Web Based Decision Support System for Water Resources: Simulation of a Large River System

Pankaj Barua
(Registration Number : 001 of 2003)

Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy
June, 2005

School of Management Sciences
Department of Business Administration
Tezpur University

Tezpur University

Certificate of the Research Supervisor

This is to certify that the thesis entitled '**Web Based Decision Support System for Water Resources : Simulation of a Large River System**' submitted to the Tezpur University in the Department of the **Business Administration** under the School of **Management Sciences** in partial fulfillment for the award of the degree of Doctor of Philosophy in **Management Science** is a record of research work carried out by **Mr. Pankaj Barua** under my supervision and guidance.

All helps received by him/her from various sources have been duly acknowledged.

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Chandana Goswami
Signature of Research Supervisor

Name: CHANDANA GOSWAMI
Designation: READER
School: MANAGEMENT SCIENCE
Department: BUSINESS ADMINISTRATION

Tezpur University

Certificate of the Joint Research Supervisor

This is to certify that the thesis entitled '**Web Based Decision Support System for Water Resources : Simulation of a Large River System**' submitted to the Tezpur University in the Department of the **Business Administration** under the School of **Management Sciences** in partial fulfillment for the award of the degree of Doctor of Philosophy in **Management Science** is a record of research work carried out by **Mr. Pankaj Barua** under my supervision and guidance.

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5/19/2005

Signature of Research Supervisor

Name: Purnendu Mandal
Designation: Professor & Chair
School: Lamar University
Department: Information Systems & Analysis, College of Business

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(Pankaj Barua)

Tezpur University

Thesis Information

Title :Web Based Decision Support System for Water Resources : Simulation of a Large River System

Author :Pankaj Barua

Supervisor :Dr.(Mrs.) Chandana Goswami and
Prof. Purnendu Mandal (Joint Supervisor)

Abstract

Growing demand for water, restricted availability, and resulting conflict over this increasingly scarce resource has generated considerable interest among the scientists, planners and water professionals for its efficient management. Since rivers are the most potential source of fresh water, management planning for water resources is generally carried out in river basin scale. Complexity of decision making process concerning water resources management on basin scale calls for use of sophisticated yet easy to use decision support (DSS) tools for processing vast amount of diverse information.

The present study involves designing a generic DSS framework on river basin scale named as **BARISS** : ***B***asin ***A***nd ***R***iver ***I***nformation and ***S***imulation ***S***ystem. Water availability and consumption pattern in any river basin is dynamic over time period; hence assessment of future water availability and consumption is required. Scenario of future water availability, consumption etc. are important constraints in decision making which needs to be visualized so as to evolve an effective strategy/planning of water resources consumption and distribution keeping availability in mind. This requires

understanding the behavior pattern of future use, therefore System Dynamics (SD) has been considered as an appropriate tool for building the model base of **BARISS.** To assess and simulate water availability on river basin scale, adequate information on water availability and consumption like flow rate of river , rainfall, ground water level, population , industry etc are needed. Such information generated in any river basin is usually from a diverse set of sources and incorporate diverse areas. In most countries of the world including India, such information is collected, viewed, stored and (re) distributed by central and provincial governments, scientific organization and their regional sub divisions. The information thus collected and stored by these organizations are hard to get. Because of the large volume even the control over the information gets lost within the organization. At a time of increasing river management consciousness, it can not be sufficient enough just to generate information; it is also needed to properly store and analyze these and offer it for scientific analysis and policy planning. RDBMS (Relational Database Management System) has that capability and therefore the information system component of **BARISS** has been built using RDBMS concept with web based user interface for easy sharing.

The application of Web based DSS framework **BARISS** has been tested on Brahmaputra Basin and named as **BRISS** (***B***rahmaputra ***R***iver ***I***nformation and ***S***imulation ***S***ystem). **BRISS** has been presented as web site using thick client and thin server approach. The information System part of **BRISS** included 12 agencies (Water resources department, irrigation department, agriculture department etc.) which are responsible for data generation on various aspect of the river basin (like Flow Records, weather, ground water, water quality, agriculture ,land, population, industry and irrigation). ORACLE RDBMS software has been used for the information

system of BRISS and ORACLE Web DB (an ORACLE product) has been used for creating web-based interface for the database.

System Dynamics Software STELLA has been used to build the Brahmaputra River System Dynamics (BRSD) model. While building BRSD model, about 285 variables have been used to represent 5 sectors, namely, population, irrigation, industry, basin water and sustainability. The part of the river basin passing through the state of Assam in India has been considered for the model. 30 years data (1971-2001) of the basin has been used for model validation. Both qualitative and quantitative validation has been done with good matching of data and trend. Sensitivity of the river basin water status to some selected parameters have been assessed through sensitivity analysis. After the sensitivity analysis BRSD model has been used for scenario generation for the year 2025 and 2050. Scenario generated has been compared and availability status of water for the basin has been presented.

The application of **BARISS** revealed that apart from being a policy tool, it can also assist in participatory decision making, public opinion building and conflict resolution in any large river system. However, in this thesis emphasis has been given on designing and testing a generic river basin DSS framework applicable to any river basin in the world rather than making detail policy analysis of any particular river basin.

Key Words : Decision Support System, System Dynamics, Simulation, Brahmaputra River, Information System

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List of Abbreviations

Abbreviation used	Meaning
AAU	Assam Agricultural University
ABS	Absolute
Aux	Auxiliary
BARISS	BAsin and River Information and Simulation System
BCM	Billion Cubic Meter (US billion 10^9)
BRISS	Brahmaputra River Information and Simulation System
BRSD	Brahmaputra River SD model
CGWB	Central Ground Water Board
CWC	Central Water Commission
DBMS	Database Management System
DFD	Data Flow Diagram
D_{pop}	Population water consumption
D_{irrig}	Irrigation water requirement
D_{ind}	Industrial water consumption
D_{env}	Environmental water demand
DSS	Decision Support System
ER	Entity Relational Diagram
GIS	Geographical Information System
GUI	Graphical User Interface
GW	Ground Water

Abbreviation used	Meaning
Ha	Hectares
HTML	Hyper Text Mark-up Language
IEEE	American Institute of Electrical Engineers and the Institute of Radio Engineers
IF	Interfacing Functionality
IMD	Indian Meteorological Department
JSP	Java Server Page
KM	Kilometer
Lpcd	litres per capita per day
M^3/S	Cubic Meter per second
MCM	Million Cubic Meter
OLAP	On line Analytical Processing
OLE	Object Linking and Embedding
OO	Object Oriented
OAS	Oracle Application Server
PA	Public Accessibility
PL	Programming Language
RDBMS	Relational Database Management System
RTC	Real Time Capability
SD	System Dynamics
S_S	Surface water supply
S_G	Ground water supply
S_R	Return flow from uses
SHBA	Statistical Hand Book of Assam

Abbreviation used	Meaning
SQL	Special Query Language
SQRT	Square root
XHTML	Extensible Hyper Text Markup Language
WRD	Water Resources Department, Assam
WWW	World Wide Web

Chapter I

Introduction

1.1.Global Water Crisis :

Water is in scarcity. Although water covers some 70% of the planet's surface, less than 3% of this consists of freshwater (Nanadalal & Simonovic, 2002). Much of the world's freshwater resources are frozen in polar ice caps (75%) followed by ground water (11%). Only 0.3% of the global water resources consist of accessible freshwater.

Mankind needs water for its survival and also for socioeconomic development. Agriculture, the basic step enabling society to develop, requires vast amount of water (as much as up to 2000 times of yield). Industry also requires freshwater. Each automobile coming out of assembly line requires at least 1,50,000 liters of water. Every liters of Gasoline represents 300 litres of water utilized in refining. (Walton, 1970). Besides these direct or consumptive uses, water is also required for power generation, recreation, navigation etc.

Rapid industrialization, expansion of Agriculture due to increase in population in the last few decades coupled with higher level of contamination has already restricted the availability of this limited resource. Concerted effort on the part of water management Professionals, Scientists and Planers is urgently required to plan , manage and use this finite resource in a sustainable manner.

1.2 River Water as source of fresh water:

The importance of River as a source of fresh water can be gauged from the fact that the English word "rival" originated from the Latin term "rivals" which means using the same river (rives). It is astonishing that at any instant rivers hold only 0.03% of all freshwater. But this minute fraction supported early civilization and caused (still causing) numerous territorial disputes between states and countries of the world. The average annual discharge of all the rivers of the earth is estimated to be 29.5X 10^3 Million M^3. There are hundreds of rivers discharging into the sea, but most of the flow occurs in a few large rivers only. For example 16 large rivers (those discharging 10,000 M^3/S or more) discharge 45% of the world total. Fifty additional rivers, with individual discharges of 500 M^3/S or more bring the total to about 60% of all the discharge (Chaturvedi., 1992). Growing demand for water and restricted availability demands that the vast volume of water discharging into the sea has to be a potential source for future water requirement. Therefore, proper water resources management and planning on basin scale is the need of the hour.

1.3 Management perspective of Water Resources planing on basin scale:

Management plan associated with utilization of water resources of any river is the process of taking appropriate decision/action to influence the behaviour of a given river system and basin it commands. The objective of such decision/action should be to fulfill the goals and objectives desired of the particular system. For any large river system the economic, social and political set up in its basin are very much complex. Therefore, the decisions/actions are to be made in a framework of sophisticated decision making process involving many stake holders and subject matter specialists.

Any decision making process has three elements in its structure : **The System** (River System in this case) , **Problem** (that require a decision) and **the Decision Maker**. The Decision maker in this case is ideally a multidisciplinary team consist of Engineers, Political Leaders, Bureaucrats and subject matter specialist drawn from a variety of fields like Economics, Environmental Science, Sociology, Law etc.. The main binding factor for joining these 3 elements (the System, the Problem and the Decision Maker) is information. Information is continuously gathered, exchanged, processed, evaluated and used during the decision making process. The quality of decision making process is enhanced (faster and better) when decision makers are provided with the most up to date, complete and correct information relevant to the problem and also a vision of the future through modeling.

To deal with the this aspect of water resources planning , water resources experts have been using different tools over the years. Some current trends are indicating stronger future reliance on computer networking, easily accessible databases, decision support systems, object oriented programming and system dynamics simulation.(Nanadalal and Simonovic, 2002)

1.4 DSS for Water Resources Planning

The intuitively perceived complexity of decision making process associated with utilization and management of water resources calls for use of tools capable of mirroring the complexity of problems under consideration. At the same time these tools have to be capable of coping effectively with large amount of diverse information that must be processed during decision making. These capabilities are provided by DSS (Decision Support System). DSSs are a specific class of computerized information system that support decision-making activities. The interactive computer-based systems and subsystems of DSS help decision makers use data, documents, knowledge and/or models to identify and solve problems and make decisions. A classic DSS has three basic component : database, modeling tools and presentation software. A good decision is not possible without data, so databases are a fundamental component of a DSS. It is also important that the data is easily accessible to the decision maker as the decision maker needs to retrieve data and transfer it to the model for predictions and simulations. Generating output is an integral part of any DSS since a large part of decision making process involves persuading and convincing other people. DSS presentation software also provides a graphic, easy to use, and flexible user interface that supports the dialogue between the user and the DSS.

Many Researchers have been working on developments of various models and DSS tools to address complexity in management of water resources. A detailed literature survey on this type of DSS may be found in Review of Literature Chapter of this dissertation.

1.5 An Overview of DSS tools for Water Resources :

Advances made in the field of information technology during the past few years have offered a wide variety of tools for use in DSS building. Notable among them are DBMS(Database Management System) and GIS (Geographical Information System) for Data Management, Internet Technology for information sharing and SD (System Dynamics) software for modeling. Some discussion on utility of these tools for water resources management has been highlighted in the following section.

1.5.1 GIS for Water Resources Management planning:

Integration of spatial analysis enhances applicability and understanding of water management tools. GIS (Geographical Information System) which is defined as "a set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes" (Burrough, 1986), provides such an alternative. Therefore, GIS has been extensively used to address spatial water resources problems. But GIS currently lack the predictive and related analytic capabilities necessary to examine complex water resources problems. Some current GIS based water resources related DSS has been discussed in Chapter 2.

Apart from being spatial, the water availability and consumption pattern is time variant as well. Any water related DSS must take this aspect into account and it would require some other technique to be incorporated with GIS. Complexity, interfacing difficulty, customization , and platform dependency are some other problem associated with use of GIS for water resources planning.

1.5.2 System Dynamics (SD) method :

The SD method consists of dynamic simulation models which explicitly consider information feedback that govern the interactions in a system. Such models are capable of synthesizing component level knowledge into system behaviour simulation at an integrated level. This capability has been very useful in analyzing and recommending policy decisions in management and social systems (Mohapatra et al., 1994). Since the works on SD reported by Forrester (1961), the method has been applied to a number of environmental studies, such as natural resource management, energy system planning, environmental impact assessment, and solid waste management (Meadows et al., 1973; Naill et al., 1992; Vizayakumar et al., 1991, 1993;).

1.5.2.1 System Dynamics as a tool for water resources management

It is only in the recent past that SD has been used for water resources modeling. Notable applications of SD in the field of water resources, although quite a few, include, river basin planning (Palmer et al., 1999), long term water resource planning and policy analysis (Simonovic & Fahmy, 1999), reservoir operation (Ahmad & Simonovic, 2000) and sustainability analysis (Xu et al. 2002). The recent use of System Dynamics for water related planning and management may be explained through the following advantages associated with this tool.

I. One of the biggest challenges for DSS is associated with enabling non technical professional to obtain answers to their questions. It is especially valid for Water Resources DSS where both questions and responses need not be expressed in technical terms, as the decision-maker need not be a technical person. At the same time the information presented must contain the same value as real consequence of option allowing straightforward description of impacts, perils and benefits in lay terms. System Dynamics Simulation model permit very detailed and realist presentation of complex physical, economic and social characteristics of a water resource system.

II. Water availability and consumption in any river basin is dynamic over time period. To evolve effective strategy/policy for water resources consumption and distribution, future demand and availability needs to be visualized. This requires understanding of behaviour pattern of future use and that makes System Dynamics an appropriate tool to address water resources related problems.

III. System Dynamics models are generally built from whatever information is available about the actual system, both qualitative as well as descriptive. System Dynamics model can also represent any non linear and dynamic system (such as water resources system).

1.5.3 Web based DSS for water resources:

The problem with traditional (standalone) DSS is that they have limited audience. Most of these models exist in papers (in an academic journal). There is no real possibility for all parties (decision maker, scientists, stake holders , policy makers and the public) to interactively test the model. Current development trends and progress in information technology associated with the Internet open new horizon for scientist, developers and users of models and DSS. Making DSS accessible through Internet can bring real progress with respect to people's improved understanding of the problem at hand and breakthrough in participatory decision making (Salewicz & Nakayama, 2004), conflict resolution and information sharing.

1.6 Problem Definition:

From the foregoing discussion it is apparent that growing demand for water and resulting conflict over increasingly scarce fresh water resources has generated considerable interest among scientist and planners for its efficient management. Since rivers are the most potential source of freshwater to meet future water requirements, Water Resources Management Planning are generally carried out in River Basin scale. Complexity of decision making process concerning Water Resources Management on Basin Scale calls for use of sophisticated yet easy to use DSS for enhancement of decision making capability.

The application of such a DSS requires efficient management of large spatial and temporal data sets, which involves data acquisition, storage, and processing of modeling inputs, as well as manipulation, reporting, and display of results. These management requirements are usually met by integrating simulation models with DSS, generating the capacity to manage large volumes of data in a common structure. The Integrated systems are then further developed by combining numerous software packages for providing interactive user interface, and by incorporating a database management system (DBMS) connectivity whenever necessary.

At present, information generated in any River Basin are often from a diverse set of sources and incorporate diverse subject areas. In most countries of the world these information are collected, viewed, stored and (re) distributed by central and provincial governments, scientific organization and their regional subdivision. The data thus collected and stored by these organizations are hard to get. Because of large volume of data even the control over the data gets lost in these organization. In this time of increasing river management consciousness, it can not be sufficient just to generate information; it is also needed to properly store and analyze these data and offer it for scientific analysis and policy planning using modern approach and tools. New approaches and tools are also required for better communication and exchange of information between decision-makers, stakeholders and the water resources professionals.

Recent advances of information technology have offered a wide variety of options . Notable among them are GIS, DBMS, System Dynamics Simulation and the Internet. Recent trend of research in this field has been to develop integrated model (integrating models with GIS or any other database). A review of the recently published literature on integrated models and DSS for water Resources has been highlighted in Review of Literature chapter of this thesis. The available models and DSS were reviewed with the principal purpose of evaluating their real time capabilities, interfacing functionality and public accessibility requirements. The review provided the rationale for the development of an integrated DSS with web based interface that would offer easy access to information, technological transparency, platform independence, visual interaction with data and cost efficiency. Such a DSS when implemented would provide the stakeholders with access to water resources related information through Internet and a vision of the future through simulation which would enable them to participate in decisions that directly affect them.

Present study has been an attempt to develop a generic, web based and dynamic DSS framework (named **BARISS** : ***BA***sin and ***RI***ver

*I*nformation and *S*imulation *S*ystem) for a large river system and test its applicability in a real world situation.

1.7 Statement of the Problem :

Water is in scarcity. It's consumption and availability needs to be monitored and regulated. For doing this one requires adequate information of various kind (like flow in river, ground water level, rainfall, consumption of water for different kind of application etc.).

The pattern of water availability and consumption in any river basin is dynamic over time period. Hence assessment of future water availability and consumption is required. Scenario of future water availability, consumption etc. are important constraints in decision making which needs to be visualized so as to evolve an effective strategy/planning of water resources consumption and distribution keeping availability in mind. This requires understanding the behavior pattern of future use and model it. To assess and simulate water availability on river basin scale, adequate information on water availability and consumption like flow rate of river , rainfall, ground water level, population , industry etc are needed. Such information generated in any river basin is usually from a diverse set of sources and involves multiple agencies and from different location. Relation between them can be established (like RIVERs have RIVER BASIN; RIVER BASIN has ADMINISTRATIVE UNIT. Information on POPULATION, INDUSTRY, AGRICULTURE, LAND etc. of RIVER BASIN is maintained on ADMINISTRATIVE UNIT basis by various AGENCYs and so on.). Therefore enhancement of river basin DSS calls for integration of an information system with the model base to incorporate these large and diverse data sets.

For any large river system the decision making process involves many stakeholders. Apart from the agencies involved in information generation and policy planning , people living across state and countries sharing the common river are the main stakeholder and are normally overlooked in the decision making process which directly affect them. Therefore, concerted efforts on the part of water resources scientists and professionals are required to allow public access to river basin DSS. Recent advances in the field of Information technology associated with Internet have opened new horizon. Making DSS accessible to public through Internet can bring transparency in river basin decision-making process and assist in participatory decision-making.

The present study is concerned with development of a dynamic river basin decision support system, integrate it with an information system and present it as a web based DSS to allow public access through Internet. The following sections present an overview of the contents of the various chapters of the thesis.

1.8. An Overview of the Thesis:

Scarcity of fresh water and necessity for using modern tools and approaches for water resources management has been emphasized in chapter 1. System dynamics method for presenting the dynamics of water availability and consumption , management and sharing of diverse information through database management system and public sharing of DSS using Internet has been shown as important considerations for water resources DSS. Statement and definition of the problem has also been given in this chapter.

Review of available water resources related DSS with respect to their real time capability, interfacing functionality and public accessibility has been presented in chapter 2, which provided the rationale for developing a new dynamic web based DSS for water resources management on river basin scale.

Chapter 3 outlines the objectives of the study, describes the concept behind the new DSS (named BARISS) and explains how BARISS and its components (river basin simulation system using system dynamics and information system using DBMS) have been built. A brief review of tools available and used for the study and merit for their selection has also been provided in this chapter.

Dynamics of water supply and consumption pattern for a river basin has been explained in chapter 4. Water supply and consumption has been aggregated through sectors and Sector wise flow diagram using SD software STELLA has been presented in this chapter.

In chapter 5, the structure of the river basin information system using database management system has been explained through descriptions (database requirement, conceptual schema and database description) and diagrams (context diagram, data flow diagram and E-R diagram).

Chapter 6 discusses the testing of applicability of the new web based DSS framework BARISS designed as result of this study through a case study system on Brahmaputra River Basin (named as **BRISS** (***B***rahmaputra ***R***iver ***I***nformation and ***S***imulation ***S***ystem). Testing of the information system of BRISS, testing and validation of Brahmaputra River SD model (BRSD)(model base of BRISS), Sensitivity testing, Scenario generation and comparison of scenario with other studies have been presented.

Summary of the study, specific contribution made through the study, limitation of the study and scope for future work have been presented in chapter 7. Conclusions from the study have also been drawn and presented in this chapter.

Chapter II

Review of literature

The literature of water resources management is quite rich and use of models and Decision Support System (DSS) for water resources management has been well documented. While the basic objectives remain the same, the style, scale and scope of the water resources related models and DSS have been changing over time in the light of technological capabilities and economic, environmental, social and political concepts. Remarkable progress has been made during the last two decades primarily because of advancement of computer related technology (Chaturvedi,1992 ;Loucks & Salewicz,1989 and Nanadalal & Simonovic,2002). In spite of the progress so made, the domain of water resources management still remains reasonably complex. Part of the complexity is because of involvement of a number of stakeholders. Of late there has been growing concerns over difficulties in communication and exchange of information between the stakeholders (Decision Maker, Scientists and General Public). This aspect has been incorporated in many of the present generation DSS and models. Graphical user interface (GUI) for easy handling, use of Internet for public access, application of state of the art tools like GIS and SD to address space and time variability etc. are some examples of information technology intervention in water resources model and DSS.

In this chapter the review of some of the recent water resources related DSS and models have been presented. Apart from the library of the Tezpur University, the on line library of Elsevier Publishers (sciencedirect.com), IEEE[1] (American Institute of Electrical Engineers and

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[1] The **IEEE** and its predecessors, the **AIEE** (American Institute of Electrical Engineers) and the **IRE** (Institute of Radio Engineers), date to 1884. In 1963 **AIEE** and **IRE** merged to form **IEEE**.

the Institute of Radio Engineers) (www.ieeexplore.ieee.org) and search engine google.com has been extensively searched for this review.

2.1 Water resources related models and DSS :

In the following sections review of currently available water resources related DSS and models have been presented. After brief description of the models a summary of the review has been presented focusing on the real time capability, interfacing functionality and public accessibility of the models and DSS.

2.1.1 IRIS and IRAS modeling systems :

IRIS and IRAS are results of research work performed by Loucks et al. (Loucks and Salewicz, 1989, Loucks et al., 1990, Loucks and Bain, 2002 and Salewicz &Loucks, 1989). The aim of their research was to develop simple, interactive, graphics-based simulation models for estimating time series of flows, storage volumes, water qualities and hydroelectric power and energy potential in a given river system. The first version of the system, called the Interactive River Simulation (IRIS), was developed in late 1980s .It was meant to be used as a decision support and alternative screening tool for assisting decision-makers and stake-holders involved in resolving conflicting issues associated with the management of international river basins. An extended and improved version of the system has been named the ''Interactive River Aquifer Simulation,'' or ''IRAS '' (Loucks & Bain, 2002). IRAS can be used for evaluating the performance of watershed or regional water resource systems.

2.1.2 ModSim

ModSim is a general-purpose river and reservoir operation simulation model. It was developed by Labadie of Colorado State University in mid 1970s (Labadie, 1995; Fredericks et al., 1998,or Department of Civil Engineering Colorado State University, 2000,or US

Department of Interior, 2000) to simulate large-scale, complex water resource systems, including scenarios for water rights, reservoir operation, and institutional and legal factors that affect river basin planning processes. From its initial development, the model has been continually upgraded and enhanced with various features and extended capabilities. Originally written in Fortran 77, ModSim currently operates on both in desktop (MS Windows) and workstation (UNIX) platforms. ModSim represents a water resources system as a connected network of nodes (diversion points, reservoirs, points of inflow/outflow, demand locations, gauge sites etc.) and links that have a specified direction of flow and maximum capacities (canals, pipelines, natural river reaches). The graphical user interface (GUI) provides users with the ability to draw a river basin network consisting of nodes and links then enter and/or import necessary data and parameters. Geographic information systems can also be used to pre-process geographical data for ModSim. The ModSim network can be visualized as a resource allocation system through which the available water resource can be moved from one point to another to meet various demands. Unlike in IRIS or IRAS systems, where the user defines the simulation sequence of nodes and links, the underlying principle of a network solver is based on optimization, minimizing the overall "cost "of water. ModSim employs an advanced optimization algorithm (Lagrangian Relaxation,) that finds the minimum cost flow through the whole network within required limits (boundaries). The model can also accommodate reservoir operations and accounting, hydropower, channel routing, and imports and exports of water from the network.

2.1.3 RiverWare

The RiverWare represents a completely new generation of tools for planning and management of river basin systems (Zagona et al., 1998, 2001). Many watershed models and decision support tools developed in the

1970s and 1980s were site-specific and applicable only to the one particular watershed for which the model had been developed. Although many decision support tools, like IRAS and ModSim, provide users with the capability to perform computations for user defined configurations and structures of a water management system, their flexibility in accounting for various possible types of reservoir operating policies is limited to rule curves and flow prioritization. These limitations result from the fact that those tools were developed using algorithmic (procedural) programming languages, such FORTRAN. These languages structure events as sequences of actions performed according to certain procedures or instructions (algorithms). RiverWare utilizes OO programming to create a flexible modeling framework. This framework combines building blocks that describe possible physical components of water management system with specific problem-solving objects capable of tackling operational issues through simulation and/or optimization. RiverWare 's model construction kit allows the user to create model system using GUI-based input. Efficient usage of RiverWare requires advanced skills; therefore, its usage is limited to a narrow range of highly skilled specialists.

2.1.4 Water Ware (Jamiesona & Fedra 1996)

'WaterWare' is the outcome of Eureka EU 487, a collaborative research programme under EU which had the objective of developing a comprehensive, easy-to-use decision-support system for river-basin planning. Its purpose was to assist government agencies, river-basin commissions, etc., in decision-making by combining the capabilities of geographical information systems, database technology, modeling techniques, optimisation procedures and expert systems. The basic architecture of WaterWare comprise of (1) a main program that co-ordinates the individual tasks and provides access through a menu of options; (2) a GIS that stores, displays all geo-coded information (satellite imagery, maps, etc.); (3) a generic database management system (DBMS) that provides access to non-spatial but nevertheless geo-referenced data; (4) at least one or more simulation, optimisation, expert systems models with access to data from both the GIS and DBMS, which provide the analytical capability; (5) a set of pre- and post-processors which support mainly editing of input data and the visualisation or analysis of model output, in addition to the handling of multiple scenarios for each of the models; (6) a user-interface with access to different functional components of the system and the various help and explain files; (7) a set of utility functions which assist in the data preparation and management tasks.

The system was structured with a variety of general-purpose UNIX work-stations in mind. Although WaterWare has been coded in C/C + + , making extensive use of a standard Tool-kit to ensure a common style, look and feel, it is also capable of integrating models written in FORTRAN 77. Compatibility with Arc/Info, GRASS and ERDAS was achieved through a set of filters which convert external formats into the specific GIS data structures used. Other formats such as DXF can be imported by first converting to, say, Arc/Info. The current release of WaterWare 1 .O occupies close to 500 MB of disk space, of which a significant proportion is taken up by the Landsat TM imagery.

2.1.5 PODIUM (IWMI, 1998)

PODIUM (the POlicy DIalogUe Model) was developed as part of the Vision 2025 exercise by IWMI(International Water Management Institute) with IFPRI (International Food Policy Research Institute).The model maps the complex relationships between the numerous factors that affect water and food security, and displays information clearly, in both graphic and tabular formats. Projections for 2025 are determined in relation to 1995 data. Users can revise this data and change any of the variables used by the model.

PODIUM has been used to explore potential impacts of the water and food security scenarios discussed during the Second World Water

Forum. It was also used to generate discussion in the eight regional dialogues held as part of the Vision 2025 exercise.The International Commission on Irrigation Drainage (ICID) has evaluated PODIUM and is recommending it as a policy tool to its member countries. India's Central Water Commission is revising PODIUM with more detailed local data to estimate water demands and supply on a state-by-state basis. There are two version of PODIUM, a country scale model and a global model. Using the country scale model, planners can analyze water availability and food production scenarios based on the data they enter. The global scale model presents a spreadsheet that organizes the countries into groups, providing a global or regional picture of water scarcity. An appropriate use of PODIUM could be to test different scenarios and the required agricultural output, by entering data from international database (such as FAOSTAT).

2.1.6 GAPSIM: (Saysel et al., 2002)

GAPSIM, a system Dynamics Model was developed as an experimental platform for policy analysis for potential long-term environmental problems of the Southeastern Anatolian Project (GAP).GAPSIM was constructed using STELLA™ *Research* software(HPS, 1996) designed for dynamic feedback modeling of complex systems. GAPSIM promises to be not only a useful laboratory for policy makers of GAP, but also a useful generic structure applicable to other similar regional development projects.

2.1.7 SIMIS: (Luciano,2002)

Scheme Irrigation Management Information System (SIMIS) was developed as a decision support system for managing irrigation schemes. It can be used either as a management tool or as a training tool. The data needed for the technical and administrative management of the scheme can be stored, edited and displayed in various forms. They can then be used for helping in water management, calculating irrigation requirements, developing irrigation layouts, scheduling water deliveries, and keeping records of water consumption. The SIMIS approach was based on simple water balance models with capacity constraints. The user can simulate management alternatives, assess the results and try out new alternatives, until a satisfactory solution is found. SIMIS also helps in the administrative aspects of managing irrigation schemes (accounting, calculating water charges, controlling maintenance activities) and in assessing their performance. SIMIS was developed in Microsoft Access 97. The calculations and graphics are programmed in Access Basic. The GIS was developed with Map Objects 1.2, an ESRI product. The whole package is compiled using Microsoft Developer to produce a runtime Microsoft Access application . A personal computer with at least 70 MB of available memory, 32 MB of RAM and 100 MHz is required to run SIMIS

2.1.8 WaterGAP 2: (Alcamo et al. ,2003)

The WaterGAP(Water - Global Assessment and Prognosis) model (http://www.usf.uni-kassel.de/wwap/), was developed at the Center for Environmental Systems Research at the University of Kassel in Germany in cooperation with the National Institute of Public Health and the Environment of the Netherlands. The aim of the model was to provide a basis (i) to compare and assess current water resources and water use in different parts of the world, and (ii) to provide an integrated long-term perspective of the impacts of global change on the water sector. WaterGAP belongs to the class of environmental models which can be classified as 'integrated' because they seek to couple and thus integrate different disciplines within a single comprehensive framework. WaterGAP 2 model can be used to answer these questions like : What is the current and future pressure on freshwater resources due to withdrawals from different water sectors? Which river basins are under particular pressure, and how will this situation change under different scenarios of future water use? How will climate change affect the availability of water in different parts of the world?

2.1.9 WORLDWATER : (Slobodan P. Simonovic 2003)

The *WorldWater* system dynamics model was developed by Simonovic (1999, 2000, 2001) using a system dynamics approach and on the basis of the World3 model (Forrester, 1973) for modeling the global water and capturing the dynamic character of the main variables affecting water availability and use. Model structure of the *WorldWater* contained seven sectors: population, agriculture (food production, land fertility, and land development and loss), nonrenewable energy resources , economy (industrial output , services output, and jobs), persistent pollution, water quantity. The water stock in the model included the precipitation, ocean resources and nonrenewable ground water resources. The model also took into account water recycling as a portion of water use. The water use side was modeled in a traditional way to include municipal water use for the needs of population, industrial, and agricultural water needs. One of the most important conceptual assumptions in the WORLDWATER was hierarchical modeling of water availability. Growing demand in different sectors was being provided for, first from the renewable surface water resources. When the water demand exceeded the available renewable surface water resources an additional amount could be taken from non-renewable ground water resources. After the demand exceeded the available surface and ground water resources, water reuse was considered. If the demand was still higher than the available supply, desalination of sea water was considered.

2.1.10 MULINO-DSS (Giupponi et al, 2004)

The project MULINO, (Multi-sectoral, integrated and operational decision support system for the sustainable use of water resources at the catchment scale), was funded by the EC 5th Framework Programme. MULINO is one of several research and development (R&D) projects that aim to contribute to Key Action i.e. 'Sustainable Management and Quality of Water', within the programme Energy, Environment and Sustainable Development. MULINO, released the prototype of a Decision Support System software (mDSS) for the sustainable management of water resources at catchment scale. The DSS developed by the MULINO consortium (mDSS) aims at addressing problems in natural resource management through the development and practical application of a decision tool. The project team was made up not only of specialists in hydrologic modeling, but also included software developers, economists, geographers, sociologists, agronomists and GIS specialists. The software integrates socio-economic and environmental modeling, with geo-spatial information and multi-criteria analysis and provides effective decision support by exploring and finding compromises between conflicting interests/perspectives in a multi-stakeholder context. The DSS is still under development.

2.1.11 WEAP (WEAP, 2004)

WEAP ("Water Evaluation And Planning" system) is a user-friendly software tool that takes an integrated approach to water resources planning. WEAP was developed by the Stockholm Environment Institute's Boston Center at the Tellus Institute. It has the following features :

- Integrated Approach : Unique approach for conducting integrated water resources planning assessments
- Stakeholder Process :Transparent structure facilitates engagement of diverse stakeholders in an open process
- Water Balance :A database maintains water demand and supply information to drive mass balance model on a link-node architecture
- Simulation Based :Calculates water demand, supply, flows, and storage, and pollution generation, treatment and discharge under varying hydrologic and policy scenarios

- Policy Scenarios: Evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems
- User-friendly Interface: Graphical drag-and-drop GIS-based interface with flexible model output graphics and tables

Other features of WEAP include : Dynamic links to spreadsheets & other models ,Embedded linear program solves allocation equations, Flexible and expandable data structures ,Powerful reporting system including graphs ,Context-sensitive help and User Guide, Minimal requirements: runs under Windows 95/98/ 2000/NT on a Pentium computer with 32 MB RAM.

2.1.12 IMPACT (IMPACT, 2005)

IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) was developed by the International Food Policy Research Institute. IMPACT was applied to a wide variety of contexts for 'medium-term and long-term policy analysis of global food markets. A wide range of factors with potentially significant impacts on future developments in the world food situation can be modeled based on IMPACT. They include: population and income growth, the rate of growth in crop and livestock yield and production, feed ratios for livestock, agricultural research, irrigation and other investment, price policies for commodities, and elasticities of supply and demand. The model is currently being extended to include the effects of water availability on food supply and demand. One of the objective of the Model is to assess the impact of alternative scenarios for water availability on food supply, demand ,trade , food security and water demand, taking into account policy reforms and investments in water and irrigation management and development.

2.1.13 TARGETS (TARGETS, 2005)

TARGETS (Tool to Assess Regional and Global Environmental and health Targets for Sustainability) developed by the Netherlands National Institute of Public Health and the Environment (RIVM) was a good effort in the field of global world modeling. The TARGETS model was constructed as a set of metamodels which have been linked and integrated. It consisted of five submodels: the population and health submodel, the energy submodel, the land and food, the water submodel and the submodel describing the bio-geo-chemical element fluxes ('cycles') (Rotmans & DeVries, 1997). The water submodel AQUA takes into account the functions of the water system that are considered most relevant in the context of global change. Human related functions considered included the supply of water for the domestic, agricultural and industrial sectors, hydroelectric power generation and coastal defense. Ecological functions taken into account were natural water supply to terrestrial ecosystems and the quality of aquatic ecosystems. A pressure module described both socio-economic and environmental pressures on the water system. The main limitation of the TARGETS modeling tool was its emphasis on assessing global change. Its structure and functionality are heavily dependent on the needs for evaluating future directions as a consequence of global climatic change and determining whether the chosen future directions are sustainable or unsustainable.

2.1.14 POLESTAR (POLSTAR, 2005)

The POLESTAR model is a comprehensive and flexible tool for sustainability studies. The software apart from being a scenario-building tool, is also a comprehensive database of current global indicators covering social, economic and environmental issues. The POLESTAR is also applicable at national , regional and global scales. The user can customize data structures, time horizons, and spatial boundaries, all of which can be expanded or altered easily in the course of an analysis. The system accepts information generated from formal models, from existing studies, or other sources. An application begins with the 'current accounts' , a snapshot of the current state of affairs. Scenarios are then developed to explore alternative futures. A scenario is a set of future economic, resource and environmental accounts, based on assumptions and models developed by the user. Finally, environmental and resource pressures are computed and evaluated in comparison to user defined sustainability criteria

2.1.15 SR-DSS (SR-DSS, 2005)

The ***Snake River Decision Support System*** (SR-DSS) is a tool designed for land use planners who make decisions in the multiple land uses and multiple stakeholders planning environment of Snake River, Idaho. It accesses and integrates the latest available spatial, financial, and qualitative information. Facet Decision Systems, together with the Bureau of Reclamation and CH2M HILL Ltd. provided this DSS to help manage competition for the natural resource and to help find a management plan that provides the maximum benefits.

The SR-DSS automatically assess the hydrologic, environmental, and institutional impacts from interactively created "What if?" planning scenarios. Potential impacts on these resources from changes in river operations (derived from MODSIM) are determined by a series of integrated models. The outcomes are fed into decision support graphics, with interim and final outputs displayed in cross-linked graphs, tables, maps, and various GUIs.

Key features of SR-DSS include:

- A new modular architecture that is efficiently expandable and scalable. There are two components: (1) The Integrated Information Environment (IIE), built with Cause & Effect and the various framework modules and integrated environmental software, and (2) The Information Network Architecture (INA) which is the computers and network of resources required to efficiently support the IIE.

- Extraordinary validation, and documentation. Important decisions are based on the results of the SR-DSS, so it must stand up to rigorous scrutiny.
- Customized interfaces, analyses, and results for key participants. Participants can flip between linked graphs, maps, and tables for any outputs.
- Ability to run selected models live or using cached results.
- "Drill down" ability from any output.
- Accessibility through Internet.

2.1.16 Geo-WAMS (Geo-WAMS , 2005)

A recent U.S. EPA funded project entitled "Development of a Geographically-based Ecological Modeling Framework for Exposure-Effects Analysis of Contaminants in the Lower Great Lakes" is a strong example of the type of environmental modeling/GIS interdisciplinary research activity. This system, which is called Geo-WAMS (Geographically-based Watershed Analysis and Modeling System), automates such modeling tasks as: spatial and temporal exploratory analysis of surface water, ground water, or watershed data; model scenario management; model input configuration; model input data editing and conversion to appropriate model input structure; model processing; model output interpretation, reporting and display; transfer of model output data between models; and model calibration, confirmation, and application.

The Geo-WAMS *Modeling Support System* was designed to facilitate the job of the water quality modeler in accomplishing the various data- interactive and model-application tasks necessary to develop and apply a site- specific, problem-specific, process- oriented mathematical modeling framework. The features built into Geo-WAMS to accomplish these goals include: straightforward user interface, a GIS (ARC/INFO),a relational database management system, process models and model-data linkages, model input and model linkage assistance tools, model scenario manager; model application tools, allowing for calibration, sensitivity analysis, diagnostics, management analysis, etc.; a model output and field data query module; and a model output and field data visualization tools.

2.1.17 A Resource Management Decision Support System for the Upper Mississippi River (UMR) (UMR, 2005)

A Resource Management Decision Support System for the Upper Mississippi River (UMR) is an effort for automation and spatial analysis on developing "tools" and information distribution mechanisms for use by resource managers, scientists, and decision makers. The digital decision support system developed is like "an electronic ecosystem encyclopedia" that planners and managers can use on a daily basis to make decisions regarding spatial and temporal conflicts and generate a variety of products for agency use and public education.

The DSS provides the following capabilities (1) MAPPING - The ability to produce maps of single or multiple combinations of data at various spatial scales (2) QUANTIFICATION - The ability to determine numerical summations of various data elements within a particular mapped area, (3) GRAPHIC DISPLAY - The ability to produce scientific tables, charts, and graphs of various sets of data, (4) MODELING - The ability to allow decision makers to "model" data to help address specific management issues.

2.1.18 DESERT (DESERT, 2005)

DESERT is a result of joint efforts of Water Resources Project of the International Institute for Applied Systems Analysis and the Institute for Water and Environmental Problems of the Siberian Branch of Russian .The main purpose DESERT was to provide a convenient, highly integrated tool for decision support for water quality management on a river basin scale. DESERT has the following features:

- Integration of most important stages of decision support, namely:
    - data management
    - model calibration
    - simulation
    - optimization
    - plotting results of simulation
- User friendly interface based on Microsoft Windows
- Unified data formats and data processing
- Flexible structure of water quality model
- Object oriented programming (C++), easily extended
- Several variants of hydraulics
- Possibility for on-line linkage to OLE servers, like Microsoft Excel, Lotus 1-2-3, etc
- Hardware and software requirements :DESERT can operate on relatively inexpensive and widely available hardware and software.IBM PC 386/486 or higher, math coprocessor is strongly recommended ,20 mb of free disk space ,4 mb of RAM, 8 or even more recommended ,Microsoft Windows 3.1 or later ,Any spreadsheet supporting Microsoft Windows OLE protocol (preferably Microsoft Excel 4.0-5.0 or above)
- DESERT is available for free for academic/research purposes.

2.1.19 AWARDS (AWARDS, 2005)

The AWARDS system developed by the Bureau of Reclamation, United States of America, is based on modern remote sensing, communication, computer, and Internet technologies. This automated information system has been designed to assist water managers and users by providing easy access to rainfall and daily crop water use estimates of

National Weather Service (NWS). The purpose of the AWARDS system is to improve the efficiency of water management and irrigation scheduling by providing guidance on when and where to deliver water, and how much water to apply.

2.2 Summary of Review :

The review of the DSSs and Model on water resources has been summarized on the basis of their real time capability, interfacing functionality and public accessibility. The summary is presented as Table 2.1.

Table 2.1 Summary of Review

DSS	Reference	Features			Software and Platform
		RTC**	IF**	PA***	
IRIS & IRAS	Loucks et al. (1989, 1990)	None	GUI	Limited	GIS Model Based
ModSim	Labadie, (1970,1995)	None	GUI	None	Fortran 77, Windows and Unix
RiverWare	Zagona et al.., (1998, 2001)	None	GUI	None	OO Programming, Rule base Simulation and Optimization
WaterWare	Jamiesona & Fedra (1996)	Full	GUI	None	C^{++}, GIS and DBMS
PODIUM	(IWMI, 1998	None	GUI	Limited	NA
Mulino-DSS	Giupponi et al., (2004)	None	GUI	Limited	GIS
GAPSIM	Saysel et al. (2002)	None	GUI	None	SD software STELLA™
SIMIS	Luciano (2002)	Limited	GUI	None	MS access, GIS
WaterGap2	Alcamo et al. 2003	Full	GUI	None	GIS, DBMS

* RTC* : Real Time Capability, IF**: Interfacing Functionality, PA***: Public Accessibility

Weap-2,21	http://www.weap21.org	None	GUI	Limited	GIS, Windows
IMPACT	(www.ifpri.cgiar.org/themes/impact.htm	NA	NA	NA	NA
TARGETS	www.baltzer.nl	NA	NA	NA	NA
POLESTAR	www.seib.org/polestar/psbro.html	NA	NA	NA	NA
WorldWater	Simonovic 1999,2000,20012003)	None	GUI	None	SD
SR-DSS	http://www.facet.com/projects/SnakeRiver html	Limited	GUI+Internet	Full	NA
Geo-WAMS	http://www.geog.buffalo.edu/igis/IGERT_environment.html	Full	GUI	None	GIS, RDBMS
DSS for UMR	http://biology.usgs.gov/dss/upmiss.html	Full	GUI	Full	GIS
DESERT	http://www.iiasa.ac.at/Research/WAT/docs/desert.html	Limited	GUI	Partial	C^{++}, MS Excel Windows
AWARDS	http://ams.confex.com/ams/annual2000/2environment/abstracts/6467.htm	Full	NA	Partial	NA

2.3 Research Gap :

From the summary table , it is clearly seen that most of the DSS and model provide GUI (Graphic User Interface). However, that does not mean that all of them provide full public accessibility. Only two DSS (SR-DSS and DSS for UMR) provide full public accessibility with real time capability. But both of them are based on GIS. As identified in chapter 1, the problem for using GIS for River Basin DSS are complexity, interfacing difficulty, customization problem and platform dependency. Also another disadvantage of using GIS for Water Resources Problems may be that most of the large river systems of the world are international in nature (covering more than one country). In most cases there are no well defined boundary or there is disputed boundary, making things further difficult.

From the above discussion it is clear that, there is scope for working on a Water Resources DSS which is real time capable, have easy user interface and available for public sharing.

It is only recently that System Dynamics (SD) principle has been applied to address river basin problem. The models using SD, demonstrates the capability to address problem that requires a vision of the future. Water resources problem of river basin is also dynamic in nature as both availability and consumption of water is time and space variant. However, it can be seen in the table above (table 2.1) that the model based on System Dynamics (SD) principle are standalone (neither real time capable nor accessible to public). Therefore, developing a River Basin SD model to address dynamics of water availability and consumption, integrating the model with a River Basin information system and presenting that as a web based DSS for water resources will be innovative. Such a study will narrow the gap of research in the area of easy to use, dynamic, real time capable and public accessible DSS for water resources on river basin scale.

2.4 Chapter Summary :

After discussing the importance of using modern tools, methods and DSS for water resources planning on basin scale in chapter 1, a brief review of available water resources DSS has been presented in this chapter. The DSS were reviewed with respect to their real time capability, interfacing functionality and public accessibility. The review enabled the author to find research gap in the study area.

Apart from the review of the models and DSS, a review of available tools for building DSS has also been made and presented in the following chapter on research methodology. Also presented in the next chapter are objectives of the present study, study plan, and tool used for the study.

Chapter III

Research Methodology

3.1 Objectives

As per the problem defined in chapter 1 and based on the review of recent works in chapter 2, following objectives have been identified for the study reported in this dissertation:

I. To introduce a new, dynamic, web based and generic Water Resources Decision Support System (DSS) framework for a large river basin,
   a. To develop System Dynamics model to act as model base for the Water Resources DSS to address the dynamics of water availability and consumption on basin scale.
   b. To design an appropriate information system as input for the Water Resources DSS using RDBMS concept with web based interface and report,

II. To test applicability of the Web Based DSS framework on a case study river system (Brahmaputra River) for analyzing consequences of some policy alternatives.

3.2 Study Plan as per Objective :

Both water availability and consumption are important constraints for river basin decision-making. To evolve effective strategy for water resources management on basin scale, dynamics of these constraints need to be studied. For this one require adequate information of various kinds like flow in river, rainfall, population etc. Present concern over fresh water crisis demands that making decision support tools for strategy and information gathering is not enough , such tools should be made available for the stakeholders. Therefore, the DSS framework proposed under the present study has the following components :

a) A river basin System Dynamics model for simulation and policy planning (objective Ia).
b) A water Resources Database for data acquisition, storage, and processing of modeling inputs (objective Ib).
c) A web based interface for the DSS (objective I).

The basic structure of the new DSS has been presented through figure 3.1

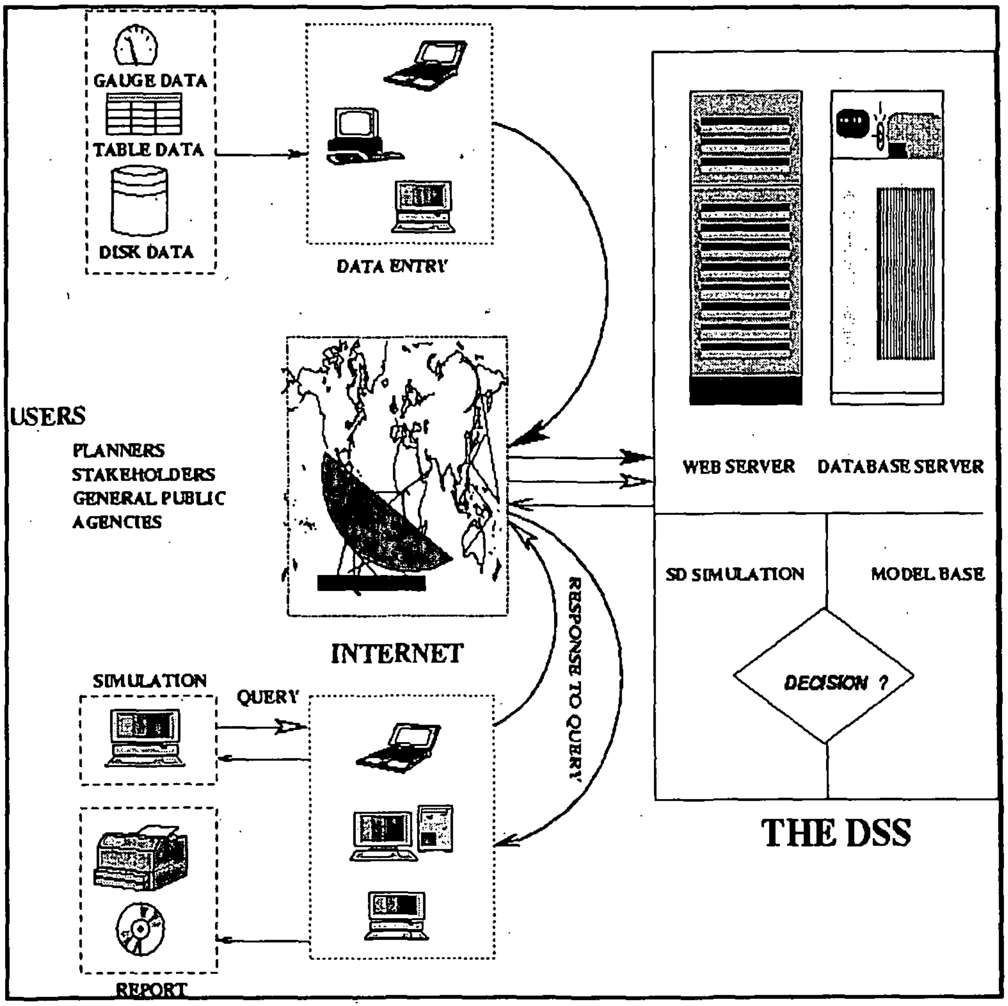


Figure 3.1 **Structure of BARISS framework**

Figure 3.1 shows that the DSS consist of a simulation model integrated with an information system. A database server hosts the database and database along with the simulation model is presented as a web site. The web site and the database is made available to the stakeholders through web server. Stakeholder can use the menus of the website for data entry, query, report generation and simulation through his/her web browser.

The new framework has been named as BARISS: Basin and River Information and Simulation System. As per objective number II , the framework (BARISS) has been tested on Brahmaputra River (one of the largest river system of the world) and presented as BRISS (Brahmaputra River Information and Simulation System). After testing, some water resources options for Brahmaputra River basin has been evaluated and presented using BRISS.

3.3 A Brief Survey of Tools :

As indicated earlier, 3 (three) basic components have been identified for the proposed Water Resources DSS framework under study, they are: a Model Base (for Simulation and Policy Planning) and Information System (for data acquisition, storage and processing of modelling inputs), and a Web Based User Interface (for public sharing). The forthcoming sections of this chapter highlight the fundamental features of the techniques and tools available and their selection for the proposed DSS. For convenience, they are arranged component wise beginning with model base.

3.3.1 Model Base for DSS:

As pointed out in earlier chapter, there are 4 approaches suggested by Simonovic (2000) through which water resources related problems are likely addressed in future. They are (a) object oriented simulation, (b) evolutionary optimization, (c) integration of fuzzy set analysis with simulation and optimization tools and (d) integration of spatial analysis with simulation and optimization tools. Though these tools are different , they are complementary in solving different important issues related to water resources management.

3.3.1.1: Object Oriented Simulation:

Object oriented modeling has been identified as a powerful approach for water management (Palmer et al., 1993; Simonovic & Bender, 1996; Simonovic et al, 1997; Simonovic & Fahmy, 1999). By separating policy questions from data, object oriented modeling makes the model results functionally transparent to all parties involved in the water management. The proposed approach is flexible, transparent, and allows for easy involvement of stakeholders in the process of water decision analysis.

There are different tools used for implementing the object oriented modeling approach. System Dynamics simulation is one such tool that has been used in water resources management very recently. Complex water resources planning problems heavily rely on systems thinking, which is defined as the ability to generate understanding through engaging in the mental model-based processes of construction, comparison, and resolution. System Dynamics is an appropriate approach for the implementation of systems thinking.

3.3.1.2 System Dynamics as Model Base:

Chapter 1 has highlighted the complexity associated with management of water resources. Complexity is infused into the system, not merely due to the large number of factors affecting the water resources system, but also due to the intrinsic nature of interactions among them. These interactions are usually non-linear and dynamic. Such characteristics are of course not unique to water resources alone but are ubiquitous to social systems in general (Forrester, 1973). This is fully recognised by System Analyst at large, but most models on social systems tend to be linear and static . This, apart from , narrowing down their scope and utility, also fails to address the problem of long term scenario forecasting. System Dynamics model can represent any such non linear and dynamic system. SD models are generally built from whatever information is available about the actual system, both qualitative as well as descriptive.

The other possible approaches as mentioned at section 3.3.2 of this chapter are (b) evolutionary optimization, (c) integration of fuzzy set analysis with simulation and optimization tools and (d) integration of spatial analysis with simulation and optimization tools. However, the power and simplicity of use of objective oriented simulation (like System Dynamics) is not comparable with the other options. User of model built on objective oriented simulation approach finds it very easy and experiences the advantages in a very short span. In addition, general principles upon which the System Dynamics simulation tools are developed apply equally to social, natural, and physical systems. Using these tools in water management allows enhancement of water models by adding the related social, economic and ecological sectors into the model structure.

These considerations and recent uses of System Dynamics Models in water resources (Xu et al. 2002, Simonovic 2002a, Simonovic 2002b) have influenced the author to adopt System Dynamics technique as the model base for the water resources DSS.

The forthcoming sections in this chapter give a short description of the System Dynamics software tools currently available.

3.3.1.3 System Dynamics software tools:

Software tools like STELLA, DYNAMO, VENSIM and POWERSIM (High Performance Systems, 1992; Lyneis et al., 1994; Ventana, 1996; Powersim Corp., 1996) were designed to facilitate the building and use of System Dynamics models. It is possible to perform good System Dynamics work with other tools including programming languages. However, this is not usually very practical.

A brief introduction of each of the software tool is given below.

3.3.1.3(a) Dynamo

DYNAMO was the first System Dynamics simulation language. For a long time the language and the field were considered synonymous. Originally developed by Jack Pugh at MIT the language was made commercially available from Pugh-Roberts in the early 1960s. DYNAMO today runs on PC compatible under DOS/Windows. It provides an equation based development environment for System Dynamics models.

3.3.1.3(b) STELLA and IThink

Originally introduced on the Macintosh in 1984, the Stella software provided a graphically oriented front end for the development of System Dynamics models. The stock and flow diagrams, used in the System Dynamics literature are directly supported with a series of tools supporting model development. Equation writing is done through dialog boxes accessible from the stock and flow diagrams. Both Stella and IThink are available for Macintosh and Windows computers.

3.3.1.3(c) Powersim

In the mid 1980s the Norwegian government sponsored research aimed at improving the quality of high school education using System Dynamics models. This project resulted in the development of Mosaic, an object oriented system aimed primarily at the development of simulation based games for education. Powersim was later developed as a Windows based environment for the development of System Dynamics models that also facilitates packaging as interactive games or learning environments.

3.3.1.3(d) Vensim

Vensim was originally developed in the mid 1980s for use in consulting projects. Vensim was made commercially available in 1992. It is an integrated environment for the development and analysis of System Dynamics models. Vensim runs on Windows and the Macintosh.

For testing of the BARISS framework, 'STELLA ' – one of the most widely used SD software has been used.

3.3.2 Information System for the Water Resources DSS:

The Information System component of any river basin water Resources DSS should be capable of coping effectively with large amount of diverse information (like flow in river , ground water level, population, industry etc.) that are to be processed during decision making. The capability to process relevant information must be accompanied by suitably presenting this information to the user and consequently to the decision maker. These capabilities are provided by Data Base Technology.

3.3.2.1. Data Base Technology:

Database technology consist of data collection and database creation , data management (including data storage and retrieval and database transaction processing) and data analysis and understanding (involving data warehousing and data mining). Since introduction in 1960s database technology has advanced considerably offering a wide variety of options. The evolutionary path of database technology has been presented as Figure 3.2.

Database technology since the mid-1980s has been characterised by the popular adoption of relational technology and an upsurge of research and development activities on new and powerful database system. These employ advanced data models such as extended relational, object oriented, object relational and deductive models. Issues related to the distribution and diversification has also been addressed. Heterogeneous database system and Internet based information system has also played a vital role.

Data warehousing and Data mining are new addition to the existing database technology. Data warehouse is defined as a " Subject oriented, integrated, non volatile, time variant collection of data in support of management decisions"(Han and Kamber ,2001). They support OLAP, DSS and data mining applications. Data warehousing may also be described as " a collection of decision support technologies , aimed at enabling the knowledge worker (executive, manager, analyst) to make better and faster decisions". Data mining refers to finding relevant and useful information from database.

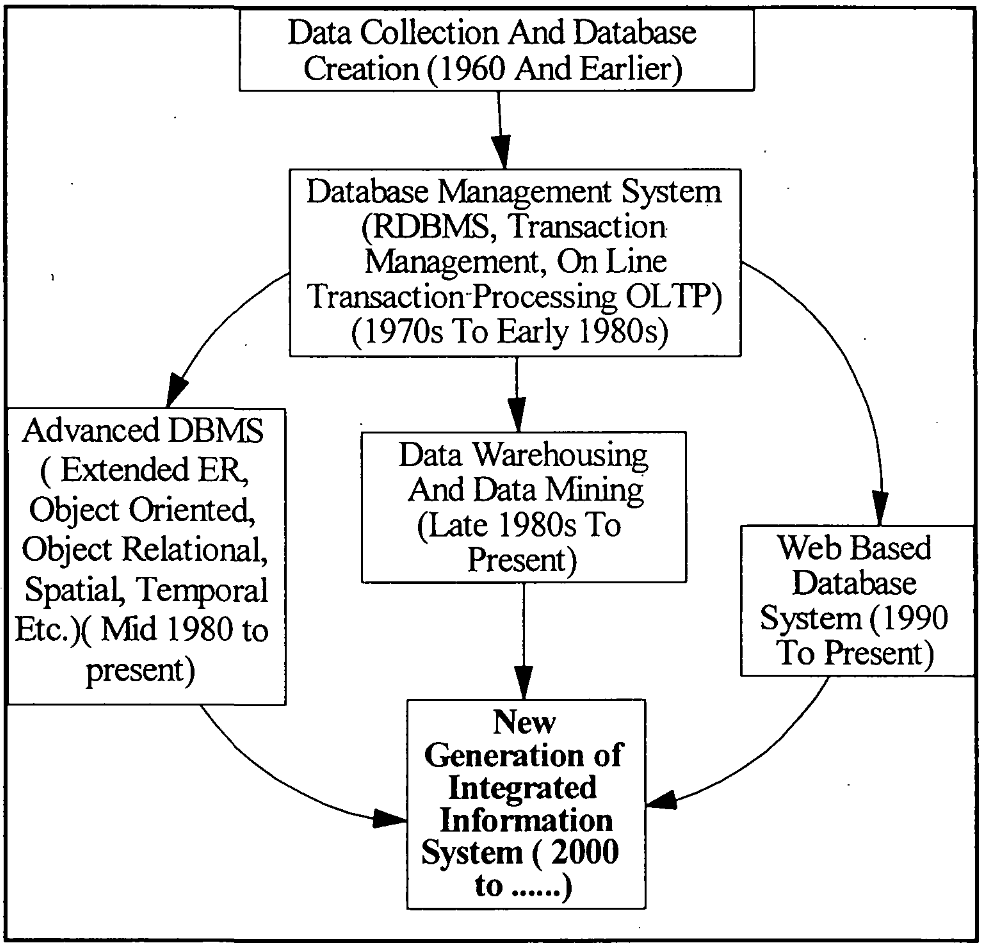


Figure 3.2 **Evolution of Data Base Technology Use**
(Source : Han and Kamber, 2001)

Conventional DBMS supports query language which are useful for query triggered data exploration whereas data mining supports automatic data exploration. If we know exactly what information we are seeking, a DBMS query will suffice, whereas if we vaguely know the possible correlation as patterns, then data mining technique are useful. Data mining systems have their own memory and storage arrangement.

From the foregoing discussion, it is clear that data warehousing and data mining technology is a competitive technology for designing information system component of water resources DSS. However, both are active research area till date with many issues that still need to be resolved. Tools for data warehousing and Data mining are not well developed and standardization of data mining language is only in progress. DBMS on the other hand has been in use for quite sometime and has well established and well supported tools. Examples of available DBMS are Oracle, SQL/Server, DB2 and Informix in the Relational Database Management System (RDBMS) world.

3.3.2.2: Relational Database System Tools :

After the relational model was introduced in 1970, there was a flurry of experiments with relational ideas. IBM developed SQL/DS for DOS/VSE (Disk Operating System/ Virtual Storage Extended) and for VM/CMS (Virtual M/C/ Conversational Monitoring System) environments developed in 1981 and DB2 for the MVS o/s introduced in 1983. Another relational DBMS, INGRES was developed at the University of California, Berkeley in the early 1970s. Some of the popular commercial RDBMS currently available include ORACLE of Oracle Inc., Sybase of Sybase Inc., RDB of Digital Equipment Corporation (now owned by Compaq), INFORMIX of Informix Inc., and UNIFY of Unify Inc. Apart from these, many implementation of relational data model appeared on the personal computers (PC) platform in the 1980s (Dbase IV. SQL server, Microsoft

Access). They were initially single user system , but recently they have started offering the client /server architecture and are becoming compliant with Microsoft's open Database Connectivity (ODBC).

As mentioned earlier the information system component of BARISS has been based on RDBMS. While testing BARISS on Brahmaputra basin through prototype DSS BRISS (Brahmaputra River Information and Simulation System), RDBMS software ORACLE 8i (one of the most widely used RDBMS) has been used. Although, any of the available RDBMS could have been used to build stable and efficient water resources information system, ORACLE was chosen because :

I. Oracle Database supports all known platforms, including Windows-based platforms, AIX-Based Systems, HP-UX systems, Linux Intel, Sun Solaris and so on.

II. Oracle has satisfactory TPC benchmarks as per the Transaction Processing Performance Council standards. Transaction Processing Performance Council (TPC.org) is an independent organization that specifies the typical transactions (transactions used in inventory control systems, airline reservation systems and banking systems) and some general rules these transactions should satisfy from time to time.

III. It is widely used, stable and well supported.

3.3.2.3 Web access to Oracle database :

Oracle supports many different ways of implementing web access to the database. It generally consist of three tier architecture (a client, an application server and a database server).To make the database available over internet , the server must be accessible. To provide network access, a second server is commonly used as a firewall , restricting the kind of commands that can be passed to the database server. The application server can act as firewall. The architecture shown in Figure 3.3 demonstrates a possible configuration.

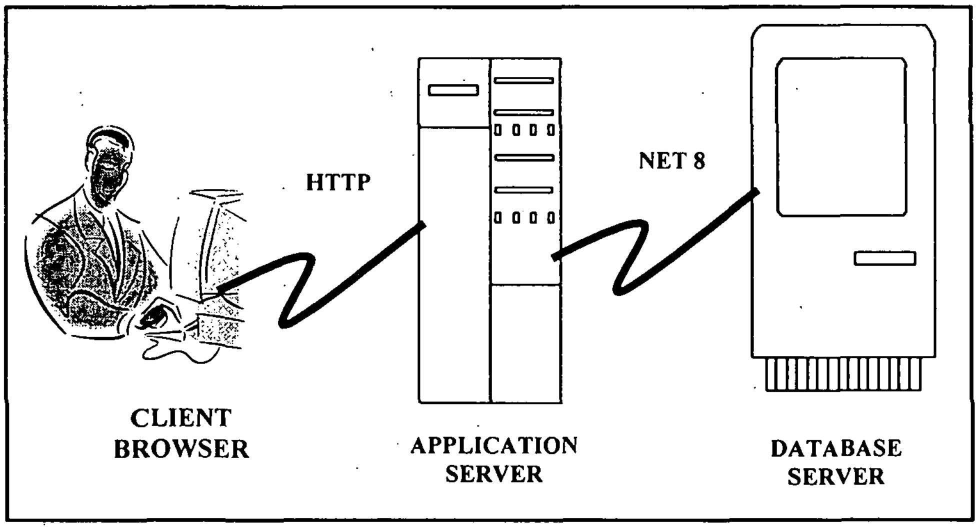


Figure 3.3 <u>**Web Access to Database**</u>

The client is a computer with access to the internet, running a browser ; the client communicates with the application server via the HTTP. The application server, in turn, executes the results in HTML and returns the results to the client. The application server provides the authentication services, database connection services and application processing services.

3.3.2.3 (a) Web access to Oracle database using Web DB :

Web DB is an Oracle product that is used to create websites and applications. The core data for the sites and application is stored in Oracle tables. When a client access the site, the clients request is handled by a web listener, such as the Oracle Application Server (OAS). The web listener executes PL/SQL functions stored within database. Those functions return the requested data embedded within HTML tags. The listener returns that data to the client and the site is displayed within the client's browser.

Web DB Architecture: Web DB features and functions are generated from PL/SQL stored procedures and tables in Oracle database. The client requires no software other than a web browser. The application server's operating system can be windows NT, Solaris or any other platform supported by Web DB.

Web DB listener: Web DB listener is a light weight web server that includes a built in gateway to the PL/SQL engine in the Oracle database. The PL/SQL gateway's function is similar to that of the Oracle Application Server (OAS) PL/SQL cartridge. It uses Database Access Descriptors (DADs) to capture the database connection information for an application. DADs are used for resolving URLs to the correct PL/SQL procedures that is to be involved.

Using other Web Server : If a web server is already available PL/SQL Gateway need not be used.

Web DB cartridge : Web DB provides a web DB cartridge which can be added to Oracle Application Server (OAS). The cartridge runs the PL/SQL stored procedures that comprise Web DB to generate dynamic HTML.

Web DB common Gateway Interface: Web DB provides a common Gateway Interface that can be used with any of Netscape, Microsoft or Apache Web server.

3.3.2.3.(b) Web access to Oracle database using JAVA:

The Java structure offers a technique to develop fast, large and independent web applications and data base access, especially, **Apache** and **Tomcat** server which can handle Java Servlets and Java Server Pages. **Servlets** are completely written in **Java** and are executed **server-side**. Servlets can apply the full power of Java, for example a Servlet can process HTML forms, use own Java classes, send an email, access a database. **Java**

Server Pages (JSP) is a new technology to integrate server-side code into static HTML code. JSPs are common to **Active Server Pages (ASP)**, but have the advantage that they run with Java and therefore on almost every operating system.

However, while implementing this concept the client's machine has to be converted to a server for database connectivity . Therefore, for a river information system, where data entry is to be done from multiple locations by different agencies (multiple client) this approach may not be feasible.

For testing of the Web based DSS BARISS on Brahmaputra Basin a river basin database has been created in ORACLE 8i using RDBMS concept. The database has been made web enabled using ORACLE Web DB (a product of ORACLE) .

3.3.3 : Web based interface for DSS :

In the context of the Web, the basic task is to communicate to a client via the HTTP protocol. The technologies that are used depend on the nature of the communication requirement . The more a requirement needs processing support, the higher the number of technologies that are involved. The key question is how much processing support does the requirement need and where should that support be located.

Hyper Text Markup Language (HTML) is a collection of platform-independent styles (indicated by markup tags) that define the various components of a World Wide Web document. These text files are processed by a Web Browser and are displayed for the user as a complex formatted document. Extensible Hypertext Markup Language (XHTML) is an application of XML for "expressing" Web pages. XHTML is the follow-on version of HTML 4, except that it is called XHTML 1.0 instead of HTML 5.XHTML supports all of HTML 4 markup elements and attributes. XHTML can be extended by anyone that uses it. New elements and attributes can be defined and added to those that already exist, making possible new ways to embed content and programming in a Web page.

Microsoft front page is also another user-friendly tool for making web page and site.

For the problem under study a combination of the tools mentioned above has been used for creating web based user interface as front end for the water resources DSS.

3.4 Scope of the study :

The works reported in this thesis offers the following scope ;

(a) **Building information system for any large, international river**: For any large River System the information are generated from a diverse set of sources and incorporate diverse subject areas. In most countries of the world these information are collected viewed and stored and (re)distributed by central and provincial governments. The data thus stored are rarely made available to the stakeholders and sometimes due to the large volume of data even the control over the data gets lost in these organizations. The study reported here involves design of modern approach and tools for water resources DSS on river basin scale . Using the tools so designed, information system for any large, international river may be built up. Therefore, the study offers the scope for better communication and exchange of information between decision-makers, stakeholders and the water resources professionals.

(b) **Conflict resolution for large international river** : There are about 260 international rivers, covering a little less than one half of the land surface of the globe affecting about 40% of the world's population (Chaturvedi, 1992) and much of the world's freshwater supplies are located within their basins. Since fresh water is essential for basic survival (Agriculture) , industry and energy production etc, sharing these trans-boundary waters between and among the border nations generally results in conflict. The web based DSS developed as a part of this study offers great scope for undertaking systematic management of shared river basins, leading to effective conflict resolution in a transparent manner.

(c) **Building public opinion** : The Web based DSS has been developed keeping in view the requirements of the stakeholders. Therefore, the Web Based DSS may be used for building public opinion for any decision-making process involving large International River.

(d) **Policy Planing:** System Dynamics Simulation Models has been used as model base for the Web Based DSS . The Simulation models play an important role in water resources assessment, development and management. They are widely accepted within the water resources community and are usually designed to predict the response of a system under a particular set of conditions. "What if" scenarios can be constructed using these models and therefore offers the scope for long term policy planning

(e) **Real time capability**: The software (BARISS) has real time capability in the sense that data entry may be done at any time from any place over internet which can be made available instantaneously to the stakeholders.

(f) **Brahmaputra River Information System**: Brahmaputra River System is one of the large river systems of the world covering 4 countries. Till date there has been no effort to design an integrated information system for Brahmaputra. Through this research work , BRISS(Brahmaputra River Information and Simulation System) has been designed as a test case of BARISS (Basin and River Information and Simulation System). BRISS provides a framework for further study on this important river of North Eastern part of India.

(g) **Policy Analysis Using BRISS** : Few policy options like normal, increased cropping intensity, increased per capita water consumption etc. have been studied using BRISS and reported elsewhere in this dissertation which will be helpful for water related policy decision making.

3.5 Chapter Summary :

After discussing the importance of using modern tools, Models and DSS for water resources management in river basin in chapter 1, a brief review of currently available models and DSS have presented in chapter 2. Based on the introduction and the review, the objective for the present study has been outlined at the beginning of this chapter followed by the plan of study. The tools currently available for the study , the tools selected for the study and the merits for their selection has been presented after the study plan. The chapter ended with discussion on scope of the study.

In the next chapter, the structure of the river basin System Dynamics model has been explained through causal diagram and flow diagram.

Chapter IV

River Basin SD Model

One of the biggest challenges for DSS is associated with enabling non-technical professional to obtain answers to their questions. It is especially valid for Water Resources DSS where both questions and responses need not be expressed in technical terms, as the decision-maker is not necessarily a technical person. At the same time the information presented must contain the same value as real consequence of option allowing straightforward description of impacts, perils and benefits in lay terms. System Dynamics (SD) Simulation model permit very detailed and realistic presentation of complex physical, economic and social characteristics of a water resource system. Also Water availability and consumption in any river basin is dynamic over time period. To evolve effective strategy/policy for water resources consumption and distribution, future demand and availability needs to be visualized. This requires understanding of behavior pattern of future use and that makes SD an appropriate tool for water resources modeling.

In this chapter the structure of the SD model which has been used as model base for the water resources DSS has been presented. In the following sections River Basin System Dynamics Model (River Basin SDM) has been described starting with the concept behind model.

4.1 River Basin System Dynamics Model (River Basin SDM):

The River Basin System Dynamics Model (River Basin SDM) has been developed as a generic model base for BARISS. The model aims to address the dynamics of availability and consumption of water in any river basin.

The concept of the model has been presented through a schematic diagram (Figure 4.1). It has been shown in the diagram that the water stock of any river basin depends on the External Flow into the Basin, Tributary flowing into the Basin, Outflow from the Basin, Ground water in the River Basin and its exchange with river water, rainfall, evaporation, water used for irrigation, water used by population and industrial water consumption.

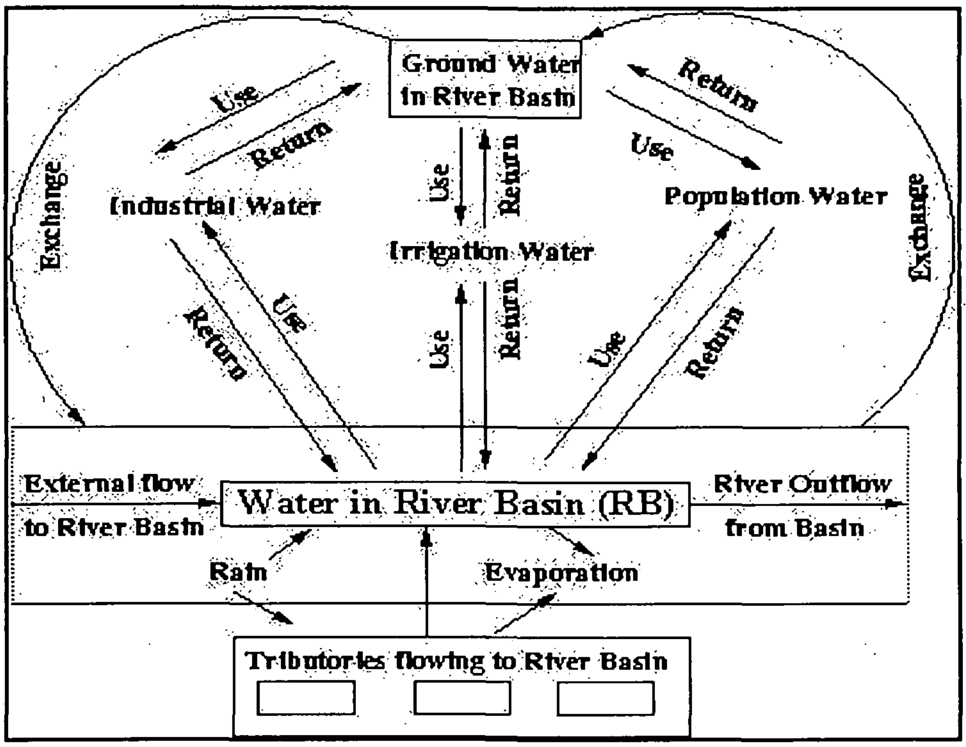


Figure 4.1 **Concept of the SD Model.**

For convenience the River Basin System has been split into 5 sectors, namely, population sector, irrigation sector, industrial sector, Basin sector and sustainability sector. Each of these sectors has been further sub divided into sub sectors. After identifying the sectors and sub sectors the next step is detailed modeling of the system. The detailed modeling involves Causal Loop diagramming for the sectors, drawing of flow diagrams, developing system equations and model validation. In the following sections, each sector of the model has been explained through Causal Loop Diagram followed by flow diagram. To maintain flow in the text, parts of the flow diagram of different sectors, system equations and list of variables have been provided as APPENDIX A. Model Validation part has been discussed during actual implementation of the River Basin SDM for Brahmaputra Basin (Chapter 6).

4.2 Causal Loop Diagram:

Causal diagram presents relationships that are difficult to verbally describe because normal language presents interrelations in linear cause and effect chains, while in actual system there are circular chains of cause and effect. Consider, for example, the "Total Population" element in adjoining Figure 4.2, it can be seen in the diagram that "Rural Population" and "Urban Population" influences "Total Population". Birth rate of Rural Population ("rural population birth rate") and birth rate of Urban Population ("urban population birth rate") depend on respective literacy rate ("Rural population literacy rate", "Urban population literacy rate"). When "Total Population" goes up "land availability" goes down; when "land availability" goes down "Immigration to Rural Population" goes down; as "Immigration to Rural Population" goes down "Rural Population" goes down and subsequently proportion of the rural population in "Total Population" goes down. Now the diagram explains it more easily than a verbal description.

When an element of a system indirectly influences itself in the way discussed for "Total Population" in the preceding paragraph, the portion of the system involved is called a feedback loop or a causal loop. (Feedback is defined as the transmission and return of information). More formally, a feedback loop is a closed sequence of causes and effects, that is, a closed path of action and information (Richardson and Pugh, 1981).

Apart from the elements, causal loop diagram also includes arrows (which are called causal links) that link these elements together (as shown in Figure 4.2) and also includes a sign (either + or -) on each link. These signs have the following meanings:

- A causal link from one element A to another element B is positive (that is, +) if either (a) A adds to B or (b) a change in A produces a change in B in the same direction.
- A causal link from one element A to another element B is negative (that is, -) if either (a) A subtracts from B or (b) a change in A produces a change in B in the opposite direction.

In the following sections sector wise causal loop diagram of the River Basin SD Model has been presented. These diagrams are self explanatory in nature. In the text efforts have been made to link these diagrams with the flow diagram (next step in SD model development) given in APPENDIX A.

4.2.1. Population Sector:

Figure 4.2 shows the causality of the population growth and water consumption. Accordingly in the river basin SD model these causalities have been incorporated through 3 sub sectors, namely, urban population, rural population and immigration population sub sector

In the urban population sub sector urban population and urban literate population has been considered as stock (Stocks represent a reservoir of material such as population, water, money etc.) and urban birth and death have been considered as flow (flows represents flow of material such as population, water, money etc taking place from stocks or into and out of undefined sources and sinks). Experiences in India (e.g. Indian state of Kerala) show that literacy is the key factor for population control in developing countries and therefore literacy rate has been incorporated as multiplier for variables representing urban birth and urban life span.

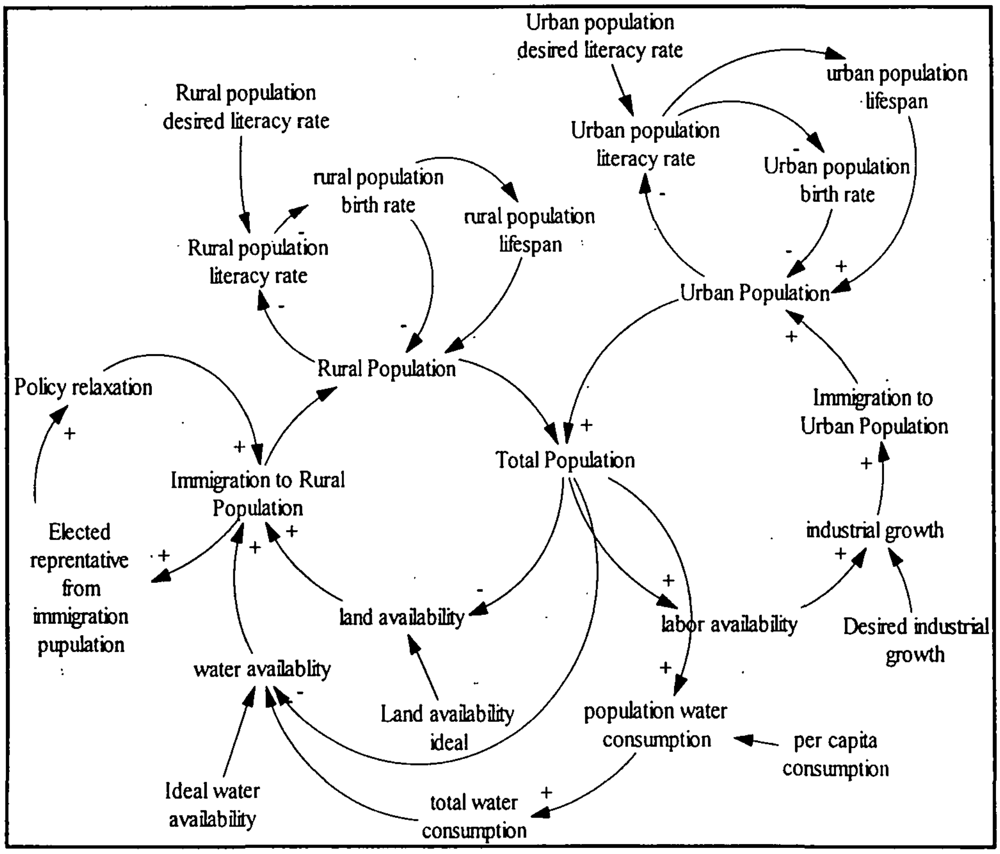


Figure 4.2 **Population Sector Causal Loop Diagram**

The same analogy has been followed for rural and immigration population. The multipliers from literacy rate has been determined against 'ratio of literacy rate actual to desired' from a relational graph. If the literacy rate actual equals literacy rate desired (ratio between them is 1), that condition will positively influence life span of respective population and therefore the multiplier value would be maximum. Under similar condition the multiplier for births will be at its minimum.

People immigrate to urban area as well as rural area. Therefore, in immigration population Sub sector, two additional flows to assess the immigration to rural and urban population have been incorporated. It has been assumed that immigration to urban area takes place due to industrial growth whereas immigration to rural area depends on availability of land, water and government policy towards immigration. These factors were taken into account through multipliers whose value has been assigned from relational graphs. For example, value for 'immigration rate to rural population multiplier from Land' has been determined against 'Ratio of actual land population ratio to ideal' from a graph. If the 'Land Population ratio actual' is more than 'Land Population Ratio Ideal' than the ratio between them will be more than one and that condition will encourage immigration to rural population. Similarly the 'immigration rate to rural population multiplier from water' has been determined from the 'Ratio of actual water population ratio to ideal' for the basin. Since in any democratic set up the elected representatives formulate policies of government, therefore, it is apparent that the ratio of elected representative from immigration population will determine its multiplier effect on rural population. More elected representative from immigration population means that there would be government policies that encourage immigration.

Total population water consumption has been estimated using per capita consumption under each population category. Total wastewater generated has also been determined from wastewater generated per capita under each category.

4.2.2 Irrigation Sector:

The dynamics of irrigation water consumption have been shown in Figure 4.3. Accordingly in the River Basin SD model, these causalities have been incorporated into 2 sectors, namely, 'Arable land' and 'Irrigated land'. In the arable land sector, arable land, wasteland, forestland and urban Land (not shown in figure) have been taken as stock . Forest conversion

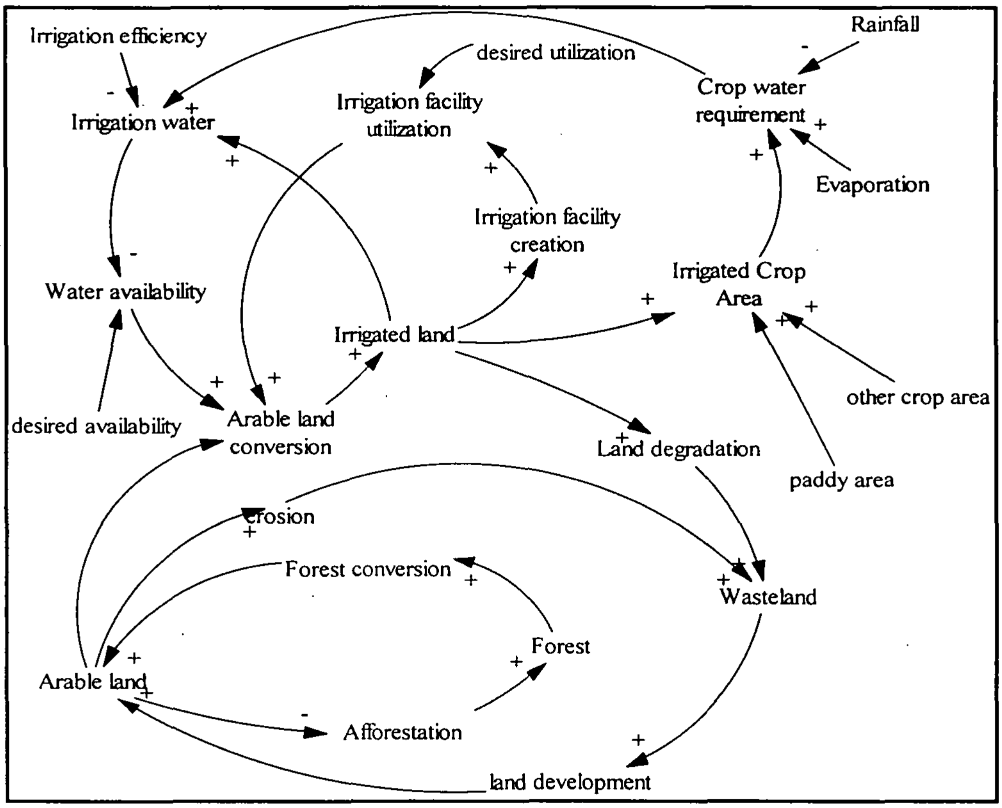


Figure 4.3 Irrigation Sector Causal Loop Diagram

rate, urban creation rate and wasteland conversion rate have been considered as flows taking place to/from the arable land.

Arable land gets converted to Irrigated land through arable land conversion and this conversion depends on water availability and actual utilization of irrigation water. Influence of water availability and actual utilization of irrigation water has been incorporated through multipliers from relational graph involving ratio of water available per capita actual to desired and ratio of irrigation potential created to irrigation potential utilized and ratio of irrigated land to arable land (actual) to ratio of irrigated land to arable land (desired).

The water requirement for each crop has been estimated as per procedure outlined in Doorenbos & Pruitt (1977). Irrigation water has been estimated by incorporating efficiency of irrigation system.

4.2.3 Industry Sector:

Figure 4.4 shows the causality of Industry Sector water consumption. As per the causal loop diagram, the river basin SD model has 2 sectors, namely, industrial working capital sub sector and industrial fixed capital sub sector. Agricultural processing, forest products, power production, petroleum refining, textiles and heavy industries are broad areas that have been considered for modeling. It has been observed that 'industrial fixed capital' inflow to any river basin depends on power availability, Infrastructure (Road, Railway and shipping) and law and order situation (not shown in figure)

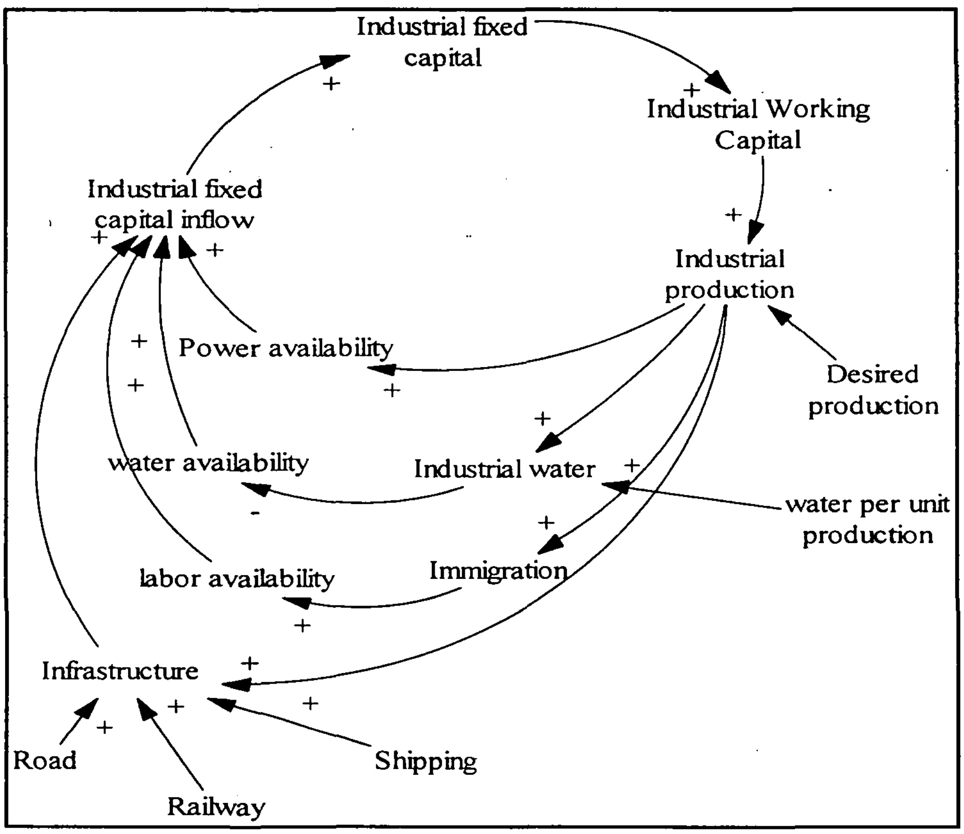


Figure 4.4 **Industry Sector Causal Loop Diagram**

Accordingly, influences of these factors have been incorporated in the model by introducing multipliers from each of these factors. Some of the variables used for estimating the multipliers are: number of police cases recorded (law and order), Power available per capita actual and power available per capita desirable (power availability), Ratio of power available per capita actual to desirable, road length per square KM actual, road length per square KM desirable, railway track per square KM actual, railway track per square KM desirable and ratio of railway track per square KM actual to desirable (infrastructure).

Working capital for industry depends on production and therefore in the model inflow to working capital has been assumed to be dependent upon actual production of each of the industry activity e.g. agricultural processing, forest products, power production, petroleum refining, textiles and heavy industries. Production multiplier estimated from relational graph of ratio of actual production to desired production has been incorporated in the model. The industrial water has been estimated by taking into account the actual production of each of these industries and the water required for per unit production of that industry. The total wastewater generated has also been estimated by taking into account the actual production of each of these industries and the wastewater generated from per unit production.

4.2.4 Basin Sector:

The dynamics of water supply of river basin have been shown in Figure 4.5 and the causal loop diagram for the sector is shown in Figure 4.6.

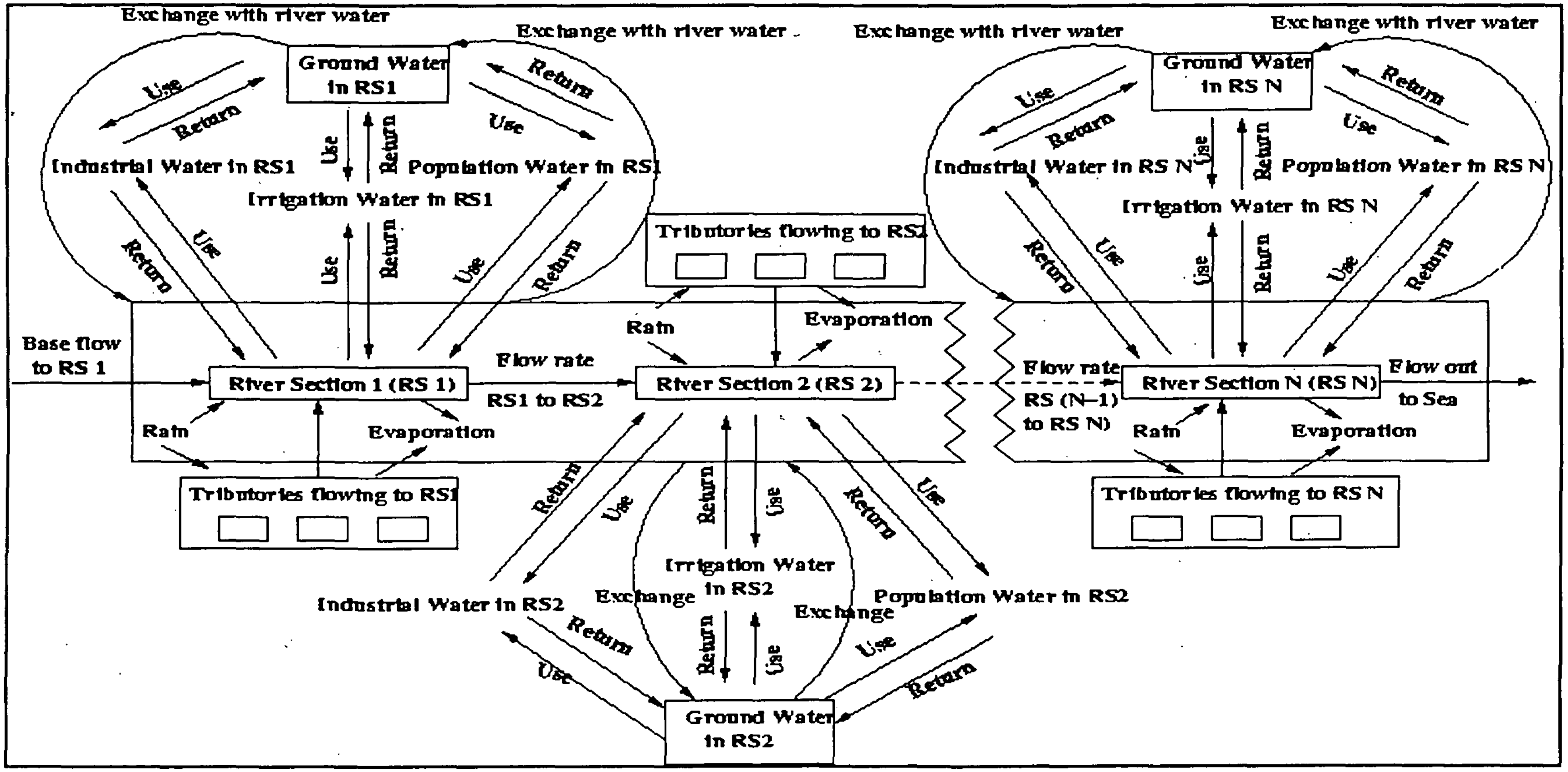


Figure 4.5 Schematic Diagram of Basin Sector

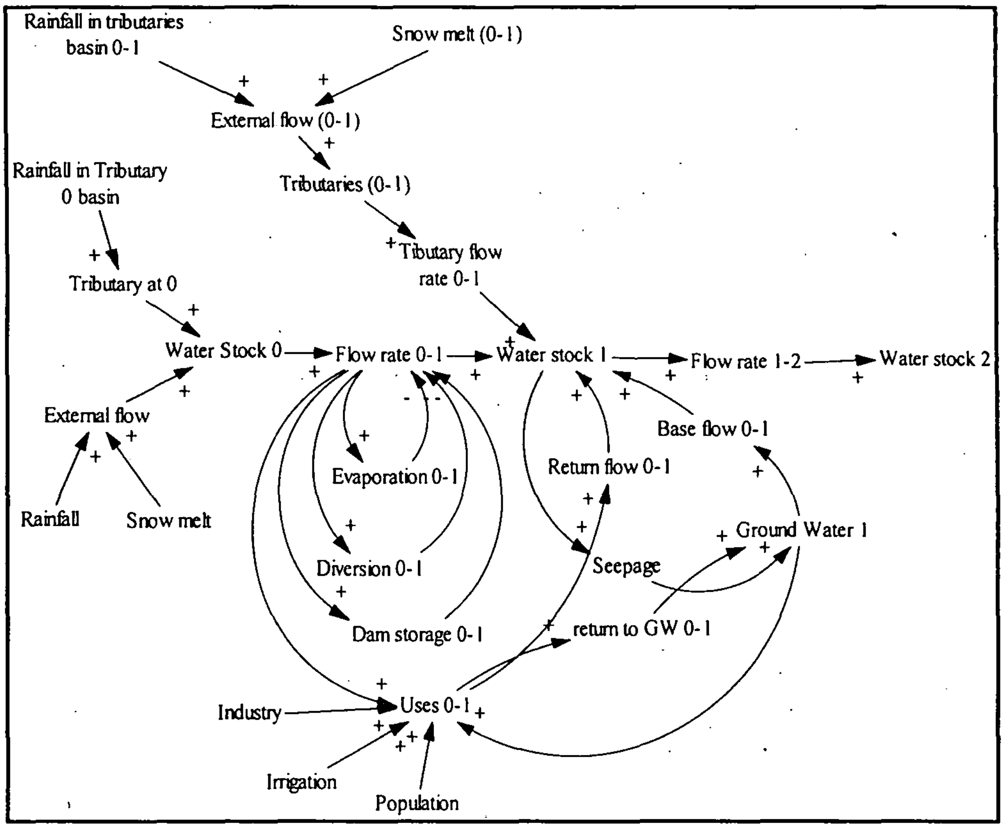


Figure 4.6 **Basin sector Causal Loop Diagram**

For convenience the river has been split into sections (0,1,2 etc). It has been shown in Figure 4.5 and 4.6 that rainfall and/or snowmelt accumulates through tributary/external flow and joins the main river flow at different sections. The water stock in any particular section is the summation of ground water supply and river water supply of that section. (Ground water supply information in his case has been 'depth to ground water table' ; the commonly monitored information in any river basin). Exchange between river water and ground water takes place through base flow and seepage. River water has been assumed to be exploited for consumptive uses (irrigation, population and industry), water storage in dams and diversion to some other site. Ground water has been assumed to be exploited for consumptive use only. Some fraction of consumptive use returns to ground water and river water. River water flow takes place from one section to the next and subsequently to the sea.

4.2.5 Sustainability Sector:

This sector mainly addresses the supply and availability aspect of the river basin water. The Causal Loop Diagram for the sector has been presented in Figure 4.7.

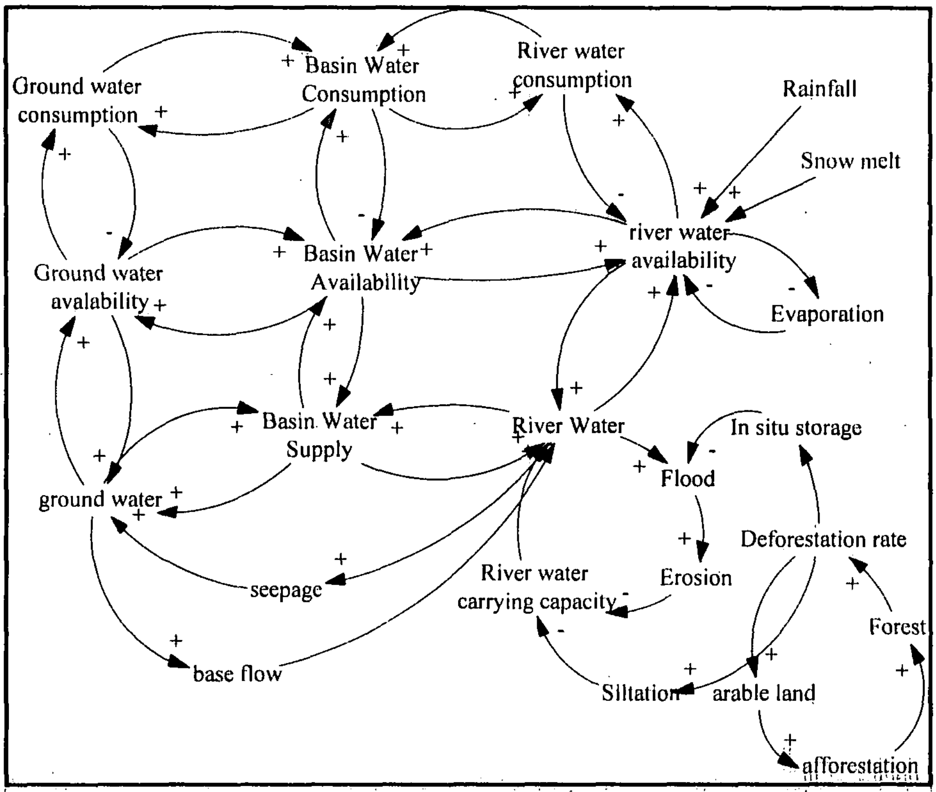


Figure 4.7 <u>**Sustainability Sector Causal Loop Diagram**</u>

4.3 Flow Diagram :

Flow diagram in System Dynamics is presented using symbols. For example a square or a rectangle represents level variable, a valve represents a rate variable and like wise. Most of the System Dynamics software (discussed in Chapter 3) have building blocks to represent these variables and draw flow diagram. Flow diagram can also be drawn using some drawing software as well. In this thesis, the flow diagram of the River Basin SD Model has been presented using SD software STELLA. In any System Dynamics software the essential features of the system (shown in Figure 4.8) are defined in terms of

- Stocks (state/level variable),
- Flows (rate variable, in and out of the state variables),
- Auxiliary variables (other algebraic or graphical relationship or fixed parameter) and
- Information flows.

Mathematically, the system is geared towards formulating models as system of ordinary differential equations and solving them numerically. The user places the icon for each of the stocks in the modeling area and then connects them by flows of material or informational relationship. Next the user defines the functional relationship that corresponds to these flows. Stocks represent a reservoir of material such as population, water, money etc. Material flows between stocks or into and out of undefined sources and sinks (represented by 'clouds' at the end of flow structures). Auxiliary variables, stocks and other flows through the use of information arrows affect flows.

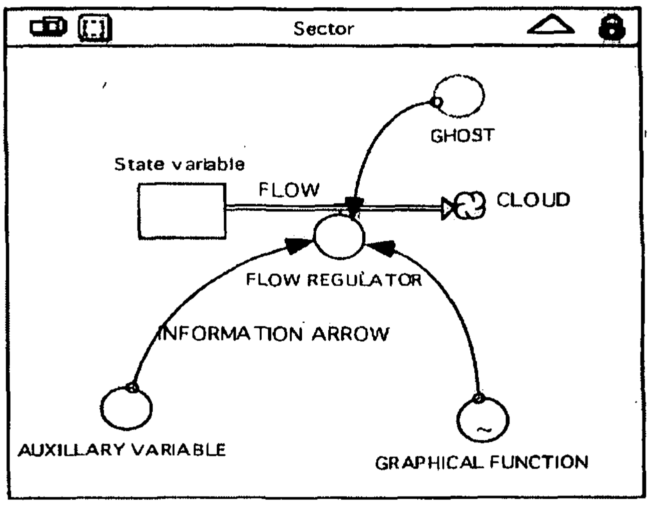


Figure 4.8 **<u>Features of STELLA flow diagram</u>**

Based on the discussion above and the causal loop diagram presented, the following sections explain the population sector flow diagram consisting of Urban, Rural and Immigration sub sector. As mentioned earlier flow diagram for other sectors have been given as APPENDIX A (Figure Aa1 to Figure Aa8) .

4.3.1 Population Sector:

Population sector has been divided into Urban Population sub sector, Rural Population sub sector, Immigration Population sub sector and Population water

Demand Sub sector and the flow diagram in STELLA has been presented as Figure 4.9, Figure 4.10, Figure 4.11 and Figure 4.12

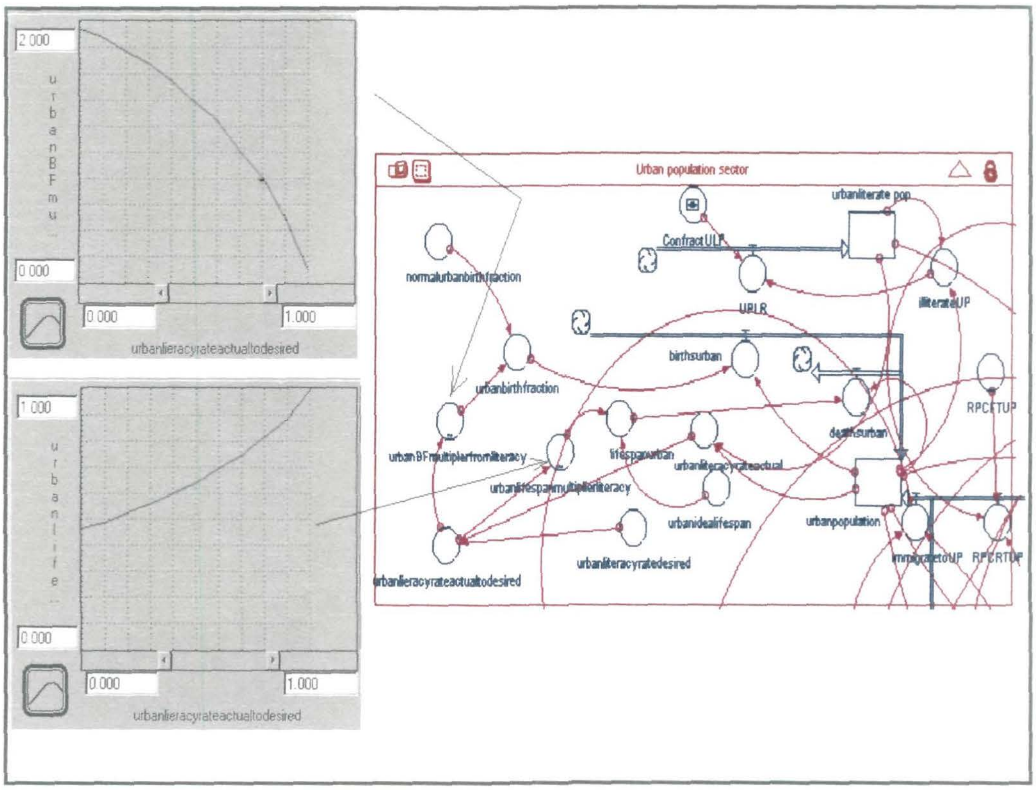


Figure 4.9 **STELLA Flow Diagram of Urban Population Sub Sector**

In the urban population sub sector urban population (urbanpopulation) and urban literate population (urbanliterate pop) have been considered as stock and urban birth (birthsurban) and life span of urban population (lifespanurban) have been considered as flow. Literacy (variable urbanBFmultiplierfromliteracy & urbanlifespanmultiplierliteracy) has been incorporated as multiplier for the flow urban birth (birthsurban) and life span of urban population (lifespanurban) (shown as graph in Figure 4.9)

For rural population sub sector also rural population (populationrural) and rural literate population (literatepoprural) have been considered as stock and rural birth (birthsrural) and life span of rural population (lifespanrural) has been considered as flow. Literacy (variable ruralBFmultiplierfromliteracy and lifespan multiplierliteracyrural) has been incorporated as multiplier for rural birth (birthsrural) and life span of rural population (lifespanrural). Similarly for migration population sub sector immigration population (immigratpopulation) and immigration literate population (immigratliteratepopulation) have been considered as stock and immigration births (birthsimmigrat) and life span of immigration population (lifespanimmigrat) have been considered as flow. Here also literacy (variable immigrationBFmultiplierfromliteracy and lifespan multiplierliteracyimmigration) has been incorporated as multiplier for immigration births (birthsimmigrat) and life span of immigration population (lifespanimmigrat). Each of these literacy multipliers have been determined against 'ratio of literacy rate actual to desired' from a relational graph .

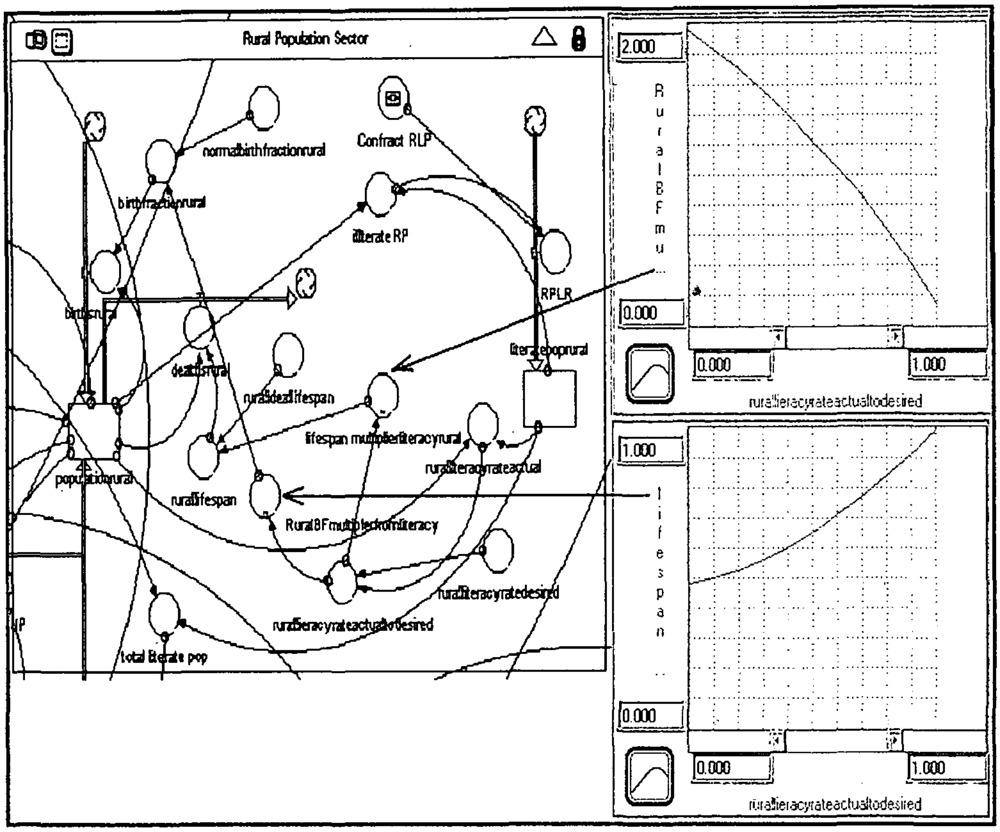


Figure 4.10 STELLA Flow Diagram of Rural Population Sub Sector

For example in Figure 4.10 'lifespanmultiplierliteracyrural' has been determined by plotting the ratio of 'ruralliteracyrateactualtodesired' in a graph. If the rural literacy rate actual (ruralliteracyactual) equals rural literacy rate desired (ruralliteracyratedesired) (ratio between them is 1) , that condition will increase the life span of rural population and therefore the multiplier value would be maximum under such condition. Under the same condition the multiplier for rural births (birthfractionmultiplierrural) will be at its minimum. UPLR, RPLR and IPLR are literacy rate of urban , rural and immigration population and it depends on the discrepancy i.e difference between respective population (urban, rural and immigration) and the literate population. The discrepancy has been named as 'illterateRP', 'illterateUP' and 'illterateIP'. A fraction of this 'illterate...'

gets converted to respective 'literate' population through 'confract RLP', 'confractULP' and 'confractILP'. These conversion fractions (confract) can be estimated from historical data.

People immigrate to urban area as well as rural area. Therefore, in immigration population Sub sector (Figure 4.11), two additional flow 'immigratRP' and 'immigratUP' has been provided to assess the immigration to rural and urban areas respectively. The immigration to urban area takes place due to industrial growth whereas immigration to rural area depends on availability of land, water and government policy. These factors have been taken into account through the multipliers: 'IR to UP multiplier from industry', 'IR to RP multiplier from Land', 'IR to RP multiplier from Water', and 'IR to RP multiplier from govt. policy'. Values of these multiplier have been assigned from relational graphs. For example, value for 'IR to RP multiplier from Land' has been determined against 'Ratio of actual land population ratio to ideal' from a graph. If the 'LPRA' (Land Population ratio actual) is more than 'LPRI'(Land Population Ratio Ideal) then the ratio between them will be more than one and that condition will encourage immigration. Similarly the 'IR to RP multiplier from Water' has been determined from the 'Ratio of actual water population ratio to ideal' for the basin. Since in any democratic set up the elected representatives formulate policies of government, therefore, it is apparent that the ratio of elected representative from immigration population (ratio of ER from IP actual to desired) will determine its multiplier effect on rural population (IR to RP multiplier from govt. policy). More elected representative from immigration population means there would be government policies that encourage immigration.

'Float Population' has been considered as an auxiliary variable. Water Demand for urban population, rural population, immigration population and float population have been estimated using constant 'lpcd'

(liter per capita per day) for each of the population category (lpcd IP, lpcdRP, lpcdUP and lpcdFP).

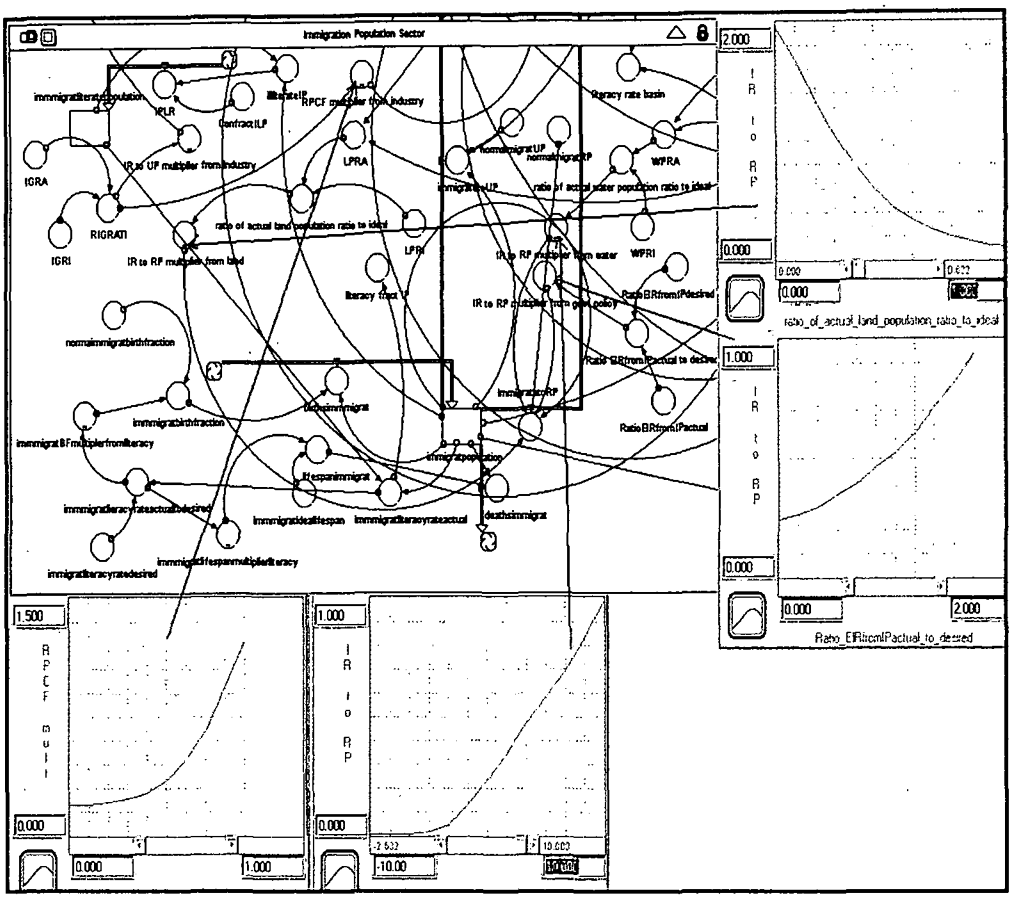


Figure 4.11 STELLA Flow Diagram of Immigration Population Sub Sector

Waste Water generated by each category of population (WwgenUP, WwgenRP , WwgenIP and WwgenFP) has been also determined as the product of population of that group (level) and waste water generated per capita (percapitaWWUP, percapitaWWRP, percapitaWWIP and percapitaWWFP) by that group (Figure 4.12). Total population water Demand and Total WW Gen by population have been determined as summation for each of the population sector.

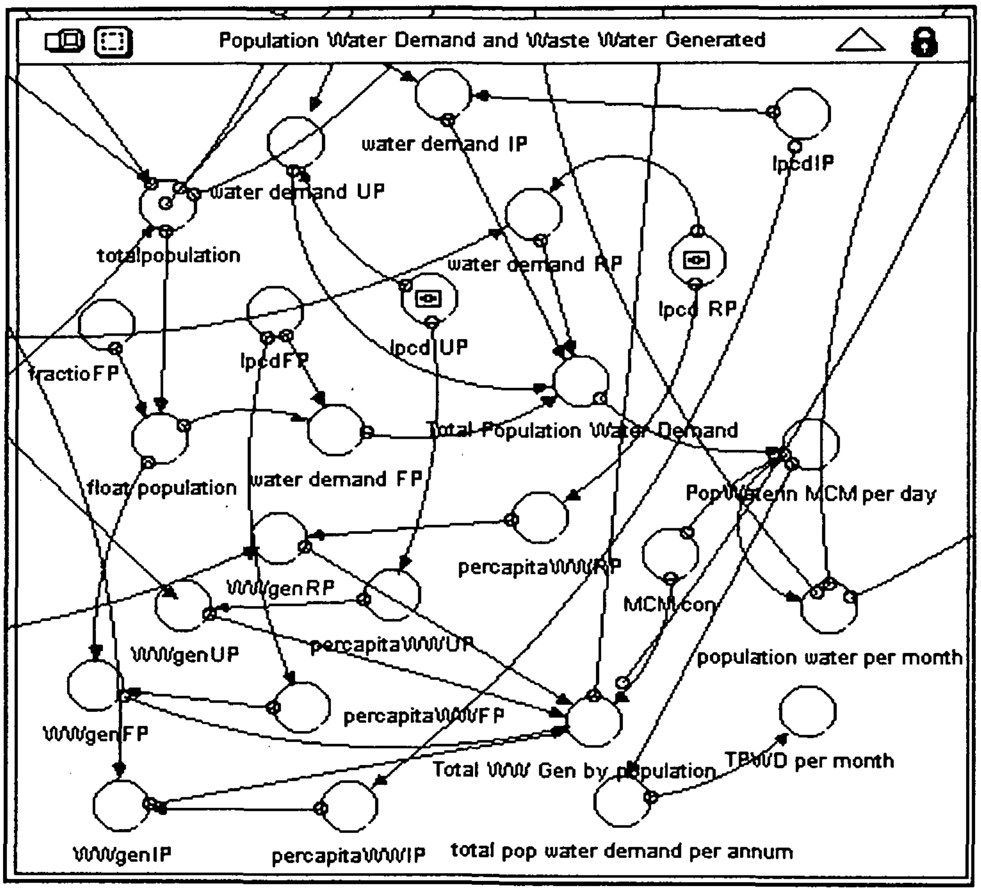


Figure 4.12 **STELLA Flow Diagram of Population Water Demand and Waste Water Generation sub sector**

4.4 Chapter Summary :

In this chapter the model base of the River Basin DSS i.e SD model representing a large river system has been presented using schematic diagram, causal loop diagram and flow diagram. Different constituent sectors and sub sectors of the model have been discussed in detail. To apply the River Basin SD model in any real world situation would require adequate information on various aspect of the river basin. The following chapter deals with the information system aspect of the BARISS framework.

Chapter V

River Basin Information System

To validate, run and simulate policy scenario using River Basin SD model, one needs to have access to various information about the river basin (like flow records, population information, industry information etc.). Apart from the information required for the River Basin SD model, growing concern for rivers demand that the information generated by the various agencies involved in river basin management be properly stored, shared, exchanged and used for scientific analysis and policy planning. This chapter deals with the information management aspect of the river basin decision support system BARISS, beginning with the information requirement of the River Basin SD model as discussed in the earlier chapter.

5.1 Information Requirement for River Basin SD Model:

The choice of appropriate initial values for stock equations and values for constants, relational graphs and table functions in any SD model is related directly to the model description and is dependent on the published data from various sources. Therefore, to validate, run and simulate policy scenario using River Basin SD Model one will require information of various kinds on the river basin. Some of these information have been listed in Table 5.1.

This list is indicative only and not exhaustive. It has been assumed that as the SD Model is modified from time to time the information requirement will also vary. These information and other such information generated in any River Basin are often from a diverse set of sources and incorporate diverse subject areas. In most countries of the world these information are collected, viewed, stored and (re) distributed by central and provincial governments, scientific organizations and their regional subdivision. The data thus collected and stored by these organizations are hard to get. Because of large volume of data even the control over the data gets lost in these organizations. At a time of increasing river management consciousness, it can not be sufficient just to generate information; it is also needed to properly store and analyze these data and offer it for scientific analysis and policy planning using modern approach and tools.

Table 5.1 Information Requirement of River Basin SD Model

Sector	Sub Sectors	Information
Population	Urban Population, Rural Population, Immigration Population, Population Water Requirement	Urban Population, Rural Population, Immigration Population, Total Basin Population, Birth Rate, Death Rate, Literacy Rate, Industrial Growth, Land availability per capita, Water availability per capita etc.
Irrigation	Arable Land, Irrigated Land, Irrigation Water	Arable Land, Forest Land, Urban Land, Irrigated Land, Cropping Intensity, Crop Area, Irrigation Efficiency, Rainfall, Evaporation, Deforestation / Afforestation rate, Erosion rate, Land Development Rate etc.
Industry	Industrial Fixed Capital, Industrial Working Capital ,Industrial Water	Industry Type and Units, Production, Water per unit production, Fixed capital Inflow, Fixed Capital Depreciation, Working Capital, Power availability, Infrastructure Facility (Road, Railway) etc.
Basin Sector	–	Discharge rate of Rivers and Tributaries, Water level, Ground Water, External flow into the basin, Out flow to sea, Rainfall, Evaporation etc.

Therefore, as a part of the River Basin DSS (BARISS), a River Basin Information System has been developed using relational database concept. In the following sections database requirement, initial conceptual design of the database and structured analysis through context diagram and DFD (Data Flow Diagram) have been discussed. Some DFD and the database description part have been incorporated as APPENDIX -B to maintain continuity in text reading.

5.2 Database Requirement:

The database requirement of any river basin can be explained in following words:

RIVERs have RIVER BASIN; RIVER BASIN has ADMINISTRATIVE UNIT. Information on POPULATION, INDUSTRY, AGRICULTURE, LAND etc. of RIVER BASIN is maintained on ADMINISTRATIVE UNIT basis by various AGENCYs. WEATHER RECORD, FLOW RECORD of RIVER, GROUND WATER and WATER QUALITY etc. are maintained at different LOCATIONs by various AGENCYs on RIVER and RIVER BASIN basis.

5.3 Conceptual Schema:

From the database requirement mentioned in 5.2 the schema for the River Basin Database has been conceptualized as follows

a. Rivers have a river_basin that is identified by basin_name and basin_description.
b. Rivers are identified by a riverID, a river_name and river_description.
c. Agencies (e.g. Water Resources, Ground Water Authority, Meteorological Department etc.) are responsible for collecting and maintaining river basin data (flow_records, rainfall, other_met_obver, river_water_qlty, ground_water_qlty , population, land ,industry, agriculture etc.) from different locations . AgencyID, and Agency_name identify an Agency. LocationID and location_name identify location.

d. River_gauging_station records flow_records (water_level, highest_flood_level and water level trend) and is identified by RGS_ID , RGS_name and LocationID.

e. Weather_station (identified by ws_ID, ws_name, LocationID and AgencyID) records weather. Weather is categorized based on the record type, namely, rainfall (date, amount, intensity and duration), Evaporation, and other meteorological observation (temp., humidity, wind and sunshine, evaporation etc.).

f. River_basin has, within its boundary, different administrative_unit (admin_unit) identified by (au_ID, administrative_unit_name).

g. Admin_unit data are based on four identified data type, namely Industry (class, type, code), Irrigation (Area irrigated – by canal, by ground water, by tank, potential created and utilized), Land (arable land, forest land, Fallow land etc.) and population (rural, urban, male and female).

h. Ground water of river_basin is catagoized by the well_type; observation_well (o_well_no, depth to GW table) and expository_well (e_well_no and well characteristics like lithology, pumping data etc.)

i. Water_quality (physical: conductance, turbidity, pH etc and bacteriological parameter like Total coliform and faucal coliform of river_basin is categorized as GW_qlty (of GW), River_water_qlty (of River) and other_water_qlty (to accommodate water from any other source).

Based on the database requirement an EER schema diagram for the river basin database has been prepared and presented as Figure 5.3.

5.4 Structured analysis:

Structured analysis is most widely used method for system analysis and this method relies on the flow model as a first element of graphical representation of computer based system. A variety of tools such as context diagram, data flow diagram, data dictionary, decision tree etc. are used in structured analysis. For the work reported in this dissertation, context diagram, data flow diagram (DFD) and data dictionary has been used.

5.5 Context Diagram:

The context diagram presented as Figure 5.1 depicts the user interaction with the system. It is also called the 0-level data flow diagram (DFD). A context diagram for the entire system with various data flows has been presented as Figure 5.2.

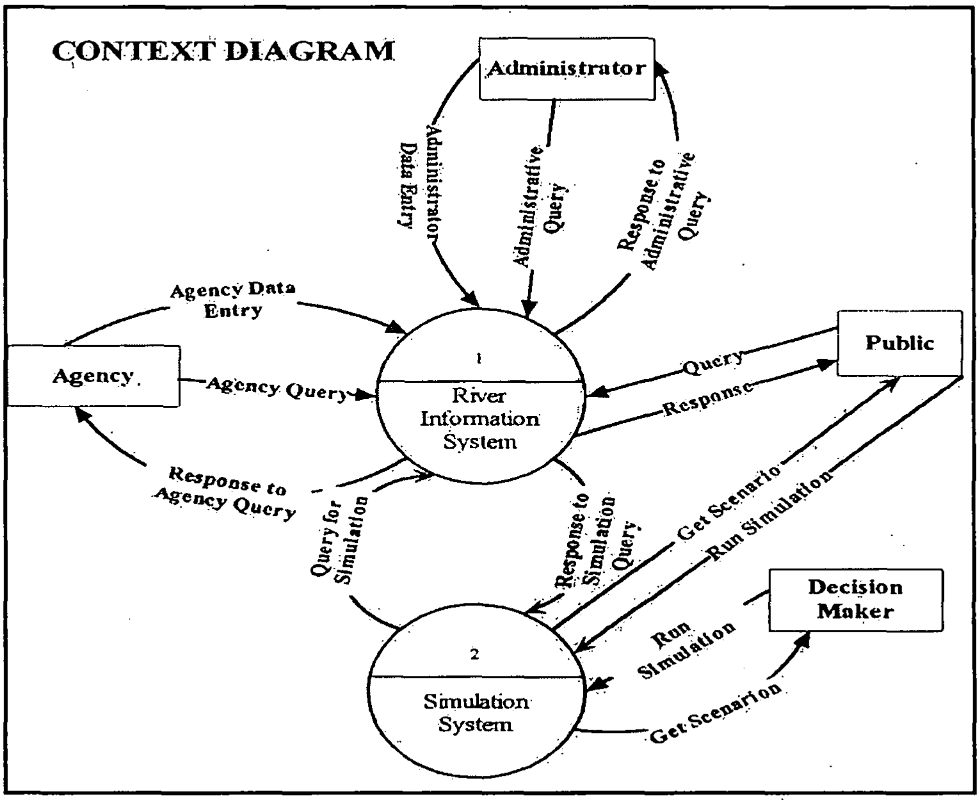


Figure 5.1 Context Diagram for the Entire System

5.6 Data Flow Diagram:

A data flow diagram (DFD) is a graphical technique that depicts information flow transformation that is applied as data move from input to output. The 1-level data flow diagram for the River Basin Database has been presented as Figure 5.2. The 1-level DFD has been further expanded to accommodate more details about the river basin data flow (as presented in APPENDIX -B as Figure A B1 to Figure A B6)

Data Store Description, Data Dictionary and Database Description (including List of database table) pertaining to the river basin database have been incorporated as APPENDIX -B

5.7 E-R Diagram:

Entity-Relationship (E-R) diagram is the framework used to data modeling for relational database (Elmasri and Navathe, 1994). The E-R diagram for the River Basin Database has been presented as Figure 5.3. An expanded form of the ER diagram along with the Entity and their attributes and Relational Schema Design part have been provided in APPENDIX -B

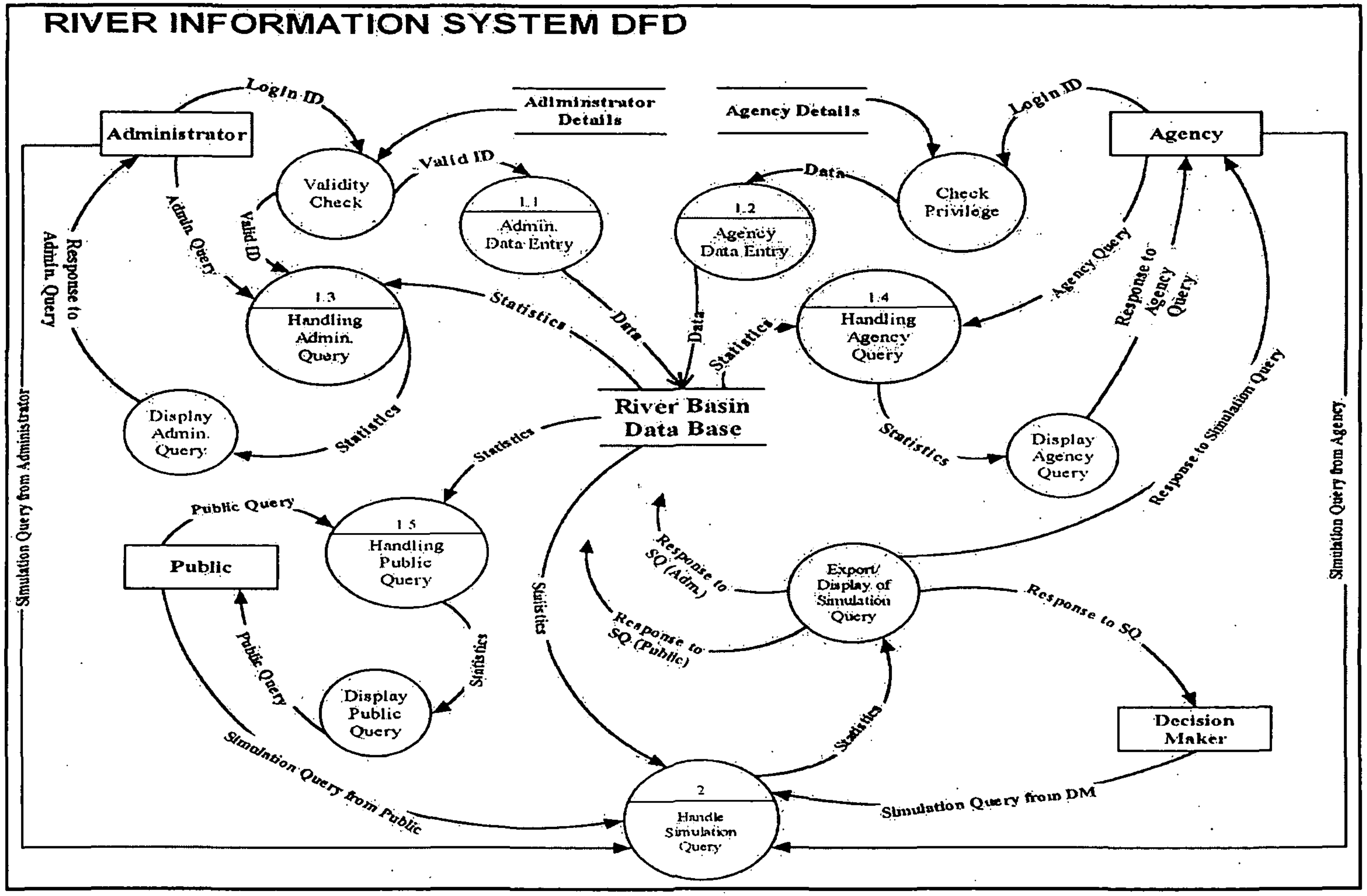


Figure 5.2 **1-Level DFD for the River Basin Database**

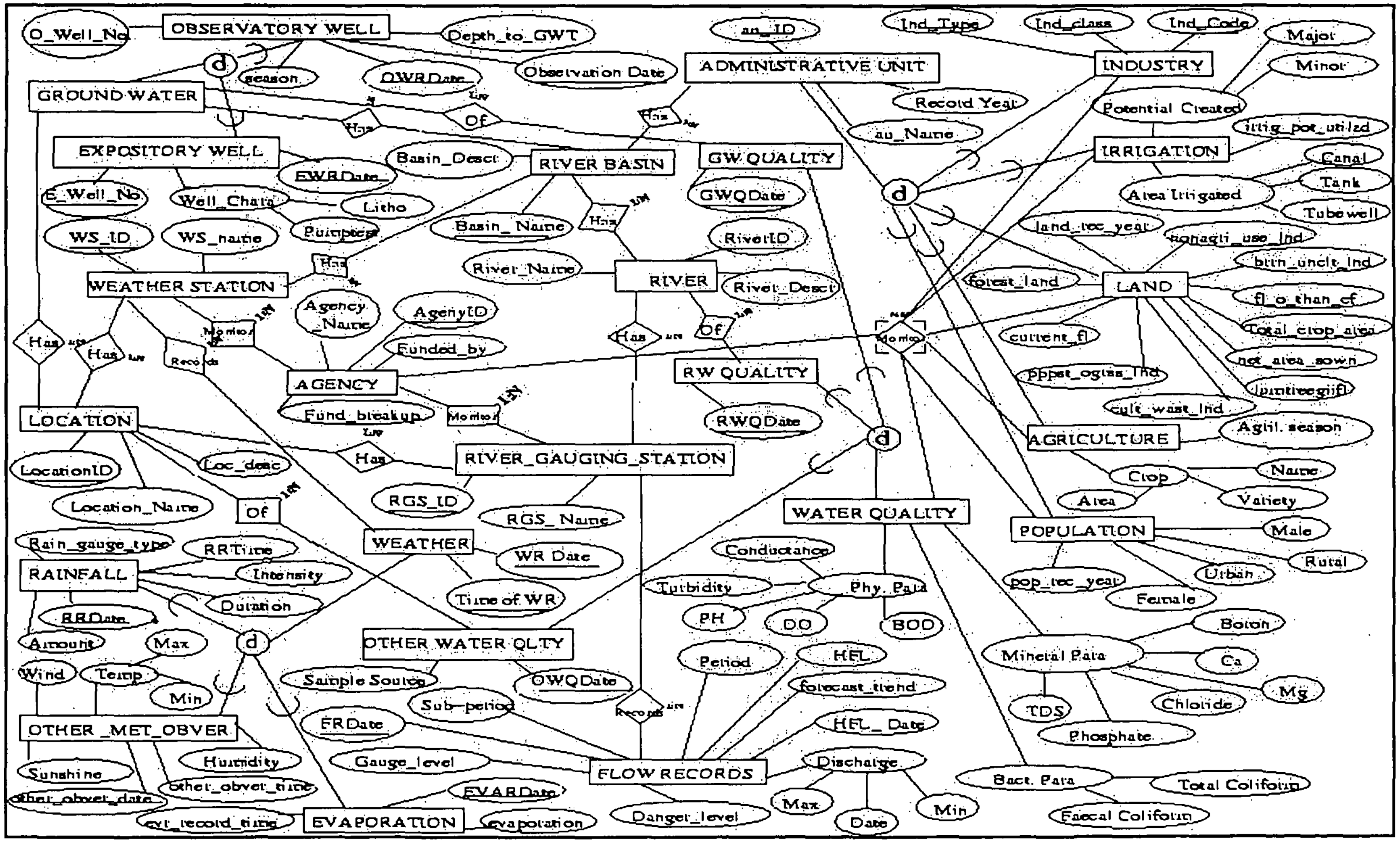


Figure 5.3 <u>**ER Diagram**</u>

5.8 Chapter Summary:

In this chapter, River Information System as a component of the River Basin DSS has been explained. The Information System based on RDBMS (Relational Database Management System) has been explained through context diagram, data flow diagram and ER diagram. Efforts have been made to incorporate all possible and relevant information of any large river system of the world. The information stored in the database can be subsequently used for river basin policy analysis using the model base of the river basin DSS under study.

Till now, the focus has been to present the framework, a schema for a River Basin DSS which consist of a model base (River Basin SD model) and River Basin Information System, bound by a web based interface. The framework has been named as '**BARISS**' (***B***asin ***A***nd ***R***iver ***I***nformation and ***S***imulation ***S***ystem). **BARISS** has been tested on Brahmaputra River, one of the largest river system of the world extending over 4 countries. The web based DSS for the Brahmaputra River Basin has been named as **BRISS** (***B***rahmaputra ***R***iver ***I***nformation and ***S***imulation ***S***ystem). The next chapter discusses the **BRISS** in detail.

Chapter 6

Applicability of 'BARISS' Framework

In earlier chapters the discussions have been focused on the framework of a generic DSS for managing water resources of large river system and design aspects of such a DSS. Two major constituent components of the DSS (named BARISS) i.e. the river basin System Dynamics model and the river basin information system have been discussed in detail. In this chapter , testing the applicability of the BARISS framework has been presented. Since BARISS has been designed for web based implementation, the discussion starts with web implementation aspect of DSS

6.1 Web Implementation of DSS

Web implementation of DSS has many challenges unlike in traditional implementation of DSS where user has the DSS made available either through the software installed on the operating system or through a user interface to a remote application server (Salewicz and Nakayam 2004) . Results obtained by the user can be stored for further use; working sessions can be suspended and then started again without losing information and data created during sessions. When DSS is implemented over the World Wide Web, user would be using a web browser only, and providing the same level of capability as that of operating system is very much difficult. Special developmental efforts on server side would be required for access. On the other hand, in developing countries, client computers are often connected to the Internet through low-end communication and/or telephone lines with low bandwidth. Thus, the time needed to load one page or to obtain a response to an action or choice made by the user can be very long (even several minutes), not to mention the time required to perform computations on the server side.

The distribution of computing power available for DSS in the Internet environment can be described by two models (concepts) (Salewicz, 2001), they are -

(i) The thin client and thick server concept, or

(ii) The thick client and thin server concept

The principle, and relative advantage, disadvantage of each concept has been outlined in Table 6.1

Table 6.1 **Client Server concept for web implementation of DSS**

	THIN CLIENT AND THICK SERVER CONCEPT	THICK CLIENT AND THIN SERVER CONCEPT
Principle	User's is connected to Internet and his PC act as communication terminal only. He can enter certain data (chosen among available alternatives) and display results of the computations performed on a remote computer (server).	User' s PC would be used as a platform to perform all computations using programs and data transferred (downloaded) through the server. The role of the server is therefore reduced to a repository of programme, software and data.
Advantages	1. Low amount of data has to be transmitted. 2. High security and consistency of data and models as both data and models reside on the server.	1. Number of DSS or models can be downloaded (at least a trial version) by anyone 2. Useful in countries where client computers are connected to the Internet through low-end communication.
Disadvantage	Very heavy computation burden and data loads on the server side require installation of very powerful machines to act as servers.	Skills required to download , install and learn DSS, and then resolve a problem. This may sometimes be beyond the interest of the average representative of "general public". (DSS for this approach should be as simple as possible)

Since in most of the developing countries a clients computer would be connected to the internet through low end communication (telephone lines with poor bandwidth); therefore the web based DSS introduced through the present study has been proposed to be implemented using thick client and thin server concept.

6.2 The BARISS framework:

The research reported in this dissertation involved development of a Web Based DSS for water resources on Basin Scale. The main motive for this research has been to bring transparency in river basin decision making (involving a broad range of stake holders) by developing a web based DSS, which may act as a conflict resolution tool and also a tool for public opinion building. A framework for a web based DSS designed as a result of this study (named BARISS) has been proposed to be implemented on thick client thin server concept as discussed above.

It has been assumed that -

- A prospective user of this DSS has very little knowledge about computer tools and can be termed as representative of general public,
- River Basin Information System (a part of the DSS) is updated dynamically over time and space.
- Decision Maker (a part of stake holder) is interested in assessing consequence of certain policy expressed in terms of clearly identified alternative action;

6.3 BRISS as a case study of BARISS

The result of the study has been reported through a case study system comprising of the following activities:

- Selection of a case study river system;
- Building the River Basin SD model in SD software 'STELLA research version 5'
- Building a test river basin information system in BARISS framework using RDBMS software 'ORACLE 8i' ;

- Technical implementation of the DSS, which involved ;
    - Providing user friendly and web based interface,
    - Presenting the DSS in the form of web site,
    - Testing applicability using thick client thin server concept.

The river system for the case study has been selected based on

- o Possibility of researcher's association and understanding of a particular river system,
- o A river system for which similar effort on this line has not been done earlier,
- o A large and international river system;
- o Concerns a controversial issue involving conflicting interest between states, countries or stake holders

The search led to Brahmaputra River Basin being selected as a case study for the reasons that :

- Being from the same region researcher's understanding of the river system is satisfactory,
- The river is large and international in character (one of the largest river system of the world and flows through 4 countries)
- No earlier studies on similar line has been carried out for this river;
- Government of India has an ambitious project for inter linking of all the rivers of India, which has been of concern to the neighboring country of Bangladesh, and also to the general public, environmental scientists of the Brahmaputra Basin.

The Web based DSS BARISS has, therefore, been tested on Brahmaputra Basin and named as BRISS (Brahmaputra River Information and Simulation System). In the following sections BRISS has been discussed in details and before that a brief introduction to the Brahmaputra River system has been given.

6.3.1. The Brahmaputra River :

The origin of the Brahmaputra River is just south of Lake Konggyu Tsho in Tibet, near Manasarovar Lake at an elevation of 5150M. Brahmaputra in Tibet is known by its Tibetan name "Tsangapo". Tsangapo flows through southern Tibet for about 1625 KM eastward parallel to the main range of the Himalayas. Tsangpo takes the name of "Siang" and "Dehang" as it enters the Indian state of Arunachal Pradesh. Two important tributaries , namely, "Debang" and "Lohit" joins "Dehang" at Sadiya in Assam and thereafter it is known as Brahmaputra. Brahmaputra flows through the Assam Valley from East to West for a distance of about 640 KM before entering Bangladesh. In Bangladesh it joins with another mighty river "Ganga" and subsequently drains itself into the Bay of Bengal. The entire length of the river from Tibet (China) to Bangladesh is 2880 KM. The Brahmaputra covers a drainage area of 580,000 sq. km. 50.5 percent of which lie in China, 33.6 percent in India, 8.1 percent in Bangladesh and 7.8 percent in Bhutan. Its basin in India is shared by Arunachal Pradesh (41.88%), Assam (36.33% i.e. 70634 Sq. KM), Nagaland (5.57%), Meghalaya (6.10%), Sikkim (3.75%) and West Bengal (6.47%). The location of the study area is presented in Figure 6.1. A map showing Brahmaputra River and its Tributaries and schematic diagram showing the Brahmaputra River System has been given as APPENDIX-E (1 & 2)

6.3.1.1 Present Status:

The Brahmaputra River Basin, though very rich in water resources is economically one of the poorest regions of the world. Presently there are multiple agencies responsible for the information generation and no concerted effort has been made so far to develop integrated Decision Support System for the basin.

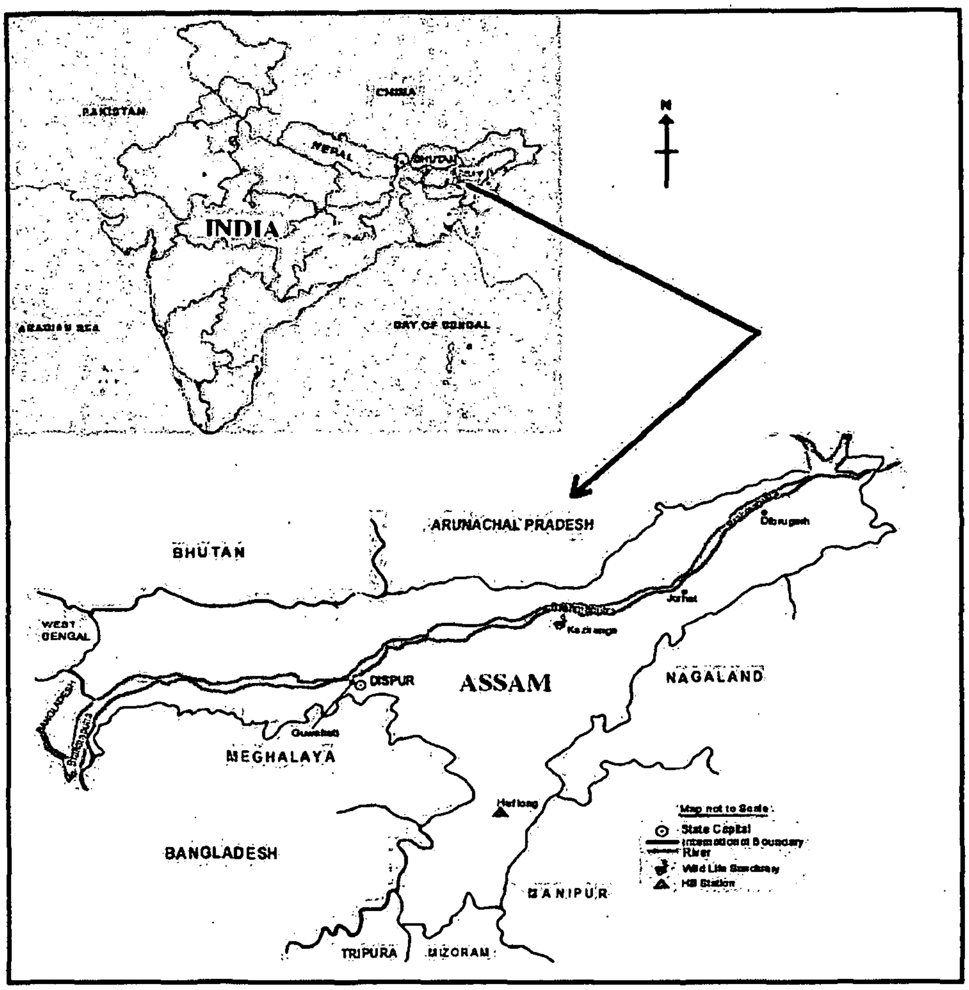


Figure 6.1 <u>**The Study Area**</u>

According to an estimate made in 1993 (Goswami and Das, 2000) there were altogether 336 ordinary rain gauges and 113 self-recording rain gauges in the Brahmaputra basin covering India and Bhutan with a total area of 240,000 Sq. Km.. At present there are six major gauge stations on the Brahmaputra where stage, discharge and sediment measurements are carried out on a daily basis. In case of tributaries there are more than 50 gauge stations, the major tributaries having at least one site on the upstream and one on the downstream section. The water levels are measured using conventional methods. The flood water level data are transmitted mainly through wireless and occasionally through telephone, telegraph or fax. During the period of high flood, flood-warning messages are broadcast through local radio and television centers and also through the printed media. The information is also supplied to the various user agencies or departments. Although the technology of satellite telemetry is available in the country it is not yet being used on operational basis for flood forecasting activities in the Brahmaputra basin.

The region is in some places inaccessible and is affected by extremist violence.

For the present study the part of the river flowing through Indian state of Assam has been considered for testing of the BARISS framework.

6.4 The Structure of BRISS

Specifications :

Following are the hardware and software requirement for BRISS

Database Server:

Operating System	:Linux server (Red Hat 6.1) Hardware: Pentium III processor, 120 MB RAM, 20 GB HD
RDBMS software	: Oracle 8i and above (minimum 200 concurrent user's license)

Web Server :

Operating System	: Linux Server (Red Hat 8) Hardware: Pentium III processor, 128 MB RAM, SCSI HDD 2X8 GB
Software	: Oracle Web DB

Client's PC

Operating System	: Any operating system with web browser and capability to install and

run SD software 'STELLA research 5 and above"

Specifications for 'STELLA'

For **WINDOWS** :

Pentium Processor, MS windows 95/98/NT/2000/XP, 64 MB RAM, 10 MB of disk space.

For **MACINTOSH**

Power PC, System Software 8.6 or better, 64 MB RAM , 16 MB of disk space

6.5 Testing Applicability of BRISS

BRISS (Brahmaputra River Information and Simulation system) has been presented as a website. As mentioned earlier BRISS consist of River Basin Simulation Model using System Dynamics theory and River Basin Information System built on RDBMS concept. In the present set up under study, 'Oracle 8i' RDBMS has been used for building the Information System component. The internet access to the information system has been provided using 'oracle web DB' (an ORACLE Product) .

BRISS is currently available at the URL

http://202.141.129.18/~p_barua/bris/index.htm

When the user of the DSS accesses the URL through his web browser , a screen as shown in Figure 6.2 will be displayed on his computer screen.

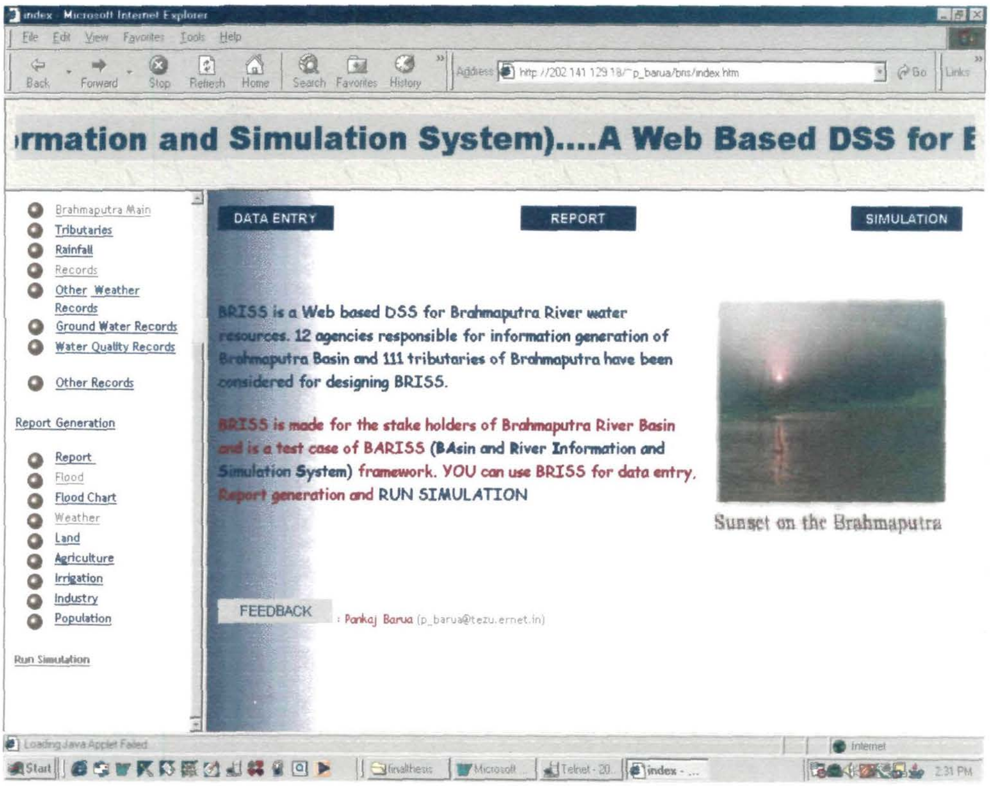


Figure 6.2 Index Page of BRISS DSS

A user may access the DSS for any of the following :

- Data Entry if he is from any of the agencies responsible for generating information (River data, weather, Crop etc)
- Report generation, if he is interested in getting information on any of the river basin parameters, or part of the organization for data sharing and presentation.
- Simulation, if he is a part of the policy maker or general public interested to know the status of the river basin.

6.5.1: Data Entry

As per the database Schema described in chapter 5, the Brahmaputra River Basin Information System has been built using RDBMS concept keeping in mind the requirement of the agencies responsible for information generation on various aspect. Some of the agencies with their responsibilities are as follows;

I . Water resources Department (State Government)

It maintains a series of gauging stations for collecting flow records in Brahmaputra and other major tributaries, takes flood control measures, maintains a series of rain gauges.

II . Central Water Commission (Central Government)

Collects river records and does long term planning for river water uses.

III . Central Ground Water Board (Central Government)

Monitors and records ground water information.

IV. Indian Meteorological Department:

Collects Meteorological data and provides weather forecasting,

V . Other Departments:

a) Agriculture Department of State Government : maintains raingauges, collects agriculture information, designs agriculture policy,
b) Irrigation Department of State Government : plans and executes irrigation projects ,
c) Economics and Statistics Department of State Government: Collects , stores and publishes all information, does policy planning
d) State Pollution Control Board of State Government: Collects and generates pollution related information,
e) Industry Department of State Government: Prepares industrial policy
f) State Agricultural University: Collects Meteorological data and providse weather

forecasting, maintains ground water information at some locations

Apart from the main river Brahmaputra , its major tributaries have also been considered. The Information System has been designed to accommodate information on following broad areas :

I. Flow Records of Brahmaputra and its tributaries
II. Rainfall and Weather information of the river basin
III. Ground water information of the river basin
IV. Water quality information of the river basin
V. Agriculture information of the river basin
VI. Information regarding land, population, industry and irrigation of the river basin

when the user clicks the menu option data entry, he will be given another menu options as shown in Figure 6.3

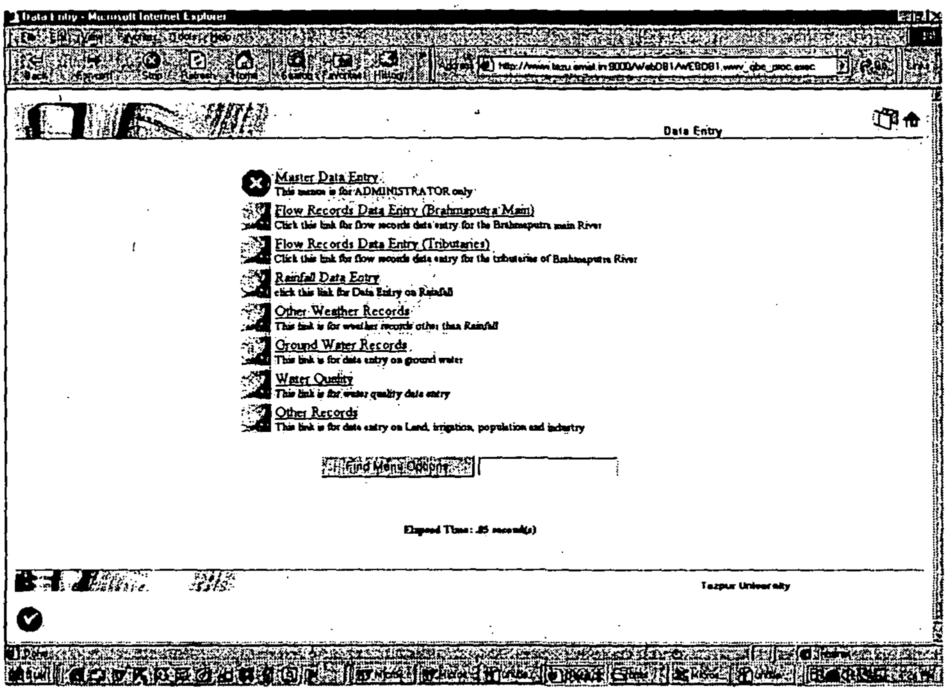


Figure 6.3 <u>**Screen Image of Data Entry Menu**</u>

Each of the menu option leads to the respective data entry form under the categories. However, to provide database security, access to data entry operation has been restricted and necessary privilege has been granted as per requirement only. To save time user can directly paste the URL of the respective pages to access the forms for data entry. The various data entry forms and reports as they appeared on screen are shown in APPENDIX-C (Figure Ac1 to Ac4)

6.5.2 : Report Generation

Similarly for report generation also links and menus such as flood report, weather report, agriculture report etc. has been provided as shown on Figure 6.4

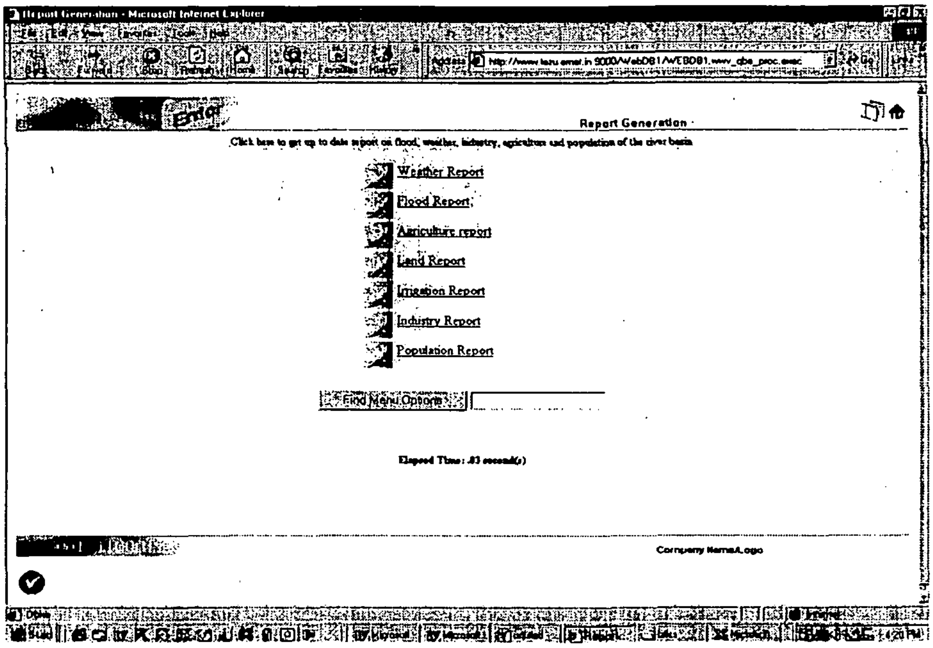


Figure 6.4 <u>**Screen Image for Report Generation Menu**</u>

Apart from Data Entry and Report generation menu, various information on the river basin such as the About the River , Stakeholder for the basin etc. have also been incorporated in the information system.

Simulation is another important aspect of the BRISS and System Dynamics Model has been used as model base for simulation. In BRISS a link for "run simulation" has been provided which leads to step-by-step procedure for running the SD model. SD software 'STELLA Research 5' has been used to build the Brahmaputra River Basin SD model (BRSD). For a user who does not have access to the software, a link for free download of trial version of 'STELLA demo version' and/or '*iseePlayer8_1' has been provided.*

In the following sections BRSD has been discussed with a brief introduction followed by description of the model, validation, sensitivity analysis and policy analysis

6.6 BRSD (Brahmaputra River SD model):

Based on the framework discussed in chapter 4, BRSD has been designed as an dynamic DSS tool that allows users to explore a wide variety of water consumption and availability scenario for Brahmaputra Basin. By estimating future consumption and availability, user can assess how various assumptions actually affect the performance of the water resources system. 'What if ?' type of scenario can be generated using BRSD and sustainability of the water resources of the River basin can be determined .

6.6.1 Model Description :

This section describes the water balance equations which formed the basis of the Brahmaputra River SD model. The concept has been discussed earlier in section 4.1.1 of this thesis and explained through Figure 4.1. The detail equations and relations has been included in APPENDIX-D and the test plan has been given as APPENDIX-E (Figure Ae1)

Total Water Available:

The total water available has been estimated as

$$S = S_S + S_G + S_R \text{ -- } (6.1)$$

$$S_S = S_{EW} + S_{TR} + \text{Rainfall} + S_{RS} - D_{SW} - S_{OUT} - \text{Evaporation} \text{ --- } (6.2)$$

$$S_{GW} = S_{GW} + S_{Recharge} - D_{GW} \text{ ---------------------------------- } (6.3)$$

Where,

S	=	Total water
S_S	=	Surface water
S_G	=	Ground water
S_R	=	Return flow from uses
S_{EW}	=	External flow into the basin
S_{TR}	=	Tributary inflow
S_{RS}	=	Return flow to surface water from uses
D_{SW}	=	Water demand met from surface water
S_{OUT}	=	Surface water outflow from the basin
S_{GW}	=	Total ground water potential of the basin
$S_{Recharge}$	=	Ground water recharge from rainfall, surface water and return flow from uses
D_{GW}	=	Water demand met from ground water

N.B. The unit of water measurements has been taken as MCM (Million Cubic Meter) in the above equations.

As explained, Rainfall and Evaporation have been considered as inflow and outflow from available water. Return flow from various uses has also been considered as inflow to available water.

Water Consumption Estimation:

The total water consumption for the Brahmaputra river basin has been estimated as

$$D = D_{Pop} + D_{Ind} + D_{Irrig} + D_{Envr} \text{ ------------------ } (6.4)$$

Where,

D	=	Total water Consumption
D_{Pop}	=	Population water consumption
D_{Ind}	=	Industrial water consumption

D_{Irrig} = Irrigation water requirement

D_{Envr} = Environmental water requirement

Population water consumption has been estimated by multiplying projected Population and per capita water consumption (a decision variable). Each of the projected population from urban, rural and immigration population has been considered and multiplied by the respective per capita consumption to estimate population water consumption. The normal per capita consumption for urban and rural population have been taken from planning commission of India estimate (GOI, 1999) and that of immigration population have been author's estimate. This estimate have been made on the assumption that immigration population generally thrives on minimum available resources and can not exploit the resources up to the extent as a permanent resident does. Some of the inputs considered for this sector are literacy rate, resources availability (land and water), industrial growth and government policy. Values for the these inputs have been taken from published report of the state government. The details of the inputs as used in the model have been given in list of variables (APPENDIX-D1)

Arable land in the basin gets converted to irrigated land. This conversion depends on water availability and government policy. Crops considered for estimating Irrigation Water consumption have been Paddy, Jute and other Crops. Paddy occupies nearly 95% of the total irrigated land and Paddy and Jute require huge amount of water for growth.

The water required for irrigation has been estimated as per procedure outlined in FAO (Food and Agricultural Organization of UNO) Irrigation and Drainage Paper by Doorenbos and Pruitt (1977). This FAO paper illustrates methods to calculate crop water needs based on climatic factor and subsequently irrigation water needs for a geographical area in a very simple manner. The net irrigation water requirements has been defined here as the volume of water needed to compensate for the deficit between potential evapotranspiration and effective precipitation over the growing period of the crop. It varies considerably with climatic conditions, seasons, crops and soil types. For a given week/month/year, the crop water balance can be expressed as

$$\mathbf{IWR} \cong \{\ \mathbf{Kc, ET, P, \Delta S}\ \} \text{ --------------------------(6.5)}$$

where:

IWR	is the net irrigation water requirement needed to satisfy crop water demand
Kc	is a coefficient varying with crop type and growth stage
ET	is the evapotranspiration, depending on climatic factors
P	is the precipitation
ΔS	is the change in soil moisture from previous week/month/year

In the specific case of paddy crop irrigation and Jute crop irrigation additional water is needed for flooding to facilitate land preparation and for plant protection. In that case, irrigation water requirement has been considered as the sum of rainfall deficit and the water needed to flood the fields. For the present study, irrigation water requirement has been computed for the basin in a dynamic manner considering among others the seasonal water availability, arable land conversion to irrigated land, government investment and utilization of existing facility. A flow diagram showing the approximate method for estimation of irrigation water demand has been shown as Figure Ad2 (APPENDIX-D)

Water consumption figures for industry are often expressed in terms of cubic meters or litres of water used per unit of product produced. For example for steel production water use is measured as M^3/ton of steel produced. The method of manufacture used by a particular industry affects its water use. Some industries are relatively consistent in their water use because they use the same processes and the same equipment .The per unit consumption of these industries are more or less uniform all over the world.

There are some industries where such consumption data are available from a wide range of sources, for other industries the data available are limited. For industries that consume significant quantities of water, water consumption varies in approximately linear manner with increase in production. Hence apart from actual production, planned production capacity (desired production) of an industrial plant is important in establishing the water consumption.

Industries considered for estimating Industrial water Consumption for Brahmaputra Basin in the present study have been : Agricultural Processing, Petroleum crude refining, Heavy industries, Forest Products, Power And Textile. These are the actual classes of industries as per the classification of Department of Industries of the State Government. Since there has been no studies to estimate per capita consumption of the industries under local condition, compiled tabulated data from other sources (Leeden, 1975 ; DFID, 2005) has been used for this study.

Not all the water that is abstracted from surface source (e.g. river) or a ground water source (e.g. tubewell) by an industrial plant or by population is consumed. A significant quantity gets recycled into the surface as well as ground water. In the present study, it has been assumed that 30% of the water abstracted for population use would be actually consumed and rest would return to the surface water or be retained as ground water. Similarly for industrial use 20% would be consumed and rest would return to the surface water or be retained as ground water (after Mohile , 2001).

The environmental flow requirements (EFR) of river basins have been attracting increasing attention in recent years. The increasing demands of irrigation, domestic and industrial sectors in the past have been met without consideration of the needs of freshwater ecosystems themselves. Most of Indian rivers including Brahmaputra have monsoon-driven hydrological regimes, where 60 to 80% of the total flow occurs in 3-4 wet months. Such rivers fall into a category of highly variable flow regimes. The total EFR for most of Indian rivers, estimated by Amarsinghe (2004), range between 20 to 27% of the renewable water resources. It is also suggested in the study that environmental allocations of less then 20% of the total flow may degrade any river beyond the limits of possible re-habilitation and may decreases the ability of a river to cope with pollution loads. For the present study, therefore, the environmental water requirement has been taken as 27% of the total available water.

Water Resources System Evaluation :

In this study sustainability index (SI) as introduced by Xu et al, (2002) and defined as the ratio of aggregated possible water deficit relative to the corresponding supply in the same region has been calculated.

$$SI = (S-D)/S, \quad \text{when } S>D \qquad \text{------------------------------(6.6)}$$

$$SI = 0, \text{ when } S<D$$

Where, D is the water Consumption and S is the available water supply

SI value greater than 0.2 corresponds to low or no stress of water supply, which implies that water consumption is less than or equal to 80% of the water supply. SI value smaller than 0.2 reflects vulnerable condition and SI value zero or less indicates unsustainable water supply.

6.6.2 The Model :

The Brahmaputra River SD Model (BRSD) has been built as part of BRISS (Brahmaputra River Information and Simulation System) using 'STELLA Research version 5' (High Performance Systems, Inc.,1999). Menu based user interface has been provided for easy navigation. The welcome and main menu of BRSD has been presented as Figure 6.4 and 6.5 respectively. For simulation a user may query for data through BRISS and use it to run the simulation

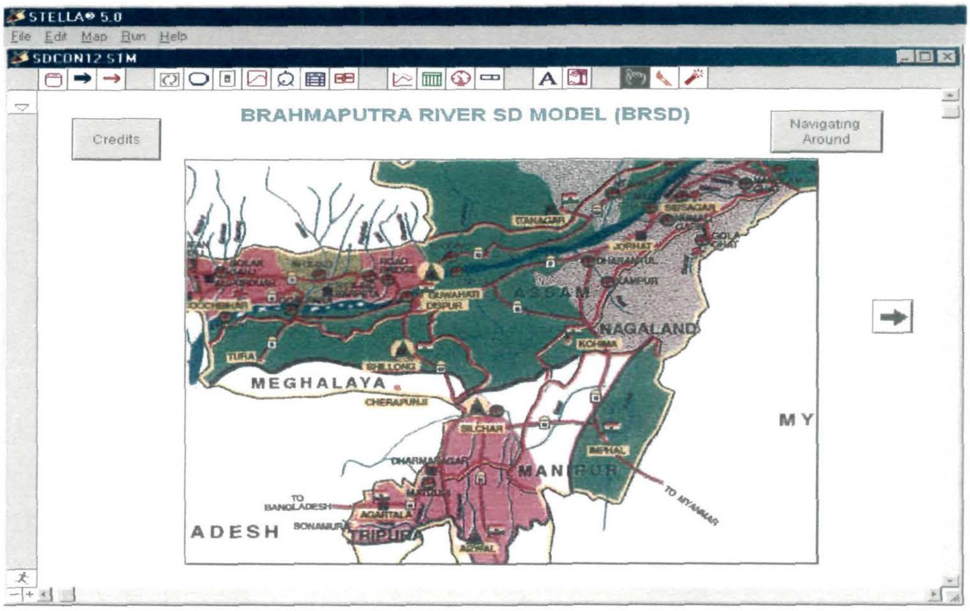


Figure 6.5 Welcome menu of BRSD

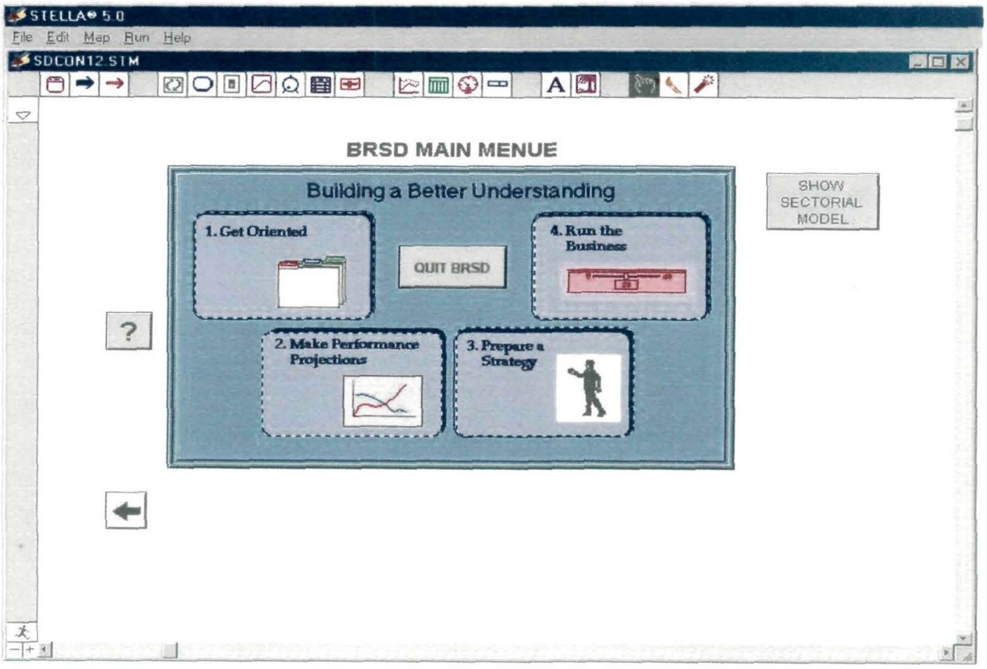


Figure 6.6 Main menu of BRSD

6.7 Model Validation

A model is built for the purpose of policy experimentation. But, before policy experimentation are carried out it is required that the model should be realistic and therefore, validation tests are done. In traditional modeling, such as in econometric modeling, single equation statistical testing is the primary approach that is employed in testing the models. Because each of the equation is statistically validated, it is normally assumed that the predicted behavior produced by the model will also be reliable (Mahapatra et al, 1994).

Validation in System Dynamics is a multi test process. Model validation in System Dynamics incorporates both statistical tests and model-behavior test. Considering practical utilities, two type of tests i.e. structural and behavioral validation tests are commonly employed. Structural validation tests employ application of judgment to decide the model adequacy and the correctness of the equations. Model adequacy refers to fixing up model boundary and to judge whether or not all sub systems conforming to the descriptive knowledge of the system have been taken into account during model formulation. Appropriateness in equation formulation is judged through equation verification, parameterization and dimensional consistency of equations. Behavioral validation is done through behavior reproduction test (Mahapatra et al., 1994).

In the following sections the behavior reproduction test for BRSD model is discussed and presented.

6.7.1 Behavior Reproduction Test

The most important and commonly used test for behavior validation is the behavior reproduction test. In this test, the model generates the past behavior for some major variables of the system. This simulated behavior is judged against the actual past behavior of the system for the trend and closeness. The simulated and actual values should follow the same trend and should exhibit similar fluctuations. Also, the simulated and actual value should not differ much. This can be measured by the standard statistical tests.

For the present study, 30 years data (1971-2001) of Brahmaputra river basin have been used for behavior reproduction test of BRSD model. Table 6.2((a) to (d)) shows the tabulated values and Figure 6.7 ((a) to (c)) shows the corresponding graphs for the model simulated and actual behavior for Industry (Industrial Fixed Capital and Industrial Working Capital) Population (Urban, Rural and Total Population) and Land (Forest land, urban land and irrigated land) parameter of Brahmaputra River Basin.

Table 6.2 (a) **Test Results (Industry)**

Year	Fixed capital			Working capital		
	Simulated	Actual	Relative error*	Simulated	Actual	Relative error*
1971	59	NA	_	73	NA	_
1981	222.22	287.71	0.224045	80.58	295.99	0.728606
1991	836.99	1032.09	0.181505	256.14	569.4	0.557025
1998	2,117.74	2274.85	0.05738	1,091.26	842.16	0.285397
1999	2,418.05	2448.03	0.000613	1,339.64	1358.98	0.020236
2000	2,760.95	NA	-	1,637.60	NA	-
2001	3,152.48	NA	-	1,991.98	NA	-

* Relative Error = ABS (Simulated Value- Actual Value)/Actual Value

Table 6.2 (b) **Test Results (Population)**

Year	Rural population			Urban population			Total population		
	Simulated	Actual	Relative error*	Simulated	Actual	Relative error*	Simulated	Actual	Relative error*
1971	13,335,930	NA	_	1,289,222	NA	_	14,625,152	14,625,152	0
1981	17,142,818	NA	_	1,662,401	NA	_	18,805,220	18,041,000	0.04236
1991	20,711,398	19926527	0.039388	2,325,622	2,487,795	0.065187	23,037,021	22,414,322	0.027781
2001	23,243,745	23248994	0.000226	3,383,455	3389413	0.001758	26,627,200	26,638,407	0.000421

Table 6.2 (c) **Test Results (Land)**

Year	Forest Land			Irrigated land			Urban Land		
	Simulated	Actual	Relative error*	Simulated	Actual	Relative error*	Simulated	Actual	Relative error*
1971	2,011,000	NA	-	17,000	NA	-	852,000	NA	-
1977	1,992,848	1984000	0.00446	174,099	NA	-	900,100	881,000	0.021681
1978	1,989,839	1984000	0.002943	197,330	NA	-	907,816	897,000	0.012058
1979	1,986,835	1984000	0.001429	219,375	NA	-	915,454	912,000	0.003788
1980	1,983,835	1984000	8.32E-05	240,211	NA	-	923,019	914,000	0.009868
1993	1,945,243	NA	-	429,866	458071	0.061572	1,016,247	NA	-
1995	1,939,372	2012000	0.036097	450,398	NA	_	1,029,943	1030780	0.000812
1996	1,936,444	1930289	0.003189	460,090	480078	0.041634	1,036,740	1,044,644	0.007566
1997	1,933,520	1930289	0.001674	469,433	NA	-	1,043,505	1,044,644	0.001089
1998	1,930,600	1930289	0.000162	478,447	481099	0.005511	1,050,240	1051381	0.001085
2001	1,921,868	NA	-	503,753	503993	0.000475	1,070,271	NA	-

Table 6.2 (d) **Root Mean Square Error of behavior reproduction test**

	Population			*Land*			*Industry*	
	Rural	Urban	Total	Forest	Irrigated	Urban	Fixed Capital	Working Capital
Root Mean Square Error (%)**	2.80	4.73	1.62	1.88	5.45	1.81	23.17	79.56

* Relative Error = ABS (Simulated Value- Actual Value)/Actual Value
** Root Mean Square Error
=100* SQRT (SUM ((Simulated Value- Actual Value)/Actual Value)^2 / No. of Observation

---

***Relative error** is one of the most commonly used measure of success of model prediction and mathematically expressed as the absolute difference between predicted value and actual value with respect to the actual value. Root mean square error is the square root of the mean of the squared relative error. Root mean square error exaggerates the difference between prediction value and actual value of a test case with reference to the actual value and generally expressed as percentage.

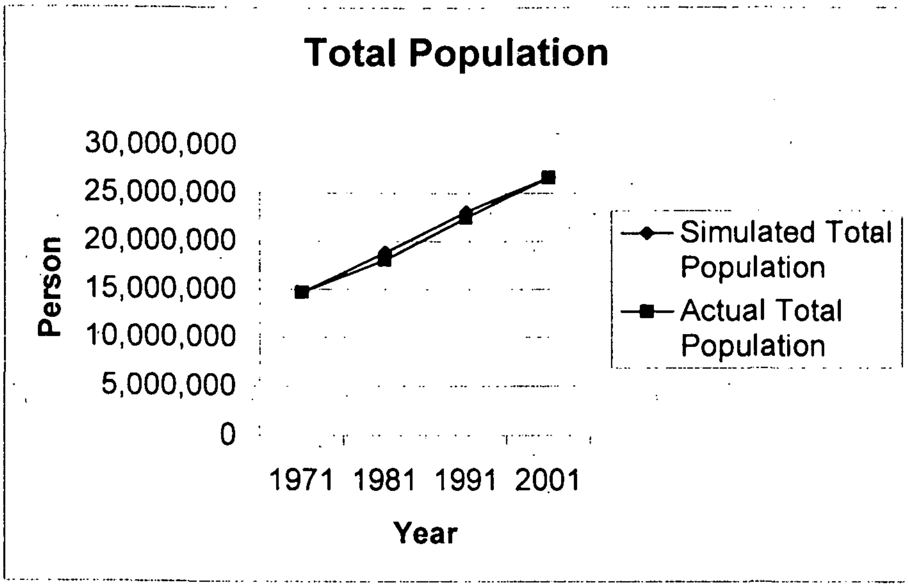


Figure 6.7(a) Total Population (Simulated Vs Actual)

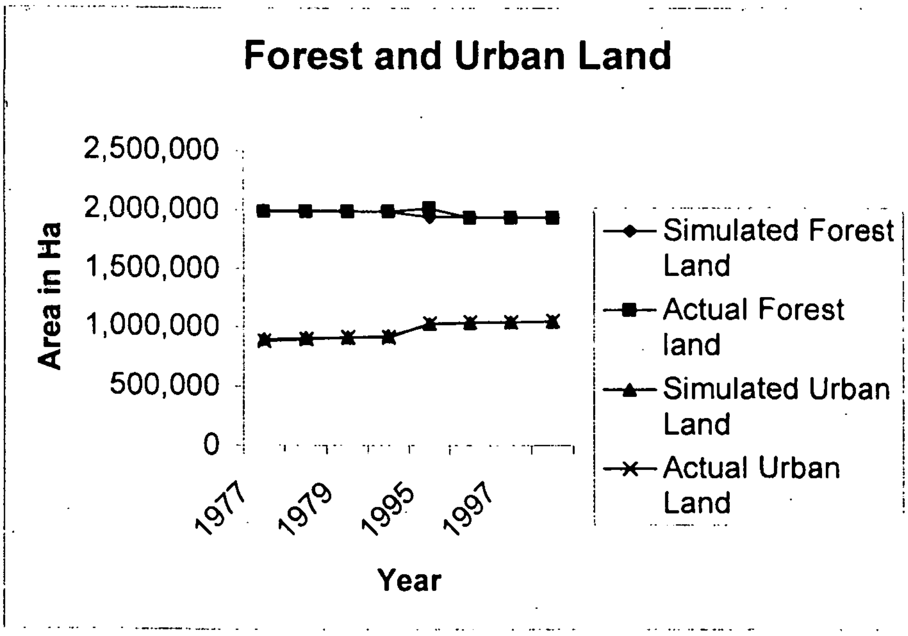


Figure 6.7(b) Forest and Urban Land (Simulated Vs Actual)

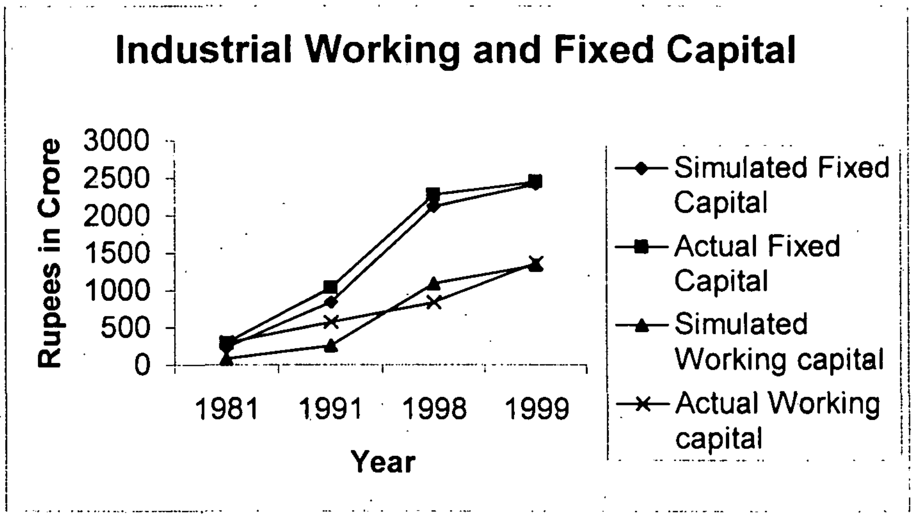


Figure 6.7 (c) **Industrial Working and Fixed Capital (Simulated Vs Actual)**

It can be seen in the table (6.2 (a) to (d)) that simulated value for Population (Urban, Rural and Total Population) and Land (Forest land, urban land and irrigated land) match with that of available actual data as evident from the values of relative error. However, the simulated values for Industry (Industrial Fixed Capital and Industrial Working Capital) did not match with the same degree of accuracy. The error could be due to uncertainties and inaccuracies during data collection and/or analysis. This may also be due to the political turmoil, ethnic clashes and extremist violence experienced in the river basin during the period. !980 saw the beginning of Assam Agitation which spread for 5 years and diffused by the political agreement in 1985. This period witnessed a lot of disruption in socioeconomic scenario affecting industrial growth. Even after signing of the treaty in 1985, business houses were not very convinced of the return of a conducive environment and industrial activity progressed on a wary note. The new industrial policy of 1990 provided a host of incentive to encourage industrial development in Assam. This policy acted as one of the drivers of industrial growth prompting a growth of 258.7% from 1981 to 1991.

Figure 6.6 ((a) to (c)) shows that the trend of simulated and actual values for Population (Urban, Rural and Total Population) , Land (Forest land, urban land and irrigated land) and Industry (Industrial Fixed Capital and Industrial Working Capital) is nearly the same.

6.8 Model Analysis :

Experimenting various policies and analyzing them achieve the real benefit of modeling. The ability of the model in revealing the effects of a policy on various sectors of the system is the real test of worthiness of the model. The effect of a policy can be analyzed both qualitatively and quantitatively. Coyle (1977) has suggested two methods (loop analysis and sensitivity analysis) for model analysis. Qualitative analysis is based on the explanation of the causal relationship in the causal loop diagrams. For quantitative analysis, it is required to generate the quantitative values of the system variables at different time points. Sensitivity analysis assists in understanding system behavior in quantitative terms.

6.8.1 Sensitivity Analysis

Sensitivity analysis on parameters and table values are often carried out to determine how important a parameter or table value is for system behavior. The aim of sensitivity analysis is to identify the sensitive parameters through simulation experiments. Here the idea is to quantify the changes in the model performance if parameter values are altered (Mahapatra et al., 1994).

For the present study, a series of sensitivity analysis have been undertaken to examine the BRSD model's response to variations of input parameters. To quantify the sensitivity analysis , a concept of sensitivity degree as defined by Guo et al (2001) has been used

$$S_Q = \left| \left[\frac{\Delta Q(t)}{Q(t)} \right] \Big/ \left[\frac{\Delta X(t)}{X(t)} \right] \right| \quad \text{-- -- (6.7)}$$

Where,

t = time

Q(t) = System state at time t

X(t) = System parameter that affect the system state at time t

S_Q = Sensitivity degree of state Q to parameter X

ΔQ(t) and ΔX(t)= Increments of state Q and parameter X at time t

For 'n' state variables (Q_1, Q_2 .....Q_n), the general sensitivity degree of parameter at time 't' can be defined as

$$S = (1/n)\sum_{1}^{n} S_{Q_i} \qquad \text{----------------- (6.8)}$$

Here the objective is to measure how much change occurs in Q (a dependent variable representing system state in this case) due to change in X (an independent variable representing system parameters in this case) over time 't'

For the sensitivity analysis of BRSD model 11 variables have been identified for representing system state of population, land / irrigation , industry and sustainability . 18 parameters have been analyzed to examine their impact on the system states. To examine sensitivity degree of each state variable, each parameter is increased or decreased) by 10% per 3 years for the study period from 1971 to 2001. The sensitivity degree as per equation (1) has been determined using the simulation values of the state variables on starting and closing of simulation. Further, using Equation (II), an average for all 11 state variables has been calculated for each parameter tested, which represents the general sensitivity degree of the 11 system states to the particular parameter tested. The sensitivity degree analysis has been presented as Table 6.3 (a,b,c) . It can be seen in the table that the BRSD model responded to most of the parameters with low degree of sensitivity. This fact demonstrates that the model can be used for effective prediction of the system's behavior.

Table 6.3 (a) **Sensitivity Analysis**

VARIABLES/ PARAMETERS	LITER PER CAPITA PER DAY FOR RURAL POPULATION	LITER PER CAPITA PER DAY FOR URBAN POPULATION	IRRIGATION EFFICIENCY	OUT FLOW TO SEA	CONVERSION FRACTION OF URBAN POPULATION TO URBAN LITERATE POPULATION	CONVERSION FRACTION OF RURALPOPULATION TO RURAL LITERATE POPULATION
Total water Consumption	0.0020	0.0010	0.04761	0.0698	0	0.000621593
Total Industrial Water Consumption	0	0	0	0	0	0
Irrigation Water	0.0002	8.5E-05	2.0107	1.1380	0.0004	0
Total Population	4.19E-07	1.8E-07	1.62E-05	0.0077	0.0437	0
Total Water Supply	0.0002	0.0001	0.0135	1.9804	2.36E-05	0
Urban Land	6.4E-06	2.56E-06	0.0001	0.0408	0.0408	0
Rural Population	6.72E-07	2.87E-07	2.4E-05	0.0116	0.0116	0
Urban Population	1.32E-06	0	3.9E-05	0.0189	0.0189	0
Literacy rate	0	0	0	0	0	0
Sustainability Index	0	0	0.0283	0.4000	0	0
Annual Population Water Consumption	0.6666	0.2999	0	0.0141	0.1275	0.0620
Average	0.0608	0.0273	0.1909	0.3346	0.0220	0.0056

Table 6.3 (b) Sensitivity Analysis

VARIABLES/ PARAMETERS	FIXED CAPITAL INFLOW RATE FRACTION	EXTERNAL FLOW	TRIBUTARY FLOW	CROPPING INTENSITY	NORMAL URBAN BIRTH FRACTION	RURAL POPULATION CONVERSION FRACTION TO URBAN POPULATION
Sustainability Index	0	0.4047	0.5227	0	0	0
Total water Consumption	0.0010	0.0629	0.0866	0.0365	0.0001	0.0006
Annual Population Water Consumption (BCM)	0	0	0.0140	0.6821	0.1323	0.0620
Total Industrial Water Consumption	1.1275	0	0	0	0	0
Irrigation Water	0	0.8413	0.9189	1.0020	0.0202	0.0006
Total Population	0	.0077	0.0128	7.98E-06	0.0467	0.0048
Total Water Supply	6.66E-05	1.073	1.3189	0.0064	3.77E-05	8.49E-05
Urban Land	0	0.0489	0.0525	9.11E-05	0.0004	8.97E-06
Rural Population	0	0.0118	0.0192	1.20E-05	4.96E-07	8.97E-06
Urban Population	5.21E-09	0.0196	0.0327	1.93E-05	0.4004	0.2352
Literacy rate	0	0	0	0	0	0.0230
Average	0.1025	0.2707	0.2245	0.1570	0.0545	0.0296

Table 6.3(c) Sensitivity Analysis

VARIABLES/ PARAMETERS	NORMAL RURAL BIRTH FRACTION	EROSION RATE	FRACTION OF PADDY AREA	FRACTION OF OTHER CROP AREA	CONVERSION FRACTION OF UNIRRIGATED LAND TO IRRIGATED LAND	IRRIGATION CONSUMPTION FRACTION FROM GROUND WATER
Sustainability Index	0	0	0.0147	0	0.0294	0
Total water Consumption	0.0003	0.0035	0.0288	0.0033	0.0367	0
Annual Population Water Consumption	0.2299	0	0	0	0	0
Total Industrial Water Consumption	0	0	0	0	0	0
Irrigation Water	0.0346	0.0600	0.5002	0.0606	0.6863	0.0004
Total Population	0.0862	1.08E-05	3.07E-06	3.54E-07	9.19E-05	1.16E-06
Total Water Supply	2.83E-05	0.0010	0.0025	0.0002	0.0072	0.0092
Urban Land	0.0007	0.0014	358E-05	4.12E-06	0.0260	1.28E-05
Rural Population	4.86E-05	1.25E-05	4.60E-06	5.31E-07	0.0001	1.7E-06
Urban Population	0.5843	4.5E-07	7.42E-06	8.55E-07	1.54E-05	2.78E-06
Literacy rate	0	0	0	0	0	0
Average	0.0851	0.0059	0.0499	0.0058	0.0714	0.0008

6.9 Model Application and Scenario Generation:

After the sensitivity analysis BRSD model has been used for scenario generation. 6 possible scenarios as described in Table 6.4 have been evaluated.

Table 6.4 **Scenarios Evaluated**

Water Flow in River	Water Uses	Scenario
Maximum	Normal	A
Maximum	High	B
Mean	Normal	C
Mean	High	D
Minimum	Normal	E
Minimum	High	F

Maximum = Maximum recorded flow of the river,
Minimum= Minimum recorded flow of the river,
Mean =Mean value of recorded flow of the river ,
Normal =Rural population water requirement 20 lpcd,
Urban population water requirement 100 lpcd,
Immigration Population water requirement 15 lpcd,
Floating Population water requirement 50 lpcd,
Cropping Intensity 1.25,
High = Rural population water requirement 100 lpcd, Urban population water requirement 400 lpcd,
Immigration Population water requirement 40 lpcd,
Floating Population water requirement 75 lpcd,
Cropping Intensity 1.30

The results of the scenarios generated through simulation has been presented as Figure 6.8 and Tabulated in APPENDIX-D4 (Table Ad3)

The simulation results in Figure 6.8 shows that when simulated with minimum flow condition (Scenario E & F) , Brahmaputra River Basin appeared to be deficit in water as evident from the Sustainability Index. When simulated with Mean (Scenario C & D) and maximum flow (Scenario A and B) condition the river basin water status appeared to be sustainable till 2050. Further simulation revealed (Table 6.5 and Figure 6.9) that the water status is unlikely to cross the benchmark sustainability index of 0.20 till 2125 after which the scenario turns to be unsustainable. Since huge differences in water availability could be observed between Minimum and Maximum Flow condition, water storage in dams to augment the lean season flow may be a possible policy option.

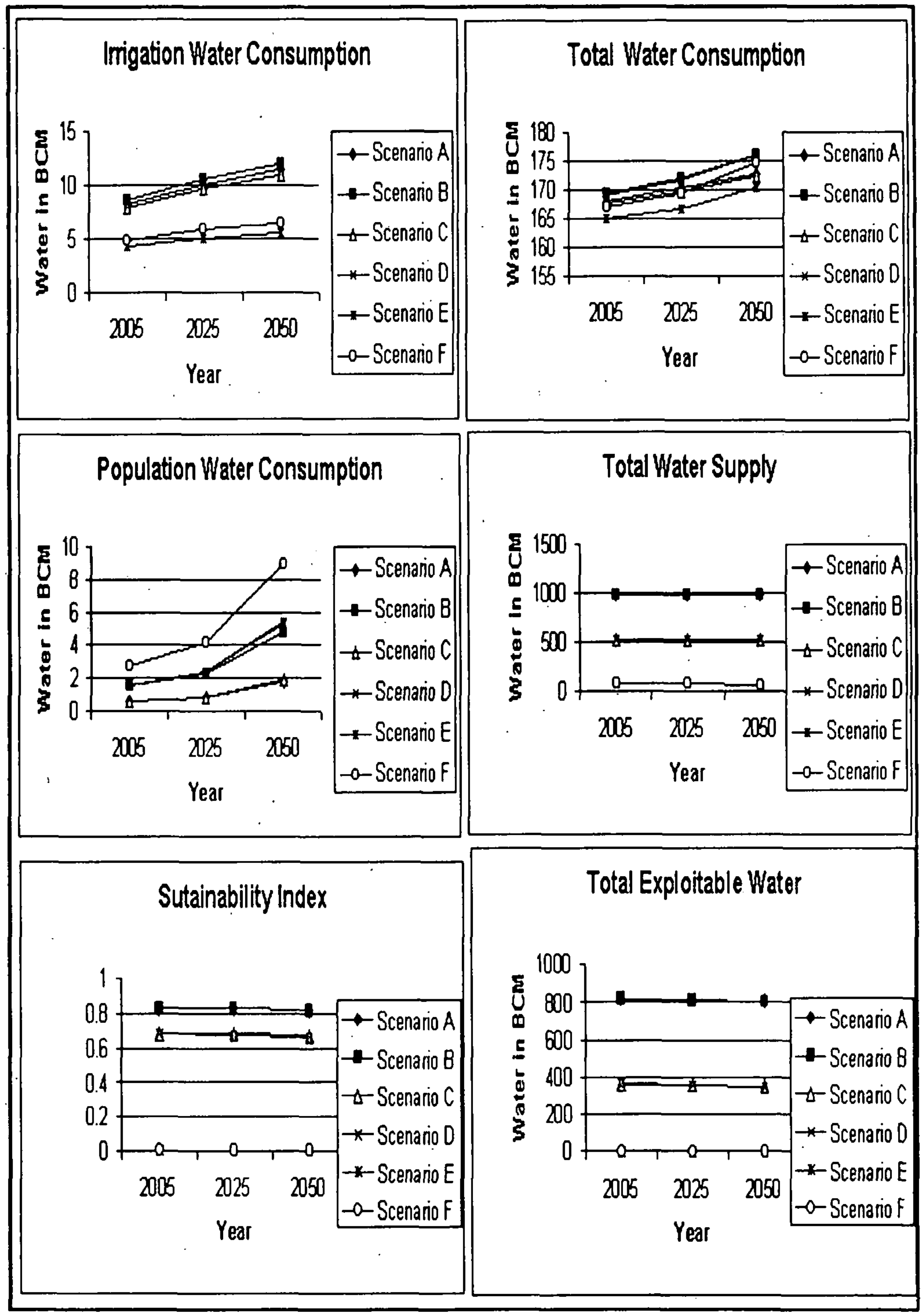


Figure 6.8 **Water Availability Status of Brahmaputra Basin up to year 2050**

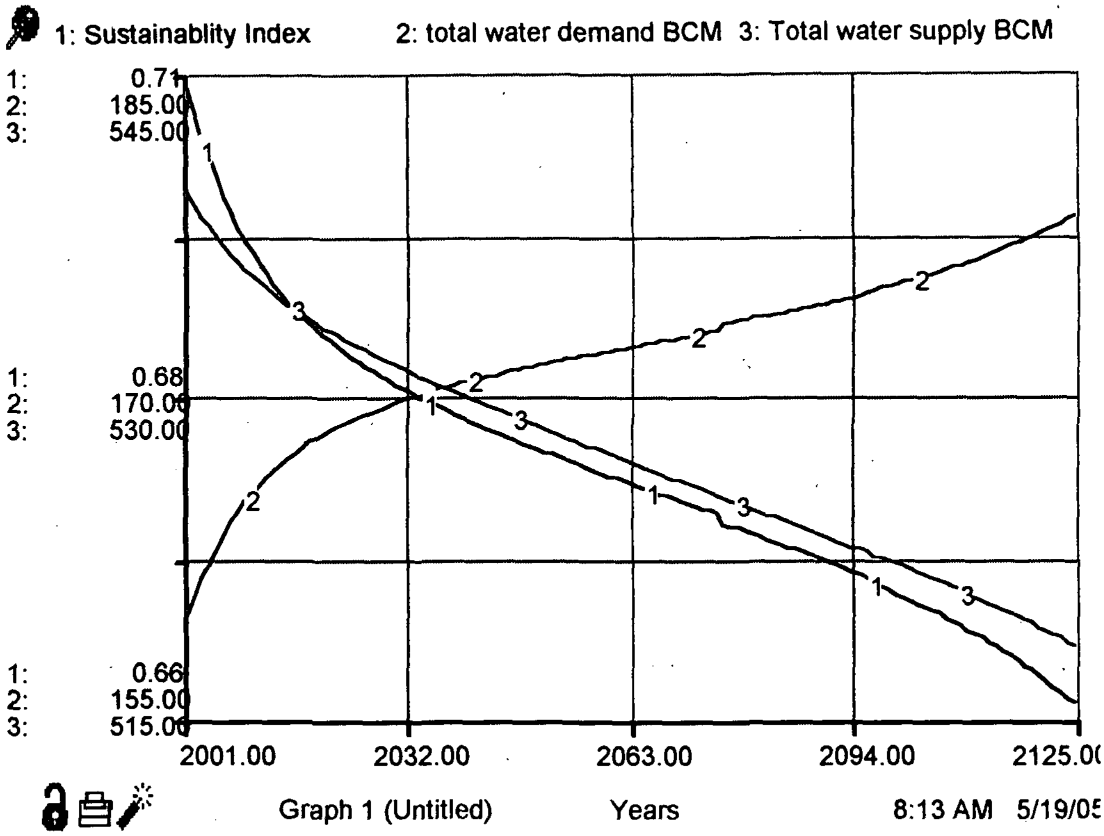


Figure 6.9 Scenario Beyond 2050

Table 6.5 Water Availability Status beyond 2050 (under Scenario 'D')

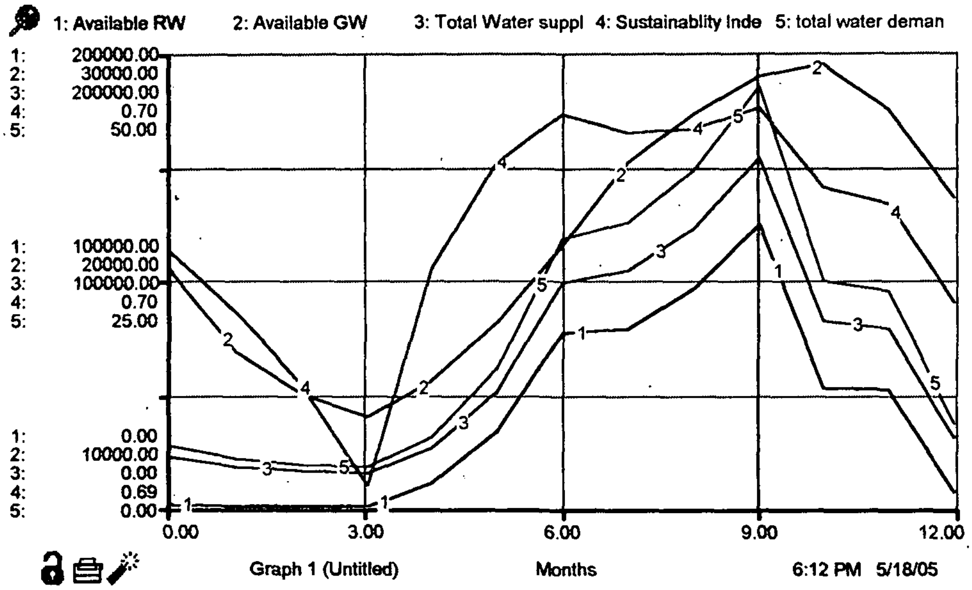
	Water Consumption (in BCM)						
Year	Irrigation	Industrial	Population	Total Water	Total Supply (in BCM)	Total Exploitable Water (in BCM)	Sustainability Index
2070	12.12	830.2	11.28	183.53	516.29	332.76	0.64
2125	12.61	501.44	92.43	264.85	345.16	80.31	0.23
2126	12.62	501.44	95.76	268.18	323.67	55.49	0.17
2127	12.62	501.44	99.2	271.62	300.45	28.83	0.1
2128	12.62	501.44	102.75	275.18	275.43	0.25	0

6.9.1 Seasonal Variability

Since wide seasonal fluctuations exist in the river flow, some efforts were made to assess the pattern of seasonal water availability and consumption. Due to lack of sufficient data, seasonal water availability could not be assessed through BRSD model. Another simulation technique, Monte Carlo Simulation has been carried out to simulate the time series data of discharge rate of Brahmaputra river and its tributaries and forecast discharge for the year 2025 and 2050. The weekly forecasted discharge rate of Brahmaputra and its tributaries has been given in APPENDIX-D3 (Table Ad2). These forecasted values of weekly/monthly average discharge rate values along with average monthly rainfall and evaporation values have been used in the BRSD model to assess seasonal water availability. The population and industry water consumption have been assumed to be of constant rate through out the year. The irrigation water consumption dynamics has been assessed by using seasonal crop area, rainfall and evaporation records for the river basin.

Graphs in Figure 6.10 and 6.11 shows the seasonal variations in water availability and consumption for the Brahmaputra River Basin. It can be seen in the graphs that the for both the years (2025 and 2050) the water supply peaks during August and September and goes down thereafter till March after which it starts going up again. March signifies the onset of pre-monsoon showers for the basin and heavy rains occur during the months of July to September. The graphs show the trend for water demand (consumption) as similar to water supply. It is because the Environmental consumption for the basin has been taken as 27% of available water.

Irrigation Water for the basin peaks during last quarter (both 2025 and 2050) as the basin receives very little or no rainfall during this period. High values for irrigation water during July/August and March are because of Paddy cultivation which requires very high amount of water (Paddy occupies nearly 80% of the total crop area of the Basin)



RW = River Water, GW= Ground Water, Suppl= Supply, Deman=Demand, BCM= Billion Cubic Meter

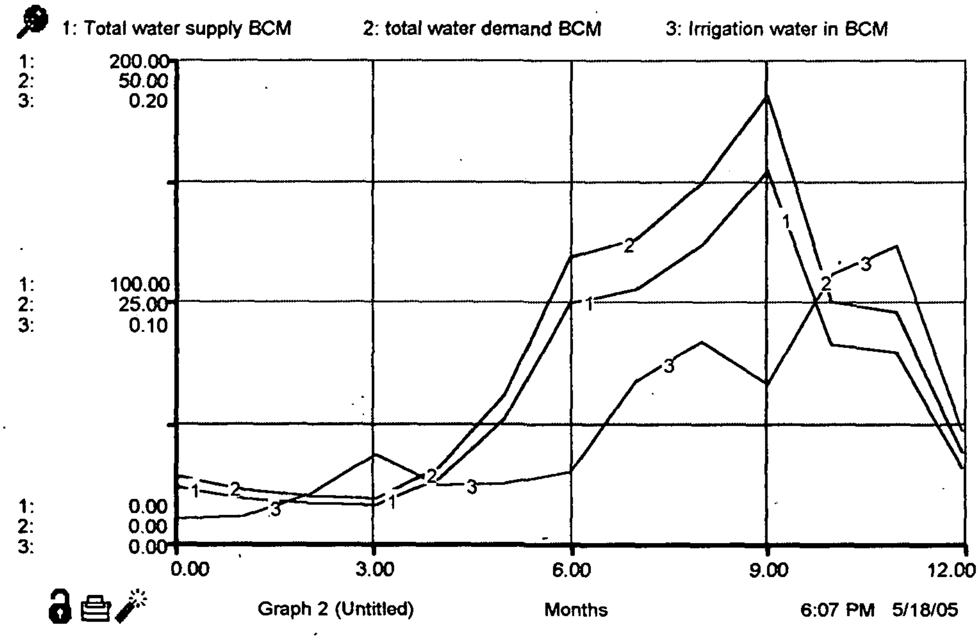
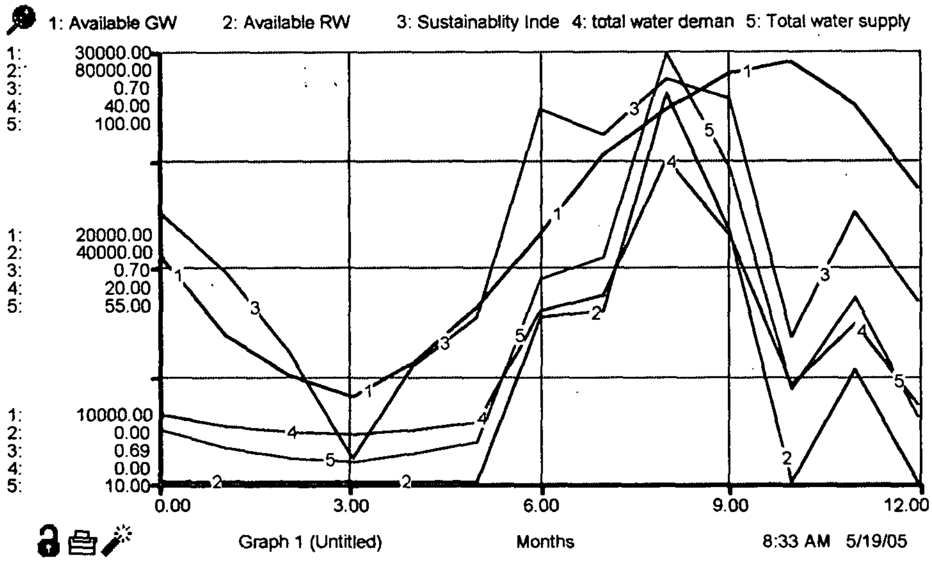


Figure 6.10 Seasonal Variations in Water Consumption and Availability (2025)



RW = River Water, GW= Ground Water, Suppl= Supply, Deman=Demand, BCM= Billion Cubic Meter

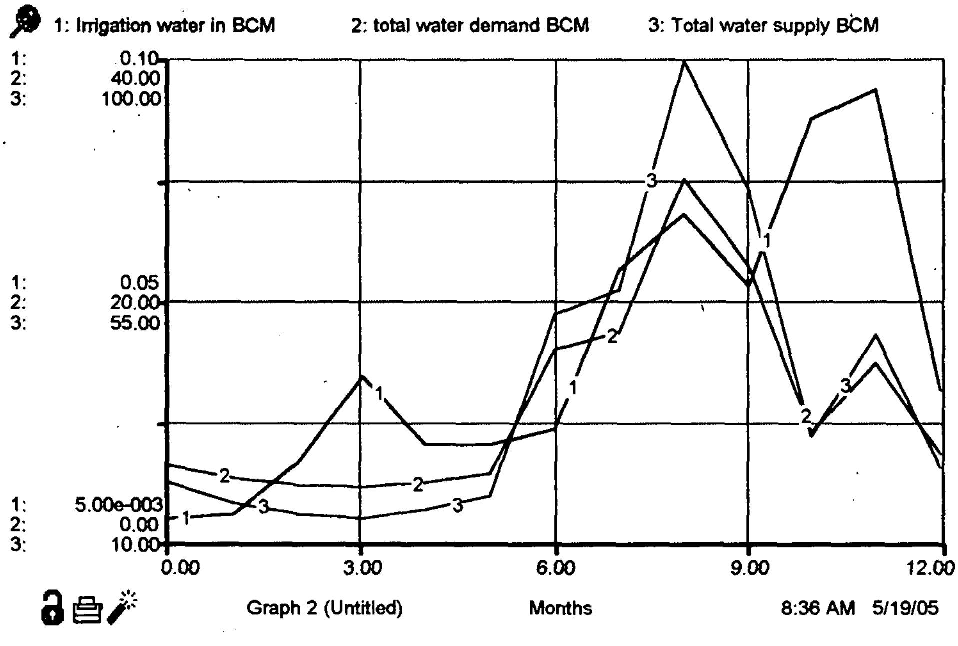


Figure 6.11 **Seasonal Variations in Water Consumption and Availability (2050)**

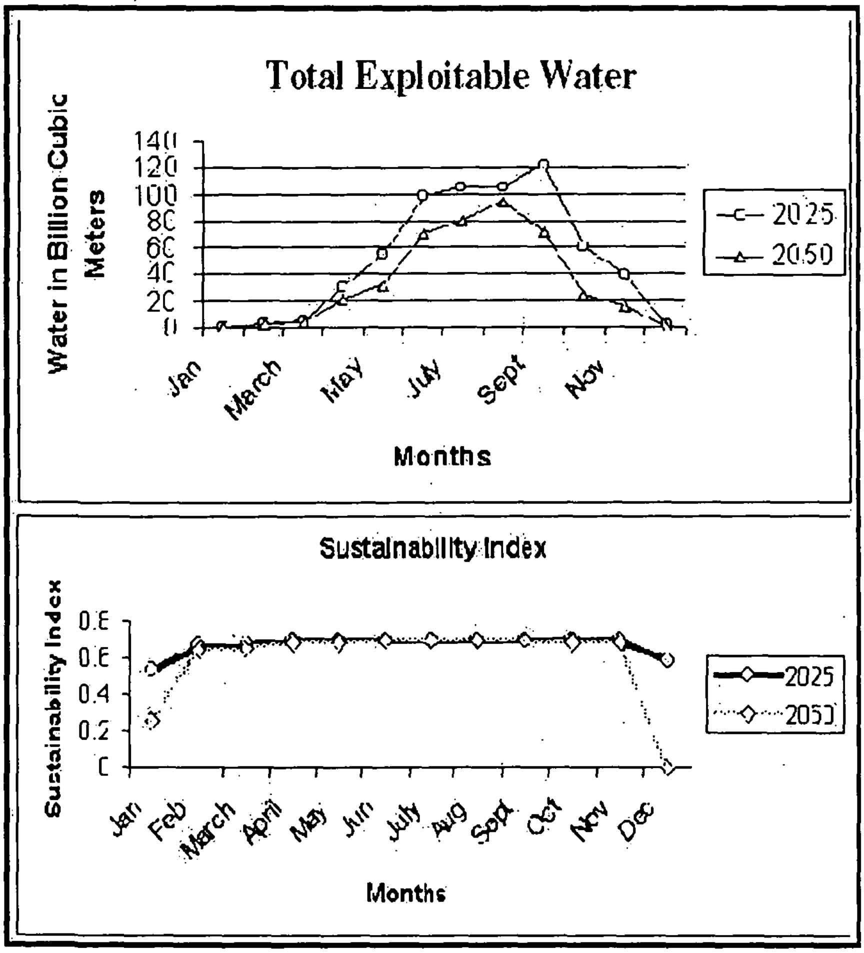


Figure 6.12 Comparative Status of Water Availability

6.9.2 Scenario Comparison

Graphs in Figure 6.12 shows the comparative status of Total Exploitable Water (Total Forecasted Availability – Total Forecasted Consumption) and Sustainability Index for the Brahmaputra Basin during the year of 2025 and 2050. It has been clearly revealed that the Total Exploitable Water for the basin has gone down substantially during 2050 throughout the months. It has also been revealed that the Sustainability Index although remain mostly above 0.60 from March to November in both the years, the same has gone down drastically during January in 2050 and touched 0.00 during December 2050. It has been mentioned earlier that 0.20 is the benchmark for Sustainability Index and therefore, water status for Brahmaputra Basin during 2050 is a matter of concern.

Based on the discussions above it can be concluded that,

- Water consumption pattern for Brahmaputra Basin has showed a rising trend when simulated with BRSD model for the period 2025- 2050.
- Water availability in the River Basin has showed wide seasonal variation.
- Water supply remained more or less same whereas the consumption has been rising; therefore water availability status for the basin has been going down over the years.
- With the present consumption pattern the basin will face water scarcity during the lean season (December to February) before the year 2050.
- Flood storage reservoir to store excess water during high flood and augment flow during lean season may be an option.

6.10 Comparison with earlier studies :

The Brahmaputra Basin has not been studied extensively till now. There has been no report of any study to assess the dynamics of water availability and consumption using System Dynamics theory. Most of the studies that the author came across (dealing with Brahmaputra River Basin) have been done as part of routine government business. Simulated results of some of the parameters of BRSD model developed as part of the present study have been compared with the available reports and presented in Table 6.6

Table 6.6 Comparison with other studies

Parameter	Year of Projection	Projected Value		Reference	Procedure / Method used for making projection
		BRSD	Other study		
Total Population	2010	30.24 Million	30.11 Million	NEDFI, 2005	Not available
Population Water Consumption	2050	4.77 BCM	5.147 BCM	Mohile 2001	The referred study includes farm animal water as well. Detailed procedure not available
Total Population	2016	32.72 Million	29.7 Million	GOI, 1999	Not available

6.11 Chapter Summary:

In the present chapter applicability of **BARISS** framework through a case study approach on Brahmaputra River (one of the largest river system of the world extending over 4 countries) has been discussed .The internet implementation part of the prototype DSS built as test case of BARISS and named as **BRISS** (*B*rahmaputra *R*iver *I*nformation and *S*imulation *S*ystem) has been discussed first followed by different menu options and user interface. The validation, sensitivity analysis of the Brahmaputra River SD model (BRSD)(a part of BRISS) has also been presented. The utility of BRISS has been explained through some examples of scenario generation and comparison with earlier studies.

In the next chapter this study has been summarized and conclusions has been drawn with a brief discussion on limitations of the study and scope for future work.

Chapter VII

Summary and Conclusion

Scarcity of fresh water in the face of increasing demand is of major concern for policy planers, scientists and water professionals. This thesis is an attempt to address some of the complexities associated with the river decision making process, make it simpler (through use of modern tools and approaches) and available for public sharing. A review of the currently available water resources related tools approaches and literature has been done with the purpose of evaluating their real time capabilities, interfacing functionality and public accessibility. The review provided the rationale for development of a model driven DSS with web based interface for public sharing of information, offering technological transparency and assistance in participatory decision making.

A generic DSS framework on river basin scale with web based interface has therefore been developed as a part of the study and named as **BARISS**: *B*asin *A*nd *R*iver *I*nformation and *S*imulation *S*ystem. Water availability and consumption pattern in any river basin is time as well as space variant. Scenario of future water availability, consumption etc. are important constraints in decision making which needs to be visualized so as to evolve an effective strategy/planning of water resources consumption and distribution keeping availability in mind. This requires understanding the behavior pattern of future use, therefore System Dynamics (SD) has been considered as an appropriate tool for building the model base of BARISS.

To assess and simulate water availability on river basin scale, adequate information on water availability and consumption (like flow records, population information, industry information etc.) is required. Also, growing concern for river demands that such information generated by the various agencies be properly stored, shared, exchanged and used for scientific analysis and policy planning. To facilitate this an information system component has been incorporated in **BARISS** with web based user interface for easy sharing.

The important features of this study are

I. Development of a dynamic, model driven and web based DSS for water resources on river basin scale (named **BARISS**) and in doing so built

   a) A River Basin System Dynamics Model to assess dynamics of water consumption and availability,

   b) A web based information system for a large river basin using RDBMS concept;

II. Testing applicability of the framework so developed using a case study approach,

Brahmaputra River (one of the large river systems of the world) has been selected as case study river system as no earlier studies on similar line was ever carried out for this river. Another reason for selecting Brahmaputra river has been that, Government of India has an ambitious project for inter linking of all the rivers of India, which has been of concern to the neighboring country of Bangladesh, and also to the general public, environmental scientists of the Brahmaputra Basin. The test case of BARISS framework on Brahmaputra Basin has been named as **BRISS** (**B**rahmaputra **R**iver **I**nformation and **S**imulation **S**ystem). The information system part of BRISS has been built using RDBMS software ORACLE 8i and ORACLE web DB has been used to provide web access to ORACLE database. 12 agencies responsible for data generation on various aspects of the river basin (like flow records of Brahmaputra and it's tributaries, information regarding weather, ground water, water quality, agriculture, land, population, industry and irrigation of the river basin) have been considered for building the database of the Brahmaputra River basin. The Brahmaputra River Basin SD Model (BRSD) has been built using SD software 'STELLA research version 5'. While building BRSD model, about 285 variables (see APPENDIX-D1) have been used to represent 5 sectors, namely, population, irrigation, industry, basin water and sustainability. The part of the river basin passing through Assam, a state in India, has been considered for the model. 30 years data (1971-2001) has been used for model validation. The parameters used for validation were Population (urban, rural and total population), Land (forestland, urban land and irrigated land) and Industry (industrial fixed capital and industrial working capital). Sensitivity of the river basin water status to some selected parameters were assessed through sensitivity analysis .11 variables have been identified for representing system state of population, land / irrigation, industry and sustainability. 19 parameters have been analyzed to examine their impact on the system states. The sensitivity results demonstrated that the model could be used for effective prediction of the system's behavior. After the sensitivity analysis BRSD model has been used for scenario generation for the year 2025 and 2050. Some scenarios representing normal and high use rates have been evaluated and compared with earlier studies. Since wide fluctuations were observed regarding water availability when minimum, mean and maximum values of flow in the river and its tributaries were used for simulation, therefore, to assess dynamics of monthly availability forecasted time series data has been used. The forecasting of time series data has been done using Monte Carlo Simulation.

The test simulations for the Brahmaputra River basin demonstrates that

- Water consumption pattern for Brahmaputra Basin has showed a rising trend during the years from 2025 till 2050.

- Water availability in the River Basin has showed wide seasonal variations.
- Water supply remained more or less same primarily because there has not been any significant change in the inputs for supply (like rainfall, tributary discharge etc.) whereas the consumption has been rising; therefore water availability status for the basin has been going down over the years.
- With the present consumption pattern the basin will face water scarcity during the lean season (December to February) before the year 2050.
- Flood storage reservoir to store excess water during high flood and augment flow during lean season may be an option.
- Considering the seasonal fluctuations in water availability, construction of flood storage reservoir (that stores water during high flood to augment flow during lean flow) may be considered as a policy option.

The present study has been carried out to narrow the research gap for an easy to use, dynamic, real time capable and web based DSS for water resources on river basin scale. A new web based DSS framework (named **BARISS**: **BA**sin **A**nd **R**iver **I**nformation and **S**imulation **S**ystem) has been introduced. **BARISS** has two systems, namely, an information system and a simulation system. The information system part of BARISS has been built using RDBMS concept and simulation system has been based on system dynamics theory. The new DSS framework (**BARISS**) has been tested using case study approach on Brahmaputra River and named as **BRISS** (**B**rahmaputra **R**iver **I**nformation and **S**imulation **S**ystem). The DSS has been presented as web site and implemented through thick client and thin server approach. Implementation of **BARISS** framework through **BRISS** demonstrates that it can be successfully used as Web based DSS for any large river system.

Although a few examples of policy analysis have been done for demonstration using the prototype DSS (**BRISS**), the main focus of the study has been to build and test a generic web based DSS framework for water resources management on basin scale and test it's applicability in a real river basin rather than make detail policy analysis for any particular basin.

Specific Contribution made through the study

A Dynamic, web based and generic Water Resources Decision Support System framework on River Basin Scale (named **BARISS**) has been developed through this study. **BARISS** has a River Basin SD model as model base and an information system component for information sharing. The BARISS framework has been successfully tested on Brahmaputra Basin in India through **BRISS.**

There are many River Basin DSS developed over the years. Only a few of them are available for public sharing and none of them are based on System Dynamics method. This makes BARISS unique in the sense that it uses predictive and analytic capabilities of System Dynamics to address the complexities associated with the dynamics of water availability and consumption on river basin scale.

Since the works on System Dynamics reported by Forrester (1961), this method has been applied to a number of environmental studies. Only in the recent past System Dynamics method has been used for water resources modeling. Most of these models are site specific. The River Basin System Dynamics model in **BARISS** has been designed as generic one applicable to any river basin across the world but more suitable for developing countries. Also most of the earlier models addressed the water consumption dynamics of river basin effectively but NOT the water supply dynamics. In the present study, some efforts to address the dynamics of water supply in a river basin have been initiated through the River Basin System Dynamics model of **BARISS**.

Problems of River Basin Water Resources are both temporal as well as spatial in nature. System Dynamics has been used to model and simulate temporal behavior of water resources problems in earlier models but NOT spatial aspect. In the present study this aspect has been addressed by decomposing the river basin into smaller sections to get reasonable spatial resolution.

Brahmaputra River is one of the large river systems of the world. It is unfortunate that there is no information System and/or DSS available for this important river basin. The water resources of this river is a matter of conflict between India and Bangladesh because Government of India has an ambitious project for inter linking of all the rivers of India, which has been of grave concern to Bangladesh, and also to the general public, environmental scientists of the Brahmaputra Basin. The **BARISS** framework developed through this study has been tested on Brahmaputra Basin and presented as web based DSS named **BRISS** (**B**rahmaputra **R**iver **I**nformation and **S**imulation **S**ystem). Being the only available web based DSS for Brahmaputra basin; **BRISS** can be used as conflict resolution tool and also as a tool for policy analysis and information sharing of the water resources of the basin.

Limitations

The study has a few limitations. They are -

(a) The supply dynamics of the River Basin (Basin Sector) as proposed in **BARISS** framework (dividing the River Basin into sections to incorporate spatial dimension) could not be demonstrated in true sense in **BRISS** due to difficulties in getting historical data.

(b) New software and hardware are being made available in the market everyday making the earlier versions obsolete.

Although efforts have been made to use the state of the art software available at present for designing the DSS, it is likely that the same may have to be modified periodically.

(c) Being a web based DSS; there are costs involved for access and hosting.

(d) The SD models of the DSS have been validated for Brahmaputra Basin from the data available through state Government agencies. Using the model for any other Basin will require it to be validated for that location.

Scope for future work

I. Spatial Component: It has been well understood during the course of this study that spatial representation is critical to river basin problem solving. Spatial component in River Basin SD Model in present study has been incorporated by use of a series of stocks and flows. However, it has been felt that this aspect needs further work. Another approach to address this aspect may be by building effective linkage and co-evolution between SD and GIS as GIS excels in spatial representation but unlike SD lacks the predictive and analytic capabilities necessary to examine complex problems.

II. Web access to river basin Information System: During implementation of the DSS framework BARISS, software ORACLE Web DB was used for web access to river basin database. Other approaches (like using JAVA with TOMCAT server) may be used in future work.

III. Considering low bandwidth available in most developing countries the testing of prototype DSS for Brahmaputra basin (BRISS) has been done using thick client and thin server approach, the other approach i.e. thin client and thick server approach may be tried wherever suitable.

IV. The River Basin System Dynamics Model can be modified and new sectors may be added to incorporate pollution and other aspects.

V. The web site that presents the DSS may be modified to incorporate many more information about the basin, discussion forum etc.

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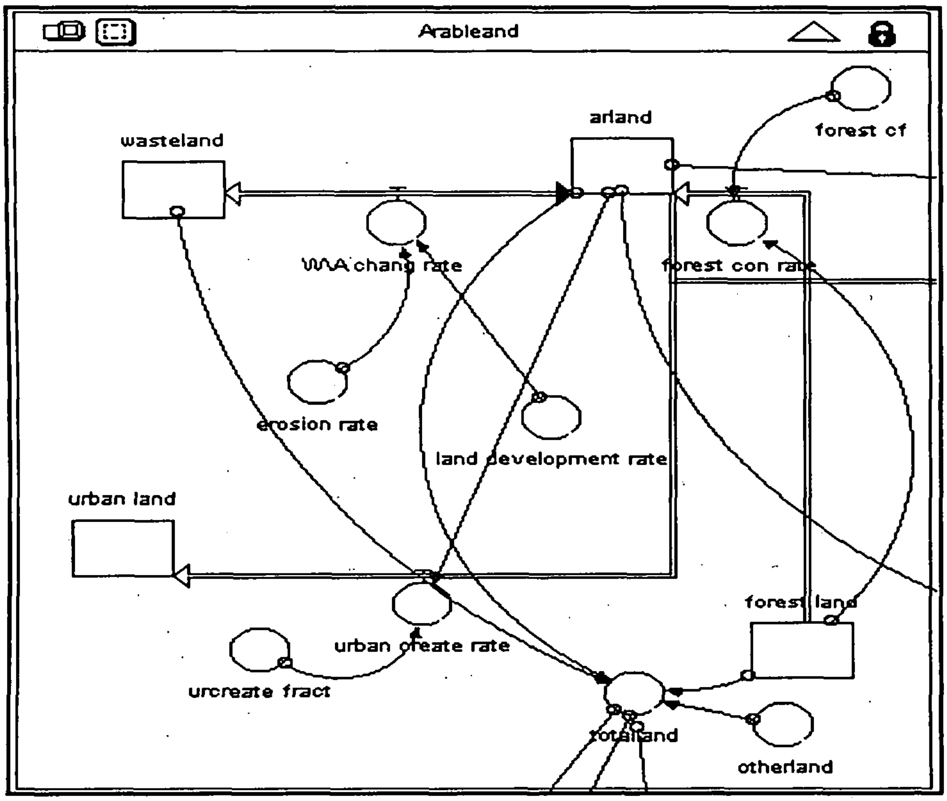
APPENDIX -A

(Supplement to Chapter 4 : River Basin SD Model)

Irrigation Sector:

In STELLA flow diagram of Brahmaputra river SD Model, irrigation sector has been divided into four sub sectors, namely, 'arableland', 'irrigated land' and 'irrigation water'.



FigureA a1 **Stella flow diagram of arable land sub sector**

In the arable land sub sector (Figure A a1), arable Land ('arland'), Waste land ('wasteland'), Forest land ('forestland') and urban Land ('urban land') have been taken as stock. Forest Conversion rate ('forest con rate'), Urban Creation Rate ('urban creat rate') and Waste Land to Arable Land ('W\A change rate') are flows taking place to/from the Arable Land.

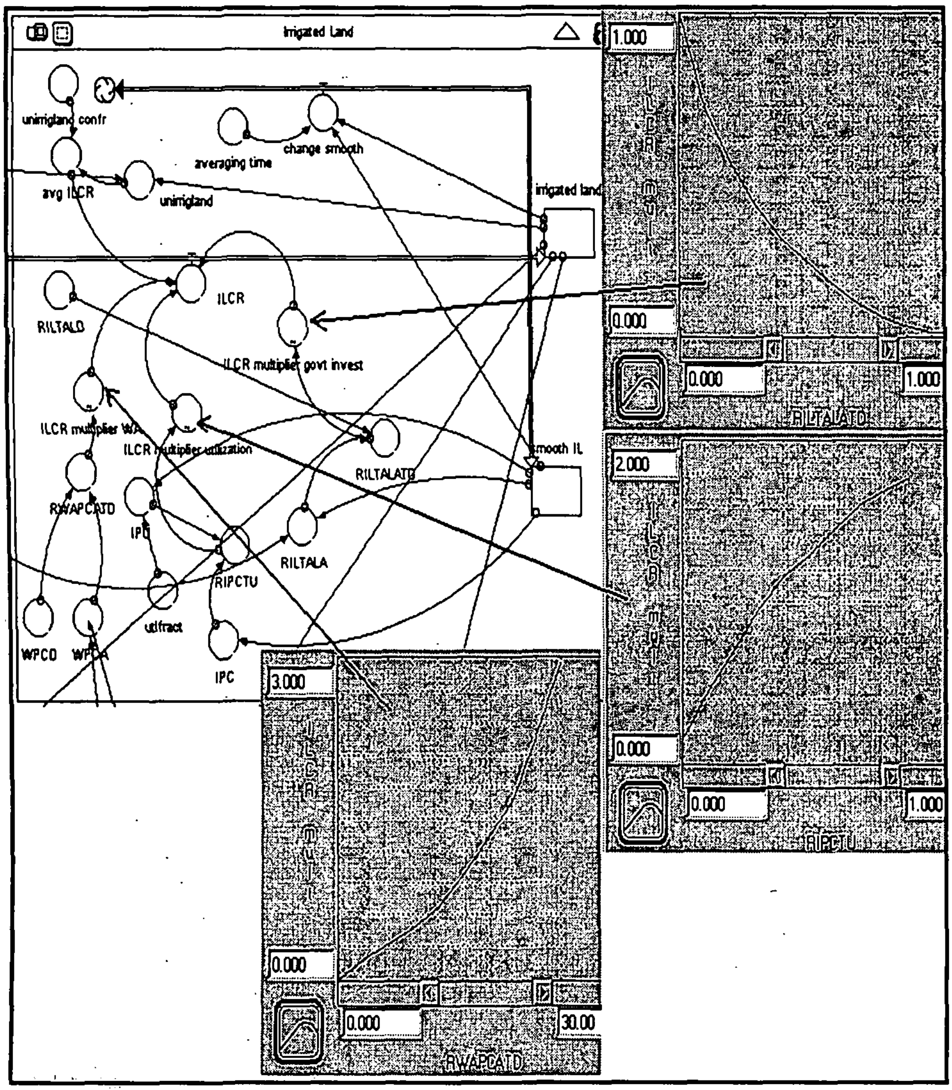


Figure A a2 **Stella flow of diagram irrigated land sub sector**

Arable Land gets converted to Irrigated Land (Figure A a2) through Irrigated Land Conversion Rate (ILCR) and this conversion rate depends on water availability, water utilization, and government investment. Water availability depends on ratio of actual water per capita for the basin to desirable (RWAPCATD). Utilization depends on ratio of irrigation potential created to irrigation potential utilized (RIPCTU) and government investment depends on ratio of irrigated land to arable land (actual) to ratio of irrigated land to arable land (desired).Average ILCR (avg ILCR) has been assumed as fraction of unirrigated land (discrepancy between irrigated land and arable land). The stock "Smoothed IL" has been the smoothed stock of "Irrigated land". The crop areas under different crops have been taken as fraction of "Smoothed IL". The water requirement for each crop has been determined as per procedure given by Doorenbos and Pruitt (1977) and explained in chapter 6.

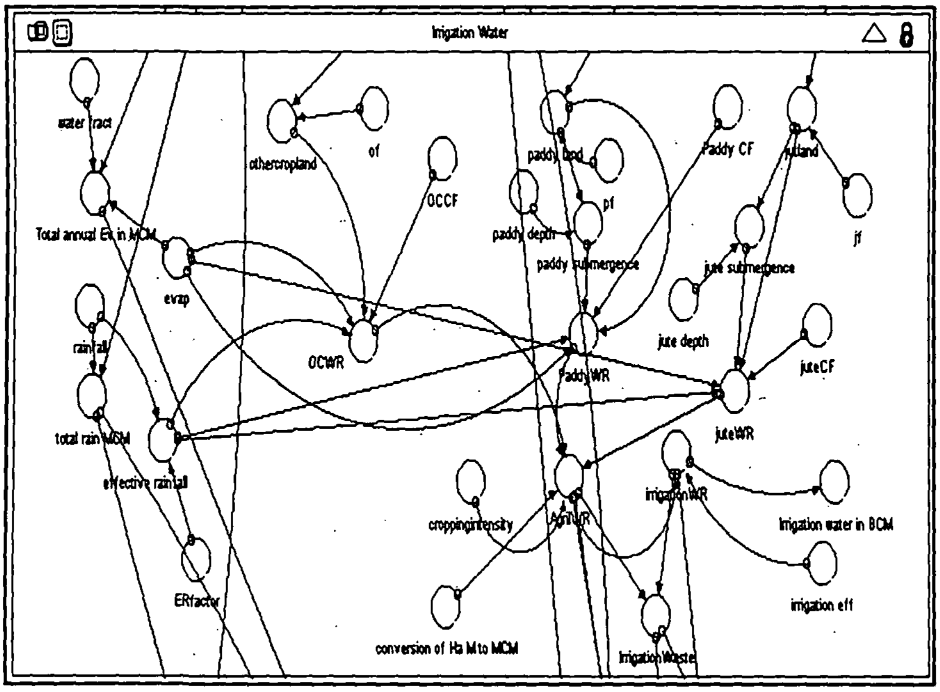


Figure A a3 <u>**Stella flow diagram of irrigation water sub sector**</u>

The Agricultural water Requirement (AgriWR) has been estimated as summation of paddy water requirement, jute water requirement and other crop water requirement and also by incorporating cropping intensity.

Irrigation water (irrigationWR) requirement has been estimated by incorporating efficiency of irrigation system.

Industry Sector:

Industry Sector has been divided into three sub sectors, namely, working capital sub sector, fixed capital sub sector and industrial water requirement and waste water generation sub sector. For modeling the industry sector , major industrial activities associated with the river basin should be studied extensively. In the present river basin SD model , industrial activities considered have been agricultural processing, forest products, mineral products, power, textiles and heavy industries. New industrial sector may be added as and whenever necessary.

In the industrial fixed capital sub sector (Figure A a4), 'industrial fixed capital' has been considered as stock with fixed capital inflow rate (FCIR) as flow. It has been observed that 'industrial fixed capital' inflow to any river basin depend on power availability, Infrastructure (Road, Railway and shipping) and law and order situation. Accordingly influence of these factors have been incorporated in the model by introducing multipliers from each of these factors (FCIR multiplier laworder, FCIR multiplier from infrastructure1, FCIR multiplier from infrastructure2, FCIR multiplier from Power). The variables considered have been number of police cases recorded (law and order), Power available per capita actual (PAPCA) and power available per capita desirable (PAPCD), (power availability), Ratio of power available per capita actual to desirable(RPAPCATD), road length per square KM actual(RLPSKA), road length per square KM desirable (RLPSKD), railway track per square KM actual (RTPSKA), railway track per square KM desirable (RTPSKD) and ratio of railway track per square KM actual to desirable (RRTPSKATD) (infrastructure 1 and 2).

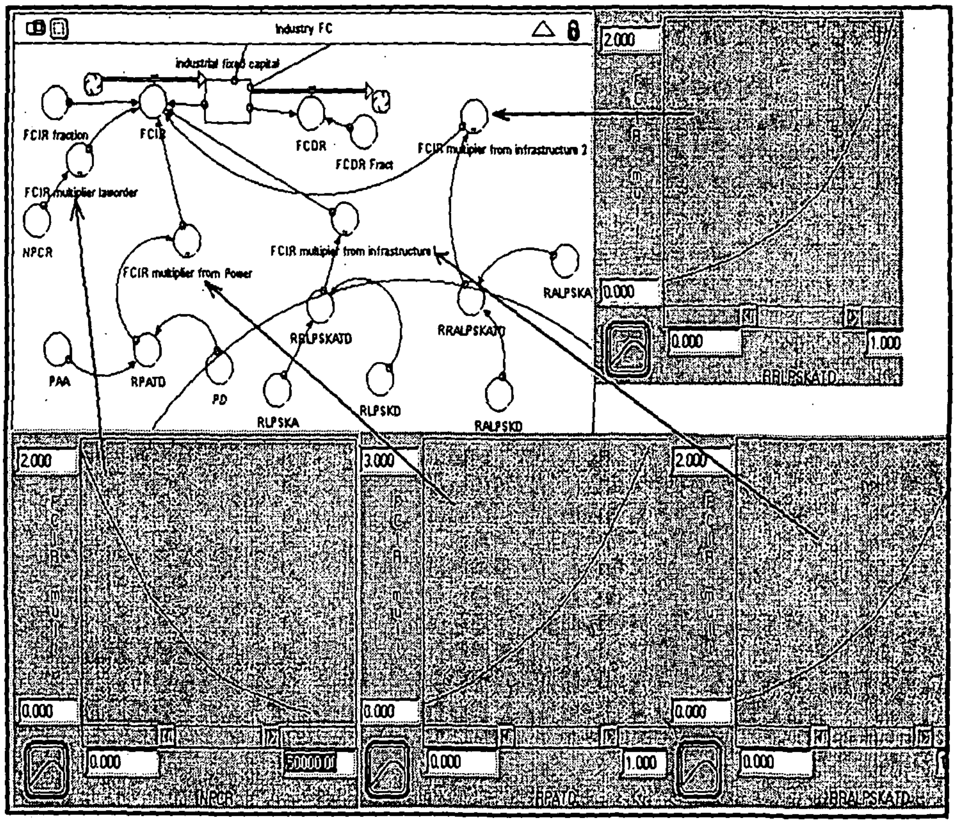


Figure A a4 <u>**Stella flow diagram of industrial fixed capital sub sector**</u>

Working capital for industry depends on production and therefore in the model the Working Capital Inflow Rate (WCIR) has been assumed to be dependent on production of each of the industry activity e.g. agricultural processing, forest products, mineral products, power, textiles and heavy industries. Multipliers for each of these groups have been incorporated in the model. These multipliers have been determined from relational graph of ratio of actual production to desired production (Figure A a5)

In the model the industrial water demand has been estimated by taking into account the actual production of each of these industry and the water required for per unit production of that industry (Figure A a5) . The total wastewater generated has been estimated by taking into account the actual production of each of these industries and the waste water generated from per unit production. Total industrial Water Demand (total industry water demand) and total industrial waste water generated (totalindustry waste water generated) have been estimated as summation from each industrial group.

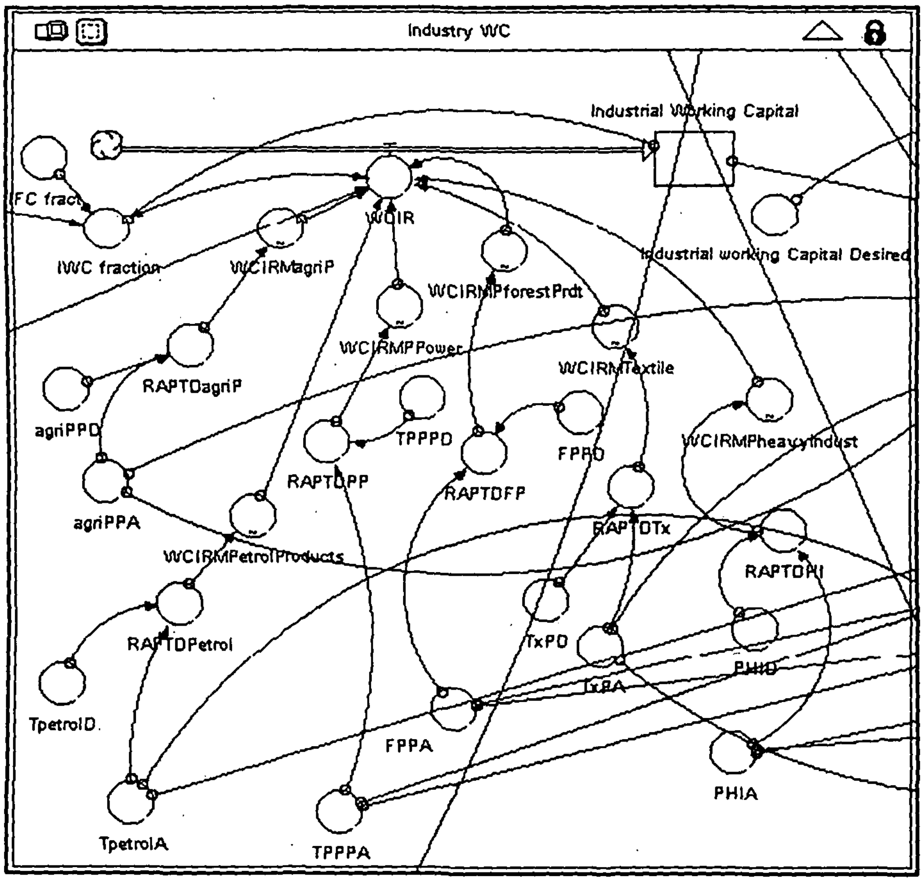


Figure A a5 <u>**Stella flow diagram of industrial working capital**</u>

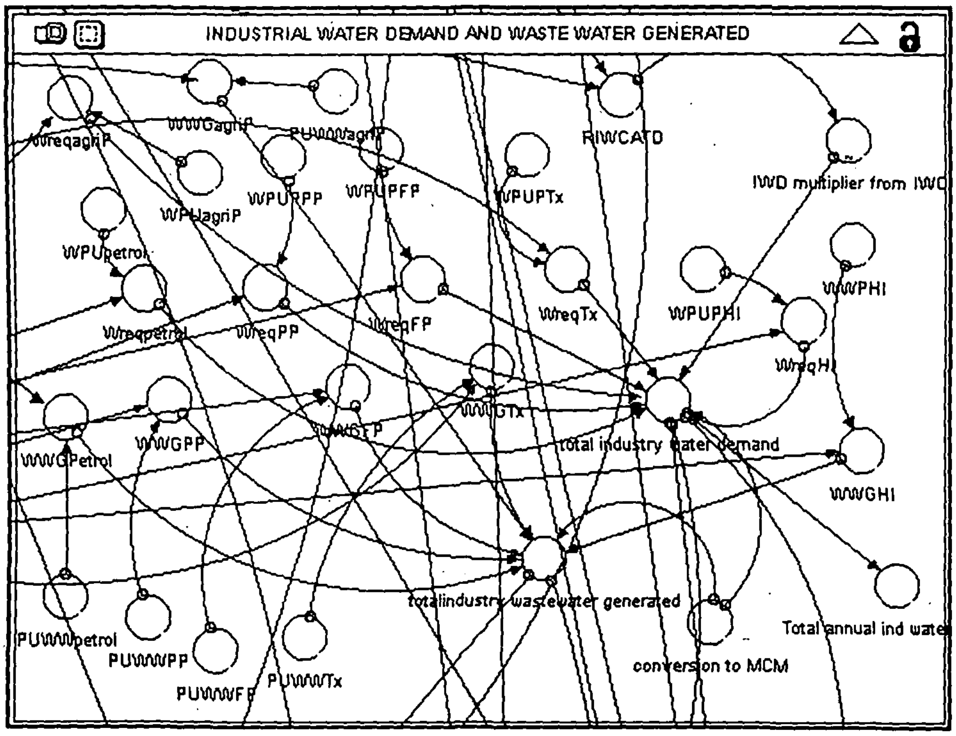


Figure A a6 **Stella Flow diagram of industrial water demand and waste water generated**

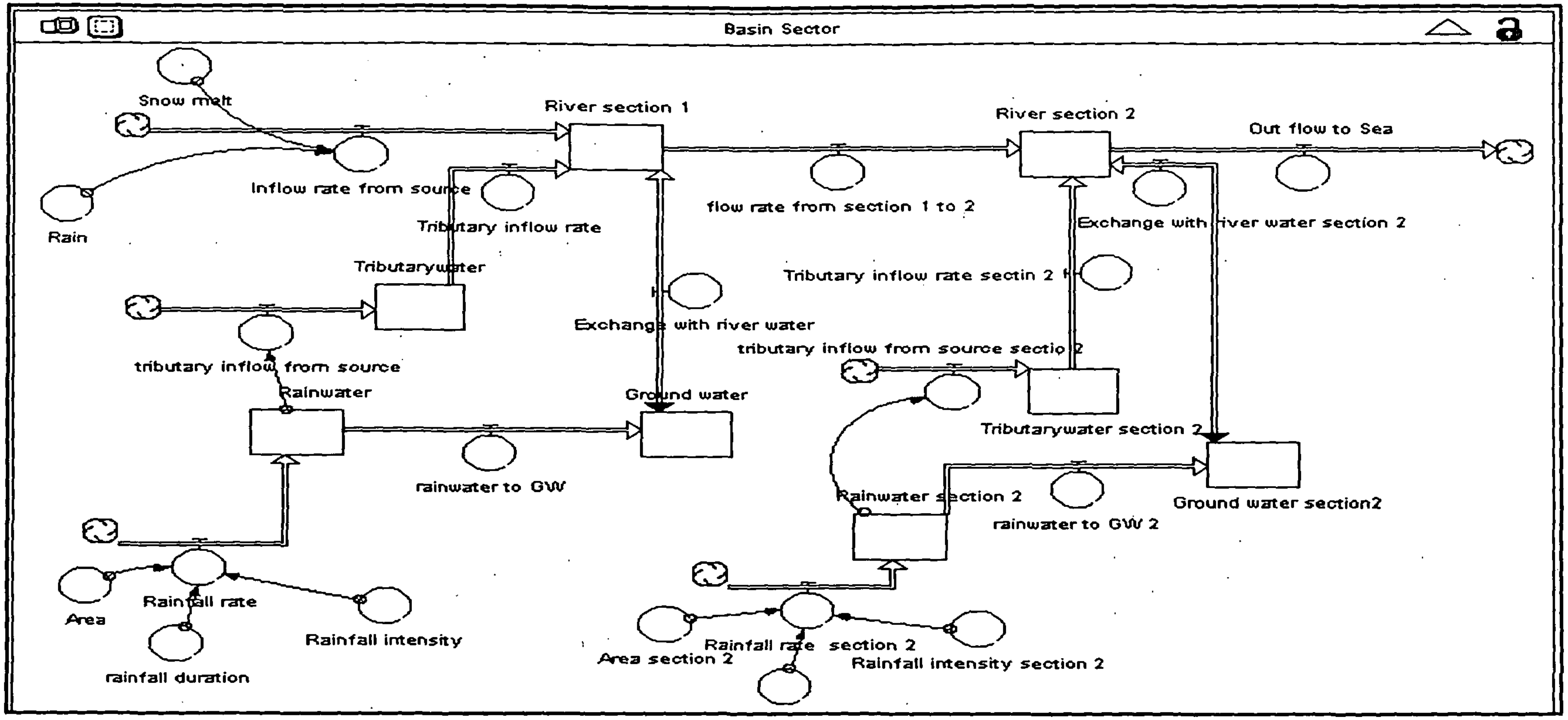


Figure A a7 Stella flow diagram of basin water sector

Basin Sector :

In the basin water sector of the model (Figure A a6) River Water and Ground Water have been considered as stock. Inflow into River Water takes place through 'External Flow' flowing into the basin , 'tributary inflow', 'return flow rate' from uses and 'exchange with GW'. The out flows considered have been to the sea (outflow to sea) and to the sink through consumption (water use rate).

Flow into the Ground Water have been considered to be through exchange and return flow from uses ('return flow to GW'). Flow out of ground water level has been assumed to be through consumption only. ('GW use rate').

Sustainability Sector:

The sustainability of river basin has been determined as

Sustainability Index (SI)

= (Total Water Supply- Total Water Demand)/Total Water Supply.

= 0 when Demand exceeds Supply

The STELLA flow diagram of Sustainability Sector has been presented as Figure A a7

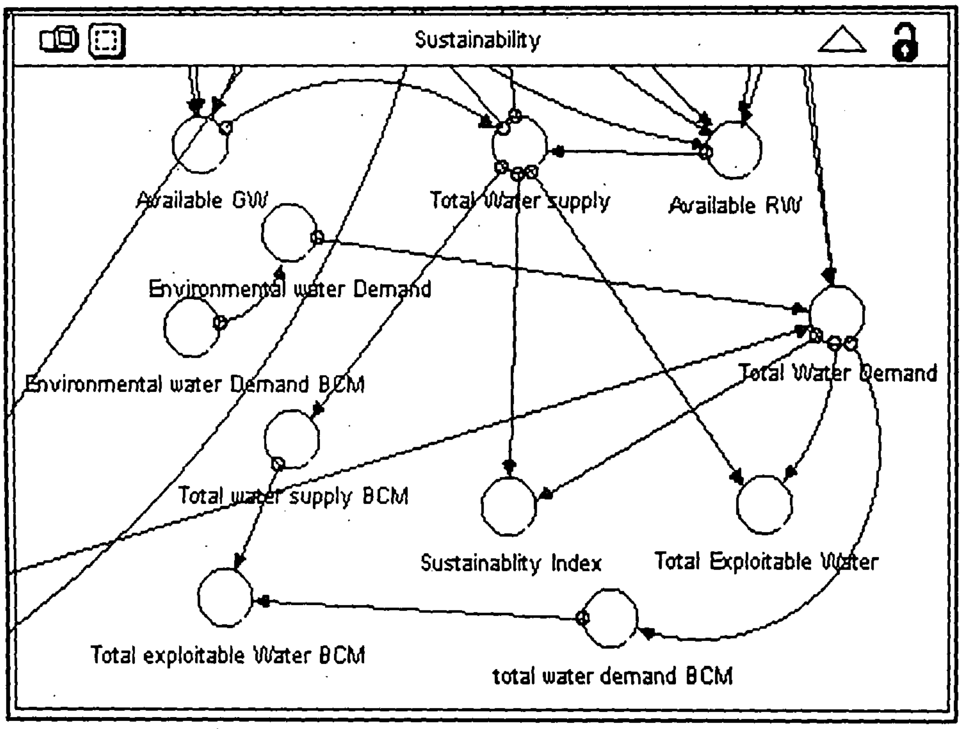


Figure A a8 **Stella flow diagram of Sustainability Sector**

APPENDIX –B (Supplement to Chapter V: River Basin Information System)

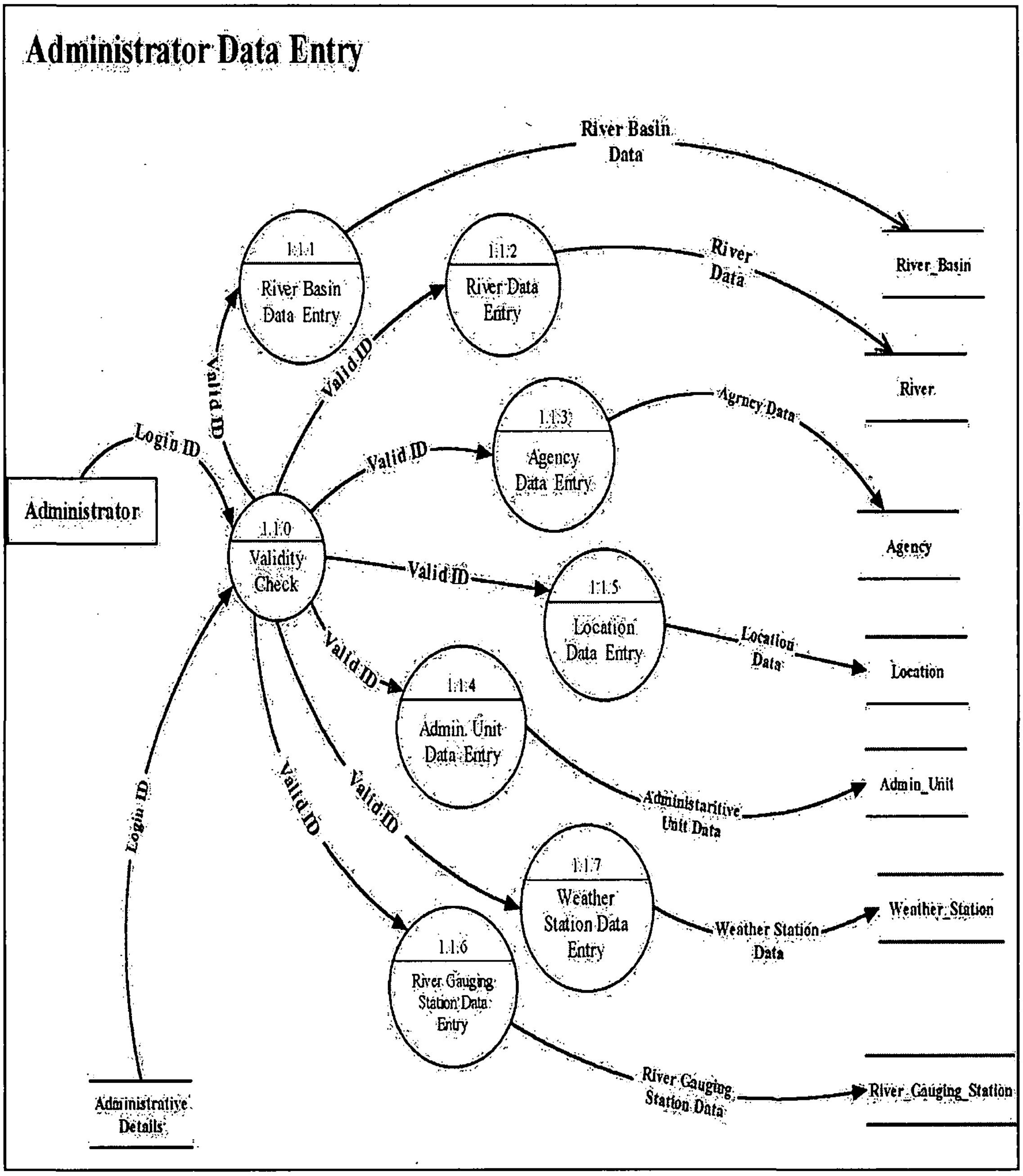


Figure Ab1 **DFD for the Administrator Data Entry**

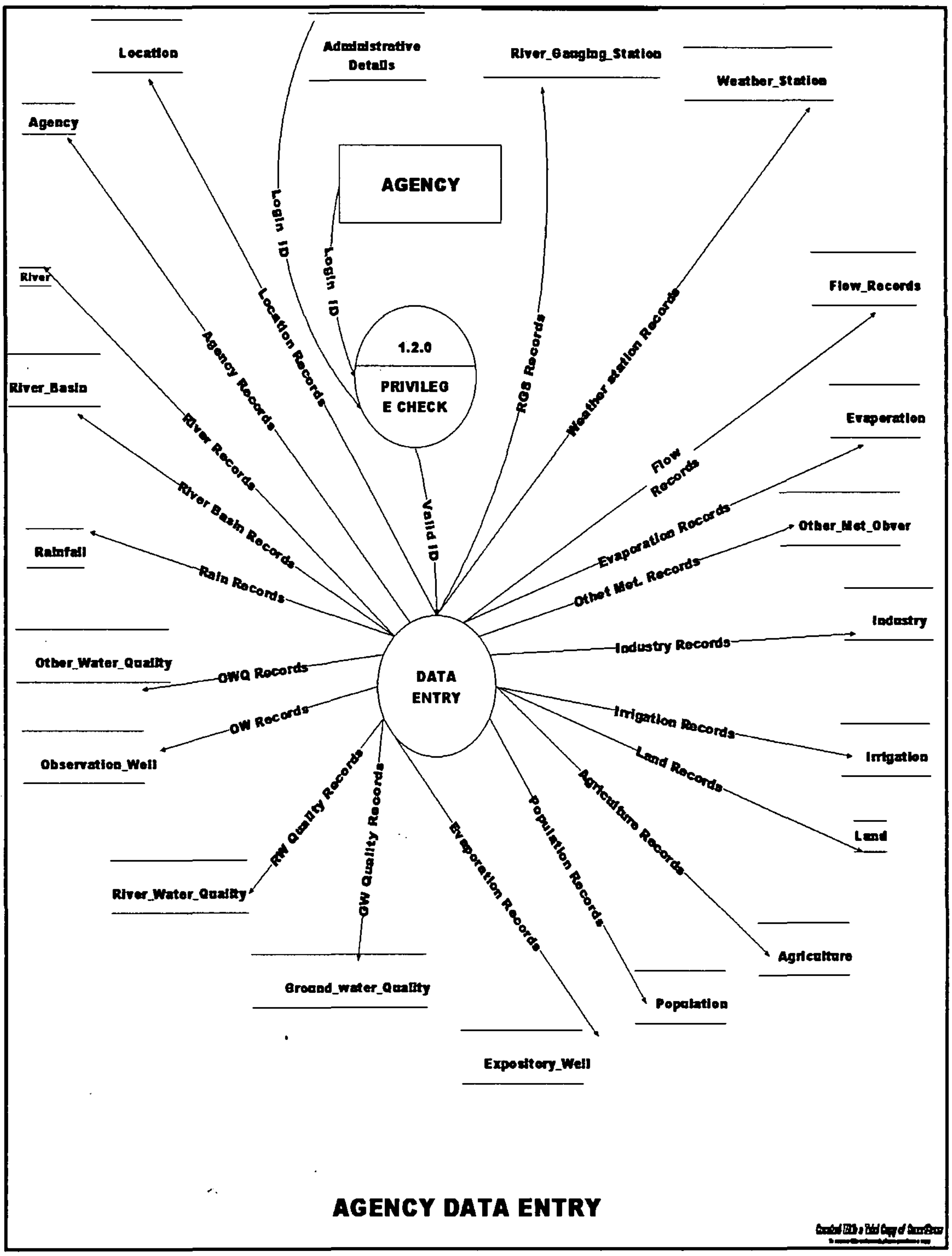


Figure Ab2 DFD of Agency Data Entry

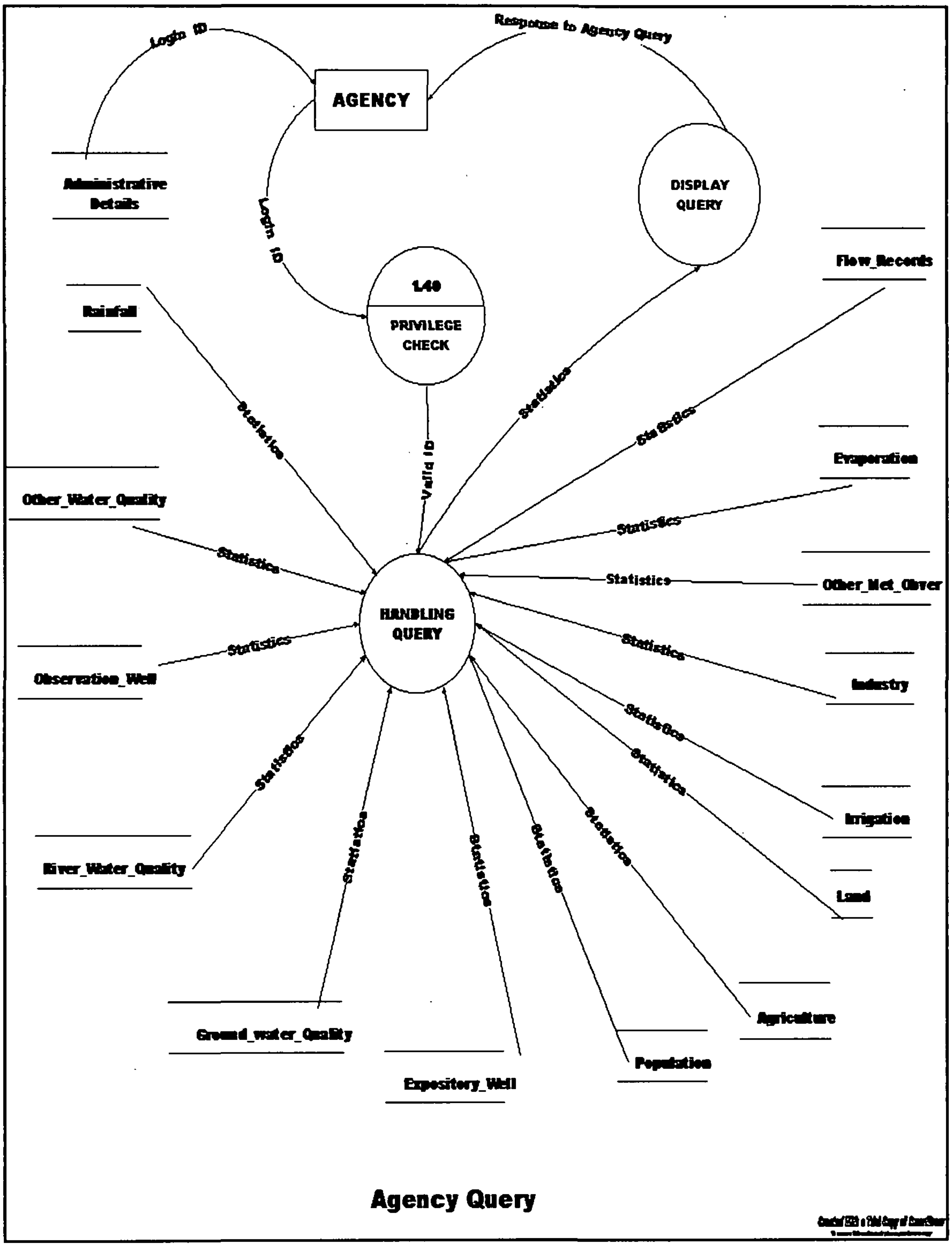


Figure Ab3 <u>DFD of Agency Query</u>

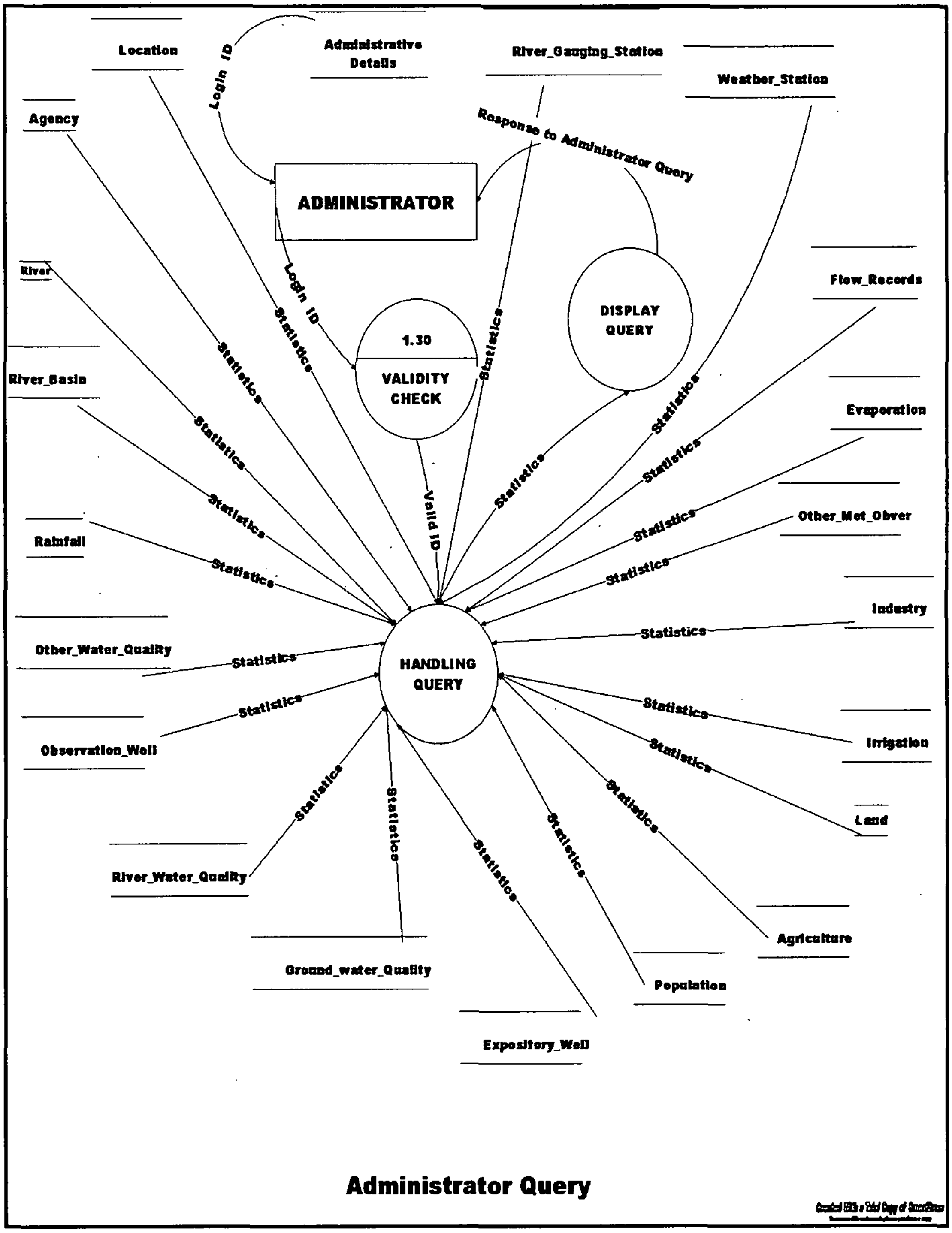


Figure Ab4 <u>**DFD of Administrator Query**</u>

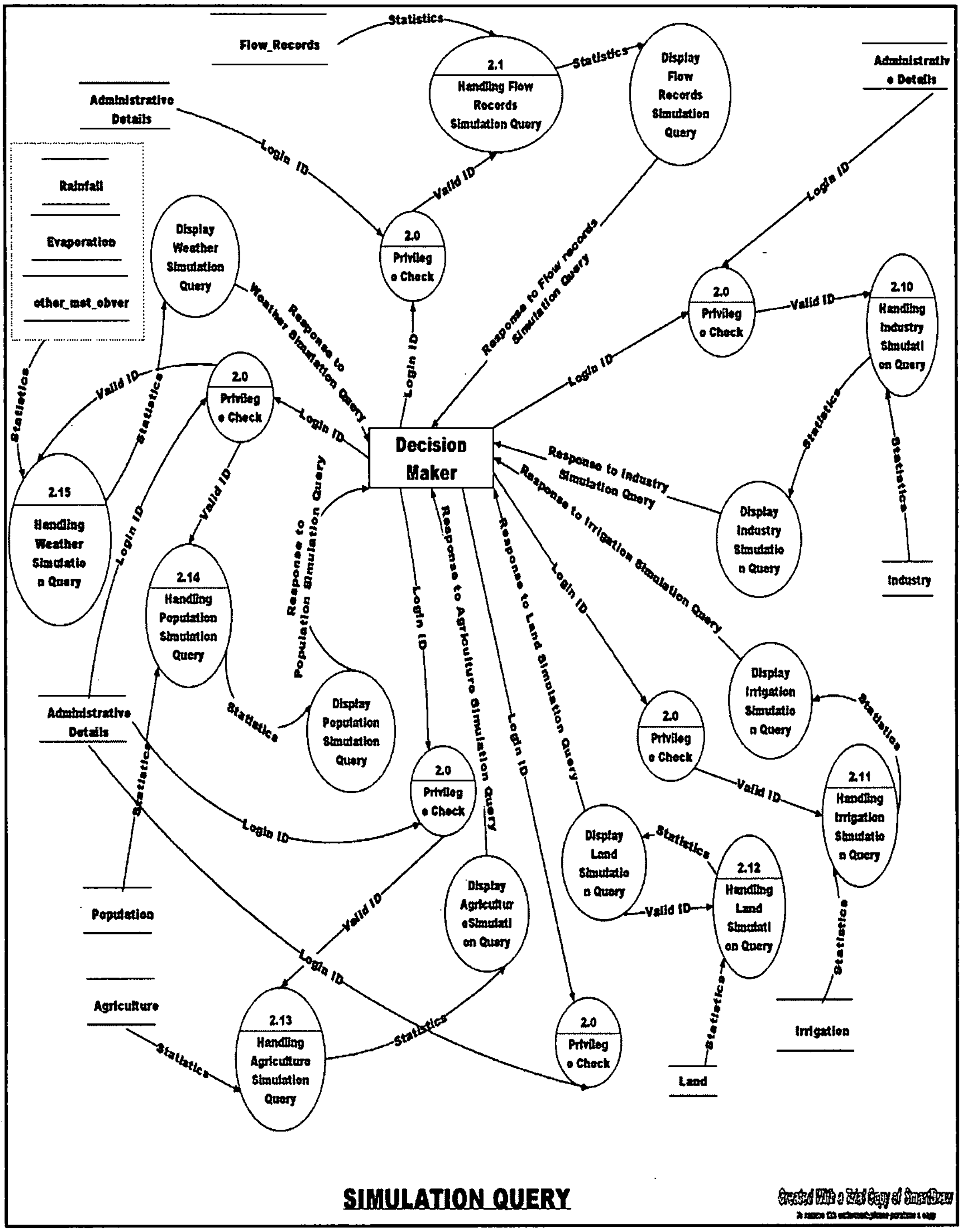


Figure Ab5 **DFD for Simulation Query**

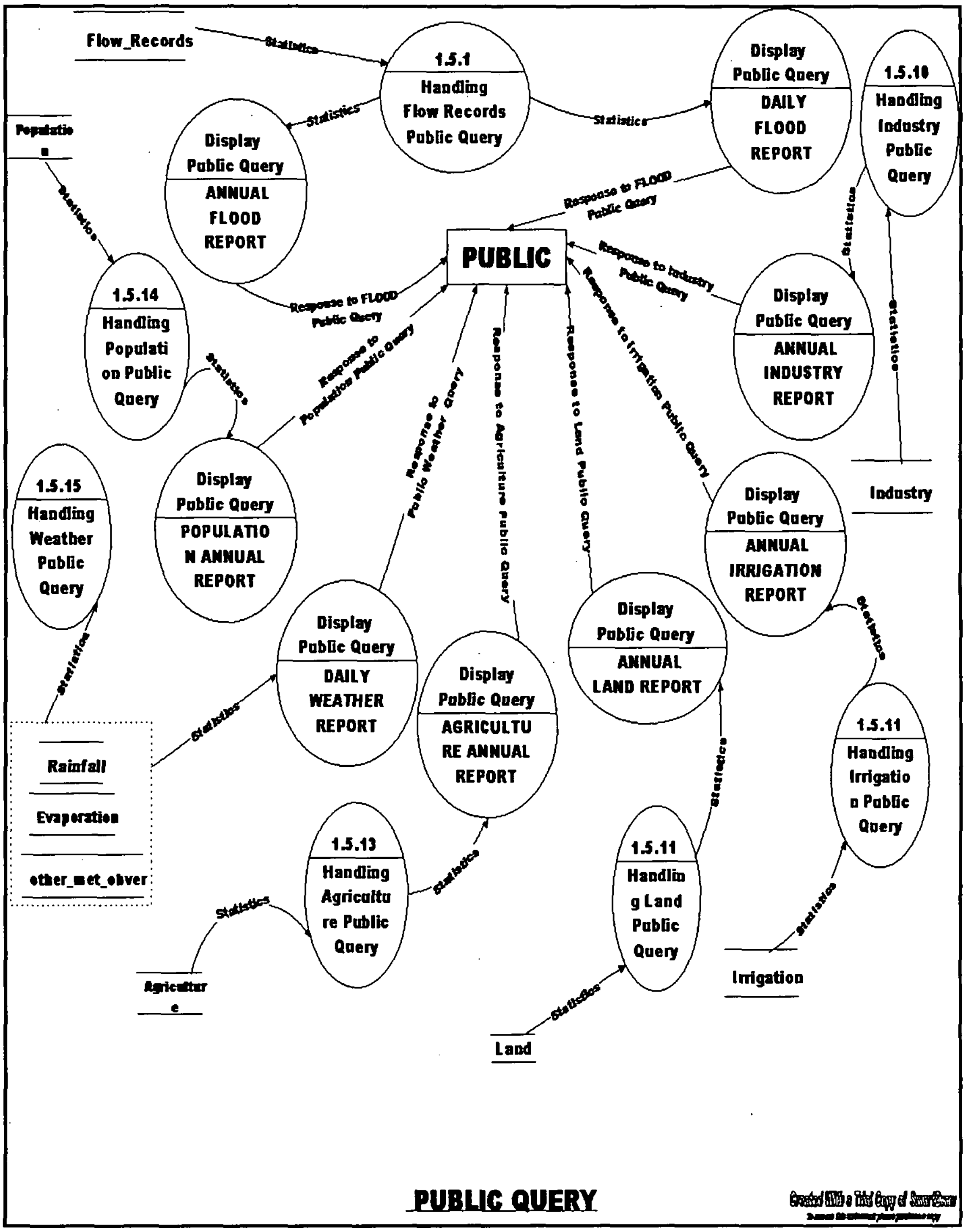


Figure Ab6 **DFD for Public Query**

Data Store Description:

Data Store name : Admin_Details

Description : It stores the information about the administrator.

Data Structure : Login_ID, password

Data Store name : River_Basin_Database

Description : It stores the information about various data related to any large River System for the use of the stakeholders (Agencies involved, Decision-Maker and Public).

Data Structure : Basin_name, AgencyID, LocationID, RiverID etc. The rest are shown in the database description below.

Data Dictionary:

Sl. No	Field Name	Field Description	Field Type	Field Length	Source Table
1	Basin_name	Name of River Basin	Varchar	20	River_basin
2	RiverID	River ID of the river	Varchar	10	River
3	AgencyID	Agency ID of the agency	Varchar	10	Agency
4	AU_ID	Administrative Unit's ID	Varchar	10	Adm_Unit
5	LocationID	Location ID of the location	Varchar	70	Location
6	RGS_ID	River gauging station's ID	Varchar	50	River_Gauging_Station
7	WS_ID	Weather Station's ID	Varchar	50	Weather_Station
8	FRDate	Flow record date	Varchar	10	Flow_Records
9	O_Well_No	Observation well number	Varchar	30	Observation_well
10	OWRDate	Observation well record date	Varchar	10	Observation_well
11	E_Well_No	Expository well number	Varchar	30	Expository_Well
12	EWRDATE	Expository well number	Varchar	10	Expository_Well
13	RWQDate	River water quality date	Varchar	10	River_Water_Qlty
14	Gr_W_QDate	Ground water quality date	Varchar	10	Ground_Water_Qlty
15	O_W_QDate	Other water quality date	Varchar	10	Other_Water_Qlty
16	RRDate	Date of Rainfall record	Varchar	10	Rainfall
17	Evar_date	Date of Evaporation record	Varchar	10	Evaporation
18	Other_obs_Date	Other Meteorological Observation Date	Varchar	10	Other_met_obver
19	Ind_Rec_Year	Industry record year	Varchar	10	Industry

20	Irri_Rec_Year	Irrigation record year	Varchar	10	Irrigation
21	Land_Rec_Year	Land record year	Varchar	10	Land
22	Pop_Rec_Year	Population record year	Varchar	10	Population
23	Agri_Rec_Year	Agriculture record year	Varchar	10	Agriculture
24	Agri_Rec_Season	Agriculture record season	Varchar	20	Agriculture

Database Description:

List of database table:

Table 1 name **River _basin**

Field name	**Field type**	**Field length**	**Key**	**Description**
Basin_name	Varchar	20	Primary	Basin name
Basin_description	Varchar	3000		Basin description
Table 2 name:	**River**			
RiverID	Varchar	10	Primary	River ID
River_name	Varchar	30		River name
Basin_name	Varchar	20	Foreign	Basin name
River_description	Varchar	1000		River Description
Table 3 name:	**Agency**			
AgencyID	Varchar	10	Primary	Agency ID
Agency_name	Varchar	60		Agency name
Funded_by	Varchar	60		Funded by whom
Fund_breakup	Varchar	60		Fund break up
Table 4 name:	**Adm_Unit**			
au_ID	Varchar	10	Primary	Administrative unit ID
au_name	Varchar	30		Administrative unit name
Basin_name	Varchar	20	Foreign	Basin name
Table 5 name:	**Location**			
LocationID	Varchar	70	Primary	Location ID
Location_name	Varchar	30		Location name
AU_ID	Varchar	10	Foreign	Administrative unit ID
Location_descr	Varchar	100		Description of location
Table 6 name:	**River_Gauging_Station**			
RGS_ID	Varchar	50	Primary	River gauging station ID
RGS_name	Varchar	50		River gauging station name
RiverID	Varchar	10	Foreign	River ID
AgencyID	Varchar	10	Foreign	Agency ID
LocationID	Varchar	70	Foreign	Location ID
Table 7 name:	**Weather_Station**			
WS_ID	Varchar	50	Primary	Weather station ID
WS_name	Varchar	50		Weather station name
AgencyID	Varchar	10	Foreign	Agency ID
LocationID	Varchar	70	Foreign	Location ID

Basin_name	Varchar	20	Foreign	Basin name
Table 8 name:	**Flow_Records**			
RGS_ID	Varchar	50	Foreign	River gauging station ID
AgencyID	Varchar	10	Foreign	Agency ID
FRdate	Varchar	10	Primary	Flow record date
Period	Varchar	20		Period of collecting record
Subperiod	Varchar	20		Subperiod of collecting record
Discharge	Varchar	(10, 3)		Discharge of water
Gauge_level	Varchar	10		Gauge level
Danger_level	Varchar	10		Danger level
HFL	Varchar	10		Highest flood level
HFL_date	Varchar	10		Highest flood level date
Forecast_trend	Varchar	10		Forecast trend (rising, falling etc)
Max_discharge	Varchar	10		Maximum discharge recorded
Max_discharge_date	Varchar	10		Date of max. discharge
Min_discharge	Varchar	10		Minimum discharge recorded
Min. discharge_date	Varchar	10		Date of minimum discharge
Table 9 name:	**Observation_well**			
O_well_no	Varchar	30	Primary	Observation well Varchar
LocationID	Varchar	70	Foreign	Location ID
OWRdate	Varchar	10	Primary	Observation well record date
Season	Varchar	20		Record Season
Depth_to_gwt	Varchar	10		Depth to ground water level
Table 10 name:	**Expository_Well**			
E_well_no	Varchar	30	Primary	Expository well Varchar
LocationID	Varchar	70	Foreign	Location ID
EWRdate	Varchar	10	Primary	Expository well record date
Lithology	Varchar	500		Litho logy
Pump_test	Varchar	200		Pump test
Well_log	Varchar	400		Well log
Table 11 name:	**River_Water_Qlty**			
RiverID	Varchar	10	Foreign	River ID
AgencyID	Varchar	10	Foreign	Agency ID
LocationID	Varchar	70	Foreign	Location ID
RWQ_Date	Varchar	10	Primary	River water quality date
Conductance	Varchar	10		Conductance of river water
PH	Varchar	10		PH of river water
DO	Varchar	10		Dissolved Oxygen
BOD	Varchar	10		Biological Oxygen Demand
Turbidity	Varchar	10		Turbidity of river water

Total_Coliform	Varchar	10		Total Coliform bacteria in river water
Foecal_Coliform	Varchar	10		Total Foecal Coliform bacteria in river water
Ca_as_CaCO3	Varchar	10		Calcium as calcium carbonate
Mg_as_MgCO3	Varchar	10		Magnesium as magnesium carbonate
TDS	Varchar	10		Total Dissolved Solid
Boron	Varchar	10		Amount of boron
Phosphate	Varchar	10		Amount of phosphate
Chloride	Varchar	10		Amount of chloride

Table 12 name: **Ground_Water_Qlty**

AgencyID	Varchar	10	Foreign	Agency ID
LocationID	Varchar	70	Foreign	Location ID
O_Well_No	Varchar	30	Foreign	Observation well Varchar
Gr_W_Qdate	Varchar	10	Primary	Ground water quality date
Conductance	Varchar	10		Conductance of water
PH	Varchar	10		PH factor
DO	Varchar	10		Dissolved Oxygen
BOD	Varchar	10		Biological Oxygen Demand
Turbidity	Varchar	10		Turbidity
Total_Coliform	Varchar	10		Total_Coliform bacteria
Foecal_Coliform	Varchar	10		Foecal Coliform
Ca_as_CaCO3	Varchar	10		Calcium as calcium carbonate
Mg_as_MgCO3	Varchar	10		Magnesium as magnesium carbonate
TDS	Varchar	10		Total Dissolved Solid
Boron	Varchar	10		Amount of boron
Phosphate	Varchar	10		Amount of phosphate
Chloride	Varchar	10		Amount of chloride

Table 13 name: **Other_Water_Qlty**

AgencyID	Varchar	10	Foreign	Agency ID
LocationID	Varchar	70	Foreign	Location ID
O_W_QDate	Varchar	10	Primary	Other water quality date
Sample Source	Varchar	100		Sample source of water
Conductance	Varchar	10		Conductance of water
PH	Varchar	10		PH factor
DO	Varchar	10		Dissolved Oxygen
BOD	Varchar	10		Biological Oxygen Demand
Turbidity	Varchar	10		Turbidity
Total_Coliform	Varchar	10		Total_Coliform bacteria
Foecal_Coliform	Varchar	10		Foecal Coliform
Ca_as_CaCO3	Varchar	10		Calcium as calcium carbonate
Mg_as_MgCO3	Varchar	10		Magnesium as magnesium carbonate

TDS	Varchar	10		Total Dissolved Solid
Boron	Varchar	10		Amount of boron
Phosphate	Varchar	10		Amount of phosphate
Chloride	Varchar	10		Amount of chloride
Table 14 name:	**Rainfall**			
WS_ID	Varchar	50	Foreign	Weather station ID
RRdate	Varchar	10	Primary	Rainfall record date
RRtime	Varchar	10		Rainfall record time
Rain_amount	Varchar	30		Rainfall amount
Rain_gauge_type	Varchar	30		Type of raingauge
Rain_numensity	Varchar	30		Rainfall Intensity
Rain_duration	Varchar	30		Rainfall Duration
Table 15 name:	**Evaporation**			
WS_ID	Varchar	50	Foreign	Weather station ID
EVARdate	Varchar	10	Primary	Evaporation record date
Evaporation	Varchar	10		Evaporation Amount
Ev_meter_type	Varchar	30		Evaporation amount
Evr_record_time	Varchar	20		Evaporation Record Time
Table 16 name:	**Other_met_obver**			
WS_ID	Varchar	50	Foreign	Weather station ID
Other_obver_date	Varchar	10	Primary	Other Met. Observation Record date
Other_obver_Time	Varchar	20		Other Met. Observation record time
temp_humd_i_type	Varchar	30		Type of Temp. and Humidity measuring instrument
Max_Temp	Varchar	15		Maximum temperature
Min_Temp	Varchar	15		Minimum temperature
Avg._temp	Varchar	15		Average temperature
Abs_Humd	Varchar	15		Absolute humidity
RH	Varchar	15		Relative humidity
Anemometer_type	Varchar	30		Type of anemometer used
Max_Wind_Velo	Varchar	10		Maximum wind velocity
Wind_Direction	Varchar	30		Wind direction
Sunshine_Hrs	Varchar	10		Sunshine hours
Table17 name:	**Land**			
AU_ID	Varchar	10	Foreign	Administrative unit ID
AgencyID	Varchar	10	Foreign	Agency ID
Land_Rec_Year	Varchar	10	Primary	Land record year
Forest_Land	Varchar	(20,3)		Forest land
Nonagri_Use_Lnd	Varchar	(20,3)		Non agricultural used land
Brrn_Unclt_Lnd	Varchar	(20,3)		Barren and uncultivable land
Pppst_Ogrss_Lnd	Varchar	(20,3)		Permanent Pasture and other grass land
Lumlreegrniifl	Varchar	(20,3)		Land under Misc. tree grooves
Cult_Waste_Land	Varchar	(20,3)		Cultivable waste land

Fl_o_then_cf	Varchar	(20,3)		Fallow land other than current fallow
Current_fl	Varchar	(20,3)		Current fallow land
Total_Crop_Area	Varchar	(20,3)		Total crop area
Net_Area_Sown	Varchar	(20,3)		Net area sown
Table18 name:	**Industry**			
AU_ID	Varchar	10	Foreign	Administrative unit ID
AgencyID	Varchar	10	Foreign	Agency ID
Ind_Rec_Year	Varchar	20	Primary	Industry record year
Ind_Code	Varchar	30		Industry code
Ind_Type	Varchar	100		Industry type
Ind_Class	Varchar	30		Industry class
Ind_units	Varchar	50		Varchar of industrial units
Table19 name:	**Irrigation**			
AU_ID	Varchar	10	Foreign	Administrative unit ID
AgencyID	Varchar	10	Foreign	Agency ID
Irrg_Rec_Year	Varchar	10	Primary	Irrigation record year
Maj_Irri_Pot_Crea	Varchar	20		Major irrigated potential created
Mi_Irri_Pot_Crea	Varchar	20		Minor irrigated potential created
Irrig_pot_utilzd	Varchar	30		Irrigation potential utilized
Canal_Irrgtd_Ar	Varchar	30		Canal irrigated area
Tankl_Irrgtd_Ar	Varchar	30		Tank irrigated area
Twell_Irrgtd_Ar	Varchar	30		Tube well irrigated area
Table20 name:	**Population**			
AU_ID	Varchar	10	Foreign	Administrative unit ID
AgencyID	Varchar	10	Foreign	Agency ID
Pop_Rec_Year	Varchar	10	Primary	Population record year
Urban_Pop	Varchar	20		Population in urban area
Rural_Pop	Varchar	20		Population in rural area
Male_Pop	Varchar	20		Male population
Female_Pop	Varchar	20		Female population
Table21 name:	**Agriculture**			
AU_ID	Varchar	10	Foreign	Administrative unit ID
AgencyID	Varchar	10	Foreign	Agency ID
Agri_Rec_Year	Varchar	10	Primary	Agriculture record year
Agri_Rec_Season	Varchar	20	Primary	Agriculture record season
Crop_Name	Varchar	20		Name of the crop
Crop_Variety	Varchar	20		Variety of the crop
Crop_Area	Varchar	20		Crop area
Crop_Production	Varchar	20		Crop production

E-R Diagram:

Entity-Relationship (E-R) diagram is the framework used to data modeling for relational database. The E-R diagram for the River Basin Database has been presented as Figure A b7. The ER contains the following Entity and their attributes.

River_Basin	:	Basin_name, Basin_description
River	:	RiverID,River_name, Basin_name, River _description
Agency	:	AgencyID,Agency_name,Funded_by, Fund_breakup
Adm_Unit	:	au_ID, au_name, Basin_name
Location	:	LocationID, Location_name, AU_ID, Location_descr
River_Gauging_Station	:	RGS_ID, RGS_name, RiverID, AgencyID, LocationID
Weather_Station	:	WS_ID, WS_name, AgencyID, LocationID, Basin_name
Flow_Records	:	RGS_ID, AgencyID, Frdate, Period, Subperiod, Discharge, Gauge_level, Danger_level, HFL, HFL_date, Forecast_trend, Max_discharge, Max_discharge_date,Min_discharge,Min discharge_date
Observation_well	:	O_well_no,LocationID, OWRdate, Season, Depth_to_gwt
Expository_Well	:	E_well_no, LocationID, EWRdate, Lithology, Pump_test, Well_log
River_Water_Qlty	:	RiverID, AgencyID, LocationID, RWQ_Date, Conductance, PH,DO, BOD, Turbidity, Total_Coliform, Foecal_Coliform,Ca_as_CaCO3, Mg_as_MgCO3,TDS,Boron,Phosphate, Chloride
Ground_Water_Qlty	:	AgencyID, LocationID, O_Well_No, Conductance, PH, DO, BOD, Turbidity, Total_Coliform, Foecal_Coliform, Ca_as_CaCO3, Mg_as_MgCO3, TDS, Boron, Phosphate ,Chloride
Other_Water_Qlty	:	AgencyID, LocationID, O_W_Qdate, Sample Source, Conductance, PH, DO, BOD, Turbidity, Total_Coliform, Foecal_Coliform, Ca_as_CaCO3, Mg_as_MgCO3, TDS,Boron,Phosphate ,Chloride
Rainfall	:	WS_ID, Rrdate, Rrtime, Rain_amount, Rain_gauge_type, Rain_numensity, Rain_duration
Evaporation	:	WS_ID, EVARdate, Evaporation, Ev_meter_type , Evr_record_time
Other_met_obver	:	WS_ID,Other_obver_date, Other_obver_Time, Temp_humd_i_ type , Max_Temp, Min_Temp, Avg._temp, Abs_Humd, RH, Anemometer_type, Max_Wind_ Velo, Wind_Direction, Sunshine_Hrs
Land	:	AU_ID, AgencyID, Land_Rec_Year, Forest_Land, Nonagri_Use_Lnd, Brrn_Unclt_Lnd, Pppst_Ogrss_Lnd,

		Lumtreegrniifl, Cult_Waste_Land, Fl_o_then_cf,Current_fl, Total_Crop_Area, Net_Area_Sown
Industry	:	AU_ID, AgencyID,Ind_Rec_Year, Ind_Code, Ind_Type, Ind_Class,Ind_unit
Irrigation	:	AU_ID,AgencyID,Irrg_Rec_Year, Maj_Irri_Pot_Crea,Mi_Irri_Pot_Crea, Irrig_pot_utilzd,Canal_Irrgtd_Ar, Tankl_Irrgtd_Ar, Twell_Irrgtd_Ar,
Population	:	AU_ID, AgencyID, Pop_Rec_Year, Urban_Pop,Rural_Pop ,Male_Pop, Female_Pop
Agriculture	:	AU_ID, AgencyID, Agri_Rec_Year, Agri_Rec_Season, Crop_Name, Crop_Variety, Crop_Area, Crop_Production

Schema Design:

In a data model it is important to distinguish between the description of the database and the database itself. The description of the database is called database schema. Most data model has certain convention for diagrammatically displaying the schemas, called schema diagram

Relational Schema Design

River_Basin

Basin_Name (P.K)	Basin_Description

River

RiverID (P.K)	River_Name	Basin_Name (F.K)	River_description

Agency

AgencyID (P.K)	Agency_Name	Funded_By	Fund_breakup

Adm_Unit

AU_ID (P.K)	Adm_Unit_Name	Basin_Name (F.K)

Location

LocationID (P.K)	Location_Name	AU_ID (F.K)	Location_descr

River_Gauging_Station

RGS_ID (P.K)	RGS_Name	RiverID (F.K)	AgencyID (F.K)	LocationID (F.K)

Weather_Station

WS_ID (P.K)	WS_Name	AgencyID (FK)	LocationID (F.K)	Basin_Name (F.K)

Flow_Records

RGS_ID (F.K)	AgencyID (F.K)	FRdate (P.K)	Period	Subperiod	Discharge	-----

Observation_well

O_Well_No (P.K)	LocationID (F.K)	OWR_Date (P.K)	Depth_To_GWT

Expository_Well

E_Well_No (P.K)	LocationID (F.K)	Lithology	Pump_Test

River_Water_Qlty

RiverID (F.K)	AgencyID (F.K)	LocationID (F.K)	RWQ_Date (P.K)	Conductance	PH	----

Ground_Water_Qlty

AgencyID (F.K)	LocationID (F.K)	O_Well_No (F.K)	OWR_Dat e (F.K)	Gr_W_Qda te (P.K)	Condu ctance	--

Other_Water_Qlty

AgencyID (F.K)	LocationID (F.K)	O_W_QDate (P.K)	Sample_Sourc e	Conduct ance	PH	--

Rainfall

WS_ID (F.K)	RRdate (P.K)	RRtime	Rain_amount

Evaporation

WS_ID (F.K)	EVARdate (P.K)	Evaporation	Evr_record_time

Other_met_obver

WS_ID (F.K)	Other_obve r_date (P.K)	Other_obver _Time	Max_Temp	Min_Te mp	Abs_Hu md	RH	--

Industry

AU_ID (F.K)	AgencyID (F.K)	Ind_Rec_Year (P.K)	Ind_Code	Ind_Typ e	Ind_Class

Irrigation

AU_ID (F.K)	AgencyID (F.K)	Irri_Rec_Year (P.K)	Maj_Irri_Pot_C reated	-----

Land

AU_ID (F.K)	AgencyID (F.K)	Land_Rec_Year (P.K)	Forest_Land	Total_Crop_Area	---

Population

AU_ID (F.K)	AgencyI D (F.K)	Pop_Rec_Y ear (P.K)	Urban_P op	Rural_po p	Male_Pop	Female_Pop

Agriculture

AU_ID (F.K)	AgencyID (F.K)	Agri_Rec_Yea r (P.K)	Agri_Rec_Season (P.K)	Crop_Name	----

APPENDIX-C

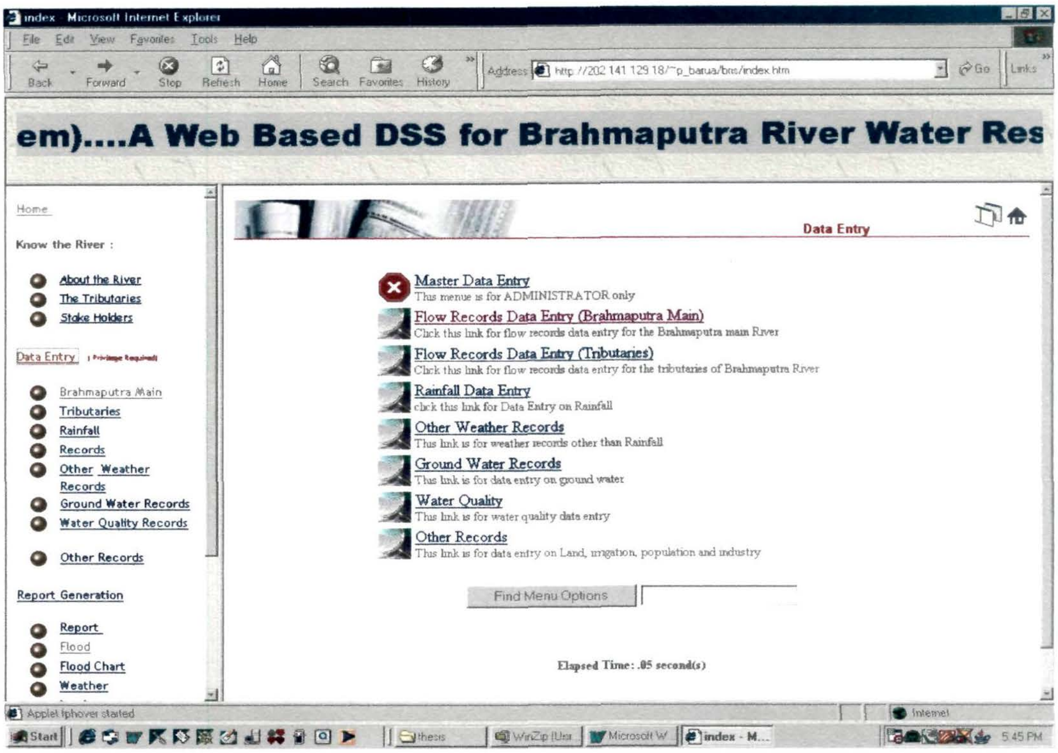


Figure Ac1 Data entry (main menue)

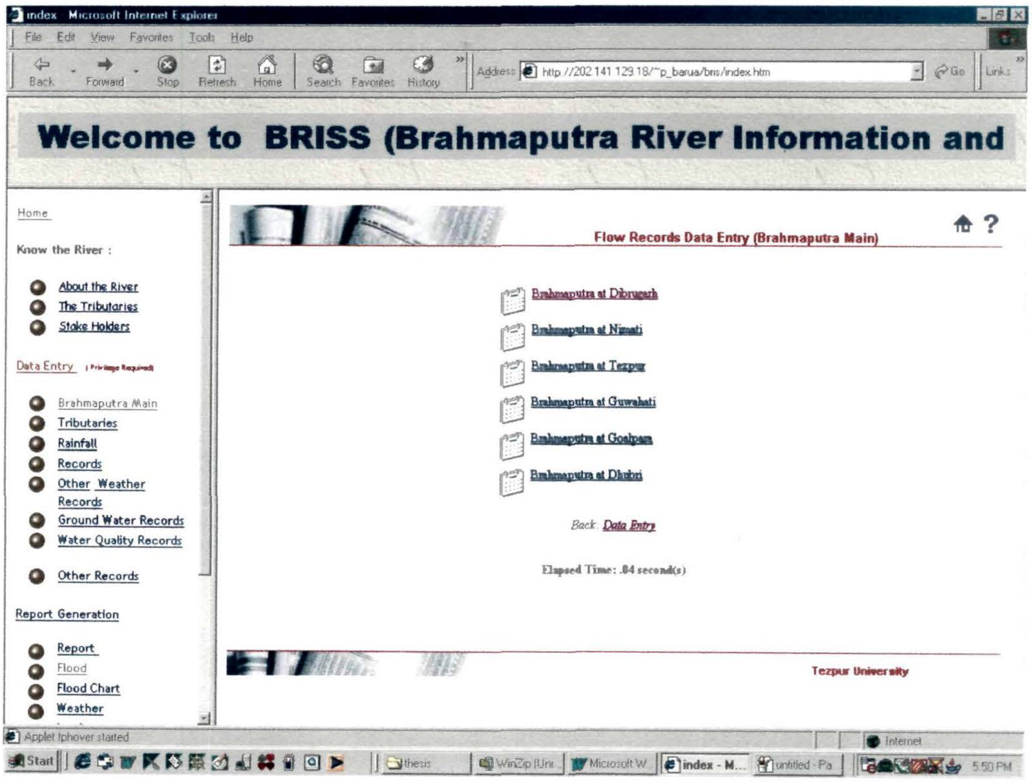


Figure Ac2 Data entry menu (river)

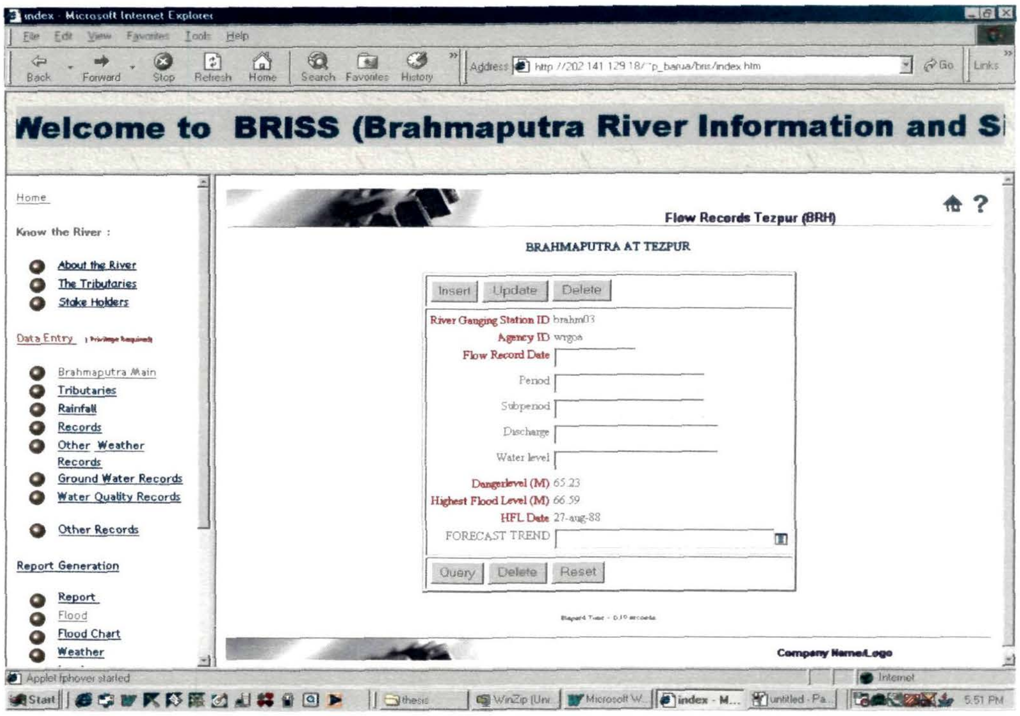


Figure Ac3 Data entry form (river)

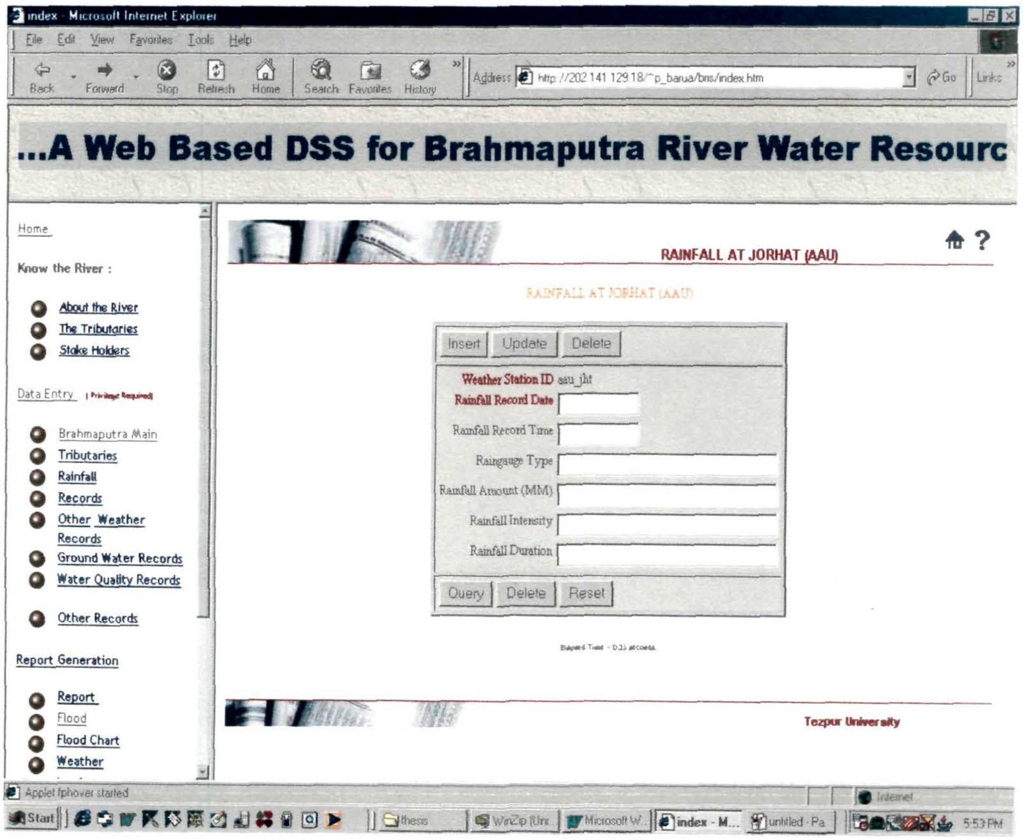


Figure Ac4 Data entry form (rainfall)

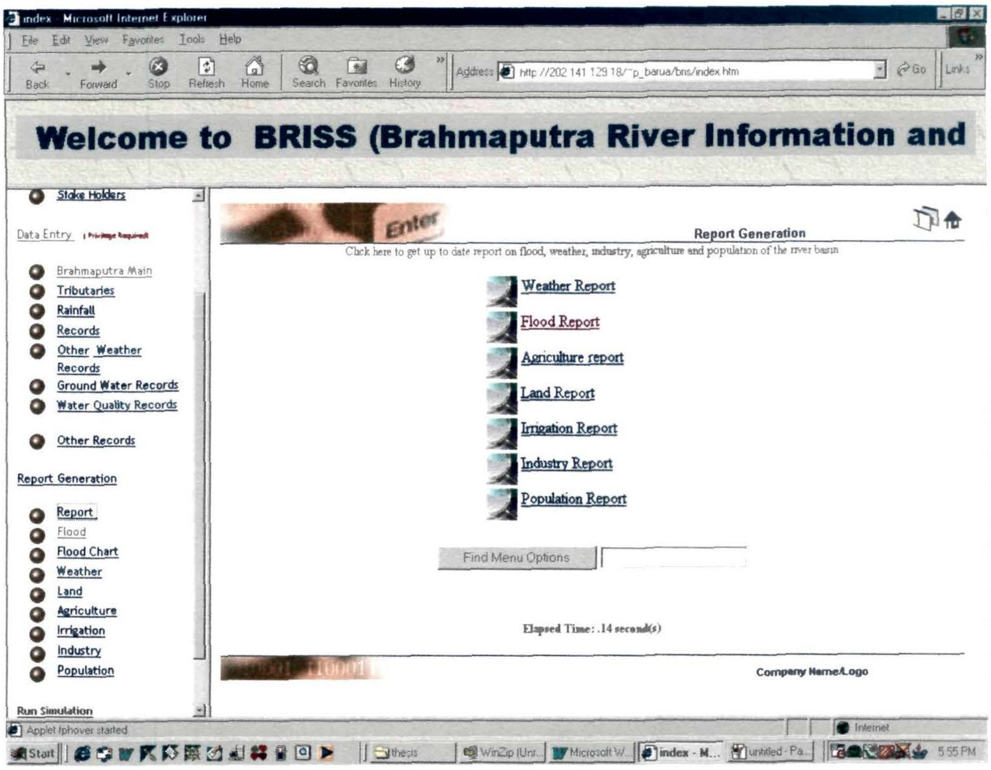
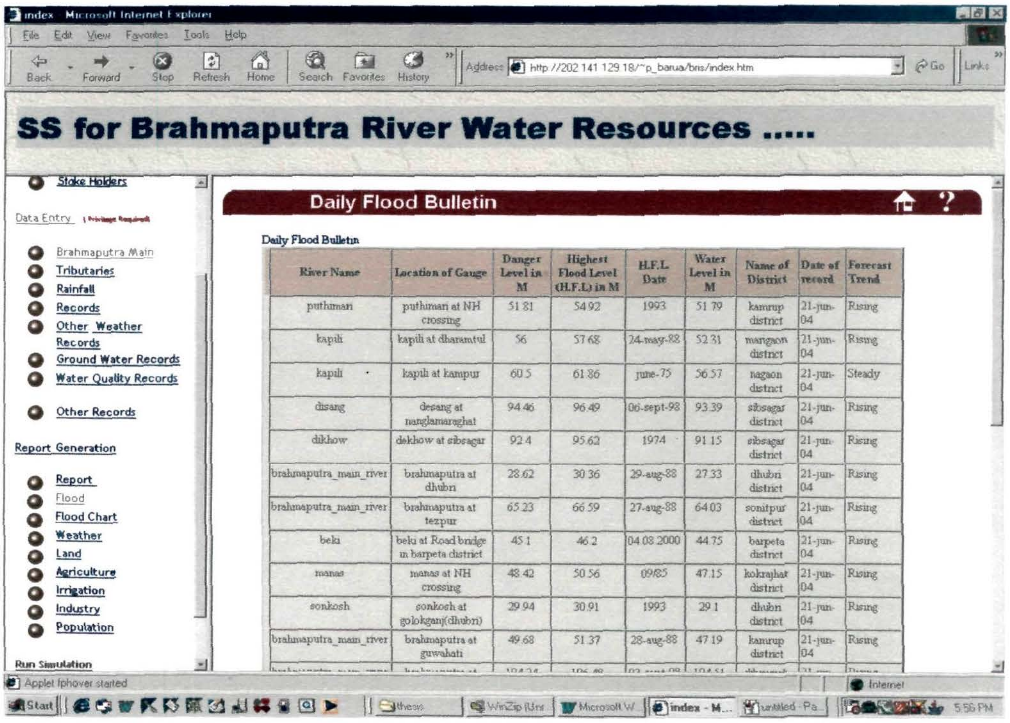


Figure Ac5 Report main menu



River Name	Location of Gauge	Danger Level in M	Highest Flood Level (H.F.L) in M	H.F.L. Date	Water Level in M	Name of District	Date of record	Forecast Trend
puthimari	puthimari at NH crossing	51 81	54 92	1993	51 79	kamrup district	21-jun-04	Rising
kapili	kapili at dharamtul	56	57 68	24-may-88	52 31	marigaon district	21-jun-04	Rising
kapili	kapili at kampur	60 5	61 86	june-75	56 57	nagaon district	21-jun-04	Steady
disang	desang at nanglamaraghat	94 46	96 49	06-sept-98	93 39	sibsagar district	21-jun-04	Rising
dikhow	dekhow at sibsagar	92 4	95 62	1974	91 15	sibsagar district	21-jun-04	Rising
brahmaputra_main_river	brahmaputra at dhubri	28 62	30 36	29-aug-88	27 33	dhubri district	21-jun-04	Rising
brahmaputra_main_river	brahmaputra at tezpur	65 23	66 59	27-aug-88	64 03	sonitpur district	21-jun-04	Rising
beki	beki at Road bridge in barpeta district	45 1	46 2	04 08 2000	44 75	barpeta district	21-jun-04	Rising
manas	manas at NH crossing	48 42	50 56	09/85	47 15	kokrajhar district	21-jun-04	Rising
sonkosh	sonkosh at golokganj(dhubri)	29 94	30 91	1993	29 1	dhubri district	21-jun-04	Rising
brahmaputra_main_river	brahmaputra at guwahati	49 68	51 37	28-aug-88	47 19	kamrup district	21-jun-04	Rising

Figure Ac6 Flood report

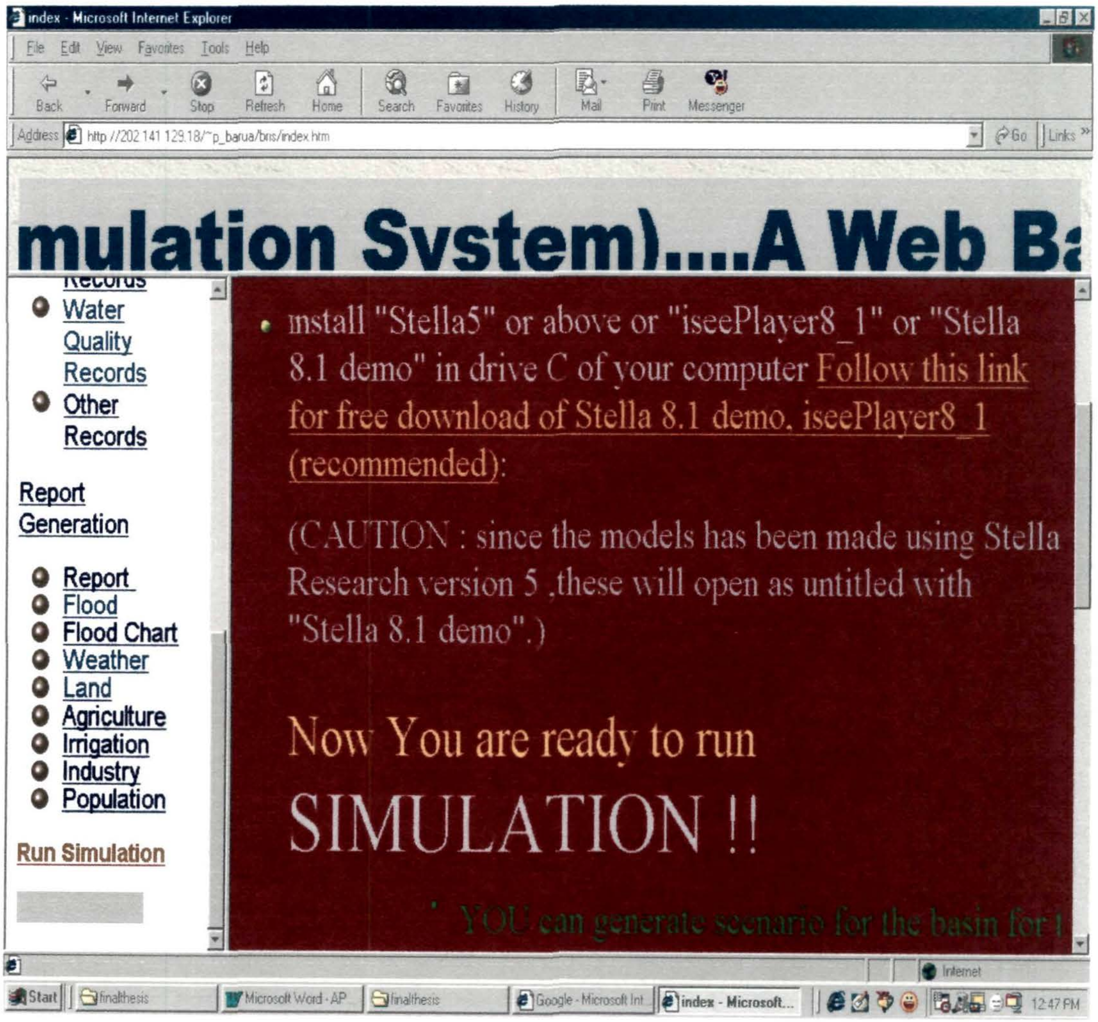


Figure Ac7 Simulation menu

APPENDIX- D1

Table A d1 **List of Variables**

Land Sector

No.	Abbreviation	Description	Type	Unit	Data Source
1	Arableand	Arable Land	Level	Hectare	SHBA
2	forest_con_rate	Forest Conversion Rate	Rate	Hectare per year	SHBA
3	ILCR	Irrigate land Conversion Rate	Rate	Hectare per year	SHBA
4	W\A_chang_rate	Waste land to Arable Land Change rate	Rate	Hectare per year	SHBA
5	urban_create_rate	Creation rate for Urban Land	Rate	Hectare per year	SHBA
6	wasteland	Waste Land	Level	Hectare	SHBA
7	erosion_rate	Erosion rate	Rate	Hectare per year	WRD
8	land_development_rate	Land development Rate	Rate	Hectare per year	SHBA
9	forest_cf	Forest Conversion Rate	Aux	-	SHBA
10	otherland	Other type of land	Aux	Hectare	SHBA
11	Totalland	Total Land	Aux	Hectare	SHBA
12	urcreate_fract	Creation Fraction of Urban Land	Aux	-	SHBA
Basin Sector					
13	Ground_Water	Ground Water	Level	MCM	NER data bank
14	return_flow_to_GW	Return flow rate to Ground Water	Rate	MCM per Year	Assumption
15	GW_use_rate	Ground water Use Rate	Rate	MCM per year	Assumption
16	GW_Base_flow	Base Flow of Ground water	Rate	MCM per Year	Assumption
17	Total_WW_Gen_by_population	Total waste Water Generated by Population	Aux	MCM	Mohile 2001
18	popreturnfractGW	Return fraction of Total waste Water Generated by Population to Ground water	Aux	_	Assumption
19	totalindustry_wastewater_generated	Total industrial waste water generated	Aux	MCM	Mohile 2001
20	IndustryreturnfractGW	Return fraction of Total industrial waste water generated to Ground water	Aux	_	Mohile 2001
21	IrrigationWaste	Irrigation waste water	Aux	MCM	Amarsinghe 2004
22	irrigreturnfractGW	Return fraction of irrigation waste water to ground water	Aux	_	Assumption
23	RainfractGW	Rainfall fraction to ground water	Aux	_	Assumption
24	total_rain_MCM	Total annual rainfall in MCM	Aux	MCM	SHBA
25	GW_use_rate	Ground water use rate	Rate	-	-
26	AgrilWR	Total agricultural water requirement	Aux	MCM	_
27	irrigDemandFra	Irrigation Demand Fraction	Aux		Assumption

	ctGW	from ground water			
28	total_industry_w ater_demand	Total Industrial water demand	Aux	MCM	_
29	IndustryDemand fractionGW	Industrial Water Demand Fraction from Ground water	Aux	_	Assumption
30	popdemandfract GW	Population Demand fraction from Ground water	Aux	_	Assumption
31	annual_popwate r_in_MCM	Annual Population water Demand in MCM	Aux	MCM	-
32	GW_Base_flow	Base flow of Ground water	Aux	_	Assumption
33	Fract	Fraction of Ground water lost as base flow	Aux	_	Assumption
34	RiverWater	River water	Level	MCM	-
35	External_Flow	External flow rate into river water	Rate	MCM per year	WRD
36	return_flow_rate	Return flow rate into the river water	Rate	MCM per year	_
37	Tributary_inflo w	Tributary flowing into the river	Rate	MCM per year	WRD
38	Outflow_to_Sea	Out flow from river to the sea	Rate	MCM per year	WRD
39	Water_use_rate	Water use rate from river water	Rate	MCM per year	_
40	ext_flow	External flow		Cusec	WRD
41	con_fract	Conversion of Cusec to MCM per annum	Aux	60*60*24* 365/100000 0	_
42	rainfractRW	Rainfall fraction contributing to River water	Aux	Fraction	Assumption
43	Industryreturnfr act	Industrial waste water return fraction to River water	Aux	Fraction	Assumption
44	popreturnfract	Population waste water return fraction to river water	Aux	Fraction	Assumption
45	irrigreturnfract	Irrigation waste water return fraction to river water	Aux	Fraction	Assumption
46	Tributary	Tributary flow	Aux	Cusec	WRD
47	Outflow	Out flow from the river to sea	Aux	Cusec	WRD
48	IrrigDemandFra ct	Irrigation Water Demand fraction met from river water	Aux	Fraction	Assumption
49	industrydemand _fract	Industrial water demand fraction met from river water	Aux	Fraction	Assumption
50	popdemandfract	Population water demand fraction met from river water	Aux	Fraction	Assumption
51	Total_annual_E v_in_MCM	Total annual evaporation in MCM	Aux	MCM	IMD
	Immigration Population Sector				
52	immigratpopul ation	Immigration Population	Level	Persons	Assumption
53	birthsimmmigr a	Births of immigration population	Rate	Person per year	Assumption

54	immigratetoUP	Immigration rate to Urban population	Rate	Person per year	Assumption
55	ImmigratetoRP immigratetoRP	Immigration to rural population	Rate	_	Assumption
56	Deathsimmigrat	Death rate of immigration population	Rate	Person per year	Assumption
57	immmigratbirthfraction	Birth fraction of immigration population	Aux	_	Assumption
58	normalmigratUP	Normal immigration fraction of Immigrations Population to Urban Population	Aux	-	Assumption
59	IR_to_UP_multiplier_from_industry	IR to Urban Population multiplier from industry	Table Function	_	Assumption
60	normalmigratRP	Normal immigration fraction of Immigration Population to Rural Population	Aux	_	Assumption
61	IR_to_RP_multiplier_from_govt_policy	IR to Rural Population multiplier from government policy	Table Function	_	Assumption
62	IR_to_RP_multiplier_from_land	IR to Rural Population multiplier from land availability	Table Function	_	Assumption
63	IR_to_RP_multiplier_from_water	IR to Rural Population multiplier from water availability	Table Function	_	Assumption
64	lifespanimmigrat	Lifespan of immigration population	Aux	_	Assumption
65	immmigratliteratepopulation	Literate Immigration Population	Level	Persons	Assumption
66	IPLR	IP literacy rate	Rate	Person per year	Assumption
68	illiterateIP	Illiterate Immigration Population	Aux	Persons	Assumption
69	ConfractILP	Conversion fraction of illiterate Immigrations Population to literate Immigrations Population	Aux	_	Assumption
70	IGRA	Industrial Growth rate actual	Aux	_	SHBA
71	IGRI	Industrial Growth rate ideal	Aux	-	Assumption
72	RIGRATI	Ratio of industrial growth rate actual to desired	Aux	_	_
73	immmigratBFmultiplerfromliteracy	IP birth fraction multiplier from literacy	Table Function	_	Assumption
74	immmigratlieracyrateactualtodesired	Ratio of Immigration Population literacy rate actual to desired	Aux	_	Assumption
75	immmigratliteracyrateactual	IP literacy rate actual	Aux	_	Assumption
78	immigratliteracyratedesired	IP literacy rate desired	Aux	_	Assumption
79	immmigratideallifespan	Ideal lifespan of Immigration Population	Aux	Years	Assumption
80	immmigratlifespanmultiplierliteracy	IP lifespan multiplier from literacy	Table Function		Assumption

81	total_literate_pop	Total literate population of the basin	Aux	Persons	SHBA
82	literacy_rate_basin	Literacy of the basin population	Aux	percentage	SHBA
83	LPRA	Land to population ratio actual	Aux	-	_
85	LPRI	Land to population ratio ideal	Aux	-	Assumption
86	RatioElRfromIPactual	Ratio of elected representative from Immigration Population actual	Aux	-	SHBA
88	RatioElRfromIPdesired	Ratio of elected representative from Immigration Population desired	Aux	-	Assumption
89	Ratio_ElRfromIPactual_to_desired	Ratio of elected representative from Immigration Population actual to desired	Aux	-	Assumption
90	WPRA	Water to population ratio actual	Aux	-	_
91	WPRI	Water to population ratio ideal	Aux	-	Upali Amarsinghe ,2004
92	ratio_of_actual_water_population_ratio_to_ideal	Ratio of actual Water to population ratio to ideal	Aux	-	-
93	Total_Water_supply	Total water supply in the River Basin	Aux	-	-
94	immmigratlieracyrateactualtodesired	Ratio of Immigration Population literacy rate actual to desired	Aux	-	-
95	RPCF_multiplier_from_industry	RP to Urban Population conversion fraction multiplier from industry	Table Function		

Industrial water Demand and Waste water Generation Sector

96	PUWWagriP	Per unit waste water generated due to Agricultural Processing	Aux	Liter per ton	Leeden, 1975
98	PUWWFP	Per unit waste water generated due to forest products	Aux	Liter per meter	Leeden, 1975
99	PUWWpetrol	Per unit waste water generated due to refining of petroleum crude	Aux	Liter per ton	Leeden, 1975
100	PUWWPP	Per unit waste water generated due to power production	Aux	Liter per megawatt	Leeden, 1975
101	PUWWTx	Per unit waste water generated due to textile production	Aux	Liter per ton	Leeden, 1975
102	Industrial_working_Capital_Desired	Industrial Working capital desired	Aux	Rupees	Assumption
103	RIWCATD	Ratio of Industrial Working capital actual to desired	Aux	-	-
104	totalindustry_wastewater_generated	Total industrial waste water generated	Aux	-	-
105	WWGagriP	Waste water generated by Agricultural Processing	Aux	-	-
106	WWGFP	Waste water generated by	Aux	-	-

		Forest Product			
107	WWGHI	Waste water generated by Heavy Industry	Aux	-	-
108	WWGPetrol	Waste water generated by petroleum refining	Aux	-	-
109	WWGPP	Waste water generated by Power production	Aux	-	-
110	WWGT	Waste water generated by Textile Production	Aux	-	-
111	WWPHI	Per unit waste water generated due to heavy industries	Aux	-	-
112	WPUagriP	Water Required for per unit of Agril. Processing	Aux	Liter per meter	Leeden, 1975
113	WPUFP	Water Required for per unit of Forest product	Aux	Liter per meter	Leeden, 1975
114	WPUHI	Water Required for per unit production of Heavy Industry	Aux	Liter per meter	Leeden, 1975
115	WPUPetrol	Water Required for per unit production of petroleum products	Aux	Liter per meter	Leeden, 1975
116	WPUPP	Water Required for per unit production power	Aux	Liter per meter	Leeden, 1975
117	WPUTx	Water Required for per unit production textile	Aux	Liter per meter	Leeden, 1975
118	WreqagriP	Water required for agril. Processing	Aux	Liter per meter	Leeden, 1975
119	WreqFP	Water required for Forest products	Aux	-	-
120	WreqHI	Water required for Heavy Industry	Aux	-	-
121	WreqPetrol	Water required for petroleum products	Aux	-	-
122	WreqPP	Water required for Power Production	Aux	-	-
123	WreqTx	Water required for textile production	Aux	-	-
124	IWD_multiplier_from_IWC	Industrial water Demand multiplier from Industrial working capital	Table Function		
125	RIWCATD	Ratio of actual industrial working capital to desired	Aux	-	-

Industrial Fixed Capital sector

126	industrial_fixed_capital	Industrial Fixed capital	Level	Rupees	SHBA
127	FCIR	Industrial Fixed capital Inflow rate	Rate	rupees per year	SHBA
128	FCDR	Industrial Fixed capital Depreciation rate	Rate	rupees per year	SHBA
129	FCIR_fraction	Industrial Fixed capital Inflow rate fraction	Aux	-	SHBA
130	FCIR_multipier_from_infrastructure1	Industrial Fixed capital inflow rate multiplier from infrastructure 1	Table Function	_	_
131	FCIR_multipier_from_infrastructure2	Industrial Fixed capital inflow rate multiplier from infrastructure 2	Table Function	_	_
132	FCIR_multiplier_from_Pow	Industrial Fixed capital inflow rate multiplier from power	Table Function	_	_

	er				
133	FCIR_multiplier_laworder	Industrial Fixed capital inflow rate multiplier from law and order	Table Function	–	–
134	FCDR_Fract	Industrial Fixed capital Depreciation rate fraction	Aux	-	SHBA
135	NPCR	Number police cases recorded	Aux	-	SHBA
136	PAA	Power Available Actual	Aux	Mega Watt	SHBA
137	PD	Power Available Desired	Aux	Mega Watt	-
138	RPATD	Ratio of Power Available Actual to Desired	Aux	–	–
139	RALPSKA	Railway Line per square Kilometer actual	Aux	KM per Sq. KM	SHBA
140	RALPSKD	Railway Line per square Kilometer desiredl	Aux	KM per Sq. KM	–
141	RLPSKA	Road Length per per square Kilometer actual	Aux	KM per Sq. KM	SHBA
142	RLPSKD	Road Length per per square Kilometer desired	Aux	KM per Sq. KM	–
143	RRALPSKATD	Ratio of Railway Line per square Kilometer actual to desired	Aux	–	–
144	RRLPSKATD	Ratio of Road length per square Kilometer actual to desired	Aux	–	–
	Industrial Working Capital Sector				
145	Industrial_Working_Capital	Industrial Working capital	Level	Rupees	SHBA
146	WCIR	Industrial Working capital inflow rate	Rate	Rupees per year	SHBA
147	IWC_fraction	Industrial Working capital fraction of fixed capital	Aux	–	SHBA
145	WCIRMagriP	Industrial Working capital inflow rate multiplier from agril. processing	Table Function	–	–
146	WCIRMPetrolProducts	Industrial Working capital inflow rate multiplier from petroleum product	Table Function	–	–
147	WCIRMPforestPrdt	Industrial Working capital inflow rate multiplier from forest products	Table Function	–	–
148	WCIRMPheavyindust	Industrial Working capital inflow rate multiplier from heavy industries	Table Function	–	–
149	WCIRMPPower	Industrial Working capital inflow rate multiplier from power	Table Function	–	–
150	WCIRMTextile	Industrial Working capital inflow rate multiplier from textiles	Table Function	–	–
151	FPPA	Forest products actual	Aux	Tons per year	SHBA
152	FPPD	Forest products desired	Aux	Tons per year	-
153	IFC_fract	Industrial Fixed Capital fraction	Aux	–	Assumption
154	PHIA	Production of heavy industries	Aux	Tons per	SHBA

		actual		year	
155	TPPPA	Total power production actual	Aux	Mega Watt	SHBA
156	TPPPD	Total power production desired	Aux	Mega Watt	
157	TxPA	Total textile production actual	Aux	Tons per year	SHBA
158	TxPD	Total textile production desired	Aux	Tons per year	-
159	PHID	Production of heavy industries desired	Aux	Tons per year	-
160	RAPTDagriP	agriPPA/agriPPD	Aux	-	-
159	RAPTDFP	FPPA/FPPD	Aux	-	-
160	RAPTDHI	PHIA/PHID	Aux	-	-
161	TpetrolA	Total Petrol production Actual	Aux	Tons per year	SHBA
162	TpetrolD	Total petrol production desired	Aux	Tons per year	-
163	RAPTDPetrol	TpetrolA/TpetrolD	Aux	-	-
164	RAPTDPP	TPPPA/TPPPD	Aux	-	-
165	RAPTDTx	TxPA/TxPD	Aux	-	-

Irrigated Land sector

167	Irrigated Land	Irrigated Land	Level	Hectares	SHBA
	ILCR	Irrigated Land Conversion rate	Rate	Hectares per year	-
168	avg_ILCR	Average Irrigated Land Conversion rate	Aux	Hectares per year	SHBA
169	ILCR_multiplier_govt_invest	Irrigated Land Conversion rate multiplier from government investment	Table Function	-	-
170	ILCR_multiplier_utilization	Irrigated Land Conversion rate multiplier from utilization of existing irrigation facility	Table Function	-	-
171	ILCR_multiplier_WA	Irrigated Land Conversion rate multiplier from water availability	Table Function	-	-
172	smooth_IL	Smoothed Irrigated Land	Level	Hectares	-
173	change_smooth	Change of smoothed irrigated land over time	Aux	-	-
174	averaging_time	Time for smoothed irrigated land	Aux	–	–
175	unirrigland	Unirrigated land	Aux	Hectares	SHBA
176	unirrigland_confr	Unirrigated land conversion to Irrigate land	Aux	Hectares per year	SHBA
177	IPC	Irrigation Potential created	Aux	Hectares per year	SHBA
178	IPU	Irrigation Potential utilized	Aux	Hectares per year	SHBA
179	utlfract	Utilization fraction of Irrigation potential	Aux	-	-
180	RILTALA	smooth_IL/arland	Aux	-	-
181	RILTALD	Ratio of irrigated land to arable land desired	Aux	-	-
182	RILTALATD	Ratio of irrigated land to arable land actual to desired	Aux	-	-
183	RIPCTU	IPU/IPC	Aux	-	-
184	WPCA	Water available per capita actual	Aux	–	–

185	WPCD	Water available per capita desired	Aux	_	Upali Amarsighe, 2004
186	Total_Water_supply	Total water supply	Aux	_	_

Irrigation water Sector

187	AgrilWR	Agricultural water Requirement	Aux	Cubic Meter	After Doorenbos and Pruitt, 1977
189	juteWR	Jute water requirement	Aux	-	-
190	OCWR	Other crop water requirement	Aux	-	-
191	PaddyWR	Paddy Water requirement	Aux	-	-
192	croppingintensity	Cropping Intensity	Aux	_	SHBA
193	conversion_of_Ha_M_to_MCM	Conversion of Hectre Meter to MCM	Aux	-	-
194	effective_rainfall	Effective rainfall	Aux	MM	SHBA
195	rainfall	Rainfall	Aux	MM	SHBA
196	ERfactor	Effective rainfall factor	Aux	-	-
197	evap	Evaporation	Aux	MM	SHBA
198	irrigationWR	Irrigation water requirement	Aux	Cubic Meter	-
199	IrrigationWaste	irrigationWR-AgrilWR	Aux	Cubic Meter	-
200	irrigation_eff.	Irrigation Efficiency	Aux	-	Assumption
201	Irrigation_water_in_BCM	Irrigation water in BCM	Aux	BCM	_
202	jf	Fraction of total land to jute land	Aux	_	
203	juteCF	Jute crop factor	Aux	-	After Doorenbos and Pruitt, 1977
204	jutland	Jute land	Aux	_	SHBA
205	jute_submergence	Jute submergence rquired	Aux	-	Assumption
206	jute_depth	Jute submergence depth required	Aux	-	Assumption
207	othercropland	Other crop land	Aux	_	SHBA
208	OCCF	Crop factor for other crop	Aux	-	After Doorenbos and Pruitt, 1977
209	of	Fraction of total land to other crop land	Aux	_	
210	PaddyWR	Paddy water requirement	Aux	_	
211	Paddy_CF	Paddy Crop factor	Aux	-	After Doorenbos and Pruitt, 1977
212	paddy_submergence)	Paddy submergence required	Aux	-	-
213	paddy_depth	Paddy depth of submergence	Aux	-	Assumption

		required			
214	pf	Fraction of total land to paddy land	Aux	-	SHBA
215	Total_annual_Ev_in_MCM	Total annual evaporation in MCM	Aux	_	_
216	water_fract	Fraction of area coverage by water body	Aux	_	_

Population Water Demand and Waste Water Generated

217	annual_popwater_in_MCM	Annual population water demand in MCM	Aux	MCM	_
218	PopWaterin_MCM_per_day	Population water demand in MCM per day	Aux	MCM per day	_
	float_population	= totalpopulation*fractioFP	Aux	Persons	Assumption
219	fractioFP	Fraction of float population to total population	Aux	_	Assumption
220	totalpopulation	Total population in the basin (populationrural+urbanpopulation)	Aux	Persons	SHBA
221	lpcdFP	Liter per capita per day for float population	Aux	Liter per capita per day	Assumption
222	lpcdIP	Liter per capita per day for immigration population	Aux	Liter per capita per day	Assumption
223	lpcd_RP	Liter per capita per day for rural population	Aux	Liter per capita per day	GOI,1999
224	lpcd_UP	Liter per capita per day for urban population	Aux	Liter per capita per day	GOI,1999
225	MCM_con	MCM conversion	Aux	-	-
226	percapitaWWIP	Per capita waste water generated by IP	Aux	-	-
227	percapitaWWRP	Per capita waste water generated by Rural Population	Aux	-	-
228	percapitaWWUP	Per capita waste water generated by Urban Population	Aux	-	-
229	water_demand_RP	Water demand by Rural Population	Aux	-	-
230	water_demand_FP	Water demand FP	Aux	-	-
231	water_demand_IP	Water demand IP	Aux	-	-
232	water_demand_UP	Water demand Urban Population	Aux	-	-
233	WWgenFP	Waste water generated by FP	Aux	-	-
234	WWgenIP	Waste water generated by IP	Aux	-	-
235	WWgenRP	Waste water generated by Rural Population	Aux	-	-
236	WWgenUP	Waste water generated by Urban Population	Aux	-	-

Rural Population Sector

237	literatepoprural	Literate Rural Population	Level	Persons	SHBA
238	RPLR	Rural Population literacy rate	Aux	Fractio n	SHBA
239	populationrural	Rural Population	Aux	Persons	SHBA
241	illterateRP	Illiterate Rural Population	Aux	-	-
242	Confract_RLP	Conversion fraction of Rural Population to Literate Rural Population	Aux	-	-
243	birthsrural	Rural Population birth fraction	Rate	Persons per year	SHBA
244	deathsrural	Rural Population death fraction	Rate	Persons per year	SHBA
245	rurallifespan	Rural Population lifespan	Aux	Years	SHBA
246	normalbirthfra ctionrural	Rural Population normal birth fraction	Aux	Fractio n	SHBA
247	RuralBFmultip lerfromliteracy	Rural Population birth fraction multiplier from literacy	Table function	_	_
248	ruralideallifesp an	Rural Population ideal lifespan	Aux	Years	Assumption
249	ruralliteracyrat eactual	Rural Population literacy rate actual	Aux	Fractio n	SHBA
250	lifespan_multi plierliteracyrur al	Life span multiplier from Rural Population literacy rate	Table Function	-	- •
251	ruralliteracyrat edesired	Rural Population literacy rate desired	Aux	-	Assumption
252	total_literate_p op	literatepoprural+urbanliterate_p op	Aux	-	-

Sustainability

253	Available_GW	Available Ground Water	Aux	Cubic Meter	CGWB
254	Ground_Water	Ground Water	Level	Cubic Meter	CGWB
255	return_flow_to _GW	Return flow rate to Ground Water	Rate	Cubic Meter over time	- _
256	Available_GW	Available Ground Water	Aux	-	-
257	Available_RW	Available River water	Aux	-	-
258	Environmental _water_Deman d	Environmental water demand	Aux	-	Upali Amarsinghe, 2004
259	Sustainablity_I ndex	Sustainability index	Aux	_	_
260	Total_Exploita ble_Water	Total_Water_supply - Total_Water_Demand	Aux	MCM	-
261	Total_exploita ble_Water_BC M	Total_water_supply_BCM-total_water_demand_BCM	Aux	BCM	_
262	Total_Water_ Demand	irrigationWR+total_industry_w ater_demand+annual_popwater _in_MCM+Environmental_wat er_Demand	Aux	MCM	-
263	total_water_de mand_BCM	Total water demand in BCM	Aux	BCM	

Urban population sector

264	urbanliterate_p	Urban literate population	Level	Persons	SHBA

	op				
265	UPLR	Urban population literacy rate	Aux	Fraction	SHBA
266	illiterateUP	Illiterate urban population	Aux	Persons	SHBA
267	ConfractULP	Conversion fraction of urban population to urban literate population	Aux	-	-
	Birthsurban	Urban births	Rate	Persons per year	-
268	deathsurban	Urban deaths	Rate	Persons per year	
269	Urbanbirthfraction	Urban birth fraction	Aux	Fraction	SHBA
270	lifespanurban	Urban Population life span	Aux	Year	SHBA
271	Normalurbanbirthfraction	Normal urban birth fraction	Aux	Fraction	SHBA
272	Urbanideallifespan	Urban ideal lifespan	Aux	Years	Assumption
273	urbanlifespanmultiplierliteracy	Urban life span multiplier from literacy	Table function	–	–
274	Rural PopulationCFTUP	Rural population conversion fraction to Urban population	Aux	fraction	Assumption
275	urbanlieracyrateactualtodesired	Urban population literacy rate actual to desired	Aux	–	–
276	urbanliteracyrateactual	Urban population literacy rate actual	Aux	Fraction	SHBA
277	urbanliteracyratedesired	Urban population literacy rate desired	Aux	Fraction	Assumption
278	UrbanBFmultiplerfromliteracy	Urban birth fraction multiplier from literacy	Table Function	-	-
279	Rural PopulationCRTUP	Rural population conversion rate to Urban population	Rate	Persons per year	Assumption
280	Rural PopulationCF_multiplier_from_industry	Rural population conversion fraction multiplier from industry	Table Function	-	-

<u>Abbreviations used in the list of variables</u>: WRD = Water Resources Department, Government of Assam, India; IMD= Indian Meteorological Department, India; SHBA = Statistical Hand Book of Assam, Department of Economics and Statistics, Government of Assam, India; CGWB= Central Ground Water Board, India

APPENDIX-D2 (Model Equations)

Arable land

arland(t) = arland(t - dt) + (forest_con_rate - ILCR - W\A_chang_rate - urban_create_rate) * dt
INIT arland = 2600000
INFLOWS:
forest_con_rate = forest_land*forest_cf
OUTFLOWS:
ILCR (IN SECTOR: Irrigated Land)
W\A_chang_rate = land_development_rate-erosion_rate
urban_create_rate = arland*urcreate_fract
forest_land(t) = forest_land(t - dt) + (-forest_con_rate) * dt
INIT forest_land = 2011000
OUTFLOWS:
forest_con_rate = forest_land*forest_cf
urban_land(t) = urban_land(t - dt) + (urban_create_rate) * dt
INIT urban_land = 852000
INFLOWS:
urban_create_rate = arland*urcreate_fract
wasteland(t) = wasteland(t - dt) + (W\A_chang_rate) * dt
INIT wasteland = 1619000
INFLOWS:
W\A_chang_rate = land_development_rate-erosion_rate
totalland = arland+forest_land+wasteland+otherland

basin water

Ground_Water(t) = Ground_Water(t - dt) + (return_flow_to_GW - GW_use_rate - GW_Base_flow) * dt
INIT Ground_Water = 2.48*10000
INFLOWS:
return_flow_to_GW =
Total_WW_Gen_by_population*popreturnfractGW+totalindustry_wastewater_generated*IndustryreturnfractGW+IrrigationWaste*irrigreturnfractGW+rainfractGW*total_rain_MCM
OUTFLOWS:
GW_use_rate =
AgrilWR*irrigDemandFractGW+total_industry_water_demand_per_month*IndustryDemandfractionGW+popdemandfractGW*population_water_per_month
GW_Base_flow = Ground_Water*Fract
RiverWater(t) = RiverWater(t - dt) + (External_Flow + return_flow_rate + Tributary_inflow - Outflow_to_Sea - Water_use_rate) * dt

INIT RiverWater = 1000
INFLOWS:
External_Flow = ext_flow*con_fract+total_rain_MCM*rainfractRW+base_flow
return_flow_rate =
Industryreturnfract*totalindustry_wastewater_generated+popreturnfract*Total_WW_Gen_by_population+irrigreturnfract*IrrigationWaste
Tributary_inflow =
(Tributary1+Tributary2+Tributary3+tributary4+Tributary5+other_tributary)*con_fract
OUTFLOWS:

Outflow_to_Sea = outflow*con_fract
Water_use_rate =
AgrilWR*irrigDemandFract+industrydemand_fract*total_industry_water_demand_per_month+population_water_per_month*popdemandfract+monthly_evaporationEv_in_MCM
base_flow = GW_Base_flow
month = TIME
ext_flow = GRAPH(month)
(1.00, 2327), (2.00, 2589), (3.00, 1948), (4.00, 4502), (5.00, 7869), (6.00, 18888), (7.00, 22136), (8.00, 19735), (9.00, 15094), (10.0, 10392), (11.0, 7412), (12.0, 4049)
Fract = GRAPH(month)
(1.00, 0.181), (2.00, 0.137), (3.00, 0.116), (4.00, 0.093), (5.00, 0.08), (6.00, 0.066), (7.00, 0.06), (8.00, 0.056), (9.00, 0.057), (10.0, 0.064), (11.0, 0.085), (12.0, 0.143)
other_tributary = GRAPH(month)
(1.00, 360), (2.00, 109), (3.00, 300), (4.00, 1410), (5.00, 10710), (6.00, 19797), (7.00, 23991), (8.00, 32991), (9.00, 28010), (10.0, 22054), (11.0, 18205), (12.0, 710)
outflow = GRAPH(month)
(1.00, 7509), (2.00, 6698), (3.00, 7008), (4.00, 9759), (5.00, 14840), (6.00, 21095), (7.00, 30486), (8.00, 28046), (9.00, 6698), (10.0, 21982), (11.0, 11661), (12.0, 7585)
Tributary1 = GRAPH(month)
(1.00, 1301), (2.00, 1040), (3.00, 1142), (4.00, 2103), (5.00, 2020), (6.00, 2871), (7.00, 4200), (8.00, 4259), (9.00, 3674), (10.0, 3340), (11.0, 2613), (12.0, 1867)
Tributary2 = GRAPH(month)
(1.00, 383), (2.00, 346), (3.00, 646), (4.00, 704), (5.00, 777), (6.00, 1364), (7.00, 2044), (8.00, 1593), (9.00, 1544), (10.0, 1044), (11.0, 418), (12.0, 355)
Tributary3 = GRAPH(month)
(1.00, 80.8), (2.00, 54.0), (3.00, 169), (4.00, 157), (5.00, 341), (6.00, 449), (7.00, 616), (8.00, 303), (9.00, 404), (10.0, 380), (11.0, 172), (12.0, 110)
tributary4 = GRAPH(month)
(1.00, 25.0), (2.00, 25.0), (3.00, 19.1), (4.00, 19.0), (5.00, 36.6), (6.00, 78.0), (7.00, 77.6), (8.00, 66.0), (9.00, 54.3), (10.0, 46.3), (11.0, 35.5), (12.0, 23.0)
Tributary5 = GRAPH(month)
(1.00, 61.5), (2.00, 48.0), (3.00, 51.3), (4.00, 121), (5.00, 157), (6.00, 414), (7.00, 595), (8.00, 616), (9.00, 840), (10.0, 908), (11.0, 297), (12.0, 152)

Immigration Population Sector

immigratpopulation(t) = immigratpopulation(t - dt) + (birthsimmmigrat - immigratetoUP - immigratetoRP - deathsimmigrat) * dt
INIT immigratpopulation = 1000000
INFLOWS:
birthsimmmigrat = immigratpopulation*immmigratbirthfraction
OUTFLOWS:
immigratetoUP =
immigratpopulation*normalmigratUP*IR_to_UP_multiplier_from_industry
immigratetoRP =
immigratpopulation*normalmigratRP*IR_to_RP_multiplier_from_govt_policy*IR_to_RP_multiplier_from_land*IR_to_RP_multiplier_from_water
deathsimmigrat = immigratpopulation/lifespanimmigrat
immmigratliteratepopulation(t) = immmigratliteratepopulation(t - dt) + (IPLR) * dt
INIT immmigratliteratepopulation = 1000000*.20
INFLOWS:
IPLR = illiterateIP*ConfractILP
illiterateIP = immigratpopulation-immmigratliteratepopulation
immigratliteracyratedesired = 1
immmigratbirthfraction = normaimmigratbirthfraction*immmigratBFmultiplerfromliteracy

immmigratlieracyrateactualtodesired =
immmigratliteracyrateactual/immigratliteracyratedesired
immmigratliteracyrateactual = immmigratliteratepopulation/immigratpopulation
lifespanimmigrat = immmigratidealifespan*immmigratlifespanmultiplierliteracy
literacy_fract_IP = (1-immmigratliteracyrateactual)*.20
literacy_rate_basin = total_literate_pop/totalpopulation
LPRA = totalland/totalpopulation
LPRI = .25
Ratio_EIRfromIPactual_to_desired = RatioEIRfromIPactual/RatioEIRfromIPdesired
ratio_of_actual_land_population_ratio_to_ideal = LPRA/LPRI
ratio_of_actual_water_population_ratio_to_ideal = (WPRA/WPRI)/10
RIGRATI = IGRA/IGRI
WPRA = Total_Water_supply*1000000/totalpopulation
immmigratBFmultiplerfromliteracy = GRAPH(immmigratlieracyrateactualtodesired)
(0.00, 1.94), (0.1, 1.88), (0.2, 1.80), (0.3, 1.68), (0.4, 1.55), (0.5, 1.39), (0.6, 1.21), (0.7, 0.97), (0.8, 0.73), (0.9, 0.41), (1, 0.1)
immmigratlifespanmultiplierliteracy = GRAPH(immmigratlieracyrateactualtodesired)
(0.00, 0.00), (0.1, 1.28), (0.2, 2.08), (0.3, 2.83), (0.4, 3.90), (0.5, 4.70), (0.6, 5.40), (0.7, 6.20), (0.8, 7.00), (0.9, 8.50), (1, 9.40)
IR_to_RP_multiplier_from_govt_policy = GRAPH(Ratio_EIRfromIPactual_to_desired)
(0.00, 0.245), (0.2, 0.265), (0.4, 0.295), (0.6, 0.345), (0.8, 0.395), (1.00, 0.465), (1.20, 0.525), (1.40, 0.605), (1.60, 0.715), (1.80, 0.815), (2.00, 0.935)
IR_to_RP_multiplier_from_land =
GRAPH(ratio_of_actual_land_population_ratio_to_ideal)
(0.00, 1.94), (0.0526, 1.68), (0.105, 1.34), (0.158, 1.04), (0.211, 0.8), (0.263, 0.6), (0.316, 0.44), (0.368, 0.34), (0.421, 0.26), (0.474, 0.2), (0.526, 0.16), (0.579, 0.12), (0.632, 0.105), (0.684, 0.085), (0.737, 0.065), (0.789, 0.055), (0.842, 0.045), (0.895, 0.035), (0.947, 0.025), (1, 0.015)
IR_to_RP_multiplier_from_water =
GRAPH(ratio_of_actual_water_population_ratio_to_ideal)
(-10.0, 0.00), (-8.95, 0.00), (-7.89, 0.005), (-6.84, 1e-005), (-5.79, 1e-005), (-4.74, 1.1e-005), (-3.68, 1e-005), (-2.63, 1e-005), (-1.58, 1e-005), (-0.526, 1e-005), (0.526, 0.015), (1.58, 0.045), (2.63, 0.135), (3.68, 0.235), (4.74, 0.345), (5.79, 0.475), (6.84, 0.585), (7.89, 0.695), (8.95, 0.835), (10.00, 0.985)
IR_to_UP_multiplier_from_industry = GRAPH(RIGRATI)
(0.00, 0.19), (0.111, 0.19), (0.222, 0.21), (0.333, 0.23), (0.444, 0.27), (0.556, 0.338), (0.667, 0.473), (0.778, 0.653), (0.889, 0.938), (1.00, 1.23)
RPCF_multiplier_from_industry = GRAPH(RIGRATI)
(0.00, 0.19), (0.111, 0.19), (0.222, 0.21), (0.333, 0.23), (0.444, 0.27), (0.556, 0.338), (0.667, 0.473), (0.778, 0.653), (0.889, 0.938), (1.00, 1.23)

Industrial Water Demand And Waste Water Generated

conversion_to_MCM = (1/1000)*(1/1000000)
RIWCATD = Industrial_Working_Capital/Industrial_working_Capital_Desired
totalindustry_wastewater_generated =
(WWGagriP+WWGFP+WWGHI+WWGPetrol+WWGPP+WWGTx)*conversion_to_MCM/12
Total_annual_ind_water_in_BCM = total_industry_water_demand_per_month*12/1000
total_industry_water_demand_per_month =
((WreqagriP+WreqFP+WreqHI+Wreqpetrol+WreqPP+WreqTx)*conversion_to_MCM*IWD_multiplier_from_IWC)/12
WreqagriP = agriPPA*WPUagriP
WreqFP = FPPA*WPUPFP
WreqHI = PHIA*WPUPHI

Wreqpetrol = WPUpetrol*TpetrolA
WreqPP = WPUPPP*TPPPA
WreqTx = TxPA*WPUPTx
WWGagriP = agriPPA*PUWWagriP
WWGFP = FPPA*PUWWFP
WWGHI = PHIA*WWPHI
WWGPetrol = PUWWpetrol*TpetrolA
WWGPP = PUWWPP*TPPPA
WWGTx = PUWWTx*TxPA
IWD_multiplier_from_IWC = GRAPH(RIWCATD)
(0.00, 1.18), (0.1, 2.26), (0.2, 4.55), (0.3, 6.65), (0.4, 8.65), (0.5, 9.35), (0.6, 9.65), (0.7, 9.75), (0.8, 9.65), (0.9, 8.85), (1, 5.85)

Industry Fixed Capital

industrial_fixed_capital(t) = industrial_fixed_capital(t - dt) + (FCIR - FCDR) * dt
INIT industrial_fixed_capital = 59
INFLOWS:
FCIR =
industrial_fixed_capital*FCIR_fraction*FCIR_multipier_from_infrastructure1*FCIR_multipier_from_infrastructure_2*FCIR_multiplier_from_Power*FCIR_multiplier_laworder
OUTFLOWS:
FCDR = industrial_fixed_capital*FCDR_Fract
RPATD = PAA/PD
RRALPSKATD = RALPSKA/RALPSKD
RRLPSKATD = RLPSKA/RLPSKD
FCIR_multipier_from_infrastructure1 = GRAPH(RRLPSKATD)
(0.00, 0.16), (0.1, 0.2), (0.2, 0.26), (0.3, 0.32), (0.4, 0.42), (0.5, 0.53), (0.6, 0.67), (0.7, 0.83), (0.8, 1.09), (0.9, 1.44), (1, 1.99)
FCIR_multipier_from_infrastructure_2 = GRAPH(RRALPSKATD)
(0.00, 0.151), (0.1, 0.191), (0.2, 0.29), (0.3, 0.37), (0.4, 0.47), (0.5, 0.612), (0.6, 0.75), (0.7, 0.97), (0.8, 1.25), (0.9, 1.55), (1, 1.95)
FCIR_multiplier_from_Power = GRAPH(RPATD)
(0.00, 0.21), (0.1, 0.3), (0.2, 0.42), (0.3, 0.6), (0.4, 0.78), (0.5, 0.99), (0.6, 1.23), (0.7, 1.53), (0.8, 1.95), (0.9, 2.43), (1, 2.93)
FCIR_multiplier_laworder = GRAPH(NPCR)
(0.00, 0.13), (5000, 0.21), (10000, 0.31), (15000, 0.41), (20000, 0.55), (25000, 0.69), (30000, 0.85), (35000, 1.05), (40000, 1.27), (45000, 1.52), (50000, 1.88)

Industry Working Capital

Industrial_Working_Capital(t) = Industrial_Working_Capital(t - dt) + (WCIR) * dt
INIT Industrial_Working_Capital = 73
INFLOWS:
WCIR =
industrial_fixed_capital*IWC_fraction*WCIRMagriP*WCIRMPetrolProducts*WCIRMPforestPrdt*WCIRMPheavyindust*WCIRMPPower*WCIRMTextile
Industrial_working_Capital_Desired = 100000000
IWC_fraction = (industrial_fixed_capital-Industrial_Working_Capital)*IFC_fract
RAPTDagriP = agriPPA/agriPPD
RAPTDFP = FPPA/FPPD
RAPTDHI = PHIA/PHID
RAPTDPetrol = TpetrolA/TpetrolD
RAPTDPP = TPPPA/TPPPD
RAPTDTx = TxPA/TxPD
WCIRMagriP = GRAPH(RAPTDagriP)

(0.00, 0.135), (0.1, 0.15), (0.2, 0.175), (0.3, 0.21), (0.4, 0.255), (0.5, 0.305), (0.6, 0.395), (0.7, 0.5), (0.8, 0.63), (0.9, 0.795), (1, 0.975)
WCIRMPetrolProducts = GRAPH(RAPTDPetrol)
(0.00, 0.055), (0.1, 0.095), (0.2, 0.16), (0.3, 0.23), (0.4, 0.315), (0.5, 0.41), (0.6, 0.5), (0.7, 0.61), (0.8, 0.71), (0.9, 0.825), (1, 0.975)
WCIRMPforestPrdt = GRAPH(RAPTDFP)
(0.00, 0.065), (0.1, 0.13), (0.2, 0.18), (0.3, 0.26), (0.4, 0.345), (0.5, 0.44), (0.6, 0.525), (0.7, 0.605), (0.8, 0.715), (0.9, 0.82), (1, 0.955)
WCIRMPheavyindust = GRAPH(RAPTDHI)
(0.00, 0.065), (0.1, 0.145), (0.2, 0.235), (0.3, 0.33), (0.4, 0.42), (0.5, 0.505), (0.6, 0.595), (0.7, 0.7), (0.8, 0.79), (0.9, 0.88), (1, 0.975)
WCIRMPPower = GRAPH(RAPTDPP)
(0.00, 0.085), (0.1, 0.125), (0.2, 0.185), (0.3, 0.245), (0.4, 0.315), (0.5, 0.385), (0.6, 0.455), (0.7, 0.545), (0.8, 0.655), (0.9, 0.785), (1, 0.965)
WCIRMTextile = GRAPH(RAPTDTx)
(0.00, 0.07), (0.1, 0.14), (0.2, 0.215), (0.3, 0.295), (0.4, 0.39), (0.5, 0.475), (0.6, 0.555), (0.7, 0.645), (0.8, 0.745), (0.9, 0.865), (1, 0.965)

Irrigated Land

irrigated_land(t) = irrigated_land(t - dt) + (ILCR) * dt
INIT irrigated_land = 17000
INFLOWS:
ILCR =
Avg_ILCR*ILCR_multiplier_govt_invest*ILCR_multiplier_utilization*ILCR_multiplier_WA
smooth_IL(t) = smooth_IL(t - dt) + (change_smooth) * dt
INIT smooth_IL = 119013
INFLOWS:
change_smooth = (irrigated_land-smooth_IL)/averaging_time
averaging_time = 5
avg_ILCR = unirrigland*unirrigland_confr
IPC = smooth_IL
IPU = smooth_IL*utlfract
RILTALA = smooth_IL/arland
RILTALATD = RILTALA/RILTALD
RIPCTU = IPU/IPC
RWAPCATD = WPCA/WPCD
unirrigland = arland-irrigated_land
WPCA = Total_Water_supply*1000000/totalpopulation
ILCR_multiplier_govt_invest = GRAPH(RILTALATD)
(0.00, 0.995), (0.0909, 0.695), (0.182, 0.535), (0.273, 0.4), (0.364, 0.3), (0.455, 0.23), (0.545, 0.16), (0.636, 0.1), (0.727, 0.06), (0.818, 0.03), (0.909, 0.01), (1.00, 0.01)
ILCR_multiplier_utilization = GRAPH(RIPCTU)
(0.00, 0.16), (0.111, 0.45), (0.222, 0.7), (0.333, 0.95), (0.444, 1.15), (0.556, 1.29), (0.667, 1.45), (0.778, 1.59), (0.889, 1.69), (1.00, 1.77)
ILCR_multiplier_WA = GRAPH(RWAPCATD)
(0.00, 0.00), (3.33, 0.167), (6.67, 0.315), (10.0, 0.46), (13.3, 0.65), (16.7, 0.95), (20.0, 1.28), (23.3, 1.65), (26.7, 2.28), (30.0, 2.94)

Irrigation Water

AgrilWR =
(juteWR+OCWR+PaddyWR)*croppingintensity*conversion_of_Ha_M_to_MCM
conversion_of_Ha_M_to_MCM = 10000/1000000

effective_rainfall = Rainfall_in_meter*ERfactor
IrrigationWaste = irrigationWR-AgrilWR
irrigationWR = AgrilWR/irrigation_eff
Irrigation_water_in_BCM = irrigationWR/1000

juteWR = jutland*(juteCF*evap_in_meter-effective_rainfall)+jute_submergence
jute_submergence = jute_depth*jutland
jutland = irrigated_land*jf
OCWR = othercropland*(OCCF*(effective_rainfall-evap_in_meter))
othercropland = irrigated_land*of
PaddyWR = (paddy_land*(evap_in_meter*Paddy_CF-effective_rainfall)+paddy_submergence)
paddy_land = irrigated_land*pf
paddy_submergence = paddy_depth*paddy_land
total_rain_MCM = (Rainfall_in_meter*totalland)*10000/1000000
evaporation = GRAPH(month)
(1.00, 30.5), (2.00, 50.0), (3.00, 76.7), (4.00, 72.9), (5.00, 99.9), (6.00, 60.2), (7.00, 90.5), (8.00, 76.4), (9.00, 54.6), (10.0, 66.5), (11.0, 53.9), (12.0, 36.6)
jf = GRAPH(month)
(1.00, 0.0138), (2.00, 0.0202), (3.00, 0.026), (4.00, 0.028), (5.00, 0.03), (6.00, 0.03), (7.00, 0.03), (8.00, 0.03), (9.00, 0.03), (10.0, 0.0296), (11.0, 0.0286), (12.0, 0.027)
of = GRAPH(month)
(1.00, 0.0627), (2.00, 0.0571), (3.00, 0.0501), (4.00, 0.0434), (5.00, 0.0403), (6.00, 0.0385), (7.00, 0.0378), (8.00, 0.0378), (9.00, 0.0403), (10.0, 0.0431), (11.0, 0.0473), (12.0, 0.0599)
pf = GRAPH(month)
(1.00, 0.2), (2.00, 0.3), (3.00, 0.4), (4.00, 0.3), (5.00, 0.2), (6.00, 0.9), (7.00, 0.9), (8.00, 0.9), (9.00, 0.9), (10.0, 0.8), (11.0, 0.7), (12.0, 0.2)
rainfall = GRAPH(month)
(1.00, 3.80), (2.00, 36.3), (3.00, 48.1), (4.00, 210), (5.00, 276), (6.00, 336), (7.00, 359), (8.00, 254), (9.00, 236), (10.0, 170), (11.0, 33.0), (12.0, 0.9)

Population Water Demand and Waste Water Generated

float_population = totalpopulation*fractioFP
PopWaterin_MCM_per_day = Total_Population_Water_Demand*MCM_con
totalpopulation = populationrural+urbanpopulation
Total_Annual_pop_water_demand_BCM = population_water_per_month/1000
Total_Population_Water_Demand = water_demand_RP+water_demand_UP+water_demand_FP+water_demand_IP
Total_WW_Gen_by_population = (WWgenFP+WWgenIP+WWgenRP+WWgenUP)*MCM_con*30
water_demand_FP = float_population*lpcdFP
water_demand_IP = immigratpopulation*lpcdIP
water_demand_RP = populationrural*lpcd_RP
water_demand_UP = urbanpopulation*lpcd_UP
WWgenFP = float_population*percapitaWWFP
WWgenIP = immigratpopulation*percapitaWWIP
WWgenRP = populationrural*percapitaWWRP
WWgenUP = urbanpopulation*percapitaWWUP

Rural Population Sector

literatepoprural(t) = literatepoprural(t - dt) + (RPLR) * dt
INIT literatepoprural = 13335930*.25

INFLOWS:
RPLR = illterateRP*Confract_RLP
populationrural(t) = populationrural(t - dt) + (birthsrural + immigratetoRP - deathsrural - RPCRTUP) * dt
INIT populationrural = 13335930
INFLOWS:
birthsrural = populationrural*birthfractionrural
OUTFLOWS:
deathsrural = populationrural/rurallifespan
RPCRTUP (Not in a sector)
birthfractionrural = normalbirthfractionrural*RuralBFmultiplerfromliteracy
illterateRP = IF((populationrural-literatepoprural)>0)THEN(populationrural-literatepoprural)ELSE(0)
rurallieracyrateactualtodesired = ruralliteracyrateactual/ruralliteracyratedesired
rurallifespan = ruralideallifespan*lifespan_multiplierliteracyrural
ruralliteracyrateactual = literatepoprural/populationrural
ruralliteracyratedesired = 1
total_literate_pop = literatepoprural+urbanliterate_pop
lifespan_multiplierliteracyrural = GRAPH(rurallieracyrateactualtodesired)
(0.00, 0.48), (0.1, 0.5), (0.2, 0.525), (0.3, 0.555), (0.4, 0.6), (0.5, 0.65), (0.6, 0.71), (0.7, 0.77), (0.8, 0.84), (0.9, 0.91), (1, 0.995)
RuralBFmultiplerfromliteracy = GRAPH(rurallieracyrateactualtodesired)
(0.00, 1.96), (0.1, 1.83), (0.2, 1.71), (0.3, 1.56), (0.4, 1.40), (0.5, 1.21), (0.6, 1.04), (0.7, 0.855), (0.8, 0.625), (0.9, 0.395), (1, 0.135)

Sustainability

Available_GW = (Ground_Water+return_flow_to_GW)-GW_Base_flow
Available_RW = IF((External_Flow+return_flow_rate+Tributary_inflow+base_flow)-(Outflow_to_Sea+Water_use_rate)>0)THEN(External_Flow+return_flow_rate+Tributary_inflow+base_flow)-(Outflow_to_Sea+Water_use_rate)ELSE(0)
Environmental_water_Demand = Total_Water_supply*percent_requirement
Environmental_water_Demand_BCM = 159.3
Sustainablity_Index =
IF(Total_Water_supply>Total_Water_Demand)THEN((Total_Water_supply-Total_Water_Demand)/Total_Water_supply) ELSE(0)
Total_Exploitable_Water = Total_Water_supply-Total_Water_Demand
Total_exploitable_Water_BCM = Total_water_supply_BCM-total_water_demand_BCM
Total_Water_Demand =
irrigationWR+total_industry_water_demand_per_month+population_water_per_month+Environmental_water_Demand
total_water_demand_BCM = Total_Water_Demand/1000
Total_Water_supply =
IF(Available_GW+Available_RW)>0THEN(Available_GW+Available_RW)ELSE(0)
Total_water_supply_BCM = Total_Water_supply/1000

Urban population sector

urbanliterate_pop(t) = urbanliterate_pop(t - dt) + (UPLR) * dt
INIT urbanliterate_pop = 1289222*.367
INFLOWS:
UPLR = illiterateUP*ConfractULP
urbanpopulation(t) = urbanpopulation(t - dt) + (birthsurban + immigratetoUP + RPCRTUP - deathsurban) * dt

INIT urbanpopulation = 1289222
INFLOWS:
birthsurban = urbanpopulation*urbanbirthfraction
immigratetoUP (IN SECTOR: Immigration Population Sector)
RPCRTUP (Not in a sector)
OUTFLOWS:
deathsurban = urbanpopulation/lifespanurban
ConfractULP = .1
illiterateUP = IF((urbanpopulation-urbanliterate_pop)>0)THEN(urbanpopulation-urbanliterate_pop)ELSE(0)
lifespanurban = urbanidealifespan*urbanlifespanmultiplierliteracy
normalurbanbirthfraction = .0238
RPCFTUP = .0017
urbanbirthfraction = normalurbanbirthfraction*urbanBFmultiplerfromliteracy
urbanidealifespan = 100
urbanlieracyrateactualtodesired = urbanliteracyrateactual/urbanliteracyratedesired
urbanliteracyrateactual = urbanliterate_pop/urbanpopulation
urbanliteracyratedesired = 1
urbanBFmultiplerfromliteracy = GRAPH(urbanlieracyrateactualtodesired)
(0.00, 1.94), (0.1, 1.88), (0.2, 1.77), (0.3, 1.68), (0.4, 1.55), (0.5, 1.39), (0.6, 1.25), (0.7, 1.01), (0.8, 0.81), (0.9, 0.5), (1, 0.1)
urbanlifespanmultiplierliteracy = GRAPH(urbanlieracyrateactualtodesired)
(0.00, 0.465), (0.1, 0.485), (0.2, 0.525), (0.3, 0.555), (0.4, 0.6), (0.5, 0.64), (0.6, 0.695), (0.7, 0.745), (0.8, 0.815), (0.9, 0.885), (1, 0.995)

Not in a sector
RPCRTUP = populationrural*RPCFTUP*RPCF_multiplier_from_industry

OUTFLOW FROM: populationrural (IN SECTOR: Rural Population Sector)

INFLOW TO: urbanpopulation (IN SECTOR: Urban population sector)

APPENDIX-D3

Table Ad2 **FORECASTED DISCHARGE of BRAHMAPUTRA & it's TRIBUTARIES for the year 2050 & 2025 based on Monte Carlo Simulation)**

BRAHMAPUTRA at Pandu

Year 2050 Year 2025

MONTHS	Weeks	Discharge (Cumec)	Avg per month	MONTHS	Weeks	Discharge (Cumec)	Avg per month
JAN	1	7818		JAN	1	7925	
	2	6888			2	7818	
	3	13742			3	6873	
	4	14838	10821.5		4	7419	7508.75
FEB	1	13454		FEB	1	6630	
	2	13496			2	6748	
	3	13326			3	6669	
	4	13314	13397.5		4	6744	6697.75
MAR	1	13564		MAR	1	6782	
	2	13746			2	6697	
	3	13566			3	6680	
	4	13428	13576		4	7872	7007.75
APRIL	1	15626		APRIL	1	7813	
	2	17382			2	8691	
	3	24724			3	9246	
	4	26574	21076.5		4	13287	9759.25
MAY	1	37632		MAY	1	13791	
	2	26760			2	13380	
	3	28372			3	15976	
	4	37628	32598		4	16212	14839.75
JUN	1	39614		JUN	1	13481	
	2	22165			2	24544	
	3	44330			3	22064	
	4	48584	38673.25		4	24292	21095.25
JULY	1	31688		JULY	1	24955	
	2	44128			2	32096	
	3	50008			3	26247	
	4	51820	44411		4	38645	30485.75
AUG	1	28815		AUG	1	35240	
	2	50570			2	26295	
	3	24888			3	24353	
	4	50570	38710.75		4	26295	28045.75
SEPT	1	26247		SEPT	1	22580	
	2	42778			2	26177	
	3	27083			3	27083	

	4	63376	39871		4	25285	6697.75
OCT	1	45802		OCT	1	24888	
	2	58266			2	24292	
	3	22580			3	22818	
	4	42442	42272.5		4	15928	21981.5
NOV	1	26570		NOV	1	13285	
	2	11874			2	12969	
	3	24726			3	12460	
	4	23748	21729.5		4	7929	11660.75
DEC	1	18350		DEC	1	9175	
	2	18350			2	6645	
	3	17382			3	6591	
	4	6576	15164.5		4	7929	7585

BRAHMAPUTRA at Bessamara

Year 2050 Year 2025

MONTHS	Weeks	Discharge(Cumec)	Avg per month	MONTHS	Weeks	Discharge(Cumec)	Avg per month
JAN	1	2113		JAN	1	3985	
	2	1792			2	1792	
	3	1875			3	1875	
	4	1414	1798.5		4	1654	2326.5
FEB	1	1643		FEB	1	1647	
	2	1439			2	1439	
	3	1211			3	3668	
	4	1212	1376.25		4	3600	2588.5
MAR	1	2534		MAR	1	2534	
	2	2017			2	2344	
	3	1947			3	1461	
	4	1985	2120.75		4	1452	1947.75
APRIL	1	3287		APRIL	1	3398	
	2	4760			2	4760	
	3	4923			3	4923	
	4	4925	4473.75		4	4925	4501.5
MAY	1	3873		MAY	1	6090	
	2	4994			2	6256	
	3	6163			3	8129	
	4	6236	5316.5		4	11000	7868.75
JUN	1	15519		JUN	1	12343	
	2	12628			2	12855	
	3	13603			3	20228	
	4	30125	17968.75		4	30125	18887.75
JULY	1	27439		JULY	1	27439	
	2	16529			2	18829	
	3	11131			3	20862	

	4	17254	18088.25		4	21412	22135.5
AUG	1	25025		AUG	1	25025	
	2	12582			2	15595	
	3	26932			3	16864	
	4	21454	21498		4	21454	19734.5
SEPT	1	24192		SEPT	1	18108	
	2	16967			2	14773	
	3	16406			3	11040	
	4	14565	18032		4	16454	15093.75
OCT	1	8285		OCT	1	8285	
	2	8528			2	12536	
	3	8782			3	12481	
	4	11424	9254.75		4	8265	10391.75
NOV	1	6071		NOV	1	9238	
	2	8677			2	8677	
	3	3566			3	8408	
	4	3325	5409.75		4	3325	7412
DEC	1	8080		DEC	1	2925	
	2	2571			2	7584	
	3	2361			3	2361	
	4	2211	3805.75		4	3325	4048.7

SUBANSIRI at Khabalughat

Year 2050 Year 2025

MONTHS	Weeks	Discharge(Cumec)	Avg per month	MONTHS	Weeks	Discharge(Cumec)	Avg per month
JAN	1	2002		JAN	1	1463	
	2	1463			2	1363	
	3	1027			3	1366	
	4	1050	1385.5		4	1013	1301.25
FEB	1	1318		FEB	1	1264	
	2	1264			2	973	
	3	1414			3	942	
	4	1311	1326.75		4	980	1039.75
MAR	1	980		MAR	1	1009	
	2	1500			2	943	
	3	1570			3	955	
	4	987	1259.25		4	1662	1142.25
APRIL	1	1845		APRIL	1	2239	
	2	2239			2	2287	
	3	2287			3	2432	
	4	2000	2092.75		4	1453	2102.75
MAY	1	2534		MAY	1	1385	
	2	3597			2	1571	
	3	1571			3	3319	

	4	1961	2415.75		4	1806	2020.25
JUN	1	2321		JUN	1	2733	
	2	3502			2	2653	
	3	4434			3	2899	
	4	4373	3657.5		4	3198	2870.75
JULY	1	3939		JULY	1	4430	
	2	4757			2	4399	
	3	4988			3	4642	
	4	4387	4517.75		4	3330	4200.25
AUG	1	4623		AUG	1	4194	
	2	3848			2	4531	
	3	4010			3	4702	
	4	4740	4305.25		4	3609	4259
SEPT	1	3938		SEPT	1	3082	
	2	3400			2	3167	
	3	4258			3	4440	
	4	4440	4009		4	4006	3673.75
OCT	1	4006		OCT	1	4262	
	2	4262			2	2758	
	3	3576			3	2826	
	4	3545	3847.25		4	3513	3339.75
NOV	1	3513		NOV	1	3031	
	2	3031			2	3047	
	3	3047			3	2376	
	4	2994	3146.25		4	1996	2612.5
DEC	1	2175		DEC	1	1835	
	2	2225			2	2029	
	3	2029			3	1780	
	4	1916	2086.25		4	1823	1866.75

JIABHARALI at NH crossing

Year 2050 Year 2025

MONTHS	Weeks	Discharge(Cumec)	Avg per month	MONTHS	Weeks	Discharge(Cumec)	Avg per month
JAN	1	367		JAN	1	363.5	
	2	391			2	394	
	3	399			3	386.5	
	4	224	345.25		4	387	382.75
FEB	1	325		FEB	1	325	
	2	273			2	348.5	
	3	301			3	348	
	4	461	340		4	361.5	345.75
MAR	1	273		MAR	1	723	
	2	880			2	880	
	3	279			3	485	

	4	314	436.5		4	494	645.5
APRIL	1	354		APRIL	1	354	
	2	410			2	410	
	3	383			3	667.5	
	4	468	403.75		4	1384	703.875
MAY	1	433		MAY	1	769	
	2	346			2	885.5	
	3	503			3	503	
	4	750	508		4	949	776.625
JUN	1	1285		JUN	1	1285	
	2	928			2	928	
	3	1914			3	1425	
	4	1818	1486.25		4	1818	1364
JULY	1	1687		JULY	1	2289	
	2	2019			2	2019	
	3	1615			3	1957	
	4	1805	1781.5		4	1912	2044.25
AUG	1	1200		AUG	1	1828	
	2	1985			2	1223	
	3	1501			3	1501	
	4	1820	1626.5		4	1820	1593
SEPT	1	1295		SEPT	1	1295	
	2	1489			2	1540.5	
	3	1566			3	1566	
	4	1774	1531		4	1774	1543.875
OCT	1	1382		OCT	1	1257	
	2	1623			2	1260	
	3	1141			3	1141	
	4	516	1165.5		4	516	1043.5
NOV	1	467		NOV	1	515	
	2	421			2	421	
	3	419			3	393.5	
	4	389	424		4	344	418.375
DEC	1	385		DEC	1	330	
	2	379			2	379	
	3	366			3	366	
	4	373	375.75		4	345	355

BURIDIHING

Year 2050 Year 2025

MONTHS	Weeks	Discharge(Cumec)	Avg per month	MONTHS	Weeks	Discharge(Cumec)	Avg per month
JAN	1	83		JAN	1	83	
	2	78			2	78	
	3	90			3	92	
	4	69	80		4	70	80.75

FEB	1	25		FEB	1	74	
	2	82			2	58	
	3	32			3	32	
	4	32	42.75		4	52	54
MAR	1	146		MAR	1	103	
	2	165			2	116	
	3	171			3	171	
	4	285	191.75		4	285	168.75
APRIL	1	235		APRIL	1	112	
	2	66			2	415	
	3	324			3	55	
	4	297	230.5		4	45	156.75
MAY	1	109		MAY	1	218	
	2	312			2	493	
	3	393			3	368.5	
	4	232	261.5		4	284	340.875
JUN	1	259		JUN	1	239.5	
	2	410			2	422	
	3	335			3	569	
	4	738	435.5		4	565	448.875
JULY	1	1098		JULY	1	589	
	2	869			2	869	
	3	622			3	566	
	4	472	765.25		4	441	616.25
AUG	1	364		AUG	1	364	
	2	349			2	349	
	3	577			3	241	
	4	256	386.5		4	256	302.5
SEPT	1	339		SEPT	1	483	
	2	503			2	397	
	3	230			3	342.5	
	4	395	366.75		4	395	404.375
OCT	1	236		OCT	1	489	
	2	224			2	224	
	3	499			3	499	
	4	307	316.5		4	307	379.75
NOV	1	217		NOV	1	217	
	2	193			2	193	
	3	184			3	132.5	
	4	49	160.75		4	144	171.625
DEC	1	128		DEC	1	128	
	2	81			2	103	
	3	92			3	92	
	4	56	89.25		4	117	110

MANAS

Year 2050 Year 2025

MONTHS	Weeks	Discharge (Cumec)	Avg per month	MONTHS	Weeks	Discharge (Cumec)	Avg per month
JAN	1	20		JAN	1	31	
	2	38			2	17	
	3	39			3	16	
	4	13	27.5		4	36	25
FEB	1	30		FEB	1	30	
	2	27			2	27	
	3	22			3	18	
	4	25	26		4	25	25
MAR	1	20		MAR	1	17.5	
	2	26			2	26	
	3	20			3	20	
	4	19	21.25		4	13	19.125
APRIL	1	19		APRIL	1	19	
	2	19			2	19	
	3	20			3	20	
	4	16	18.5		4	18	19
MAY	1	49		MAY	1	31.5	
	2	49			2	49	
	3	41			3	16	
	4	53	48		4	50	36.625
JUN	1	29		JUN	1	45	
	2	26			2	115	
	3	61			3	68	
	4	63	44.75		4	84	78
JULY	1	64		JULY	1	78.5	
	2	58			2	86	
	3	53			3	61	
	4	46	55.25		4	85	77.625
AUG	1	94		AUG	1	60	
	2	103			2	82	
	3	50			3	50	
	4	48	73.75		4	72	66
SEPT	1	48		SEPT	1	53	
	2	53			2	50	
	3	46			3	72	
	4	65	53		4	42	54.25
OCT	1	48		OCT	1	45.5	
	2	46			2	44.5	
	3	42			3	56.5	
	4	34	42.5		4	38.5	46.25
NOV	1	50		NOV	1	50	

	2	48			2	41	
	3	27			3	27	
	4	24	37.25		4	24	35.5
DEC	1	24		DEC	1	24	
	2	25			2	25	
	3	22			3	22	
	4	25	24		4	21	23

KAPILI

Year 2050 Year 2025

MONTHS	Weeks	Discharge(Cumec).	Avg per month	MONTHS	Weeks	Discharge(Cumec)	Avg per month
JAN	1	60		JAN	1	60	
	2	54			2	80	
	3	56			3	56	
	4	43	53.25		4	50	61.5
FEB	1	70		FEB	1	39	
	2	37			2	65	
	3	37			3	37	
	4	35	44.75		4	51	48
MAR	1	31		MAR	1	37	
	2	54			2	54	
	3	48			3	85	
	4	29	40.5		4	29	51.25
APRIL	1	108		APRIL	1	108	
	2	145			2	58	
	3	73			3	183	
	4	94	105		4	133.5	120.625
MAY	1	103		MAY	1	230	
	2	173			2	173	
	3	147			3	127.5	
	4	60	120.75		4	97	156.875
JUN	1	205		JUN	1	135	
	2	79			2	719	
	3	460			3	186	
	4	414	289.5		4	614	413.5
JULY	1	307		JULY	1	307	
	2	419.5			2	523	
	3	486			3	498	
	4	448	415.125		4	1053	595.25
AUG	1	751		AUG	1	751	
	2	267			2	570.5	
	3	386			3	630	
	4	511	478.75		4	511	615.625
SEPT	1	415		SEPT	1	1224	

	2	735			2	1144	
	3	648			3	585	
	4	406	551		4	406	839.75
OCT	1	466		OCT	1	477.5	
	2	2257			2	2257	
	3	1487			3	555	
	4	657	1216.75		4	341	907.625
NOV	1	307		NOV	1	167	
	2	137			2	625	
	3	277			3	196	
	4	199	230		4	199	296.75
DEC	1	200		DEC	1	200	
	2	198			2	198	
	3	121			3	121	
	4	89	152		4	89	152

APPENDIX- D4

Table Ad3 Water Availability Status of Brahmaputra Basin up to year 2050

Scenario	Year	Irrigation Water Consumption (BCM)	Industrial Water Consumption (MCM)	Population Water Consumption (BCM)	Total Water Consumption (BCM)	Total Supply BCM	Total Exploitable Water (BCM)	Sustainability Index
A	2005	8.25	4.36	0.58	168.13	987	818.87	0.83
	2025	10.05	5.85	0.87	170.22	983.63	813.41	0.83
	2050	11.48	99.75	1.8	172.68	979.87	807.19	0.82
B	2005	8.58	4.36	1.5	169.39	986.67	817.28	0.83
	2025	10.45	5.85	2.28	172.04	983.1	811.06	0.83
	2050	11.94	99.75	4.77	176.11	978.65	802.54	0.82
C	2005	7.87	4.36	0.58	167.75	529.94	362.18	0.68
	2025	9.61	5.85	0.89	169.8	526.59	356.78	0.68
	2050	10.97	99.75	1.95	172.32	522.78	350.46	0.67
D	2005	8.18	4.36	1.52	169	529.6	360.6	0.68
	2025	9.99	5.85	2.35	171.64	526.03	354.39	0.67
	2050	11.41	99.75	5.19	176	521.43	345.44	0.66
E	2005	4.24	4.36	1.52	165.06	74.77	0.00	0.00
	2025	5.07	5.85	2.37	166.75	71.61	0.00	0.00
	2050	5.59	99.75	5.39	170.38	67.19	0.00	0.00
F	2005	4.87	4.36	2.77	166.95	74.39	0.00	0.00
	2025	5.82	5.85	4.14	169.26	71.04	0.00	0.00
	2050	6.42	99.75	8.95	174.77	65.82	0.00	0.00

Water Flow in River	Water Uses	Scenario
Maximum	Normal	A
Maximum	High	B
Mean	Normal	C
Mean	High	D
Minimum	Normal	E
Minimum	High	F

Maximum = Maximum recorded flow of the river
Minimum= Minimum recorded flow of the river
Mean =Mean value of recorded flow of the river
Normal =Rural population water requirement 20 lpcd, Urban population water requirement 100 lpcd, Immigration Population water requirement 15 lpcd, Floating Population water requirement 50 lpcd, Cropping Intensity 1.25
High = Rural population water requirement 100 lpcd, Urban population water requirement 400 lpcd, Immigration Population water requirement 40 lpcd, Floating Population water requirement 75 lpcd, Cropping Intensity 1.30

APPENDIX-D5

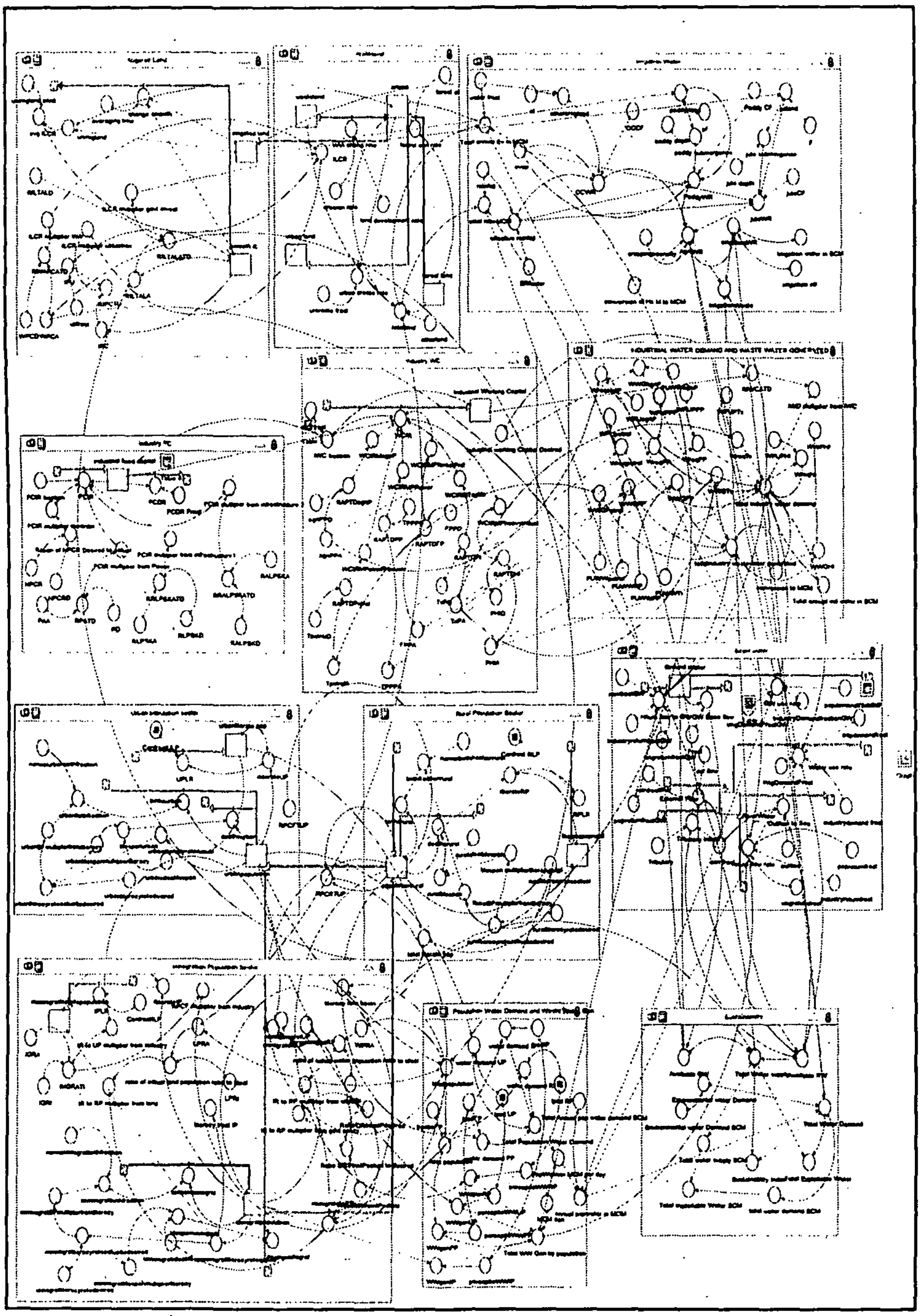


Figure Ad1 Overview of STELLA flow Diagram of BRISS

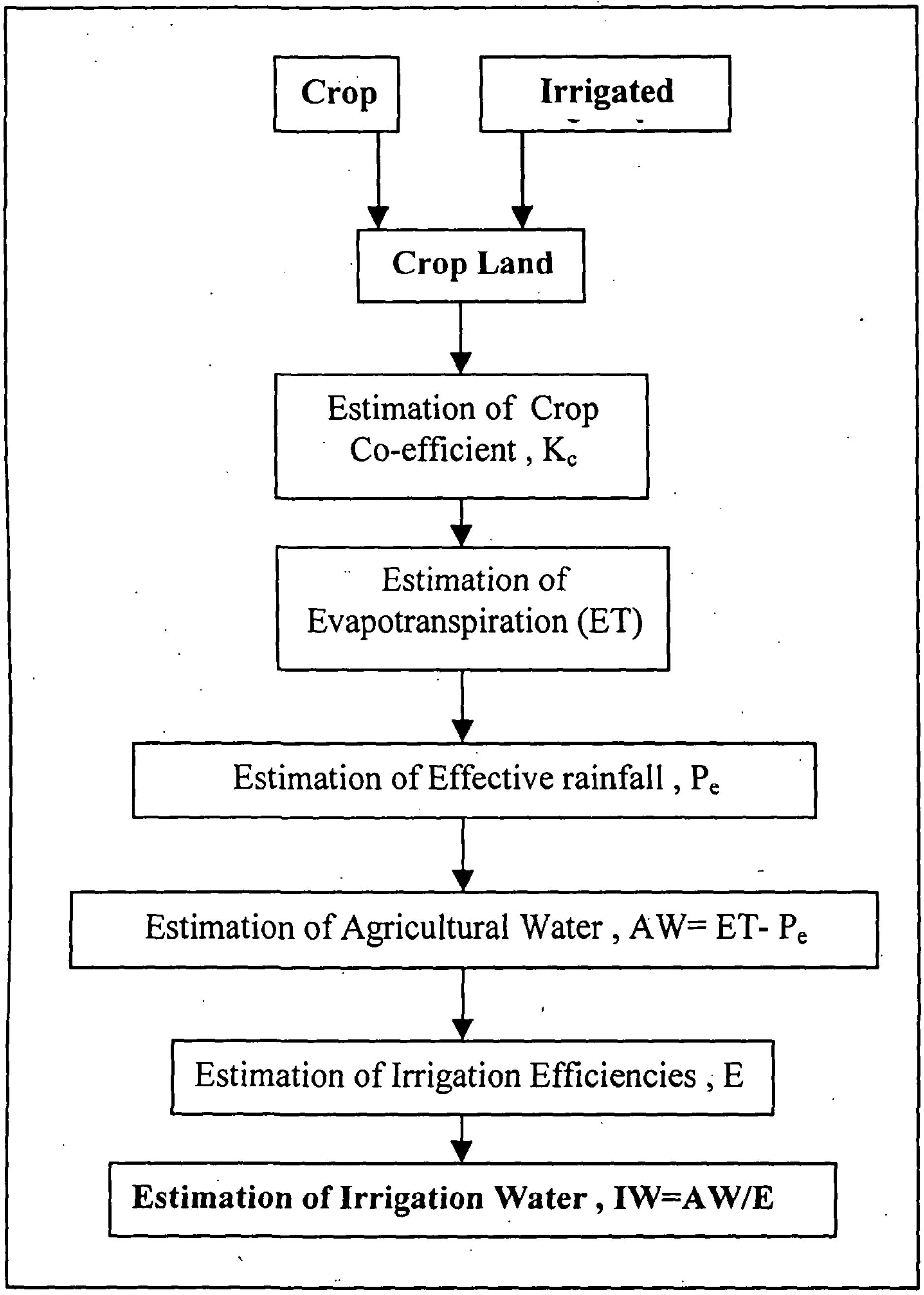


Figure Ad2 Approximate method for estimating Irrigation Water Requirement

APPENDIX-E1

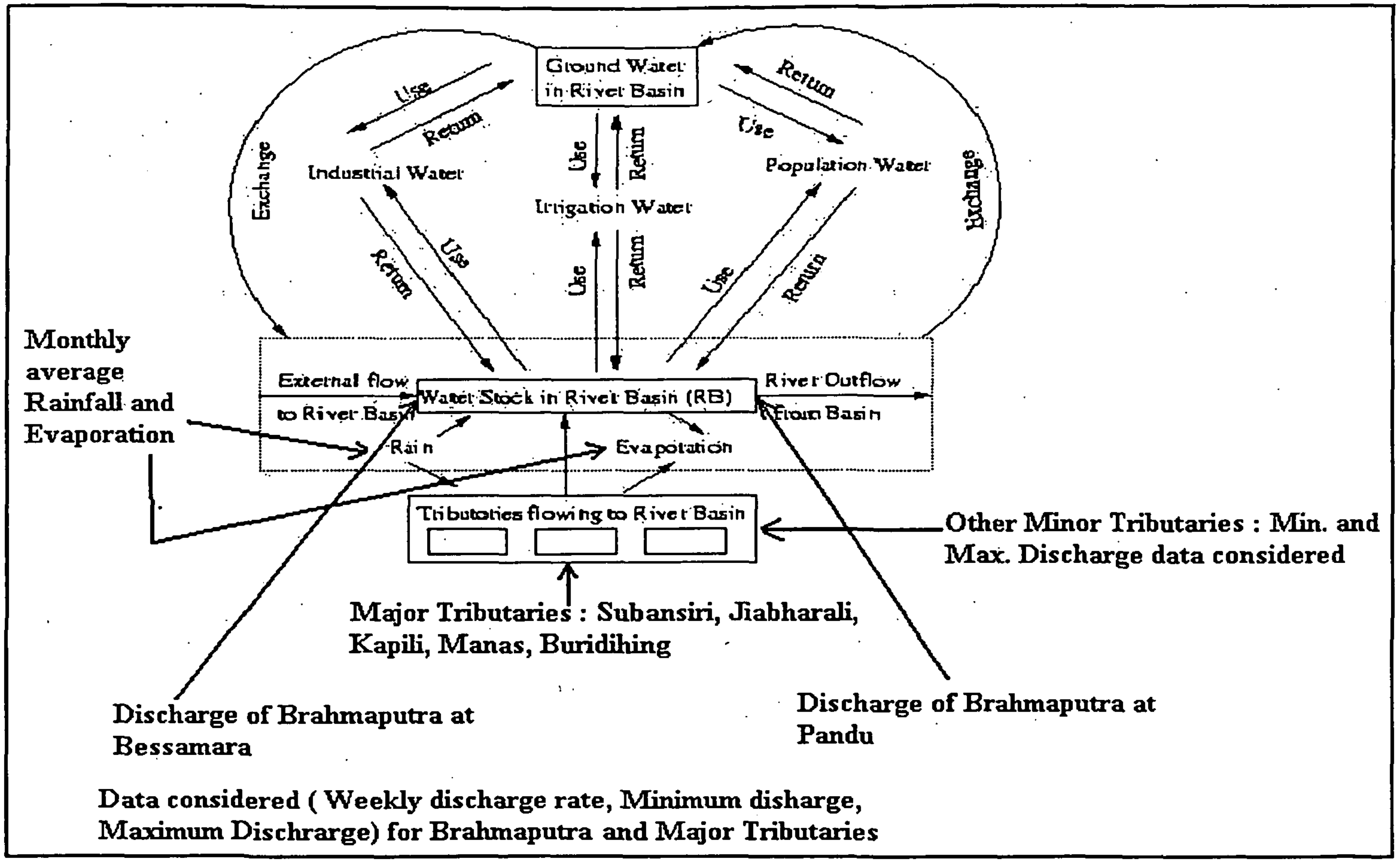


Figure Ae1 **Test Plan for BARISS on Brahmaputra River Basin**

APPENDIX-E2

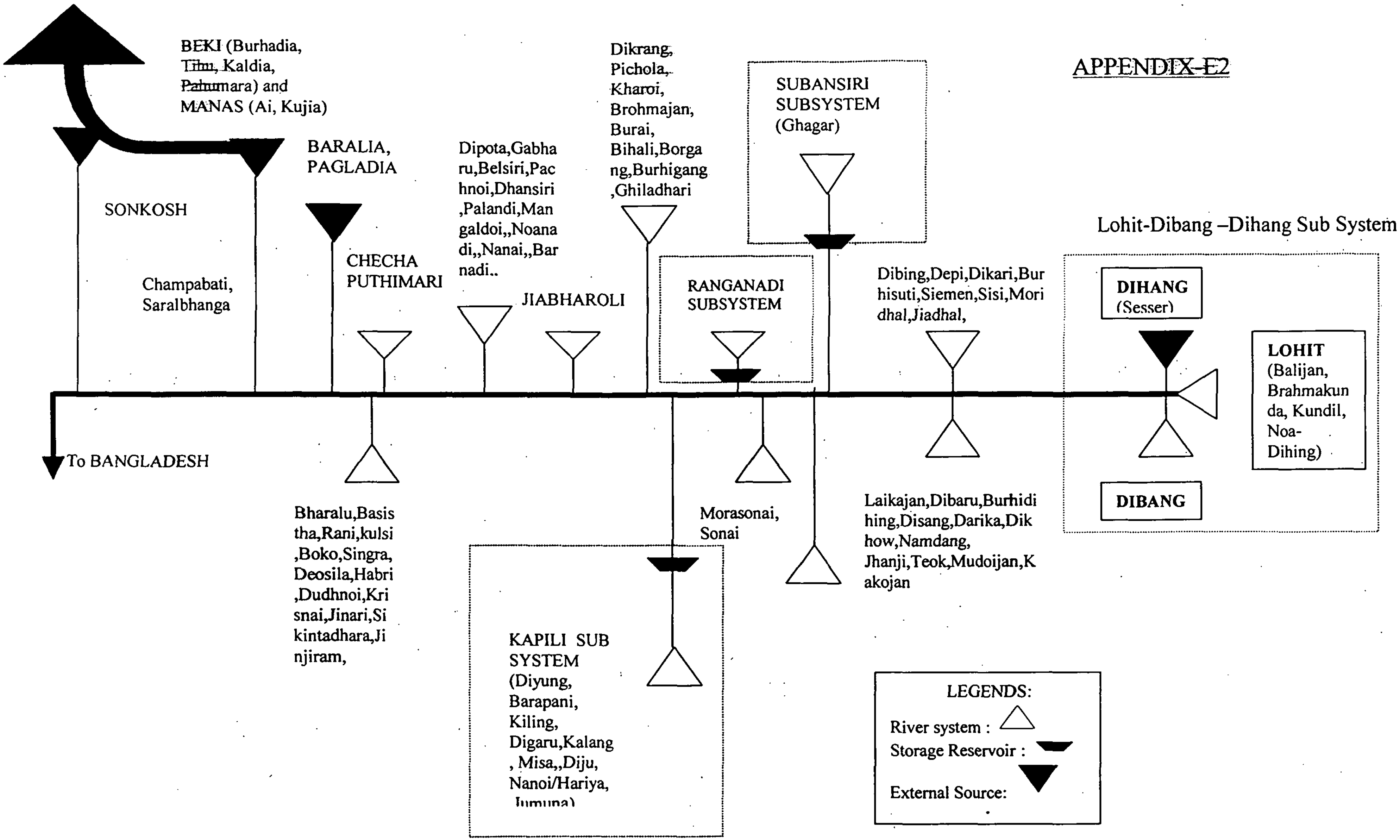


Figure Ae2 Schematic Diagram of river Brahmaputra