and Balaswar River

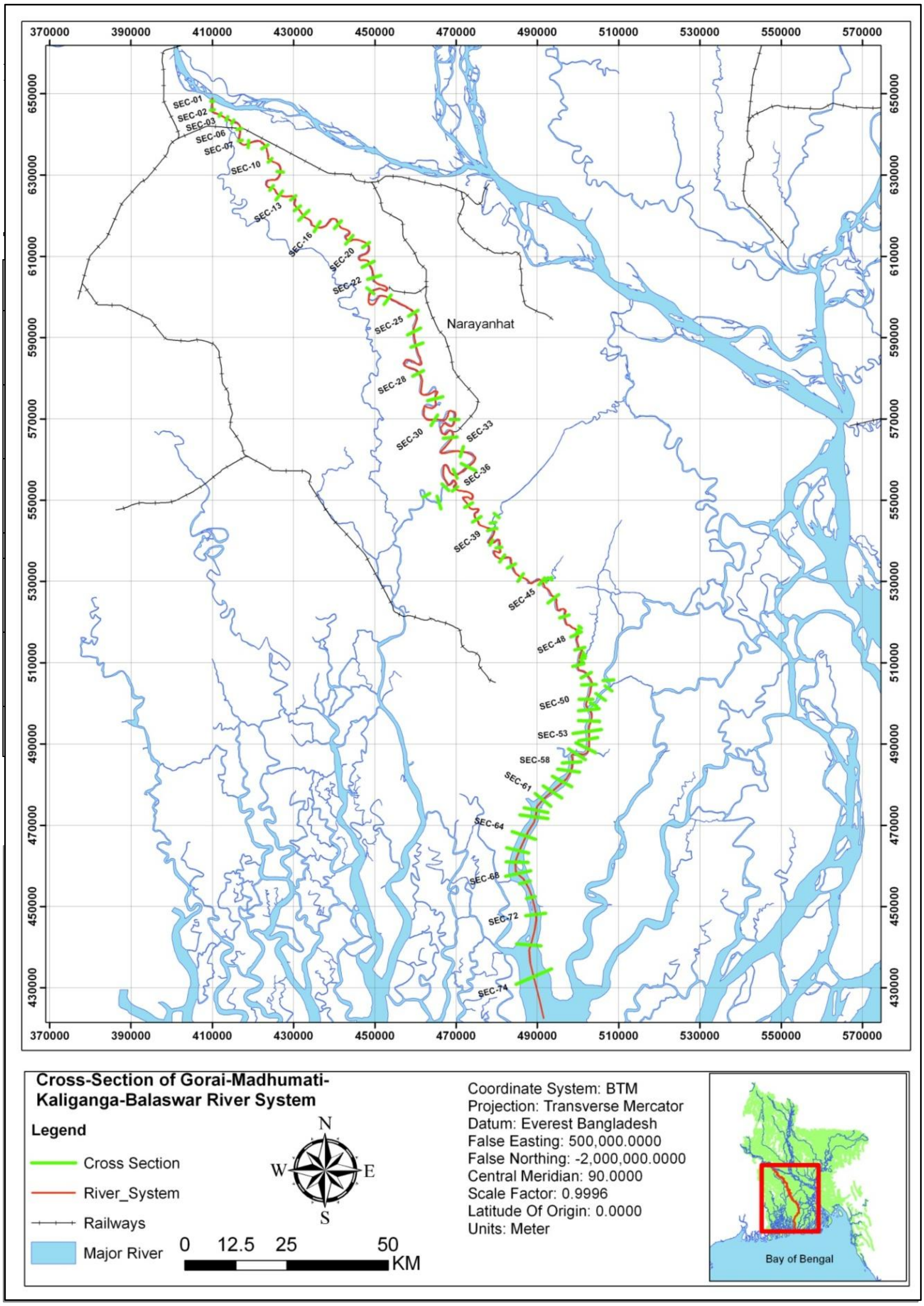


Figure 01: Relation between Water Level and Cross-Section Area of Kaliganga River at Section-50

Table 02: Flow requirement for Golda at Kaliganga River at Section-54

Parameter	Dry Season					Wet season					Dry Season	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Critical Velocity (m/s)	0.60	0.60	0.60	0.60	-	-	-	-	-	0.60	0.60	0.60
Threshold Velocity (m/s)	-	-	-	-	0.20	0.20	0.20	0.20	0.20	-	-	-
Governing Velocity (m/s)	0.60	0.60	0.60	0.60	0.20	0.20	0.20	0.20	0.20	0.20	0.60	0.60
Depth (m)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Required Level (m PWD)	-2.64	-2.56	-2.43	-2.29	-2.19	1.97	1.70	1.72	1.62	-2.02	-2.28	-2.41
Cross Sectional Area (m^2)	1406	1466	1559	1651	1712	2961	2836	2844	2803	1807	1657	1573
Discharge (cumec)	843	880	935	991	342	592	567	569	561	361	994	944

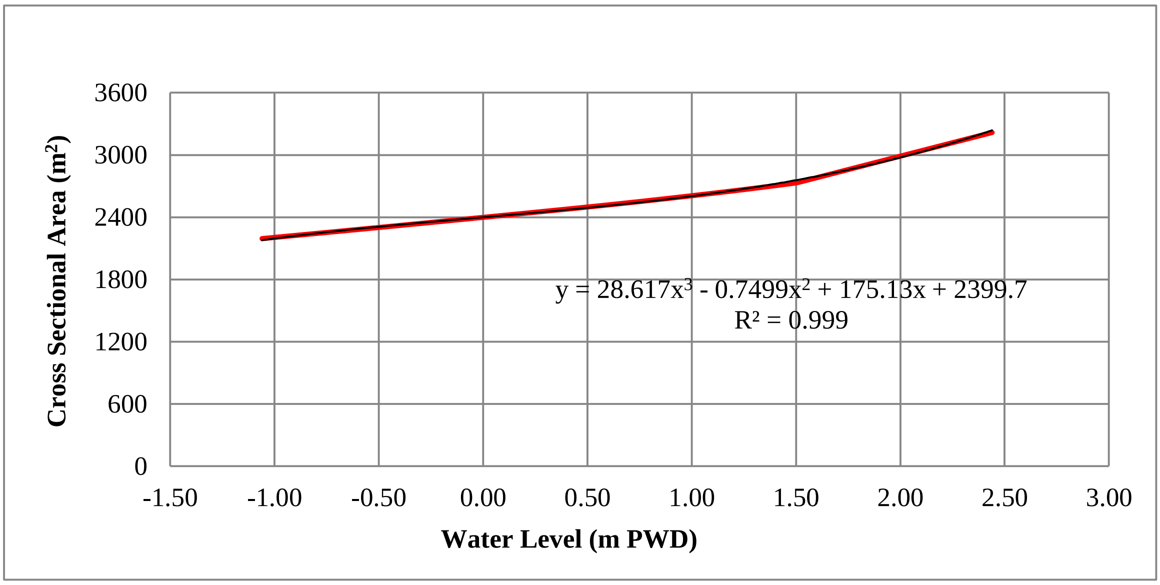


Figure 02: Relation between Water Level and Cross-Section Area of Kaliganga River at Section-54

Table 03: Flow requirement for Golda at Kaliganga River at Section-58

Parameter	Dry Season					Wet season					Dry Season	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Critical Velocity (m/s)	0.60	0.60	0.60	0.60	-	-	-	-	-	0.60	0.60	0.60
Threshold Velocity (m/s)	-	-	-	-	0.20	0.20	0.20	0.20	0.20	-	-	-
Governing Velocity (m/s)	0.60	0.60	0.60	0.60	0.20	0.20	0.20	0.20	0.20	0.20	0.60	0.60
Depth (m)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Required Level (m PWD)	-2.64	-2.56	-2.43	-2.29	-2.19	1.97	1.70	1.72	1.62	-2.02	-2.28	-2.41
Cross Sectional Area (m^2)	751	821	928	1036	1107	2861	2689	2701	2642	1220	1043	944
Discharge (cumec)	451	493	557	621	221	572	538	540	528	244	626	566

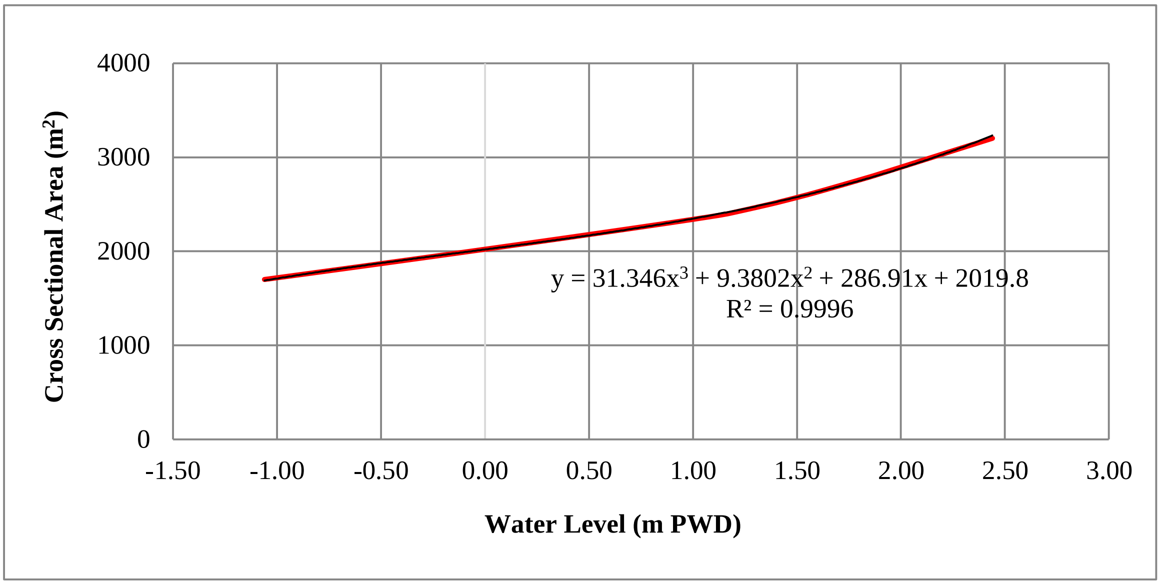


Figure 03: Relation between Water Level and Cross-Section Area of Kaliganga River at Section-58

Table 04: Flow requirement for Golda at Kaliganga River at Section 60

Parameter	Dry Season					Wet season					Dry Season	
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Critical Velocity (m/s)	0.60	0.60	0.60	0.60	-	-	-	-	-	0.60	0.60	0.60
Threshold Velocity (m/s)	-	-	-	-	0.20	0.20	0.20	0.20	0.20	-	-	-
Governing Velocity (m/s)	0.60	0.60	0.60	0.60	0.20	0.20	0.20	0.20	0.20	0.20	0.60	0.60
Depth (m)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Required Level (m PWD)	-2.64	-2.56	-2.43	-2.29	-2.19	1.97	1.70	1.72	1.62	-2.02	-2.28	-2.41
Cross Sectional Area (m^2)	618	696	816	938	1020	3137	2942	2956	2889	1149	946	834
Discharge (cumec)	371	417	490	563	204	627	588	591	578	230	568	501

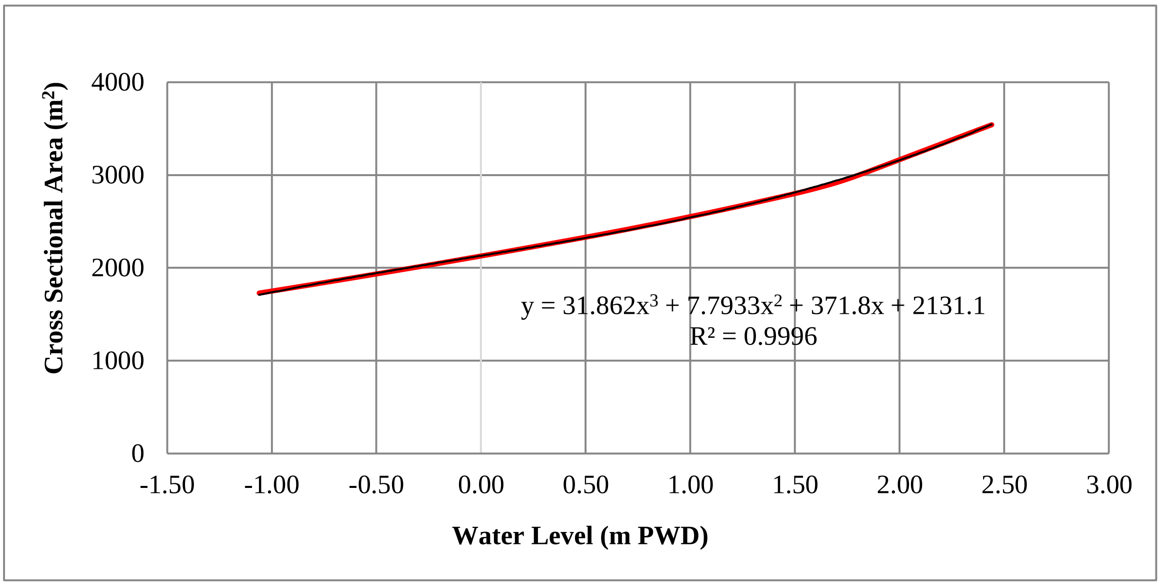


Figure 04: Relation between Water Level and Cross-Section area of Kaliganga River at Section-60

Table-05: Flow requirement for Golda at Kaliganga River at Section-61

Parameter	Dry Season					Wet season					Dry Season	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Critical Velocity (m/s)	0.60	0.60	0.60	0.60	-	-	-	-	-	0.60	0.60	0.60
Threshold Velocity (m/s)	-	-	-	-	0.20	0.20	0.20	0.20	0.20	-	-	-
Governing Velocity (m/s)	0.60	0.60	0.60	0.60	0.20	0.20	0.20	0.20	0.20	0.20	0.60	0.60
Depth (m)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Required Level (m PWD)	-2.64	-2.56	-2.43	-2.29	-2.19	1.97	1.70	1.72	1.62	-2.02	-2.28	-2.41
Cross Sectional Area (m^2)	228	337	507	679	795	3942	3681	3699	3609	982	691	532
Discharge (cumec)	137	202	304	407	159	788	736	740	722	196	414	319

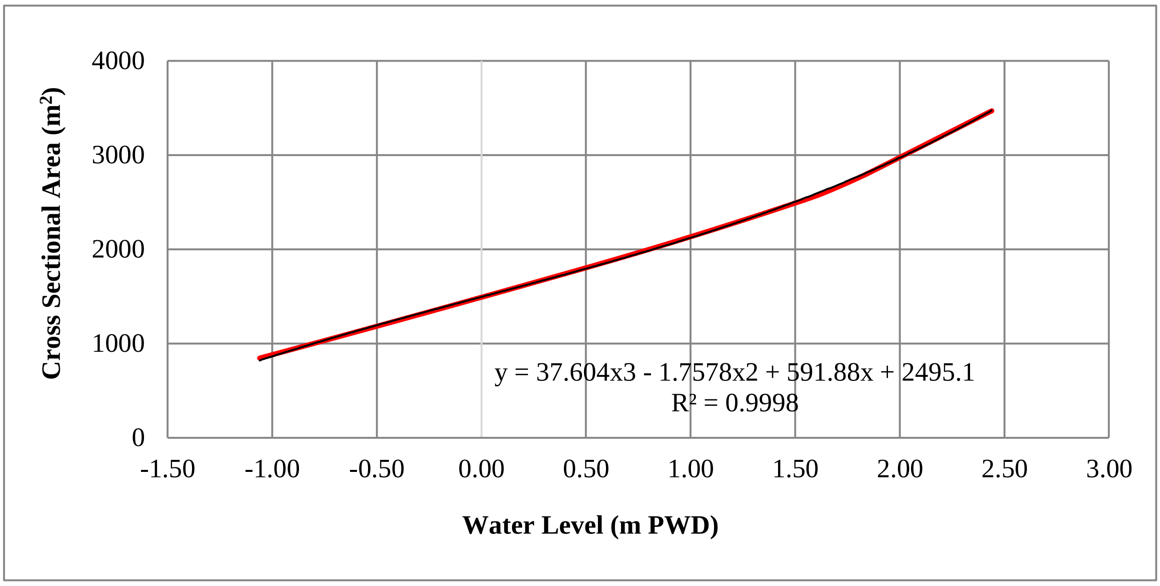


Figure 05: Relation between Water Level and Cross-Section area of Kaliganga River at Section-61

Table-06: Flow requirement for Golda at Balaswar River at Section-64

Parameter	Dry Season					Wet season					Dry Season	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Critical Velocity (m/s)	0.60	0.60	0.60	0.60	-	-	-	-	-	0.60	0.60	0.60
Threshold Velocity (m/s)	-	-	-	-	0.20	0.20	0.20	0.20	0.20	-	-	-
Governing Velocity (m/s)	0.60	0.60	0.60	0.60	0.20	0.20	0.20	0.20	0.20	0.20	0.60	0.60
Depth (m)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Required Level (m PWD)	-2.76	-2.77	-2.82	-2.64	-2.61	-2.24	-2.21	-2.23	-2.27	-2.43	-2.63	-2.71
Cross Sectional Area (m^2)	14465	14460	14437	14526	14542	14766	14787	14773	14746	14644	14531	14490
Discharge (cumec)	8679	8676	8662	8715	2908	2953	2957	2955	2949	2929	8719	8694

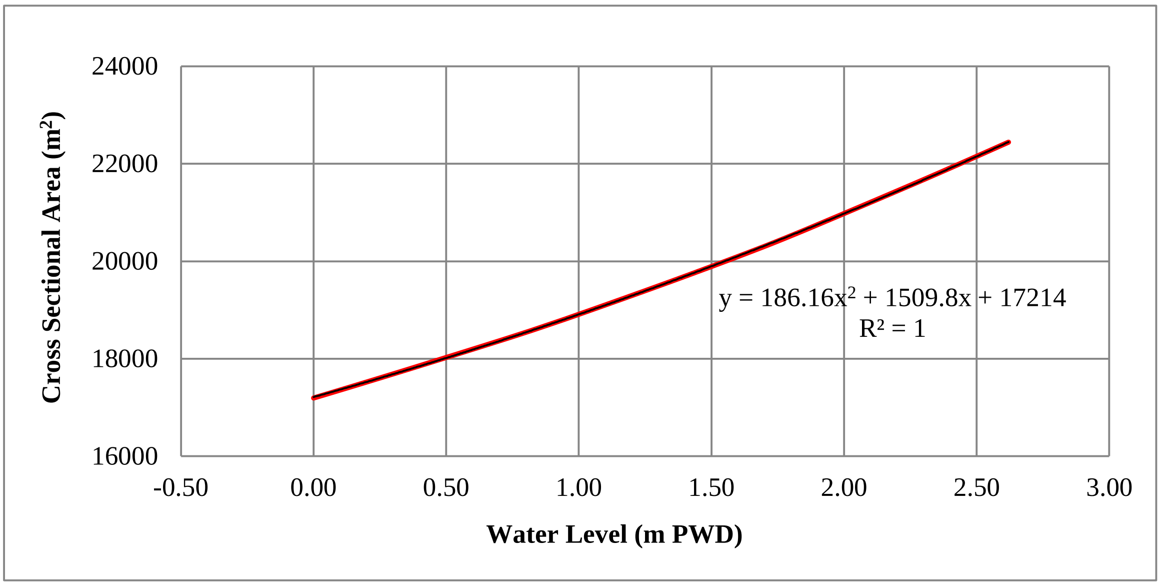


Figure 06: Relation between Water Level and Cross-Section area of Balaswar River at Section-64

Table-07: Flow requirement for Golda at Balaswar River at Section-66

Parameter	Dry Season					Wet season					Dry Season	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Critical Velocity (m/s)	0.60	0.60	0.60	0.60	-	-	-	-	-	0.60	0.60	0.60
Threshold Velocity (m/s)	-	-	-	-	0.20	0.20	0.20	0.20	0.20	-	-	-
Governing Velocity (m/s)	0.60	0.60	0.60	0.60	0.20	0.20	0.20	0.20	0.20	0.20	0.60	0.60
Depth (m)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Required Level (m PWD)	-2.76	-2.77	-2.82	-2.64	-2.61	-2.24	-2.21	-2.23	-2.27	-2.43	-2.63	-2.71
Cross Sectional Area (m^2)	17464	17459	17435	17528	17545	17795	17819	17803	17772	17658	17533	17489
Discharge (cumec)	10478	10475	10461	10517	3509	3559	3564	3561	3554	3532	10520	10494

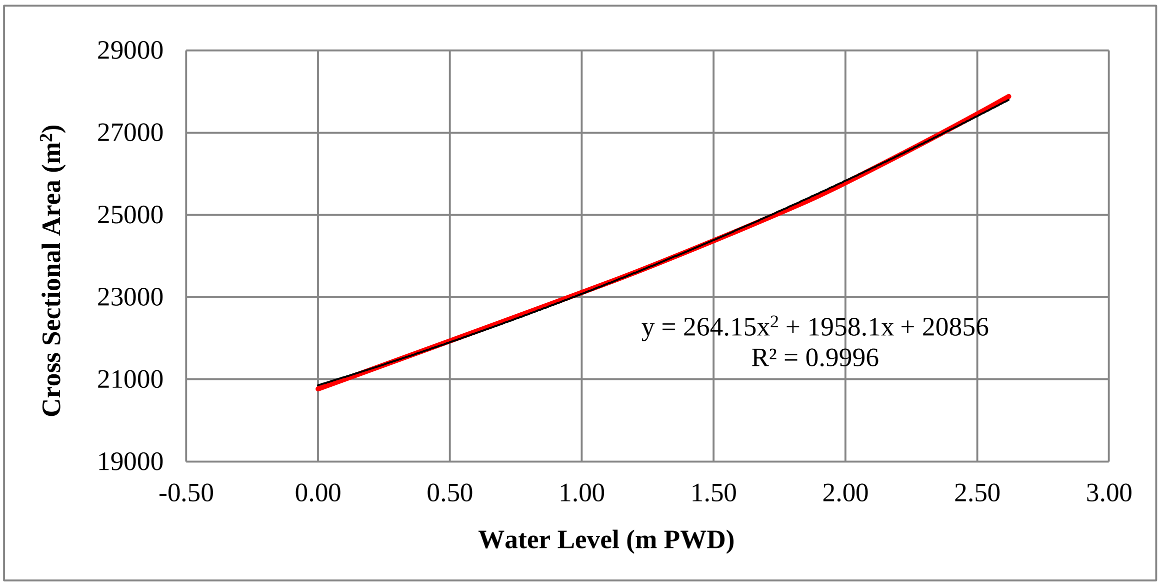


Figure 07: Relation between Water Level and Cross-Section area of Balaswar River at Section-66

Table-08: Flow requirement for Golda at Balaswar River at Section-68

Parameter	Dry Season					Wet season					Dry Season	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Critical Velocity (m/s)	0.60	0.60	0.60	0.60	-	-	-	-	-	0.60	0.60	0.60
Threshold Velocity (m/s)	-	-	-	-	0.20	0.20	0.20	0.20	0.20	-	-	-
Governing Velocity (m/s)	0.60	0.60	0.60	0.60	0.20	0.20	0.20	0.20	0.20	0.20	0.60	0.60
Depth (m)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Required Level (m PWD)	-2.76	-2.77	-2.82	-2.64	-2.61	-2.24	-2.21	-2.23	-2.27	-2.43	-2.63	-2.71
Cross Sectional Area (m^2)	17785	17787	17793	17779	17779	17841	17851	17844	17832	17795	17779	17781
Discharge (cumec)	10671	10672	10676	10667	3556	3568	3570	3569	3566	3559	10667	10669

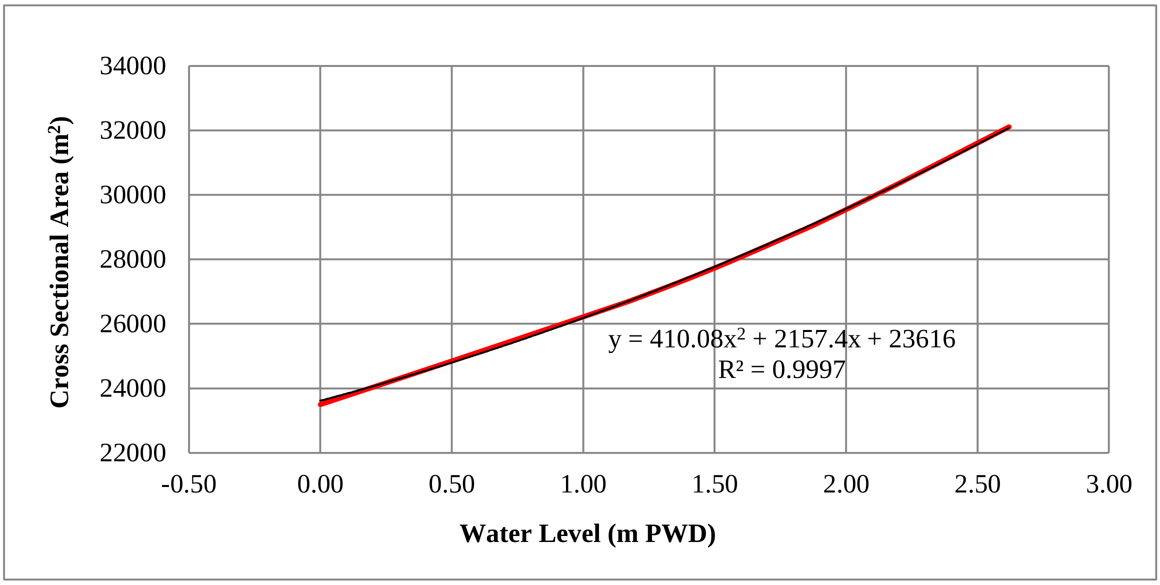


Figure 08: Relation between Water Level and Cross-Section Area of Balaswar River at Section-68

Table-09: Flow requirement for Golda at Balaswar River at Section-70

Parameter	Dry Season					Wet season					Dry Season	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Critical Velocity (m/s)	0.60	0.60	0.60	0.60	-	-	-	-	-	0.60	0.60	0.60
Threshold Velocity (m/s)	-	-	-	-	0.20	0.20	0.20	0.20	0.20	-	-	-
Governing Velocity (m/s)	0.60	0.60	0.60	0.60	0.20	0.20	0.20	0.20	0.20	0.20	0.60	0.60
Depth (m)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Required Level (m PWD)	-2.76	-2.77	-2.82	-2.64	-2.61	-2.24	-2.21	-2.23	-2.27	-2.43	-2.63	-2.71
Cross Sectional Area (m^2)	17592	17576	17500	17780	17828	18453	18506	18470	18400	18125	17796	17670
Discharge (cumec)	10555	10546	10500	10668	3566	3691	3701	3694	3680	3625	10678	10602

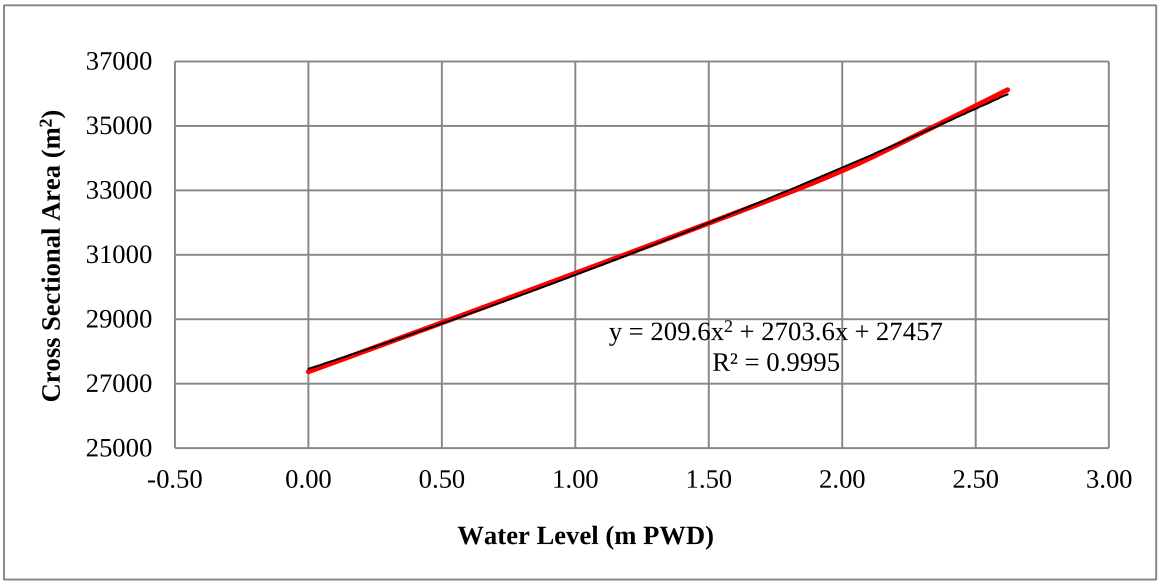


Figure 09: Relation between Water Level and Cross-Section Area of Balaswar River at Section-70

Table-10: Flow requirement for Golda at Balaswar River at Section-72

Parameter	Dry Season					Wet season					Dry Season	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Critical Velocity (m/s)	0.60	0.60	0.60	0.60	-	-	-	-	-	0.60	0.60	0.60
Threshold Velocity (m/s)	-	-	-	-	0.20	0.20	0.20	0.20	0.20	-	-	-
Governing Velocity (m/s)	0.60	0.60	0.60	0.60	0.20	0.20	0.20	0.20	0.20	0.20	0.60	0.60
Depth (m)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Required Level (m PWD)	-2.76	-2.77	-2.82	-2.64	-2.61	-2.24	-2.21	-2.23	-2.27	-2.43	-2.63	-2.71
Cross Sectional Area (m^2)	16747	16708	16516	17216	17335	18861	18989	18904	18733	18064	17256	16941
Discharge (m^3/s)	10048	10025	9910	10330	3467	3772	3798	3781	3747	3613	10353	10165

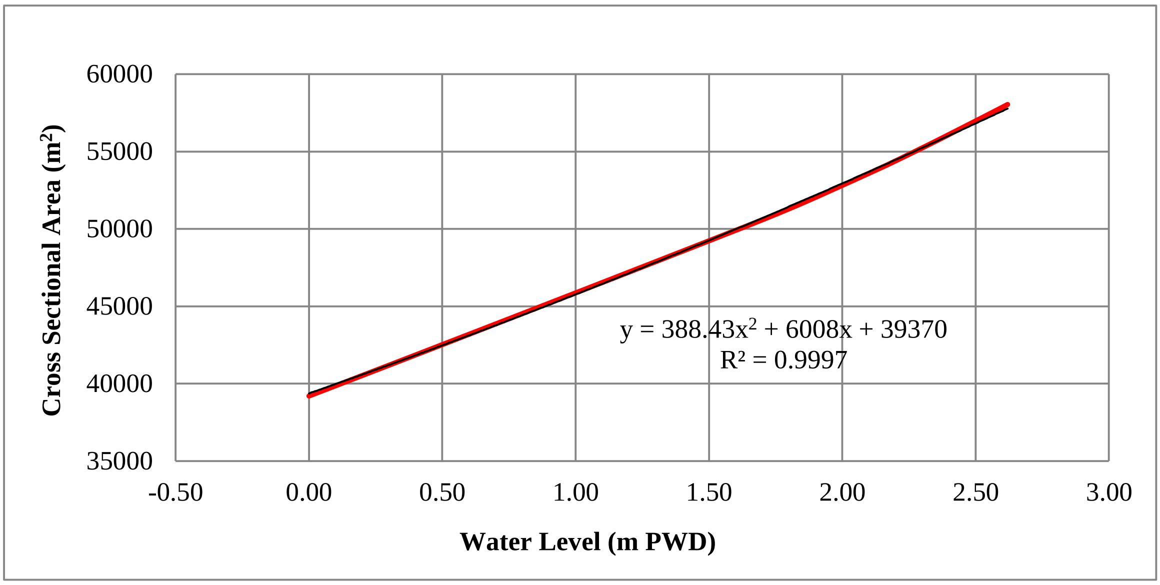


Figure 10: Relation between Water Level and Cross-Section area of Balaswar River at Section-72

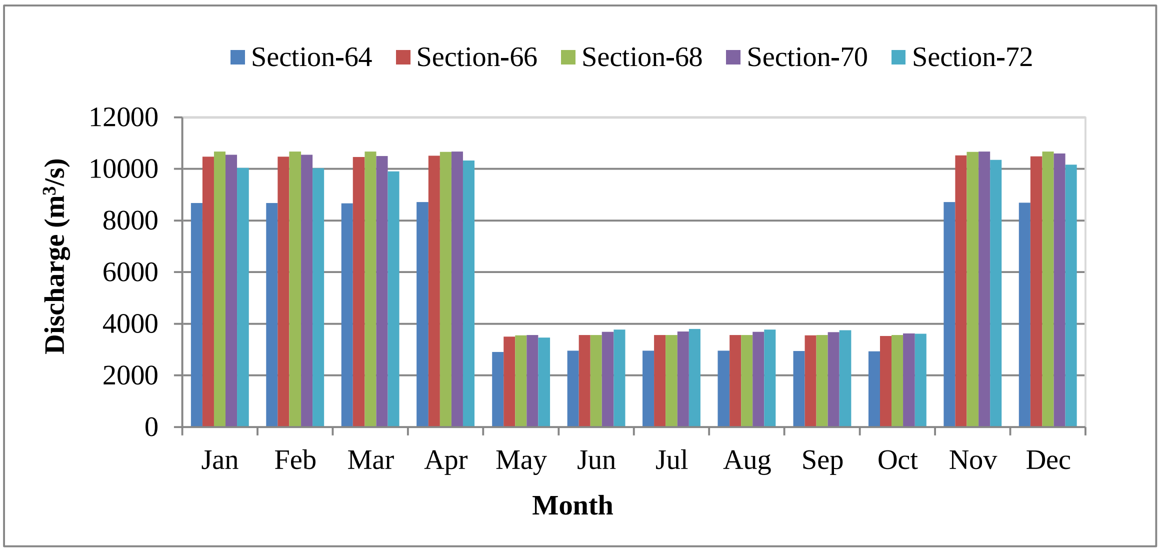


Figure 11: Flow requirement for Golda fishes at different Sections of Balaswar River

APPENDIX-F

Hydrograph as boundary conditions for the tributary and distributary river for Salinity Model

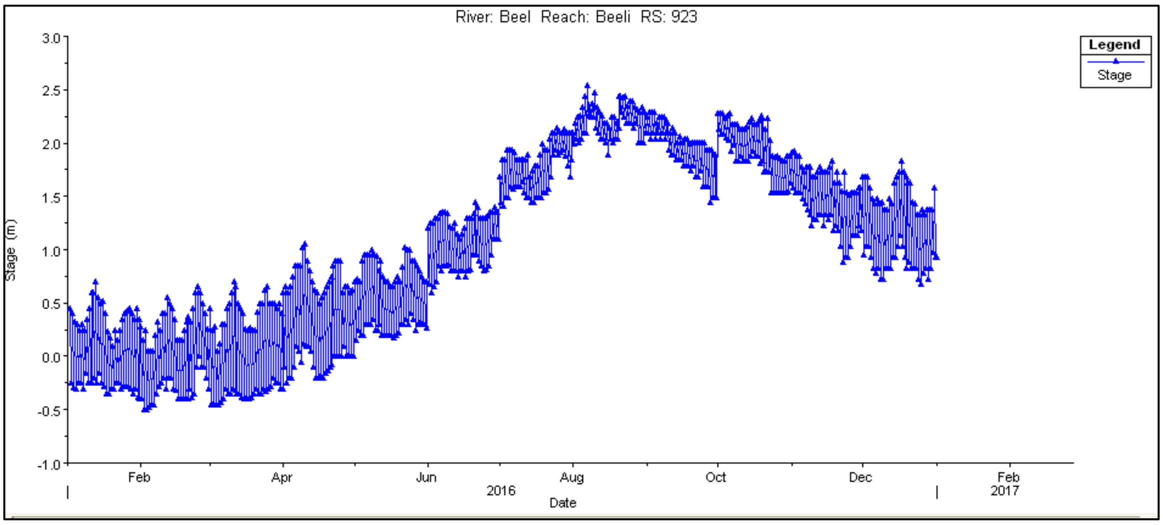


Figure 01: Stage Hydrograph for the year 2016 of Beel Route

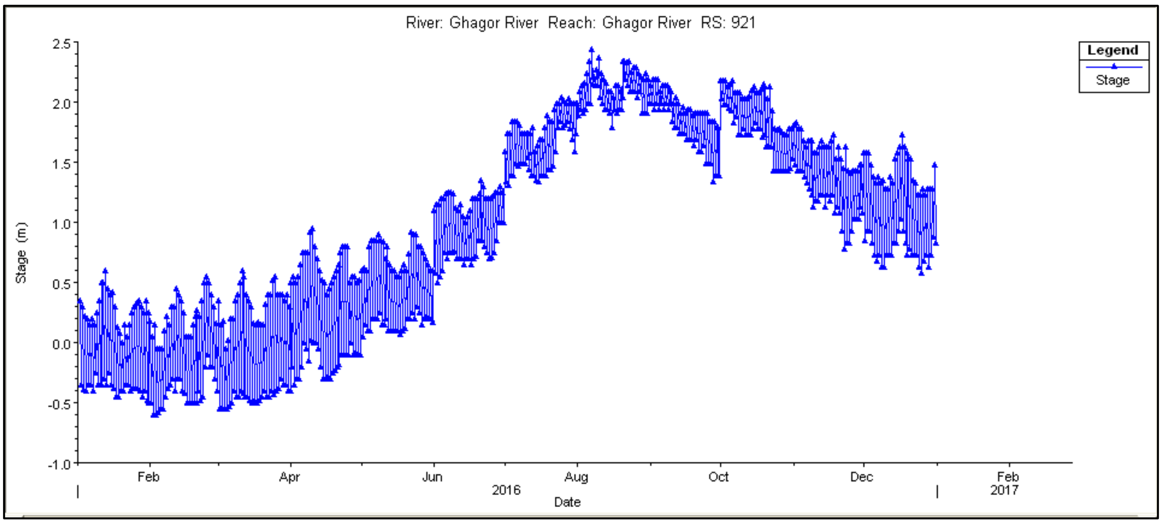


Figure 02: Stage Hydrograph for the year 2016 of Ghagor River

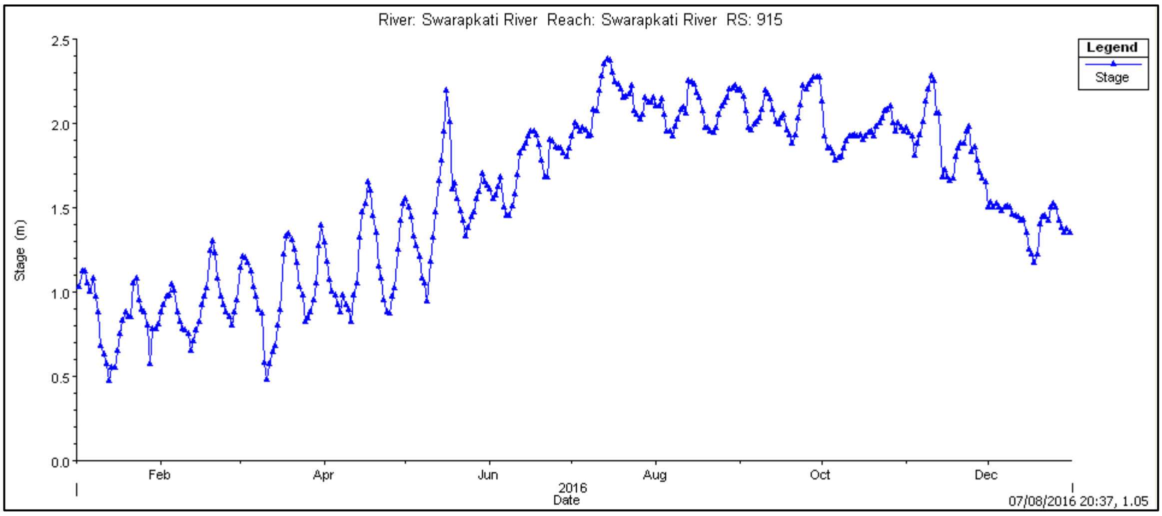


Figure 03: Stage Hydrograph for the year 2016 of Syanda River

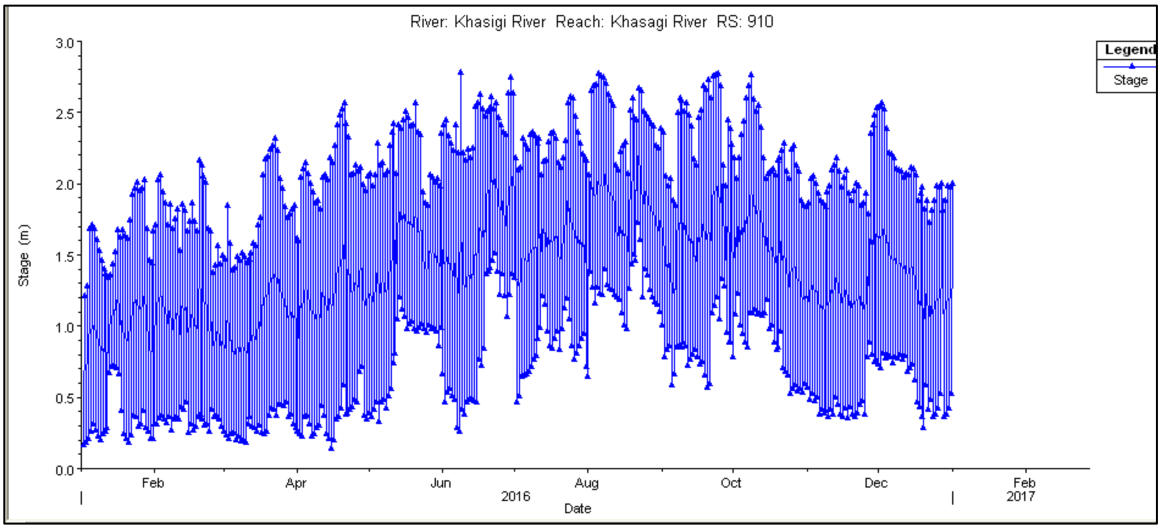


Figure 04: Stage Hydrograph for the year 2016 of Khasagi River

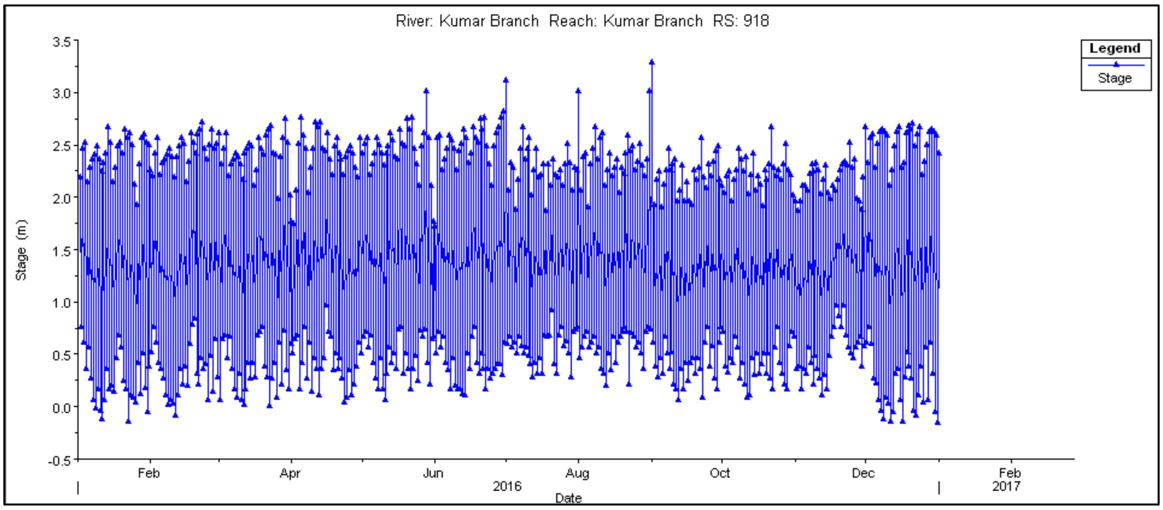


Figure 05: Stage Hydrograph for the year 2016 of Nabaganga River

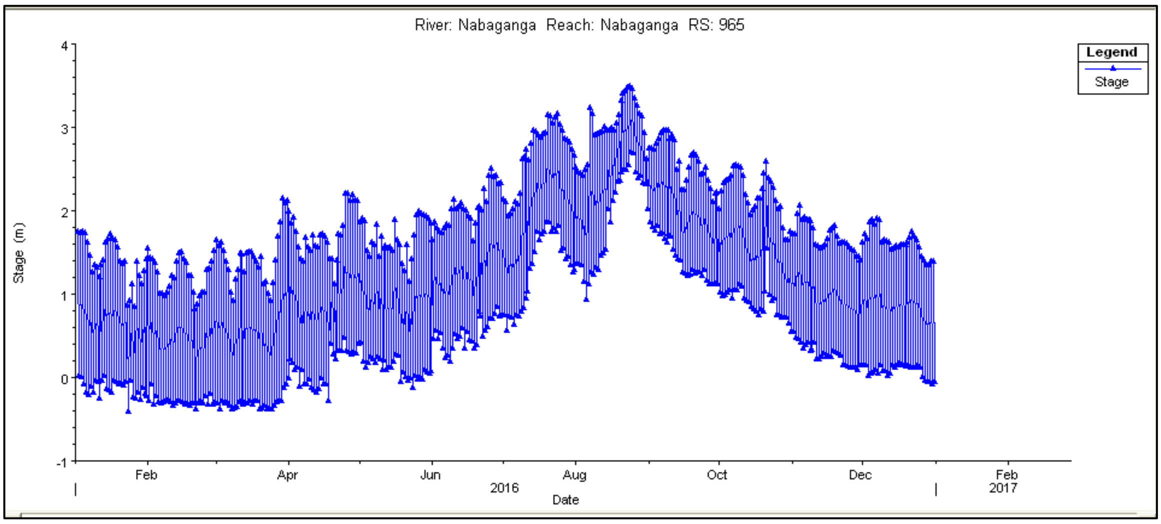


Figure 06: Stage Hydrograph for the year 2016 of Kumar River