ENVIRONMENTAL FLOW ASSESSMENT FOR ECOSYSTEM HEALTH IN A REACH OF BAITARANI RIVER

A DISSERTATION
SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF
MASTER OF TECHNOLOGY
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Submitted By

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CANDIDATE'S DECLARATION

I Anurag Singh, 2K16/ENE/04 student of M. Tech, Environmental Engineering, hereby declare that the project Dissertation title "Environmental Flow Assessment for Ecosystem Health in a Reach Of Baitarani River" which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi (ANURAG SINGH)

Date:

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CERTIFICATE

I hereby certify that the Project Dissertation titled "Environmental Flow Assessment for Ecosystem Health in a Reach Of Baitarani River" which is submitted by Anurag Singh, Roll No. 2K16/ENE/04, Environmental Engineering Department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi (DR. RAJEEV KUMAR MISHRA)

Date: SUPERVISOR

ABSTRACT

Rivers have always been vital to mankind as well as for other living beings infact, most civilizations started from the bank of Rivers. Since Rivers have been a source of food and home for variety of aquatic plants and animals and sustains an ecosystem, the alteration of the water flow is one of the most stressful factors influencing the aquatic and riverine ecosystem. Salubrious ecosystems help preserving the food, maintain the cycle of symbiotic relationship and keeps water quality healthy, therefore the condition of aquatic ecosystem is a measure for environment which depends on the flow in the stream. This essential flow is termed as Environmental Flow. Rivers need Environmental Flow to maintain the ecology of the systems and also sometimes rivers have to face water related challenges including increasing issue of the water scarcity and distribution for water among different sectors and states are being faced presently at global level. The present study aims to estimate the Environmental Flow of Baitarani River upto Anandapur, Odisha from its origin and analysis of eco-hydro relationships in time by environmental flow assessment. WMS, HMS, DSSvue and EFM software were used for assessing the Environmental Flow employing the DEM (Digital Elevation Model), precipitation, soil, Land use land cover (LULC), discharge, gauge and ecosystem data for the aquatic species in the present study. The environmental indicators employed for the research are Small Fishes, Maggar, Benthic Macro-Invertebrate Biodiversity, Wetland, Catla-Catla, Rohu, Hilsa and their corresponding assessed E-flow are 148, 6, 7, 122, 267, 254 and 272 cumecs respectively for observed flow of 17 years viz. 2000 to 2016. Through confiscate such as dams, barrages and weirs which are constructed for irrigation, drinking water, hydro-project and for other industrial demand. This does not only make restriction on the flow of water but also degrade the water quality. An attempt has also been made to estimate the E-flow which could only be provided upto certain values in case of climate change and future development flow regime for the above mentioned species and their corresponding values are 129, 5, 6, 106, 232, 221, 236 and 52, 2, 3, 43, 93, 89, 95 cumecs respectively.

ACKNOWLEDGEMENT

It is a great pleasure to have the opportunity to extend my heartiest gratitude to everybody who helped me throughout this thesis. It is distinct pleasure to express my deep sense of gratitude and indebtedness to my learned supervisors **Dr. Rajeev Kumar Mishra** in the Department of Environmental Engineering, Delhi Technological University for their invaluable guidance, encouragement, and patient review. His continuous inspiration has enabled me to complete this major project.

I would also like to take this opportunity to present our sincere regards to my Head of the Department **Prof. S. K. Singh** for his kind support and encouragement. I am thankful to my family members, friends and classmates for their unconditional support and motivation.

ANURAG SINGH

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LIST OF SYMBOLS, ABBREVIATIONS AND NOMENCLATURE

E-Flow	ENVIRONMENTAL FLOW
EFR	ENVIRONMENTAL FLOW REQUIREMENT
MSL	MEAN SEA LEVEL
EFA	ENVIRONMENTAL FLOW ASSESSMENT
HEC	HYDROLOGIC ENGINEERING CENTER
WMS	WATERSHED MODELLING SYSTEM
HMS	HYDROLOGICAL MODELLING SYSTEM
EFM	ECOSYSTEM FUNCTION MODEL
MAR	MONTHLY AVERAGE RAINFALL
DEM	DIGITAL ELEVATION MODEL
LULC	LAND USE LAND COVER
IMD	INDIAN METEROLOGICAL DEPARTMENT
CWC	CENTRAL WATER COMMISSION
G&D	GAUGE AND DISCHARGE
3D	THREE DIMENSIONAL
SMA	SOIL MOISTURE ACCOUNTING
UTM	UNIVERSAL TRANSVERSE MERCATOR
GEFS	GLOBAL ENSEMBLE FORECAST SYSTEM
CIFRI	CENTRAL INLAND FISHERIES RESEARCH INSTITUTE

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In addition to human beings a lot of other life is dependent on the water in the River. Abstraction of too much water from the river is detrimental to the sustenance of aquatic flora and fauna. Therefore, a certain minimum flow has to be maintained in the river for sustaining the aquatic ecosystems. Accordingly, River ecology started on the concept of a “minimum flows” which refers to a definite minimum flow and it must be maintained in the River for the survival of aquatic flora and fauna, and for the sustenance of the aquatic ecosystems. However, gradually it was realized that preservation of aquatic environment requires not only a definite minimum flow but also a certain water quality, temperature, velocity, frequent pulses of high flows, hence, in general a complete flow regime. Therefore, over the past few years the term “minimum flows” has been discarded in favour of a more general term Environmental Flows (EF) or Environmental Flows Requirements, (EFR). Thus, while minimum flows referred only to the quantity, EFR refers to a complete flow regime.

The need for EFR has come to the fore only recently after the abstractions in certain river reaches increased to a point where it started harming the aquatic ecosystems. Simultaneously, the awareness and concern about the health of the environment became accentuated. There has been considerable debate on the issue of minimum flows during past few years. However, no satisfactory solution has emerged to remove the difficulties in implementing EFR and improve the health of River ecosystems.

Baitarani River is one of the important Rivers of Odisha state of India, flowing eastward and joining the Bay of Bengal. The River originates in the hill ranges of Keonjhar near the Manakarancho village in Keonjhar district at a reduced level of about 900 m above (Mean Sea Level) M.S.L. On its way many tributaries join it on both the bank. The River is flashy in nature having a total length of 232 km. The river shows a considerable fall in geographical gradient from RL 367 m at Champua to RL 28 m at Anandpur. The River is ecologically rich with the presence of various species. Some of the important profound species are Catla-Catla, Rohu, Hilsa, Maggar and Benthic Macro Invertebrate. This River also encompasses wetland. The River is now facing deterioration in Riverine ecosystem because of growing water demand for other domestic, industrial and agriculture use. This study aims to assess the need of environmental flow of the Baitarani River ecosystem.

1.2 OBJECTIVES OF THE STUDY

The objective of the study includes the following:

- To determine profound vital species of Baitarani River ecosystem.
- To assess the E-flow of the identified species.
- To determine the average E-flow values for the identified species.
- To assess the E-flow requirement in climate change scenario.
- To assess the E-flow requirement in future development scenario.

1.3 ENVIRONMENTAL FLOW ASSESSMENT (EFA)

Need of the assessment of fresh water dependent ecosystems is a tough task because of the complexity of biological, chemical and physical processes and the interactions between components of freshwater ecosystem. Environmental Water Requirements (EWR) which are sometimes also called as E-flows which in the form of flow discharges of a definite magnitude, timing and frequency. Therefore these combined flows make sure of such a flow regime which is capable of sustaining complexity of aquatic ecosystem processes and are therefore called environmental flows, environmental water requirements and environmental water demand etc. Many methodologies on these E-flows have been made in recent years. They are known as Environmental Flow Assessments (EFA).

An EFA is therefore an assessment of what definite amount of the flow regime of a River should present to flow downstream in order to maintain specified characteristic of the Riverine ecosystem. It is used to assess that how much water could be abstracted from a River without an dangerous or warning level of degradation of the Riverine ecosystem.

1.4 METHODS OF ENVIRONMENTAL FLOW ASSESSMENT

Since the 1970's more than 200 methods of EFA are being used all over the world (CRC 2008).Environmental flow assessment methodologies and techniques are classified into four general categories; (1) Hydrological, (2) Hydraulic rating, (3) Habitat simulation and (4) Entirety methodologies. The details is described in the table below.

Table 1.1 Methodologies for assessment of E-flow

Methods	Advantages	Disadvantages	Scope of application
Hydrological method	Simple; need least data; do not need extensive field work.	Lack of biological basis; Not considering seasonal variation and plentiful and withered circulation of flow; Historical flow data for years are needed.	River macro strategy management;
Hydraulic method	Data acquisition by measurements or Manning formula; Measurement is relatively simple.	Not considering velocity changes; Not considering channel instability with time; Selected section cannot represent the whole channel characteristics.	Small and medium-sized Rivers (with top width less than 30 m wide) where pollution is not obvious and sediment content is low.
Habitat method	Considering the change of the habitat by species and its different stages of life.	Only consider the individual species, not considering the entire ecosystems; Need more biological data; Take a long time; Capital amount is big.	Small and medium-sized habitat or the region of clear management objectives.

Entirety analysis method	Habitat maintain and pollution control, etc.	Many subjects involved; Need expertise in ecology, geography, hydrology, Consume a large amount of human resources and time cost.	Widely used in South Africa Currently; need a lot of correction when applied to other areas.

1.5 WATERSHED MODELLING SYSTEM (WMS)

Watershed Modelling System (WMS) is a watershed solution used for delineation, hydrologic &hydraulic modelling process, floodplain mapping and storm drain modelling. It automatically delineates a watershed, basin and sub-basins using digital terrain data. Also, computes geometric basin data such as area, slope, mean elevation, maximum flow distance and more. Outlet point is given based on CWC's gauge and discharge site location. After delineation till Anandapur discharge site, inbuilt interface of HEC-HMS for setting up of hydrologic model was used.
WMS is licensed software, but the free trail of 14 days is available for evaluation purpose. So, in this study, the free trail of license was used.

1.6 HYDROLOGICAL MODELLING SYSTEM (HMS)

HMS is a tool in hydrological modelling through which the effect of a storm event on a sub-basin, sub-catchment, watershed or a continuous simulation can be checked. Although HMS works in distributed modelling but it can also deals in such a watershed which itself consist of sub-basin and reach. HMS is quite availing in a way that it has many options for hydrological evaluation and has user-defined as one of the options. One of the uses of the HMS is to calculate the runoff that can happen in a watershed and the corresponding flood that could happen. It is applicable in a wide area of geographical field to solve the widest possible range of problems.

1.7 ECOSYSTEM FUNCTION MODEL (EFM)

The Ecosystem Functions Model is a planning tool that assists in analysing ecosystem responses to changes in flow regime. The Hydrologic Engineering Centre (HEC) of the U.S. Army Corps of Engineers has created HEC-EFM for project teams to visualize existing ecologic conditions and to assess the environmental flows.

The relationships between characteristics of hydrological and hydraulic time series in terms of discharge and stage to characteristics of the ecosystem with the help of combination of four basic criteria namely season, flow frequency, duration, and rate of change. There can be different combination in working for making relationships that can be developed and it has an interface to facilitate entry and inventory of criteria.

HEC-EFM is open source software. It uses the hydrological and the hydraulic data as main parameters for simulation. The flow requirements are set and used as surrogate for breeding and feeding behaviour and spawning of each species to calculate and speculate the effects on the physical compared in terms of past and future speculated changes in flow caused by abstraction, pool creating or dam construction. The model does not consider other parameters such as wetted perimeter or velocity but rather uses flow and water depth only.

CHAPTER 2

LITERATURE REVIEW

The literatures regarding Environmental Flows are Hec-HMS and Hec-EFM are taken as reference for the present study. The approaches that have been taken in the previous research helped in finding the gaps with the aim of the present study and what has been already done before in both conflicting and simulating manner. Hence to get the approach in a right direction following literature reviews have been taken.

Acreman mike and Dunbar J Micheal **(2003).** They reviewed the various methods available for environmental flow estimation. They suggested a method from the four types of methods namely Look-up tables, Desk-top analyses, Functional analyses and Hydraulic Habitat modeling. It can't be said which method is better over other therefore every method is specific and is used according to its suitability. Look-up method is easy to understand as well as its application. These can be sometimes expensive and at the same time a little less accurate whereas hydraulic habitat method is expensive as compared to look-up method. This method has good suitability for assessment of impact at various specific places. Applying any method needs a specific framework with a decision which has a wider impact used. All the above methods are chosen on a objective so that it helps to define the flow regime of any specific river and at times these are also based on that how to determine the various characteristics of flow regime.

Conclusion drawn is that all the above mentioned methods can be very beneficial and can get better results if used for future development using good knowledge and experts experiences. The hydro ecology is itself a new field and so much is still required to be learnt in it but the present scenario of it, is although, good for improving, protecting and studying river ecosystem.

Asadi Arash, Boustani Fardin (2013). In this research paper the authors described the methodology and use of Hec-HMS software in small basin of Delibajak (16.3 km sq.) in kohgilouye and boyerahmad, iran was examined. It starts with the hydrologic model (rainfall & runoff) HEC-HMS (Hydrologic Engineering Center, Hydrologic Modelling System) relating it with Geospatial Hydrologic Modelling Extension, HEC-Geo HMS and using SCS curve number method (Soil conservation Service, 1972) which was taken in the processing step for modelling. The model during processing is first calibrated carefully and then cross checked for percentage difference in terms of discharge and peak flow using basin's historical hydrological data. The model was then merged with the local parameters and analysis was then adopted for evaluating the event model. The model after working on SCS curve also predicted peak discharge as discussed above based on historical hydrological flood discharge data. The flood volume could be then calculated and frequency (timings) were calculated by the model and then compared to the natural flow. This process gives a clear idea that the HEC-HMS software is very useful and also suitable for the studied basin. The conclusion then can be drawn after getting results that the complexity model methodology makes no effects on its efficiency and suitability. Whereas the structure of HMS software is quite simple and also it seems to be a very effective tool for the forecast of flood and its timing. Therefore the application of the HMS software must be foster for its use in the Iran basins. The parameters that were used for the trial of optimizing hydrological data using curve number were also adjusted unless a close result regarding the discharge, peak flow and timing was obtained. These parameters were at the end got adjusted accordingly. Using curve number lag time Were 52, 48 and 91 min respectively. Whereas the initial abstraction ranges from 50 to 51, and 46 mm to 50 mm respectively were obtained. This variations obtained is because of the differences in gradient, drainage density, soil strata, vegetation cover and the land use and the land pattern in sub basin.

Godinho Franciso, Costa Sergio, Pinheiro Paulo, Reis Filipa, Pinheiro Antonio (2013). They studied Integrated Procedure for Environmental Flow Assessment in Rivers. In European countries, the view over the improvement of river ecosystem is taken attention and is increasing day by day. Different policy fronts and guidelines are made for its improvement. As today, demand for water into different sectors is increasing and abstraction of water is being done from the rivers for this purpose which creates a load on river ecosystem for its survival in a natural way hence E-flows must always be present there and must be maintained using the best present knowledge. At the downstream of dam, usually the flow get restricted and generally it is less than as compared to the natural condition unless in case of extreme floods. So to provide E-flows there are different methodologies and sometimes two or more are linked at the same time to get the good results. The paper describes the application of methods and the step used in it is elaborated while working in Portugal using preliminary methodologies and also discusses the results obtained. This procedure consists of various uses of data and elaborate their collection methods for calculating the environmental flows. It is also described that these above mentioned methods can be manipulated according to the time and available budget.

Hickey John. T and Dunn Chris N (2004). The authors in this paper showed the use and specific application of Ecosystem Functions Model (EFM). It is a tool which is used in analysing the changes for the changes on ecosystem with the changes in flow regime of the river or changes due to the effect regarding any of its tributaries. The United State Army Corps of Engineer's Hydrologic Engineering Center (HEC) has developed this tool called Hec-EFM to assist the environmentalists, water managers, planners, engineers and biologists. Using the model it can be efficiently evaluated that whether the planning policies or proposed projects like dam, industry and pool creation at any specific location will enhance or decrease the health of ecosystem. It can also be used for analysing that the existing ecologic characteristic and condition. Therefore, software's is applicable quite wide. The EFM was initially developed for a reach Sacramento and San Joaquin Rivers but later on, development in software helped internationally. In 1998 Reclamation Board of California also made an effort to analyse the conditions over which flood damage could be reduced and also on restoration of ecosystem in the Central Valley, California (US).

Technically, EFM was developed for analysing inter-relationships of ecosystems and comparing it with the effects after restoration efforts. Whereas, sometimes, not specifically the details of what elements could be investigated was clearly mentioned. Later on as time passed, questions were being raised for the actual workings of the EFM. Thereby, attention over model construction and how it could be used for assessing the ecosystem characteristics highlighted during the development. The Study Team, California Department of Water Resources, HEC, and Jones and Stokes cooperatively developed the first quantitative version of the software, which could be used for the purpose of statistical analysis as indicators of ecosystem condition, elements and characteristics.

Jha Dharm Nath, Alam Absar, Joshi Kripal Datta (2014). The authors in this research paper done analysis on Sone river using 36 years of data by Indrapuri Barrage using Global Ensemble Forecast System (GEFS). The river as classified in class (F) with the mean discharge and wetted perimeter with 5.15 % MAR and 2-5 % respectively. After calculation to get the river in class (C) and class (B) the speculated MAR is 18.9 % and 34.2 % respectively to get it restored. Besides this an attempt has also been made to calculate the environmental flow and on the basis of that the loss of biodiversity and fishes is speculated as the flow was found decreased. It was the first attempt by CIFRI to calculate the E-flows at the downstream of the barrage. The preliminary data was used was hydrological data with the help of GEFC using desktop approach method. It also opens gate to further studies with multidirectional approach using holistic method.

Jha Ramakar, Sharma K. D, Singh V. P (2008). In past few years different kinds of methods and approaches were used to calculate environmental flow using hydrological data all over the world. But in Indian scenario it is not that much used. Brahmani and Baitarani are the two rivers over which many future project are up coming so there is a need to calculate the environmental flows so that this analysis could help the planner and water managers to allocate and abstract the water in a best possible way. The present study helps in evaluating the values environmental flows at various sites at the above mentioned two river system, and it also helps in using the best application of E-flows because as mentioned above in India the application of environmental flow is very limited.

The authors also wanted to suggest in this paper that at what place what kind of methodologies is good and suiting accordingly, also to get an an idea of various methodologies present internationally.

Korsgaard Louise (2006). In this research challenges of Integrated Water Resources Management (IWRM) is addressed. It becomes sometimes very difficult to allocate the water among competent users and for the planner to adjust the importance of uses. As it is seen that for people who are economically and politically strong, they justify their water needs have in a well defined methods and patterns where as this isn’t the ecosystems case. This research mainly concludes about the gaps that is being faced while defining the ecosystem needs for water and also assessing minimum flow for ecosystem while keeping about the values of economy. Hence a approach is also made linking among these.

Environmental flows are sometimes referred as flow of water for ecosystems. Ecosystems as very well known for providing the needs for humans like food and services since the human civilization existence. Thereby it can be concluded that if environmental flows is provided it isn't only a issue for ecosystems but it is also a matter for supporting human life commercially and for wellbeing. If we are talking about IWRM, the requirement of environmental flow becomes a concern for everybody. Hence the preferences among competent users become crucial and for policy of decision makers. In order to analyse the allocation of water between competent users various strategies and polices are made which itself is a huge task so in order to do so environmental flows must be used for keeping a balance among all. As various literature reviews suggests that there have been more than 200 methodologies for assessing E-flows so here simply holistic method is used.

This author has made an attempt for simplifying and making transparent decision for assessing various environmental flows regimes. This can be used as a tool and mainly takes base of an existing River basin by simulating the model by making calculation process developed in MS Excel. This sort of approach basically connects E-flows to socio-economic attribute by mainly concentrating on ecosystem values. Thereby, giving emphasis on ecosystem and it's functioning to the humans life justifying E-flows becomes a bit easy as well as their value. Hence this helps in understanding economic value by supporting by E-flows.

Liu H C, Shui1 Y, Li1L H, Cao N, Yu1 G Y and Liu J (2016). Based on the comparative analysis of calculation methods of environmental flow, a "Huaihe Method" was proposed, which consists of the hydrological estimation of the minimum environmental flow with validation by the requirement space for fish. The minimum environmental flows of the important control sections in main stream and tributaries in the Huai River basin are estimated. The recommended minimum environmental flow have been adopted in the water resources planning, which provided reference for rational allocation of environmental flow, water resources usage, and sustainable development for the local society. The main stream of Huaihe, Honghe and Yinghe have relatively stable and larger flows, while meso flows exist in Guohe according to the historical records at hydrological stations.

For Rivers with flow rates less than 80 m^3/s, 10% of annual mean discharge is allocated for environmental flow. The 5% of annual mean discharge is assigned for environmental flow when the flow rates are larger than 80 m^3/s.

CHAPTER 3

THE STUDY AREA

3.1 LOCATION

The Baitarani sub basin is situated approximately between east longitudes of 85º 10′ to 87º 03′ and between north latitudes of 20º 35′ to 22º 15′. The beginning portion of Baitarani River acts as the boundary between Odisha and Jharkhand states. The Baitarani is one of the important Rivers of Odisha flowing eastward and joining the Bay of Bengal. The River originates from Keonjhar District of Orissa which is hilly region near Manakarancho village at an elevation of about 900m above mean sea level, it is then joned by many tributaries from both banks. The major tributaries of Baitarani are the Salandi and the Matai. With the upper reach upto to Anandpur in the hilly reason. The River enters plains at Anandpur and creates deltaic zone below Akhuapada. The River is flashy in nature. The districts falling under the Baitarani basin are Balasore, Bhadrak, Jajpur, Kendrapada, Angul, Keonjhar, Mayurbhanj and Sundergarh in Odisha and West Singhbhum in Jharkhand. The major tributaries joining the River include Deo, Kanjhari, Kusei and Salandi. Location of study area in India is shown in Fig.3.1 and description of the study area is shown in Fig.3.2.

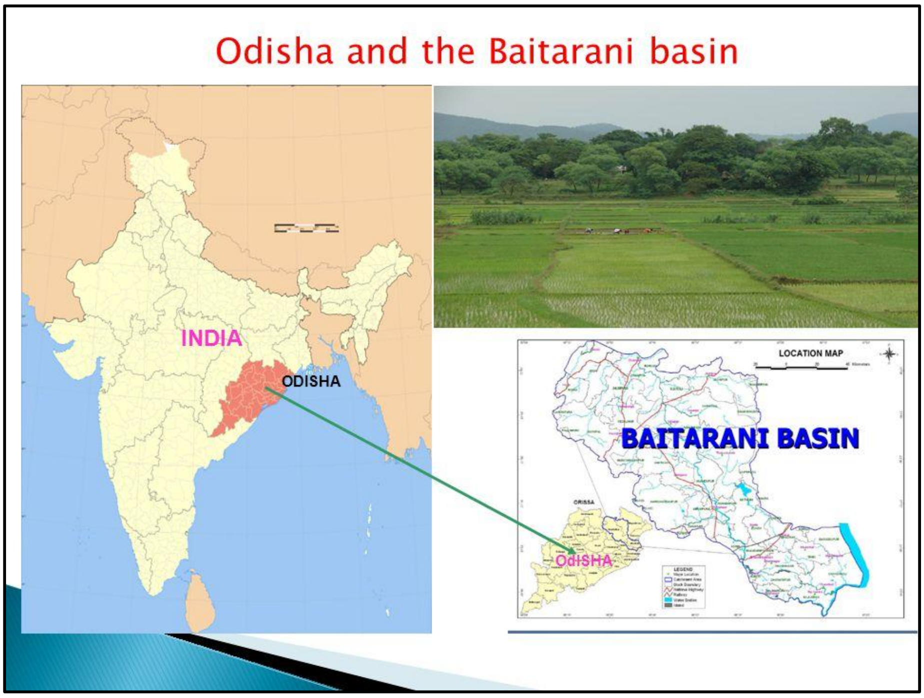


Figure 3.1 Location of Baitarani River in India

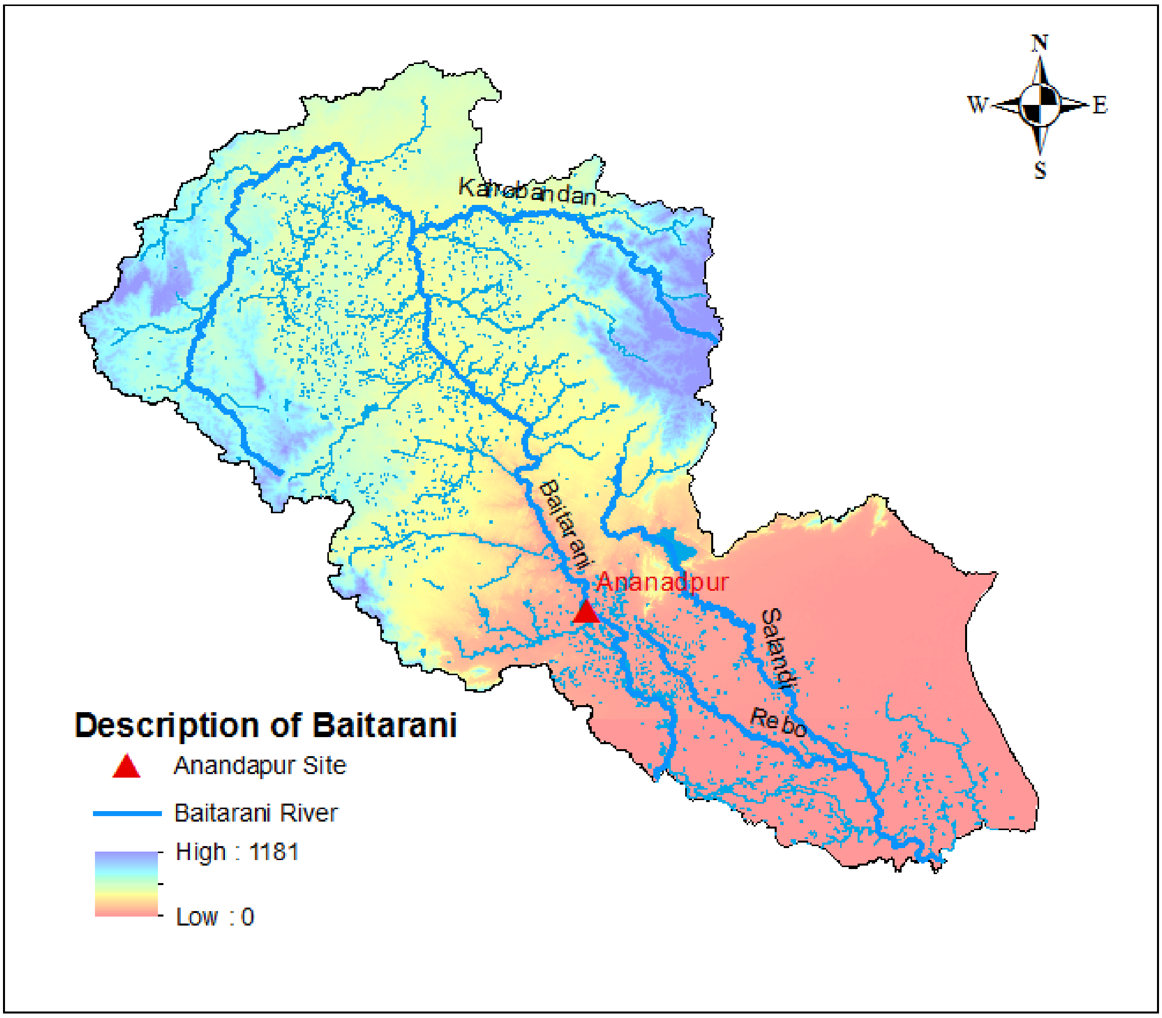


Figure 3.2 Description of study area

3.2 TEMPERATURE

In Baitarani sub-basin, maximum temperature rises to 40.5°C during summer while the minimum during winter may be as low as 8-9°C. The climate is humid and is favourable condition to various profound species.

3.3 RAINFALL

The rainfall is received from south-west monsoon from June to October. Rainfall in the study area varies from 1876 mm to 390 mm.

3.4 AQUATIC LIFE IN BAITARANI RIVER

Due to extensive estuarine belt of Baitarani River the faunal diversity is very high. The fishes, crustaceans (crabs) and molluscs (snail) are the common elements of the aquatic environment. About 126 species of fishes under 89 genera belongs to 48 families, 26 species of prawns under 11 genera belongs to 4 families, 22 species of crabs under 14 genera belongs to 8 families and 39 species of species of common wetland and wetland dependent birds.

3.4.1 Small Fishes

Abundance of small fishes (marine and fresh water) are found in Baitarani River but due to lack of environmental flow and other polluting factors, some of the fishes are getting endangered and concerned. A few of these fishes are shown in Fig. 3.3.

 Oriental Sole	 Drawf Puffer Fish
 Kolus	 Murangi

Figure 3.3 Small Fishes

3.4.2 Big Fishes

Hilsa (Ilish) –It is also known as silver sheen of Rivers. It can grow up to 60 cm in length with weight up to 3-4 kg. Hilsa grows in and requires temperature in the range of 23º to 29ºC. It is found in Rivers and estuaries in India, Bangladesh and Myanmar. It feeds on plankton and by grubbing muddy bottoms. Hilsa as shown in Fig. 4 is a migratory fish for and travels to spawn during monsoon period from sea towards inland River. In 1800s Hilsa used to migrate upto Kanpur in River Ganga but today due to decreasing quality and quantity of water the migration has only restricted to Baitarani River and in River Ganga only in west Bengal. Fig.3.4 shows typical Hilsa fish.

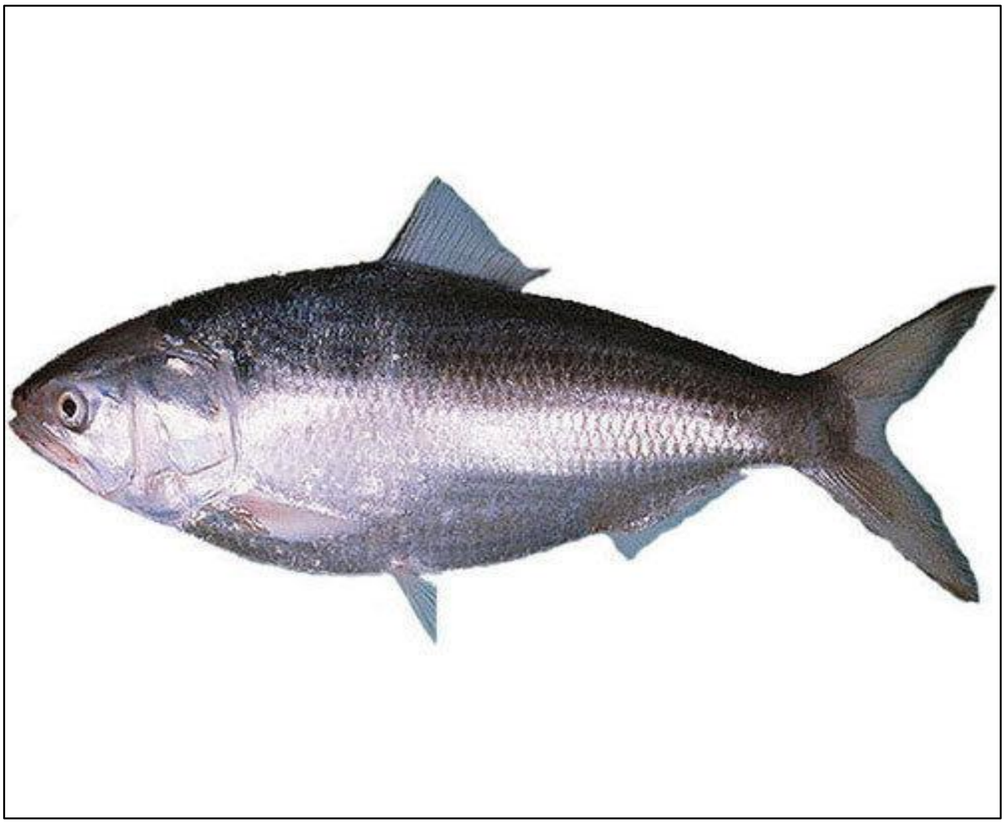


Figure 3.4 Hilsa Fish (Ilish)

Catla Catla (Labeo catla) –It is one of the fastest growing carp of major carp. It is one of the major (Indian) carp, is an economically important .It has large and broad head, a large protruding lower jaw, and upturned mouth. It grows best in range of temperature 25º to 35ºC. Its minimum tolerant temperature is 14ºC It is a surface and midwater feeder. Adult fishes feed on zooplankton using large their gill rakers, but the young ones on both the zooplankton and phytoplankton. The fish can grow upto 182 cms and can has a weight of 35-38 kgs. The existence of this fish becomes very important for the fact that it is consumed in very widely and hence commercially very important. It resides in fresh and brackish water. A typical picture of Catla Catla is shown below in Fig.3.5.

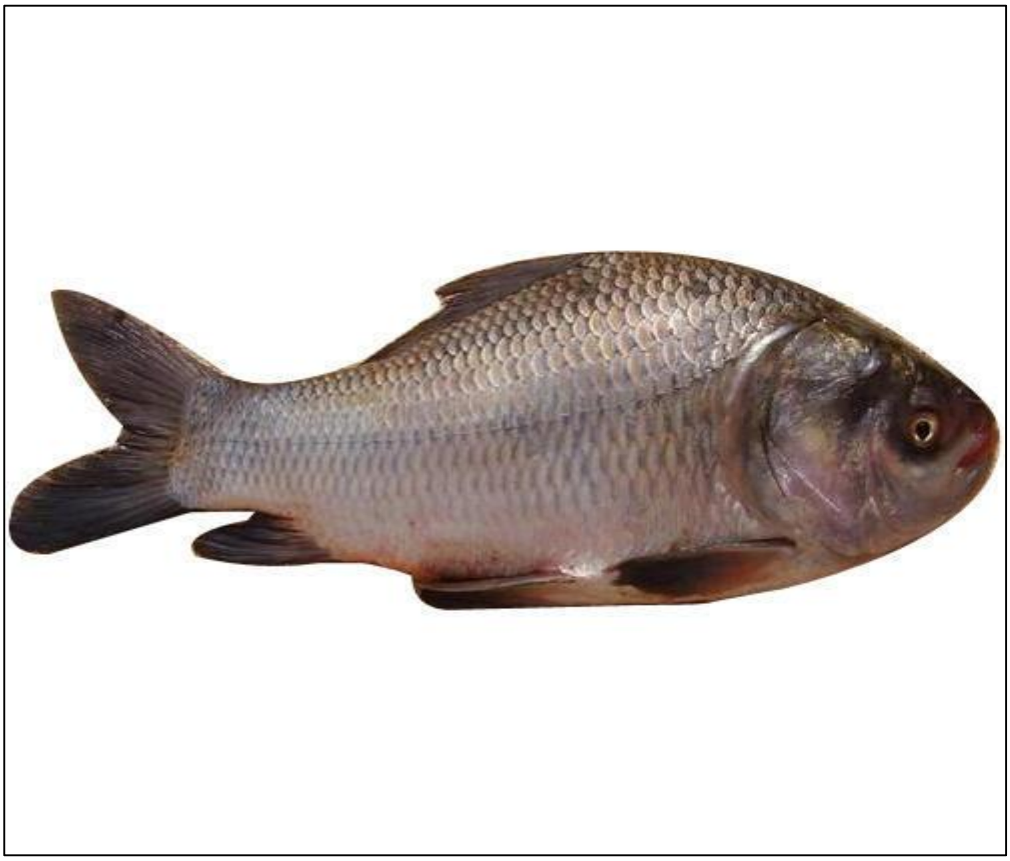


Figure 3.5 Catla Catla

Rohu (Labeo Rohita)-The Rohu, shown in Fig. 3.6 is a large silver coloured fish of freshwater of carp family. It has a thick body with narrow head and tail compared to Catla fish. Adults can have a maximum weight of 40-45 kg and maximum length of around 2 m but average length is around 0.5 m. It is found in central, eastern and north region of India. The species is an omnivore which used to have very selective kind of feeding. Juvenile depends most on zooplankton, whereas young and adult depends more on phytoplankton. It is with thin hair like gill that helps it feeded. Rohu grows well at temperature between 25º to 37º C. It generally takes the feed from the middle level of water.

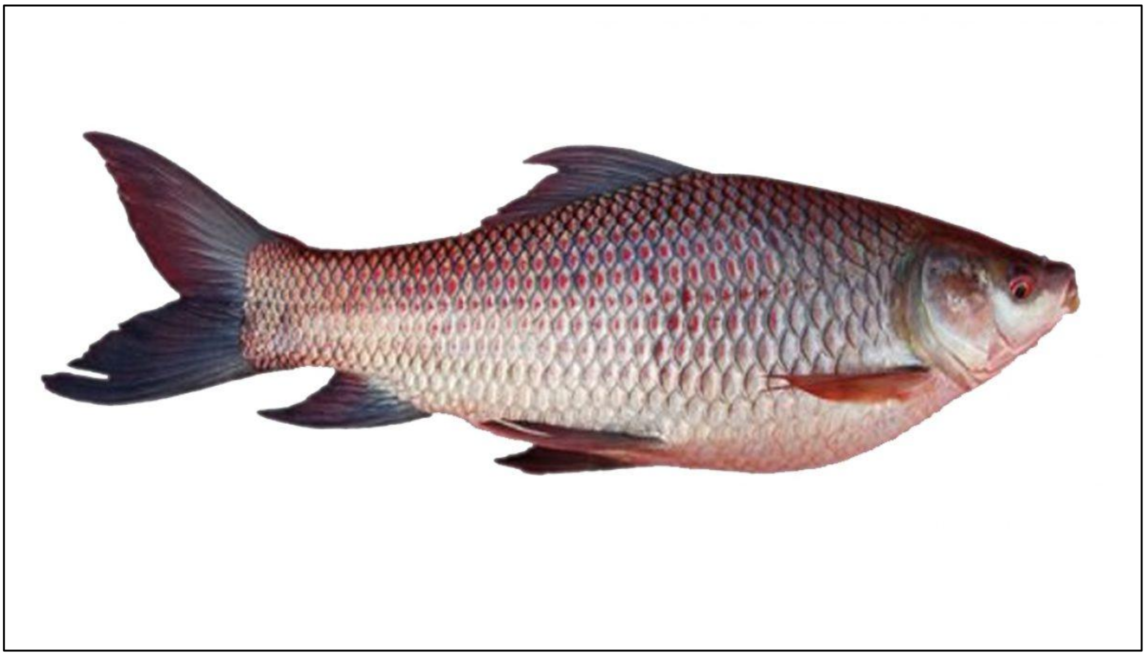


Figure 3.6 Rohu (Labeo Rohita)

3.4.3 Maggar

Maggar species of crocodile lives in freshwater and generally found in rivers and lakes. They prefer slow flowing water than that of fast flows. They are also known to grow sometimes in man-made reservoirs and irrigation canals. Generally they prefer freshwater but they have some toleration to brackish and saltwater therefore they are occasionally found in saltwater lagoons. Maggars are good in coping up with terrestrial life than most other crocodilians like their cousin the Cuban species but they are very much similar to the African Nile crocodile. They are found to be more agile on land and they used to shift from one place to another over land in search of better habitat. Maggars are known for hunting on land for small segments of distances. They used to dig burrows during the dry seasons for their shelter. A typical Maggar is shown in Fig.3.7.

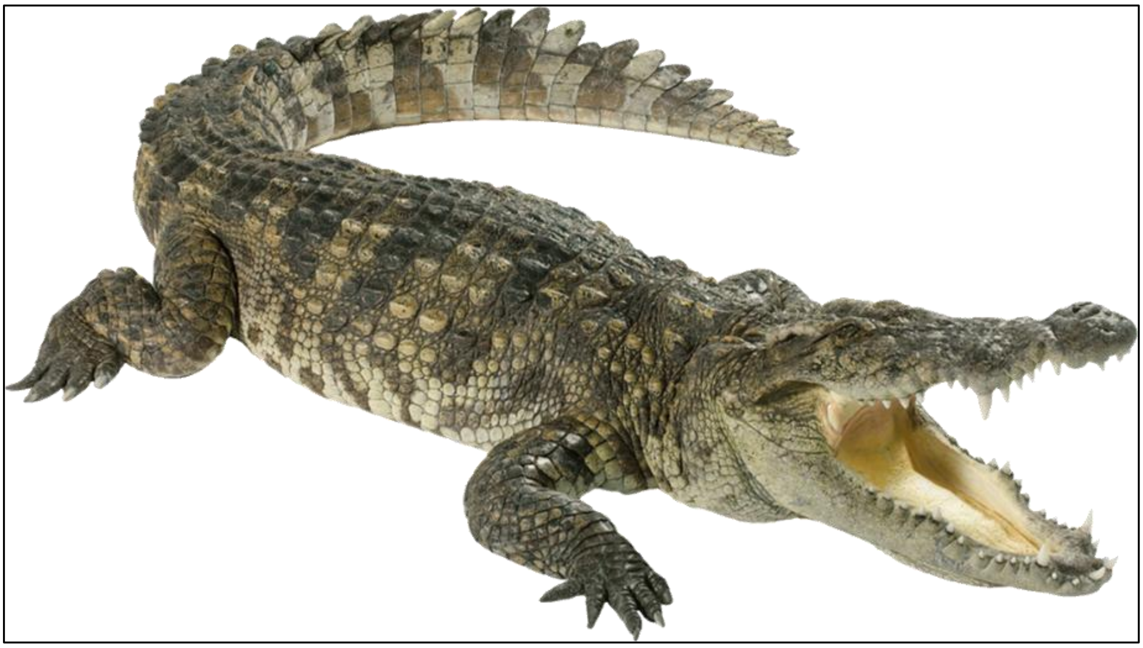


Figure 3.7 Maggar

3.4.4 Benthic Macro Invertebrate

Macro invertebrates as their name suggests are organisms which do not have backbones which are visible to the eye without the use of a microscope. Aquatic macro invertebrates live on and around the rock under as well as on sediment on the bottoms of lakes, Rivers and streams. Because of their habitat choice, macro invertebrates are also called as “benthos”. They are called so because benthic zone is the lowest or bottom of any water body like lake, River and sea. They are also called “Environmental Indicator” because of they are sensitive towards the pollution in water and can be found in much polluted water. Since they are food to many fishes and other aquatic species so their presence is an indicator that some fishes could be present if they are present and an aquatic life is present. The micro invertebrate found in Baitarani River are freshwater crabs, crayfish, shrimps, lobsters, and fresh water mollusc (snail), aquatic worms(ringed or segmented worms), snails, and leeches which are shown in Fig.3.8

 Barytelphusacunicularis (red crab)	 Gastropoda (snail)
 Charybdis affinis	 Shrimp
 Crabfish	 Segmented worm(Aquatic worm)

Figure 3.8 Benthic Macro Invertebrates

3.4.5 Wetland Health

A wetland is the land which is saturated by water either salty, fresh or brackish. Wetland plays a vital roles in the environment, mainly water purification, flood control, storm protection, carbon sink and shoreline stability. Wetlands are also taken as the most biologically and physically diverse of all ecosystems because they serve as home to a wide range of plants and animals. The destruction of wetlands is today a concern because they are often the most productive habitats on the planet.

Water is very important for the development of vegetation and small plants in wetlands. These vegetation helps in restraining the waves damage in inner land and in flood condition and also provides food for various species. Hence if there is change in water system of wetland changes in composition of a wetland occurs. Khadibahali wetland is shown in Fig. 3.9.

Figure 3.9 Khadibahali wetland on bank of Baitarani River

CHAPTER 4

MATERIAL AND METHODS

4.1 MATERIAL

The material in this study includes various input datasets e.g. Digital Elevation Model (DEM), Rainfall, Soil, Land Use Land Cover (LULC) and Ecosystem data.

4.1.1 Digital Elevation Model

Digital Elevation Model is three dimensional (3D) representation of any horizontal and vertical dimension of the land surface. DEM helps in defining flow directions with the help of elevation values incorporated in it. In this study DEM was downloaded from ASTER web. The DEM was then clipped for Baitarani area which is shown in Fig. 4.1. This DEM was converted to .hdr format and then used as input to the WMS software.

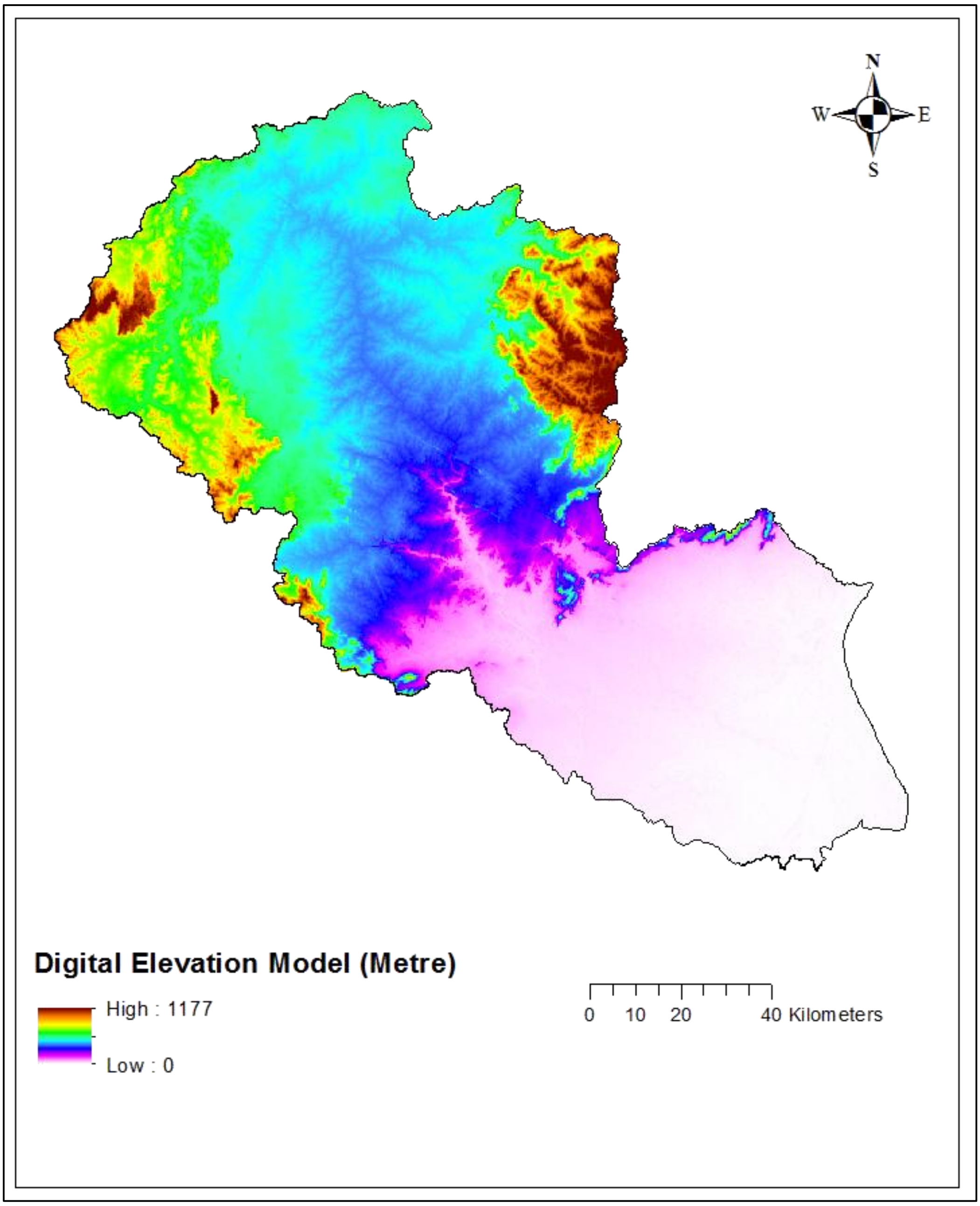


Figure 4.1 DEM of Baitarani Area

4.1.2 Soil Data

Soil maps represent the type of soil present in a particular area. The main soil types found in the study area are red and yellow soils, red sandy and loamy soils, mixed red and black soils. Fig. 4.2 shows various categories of soil in the basin. The soils are classified as sandy, loamy, clayey, loamy skeletal, clay skeletal based on the soil textural information. In this study the freely available global Soil data was downloaded from daac.ornl.gov, The Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC), in raster format and then was converted to vector format for making it compatible for the software. Soil maps helps in runoff estimation by taking the effect of different soil input sets on water balance modelling component. Soil map of Baitarani basin is shown below.

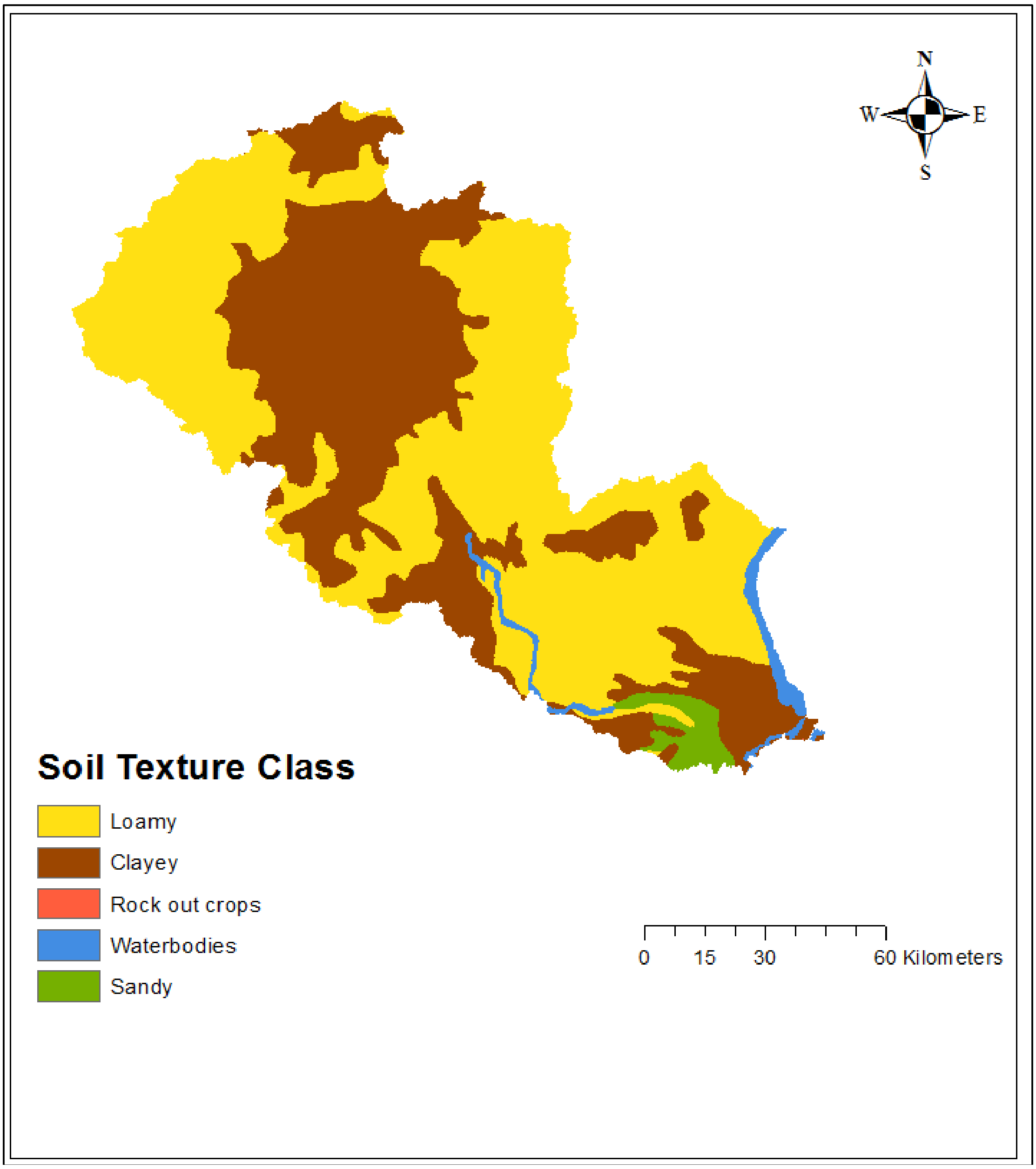


Figure 4.2 Soil textural map of study area

4.1.3 Land Use Land Cover (LULC)

The Land Use Land Cover data belongs to the data that is a consequence of class raw satellite data into "land use and land cover" (lulc) categories based on the return value of the satellite image. Nonetheless, land use land cover helps in determining the various land uses and cover types, such as constructed buildings, forested, scrubland, agriculture, etc. The freely available global LULC data was downloaded from http://glcf.umd.edu, Global Land Cover Facility which provides Moderate Resolution Imaging Spectro-radiometer (MODIS) data from NASA's Satellite Terra and Aqua. In hydrologic modeling, Land Use Land Cover (LULC) information is used to know detection values or surface roughness. For the prediction of water holding capacity and percolation, land-use information is combined with the hydrologic characteristics of soils on the land surface. From vegetated land- use types, such as forest, the amount of expected runoff is not only affected by the surface, soil and physical properties, but also by the intercept capacity of the vegetation present. As a result, for the runoff process land use and land cover are important characteristics which also affects evapo-transpiration, erosion and infiltration. LULC map of Baitarani basin is shown below in Fig. 4.3.

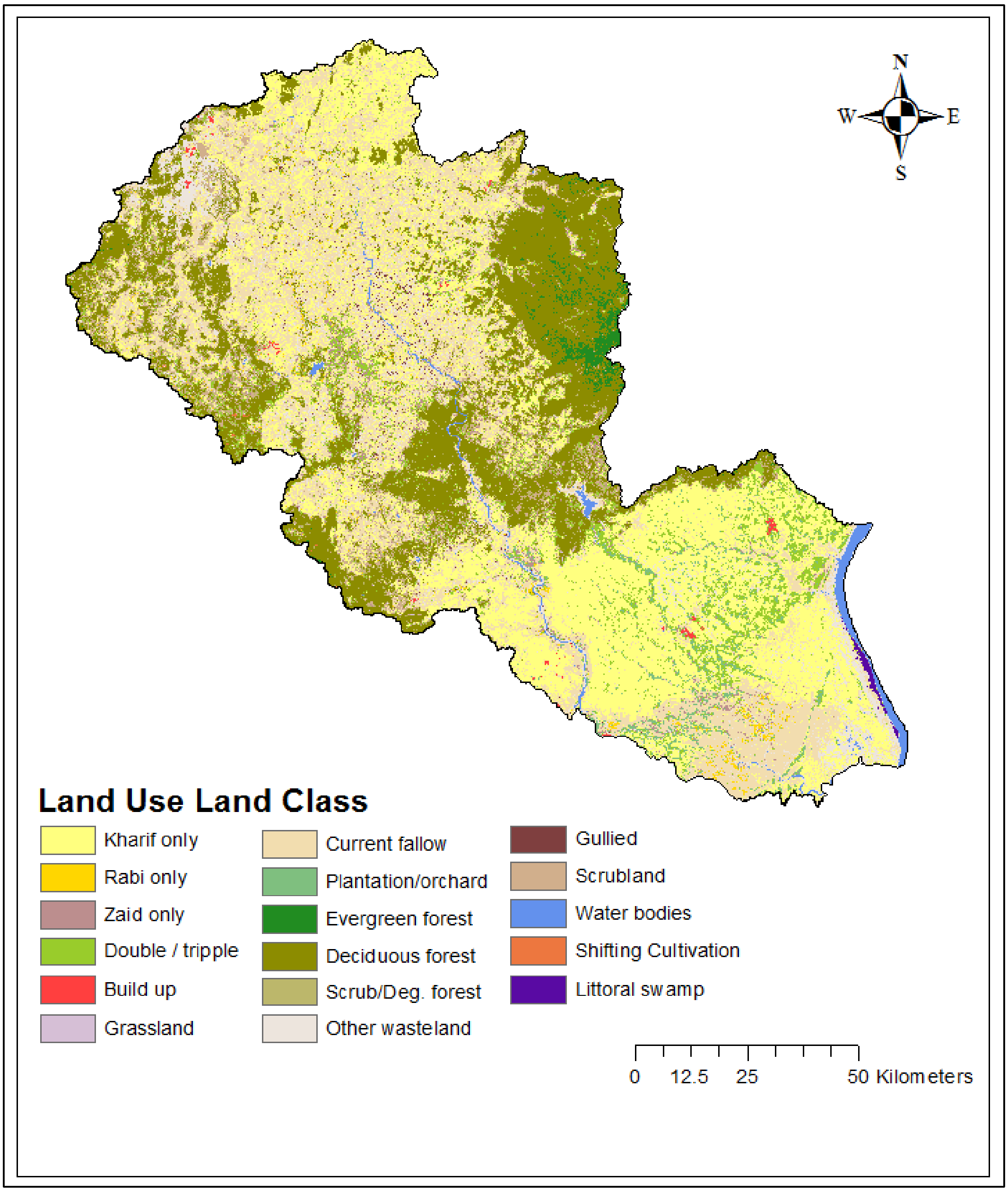


Figure 4.3 LULC map of Baitarani basin

4.1.4 Rainfall

Rainfall is the basic input for any rainfall runoff modelling. The rainfall for this project was collected from (Global Ensemble Forecast System) GEFS and CWC. Rainfall occurs in the study area mainly due to south west monsoon which is active from June to October amounting to about 80-90% of annual rainfall. The annual average rainfall is around 965 mm. The rainfall graph of 17 years from 2000 to 2016 is shown in Fig.4.4.

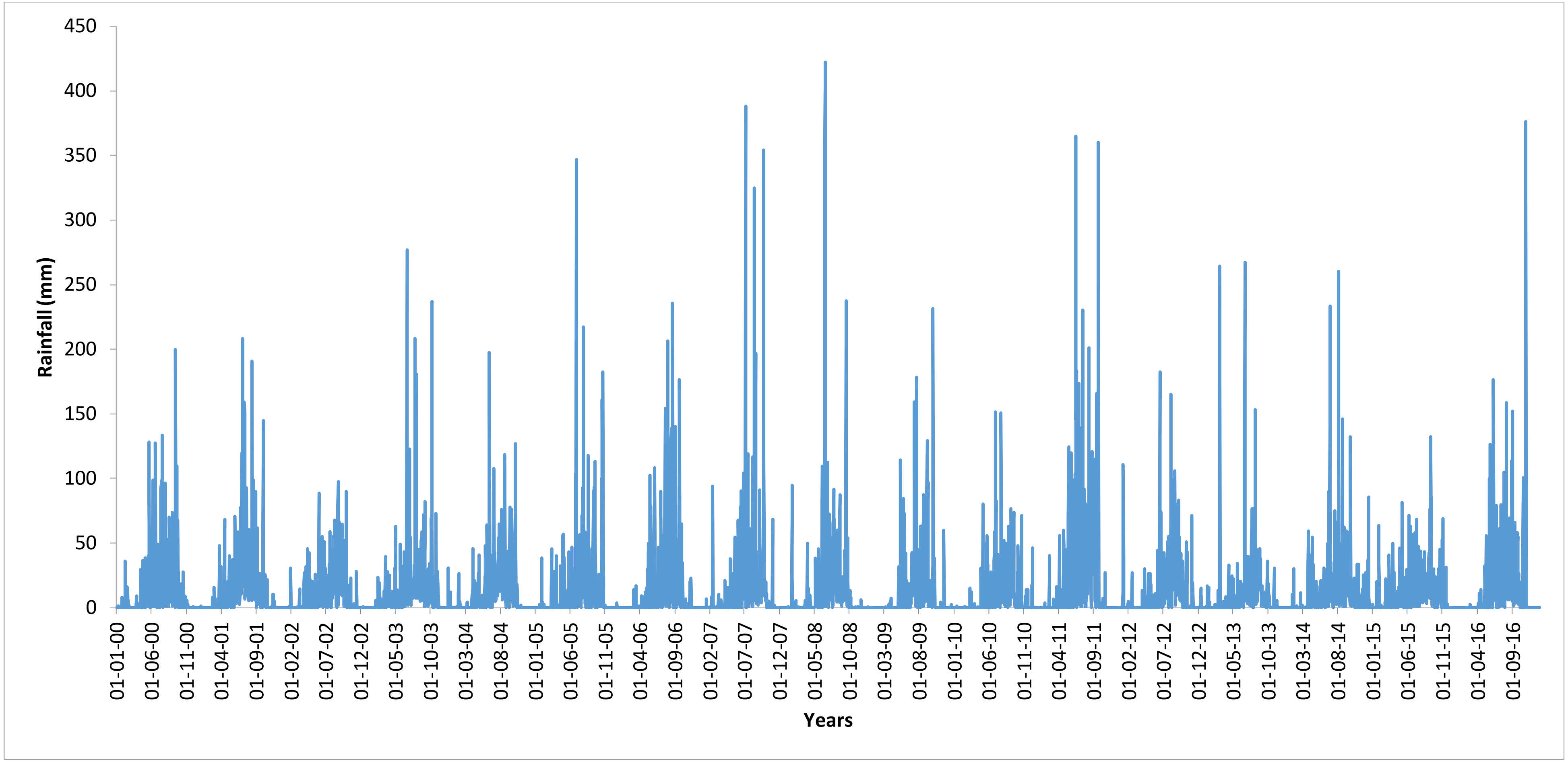


Figure 4.4 Daily rainfall graph of 17 years

4.1.5 Flow Data

Flow data is a basic input for calculating environmental flows. Three flow regimes were used for the viewing the effect of environmental change such as climate change and future development. These flow regimes were created by the help of data and various reports published by State Government and CWC. These flow regimes are discussed further in coming paragraphs.

4.1.5.1 Observed Flow Regime

The flow data at Anandapur G&D site for last 17 years from 2000 to 2016 is shown in Fig 4.5. This data was used to calibrate runoff generated from HEC-HMS software. This data is the recorded data of CWC's gauge and discharge site situated in Anandapur, Odisha. The flow data when used in HEC-EFM software was termed as flow regimes. Observed flow regime was used in HEC-EFM software to evaluate the environmental flows for present situation.

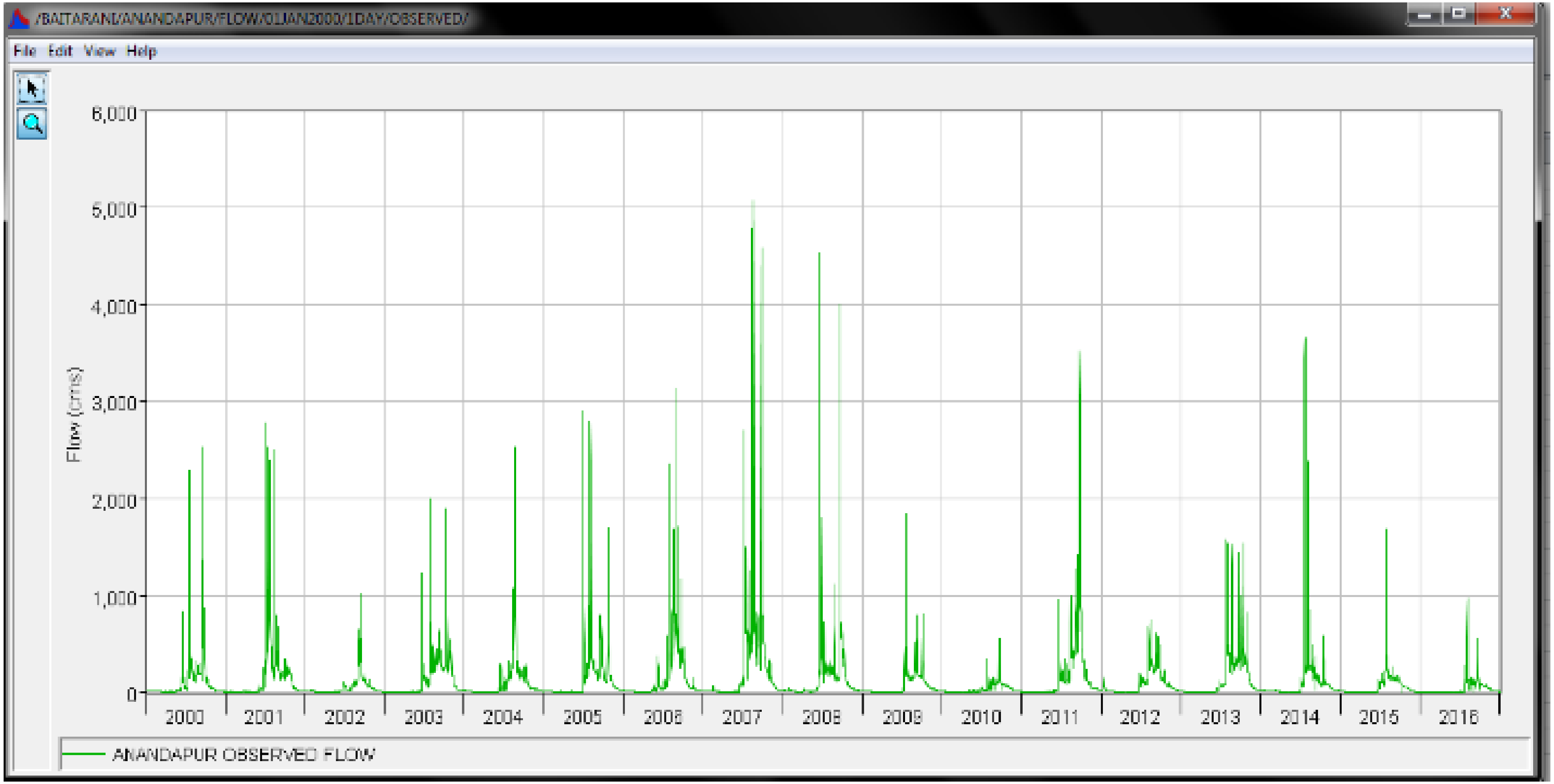


Figure 4.5 Observed Flow Regime at Anandapur

4.1.5.2 Climate Change Flow Regime

Climate change warms the atmosphere altering the hydrologic cycle thus changing the amount, timing, form, and intensity of precipitation. Change in flow of water in Rivers is one of the major effects of climate change. The intensity of hydro meteorological events will increase with undefined pattern. In other words, wet seasons will become wetter and dry seasons will be drier thus increasing the flood and drought risks.

Here in this study, the flow regime in climate change scenario was made by the help of a report published by CWC encompassing the effect of climate change on flows in the River. Fig. 4.6 shows the flow regime, which was used to evaluate environmental flows in climate change scenario.

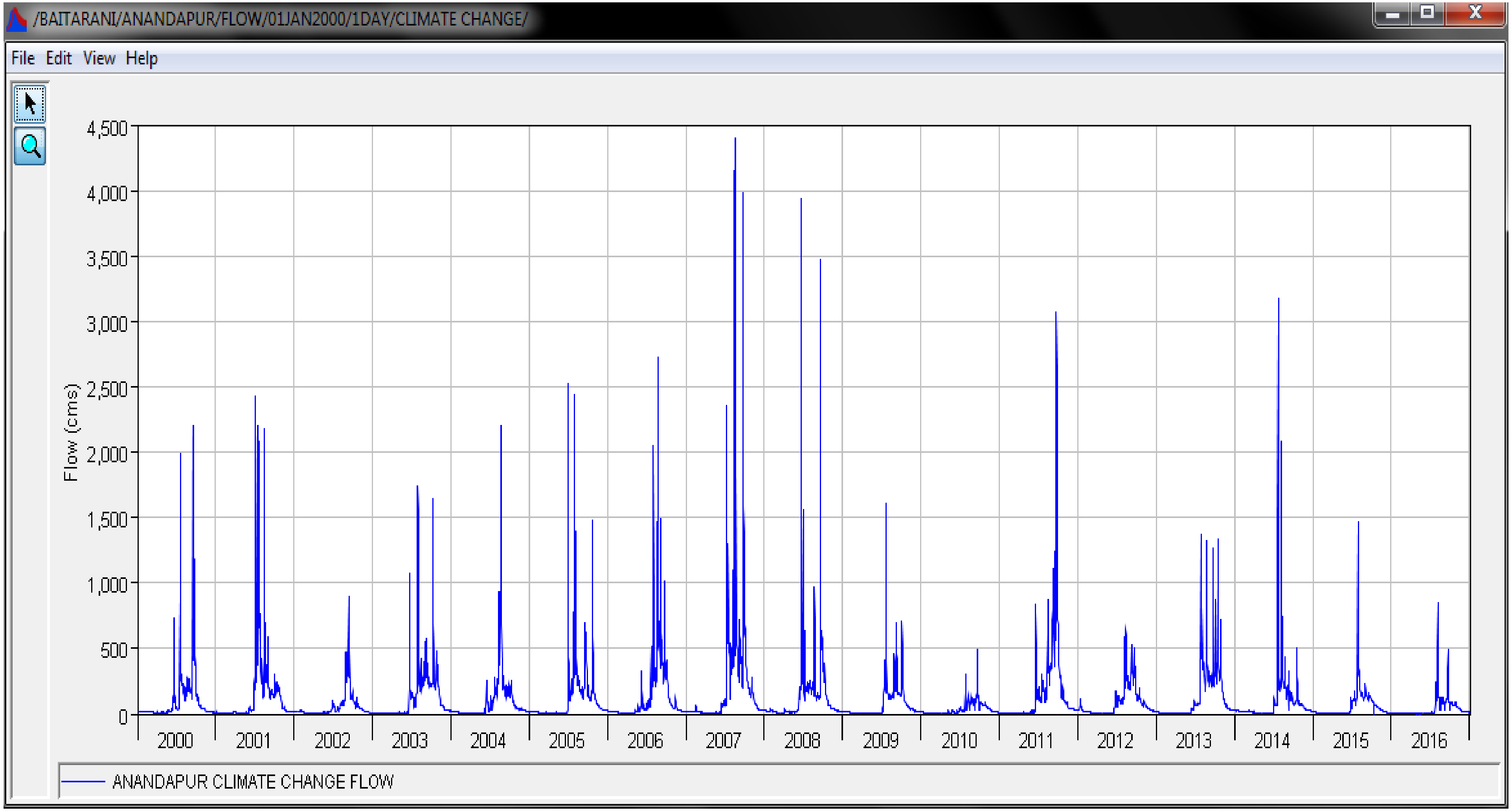


Figure 4.6 Flow regime in climate change scenario at Anandapur

4.1.5.3 Flow Regime in Future Development

As the population of the country is rising, so is the demand for water. The water is an essential element for any progressive development project e.g. setting up various industries, irrigation projects, hydroelectric projects etc. Based on the data provided by State Government to CWC, the upcoming projects on the Baitarani River were identified. Flow regime in future development scenario was generated by assessing the planned water storage in various upcoming projects.

Some of the upcoming and on-going projects consist of Deo, Kanupur, Jharpara, Musal, Bandhan, Khairi, Bhimkund, Sita, Sim, Kantamauli, and Ororei. . The existing, ongoing and proposed projects (dams) are shown in Fig. 4.7.

The upper part of the study area is rich in minerals and many industries including TATA Steel, ESSAR Steel, Jindal Steel, TISCO Ferro Alloys etc. are coming up as shown in Fig. 4.8. The industries will require water that will further reduce the flow in the River. Incorporating above planned use of water, the flow regime in future development was tabulated and graph is shown in Fig. 4.9.

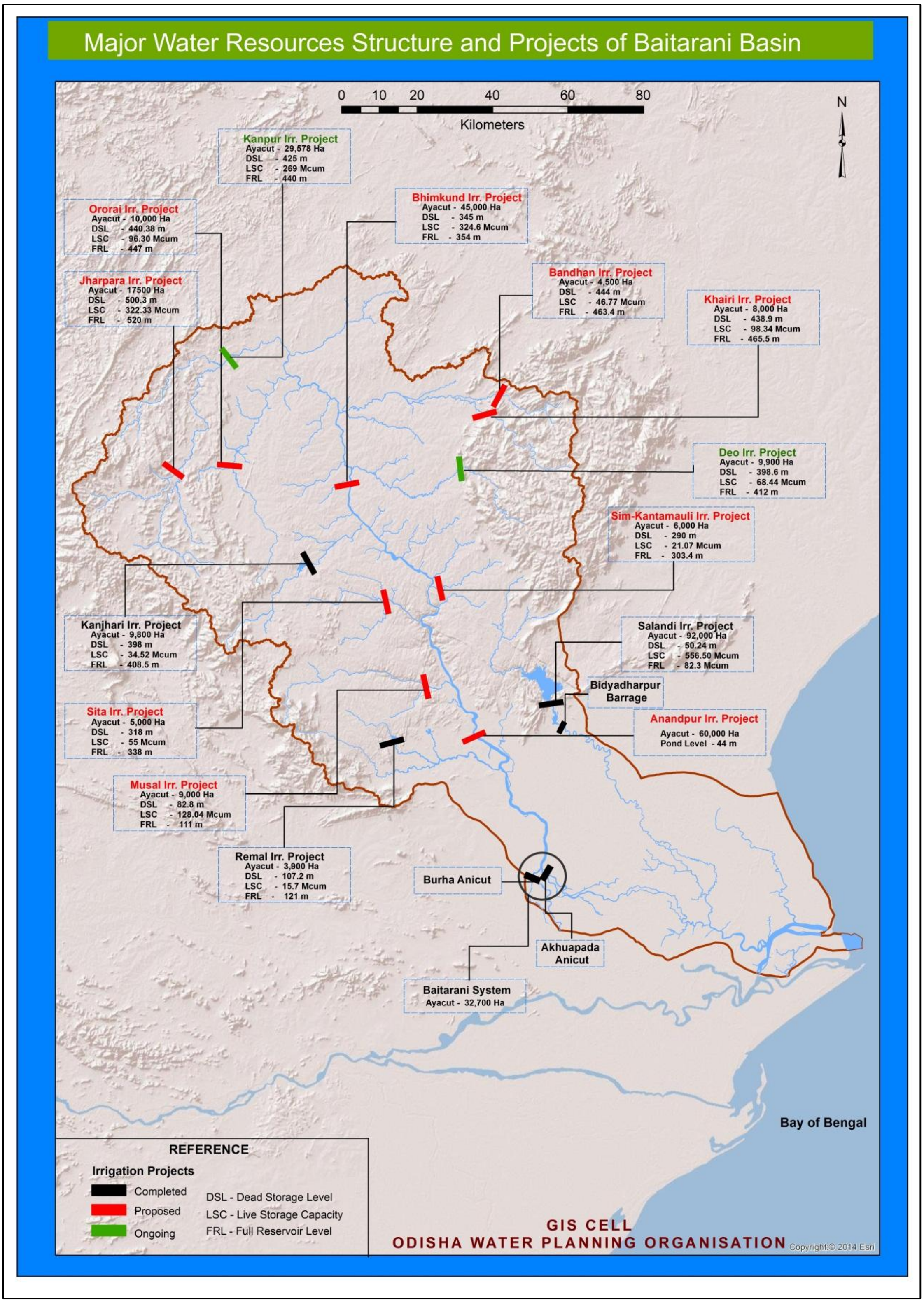


Figure 4.7 Details of Irrigation projects and dams on Baitarani River

Figure 4.8 Details of industries in Baitarani River

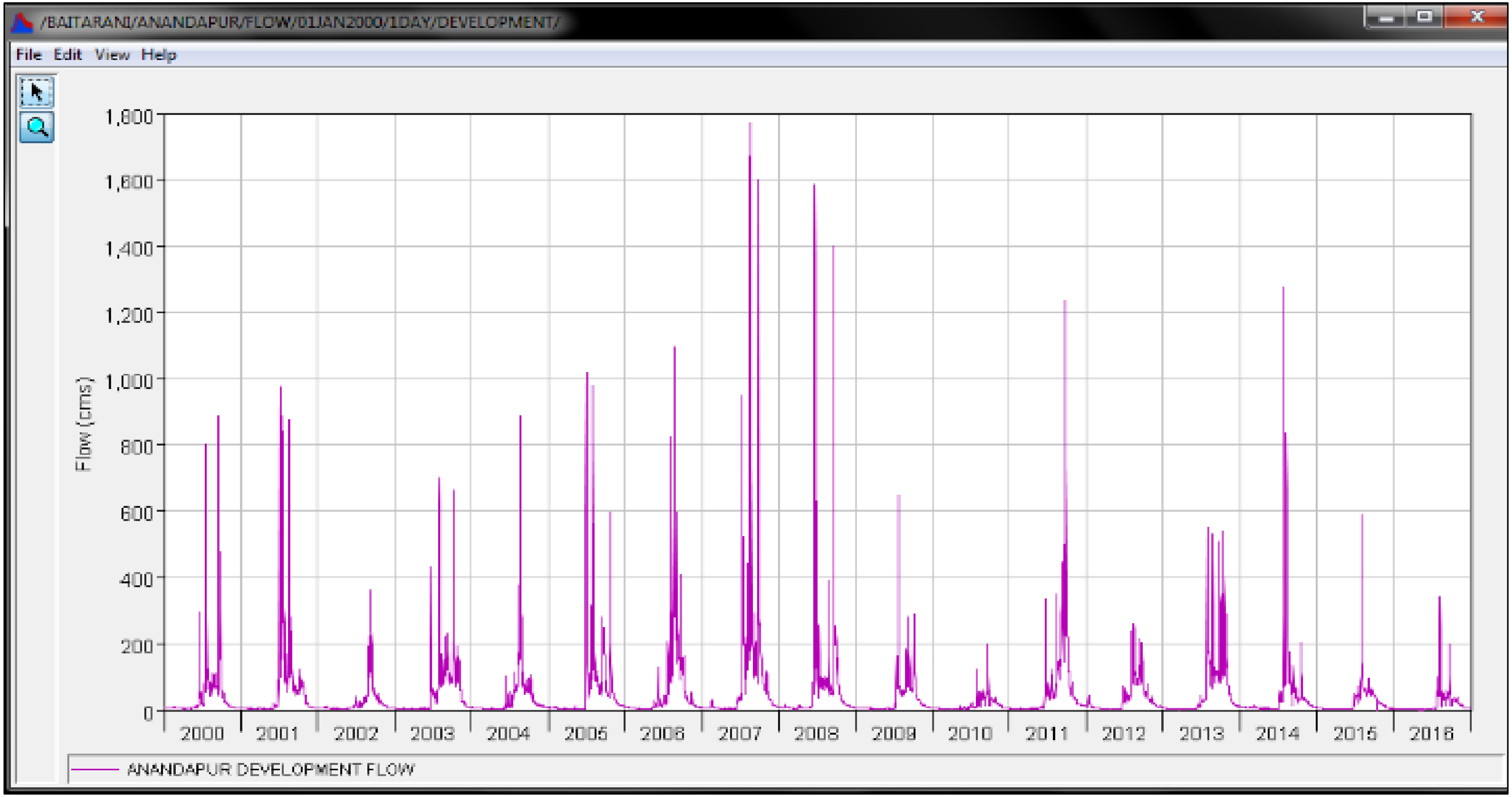


Figure 4.9 Flow regime in future development scenario at Anandapur

4.1.6 Stage data

The observed stage data at Anandapur G&D site for last 17 years from 2000 to 2016 was obtained from CWC. The same is shown in Fig. 4.10. This observed stage data is used in HEC-EFM model for assessing current situation of ecosystem. Further two more stage regimes were created by the help of data and various reports published by State Government and CWC. The stage regime of climate change and future development is shown below in Fig. 4.11 and Fig. 4.12 respectively.

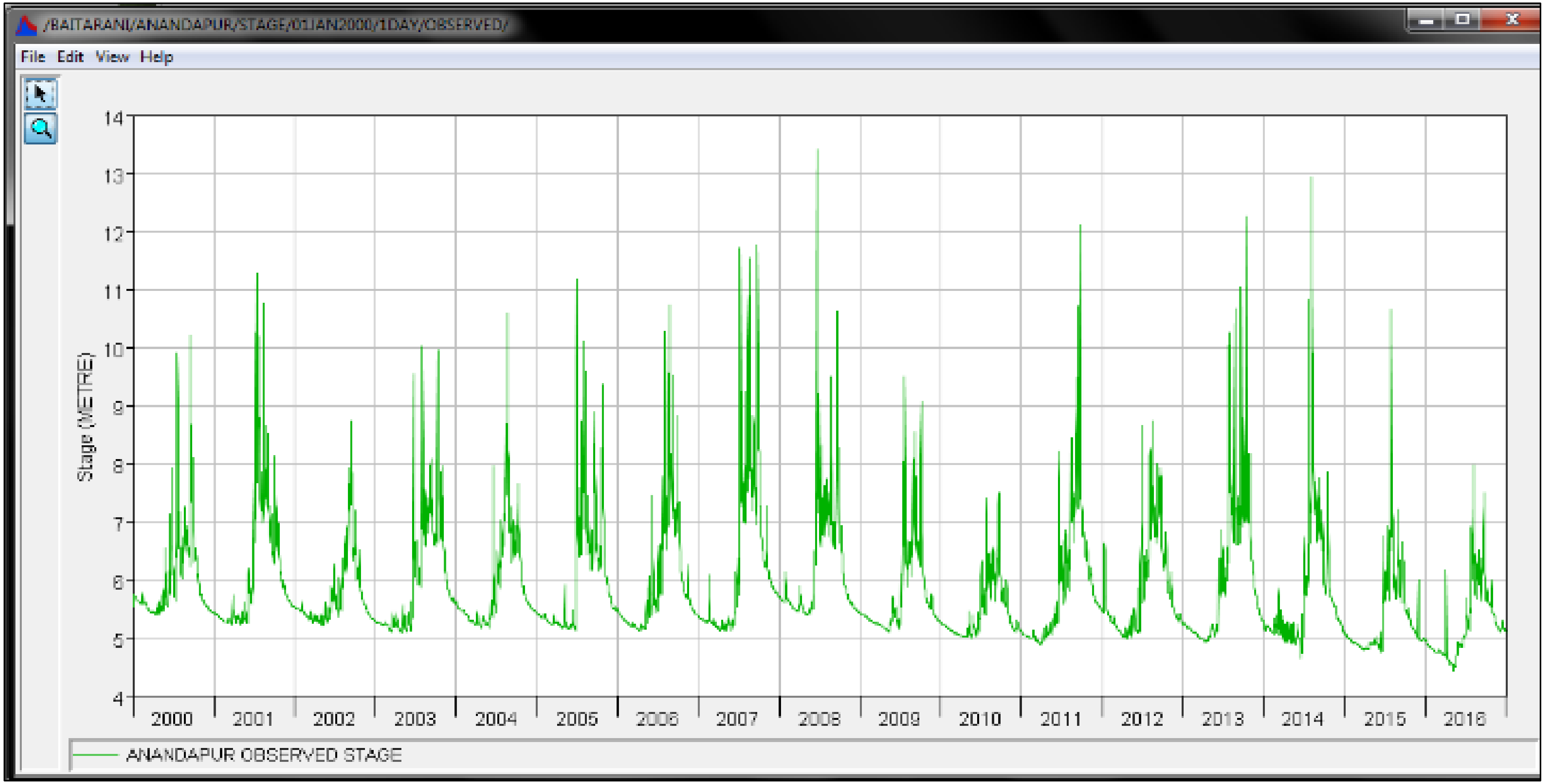


Figure 4.10 Observed Stage regime at Anandapur

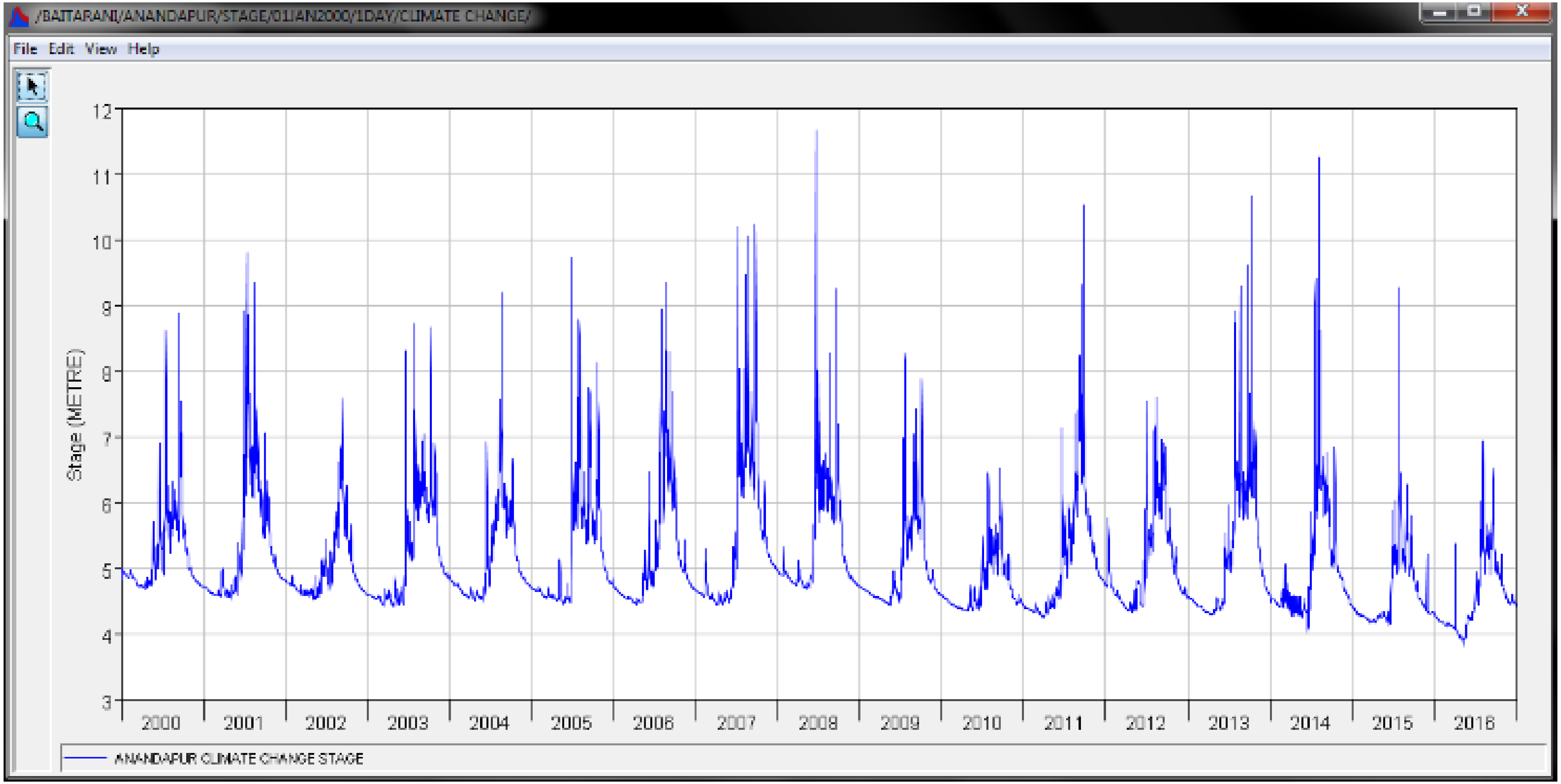


Figure 4.11 Stage regime in climate change scenario at Anandapur

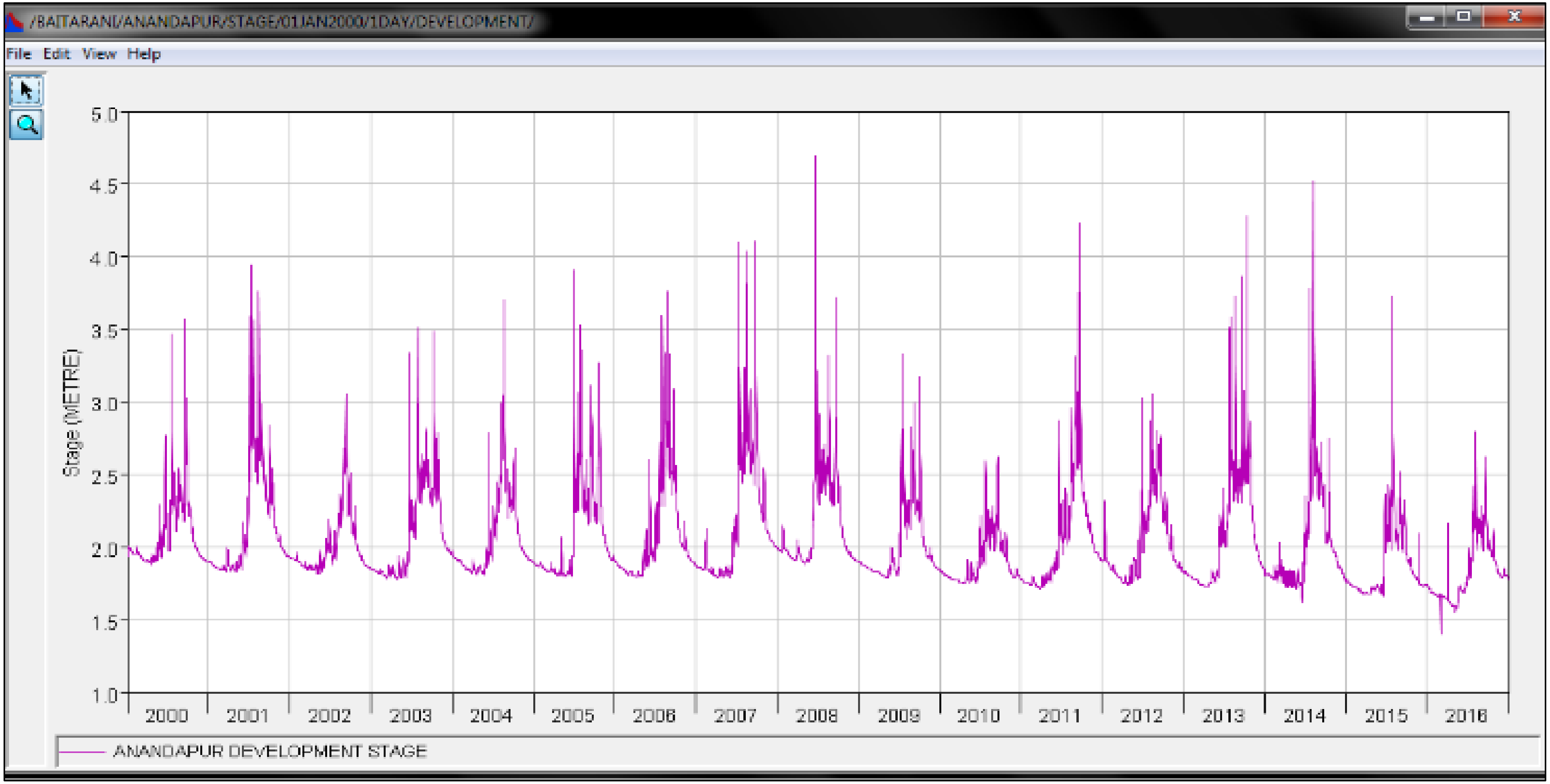


Figure 4.12 Stage regime in future development scenario at Anandapur

4.1.7 Ecosystem Data

There are some practical difficulties in planning for environmental flow requirement. The first and foremost problem is quantifying the environmental flow requirement. Ecosystem behaves in a very complex manner. After going through various literatures over the species profound in Baitarani River, some relationships are developed. The HEC-EFM relationships were developed after detailed analysis of existing studies. The same are represented below:

- **Small Fishes**

  Season: Mid May to July

  Duration: 20 days, Min (sustained highs) and then Max (largest extent)

  Percentage exceedance: 66.66% (1.5 year) – flow frequency

  Hypothesis tracking: Increased flow will improve (+) floodplain spawning

- **Maggar**

  Season: March to May

  Duration: 14 days, Min (sustained highs) and then Max (largest extent)

  Percentage exceedance: 50% (2 yr) – flow frequency

  Hypothesis tracking: Increased flow will curve eco-health, 0-0,16.8-6,28-10, 280-0

- **Benthic Macro Invertebrate Biodiversity**

  Season: Round the year

  Duration: 10 days, Min (sustained highs) and then Max (largest extent)

  Percentage exceedance: 90% flow duration

  Hypothesis tracking: Increased flow will improve (+) floodplain spawning

- **Wetland Health**

  Season: Mid-May to Mid-September

  Duration: 1 days, Min (sustained highs) and then Max (largest extent)

  Percentage exceedance: 50% flow duration

  Hypothesis tracking: Increased flow will improve (+) floodplain spawning

- **Catla Catla**

  Season: June to September

  Duration: 25 days, Min (sustained highs) and then Max (largest extent)

  Percentage exceedance: 25% (4 yr) – flow frequency

  Hypothesis tracking: Increased flow will improve (+) floodplain spawning

- **Rohu (Labeo Rohita)**

  Season: June to September

  Duration: 30 days, Min (sustained highs) and then Max (largest extent)

  Percentage exceedance: 25% (4 yr) – flow frequency

  Hypothesis tracking: Increased flow will improve (+) floodplain spawning

- **Hilsa**

  Season: Mid June to September

  Duration: 30 days, Min (sustained highs) and then Max (largest extent)

  Percentage exceedance: 25% (4 yr) – flow frequency

  Hypothesis tracking: Increased flow will improve (+) floodplain spawning

4.2 METHODOLOGY

The present study followed the hydrological methodology in combination with the habitat methodology. Thereby, the study has been done by collection of hydrological data including LULC and soil data and then used in WMS and HMS model. Eventually the ecosystem data is then collected and used with the result of above two mentioned model with the help EFM modelling tool to get the E-flow requirements. The flow chart of the methodology used in study is shown in below Fig. 4.13.

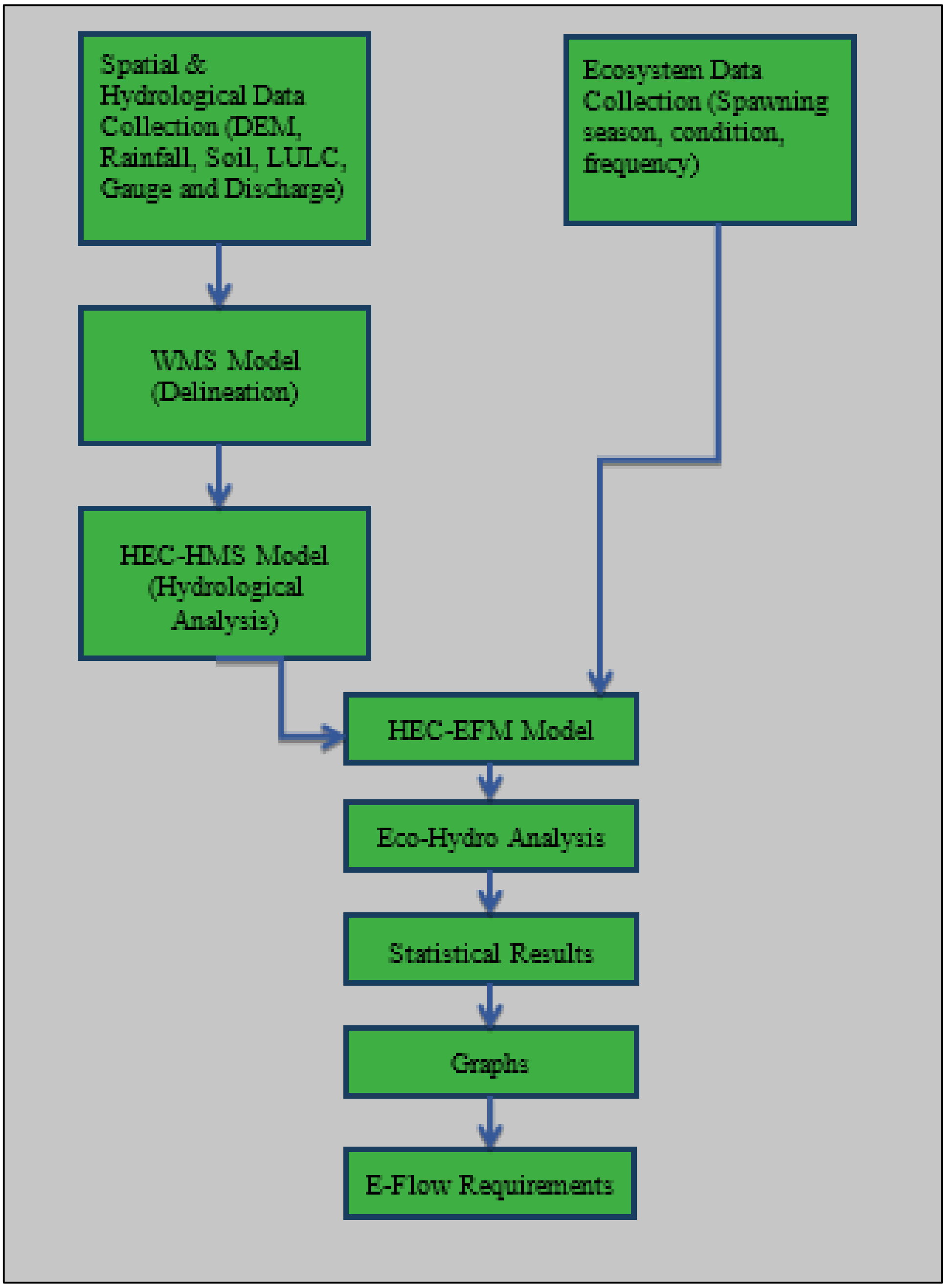


Figure 4.13 Chronological order of the methodology

4.2.1 Pre- Modelling Activities

Pre-modelling activities included collection of data from various sources and then convert it to the input format of models. The datasets collected were DEM, Rainfall, Soil, Discharge, Gauge and Ecosystem data.

4.3 MODELLING PROCESSES

Modelling process is simplification of real world systems e.g. hydrological system, ecosystem. A model aids in understanding, predicting, and managing the real world problems. In this study modelling was done by using four software viz. WMS, HEC-HMS, HEC-DSSVue and HEC-EFM. Firstly in WMS, a DEM was used for delineation of the study area with respect to Anandapur location. With the use of data of rainfall, Evaporation, Soil, Land Use Land Cover, the runoff was calculated in HEC-HMS software, which was calibrated against the observed discharge data from CWC's Anandapur site. HEC-DSSVue software was used to tabulate data in DSS format, which is default data entry format of HEC-EFM software. Lastly, HEC-EFM software was used for environmental flow assessment in Baitarani ecosystem.

4.3.1 WMS Software

WMS software was used to delineate the study area in Baitarani River and to set up hydrologic model using inbuilt HEC-HMS.

- A new project file was created in WMS and project bounds were defined as shown in Fig. 4.14 and 4.15 respectively.

- The projections for the project were setup as Universal Transverse Mercator (UTM) conformal projection which uses a 2-dimensional Cartesian coordinate system to give the locations on the surface of the Earth. Fig. 4.16 shows our study area which lies in zone 44 (78^{o}E to 84^{o}E) in northern hemisphere.

- The DEM data was converted from .TIFF format to .hdr format by the help of ArcGIS and the same file was used as input to WMS software as shown in Fig. 4.17 and 4.18.

- The flow directions were computed from the given DEM input. For computing flow directions, model wrapper was run. Screenshot of model for computing flow directions, running of model and completion of the flow direction estimation is shown in Fig. 4.19, 4.20 and 4.21 respectively.

- The computed flow directions are shown in dark blue colour. These flow directions are spatial representation of course of Baitarani River in Odisha upto Anandapur. The same is shown in Fig. 4.22.

- An outlet point was given as a reference point for creating the study area. The outlet point shown in Fig. 4.23 was taken as Anandapur with coordinates 21°12’40” N, 86°07’14” E. Anandapur is Gauge and Discharge site of CWC, which is monitored on daily basis. Also, after Anandpur area, the River starts bifurcating into many smaller streams to form Deltas. That is why Anandapur location was chosen.

- The process of delineation of study area is shown in Fig. 4.24, whereas the completed delineated study area is shown in Fig. 4.25.

- After study area delineation, a hydrological model (HEC-HMS) was selected out of many available inbuilt models as shown in Fig. 4.26.

- The LULC and soil data was given as input to the model as shown in Fig. 4.27 and 4.28 respectively.

- Fig. 4.29 shows screenshot of adopted SMA loss method for hydrologic computations.

- After the final step shown in Fig. 4.30 the file was exported to HEC-HMS software for further processes.

4.3.2 HEC-HMS Software

HEC-HMS software was used for hydrologic modelling for the purpose of calculating runoff. Soil Moisture Accounting method was used in HEC-HMS model for calculating runoff.

SMA (SOIL MOISTURE ACCOUNTING)-

Soil moisture accounting method was developed by the Hydrologic Engineering Centre. It is achieved by the simulation of the movement of precipitation through the storage volumes that represent Canopy interception, Surface depressions, the Soil profile and Groundwater layers. Computational components of this algorithm also include Evapo-transpiration (ET), surface runoff, and groundwater flow.

The soil moisture accounting loss method uses five layers to represent the dynamics of water movement above and in the soil. The layers include the Canopy Interception, surface depression storage of water, soil, upper groundwater, and two numbers of lower groundwater, which are shown in Fig. 4.31. Initial conditions for the five storage layers is to be considered as what percentage of water is going to be stored. Maximum canopy storage means it is the maximum amount of water that is held on leaves before falling to the surface starts.

Canopy is the interception by the leaves of the precipitation; surface depression shows the collected rain water into them. Surface depression once completely filled leads to generation of runoff. These two also contribute to evaporation. Later the infiltration takes place into the upper soil surface some of which goes to the tension zone (capillary saturation) and upper zone storage (hygroscopic water). There after the percolation starts which according to the model goes to the two ground layers which stores water upto saturation states and the excess water contribute to the groundwater flow and to the base flows.
The model uses Green-Ampt Equation which is shown below:

$$F\,(t) - \left|\psi\right| \boldsymbol{\Delta\theta ln(1 + F(t)\,/\,\left|\psi\right| \Delta\theta) = Kt} \quad (4.1)$$

Where, F(t) is cumulative infiltration at any time t,

ψ is suction head,

$\Delta\theta$= porosity x (100-% saturation),

K is conductivity

In HEC-HMS software, the file imported from WMS was opened as shown in Fig. 4.32.

- Fig. 4.33 shows the program settings that were set in HEC-HMS, which is reproduced below:
    - Unit System: Metric
    - Element Sorting: Hydrologic
    - Sub basin Canopy: Simple Canopy
    - Sub basin Surface: Simple Surface
    - Sub basin Loss: Soil Moisture Accounting
    - Sub basin Transform: Clark Unit Hydrograph
    - Sub basin Base flow: Linear Reservoir
    - Sub basin Precipitation: Specified Hyetograph
    - Sub basin Evapotranspiration: Monthly Average

- After setting program, the parameters for each were set. Initially some standard parameters values were taken. After running model, these values were recalculated by the software. For example, screenshot of filling values for surface parameter is shown in Fig. 4.34.

- The meteorological model inside HEC-HMS software was setup for incorporating Hyetograph i.e. rainfall data. The same is shown in Fig. 4.35.

- The job control was setup taking daily time step as all the datasets were having 24-hour data. The job control is shown in Fig. 4.36.

- A manual rain gauge was set up and the data was copied from excel sheet and pasted in the HEC-HMS table. The time step for rain gauge data was kept same i.e. 24 hour, as in the main control specifications tab. It is shown in Fig. 3.37 and Fig. 4.38.

- Similarly, discharge data was also entered in the software by creating discharge gauge and entering data manually by copying from excel and pasting in HEC-HMS. The same is shown below in Fig. 4.39 and Fig. 4.40.

- After completion of setting up, the model was run by creating simulation run as shown in Fig. 4.41.

- After simulation run, the model was optimized by doing optimization trials. The optimization trial optimizes the values of parameters entered in the starting of setting up of model in HEC-HMS. Fig. 4.42 shows completed optimization trial.

- The optimized parameters results are shown in Fig. 4.43.

- Fig. 4.44 shows the summary table of generated runoff volume, peak flow and time of peak.

4.3.3 HEC-EFM Software

HEC-EFM is open source software, which was used in this project for assessment of Environmental flow for various profound aquatic species. This software uses a DSS file, incorporating data of flow and stage over the years. Also, the relationships of ecosystem need to be entered for running the model.

- A new project was created as shown in Fig. 4.45.

- Fig. 4.46 shows importing of flow regime into HEC-HMS model. Flow regime is a DSS file containing daily flow data.

- Relationships of aquatic species were created by entering spawning season, duration, flow frequency etc. Screenshot of creating relationship of small fishes is shown in Fig. 4.47. Similarly relationship was created for all other species.

- The model was run after establishing relationship. This step is named as recalculate in the model. The same is shown in Fig. 4.48.

- A typical model run for Hilsa is shown in Fig. 4.49. After successful run of the model, the output table gets generated. The model was run for three different flow regimes and results were tabulated.

- Reverse lookup of the E-flow values of different species was calculated in HEC-EFM. Reverse lookup is a query to the HEC-HMS, which uses a value of E-flow as input (generated through previous steps) and model computes the percentage of years or percentage of time that flow is equalled or exceeded. Fig. 4.50 shows screenshot of reverse lookup standard query for Hilsa.

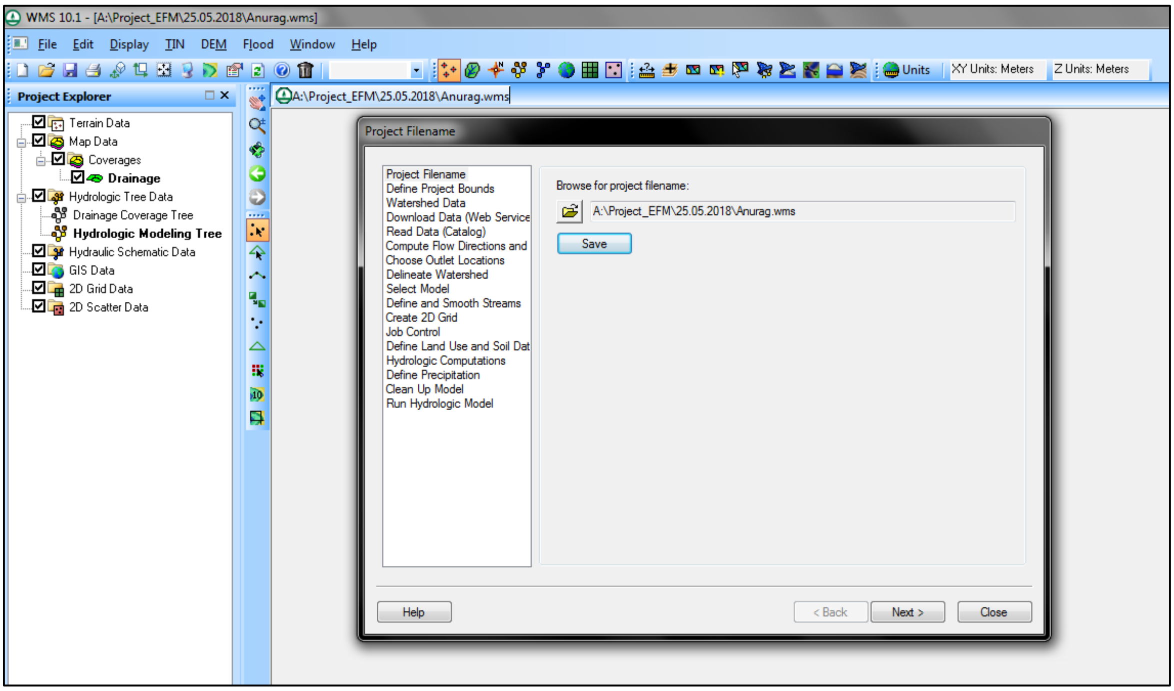


Figure 4.14 Creating a new project in WMS

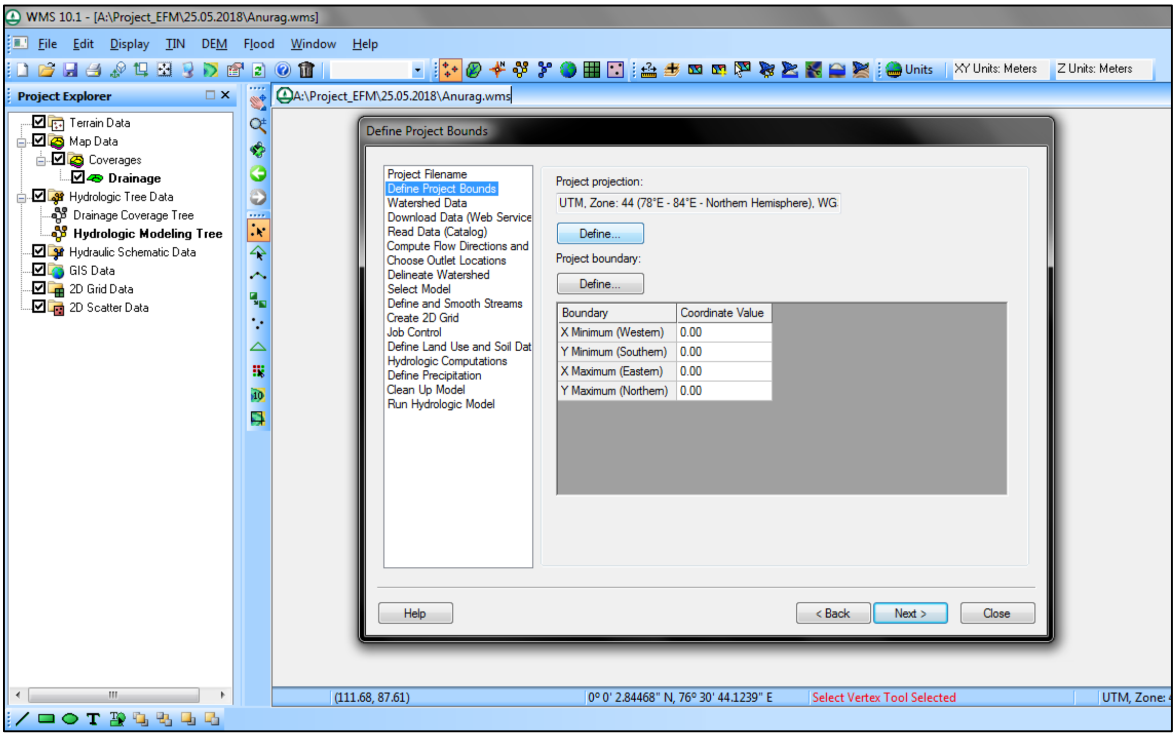


Figure 4.15 Defining project boundary in WMS

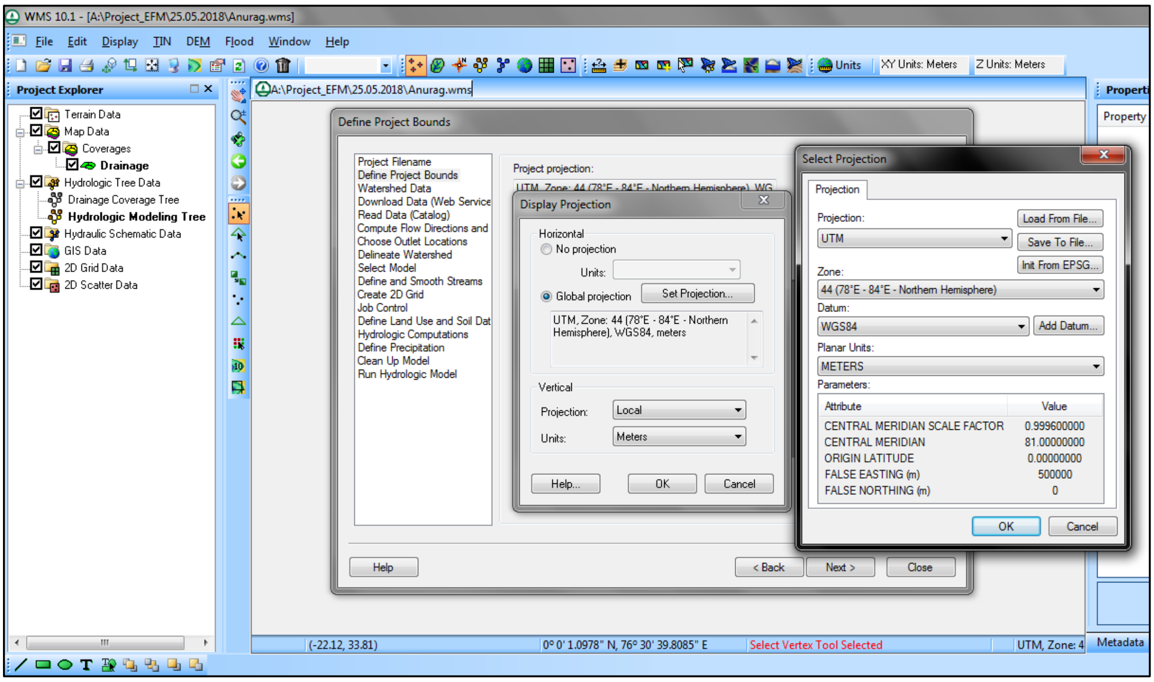


Figure 4.16 Setting up the projections in WMS

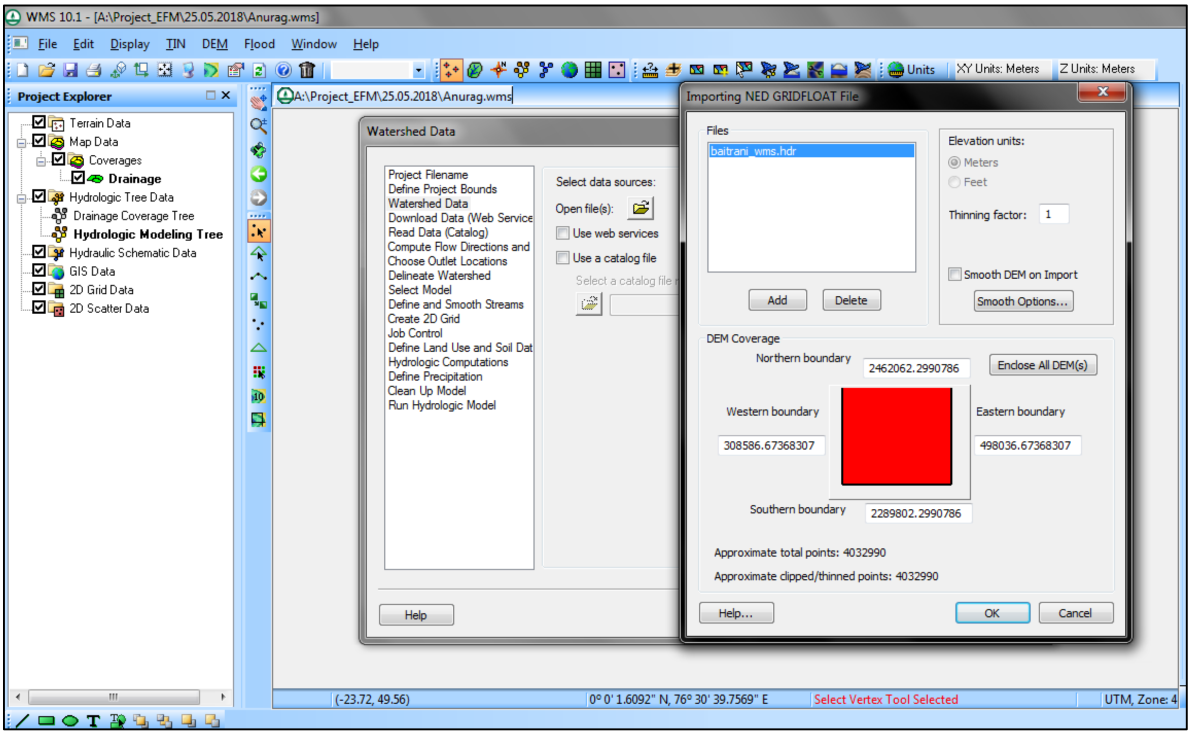


Figure 4.17 Opening DEM Data/Watershed Data in WMS

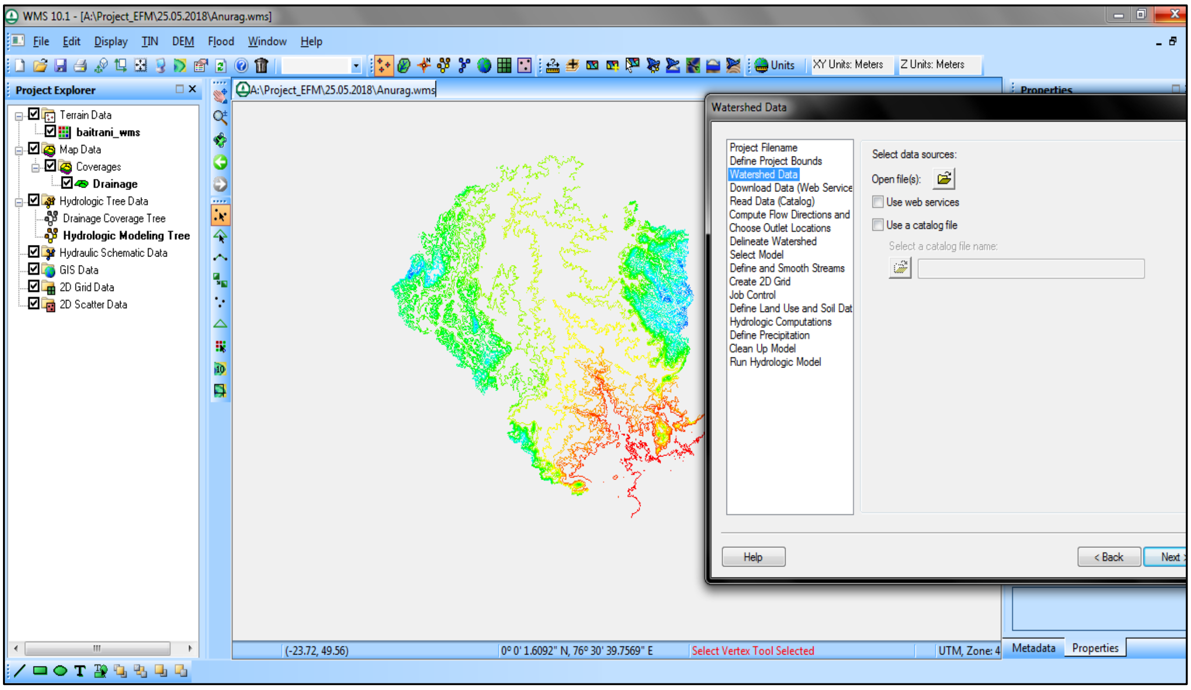


Figure 4.18 Screenshot of DEM data in WMS

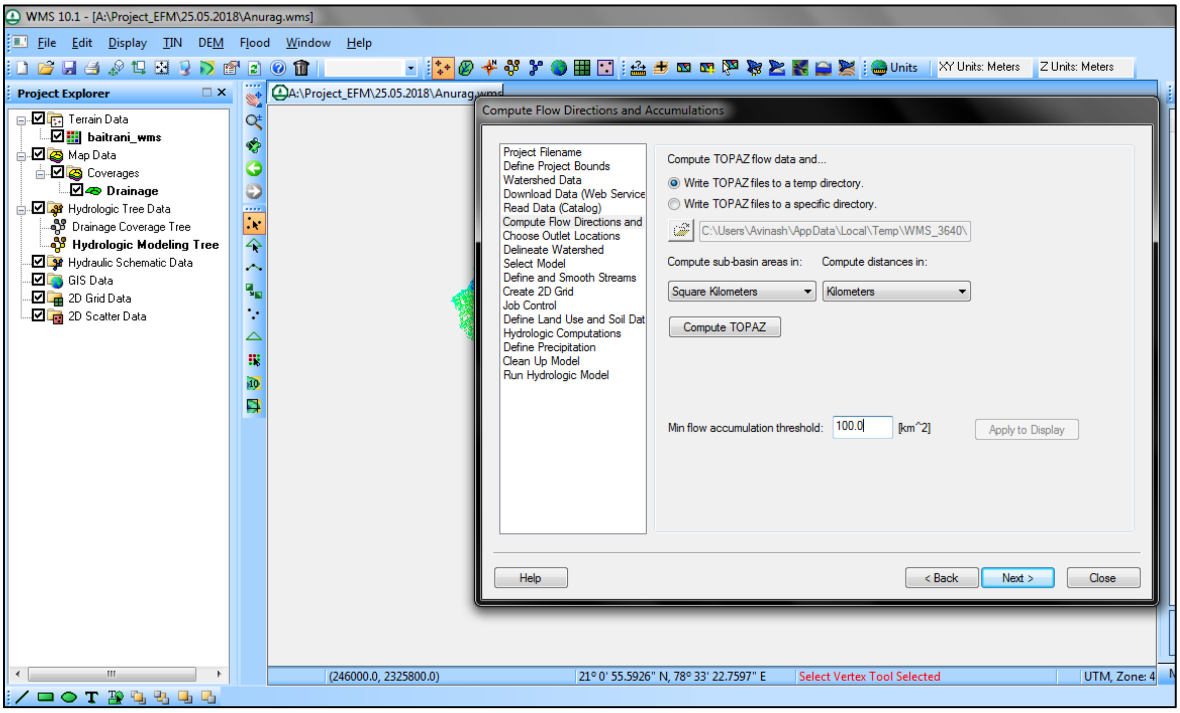


Figure 4.19 Computing flow direction form DEM data in WMS

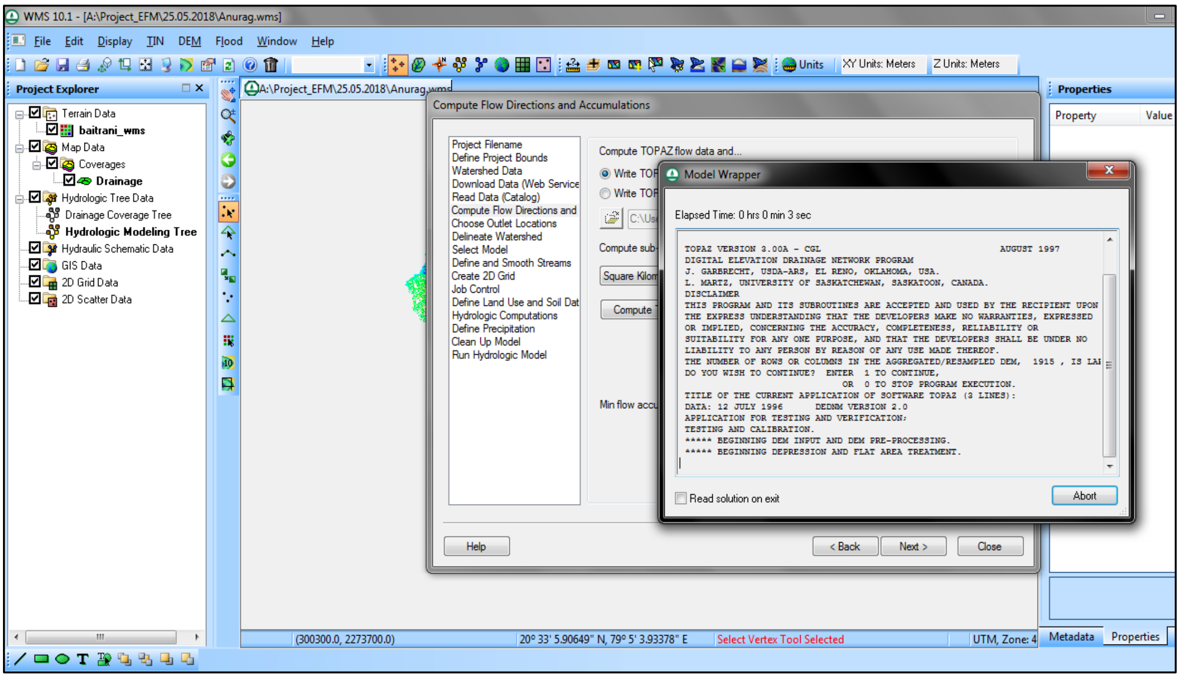


Figure 4.20 Running of model for computing Flow directions in WMS

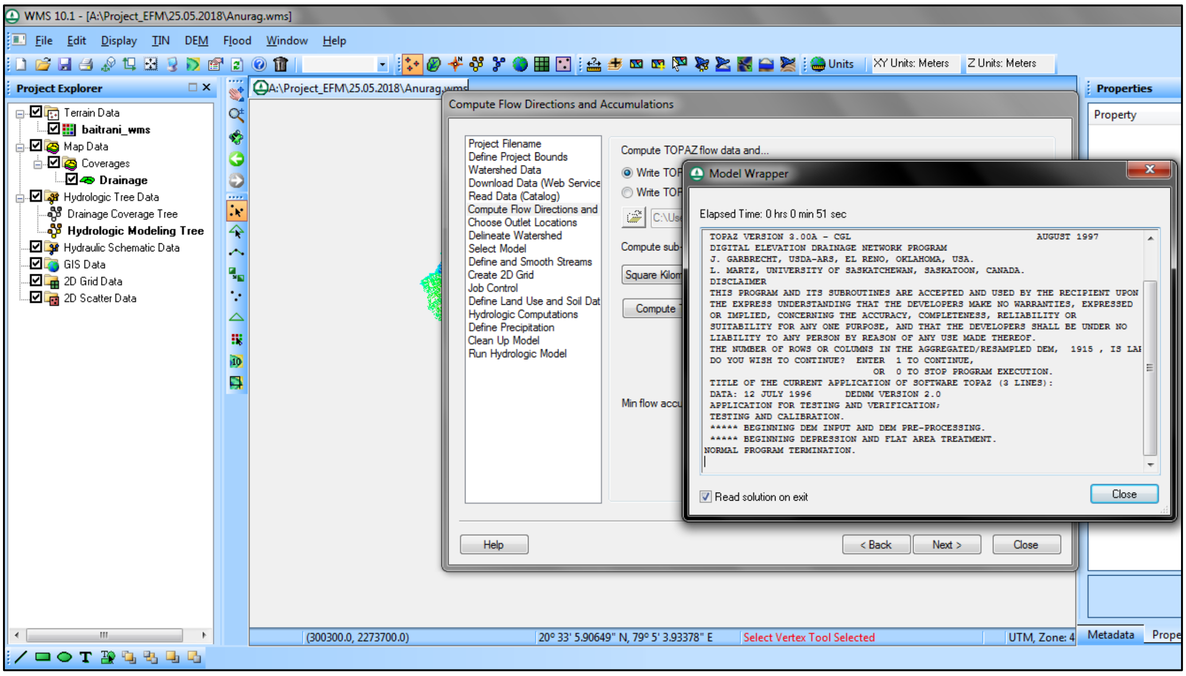


Figure 4.21 Completion of Flow direction estimation in WMS

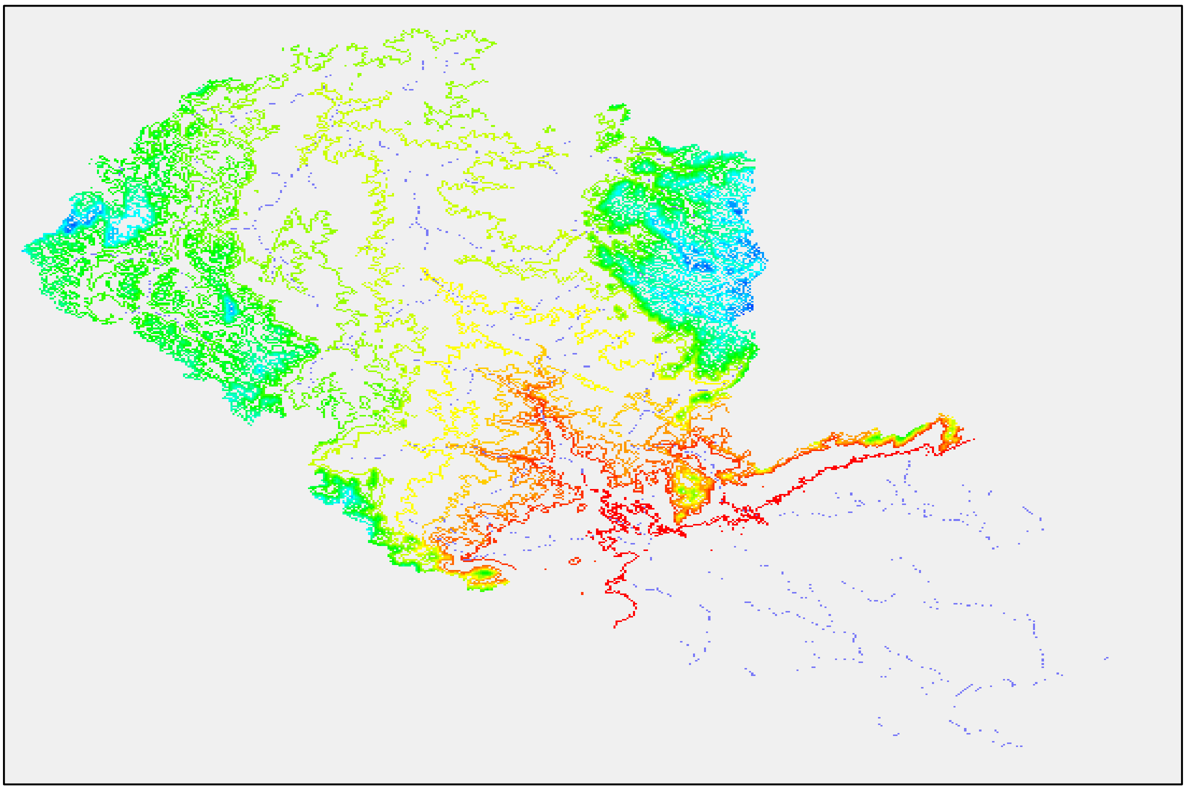


Figure 4.22 Screenshot of generated flow directions in WMS

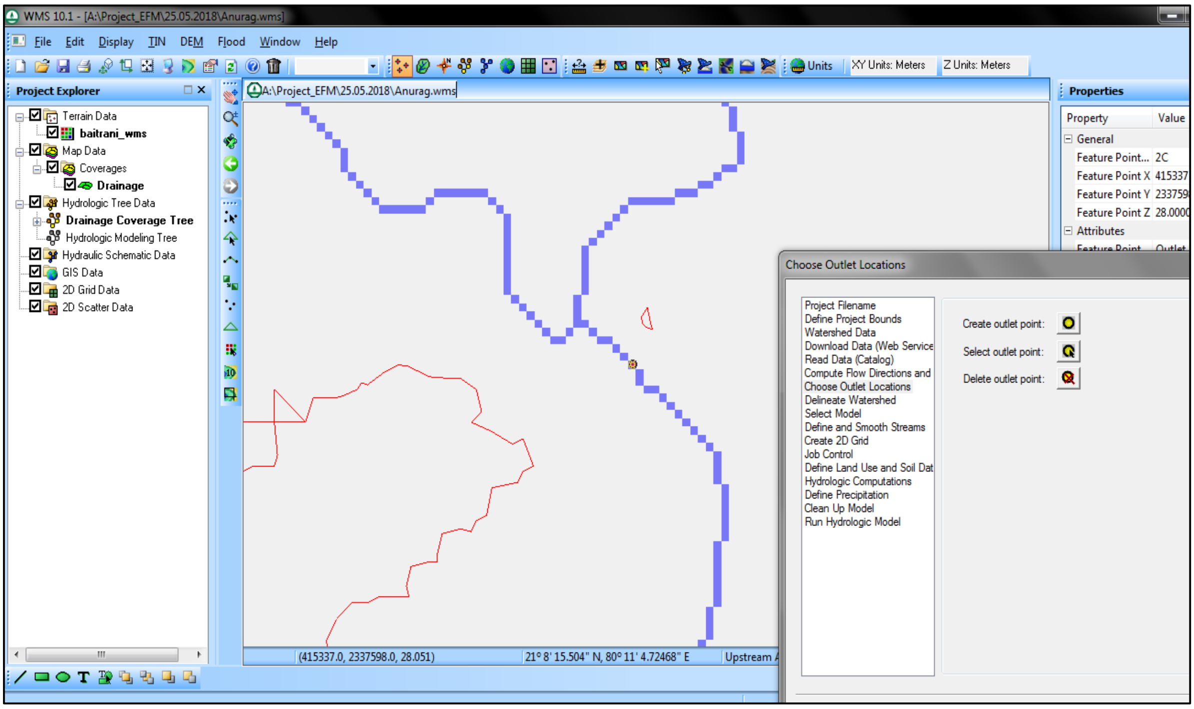


Figure 4.23 Screenshot of chosen outlet location (coordinates of Anandapur) in WMS

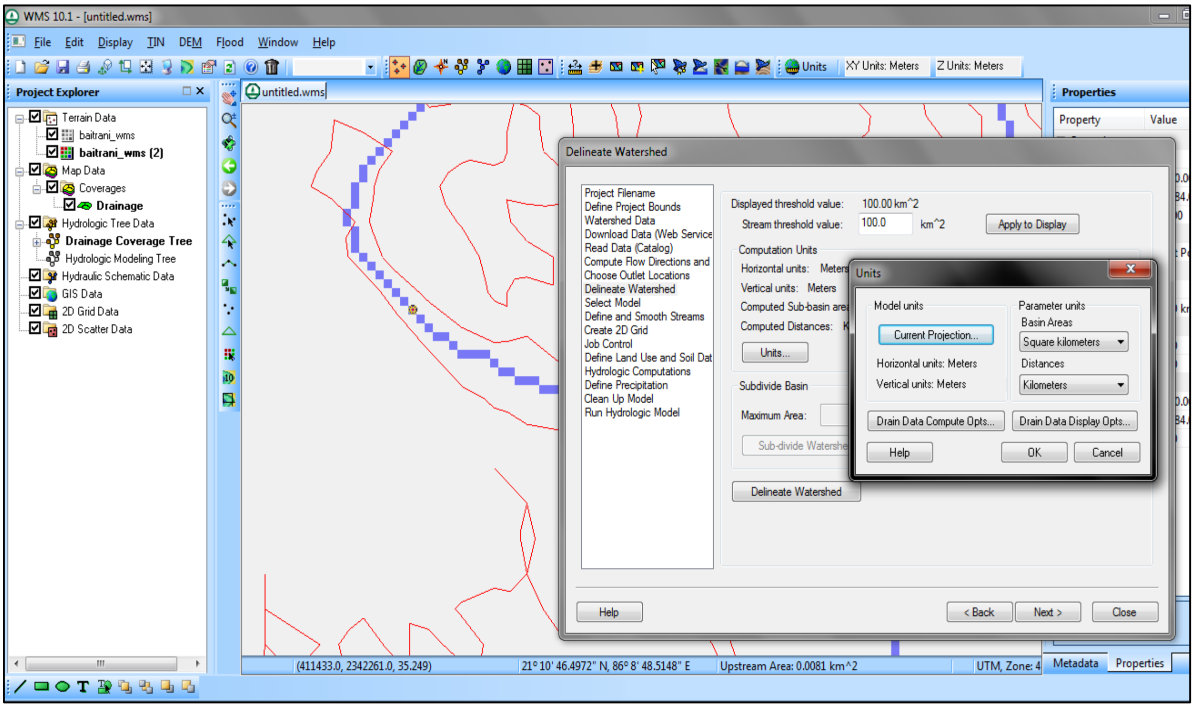


Figure 4.24 Screenshot of process of delineating study area in WMS

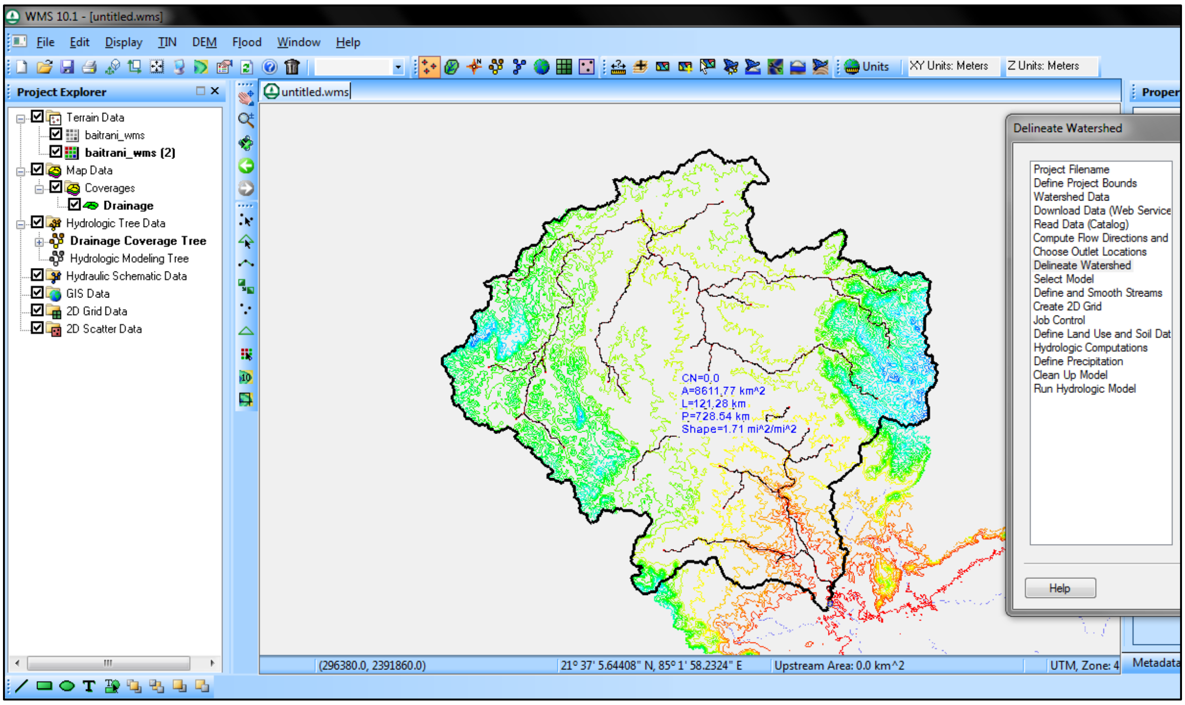


Figure 4.25 Screenshot of delineated study area in WMS

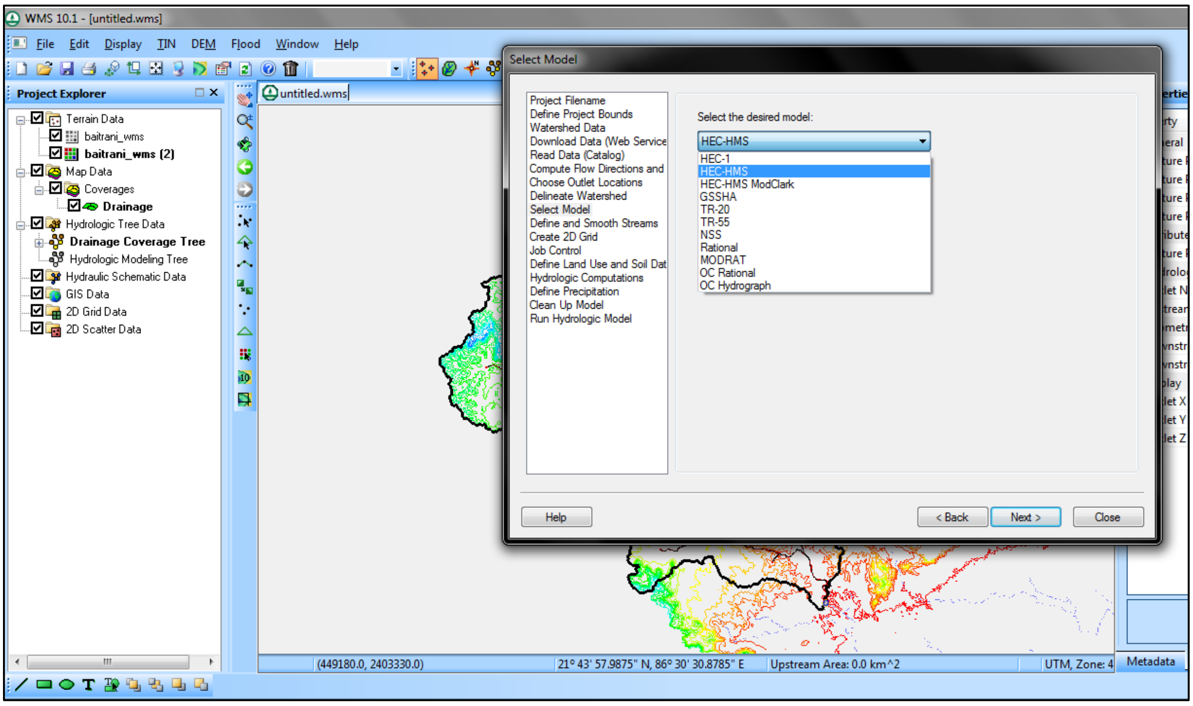


Figure 4.26 Screenshot of selection of model for hydrologic modeling in WMS

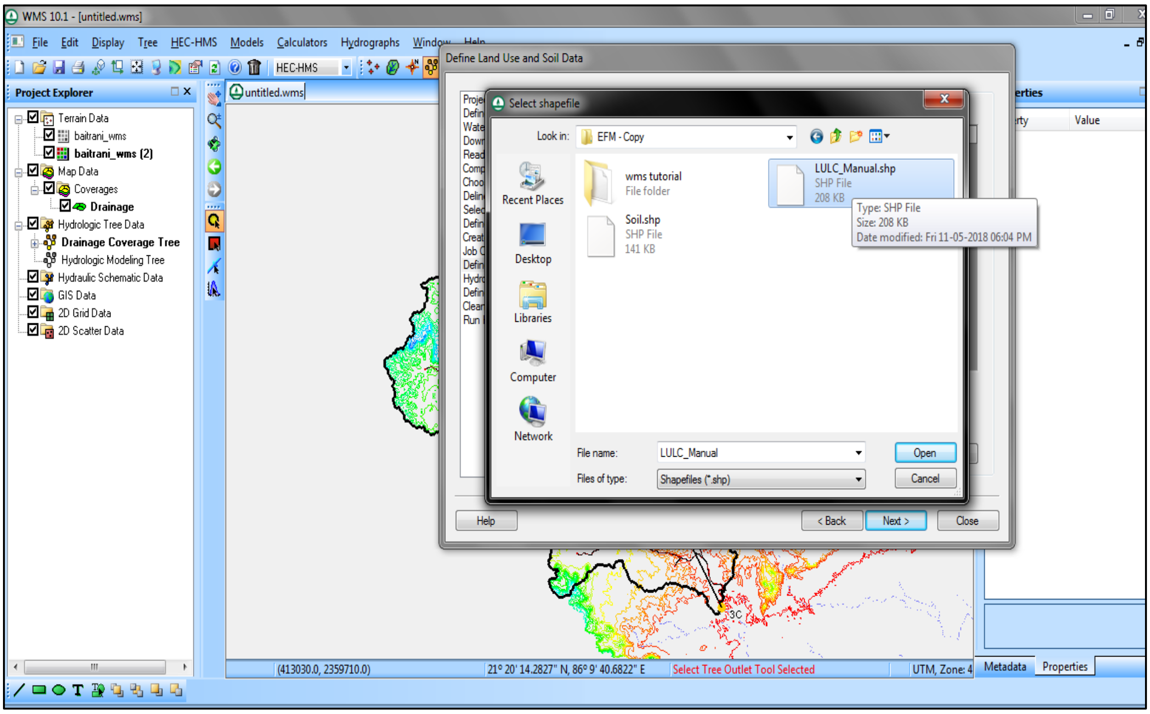


Figure 4.27 Screenshot of defining Land Use in WMS

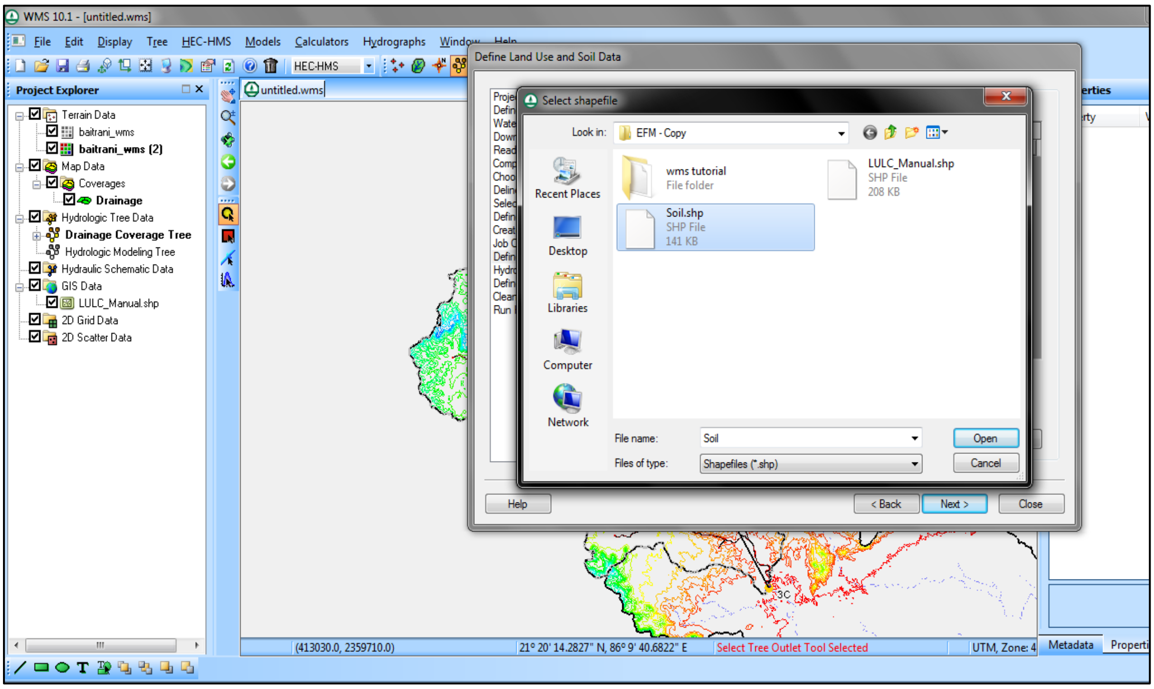


Figure 4.28 Screenshot for defining Soil in WMS

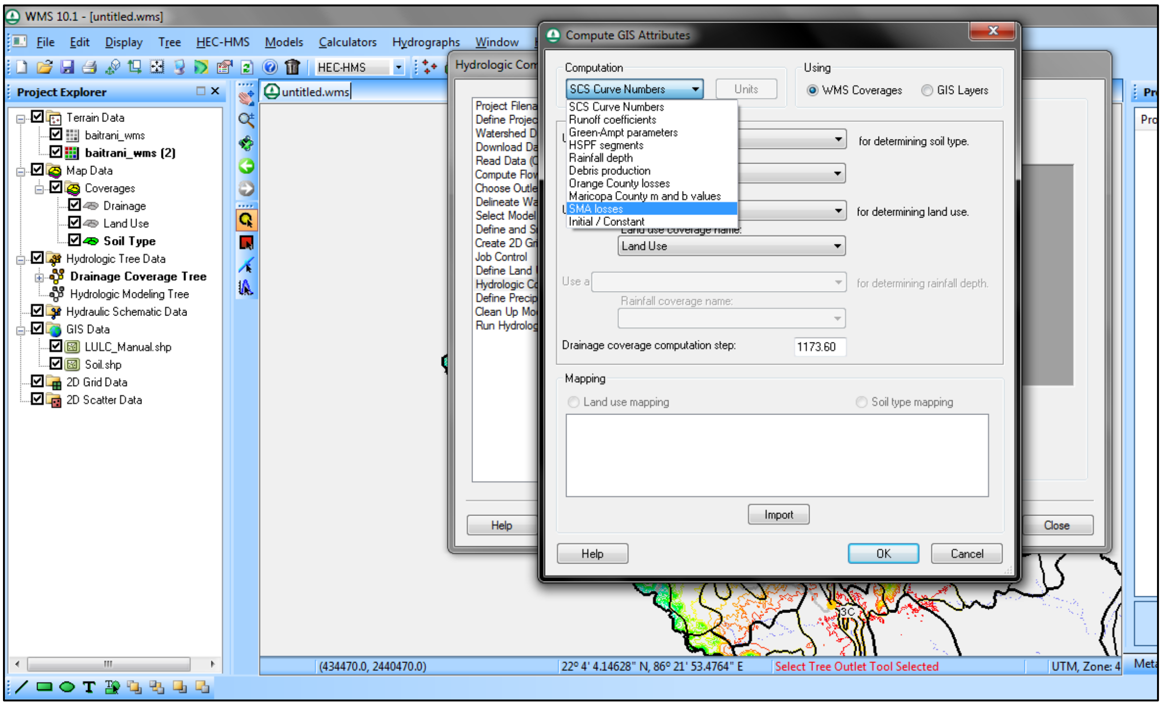


Figure 4.29 Screenshot of choosing SMA loss method in WMS

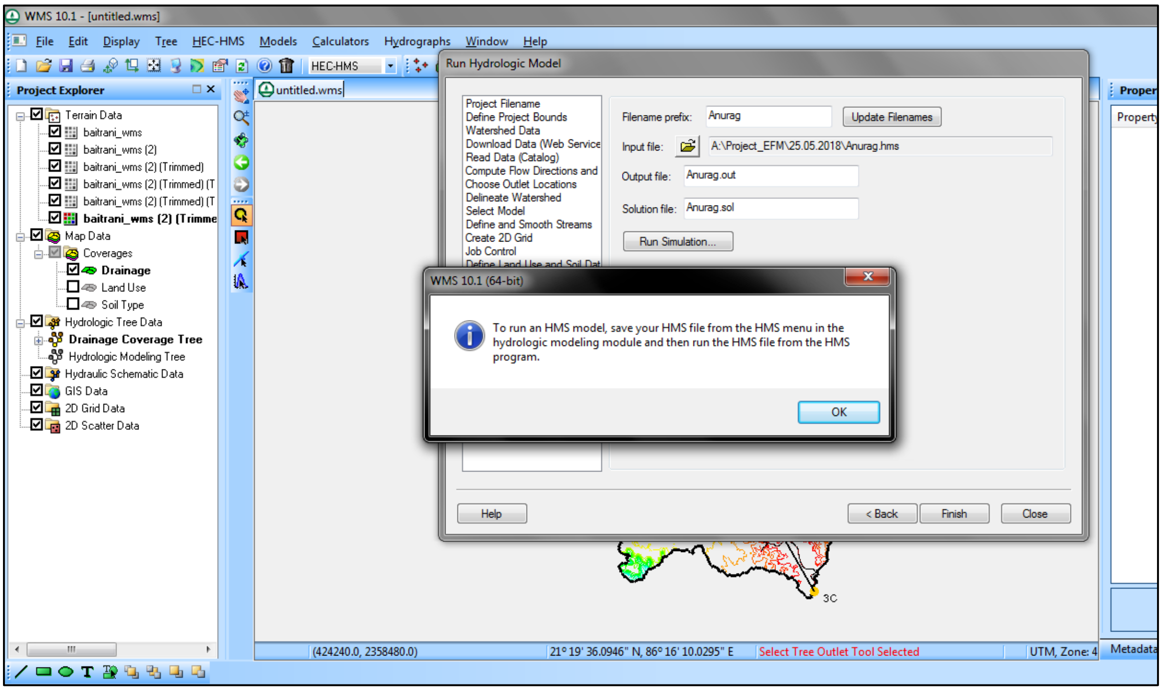


Figure 4.30 Screenshot of final step in WMS

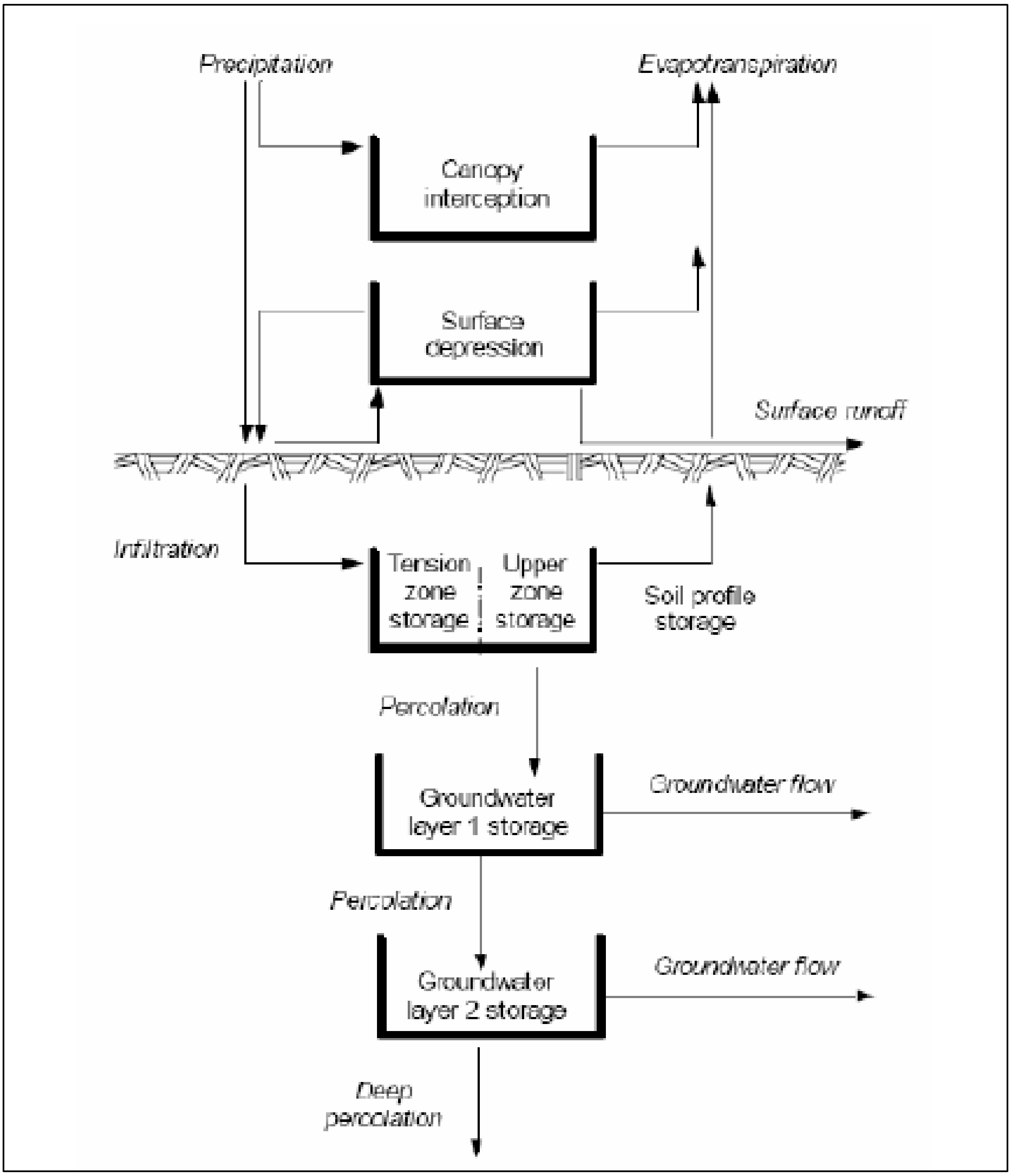


Figure 4.31 Infiltrations among layers in SMA method
Source of the image: nwa.mah.nic.in

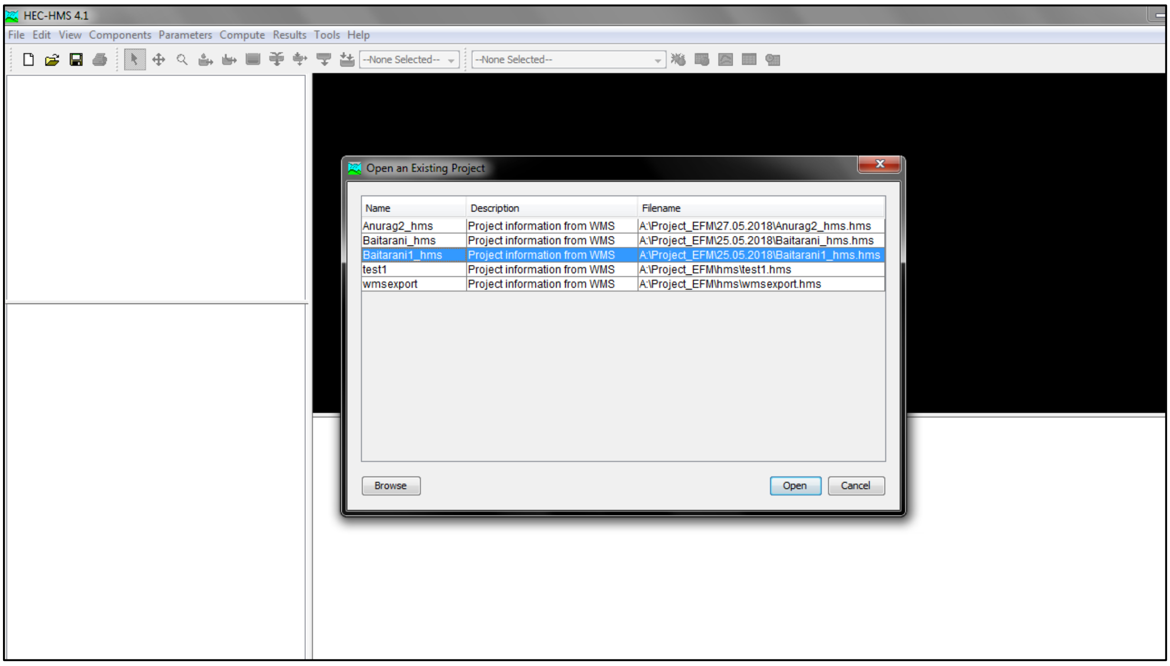


Figure 4.32 Screenshot of opening of project in HEC-HMS

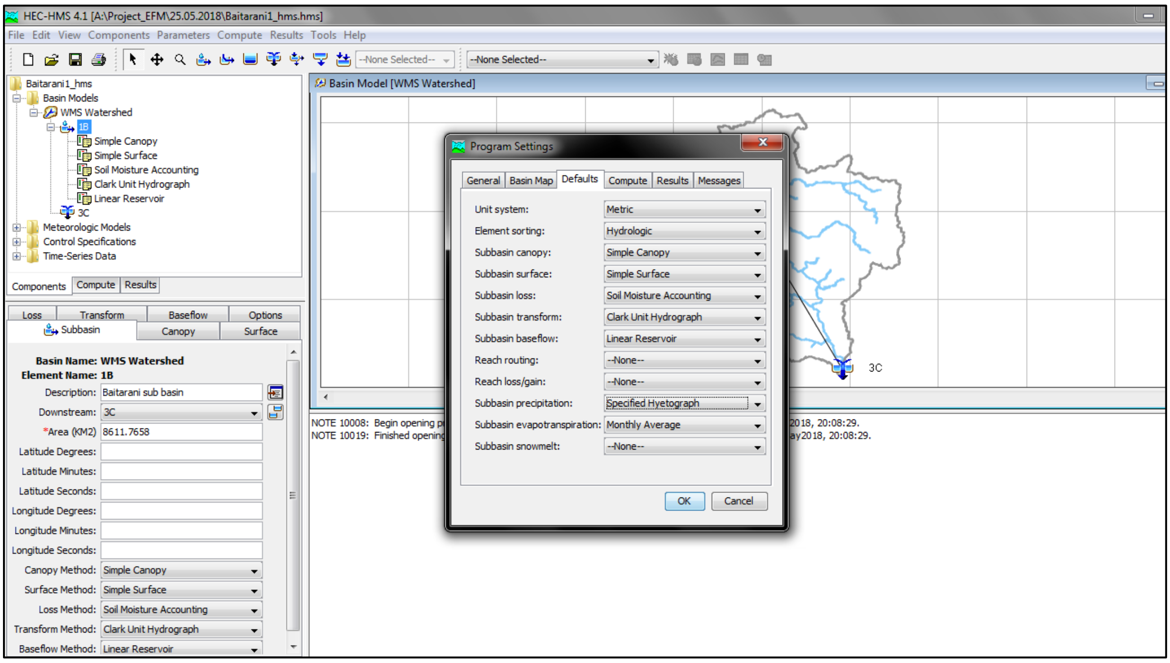


Figure 4.33 Screenshot of setting program in HMS

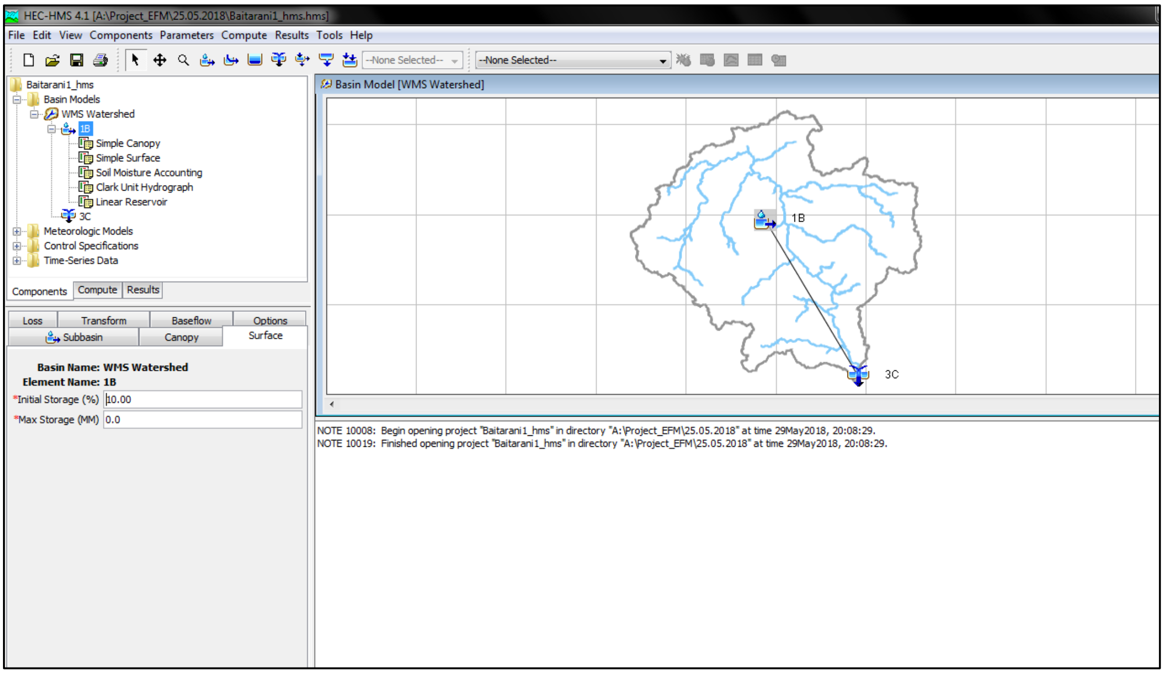


Figure 4.34 Screenshot of filling values for surface parameters in HMS

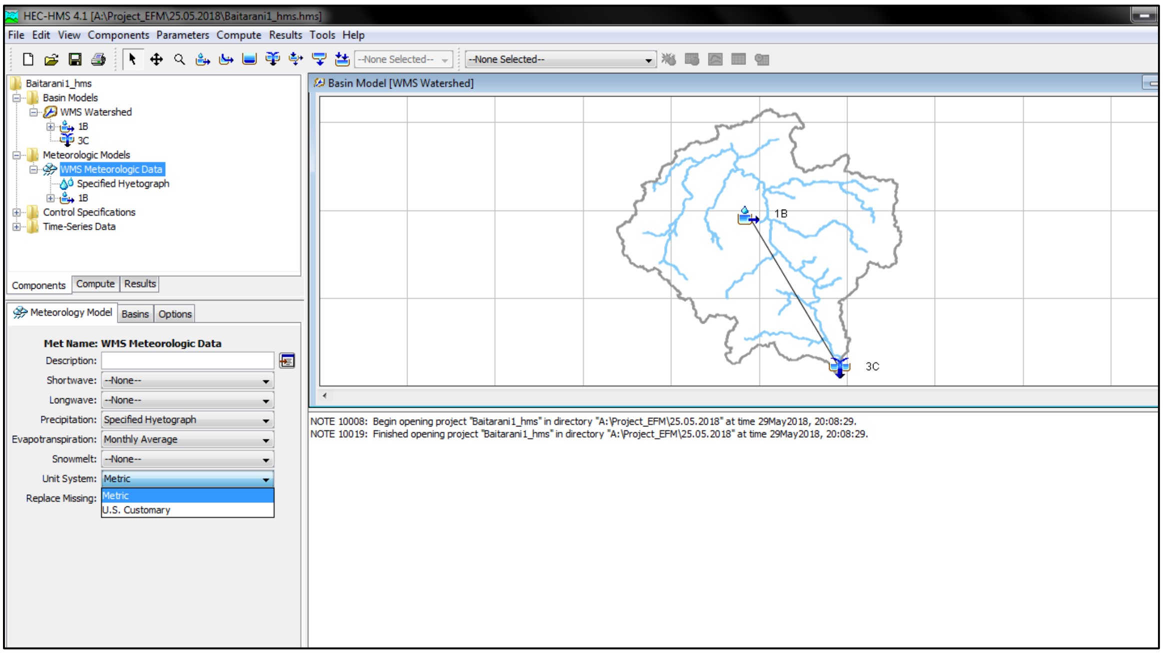


Figure 4.35 Screenshot of Meteorological data in HMS

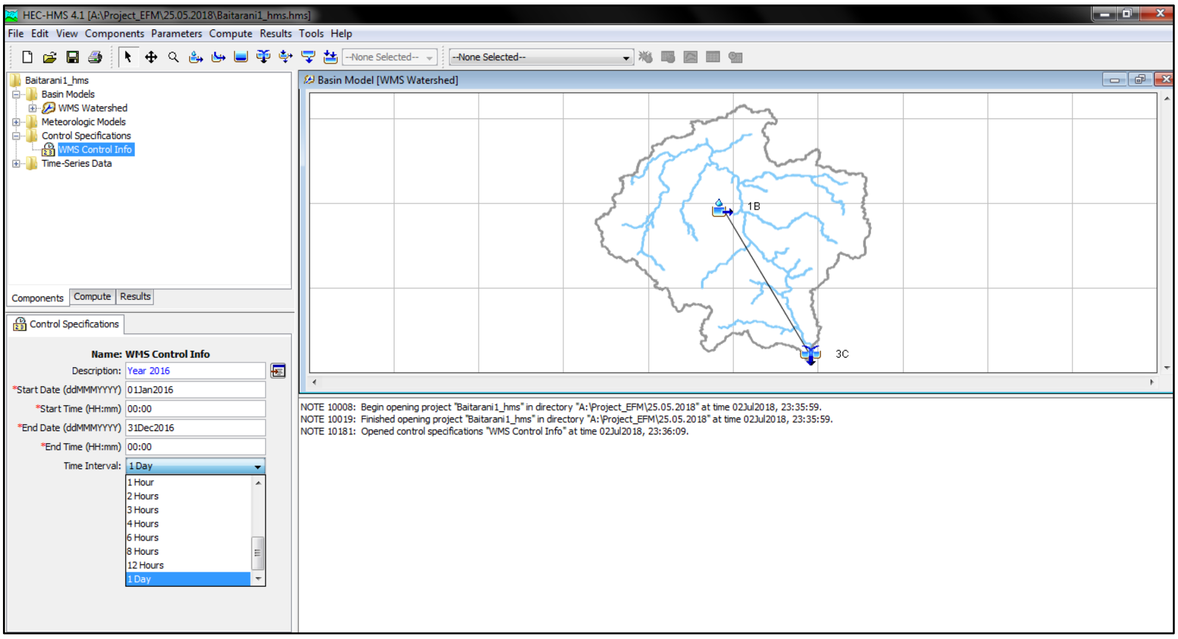


Figure 4.36 Screenshot for Setting up job control in HMS

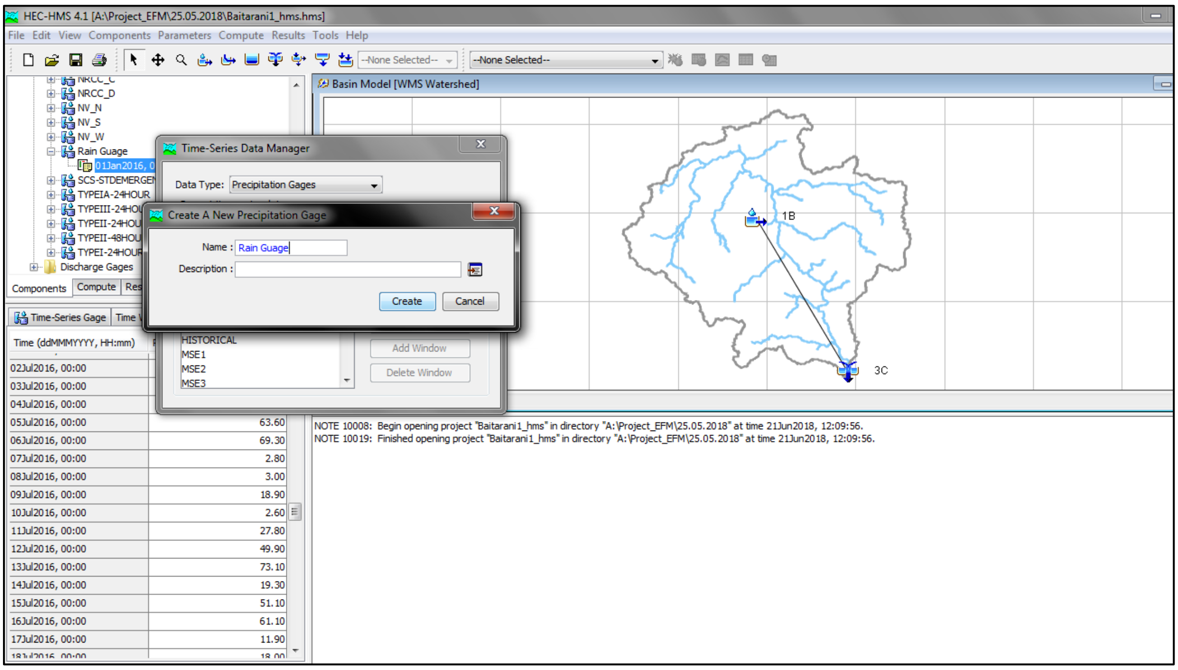


Figure 4.37 Screenshot for setting up rain gauge data in HMS

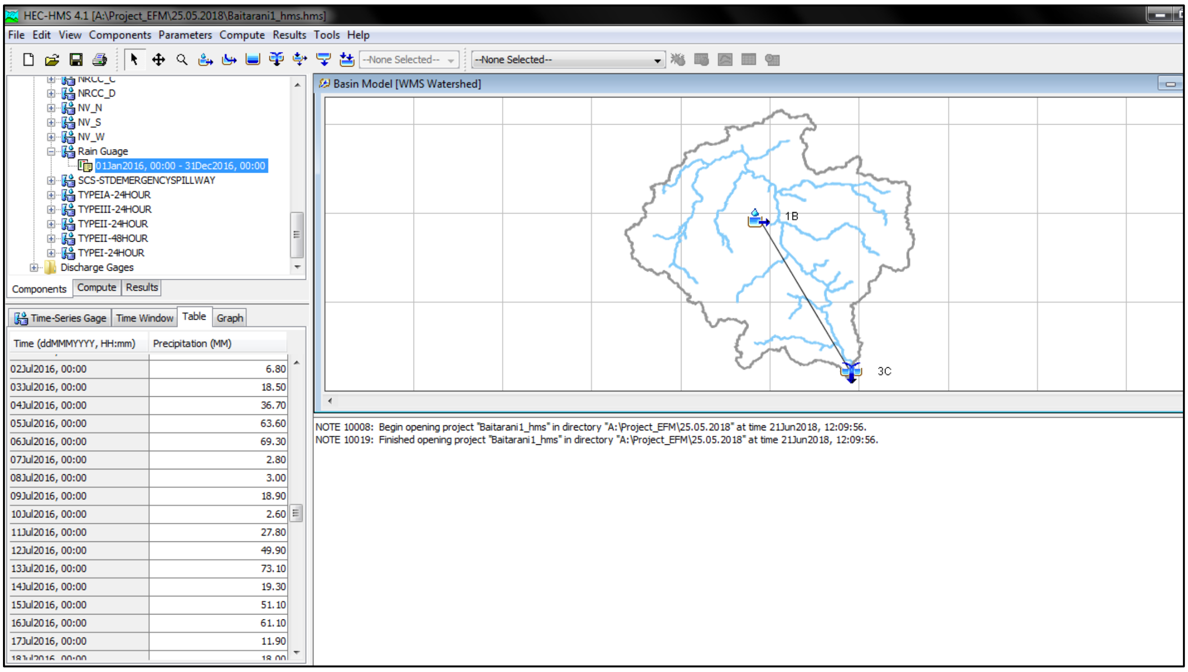


Figure 4.38 Screenshot of filling rain gauge data in HMS

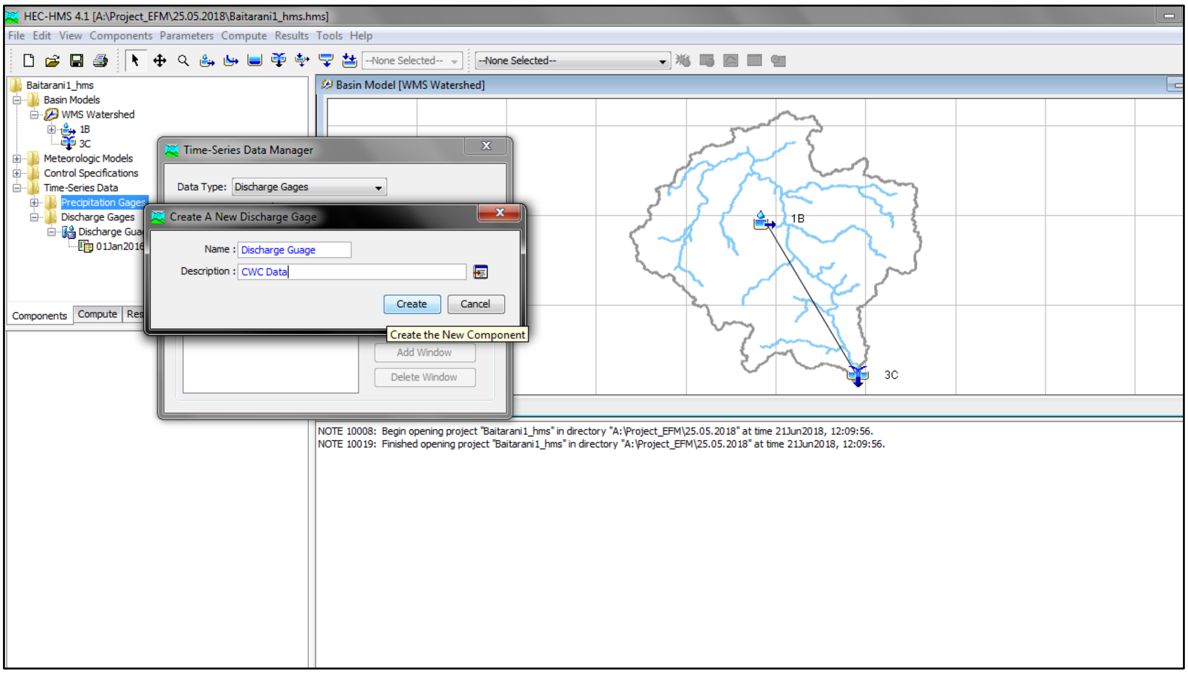


Figure 4.39 Screenshot of creating discharge gauge in HMS

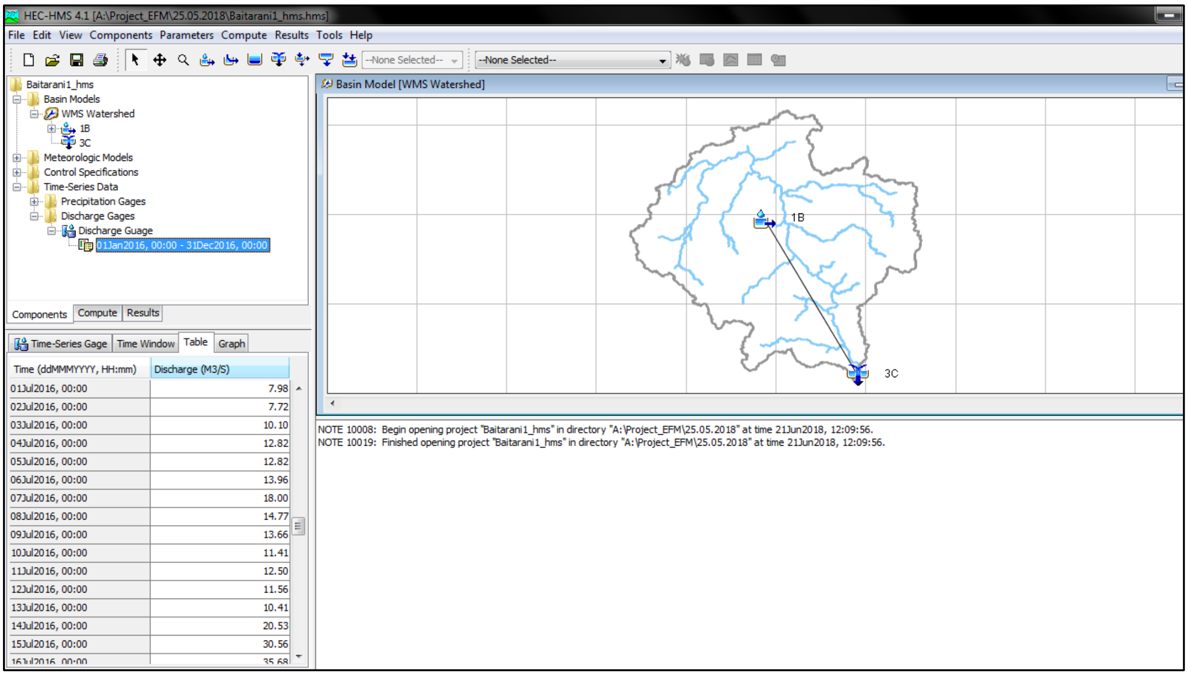


Figure 4.40 Screenshot of filling discharge data in HMS

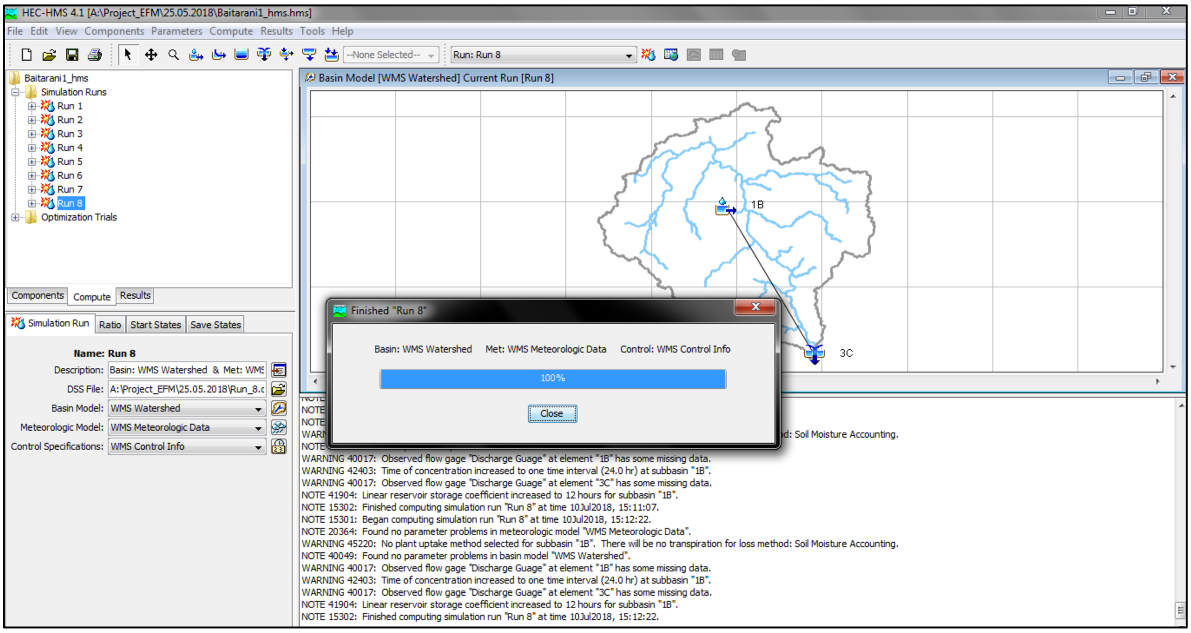


Figure 4.41 Screenshot of creating simulation run

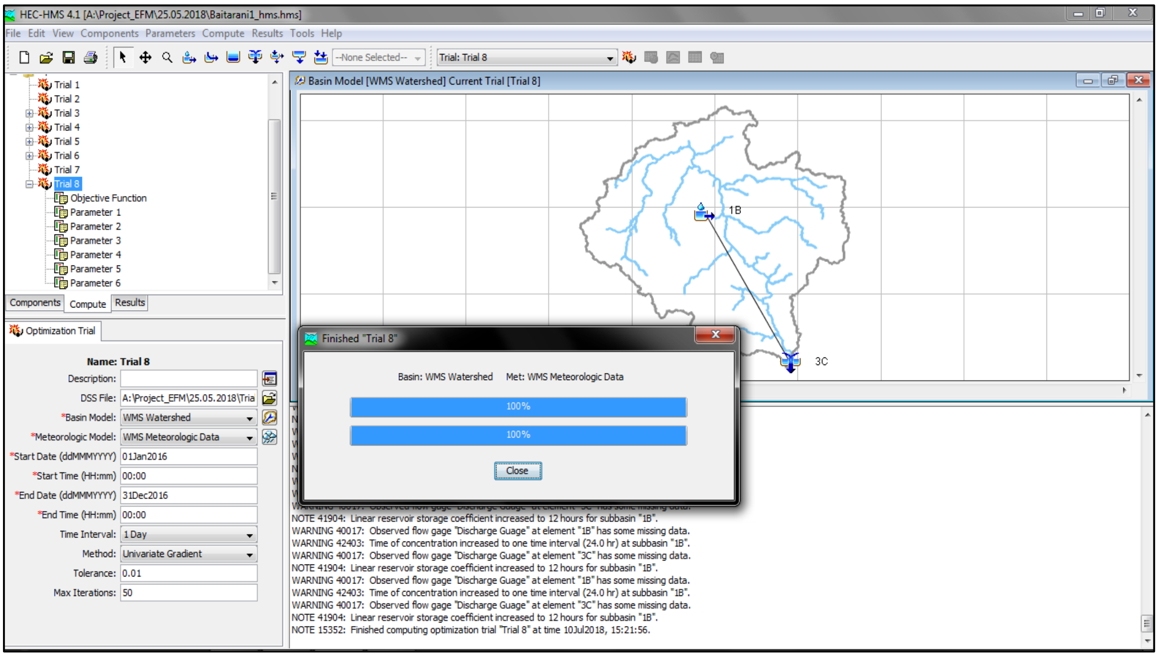


Figure 4.42 Screenshot of creating optimization run

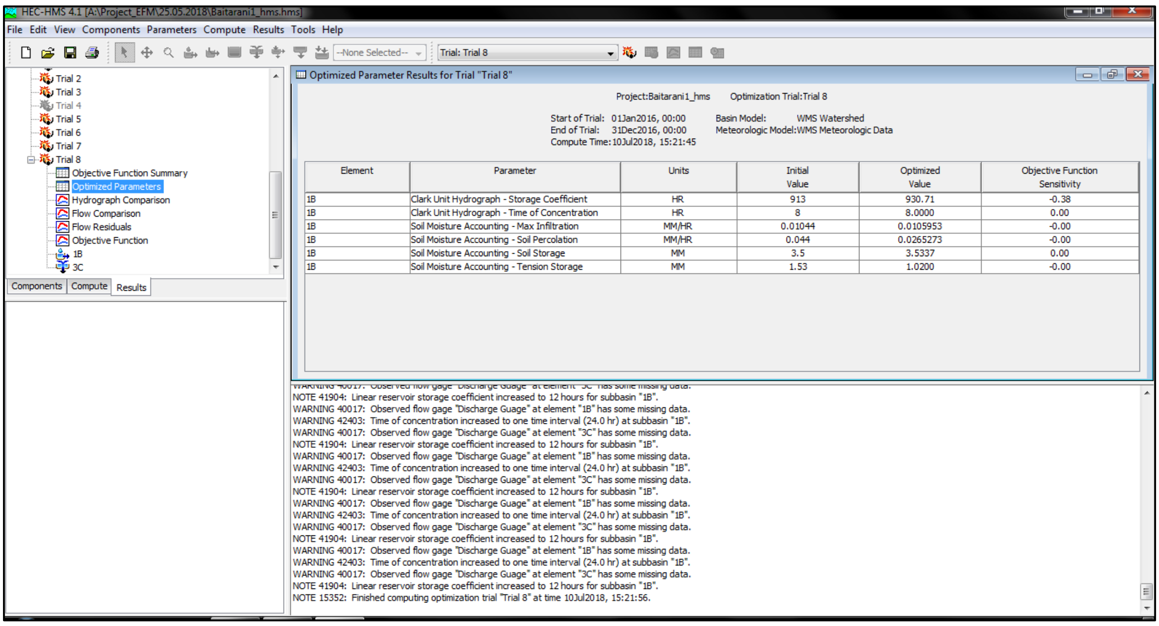


Figure 4.43 Screenshot of optimized parameters

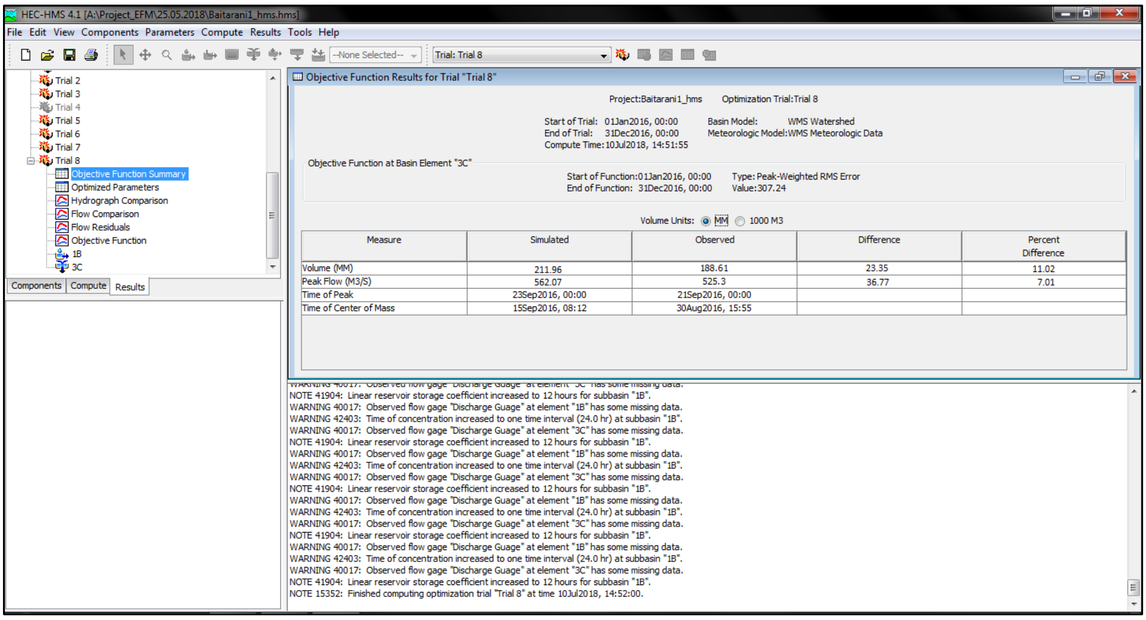


Figure 4.44 Screenshot of results after simulation and optimization

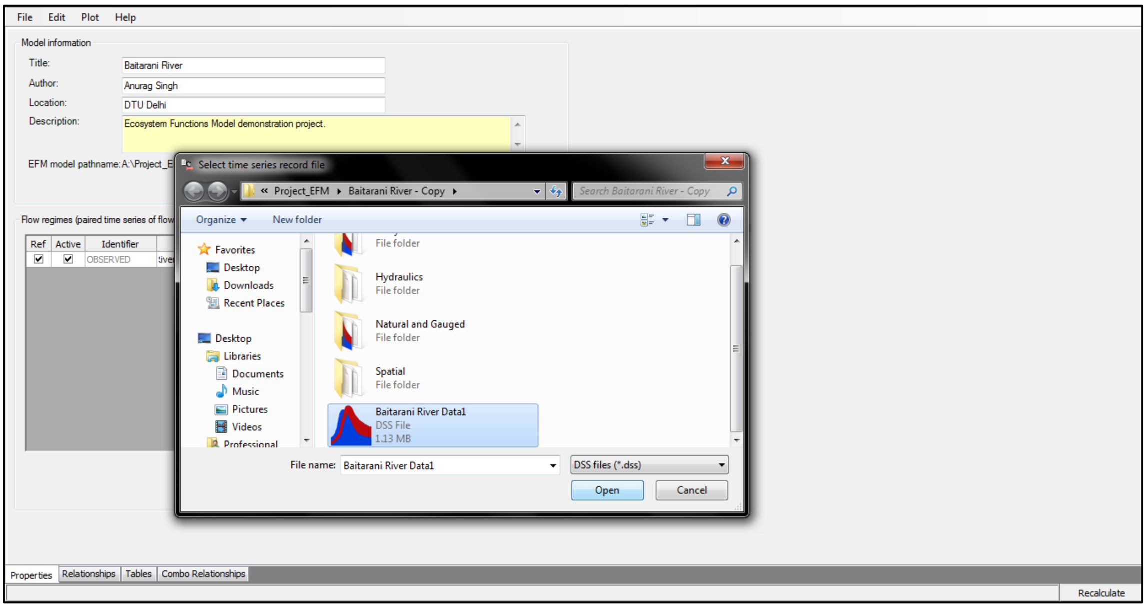


Figure 4.45 Screenshot of opening of project in HEC-EFM

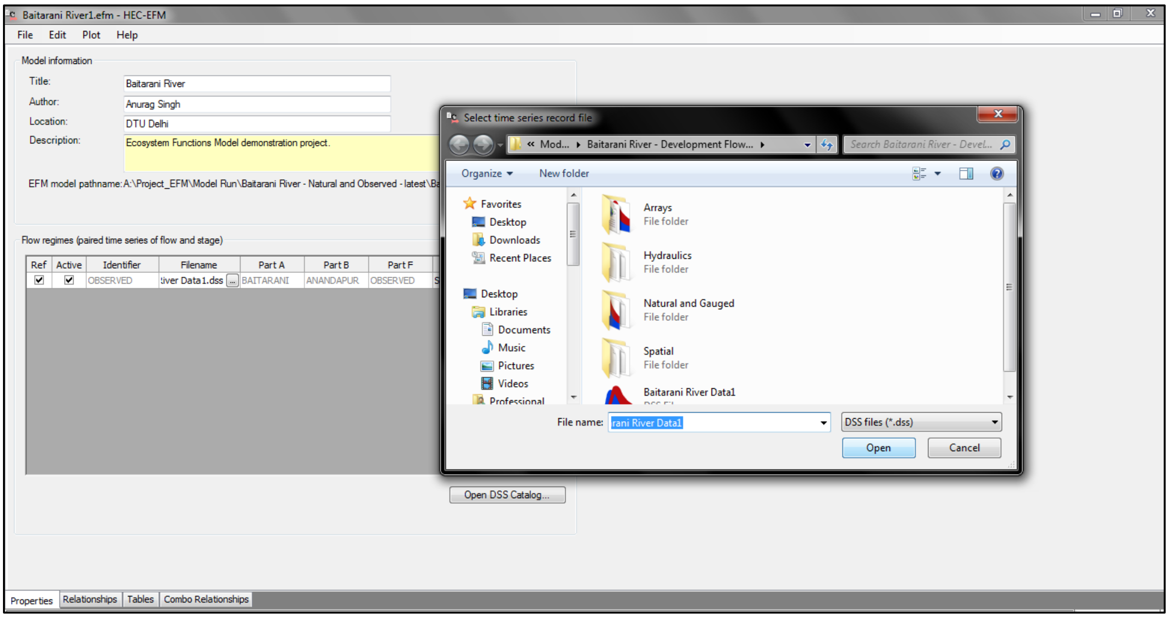


Figure 4.46 Screenshot of importing flow regime in HEC-EFM

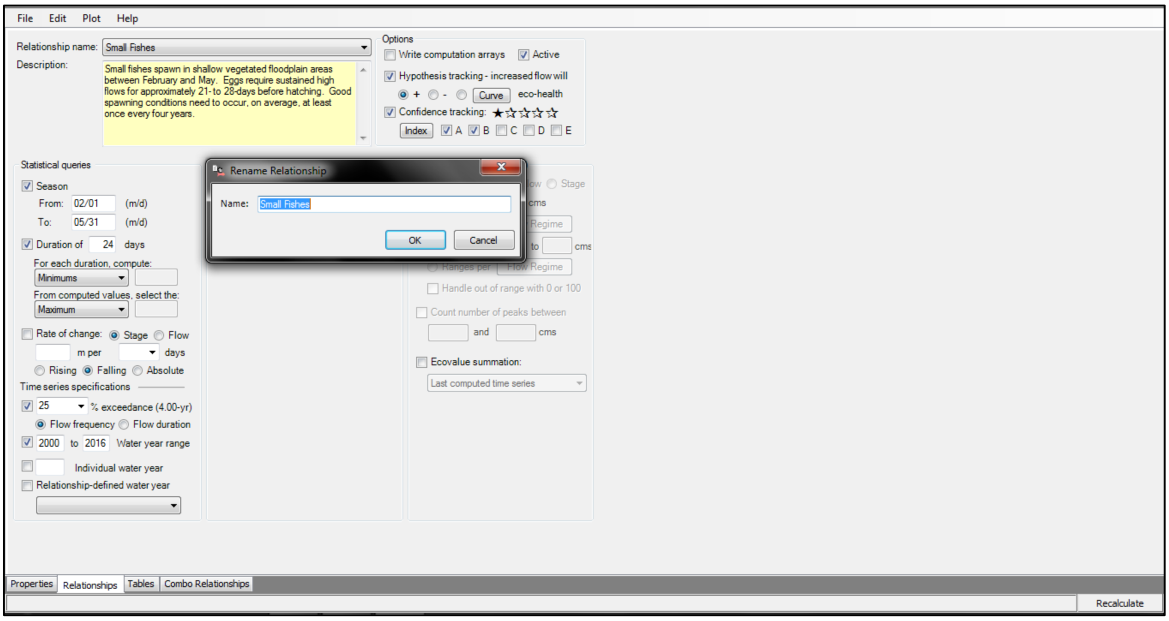


Figure 4.47 Screenshot of creating relationships of aquatic lives

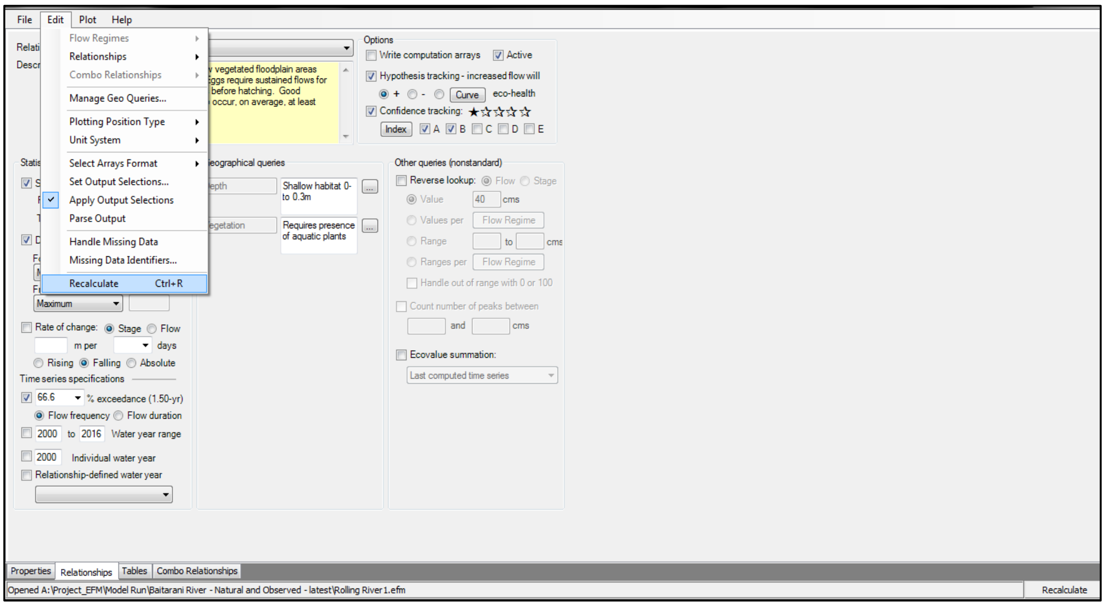


Figure 4.48 Screenshot of Recalculate step in EFM

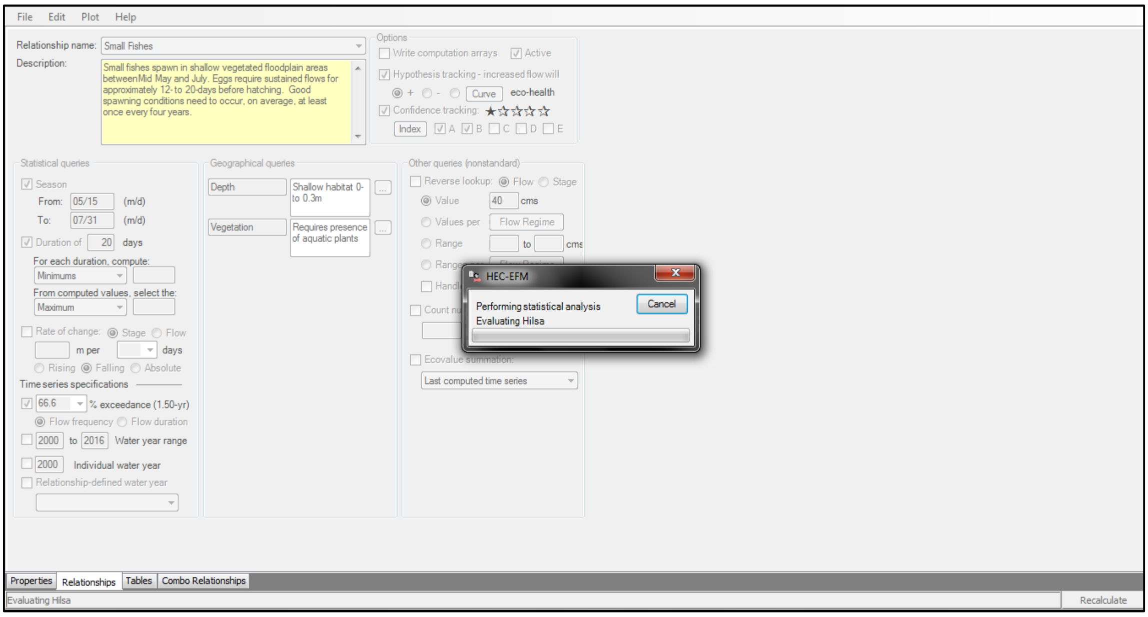


Figure 4.49 Screenshot of running the model in EFM for Hilsa

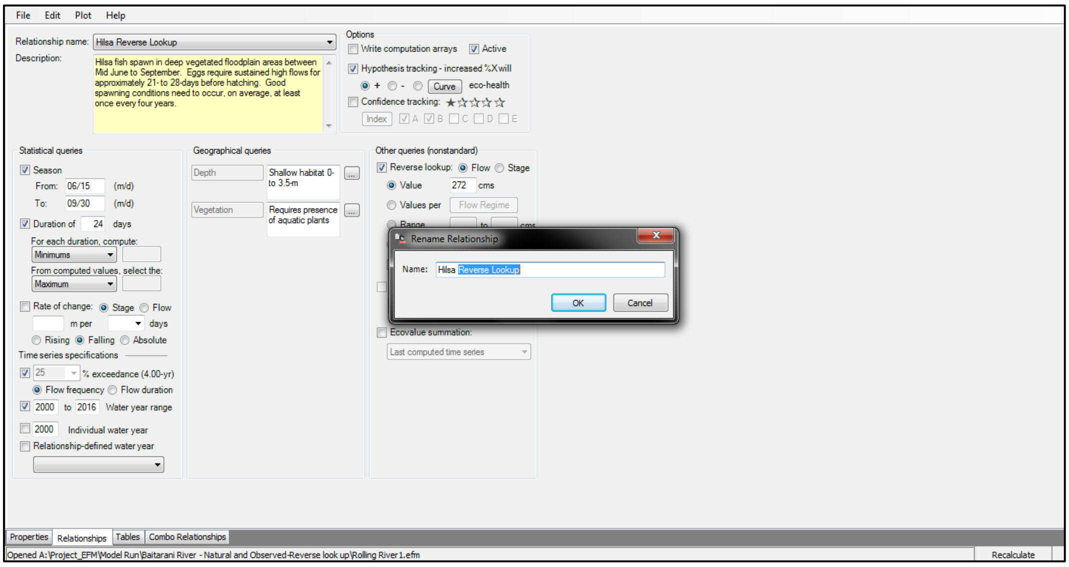
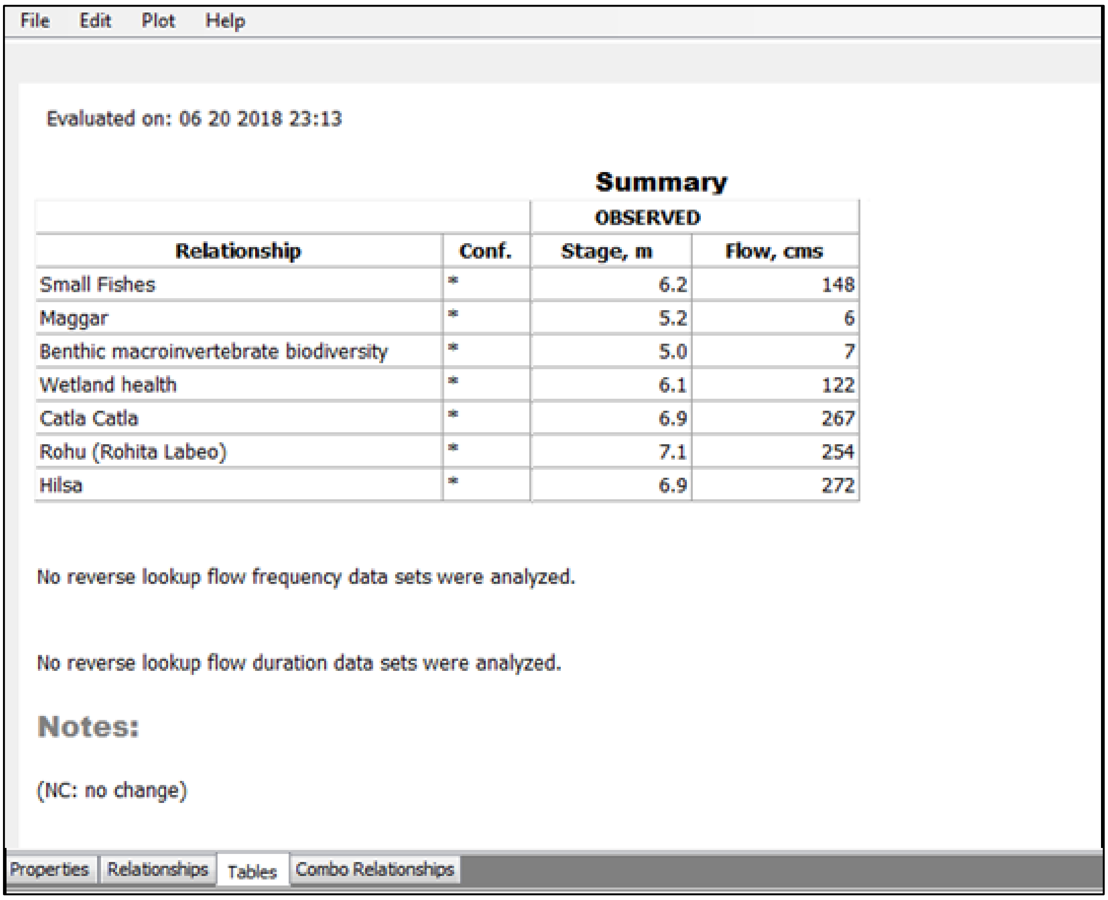


Figure 4.50 Screenshot of reverse lookup query in EFM for Hilsa

CHAPTER 5

RESULTS AND DISCUSSION

HEC-EFM model was run for three different flow regime namely observed, climate change and future development. Using above defined HEC-EFM relationship, the model was run for 17 years viz. 2000 to 2016. The generated tables from HEC-EFM software are shown in Fig. 5.1 to Fig. 5.3 for flow regime of observed, climate change and future development respectively. Reverse lookup of the E-flow values of different profound species is shown in Fig. 5.4. The average annual flow versus E-flow for Small Fishes, Catla Catla, Hilsa, Maggar, Wetland, Benthic Macro -Invertebrates and Rohu is shown in Fig. 5.5 and Fig. 5.6 shows observed flow of 2016 versus E-flow.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Summary

		OBSERVED	
Relationship	Conf.	Stage, m	Flow, cms
Small Fishes	*	6.2	148
Maggar	*	5.2	6
Benthic macroinvertebrate biodiversity	*	5.0	7
Wetland health	*	6.1	122
Catla Catla	*	6.9	267
Rohu (Rohita Labeo)	*	7.1	254
Hilsa	*	6.9	272

No reverse lookup flow frequency data sets were analyzed.

No reverse lookup flow duration data sets were analyzed.

Notes:

(NC: no change)

Properties Relationships Tables Combo Relationships

Figure 5.1 Output table for observed flow regime

The above figure shows the resultant table generated after modelling process in EFM for the observed flow regime. The table depicts the E-flows along with the stage for the profound species which were considered in this study. The E-flow and stage are given in cumecs and meter in third and fourth column respectively for different species.

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Summary

		CLIMATE CHANGE	
Relationship	**Conf.**	**Stage, m**	**Flow, cms**
Small Fishes	*	5.4	129
Maggar	*	4.1	5
Benthic macroinvertebrate biodiversity	*	4.4	6
Wetland health	*	5.3	106
Catla Catla	*	6.0	232
Rohu (Rohita Labeo)	*	6.2	221
Hilsa	*	6.0	236

No time series data sets were compared.

No reverse lookup flow frequency data sets were analyzed.

No reverse lookup flow duration data sets were analyzed.

Notes:

(NC: no change)

Properties | Relationships | Tables | Combo Relationships

Figure 5.2 Output table for flow regime in climate change

The above figure depicts the E-flows along with the stage for the profound species which were considered in present study. The E-flow and stage are given in cumces and meter in third and fourth column respectively for different species.

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Summary

		DEVELOPMENT	
Relationship	**Conf.**	**Stage, m**	**Flow, cms**
Small Fishes	*	2.2	52
Maggar	*	1.8	2
Benthic macroinvertebrate biodiversity	*	1.8	3
Wetland health	*	2.2	43
Catla Catla	*	2.4	93
Rohu (Rohita Labeo)	*	2.5	89
Hilsa	*	2.4	95

No time series data sets were compared.

No reverse lookup flow frequency data sets were analyzed.

No reverse lookup flow duration data sets were analyzed.

Notes:

(NC: no change)

Properties Relationships Tables Combo Relationships

Figure 5.3 Output table for flow regime in future development

The above figure is generated after modelling process in EFM for the flow regime in future development. The table depicts the E-flows along with the stage for the profound species which are considered in present study. The E-flow and stage are given in third and fourth column respectively for different species.

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No time series data sets were analyzed.

No time series data sets were compared.

Reverse Look-ups - Flow Frequency

		OBSERVED	
Relationship	**Conf.**	**Chg.**	**%X, of years**
Small Fishes Reverse Lookup	*	n/a	66.7
Maggar Reverse Look up	n/a	n/a	40.7
Catla Catla Reverse Lookup	n/a	n/a	24.9
Rohu (Rohita Labeo) Reverse Lookup	n/a	n/a	24.9
Hilsa Reverse Lookup	n/a	n/a	24.9

Reverse Look-ups - Flow Duration

		OBSERVED	
Relationship	**Conf.**	**Chg.**	**%X, of time**
Benthic macroinvertebrate biodiversity Reverse Lookup	n/a	n/a	90.6
Wetland health Reverse Lookup	n/a	n/a	50.0

Notes:

Properties Relationships Tables Combo Relationships

Figure 5.4 Reverse lookup table for observed flow regime

Reverse lookup of the E-flow values of different species was calculated in HEC-EFM. Reverse lookup is a query (condition) given in to the HEC-EFM, which uses a value of E-flow as input and model computes the percentage of years that flow is equalled or exceeded. In the above figure, the reverse lookup is analysed for the observed flow regime. Similarly the reverse lookup for the flow regime in climate change and future development are shown in fig. 5.5 and fig. 5.6 respectively.

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No time series data sets were analyzed.

No time series data sets were compared.

Reverse Look-ups - Flow Frequency

Relationship	Conf.	CLIMATE CHANGE %X, of years
Small Fishes_Reverse Lookup	n/a	49.0
Maggar_Reverse Lookup	n/a	25.9
Catla Catla_Reverse Lookup	n/a	21.0
Rohu (Rohita Labeo)_Reverse Lookup	n/a	20.4
Hilsa_Reverse Lookup	*	20.7

Reverse Look-ups - Flow Duration

Relationship	Conf.	CLIMATE CHANGE %X, of time
Benthic macroinvertebrate biodiversity_Reverse Lookup	n/a	86.9
Wetland health_Reverse Lookup	n/a	44.9

Notes:

Properties | Relationships | Tables | Combo Relationships

Figure 5.5 Reverse lookup table for flow regime in climate change

The above figure shows that in the case of flow regime of climate change, the E-flow may be met less percentage of time as compared to the percentage in observed flow regime. The fig.5.6 shows that in the case of flow regime in future development scenario, some species like Maggar, Catla Catla, Rohu, Hilsa may not be able to get enough E-flow for sustainable development and may even become extinct if the condition remains same in up coming future. For small fishes the reverse lookup percentage value becomes minimal indicating the reduction in quantity and quality of fishes.

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No time series data sets were analyzed.

No time series data sets were compared.

Reverse Look-ups - Flow Frequency

		DEVELOPMENT
Relationship	**Conf.**	**%X, of years**
Small Fishes_Reverse Lookup	n/a	6.1
Maggar_Reverse Lookup	n/a	above range
Catla Catla_Reverse Lookup	n/a	above range
Rohu (Rohita Labeo)_Reverse Lookup	n/a	above range
Hilsa_Reverse Lookup	n/a	above range

Reverse Look-ups - Flow Duration

		DEVELOPMENT
Relationship	**Conf.**	**%X, of time**
Benthic macroinvertebrate biodiversity_Reverse Lookup	n/a	58.0
Wetland health_Reverse Lookup	n/a	17.4

Notes:

Properties Relationships Tables Combo Relationships

Figure 5.6 Reverse lookup table for flow regime in future development

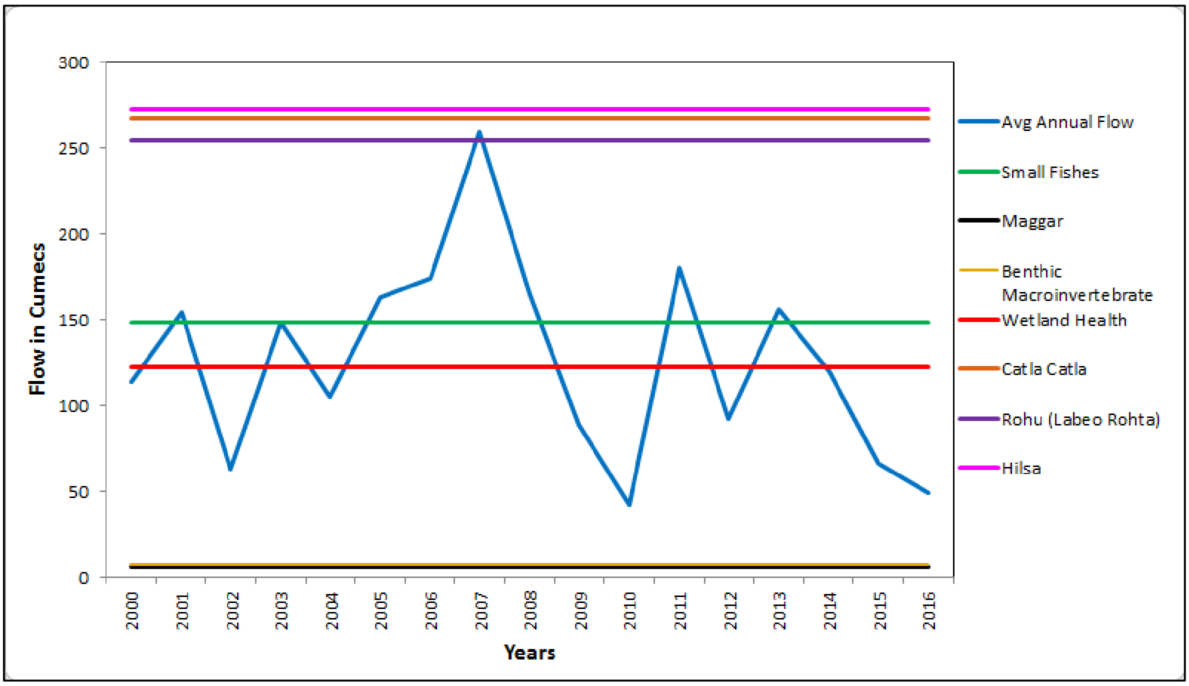

Figure 5.7 Average annual flow versus E-flow for various species over 17 years

The fig.5.7 depicts the average annual flow versus E-flow for various profound species over 17 years. The figure depicts that at certain times it can be seen that the average annual flow is less than the E-flow for some species like Hilsa and Catla-Catla although it satisfies the E-flow condition for Rohu for a smaller time, whereas the E-flow condition is satisfied for small fishes, Maggar, Wetlands and Benthic Macro-invertebrate.

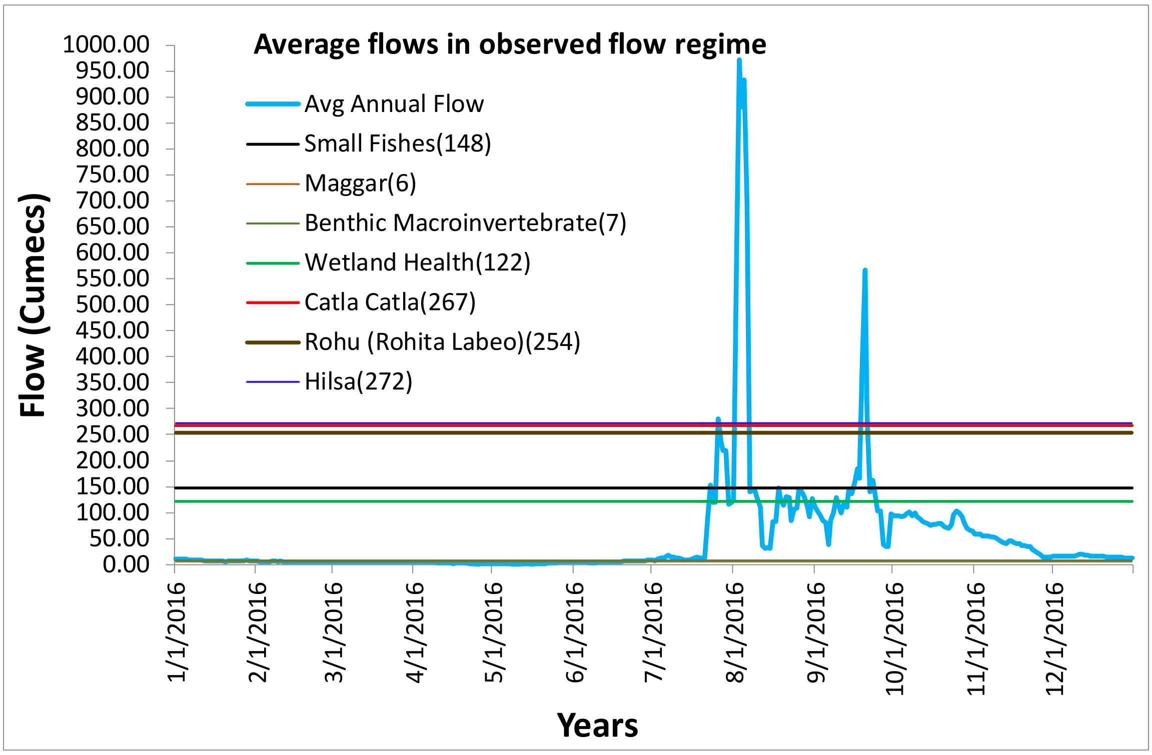

Figure 5.8 Observed flow versus E- flow for various specious in year 2016

The figure shown above is an attempt to show the comparison of E-flow in observed flow regime versus daily flow in the year 2016 which depicts that E-flow of every species satisfies over a certain period of months in the year while the same doesn't satisfies for certain months, showing that the species do not get required amount of E-flow all over the year.

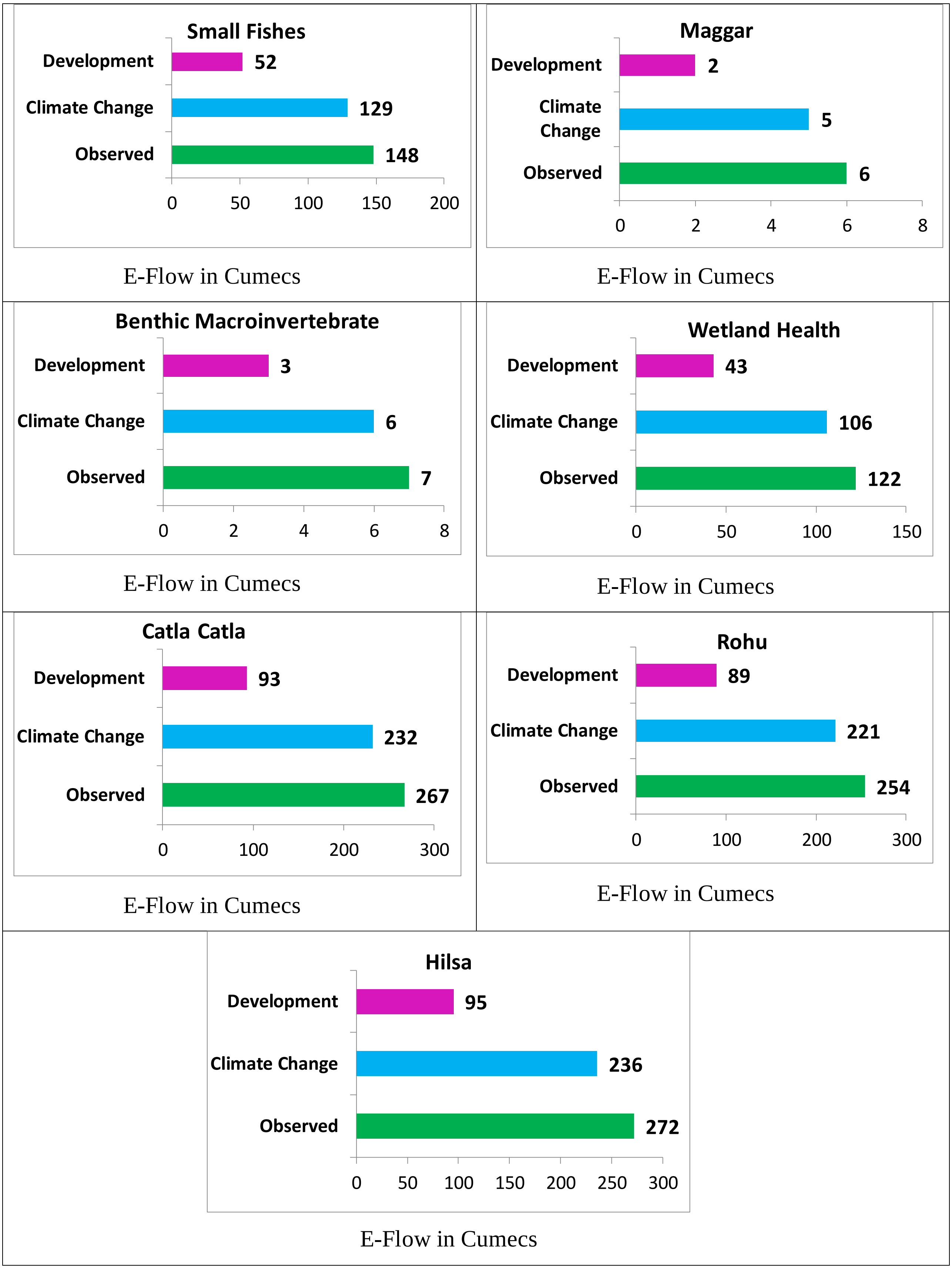

Figure 5.9 E- flows of species in observed, climate change and development flows

The previous figure shows the results of the E-flows of profound species in previously discussed three types of flow regimes in Baitarani River upto Anandapur, Odisha. Here at a glance it is clearly shown that the E-flow gets restricted to the lower values for every species in future development and climate change flow regimes respectively as compared to the E-flow required in observed flow regime.

CHAPTER 6

CONCLUSION

An attempt has been made to analyse the ecosystem of the reach under consideration using HEC-EFM model with incorporation of vital species like Small Fishes, Maggar, Catla-Catla, Rohu, Hilsa, Benthic Macro Invertebrate inhibiting in the study area. In addition the Wetland Health has been diagnosed with the help of the software.

The conclusions have been emerged from the study that Small fish, Maggar, Benthic macro-invertebrates, Wetland health, Catla Catla, Rohu and Hilsa require 148, 6, 7, 122, 267, 254 and 272 cumecs of Environmental flow in observed flow condition to maintain good ecological conditions and for better spawning, whereas this demand could only be provided to 129, 5, 6, 106, 232, 221, 236 cumecs and 52, 2, 3, 43, 93, 89, 95 cumecs for flow regime in climate change and flow regime in future development respectively.

6.1 RECOMMENDATIONS

- The minimum environmental flow should be regulated to the above calculated values for good ecological conditions.
- Planning of future development projects should be done keeping E-flows on a priority bases.
- The planned upcoming industries in upper parts of the study area should follow recycling of treated sewage waters to the extent feasible, so as to maintain quantity and quality of the River water.
- At present, the environmental needs have been taken on percentage basis with respect to average flows in different seasons. It is recommended to determine environmental flow requirements in various reaches in the sub-basin, based on scientific studies (rather than simply volumetric percentages) and E-flows commensurate with the value of the environmental assets proposed to be protected, both in-stream and off-stream.

REFERENCES

[1] Acreman M.C, Dunbar M. J, “Defining environmental river flow requirements? are view”, Hydrology and Earth System Sciences Discussions, European Geosciences Union, pp.861-876, October 2004.

[2] Asadi Arash, Boustani Fardin, “Performance Evaluation of the HEC-HMS Hydrologic Model forLumped and Semi-distributed Stormflow Simulation (StudyArea:Delibajak Basin)”, American Journal of Engineering Research (AJER), 2013.

[3] CWC Draft Report on “Reassessment of Water Availability in India using Space Inputs (Volume-I)”, Central water Commission, Basin Planning and Management Organisation, October 2017.

[4] CWC Report on “River Basin Planning of Baitarani Sub-Basin”, Central water Commission, Basin Planning and Management Organisation, September 2016.

[5] Davies PM, Naiman RJ, Warfe DM, Pettit NE, Arthington AH and Bunnc SE, “Flow-Ecology Relationships: Closing The Loop On Effective Environmental Flows”, Marine and Freshwater Research 65(2) 133-141 https://doi.org/10.1071/MF13110, April 2013.

[6] HEC-EFM 4.0 Quick Start Guide on “Ecosystem Functions Model”, U. S. Army Corps of Engineers, Institute of Water Resources, Hydraulic Engineering Centre, March 2017.

[7] HEC-HMS 4.1 User Manual on “Hydrologic Modelling System”, U. S. Army Corps of Engineers, Institute of Water Resources, Hydraulic Engineering Centre, July 2015.

[8] Gao Y, Vogel RM, Kroll CN, Poff N.L and Olden JD, "Development of Representative Indicators of Hydrologic Alteration", Journal of Hydrology, 374: 136–147, 2009.

[9] Godinho Francisco, Costa Sergio, Pinheiro Paulo,Reis Filipa, António Pinheiro, "Integrated Procedure for Environmental Flow Assessment in Rivers", Springer International Publishing Switzerland 2014.

[10] Hirji R and Davis R, "Environmental Flows in Water Resources Policies, Plans, and Projects". Case studies, The International Bank for Reconstruction and Development/THE WORLD BANK, 2009.

[11] Hickey, J. T., and Dunn, C. N. (2004). "The Ecosystem Functions Model: A tool for restoration planning," SMART Technical Notes Collection, ERDC/TN SMART-04-4 U.S. Army Engineer Research and Development Centre, Vicksburg, MS, September 2004.

[12] Jha Dharm Nath, Alam Absar, Joshi Kripal Datta, "Environmental Flow Requirements: A Case Study of River Sone", Central Inland Fisheries Research Institute Barrackpore, Bulletin No.189, February 2014.

[13] Jha Ramakar, Sharma K.D, Singh V. P, "Critical Appraisal of Methods for the Assessment of Environmental Flows and their Application in Two River Systems of India", KSCE Journal of Civil Engineering, March 2008.

[14] Korsgaard, Louise, "Ecological suitability curves and economic valuation to safeguard environmental flows and support integrated water resources management", Department of Environmental Engineering, Technical University of Denmark, Annual report:2006.

[15] Land Use Land Cover, Retrieved from http://glcf.umd.edu/data/lc/index.shtml via FTP server.

[16] Liu H.C, Shui Y, L H Li, Cao N, Yu G Y, Liu J,” Research on environmental flow in Huai River Basin, China”, IOP Conference Series: Earth and Environmental Science, July 2016.

[17] Mirza A.T.M, Tanvir Rahman, SanjidaHoque Moly, A H M Saadat, “Environmental Flow Requirement and Comparative Study of the Turag River, Bangladesh”, International Journal of Scientific Research in Environmental Sciences (IJSRES), 1(10), pp. 291-299, September 2013.

[18] Moly Sanjida, Rahman, MirzaSaadat, A H M, “Environmental Flow Characteristics of the Gorai River, Bangladesh”, International Journal of Scientific Research in Environmental Sciences, Volume-3, pp.208-218, June 2015.

[19] Petts GE, “Instream Flow Science For Sustainable River Management”, Journal of the American Water Resources Association 45: 1071-1086, 2009.

[20] Rao, D.V. and Shibananda Rath, “Fauna of Brahmani-Baitarani Estuarine complex,Odisha, Bay of Bengal”, w.s.r. to ichthyofauna and crustaceans, Estuarine Ecosystem Series, 7 : pp. 1-120, January 2014.

[21] Soil data, Retrieved from https://daac.ornl.gov/cgi-bin/dataset_lister.pl?p=19

[22] U. S. Army Corps of Engineers (USACE), “Environmental Function Model: Technical Reference Manual”, Davis, CA: U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2008.

[23] U. S. Army Corps of Engineers (USACE), “Hydrologic Modeling System: Technical Reference Manual”, Davis, CA: U.S. Army Corps of Engineers, Hydrologic Engineering Center, 2009.

[24] Verma Ravindra Kumar, Murthy Shankar, Verma Sangeeta, Mishra Surendra Kumar, “Design flow duration curves for environmental flows estimation in Damodar River Basin, India”, Online (springerlink.com), October 2016.

[25] Verma Ravindra Kumar, Murthy Shankar, Tiwary Rajani Kant, “Assessment of Environmental Flows for Various Sub-Watersheds of Damodar River Basin Using Different Hydrological Methods”, International Journal of Waste Resources, January 2015.

[26] WMS 10.1 Tutorial Manual on “Introduction to WMS”, Aquaveo 2016.

[27] WMS 10.1 Tutorial Manual on “Watershed Modelling-DEM Delineation”, Aquaveo 2016.

[28] Zhang H, “Review of Theoretical Researches on River Ecological Water Demand and Relevant Progress”, Tianjin Science & Technology 86-88, 2014.