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Applicability and Prospects of WEAP Software as a Decision Support System Tool for Water Demand Analysis in Bangladesh: A Case Study of Lakkhya Basin-Demra Catchment

A THESIS SUBMITTED TO THE DEPARTMENT OF CIVIL AND ENVRIONMENTAL ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE

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DECLARATION

We hereby declare that the work in this thesis is our own except for quotations and summaries, which have been duly acknowledged.

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DEDICATION

To our parents and all those engineers who used their knowledge for the betterment of humanity.

ABSTRACT

Bangladesh is a riverine country which is dependent mainly on water for various major purposes such as agriculture, industrialization, urbanization etc. Water demand analysis is an important process to manage water efficiently in Bangladesh in context of Integrated Water Resource Management (IWRM). Often conflicts arise among the upstream and downstream water user particularly for a water stressed catchment which can be resolved through IWRM. Decision Support Systems (DSS) can provide effective tools for water allocation, supply and demand analysis. This research used Water Evaluation and Planning System (WEAP) as a DSS to evaluate the current water management scenario. WEAP provides a seamless integration of both the physical hydrology of the region and water management infrastructure that governs the allocation of available water resources to meet the different water needs. It is a priority driven software, employs priority based optimization algorithm as an alternative to hierarchal rule based logic that uses a concept of Equity Group to allocate water in time of inefficient supply. There is need for optimization of Lakkhya River basin-Demra catchment resources future need of its population. Shitalakkhya or Lakkhya is one of the major rivers in our country which has a big influence on Narayanganj area which is one of the industrial as well as agricultural centres of Dhaka city. The study is related to applicability and prospects of WEAP Software as Decision Support System (DSS) tool for water demand analysis in Bangladesh. The results confirmed that WEAP can be applied as a decision support system (DSS) tool for the water resource management in the Lakkhya River basin-Demra catchment Bank in terms for high population growth rate, extended dry climate sequence, which are possibly the major factors going to affect the future water demand and supply of Bangladesh.

Keywords: Decision support systems, Water resources management, Simulation, WEAP model, Water demand scenarios.

LIST OF ABBREVIATIONS

BWDB	Bangladesh Water Development Board
BMD	Bangladesh Meteorological Department
DSS	Decision Support System
DPSIR	Driving forces, Pressure, State, Impact and Responses
ETP	Effluent Treatment Plant
FAO	Food and Agricultural Organisation
GHG	Green House Gas
GWP	Global Water Partnership
GIS	Geographical Information System
HKH	Hindu Kush-Himalayan
IWRM	Integrated Water Resource Management
JICA	Japan International Cooperative Agency
PET	Potential Evapotranspiration
RET	Reference Evapotranspiration
UN	United Nations
UNEP	United Nations Environment Programme
WEAP	Water Evaluation and Planning
WFD	Water Framework Directive

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CHAPTER I

INTRODUCTION

1.1 BACKGROUND

The need for water is universal and without it life will simply cease to exist. Earth's water is constantly in motion, passing from one state to another, and from one location to another, which makes its rational planning and management a very complex and difficult task under the best of circumstances (Turner et al., 2004). The availability and use of water is therefore mainly constrained by its spatial quantity and quality distribution (Mugatsia, 2010).

Earth's fresh water is stored in reservoirs such as glaciers and ice caps, surface water, underground, and in the atmosphere. The replenishment rate of this water per annum is used to determine a country's freshwater availability. Globally, a country is categorized as "water-stressed" if its annual renewable freshwater supplies are between 1,000 and 1,700 m^3 per capita and "water scarce" if its renewable freshwater supplies are less than 1,000 m^3 per capita (World Bank, 2004). Only 8.3% of the countries in the world are classified as water-scarce (Mugatsia, 2010) and Bangladesh is not one of them as shown in Figure 1.1 (FAO, 2007). But if we have to keep our country out of the list of water stressed country we should keep an eye in our valuable water resources of river which are mainly generated from the Himalayans of India and mountainous area of Nepal known as Hindu Kush-Himalayan (HKH).

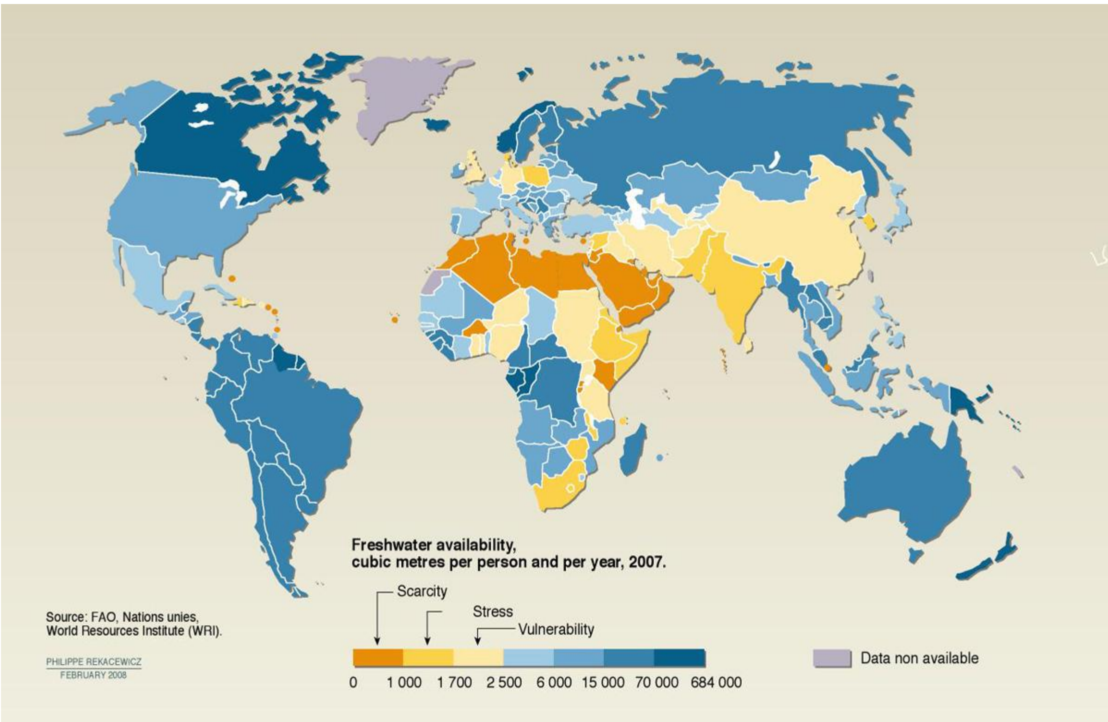

Figure 1.1 Freshwater availabilty of different countries (Source: FAO, 2007)

Three major river systems in the HKH region of South Asia are the Indus, the Ganges, and the Bramhaputra. Five countries that fall within these river systems are Bangladesh, Bhutan, India, Nepal, and Pakistan. This region is one of the largest storehouses of freshwater in the world supplying the need of about 1,500 million people living in South Asia. These rivers are not only the sources for meeting the peoples' water needs but are also major foci for both religious and cultural activities. The mountainous areas having altitudes above 5,000 m is mostly covered by ice and snow. The Himalayan range contains the world's highest three peaks, including Mt. Everest with an elevation of 8,848 m, the highest peak.

All the rivers of HKH countries are originating from the mountains and they are rain-fed and snow-fed. All HKH's five countries lie in the monsoon climatic regime. Since the monsoon rainfall is erratic and over 80 percent of total precipitation occurs during the four summer months (June to September), the volume of river water fluctuates (Moog O., 2008).

The Water Evaluation and Planning (WEAP) system developed by the Stockholm Environmental Institute is a powerful modelling tool. The Hydrologic Engineering Center of the US Army Corps of Engineers funded significant enhancements. A number of agencies, including the UN, World Bank, USAID and the Global Infrastructure Fund of Japan have provided project support. WEAP has been applied in water assessments in dozens of countries, including the United States, Mexico, Brazil, Germany, Ghana, Kenya, South Africa, Egypt, Israel, Oman, Central Asia, India, Sri Lanka, Nepal, China, South Korea, and Thailand. WEAP is river basin simulation software which includes opportunities for scenarios evaluation as well as water balance and allocation calculations (Charlotte et al., 2006). A hydrologic model of the Lakkhya River-Demra catchment area using WEAP has been developed in this study with the ultimate goal of determining the feasibility and practicality of a WEAP model for the entire Lakkhya basin.

1.2 OBJECTIVES OF THE STUDY

The main objective of this project is to explore the hydrologic capabilities of WEAP through the development of a Lakkhya River basin model with the intent of evaluating the practicality of incorporating a WEAP hydrology model for the entire Lakkhya River basin into the Physical Assessment Project. In creating the hydrologic model, data from several sources was compiled and pre-processed for use by WEAP. The WEAP model structure, data sources and parameter input techniques employed are discussed.

The hydrologic capabilities of WEAP are evaluated by comparing the flows simulated by WEAP with the flows measured by BWDB (Bangladesh Water Development Board). The practical utilization of WEAP as a large, basin scale hydrologic model to assist in water resources planning and management will be evaluated by comparing the general performance of the WEAP model with baseline condition (Charlotte et al., 2006).

The main objectives are:

1. To analyse the applicability and prospects of WEAP as Decision Support Systems (DSS) tool for water demand analysis in the context of Bangladesh.

2. To carry out a case study in Dhaka for Demra catchment -Lakhya River basin to show how it will assist in policy planning and decision making.

1.3 RATIONAL OF THE STUDY

At present three related global trends are aggravating water crisis. These are population growth, economic development and climate Change. Global warming, improved living standards, urbanization, and industrialization lead to a greater competition for water resources. On the contrary, the quantities of water that any country can economically develop, unfortunately, continue to decrease or remain limited. Also financial and technological constraints hinder the development and exploration of groundwater and reservoir resources. Decreasing inflows and groundwater recharge due to climate change aggravate this situation. For these problems the water managers and policy makers have been faced with more complexity and difficulty in the early 21st century.

A DSS tool is thus necessary to assess the performance of possible management alternatives for ensuring the sustainable use of water resources with respect to environmental, social and economic dimensions. Computer-based DSS tools allow the user to forecast and evaluate the impacts of different possible future trends and management strategies before implementing them. Olsen (2005) indicated that there is a lack of site-specific DSS that utilize local hydrological and socio-economic data for assessing regionally-based rural water supply schemes. Such a system and a user-friendly computer model would minimizes the need for gathering complex data, and incorporates non-technical factors into the computer algorithms, and greatly improve the process for managing rural water supply sources. And WEAP has an accessible interface and transparent data structure that make it suited as a tool for deliberations between diverse groups of stakeholders which is one of the main principles of Integrated Water Resource Management (IWRM).

Efficient water use is the key for sustainable management of water resources. The stress on availability of water for fast growing mega city like Dhaka is further exuberated due to the booming construction sector which is filling up the wetlands and water bodies in and around Dhaka city. This is resulting into severe water scarcity particularly during summer time (JICA, 1991; Kamal et al., 2004). These unplanned urban growths have profound adverse effect on the water resources, particularly in the humid tropical region (Sire and Balamurugan, 1991) where monsoon causes intensive rainfall. History of urban growth (Tawhid, 2004) demonstrates that Dhaka city is expanding to the eastern part, low-lying areas consisting of river networks and wetlands which usually act as retention basin. The ground water level of Dhaka city is decreasing very rapidly as retention area is decreasing which can recharge water in the aquifer. On top of it the withdrawal of water is increasing with increased demand for water supply due to population growth. The scenario would be worsening with time as erratic and intense rainfall events predicted (Islam, 2009) to be increasing their frequencies due to climate change (Climate Risk Index, 2010).

Shitalakkhya or Lakkhya is one of the major rivers in our country which has a big influence on Narayanganj area which is one of the industrial as well as agricultural centres of Dhaka city. The study is related to applicability and prospects of WEAP Software as DSS tool for water demand analysis in Bangladesh. A case study in Narayanganj for Demra catchment - Lakkhya river basin is conducted to show how it will assist in policy planning and decision making.

1.4 LIMITATION OF THE STUDY

This model represents a simplified and adjusted water system for the Lakhhya Basin and as such, excludes some of the water system components. However the limitations due to assumption and other factors are:

1. Only surface water management is considered in this study.
2. Transmission losses are excluded while predicting supply requirement.
3. Discharge from industrial sector is not included.
4. Contribution of groundwater is not considered.
5. Unavailability of data of streamflow from BWDB.
6. Water quality and cost analysis were not done.
7. Seepage, percolation loss, lateral flow during runoff is neglected.

1.5 ORGANISATION OF THE THESIS

Apart from this chapter, the remainder of the thesis consists of six chapters and an appendix.

Chapter II reviews the related literature regarding brief overview of DSS tool, introduction of WEAP, its applicability as DSS tool complying with IWRM principles.

Chapter III describes the study area in the context of various relevant hydrologic, socioeconomic and other aspects.

Chapter IV describes the methodology and development of WEAP model including input of relevant data.

Chapter V discusses the analysis and results under various future scenarios.

Chapter VI focuses on the final outcome of the research in the form of conclusion and recommendation.

CHAPTER II
LITERATURE REVIEW

2.1 WATER EVALUATION AND PLANNING SYSTEM (WEAP)

The Water Evaluation and Planning (WEAP) software is used as a simulation and evaluation tool to assess the performance of possible management alternatives. WEAP actually shows how much a river basin can be sensitive to drought conditions, and how the agricultural sector is significantly affected by irrigation deficits that increase sharply in drought periods. The indicator also verifies that, efficient water management is crucial to ensure the sustainable use of water resources with respect to environmental, social and economic dimensions (Yilmaz and Harmancioglu, 2010).

Through WEAP we can analyze the future water situation of a particular basin under different scenarios of socio-economic development and climate change. WEAP results offer a solid basis to assist planners in developing recommendations for future water resource management by revealing hot spots of action (Höllermann et al., 2010). Using WEAP we can find out the water demand of present and future of a particular basin or area. In this case different scenarios are built by using different data like land use data, stream flows, climatic data such as precipitation, evapotranspiration etc. (Ingol-Blanco and McKinney, 2009). The WEAP can model demand and supply and build different scenarios that may occur, and it is supported by Geographic Information System (GIS).

WEAP tool will allow testing of various unilateral and multilateral adaptation options under climate and socio-economic change. It helps to develop and validate initial (climate and socio-economic) scenario analyses using allocation tool, and invite further adaptation and application of the tool for specific Integrated Water Resources Management (IWRM) problems (Hoff et al., 2011).

WEAP has been used to stimulate water systems and orient management policies where Statistical Downscaling Models are used that allow the observation of climate change at local level. Thus, the study visualizes and analyzes the incidence of potential climate change on the hydroelectric sector, finding the degree of vulnerability for this or any other sector that relies on water as a source, and offers tools, strategies and criteria for the planning and orientation of projections in the different productive sectors (Ospina et al., 2009).

2.2 INTEGRATED WATER RESOURCES MANAGEMENT

IWRM is a process which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP, 2000). This definition adopted by the Global Water Partnership initiative applies to two major areas of concern; the natural system with its critical importance for resource quality and availability and the human systems which fundamentally determine the resource use, pollution and which must also set the development priorities. This definition captures a holistic view of IWRM; however critics view it as highly hypothetical, dismissing it as an amorphous definition. This is seen as having problems in concept and implementation, especially for meso to macro scale projects (Biswas, 2004). There are documented reports from around the globe by the GWP of projects which have been successfully implemented under IWRM concepts and principles. Moreover, many countries are changing the water policies to reflect the IWRM principles, for example the WFD (http://eur-lex.europa.eu/LexUriServ/) being implemented by European countries. Bangladesh is in the process of implementing water sector reforms which are based on IWRM. The new policy framework in Bangladesh, seeks to bring about integration of key sectors and stakeholders in water allocation and catchment management.

Floods during monsoon and scarcity of water during the dry seasons are the two extreme characteristics of water availability in Bangladesh. Both these events cause extreme miseries and hardship to the millions of people. Over the decades Bangladesh has been trying to overcome this twin problem by adopting various measures and projects under different water management endeavors. These measures have brought in significant gains. Thousands of hectares of lands with agriculture, homesteads and other infrastructures have been protected from the fury of floods in varying degrees. Despite these achievements, the country is now feeling the pangs of a more chronic and systematic water crisis in terms of both quality and quantity. For example: Arsenic contamination, salinity problem in coastal areas and reduction of open water fisheries due to flood control measures. IWRM could be the only tool to face these challenges.

Bangladesh believes in basin wide approach of river management instead of integrated water resource management in order to meet the water crisis during dry season, manage devastation of flood, maintain riverine ecosystem and water quality and over all environment of the country (Hossain and Ahmed, 2006). Hossain and Ahmed (2006) further identified the following deficiencies of water management practice of Bangladesh:

1. Lack of integrated approach.
2. Little involvement of stakeholders in water projects.
3. Deficiencies in institutional and legal instruments.
4. Lack of effective inter-agency cooperation.
5. Less focus on stakeholders' interests.
6. Little attention to environmental and social issues.
7. Virtually no attention to quality aspects of water.

Even though the idea of IWRM is very plausible, but when information on the resource and metaphysical interactions are not clear to a management team or committee, the IWRM process is delayed and characterized with misunderstanding. The use of scientific means to enhance understanding through modelling of the current and possible scenarios due to the various water resources development and changes in supply conditions forms a decision support for water managers at the catchment level. Such modelling can be achieved through water balance models, ground water flow models and economic water use models (Alfarra, 2004).

2.3 THE FRAMEWORK FOR INTEGRATED WATER RESOURCES PLANNING AND MANAGEMENT

There is a general consensus about integrated water management at catchment level as the approach to use for sustainable water resources management (GWP-TEC, 2009). It is therefore important to look at the overall basin and include all the elements in the basin that is affected by water. Figure 2.1 provides a schematic view of these elements, which can be stored in the form of GIS database sets.

Among the major aims of managing water resources is to safeguard human health whilst maintaining sustainable aquatic and associated terrestrial ecosystems. It is therefore important to quantify and identify the current state of, and impacts on, water environment and how these are changing with time and these interactions are shown in Figure 2.2 (Kristensen, 2004). The elements in Figure 2.1 (Mugatsia, 2010) can be evaluated analytically using a conceptual framework for water management based on the Driving forces, Pressure, State, Impact and Responses (DPSIR) framework. This allows a comprehensive assessment of the issues through examination of the relevant

Driving forces and Pressures on the environment, the consequent State of the environment and its Impacts, and the Responses undertaken, and of the inter-linkages between each of these elements are shown using a generic DPSIR framework for water management is shown in Figure 2.1

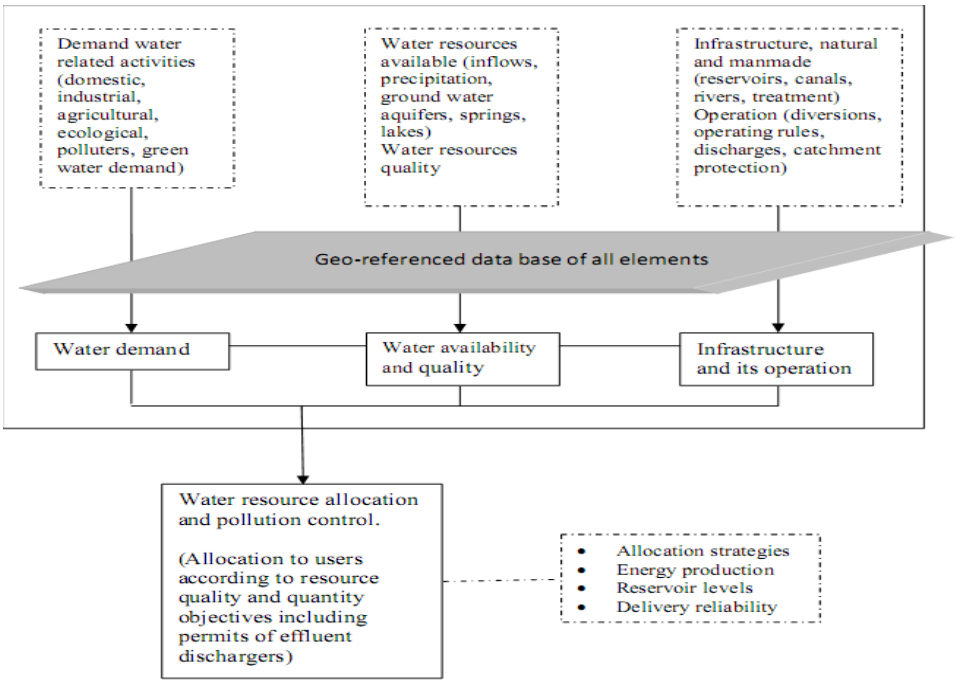

Figure 2.1 Schematic elements of water management (Source: Mugatsia, 2010)

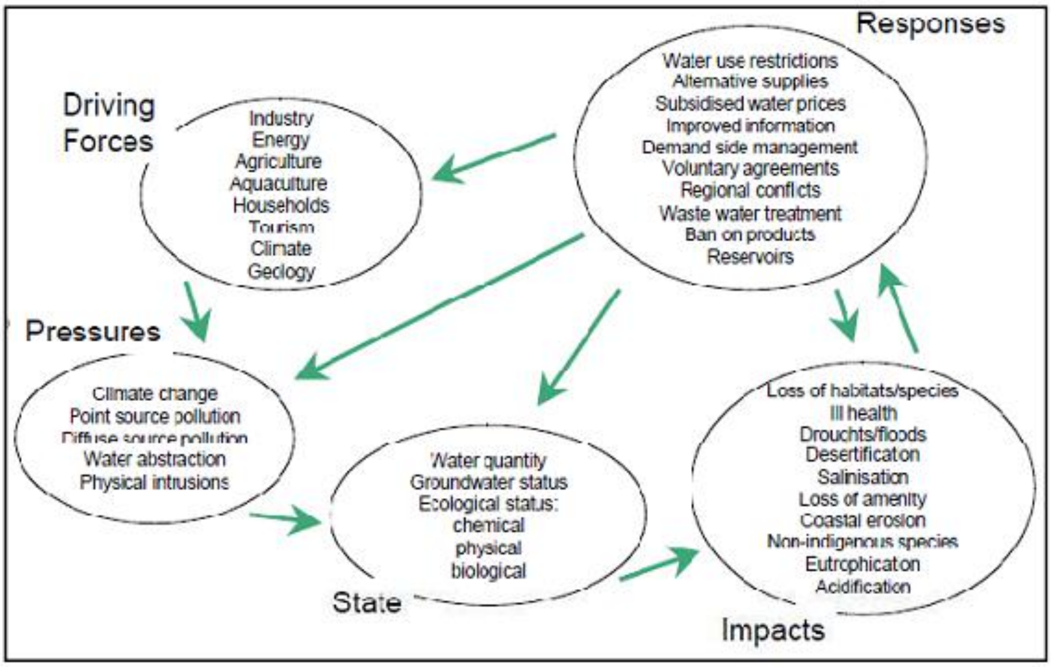

Figure 2.2 A generic DPSIR water management framework (Source: Kristensen, 2004)

In any catchment, water availability problems occur when the demand for water exceeds the amount of water available during a certain period. Freshwater shortages occur frequently in areas with low rainfall and high population density and in areas with intensive agricultural or industrial activity.

2.4 RAINFALL RUNOFF SIMULATION

Rainfall-runoff simulation is very significant in catchment management. Simulation of the catchment hydrology gives an indication of resource capacity. For the purpose of water resource assessment, it is necessary to have an understanding of flow conditions unaffected by human-induced land cover and water use changes, 'naturalised flow'. Flow naturalization adjustments consist primarily of removing the effects of historical reservoir storage and evaporation, water supply diversions, and return flows from surface and groundwater supplies and in some cases other considerations (Wurbs, 2006).

2.5 RAINFALL RUNOFF USING FAO CROP REQUIREMENT

According to WEAP software the FAO Crop requirements are calculated assuming a demand site with simplified hydrological and agro-hydrological processes such as precipitation, evapotranspiration, and crop growth emphasizing irrigated and rain fed agriculture. Non-agricultural land area can be included as well. Surface runoff found by rational method also can compare results (Jack and David, 2007). Precipitation intensity, catchment size and land cover are very important in determining runoff volume. Catchment area is obtained from ArcGIS 9.2 software, land covers are obtained from Banglapedia (http://www.banglapedia.org/HT/D_0109.HTM)

CHAPTER III
CASE STUDY AREA

3.1 INTRODUCTION

Shitalakshya River (Bengali: *ShitalokkhaNodi*) (also known as Lakkhya River) is a distributary of the Brahmaputra. In its initial stages it flows in a southwest direction and then east of the city of Narayanganj in central Bangladesh until it merges with the Dhaleswari near Kalagachhiya. A portion of its upper course is known as Banar River. The river is about 110 km long and at it widest, near Narayanganj, it is 300 meters in width. Its highest discharge has been measured at 2,600 cu ft/s (74 m^3/s) at Demra (Mahbub, 2007). It remains navigable year round. The river flows through Gazipur forming its border with Narsingdi for some distance and then through Narayanganj. The river's maximum depth is 70 feet (21 m) and average depth is 33 feet (10m) (http://en.wikipedia.org/wiki/ Shitalakshya_River).

3.2 GEOGRAPHY AND TOPOGRAPHY

Narayanganj (Bengali: *Naraeongônj*) is a city in central Bangladesh. It is located in the Narayanganj District, near the capital city of Dhaka and has a population of 220,000. The city is on the bank of the Shitalakshya River. The river port of Narayanganj is one of the oldest in Bangladesh. It is also a center of business and industry, especially the jute trade and processing plants, and the textile sector of the country. It is nicknamed the Dundee of Bangladesh due to the presence of lots of jute mills. Narayaganj district in Bangladesh map is given below in Figure 3.1

Narayanganj District is bounded by Gazipur and Narsingdi Districts on the north, Brahmanbaria and Comilla Districts on the east, Munshiganj District on the south, and Dhaka District on the west. Geologically, the area lies on the edge of the Madhupur Tract and Holocene floodplain deposits form the aquifer. The total area of the district is 759.57 km², of which 48.56 km is riverine and 0.60 km² is under forest. The district lies between 23°33´and 23°57´ north latitude and between 90°26´ and 90°45´ east longitude.

The city of Narayanganj has a population of 1.5 million and is located some twenty kilometres southeast of Dhaka, on the flat Ganges Delta and alluvial plain. The Shitalakshya River divides the town into two parts, the Narayanganj Municipal Area and Kadam Rasul Municipal Area. This area is crossed by many small artificial canals fed by monsoon rain. Average annual rainfall is 2550 mm, 80 to 90% of which occurs between May and October.

The population of the division reached 2,897,000 people as of Census 2011 (http://en.wikipedia.org/wiki/Narayanganj_District#Geography). The city Narayanganj besides the river Shitalakshya is shown in Figure 3.2.

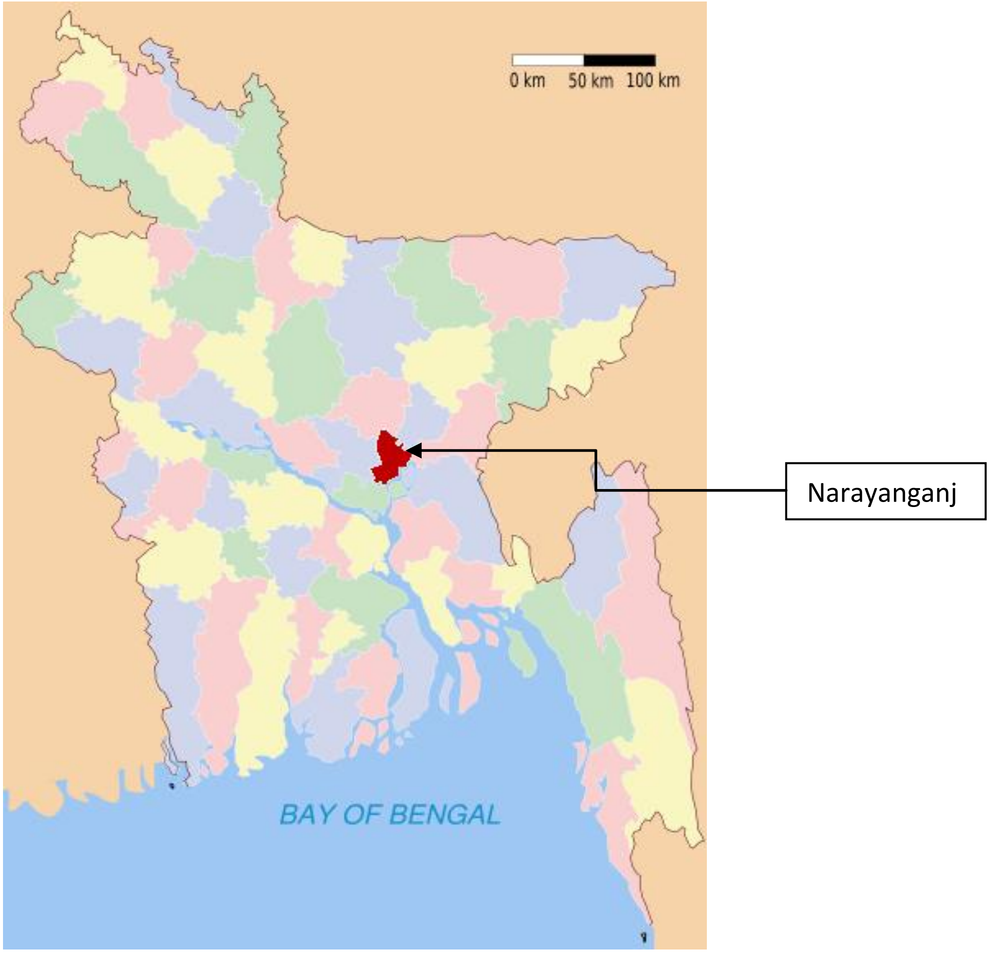

Figure 3.1 Location map of Narayanganj district (Source: http://en.wikipedia.org/wiki/Narayanganj_District)

Figure 3.2 Shitalakshya River alongside Narayanganj

3.3 CLIMATE

It is highly difficult to forecast what the weather will be like at a certain time in a very precise place. Average temperatures or rainfall can help us to get a good idea of the issue. The temperatures mentioned hereafter are expressed in degrees Celsius and represent the monthly averages observed over a great number of years. The rainfall graph can also be useful to determine the better period for rainwater harvesting. The climatic conditions are shown in Figure 3.3 to Figure 3.6 (http://www.levoyageur.net/weather-city-NARAYANGANJ.html).

The average temperature is high from the month of April to October as shown in Figure 3.3 and the variation of maximum and minimum temperature throughout the month is depicted in Figure 3.4. The area experiences heavy rainfall during monsoon. Usually the monsoon lasts from April to October and occasional rainfall in November. The rainfall amount is thus higher in these months as shown in Figure 3.5. The Figure 3.6 shows that the humidity is higher from May to October.

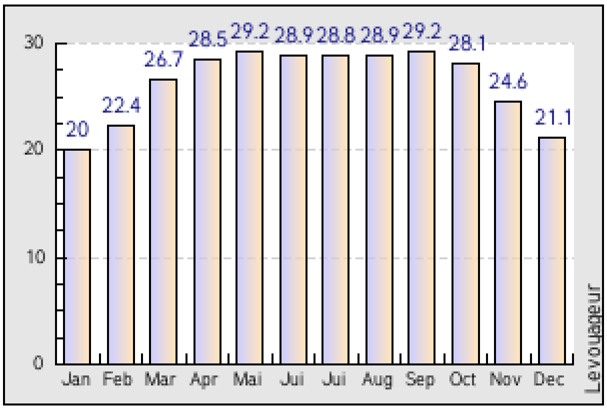

Figure 3.3 Average temperatures

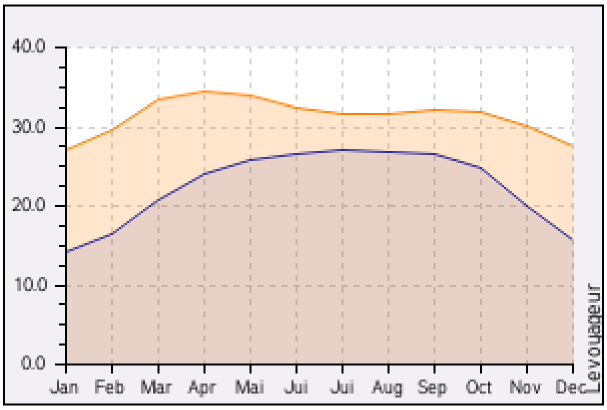

Figure 3.4 Minimum and maximum temperatures

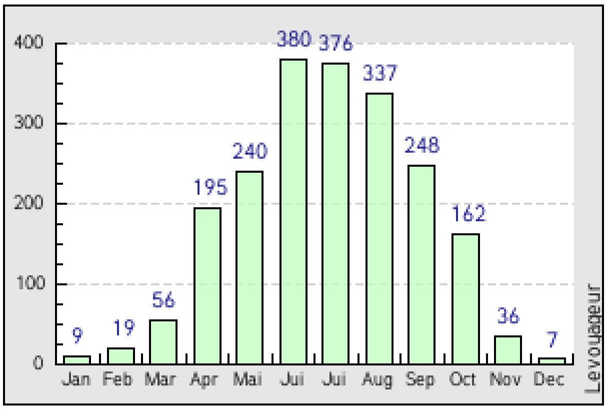

Figure 3.5 Rainfall in mm

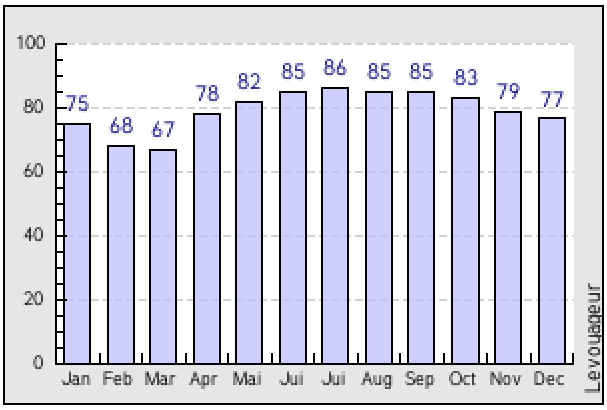

Figure 3.6 Humidity

3.3.1 Precipitation

Bangladesh is basically criss-crossed by many rivers. Moreover Bangladesh has a moderate climate. So, rainfall pattern is very much effective here for WEAP Rainfall-Runoff modelling. It is a kind of water source which will lead to a sustainable development as well as environmental safety. From Figure 3.7, it is seen that during rainy season, July has the highest total monthly rainfall.

Table 3.1 Monthly average precipitation of year 2002 (Source: BMD)

Month(Year 2002)	Value(mm/Month)
Jan	1.173
Feb	0.213
Apr	5.920
May	14.510
Jun	19.890
Jul	23.790
Aug	14.510
Sep	8.320
Oct	2.773
Nov	6.187
Dec	0.000

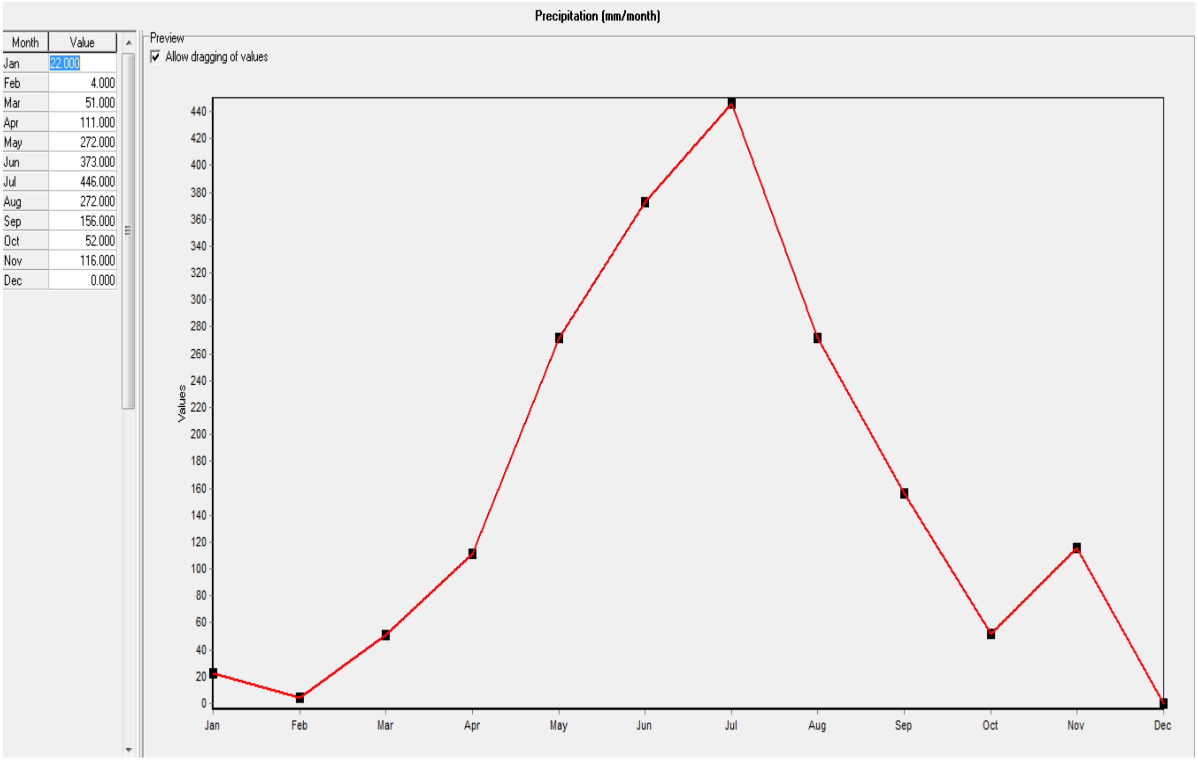

Figure 3.7 Climatic data (precipitation) are entered at the catchment level

3.4 LAND USE

Land use patterns are greatly influenced by topography, climate, and political situation. These factors are strongly affecting the distribution of agricultural, urban and industrial area. The pattern of land use change of a city may lead to the gradual degradation of the environment. The land use of Narayanganj city is changing rapidly resulting in deterioration in water quality. Narayanganj, as a city merges with the characteristics of Dhaka Mega city, facing a momentum of economic growth. This momentum has altered the land use pattern of the area. The current research has analysed the nexus between land use change and environmental degradation of Narayanganj municipality area. To accomplish this objective land use pattern of Narayanganj city and the nature of changes for different periods have been analysed (Ahmed et al., 2009). The areal distribution is shown in Table 3.2 (http://www.bangla2000.com/Bangladesh/Districts/narayanganj.shtm)

Table 3.2 Areal distribution pattern of Narayanganj

Area Type	**Area (in Acre)**
Total Land Area	172824
Cultivable Area	106353
Fallow Land	19932
Area Under Forest	100
Area Irrigated	59526
Area Under River	11804

The percentage of land use data are single crop 18.94%, double crop 61.44% and treble crop 19.43%; under irrigation land 52%. Main crops of Narayanganj are paddy, jute, wheat, mustard seed, and vegetables. The Extinct or nearly extinct crops are “Betel leaf” and “Aus paddy”. The Main fruits Mango, Jam (black bury kind), litchi, guava and banana. There are also 636 dairy farms, 860 poultry farms, 4 hatcheries and 31 nurseries for plants and trees (http://www.banglapedia.org/httpdocs/HT/N_0057.HTM).

3.5 WATER MANAGEMENT

The highest discharge has been measured at 2,600 cumec at Demra and the river is navigable throughout the year and shows little erosional tendency (http://www.banglapedia.org /HT/S_0353.HTM) Water resources include, lake and streams, reservoirs, springs, groundwater and, in recent years, effluents. Most of the natural water resources in the basin are exploited. In order to maintain water quality and sustainable ecosystem, there is a great need for an accurate monitoring of water use (domestic, agriculture, municipal, etc). On the other hand, data are collected for stream flow, industrial discharge and consumption, but the water potential is based on estimates. Water usage data from various sectors which are given as input in WEAP is shown in Table 3.3. No calibration scheme has yet been formed for the local water balances throughout the basin. A scheme, based on elaborated database, will assist in planning water allocation (Sivan et al., 2007).

Table 3.3 Water usage of different sectors

Sector	Annual Water Use (m^3)
Agriculture (Rice)	4900
Agriculture (Potato)	972
Demra City (Domestic)	350

CHAPTER IV
RESEARCH METHODOLOGY

4.1 INTRODUCTION

Modelling has become an essential tool in modern world of water management. It is used extensively and plays an important auxiliary role in fulfilling the core tasks of water management, in policy preparation, operational water management and research, and in the collection of basic data (monitoring). Besides the fact that the use of models is becoming increasingly common in water management, a development can also be discerned in items of increasing co-operation in the modelling field. The concept of a model is a very broad one; it is distinguished on the basis of the reason for the application, varying from policy analytical to scientific research models (detailed and narrow). Between the operational models (for real time control of structure, for example) and the calamity models, it is always possible to clearly distinguish between these fields (Olusheyi, 2006).

This chapter discusses the methods which were used in this research project. It focuses on hydrological analysis and water management simulation in the WEAP system. The demands in the catchment are the driving forces in the system. The pressure on the water resources comes from among other things, the quantity of abstraction, soil erosion and discharge of waste water. This in turn affects the state of water in quantity and quality. In the conceptual model, the decision variables which are in form of policies, withdrawals of water permits are used to impose control and regulation of water usage. The decision made from the various constraints will affect both the state of water resources and the demands in the catchment (Mugatsia, 2010).

4.2 MODEL STRUCTURE

WEAP is structured as a set of five different "views" onto the working Area: Schematic, Data, Results, Overview and Notes. These views are listed as graphical icons on the View Bar, located on the left of the screen. The Current Accounts represent the basic definition of the water system as it currently exists, and forms the foundation of all scenarios analysis. Scenarios are self-consistent story-lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions. The comparison of these alternative scenarios proves to be a useful guide to development policy for water systems from local to regional scales (Vogel et al., 2007).

The main screen of the WEAP system consists of the View Bar on the left of the screen and a main menu at the top providing access to the most important functions of the program. WEAP calculates water quantity and pollution mass balance for every node and link in the system on a monthly time step. Water is dispatched to meet in stream and consumptive requirements, subject to demand priorities, supply preferences, mass balance and other constraints.

The modelling of a Lakkhya basin-Demra catchment area using the WEAP consists of the following steps as stated by Levite et al. (2003):

i. Definition of the study area and time frame. The setting up of the time frame Includes the last year of scenario creation (last year of analysis) and the initial year of application.

ii. Creation of the Current Account which is more or less the existing water resources situation of the study area. Under the current account available water resources and various existing demand nodes are specified. This is very important since it forms the basis of the whole modelling process. This can be used for calibration of the model to adapt it to the existing situation of the study area.

iii. Creation of scenarios based on future assumptions and expected increases in the various indicators. This forms the core or the heart of the WEAP model since this allows for possible water resources management processes to be adopted from the results generated from running the model. The scenarios are used to address a lot of “what if situations”, like what if reservoirs operating rules are altered, what if groundwater supplies are fully exploited, what if there is a population increase. Scenarios creation can take into consideration factors that change with time.

iv. Evaluation of the scenarios with regards to the availability of the water resources for the study area plays significant role here. Results generated from the creation of scenarios can help the water resources planner in decision making, which is the core of any study by WEAP (Mugatsia, 2010).

There are three methods presented in WEAP for simulating catchment processes. These are (1) Irrigation Demands only based on the FAO Crop Requirements Approach, (2) the Rainfall Runoff and (3) the Soil Moisture Method.

Irrigation Demands only uses crop coefficients to calculate the potential evapotranspiration in the catchment. It determines any irrigation demand that may be required to fulfil that portion of the evapotranspiration requirement that rainfall cannot meet. It does not simulate runoff or infiltration processes.

The Rainfall Runoff method also determines evapotranspiration for irrigated and ‘rainfed’ crops using crop coefficients. The remainder of rainfall not consumed by evapotranspiration is simulated as runoff to a river, or can be proportioned among runoff to a river and flow to groundwater via catchment links. The rainfall runoff method was used to simulate river flows in this study.

The Soil Moisture Model is the most complex of the three methods, representing the catchment with two soil layers, as well as the potential for snow accumulation. In the upper soil layer, it simulates evapotranspiration considering rainfall and irrigation on agricultural and non-agricultural land, runoff and shallow interflow, and changes in soil moisture. This method allows for the characterization of land use and/or soil type impacts to these processes. Baseflow routing to the river and soil moisture changes are simulated in the lower soil layer. Correspondingly, the Soil Moisture Method requires more extensive soil and climate parameterization to simulate these processes. These kinds of data were not available.

4.3 DEVELOPING GIS MAP OF CASE STUDY AREA AND INPUT IN WEAP

"A geographic information system (GIS) is a computer-based information system that enables capture, modelling, manipulation, retrieval, analysis and representation of geographically referenced data" (Worboys et al., 1996). Star and Estes defined GIS as an information system that is designed with data referenced by spatial or geographic coordinates (Star and Estes et al.,1990).

A GIS map of the study area has been developed to use it as a background map in the WEAP model. WEAP allows to use both vector and raster layer. GIS layers are displayed as overlays or backgrounds on WEAP Schematic. These background maps are listed on the left side of the Schematic View, below the legend. The checkbox next to each layer can be used to hide or show it on the schematic. Figure 4.1 and 4.2 shows the raster and vector layer respectively which are developed by using GIS software ArcView 3.2.

Figure 4.1 A raster layer of the Lakkhya basin-Demra catchment area

There are options like Add Vector Layer (e.g. ArcView Shape files: *.shp) or Add Raster Layer (e.g. ArcView GRID or GeoTIFF). This menu also allows editing, deleting, setting labels or reordering the background maps. For instance, to view or edit the attribute data associated with a GIS layer, right-click on the layer name, then select Edit to go to the Map Layer window (shortcut: double click on the layer name to edit). On the Map Layer window that appears, click on an element in the map to see its data (displayed in the table to the left of the map). In Split or Table view, click the Edit button (below the map) to be able to edit the attribute values.

Vector layers display geographic features using discrete X-Y locations. Lines are constructed from strings of points, and polygons (regions) are built from lines which meets one another and make a loop. A raster display builds an image from pixels, grids, or elements of coarse or fine resolution, from centimeters to kilometers. Many satellites, like Landsat, transmit raster images of the earth's surface.

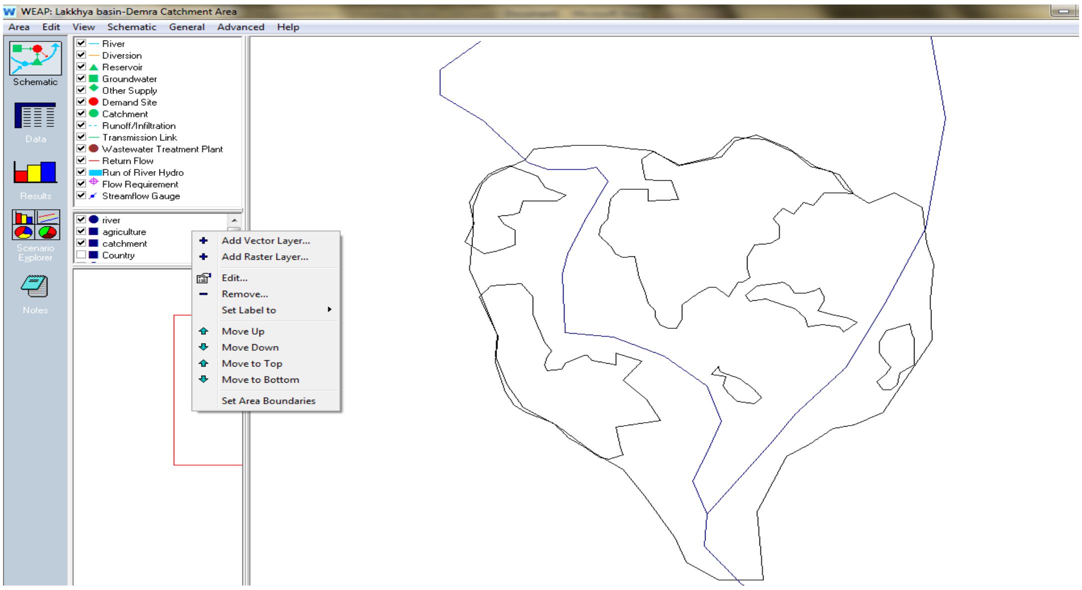

Figure 4.2 A vector layer of the Lakkhya basin-Demra catchment area

On the left side of the Schematic View, below the list of background maps, there is inset schematic in Figure 4.3. This small schematic always shows the complete area, and may be used to zoom in and out of the display on the main schematic. The large area on the right side of the Schematic View shows the Main Schematic. It is here that will help to create and edit the schematic. The schematic also provides with one-click access to the entire analysis. A more details on the various functions and utilities can be found in WEAP's user guide.

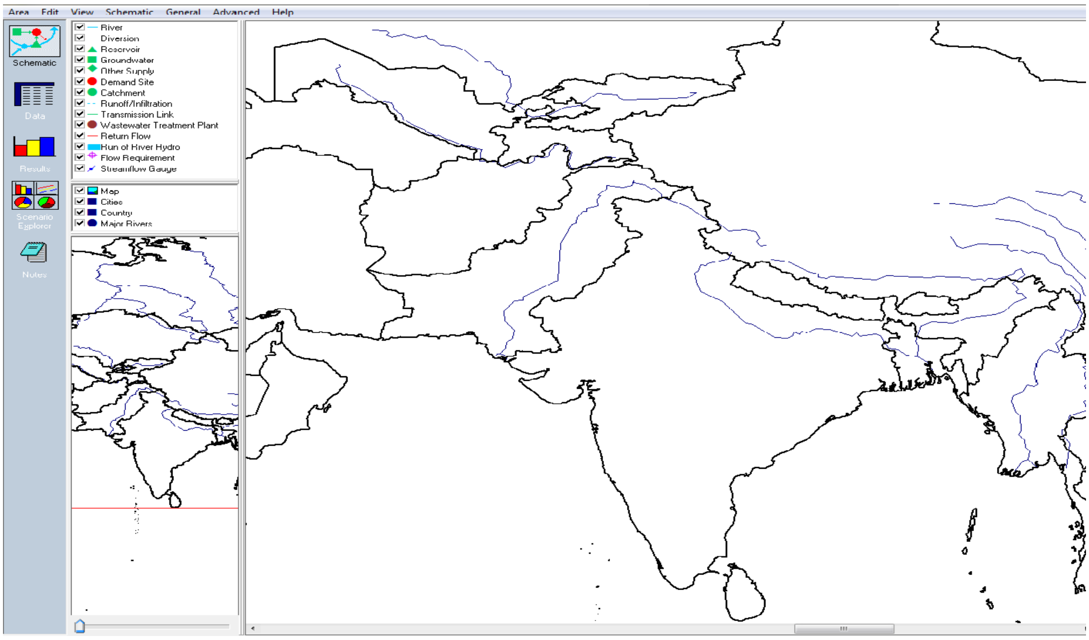

Figure 4.3 Inset schematic view in the left side

4.4 STREAMFLOW ANALYSIS

The stream flow data was obtained in the form of gauge height readings for some stations. The rating curves for some stations were missing, but the data used to construct the rating curves were available (current meter readings) (Mugatsia, 2010).

Stream flow data of 6 years (2004, 2005, 2006, 2008, 2009, and 2010) has been collected from BWDB as shown in Table 4.1. From these data the monthly average of stream flow from 2004-2010 has been calculated. The monthly average stream flow in Lakkhya during this period shows an enormous diversity with the WEAP Model.

Table 4.1 Stream flow data of Lakkhya from the year 2004 to 2010 (except 2007) (Source: BWDB).

Month	2004	2005	2006	2008	2009	2010	Average
January							
February							
March							
April							
May							
June			603.98	392.7846	354.237	546.955	474.48915
July	1117.18	1003.21	666.7	1171.966	653.66	722.971	889.28117
August	951.96	1329.52	635.34	1179.439	900.5405	639.7545	939.42567
September	766.6	1415.73	651.02	1557.085	750.781	790.5435	988.62658
October	993.67	880.02	643.18	569.675	477.1985	506.602	678.39092
November							
December							

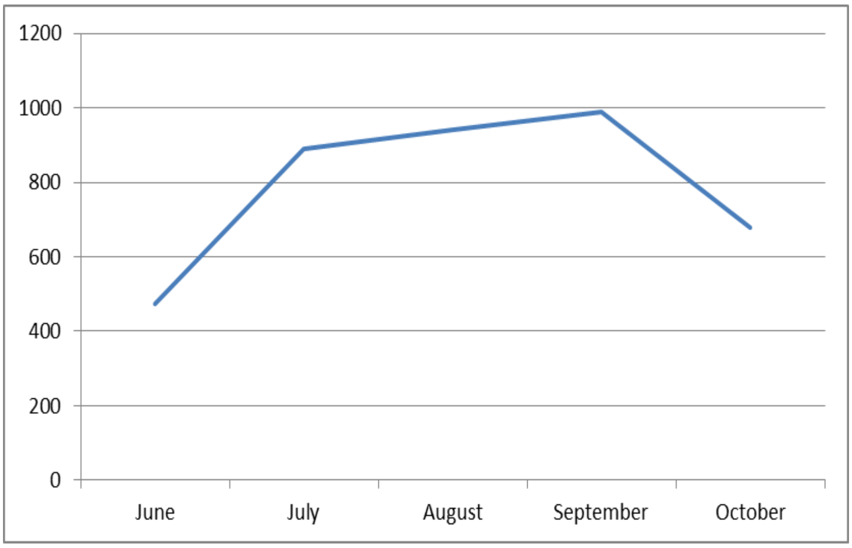

Figure 4.4 Monthly average of streamflow for the months June, July, August, September, October (5 Months) from 2004-2010 (except 2007) obtained from observed data

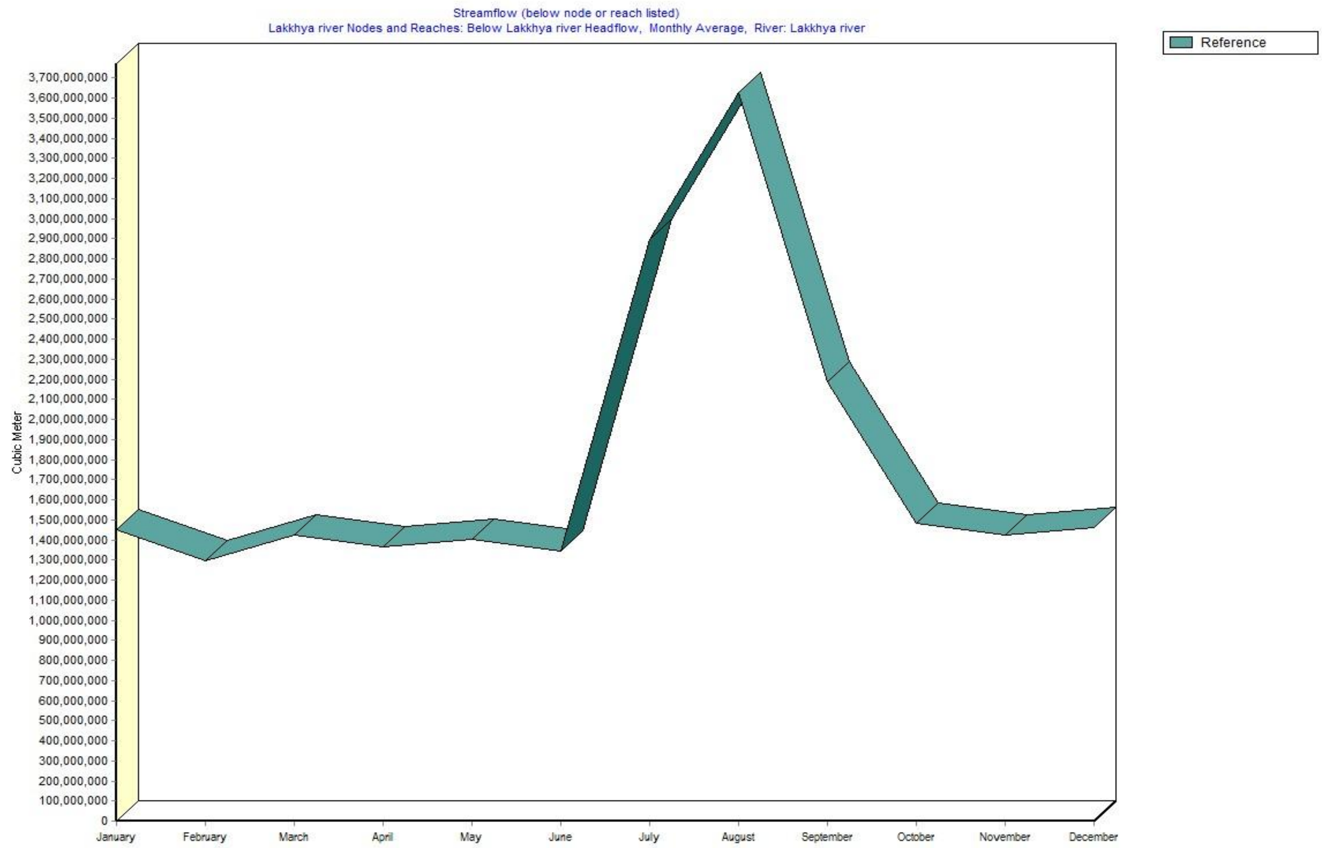

Figure 4.5 Monthly average of streamflow obtained from WEAP model for the reference scenario

Figure 4.4 is the graph which is obtained from the observed streamflow data and Figure 4.5 is the graph of simulated streamflow obtained from the WEAP model. In both Figures the highest peak is obtained from the period of July to September. It is due to heavy rainfall during this season. The streamflow generated in this period is useful for groundwater storage.

4.5 CREATING SCENARIOS

At the heart of WEAP is the concept of scenario analysis. Scenarios are self-consistent story-lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions. Using WEAP, scenarios can be built and then compared to assess their water requirements, costs and environmental impacts. All scenarios start from a common year, for which one establishes ones Current Accounts data.

The scenarios can address a broad range of "what if" questions, such as: What if population growth and economic development patterns change? What if reservoir operating rules are altered? What if groundwater is more fully exploited? What if water conservation is introduced? What if ecosystem requirements are tightened? What if new sources of water pollution are added? What if a water recycling program is implemented? What if a more efficient irrigation technique is implemented? What if the mix of agricultural crops changes? What if climate change alters the hydrology?

Scenarios in WEAP encompass any factor that can change over time, including those factors that may change because of particular policy interventions, and those that reflect different socio-economic assumptions. Sensitivity analyses may also be done by varying uncertain factors through their range of plausible values and comparing the results and details can be found in WEAP user guide.

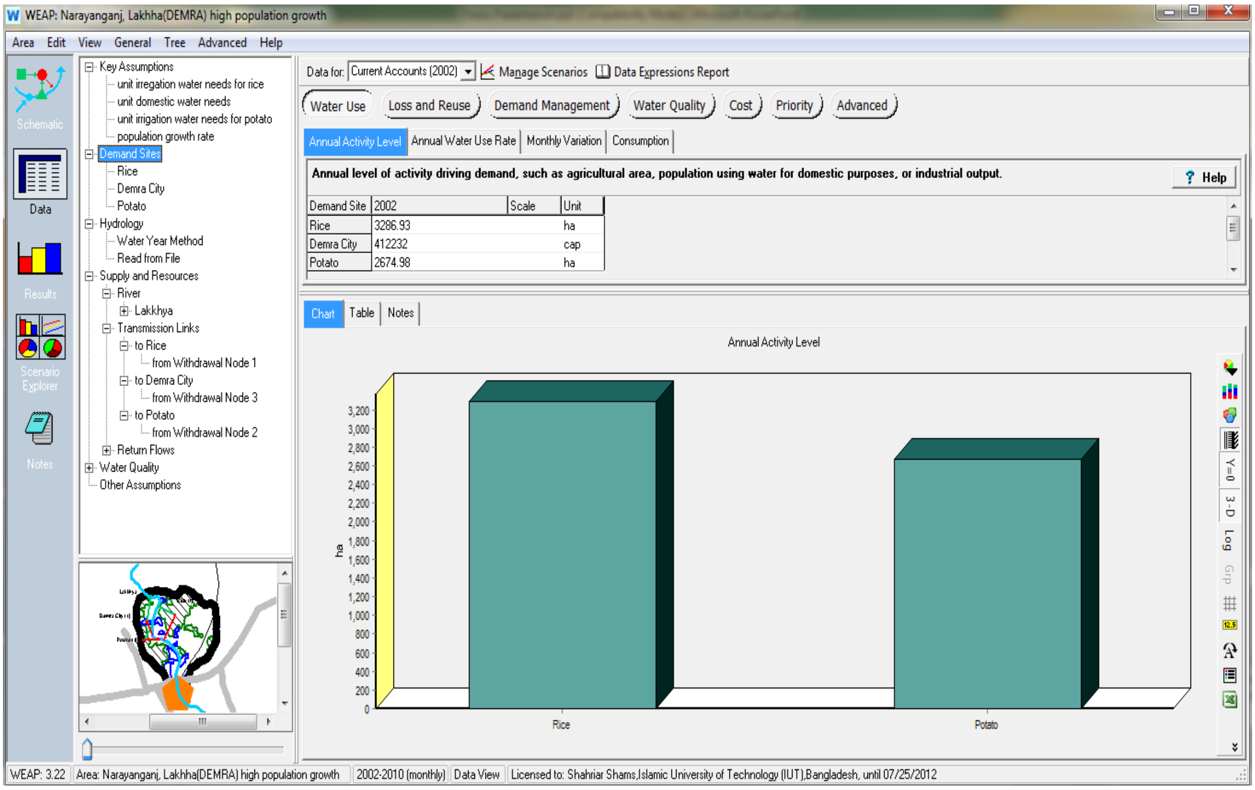

Figure 4.6 Current scenario (Baseline-year, 2002)

The year 2002 is defined as the current scenario in the WEAP model as shown in Figure 4.6 and the reference scenario is defined from the year of 2003 to 2010. Based on the current scenario and reference scenario many other scenarios have been developed by changing of various parameters. The following scenarios were therefore created based on the reference scenario and are tabulated in Table 4.2 which is illustrated by Figure 4.7.

Table 4.2 Scenario analysis based on high population growth, extended dry climate.

Level of scenario analysis	Scenario	Remarks
0	Reference	No change
1	High Population Growth	Increase in population growth rate
2	Extended Dry Climate Sequence	Climate change triggered by global warming

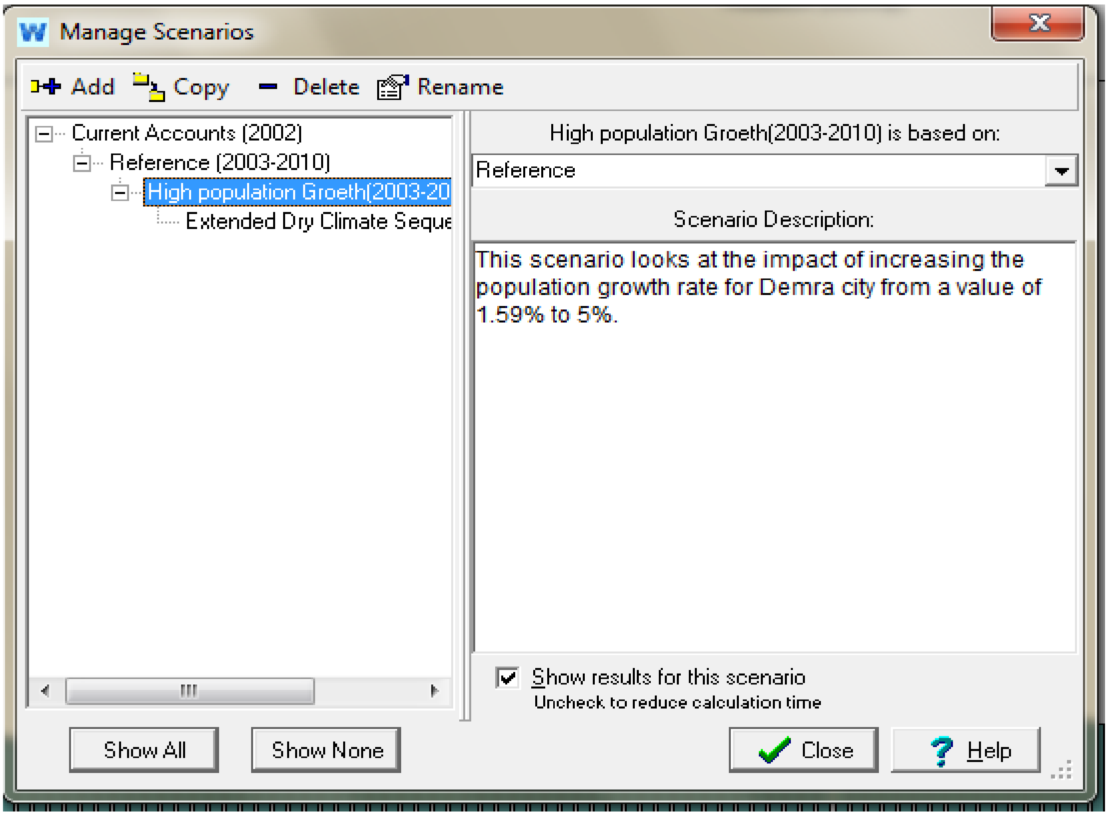

Figure 4.7 Scenarios development in WEAP

4.6 REFERENCE CROP EVAPOTRANSPIRATION

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or REF and is denoted as ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. The use of other denominations such as PET (Potential evapotranspiration) is strongly discouraged due to ambiguities in their definitions. The only factors affecting ETo are climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data. ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors (Allen et al, 1998). Reference crop evapotranspiration was calculated using CropWat program that uses the FAO (1992) Penman-Monteith method (Marica, 2012). These estimates are used in crop water requirements and irrigation scheduling calculations. The methods supersede the older FAO 24 procedures published in 1977 which are no longer recommended as they over estimate evapotranspiration. The program uses the same Penman Monteith methodology as used in CROPWAT versions 5.7 and 7.0 and uses the same data such as the CLIMWAT climate and rainfall files. The program uses a flexible menu system and file handling, and extensive use of graphics. Graphs of the input data (climate, cropping pattern) and results (crop water requirements, soil moisture deficit) can be drawn and printed with ease. In this case CROPWAT v. 8 is used and Figure 4.8 shown the interface for data input.The Reference Evapotranspiration data for current scenario input in WEAP is shown in Table 4.3

The Penman-Monteith form of the combination equation is:

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)}$$

where Rn is the net radiation, G is the soil heat flux, (es - ea) represents the vapour pressure deficit of the air, ρ a is the mean air density at constant pressure, cp is the specific heat of the air, delta represents the slope of the saturation vapour pressure temperature relationship, γ is the psychrometric constant, and rs and ra are the (bulk) surface and aerodynamic resistances.

The following weather data collected from BMD were used in CROPWAT to calculate RET:

1. Maximum temperature (degree Celsius)
2. Minimum temperature (degree Celsius)
3. Sunshine hours
4. Humidity (%)
5. Wind Speed (km/hr)

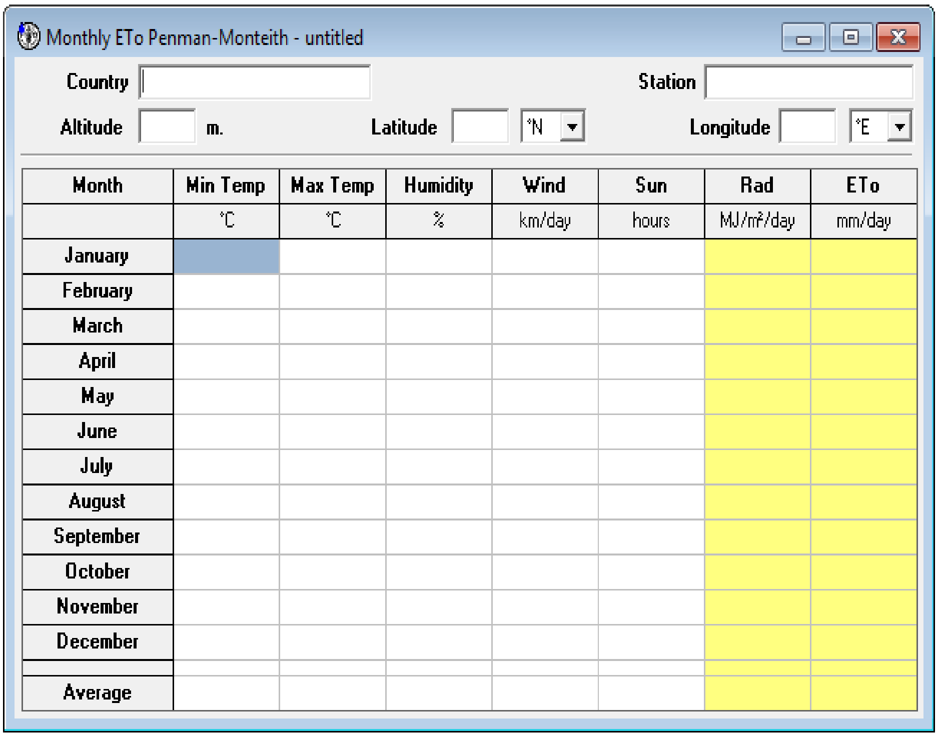

Figure 4.8 CROPWAT v. 8 interface for data input

Table 4.3 Input data (Ref. ET) in WEAP for current scenario (2002)

Month	Ref.ET (mm)
Jan	6.079
Feb	11.490
Mar	11.120
Apr	9.863
May	7.428
Jun	7.025
Jul	8.092
Aug	8.595
Sep	7.528
Oct	8.917
Nov	5.576
Dec	

4.7 MODELLING CATCHMENT WITH RAINFALL RUNOFF METHOD

The Rainfall Runoff method is a simple method that computes runoff as the difference between precipitation and a plant's evapotranspiration. A portion of the precipitation can be set to bypass the evapotranspiration process and go straight into runoff to ensure a base flow (through the ,effective precipitation parameter). The evapotranspiration is estimated by first entering the reference evapotranspiration, then defining crop coefficients for each type of land use (Kc) that multiply the reference evapotranspiration to reflect differences occurring from plant to plant as explained in WEAP's tutorial.

The rainfall runoff method was used to simulate river flows; this was constrained by the type of data available (Rainfall, evaporation and crop data). The following types of data are required to perform rainfall-runoff simulation using this method:

i. Land use (Area, Kc, Effective precipitation)

ii. Climate (Precipitation and ETo)

Where Kc- crop coefficients and ETo is the reference crop evapotranspiration. A Catchment area has been created in the Schematic view to simulate headflow for Lakkhya River as shown in Figure 4.9. This is done by pulling over a Catchment node and locating it near the starting point of the Lakkhya River. It was named as Lakkhya River Headflow. After the Catchment node was created, a dashed blue line automatically appeared in the schematic linking the node to the Lakkhya River. Some general information for the catchment area has been defined in the Figure 4.10.

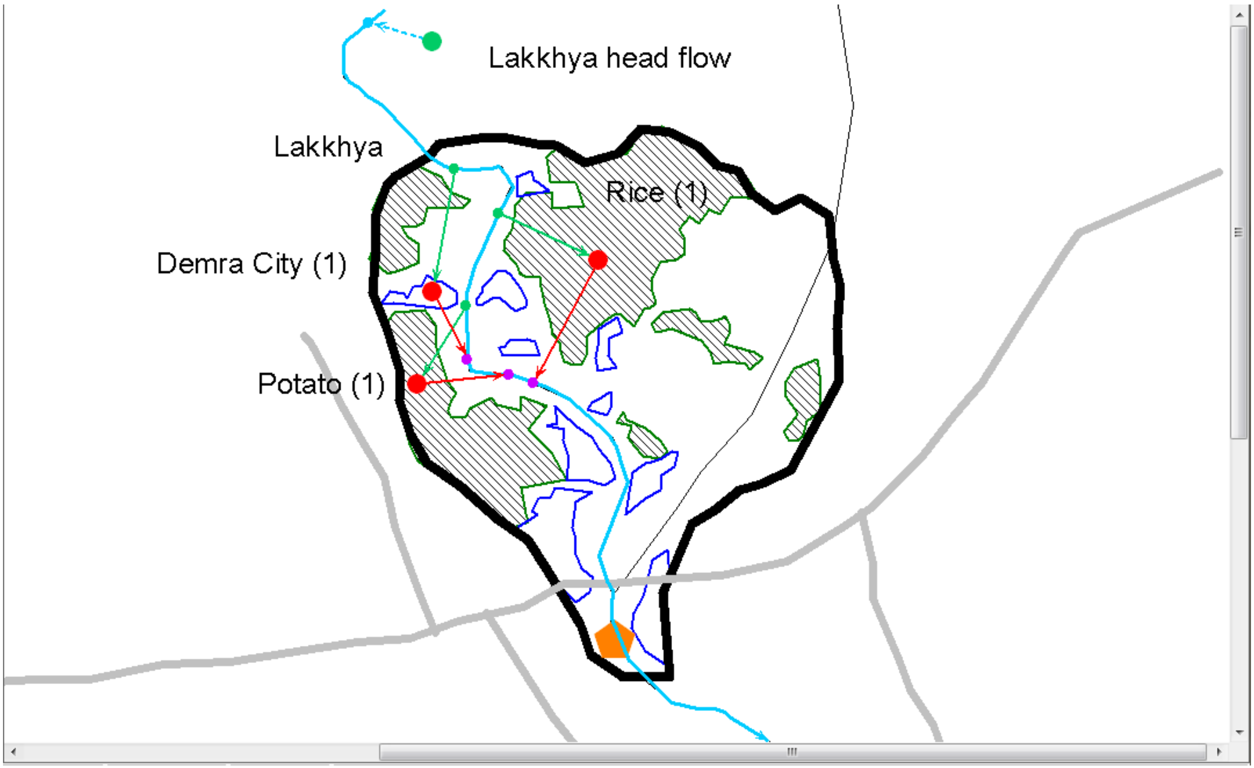

Figure 4.9 Lakkhya basin-Demra catchment area for the FAO rainfall-runoff modeling

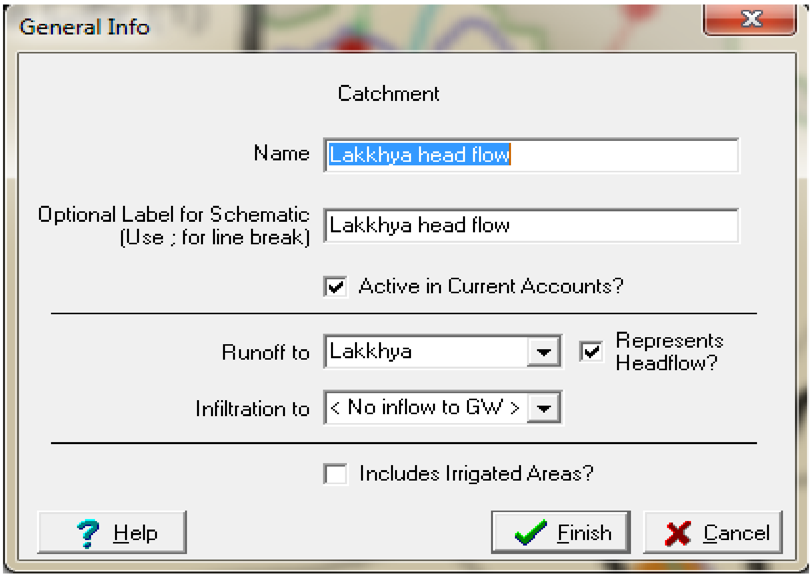

Figure 4.10 General information to define the catchment area.

From the Data Tree, a model for the catchment has been selected as shown in Figure 4.11.

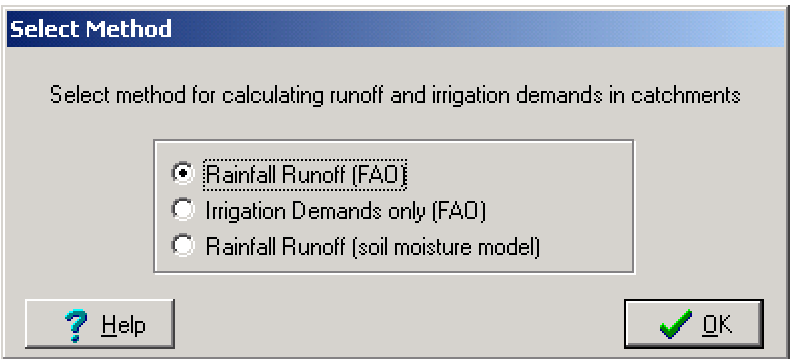

Figure 4.11 Selection of model for calculating runoff.

In the Data tree of the Data View, the Land Use and Climate data were entered.

CHAPTER V
RESULT AND DISCUSSION

5.1 INTRODUCTION

This chapter presents the results and the analysis due to the application of WEAP at Lakkhya River basin-Demra catchment area. Two main scenarios that are based on the reference scenario were analysed. These are the 'High population growth' scenario and the 'Extended dry climate sequence' scenario. From these two scenarios, the scope and applicability of WEAP in Bangladesh for IWRM has been evaluated. The impact of improved irrigation efficiency at Demra irrigation scheme has been evaluated using Rainfall Runoff Model.

For this modelling, the climate data – Reference ET and precipitation of year 2002 (Current) have been given as input. The reference ET generates the graph shown in Figure 5.1 and the input of precipitation data generates the graph shown in Figure 5.2. From these two graphs it is seen that, the reference ET is varying from the month of June to October in comparison to other months and the precipitation is higher during this period as well in comparison to other months

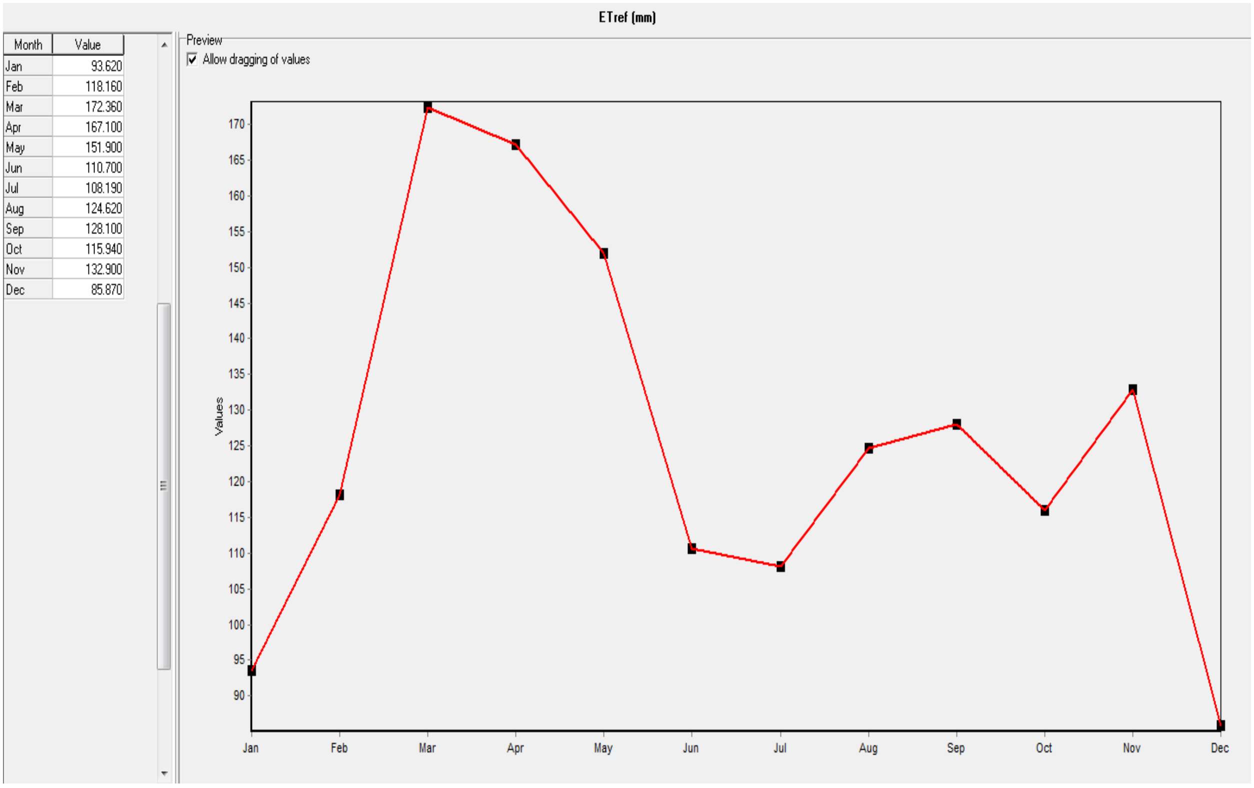

Figure 5.1 Climatic data (reference ET) are entered at the catchment level

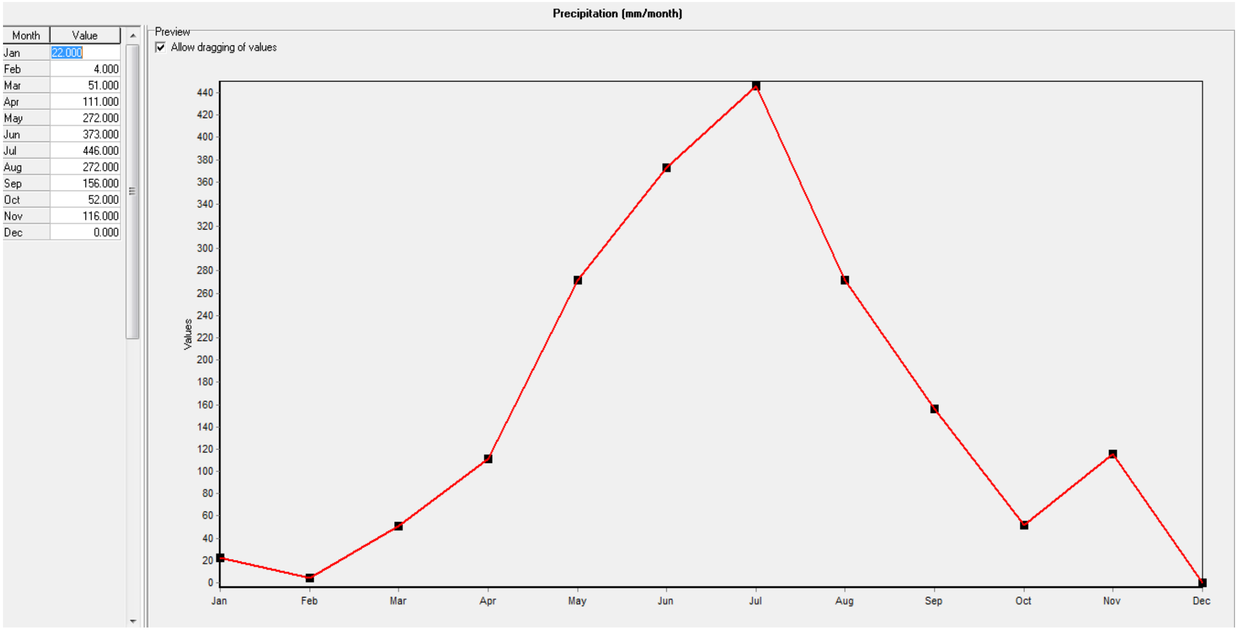

Figure 5.2 Precipitation data are entered at the catchment level

5.2 RESULT: RUNOFF FROM PRECIPITATION

Runoff from the given precipitation and the reference ET data has been determined from the WEAP Catchment Modelling by the Rainfall Runoff Model. A graph has been generated by this calculation in WEAP has been shown in Figure 5.3 and the simulated data of runoff for the year 2002 (Current) is shown in Table 5.1 From this graph it is seen that in the month of June to August the runoff is higher, especially in the month of July it is highest. It can be said that, due to heavy rainfall and variable reference ET in this period, higher runoff initiated. This is very much important for calculating the discharge of Lakkhya River basin which may influence the demand and supply variation.

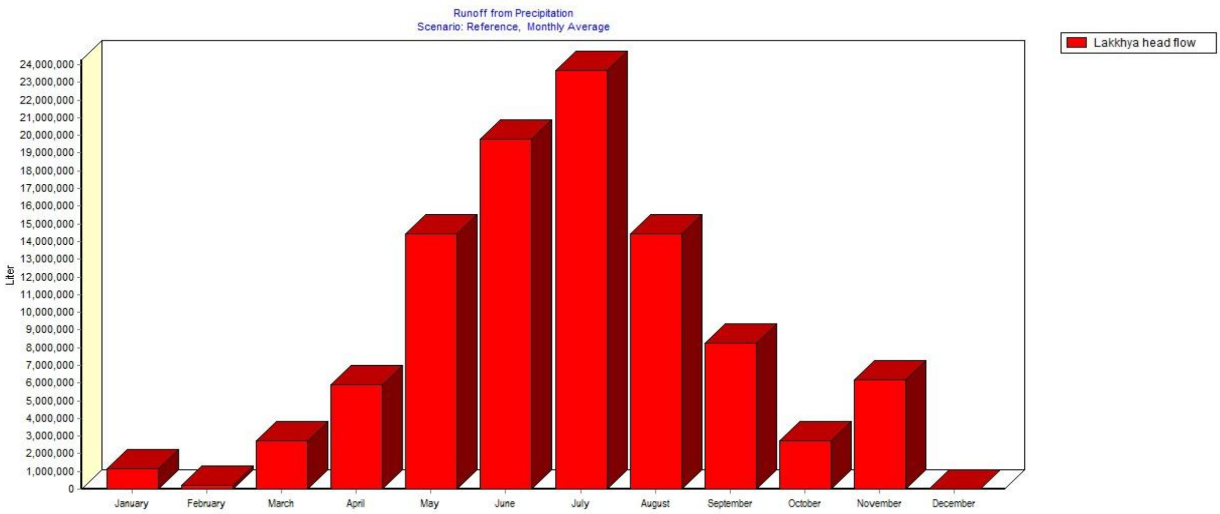

Figure 5.3 Runoff from climate data for year 2002 of Lakkhya headflow genarated from catchment modelling

Table 5.1 Simulated runoff from climate data

Month	Runoff from Climate(mm)
Jan-02	0.00138
Feb-02	0.00025094
Mar-02	0.0032
Apr-02	0.0069647
May-02	0.017071
Jun-02	0.0234
Jul-02	0.027988
Aug-02	0.017071
Sep-02	0.0097882
Oct-02	0.0032624
Nov-02	0.0072788
Dec-02	0
Sum	0.11765

5.2.1 Result: ET Actual

From the modelling, ET actual has also been calculated. It is shown that, ET actual varies throughout the year. The simulated data is shown in Table 5.2 and the WEAP generated data is shown in Figure 5.4. From the graph it is seen that, the month of July gives the highest ET actual value and the month December gives the lowest one.

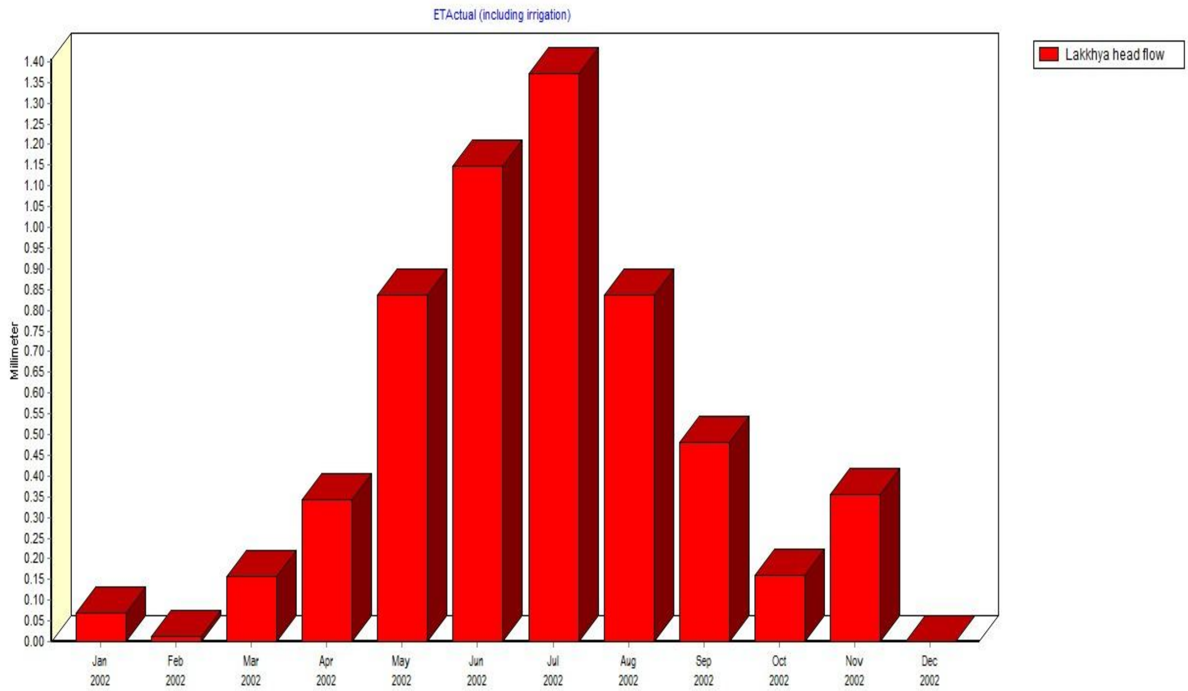

Figure 5.4 ET actual (including irrigation) for Lakkhya head flow

Table 5.2 ET Actual (including irrigation) simulated of demand sites and catchments (All Branches: Potato, Rice, Demra) of current scenario

Month	"Lakkhya head flow"(mm)
Jan-02	0.06762
Feb-02	0.012296
Mar-02	0.1568
Apr-02	0.34127
May-02	0.83646
Jun-02	1.1466
Jul-02	1.3714
Aug-02	0.83646
Sep-02	0.47962
Oct-02	0.15986
Nov-02	0.35666
Dec-02	0
Sum	5.7651

5.2.2 Result: ET Potential

From the catchment modelling ET potential has also been determined. The simulated graph and the data are shown in Figure 5.6 and Table 5.4. Table 5.3 and the Figure 5.5 are showing the observed data and variation of ET potential for the month of June to October for observed data.

The comparison between two graphs will clearly show that there is a little difference between the graph obtained from observed data and the graph obtained from WEAP simulation.

The observed data is showing the highest ET potential at the month October while the simulated data showing the highest value for the month of June for the period of June to October as we have shortage of observed data, we have to consider this period instead of the whole year of 2002.

Table 5.3 ET Potential (Source: BMD)

Month	ET Potential(mm)
Jun	2.992857
July	4.011429
August.	4.27
September	4.212857
October	4.28

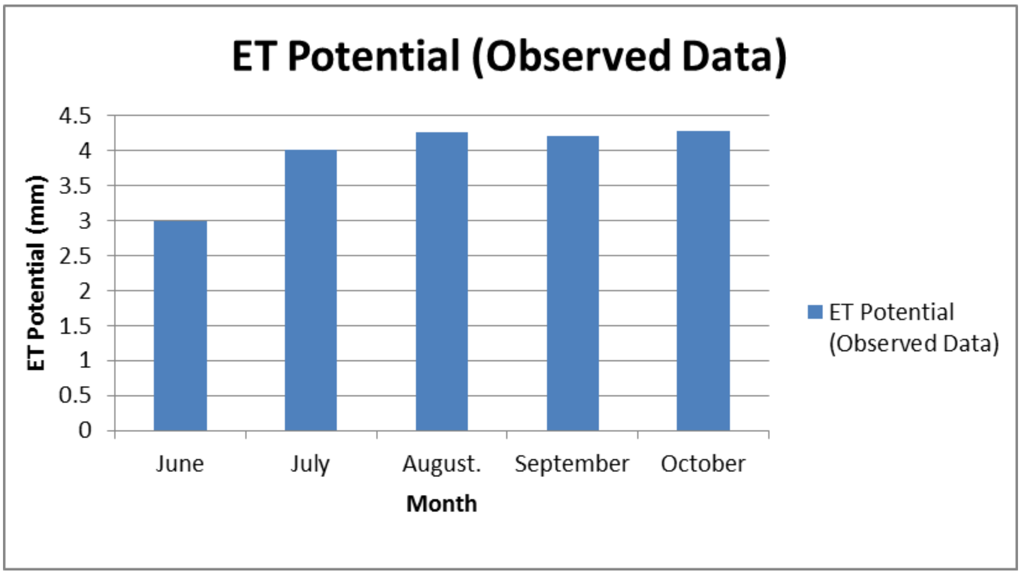

Figure 5.5 ET potential from the month June to October for 2003 to 2010 (Source: BMD)

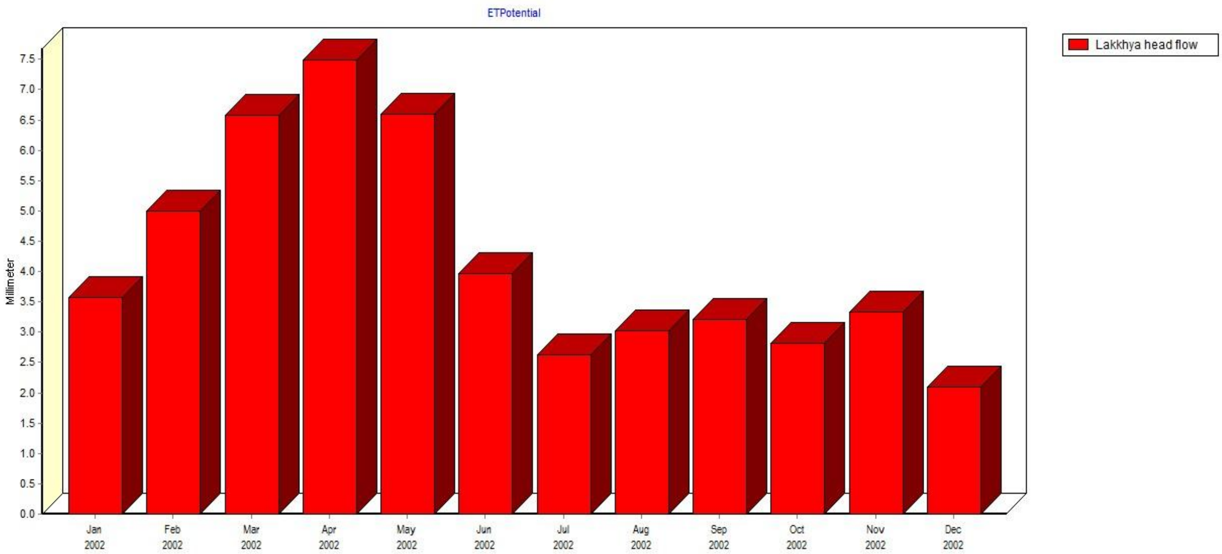

Figure 5.6 ET potential for Lakkhya head flow

The graph shown in Figure 5.7 explains the comparison between the observed data and the WEAP simulated data of ET Potential for five months (June to October). From the graph, it can be said that, there is a variation among the values of observed and simulated ET potential for all five months. In the month of June, August and September the variations of simulated data from the observed data are 24.685%, 40.956% and 30.84% accordingly. The highest variation is found at the month of August and that is 40.95%. But the variation is almost same for the month of July and October and that is 34.43% and 34.11% accordingly.

Table 5.4 ET Potential (including irrigation) of demand sites and catchments (All Branches: Potato, Rice, Demra) of current scenario

Month	"Lakkhya head flow"(mm)
Jan-02	3.5759
Feb-02	4.9965
Mar-02	6.5824
Apr-02	7.4909
May-02	6.5908
Jun-02	3.9722
Jul-02	2.6298
Aug-02	3.0293
Sep-02	3.2176
Oct-02	2.8181
Nov-02	3.3381
Dec-02	2.0874
Sum	50.329

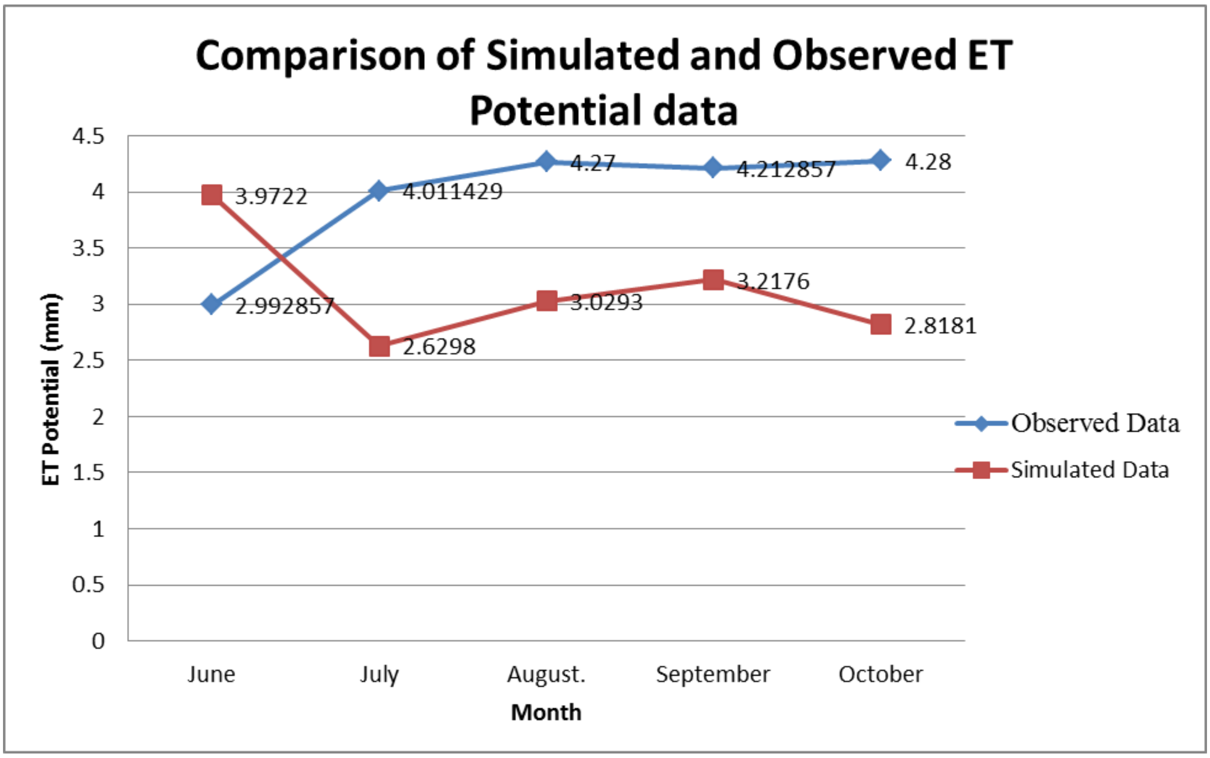

Figure 5.7 Comparison of Observed and WEAP simulated ET Potential data

5.3 SCENERIO ONE: HIGH POPULATION GROWTH

A scenario has been developed here for the high population growth rate. The rate of population growth is considered higher in this scenario. It is increased from 1.59% to 5% for the reference scenario (2003-2010). This scenario determines the future water demand and supply requirements for the increasing population which is as usual expected. The figure 5.8

is showing the schematic view of the Lakkhya River basin –Demra catchment area which is used to identify the demand sites Demra city, potato field and rice field. Each of them are defined by a number 1, which is the priority value for water supply and the number 1 means they have the first priority to extract water among all other demand sites.

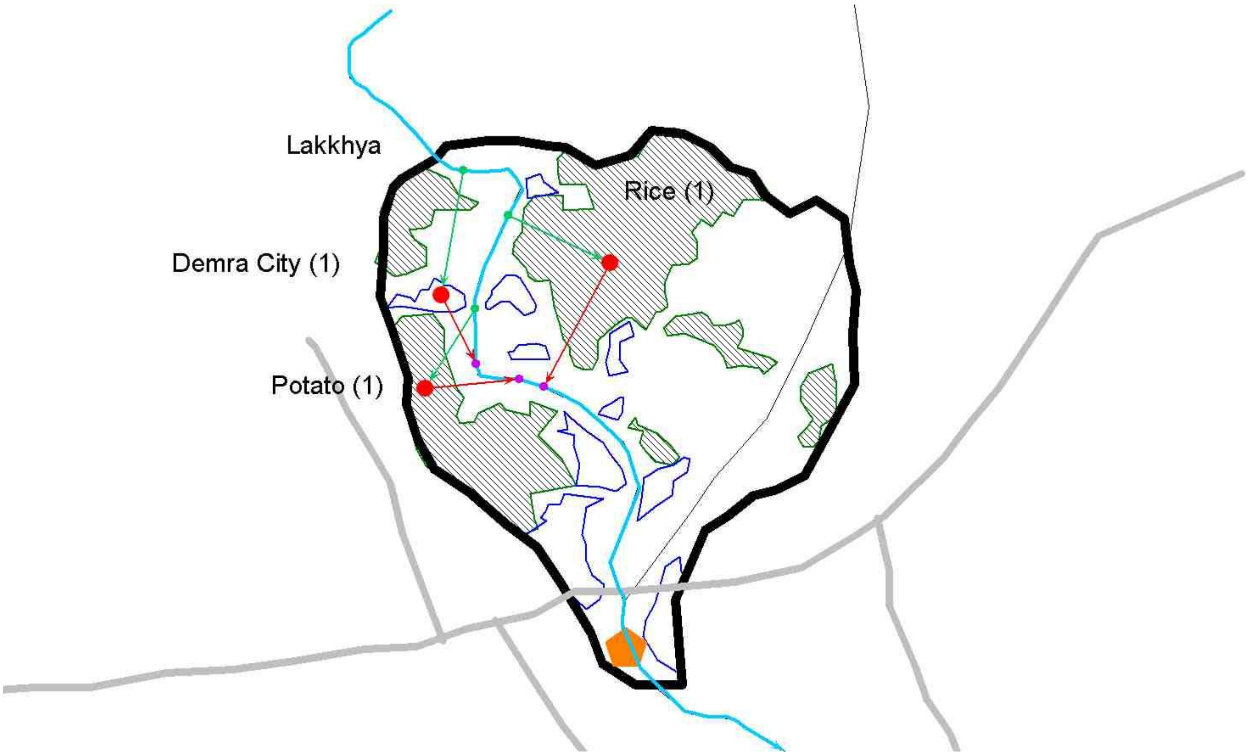

Figure 5.8 The schematic view of Lakkhya River basin-Demra catchment area for the analysis of high population growth rate effect on that area.

5.3.1Creating Reference Scenario

The reference scenario has been defined in the WEAP model by showing the population growth rate of 1.59% for the year 2003-2010 in Figure 5.9.The input of necessary data are given like the unit irrigation water need for the potato and rice , unit domestic water need etc. It is shown in the Figure 5.10. In the Data View, changes have been made for the Unit Irrigation Water Needs Key Assumption to reflect a new annual pattern for the period (2003-2010) after the Current Accounts year. To make the change, Reference scenario from the drop-down menu at the top of the screen has been selected. Then, Yearly Time-Series Wizard has been used to construct the time series. It is shown in Figure 5.11. The missing data have been calculated by interpolation method. Figure 5.12 is showing the graph for the annual water use for the population growth rate of 1.59% from the year 2003 to 2010 (Reference Scenario) simulated by WEAP. Time series is not used for any other input data because any value, for which no time series is defined at the Reference scenario, is assumed to remain constant. In our case for example, the agriculture demand will remain constant until 2010 unless we change this variable as well.

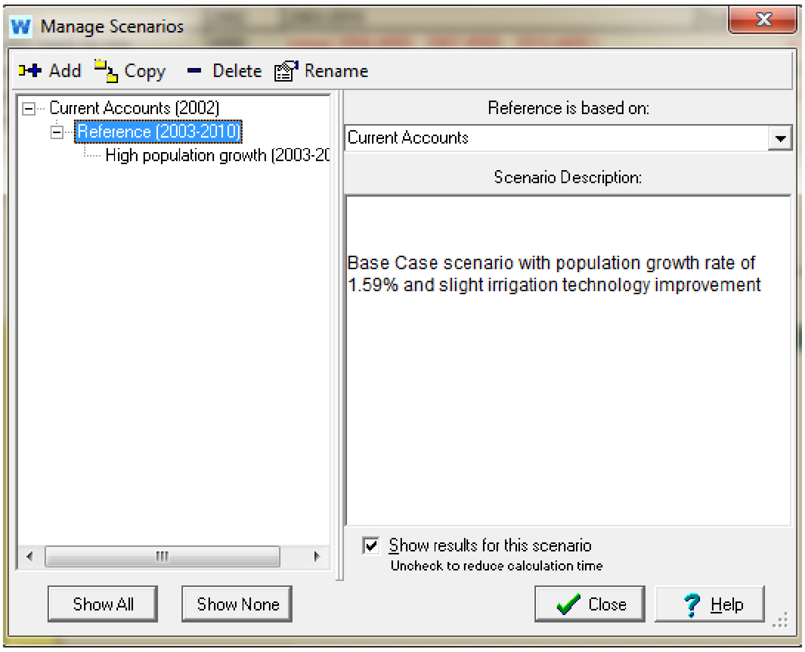

Figure 5.9 Defining reference scenarios

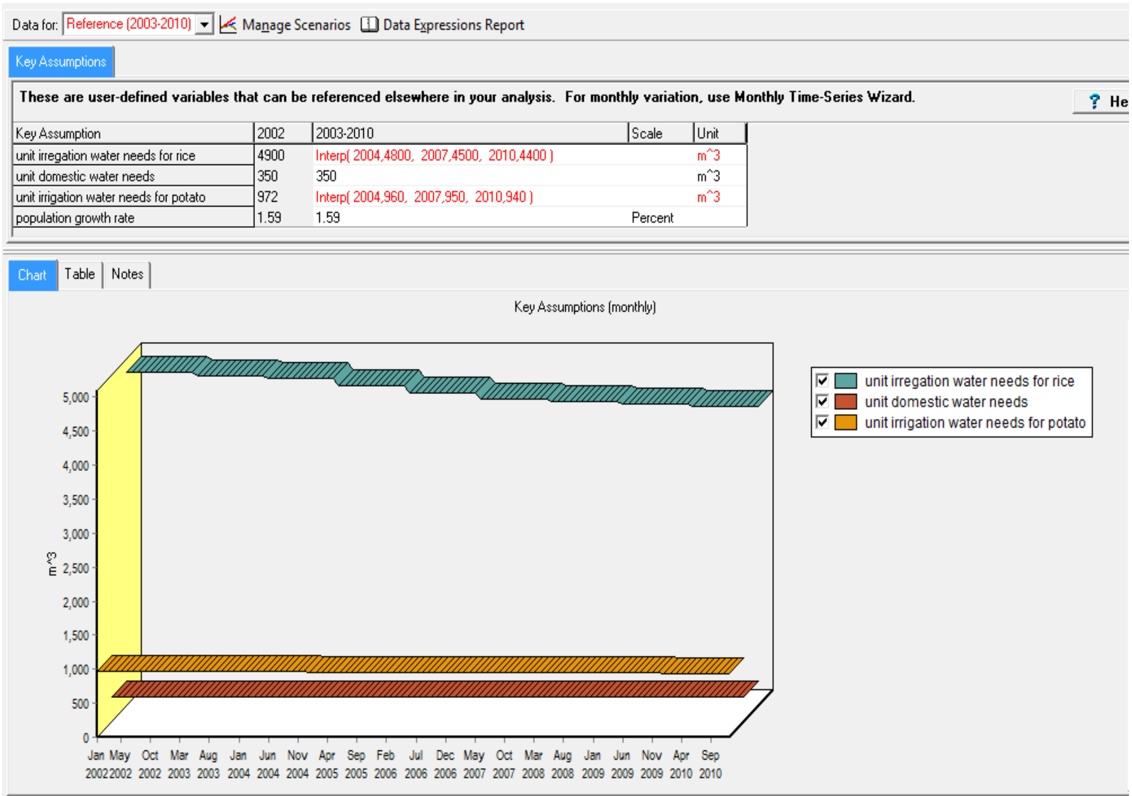

Figure 5.10 Input data for the modelling of reference scenario.

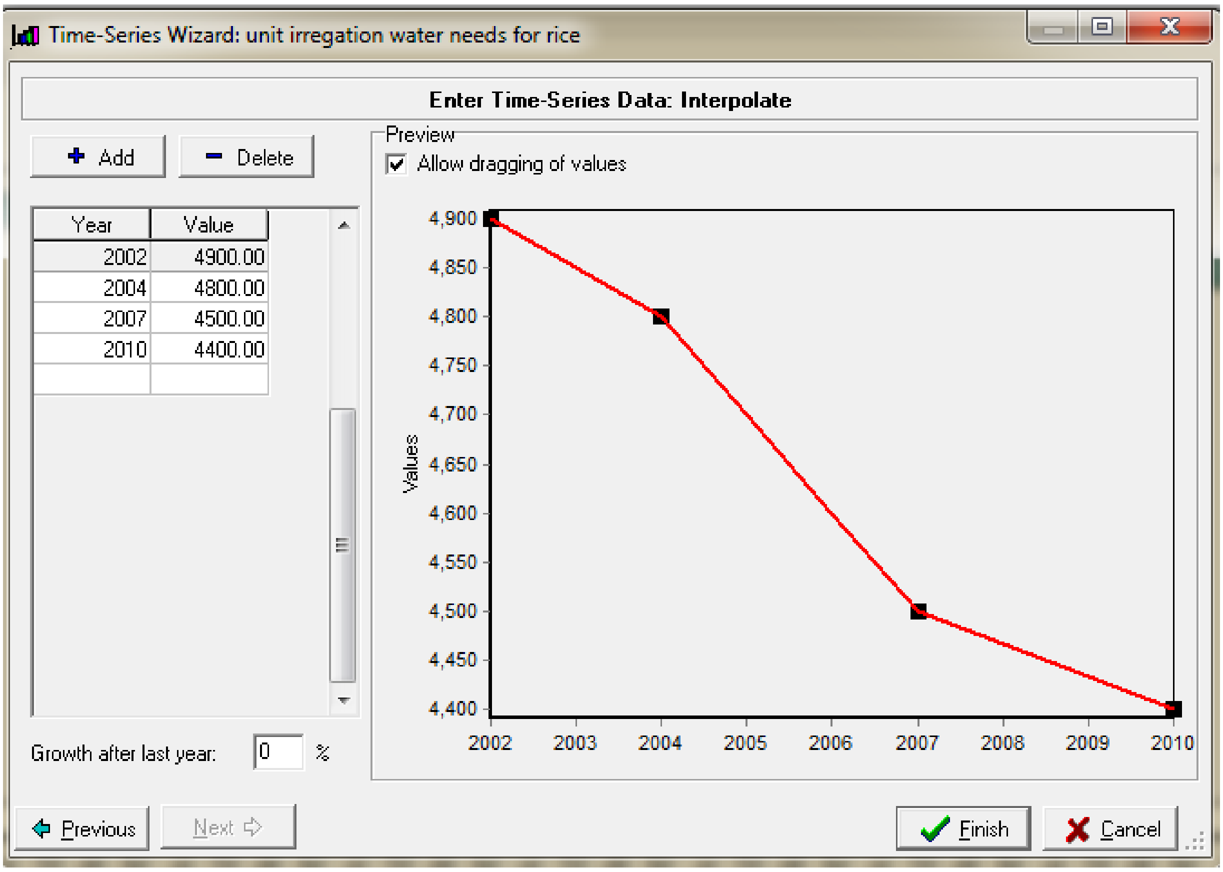

Figure 5.11 Time series data and interpolation method for assuming missed data.

5.3.2 Run the Reference Scenario

The water demand for the three demand sites are shown in the graph in Figure 5.13. Besides water demand, the other parameters like supply demand, reliability, coverage, unmet demand can also be simulated from this scenario modeling.

From the Figure 5.13 it is depicted that, water demand is increasing for the three demand sites from the year 2002 to 210. The amount of demanding water for individual demand sites in future with the constant population growth rate of 1.59% has also been calculated.

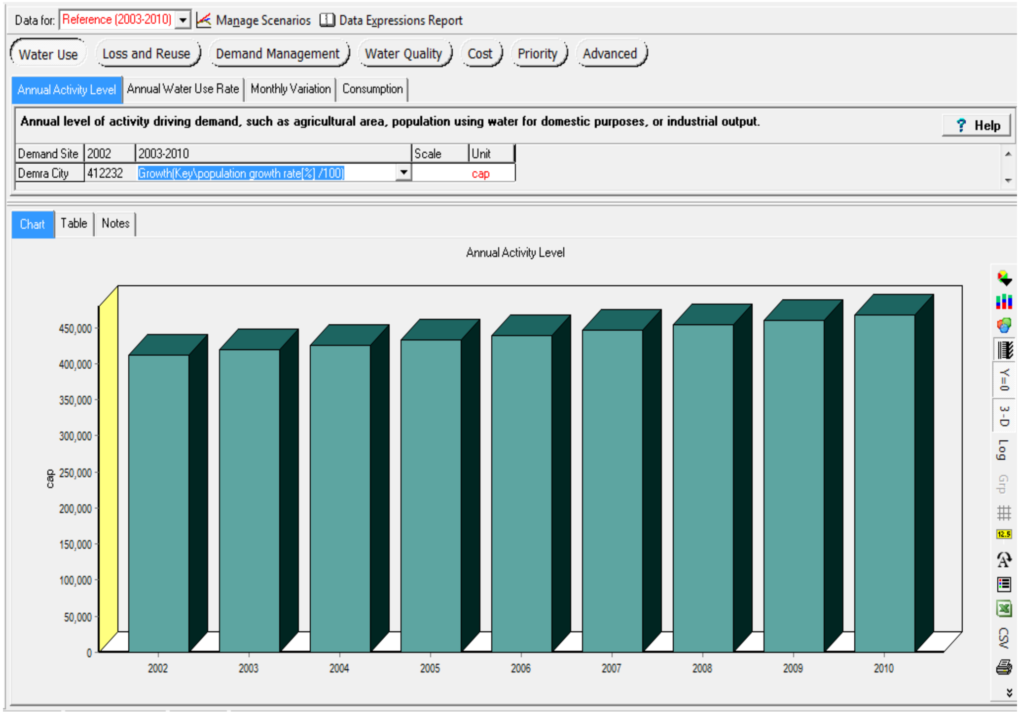

Figure 5.12 Input data of growth rate for Demra city

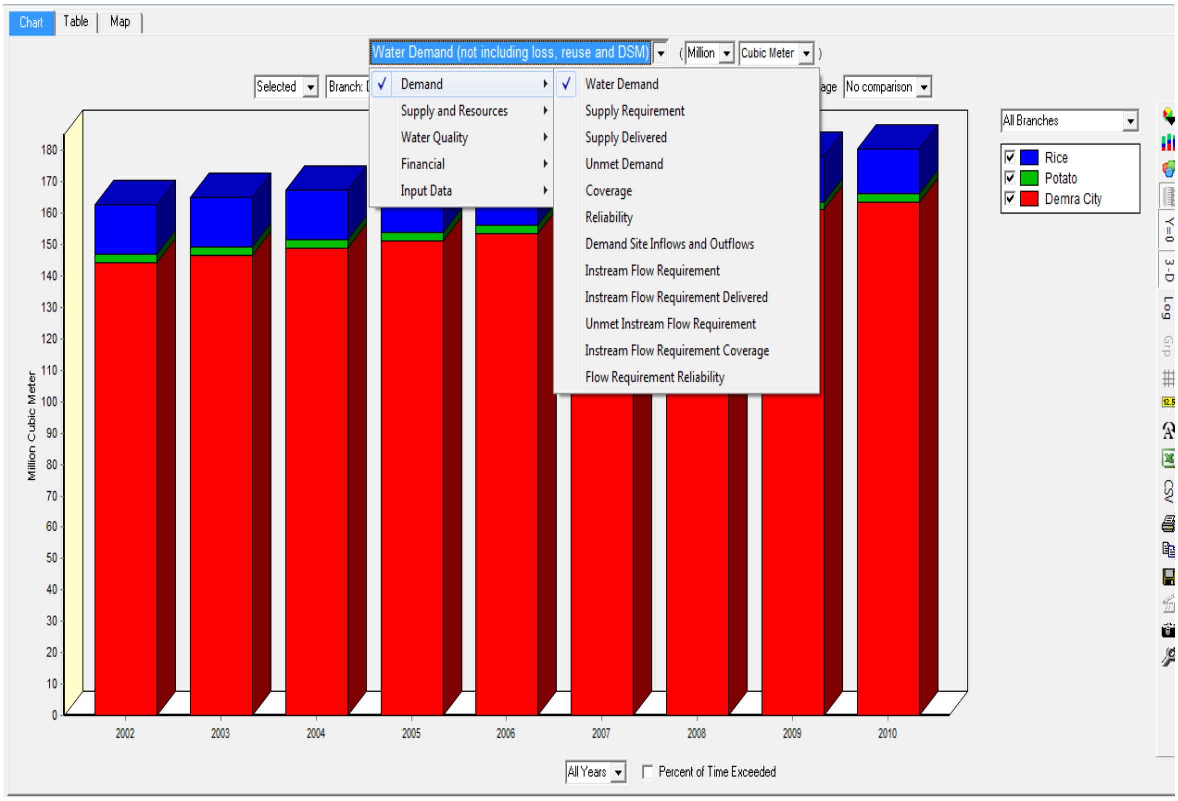

Figure 5.13 Simulated result of water demand for three demand sites and various other options to be calculated by running the model.

5.3.3 Unmet Demand

From the graph in Figure 5.14 it is depicted that unmet demand is also increasing with the time. Unmet demand is the difference between a large demand and a large supply, a small change in the supply at nearly-constant demand can have a very large impact on the unmet demand.

This model does not take any kind of inter-year storage into consideration like reservoir, groundwater etc.

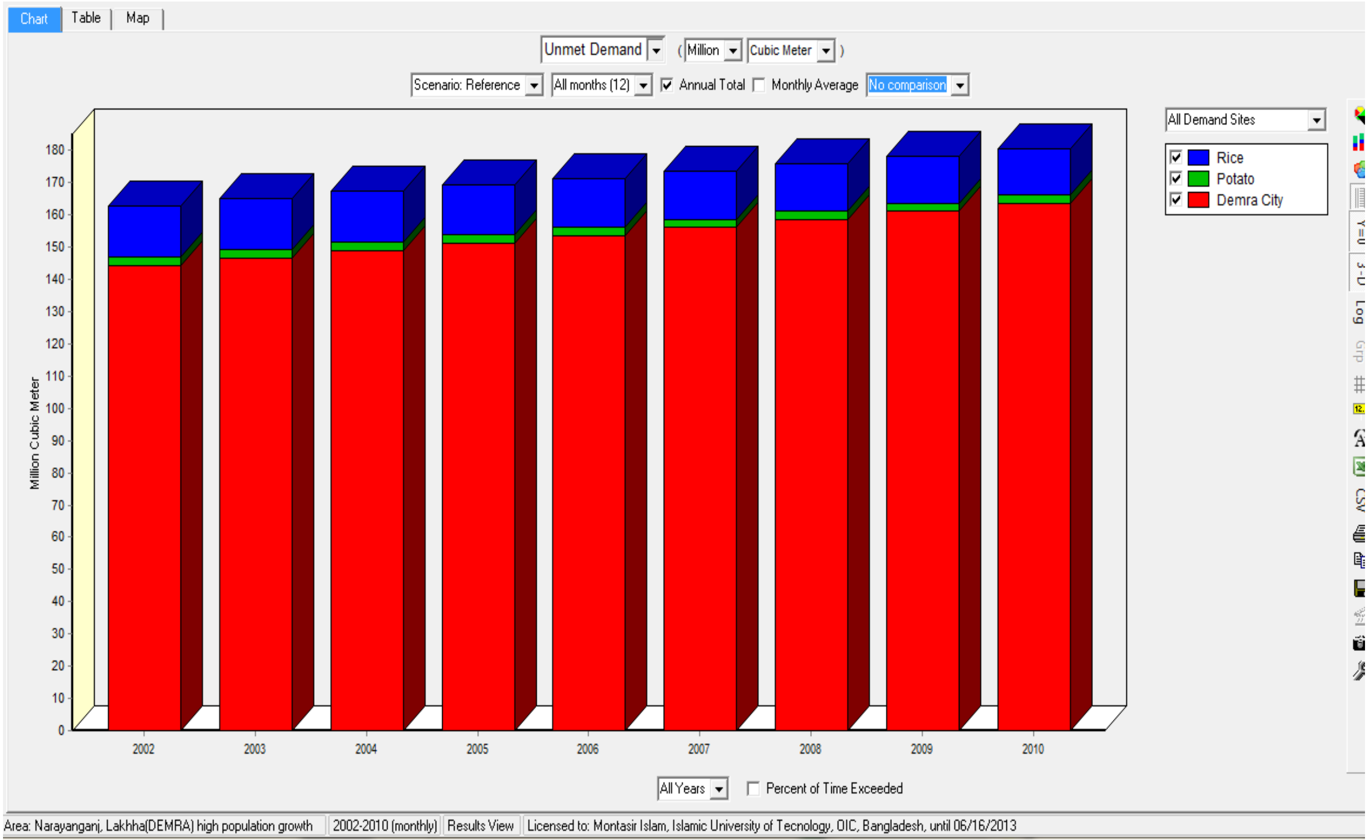

Figure 5.14 Result of unmet demand for simulated three demand sites

5.3.4 New Scenario to Model High Population Growth

A new scenario has been developed to model the high population growth rate. From the Figure 5.15 it is shown that population growth rate is increased from 1.59% to 5%, for the new scenario.

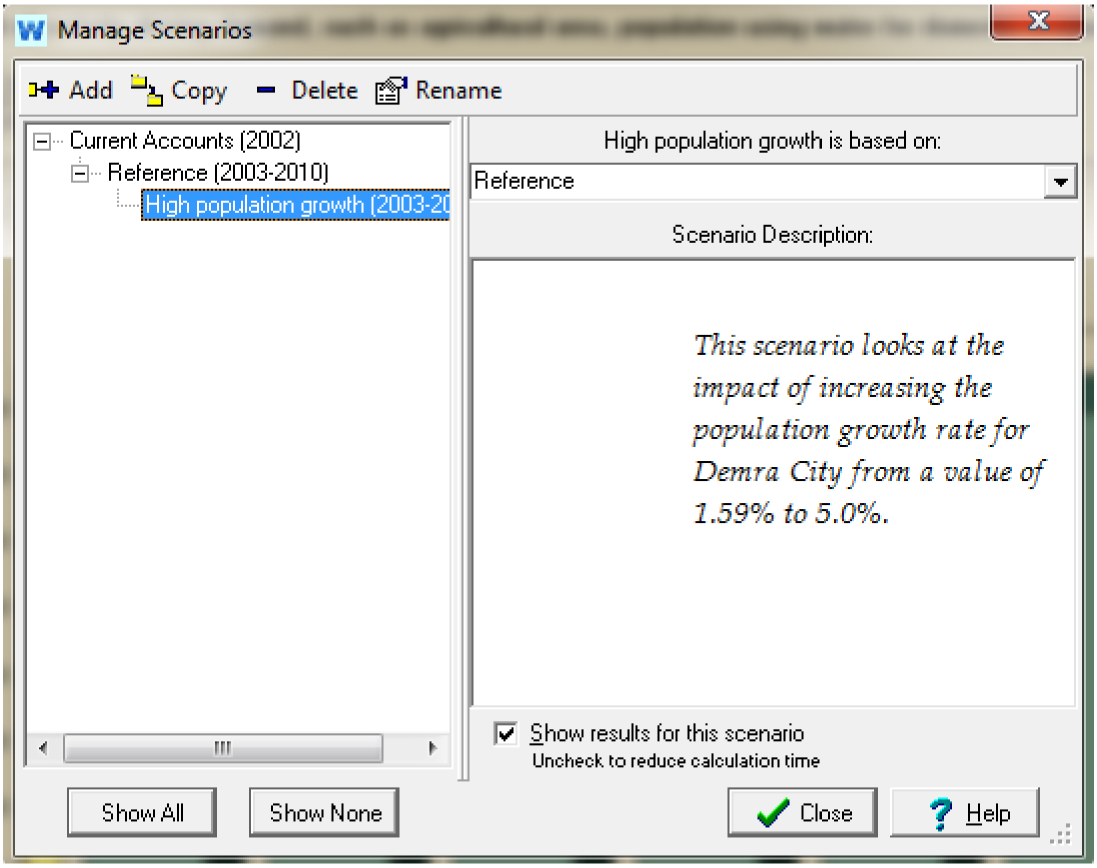

Figure 5.15 Defining the high population growth rate by increasing the rate of population growth from 1.59% to 5%

5.3.5 Enter the Data for this Scenario

The graph generated from WEAP after giving input data of increased population growth rate is showing in Figure 5.16. From the year 2003 to 2010 the population growth rate is constant which is increased after the year 2002.

5.3.6 Comparison of Results for the Reference and Higher Population Growth Scenarios

Comparison, of the results for the two scenarios we have established so far (Reference and High Population Growth) have been done here. Mainly it has been done here for water demand criteria. Because in any kind of water modelling, water demand is the main factor for which necessary measures have to take by the decision makers.

The water demand graph in Figure 5.17, exhibits clearly that the demand for water is increasing for the high population growth rate scenario from reference scenario. The Water Demand is higher for Demra city in the Higher Population Growth Rate scenario than the reference scenario, as expected. Thus the water demands for other two demand sites-potato and rice in high population growth rate can also be found from the simulation result.

The amount which will exactly increase for water demand at high population growth rate condition and by what amount it will lack from the normal population growth rate as defined in reference scenario can also be determined from this simulated graph. The Figure 5.18 depicted the unmet demand which is also increasing in comparison to reference scenario.

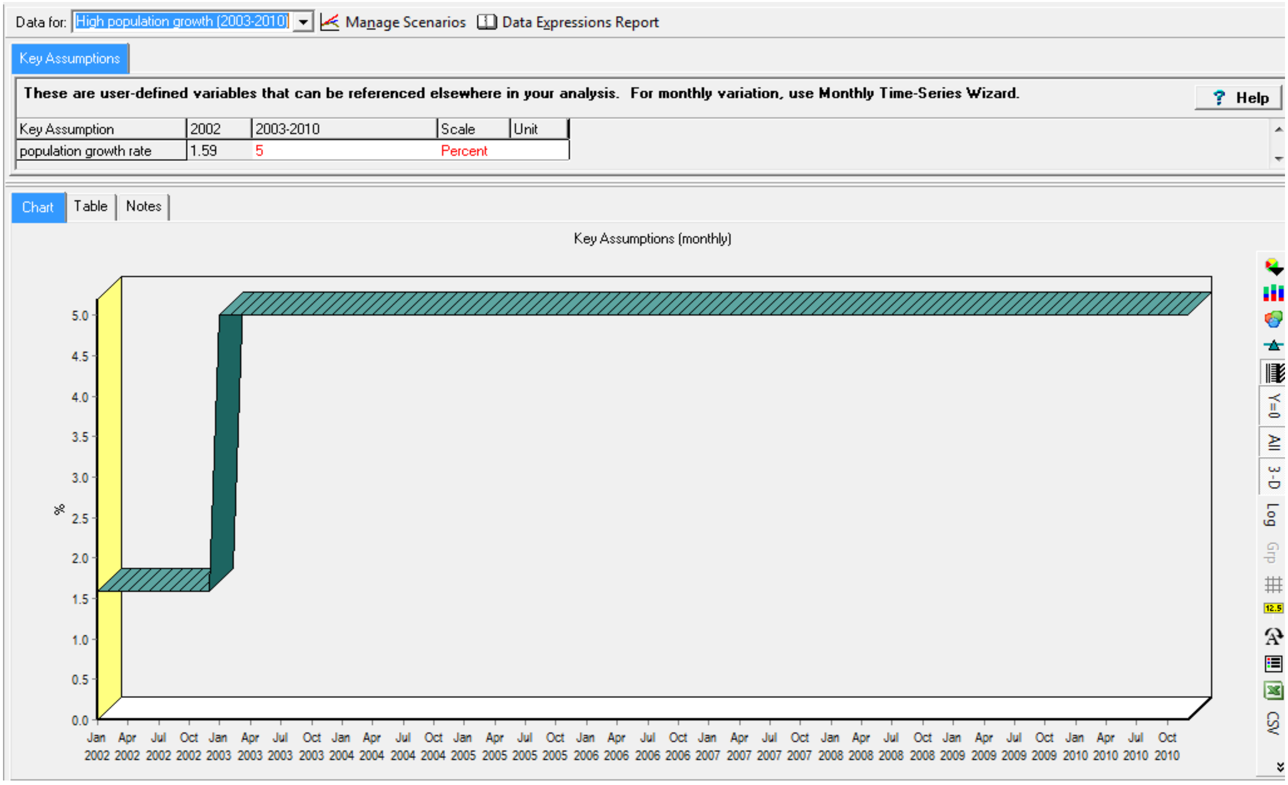

Figure 5.16 Graph showing the high population growth rate.

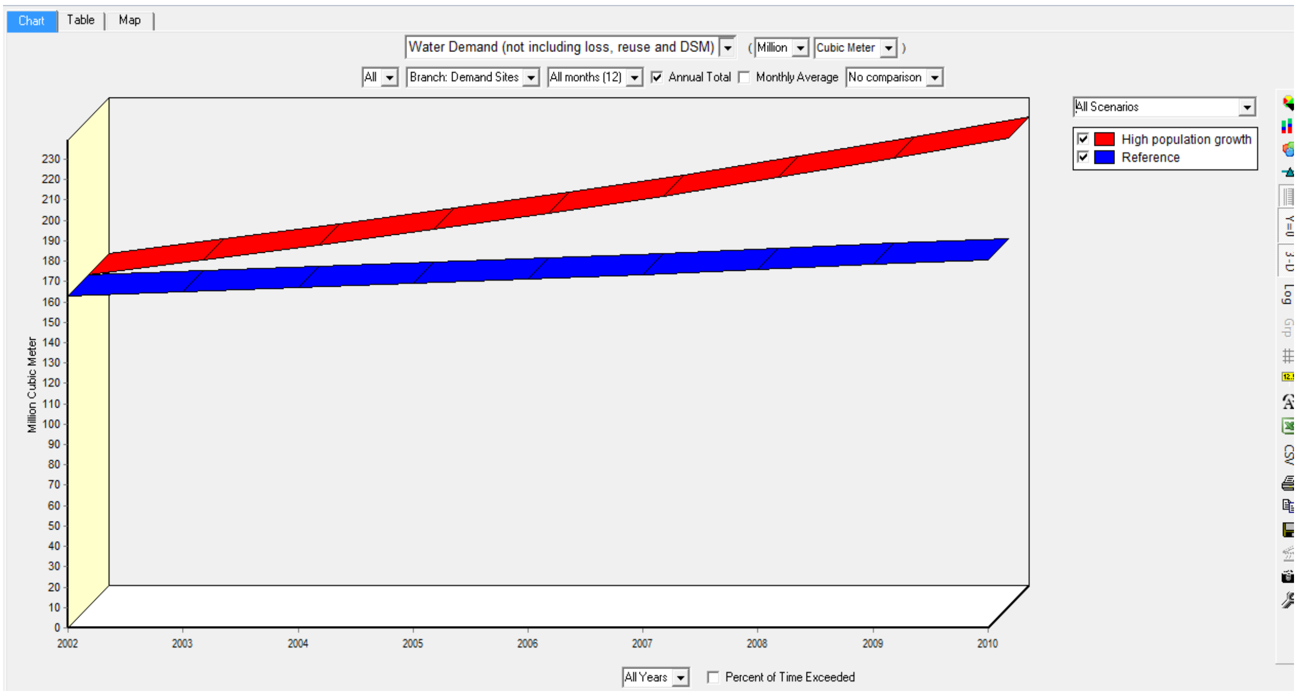

Figure 5.17 Graph showing the relative comparison of the two scenarios for water demand analysis.

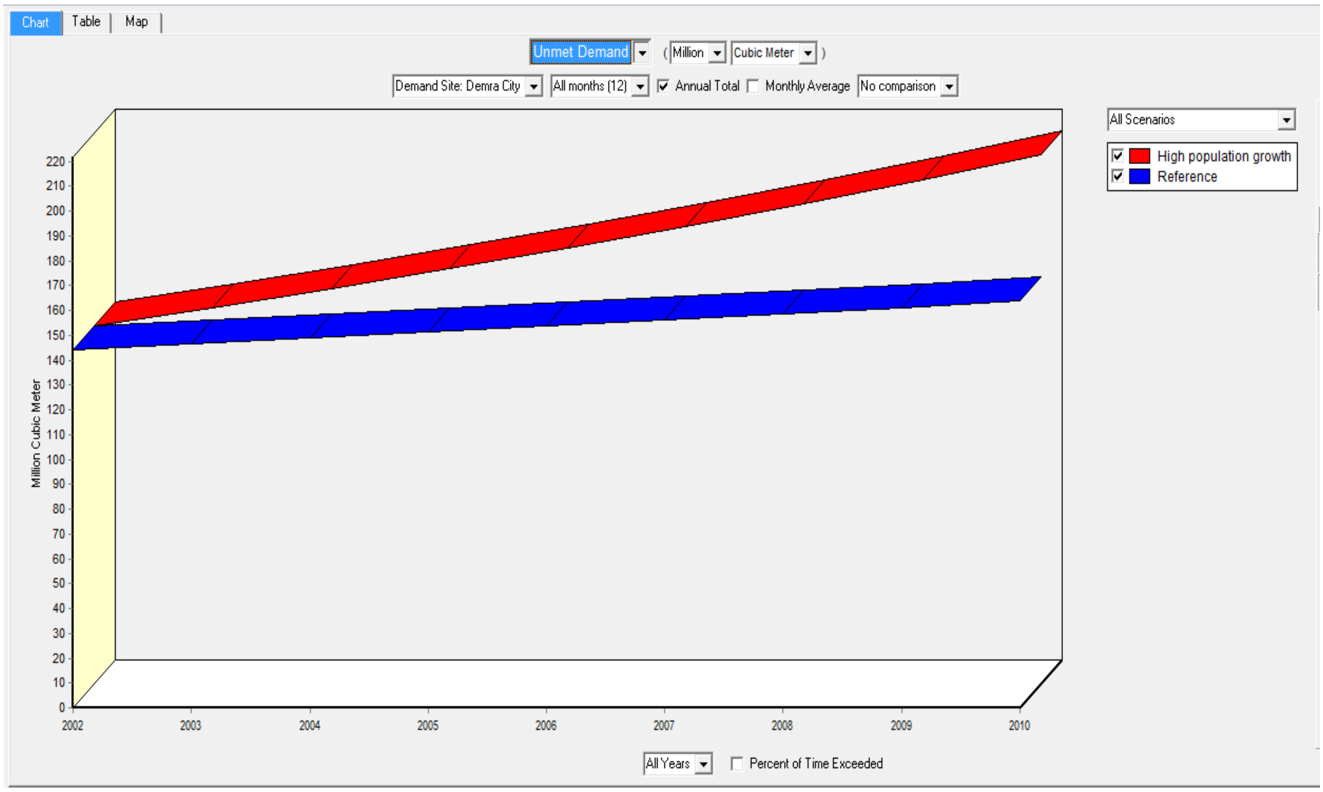

Figure 5.18 Graph showing the relative comparison of the two scenarios for unmet demand analysis.

5.3.7 Modelling Climate Scenario by Water Year Method

The previous exercise only varied demand, not supply. In this step it is shown that natural variation in climate data (stream flow, rainfall etc.) can be taken into account in WEAP through scenario analyses. The Water Year Method is used here as an example. The Water Year Method is a simple means to represent variation in climate data such as streamflow, rainfall, and groundwater recharge. The method first involves defining how different climate regimes (e.g., very dry, dry, very wet) compare relative to a normal year, which is given a value of 1. Dry years have a value less than 1, very wet years have a value larger than 1. Figure 5.19 is showing that input for the reference scenario modelling.

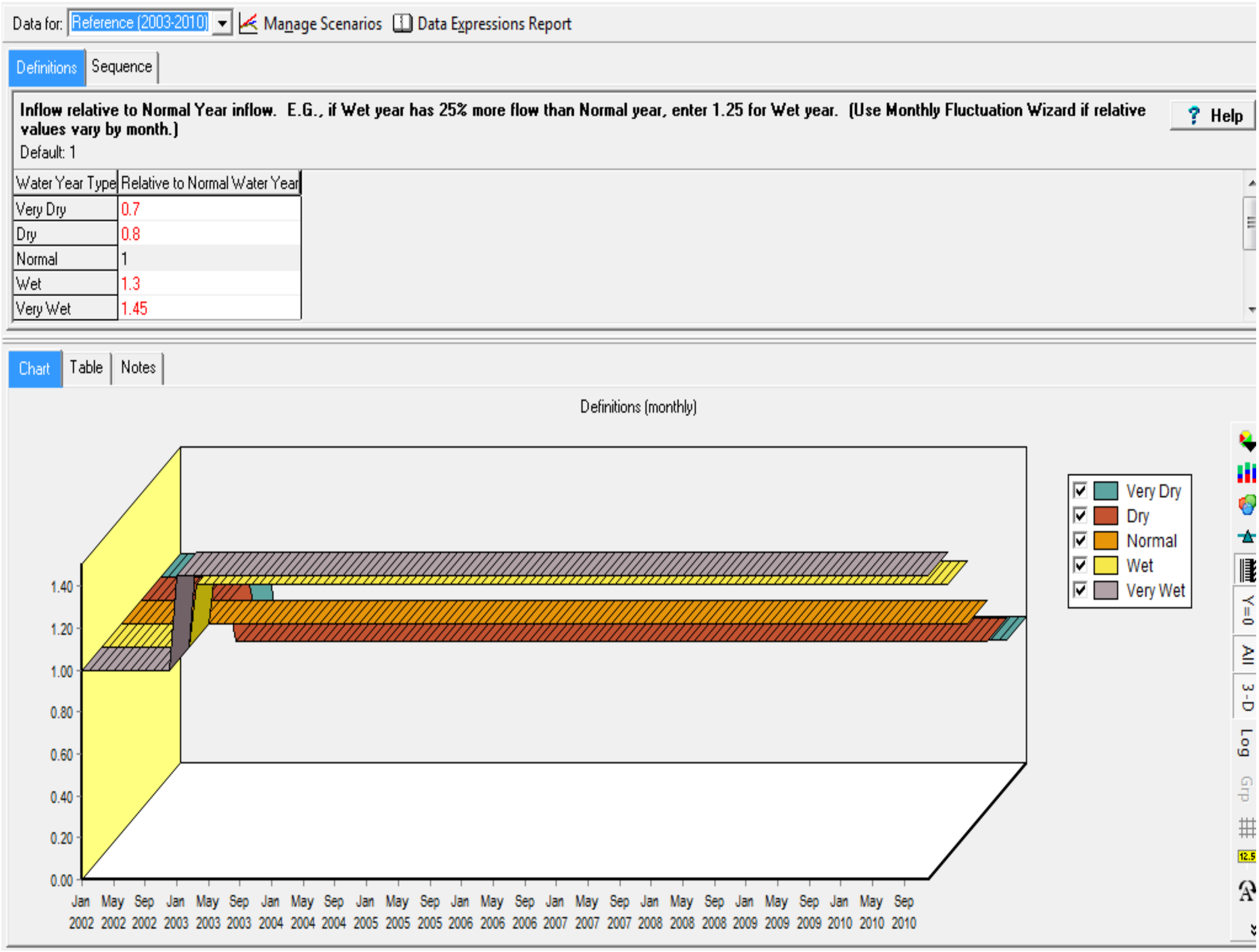

Figure 5.19 The input data for the water year method

5.3.8 Create the Water Year Sequence

Each year of the period is assigned one of the climate categories (e.g. wet). For the Reference scenario, the assumptions are in the sequence as shown in Figure 5.20.

5.3.9 Current Account is Set as Normal

The climate sequence for current account has been set as normal for the climate data (shown in Figure 5.21) to compare it from the accounts like reference scenario, high population growth rate scenario. The monthly head flow for the reference scenario in water year method is shown in Figure 5.22. It exhibits that the head flow is considerably changed in different years; there is no fixed pattern which can be identified from the graph. It both increases and decreases in different months of the reference scenario.

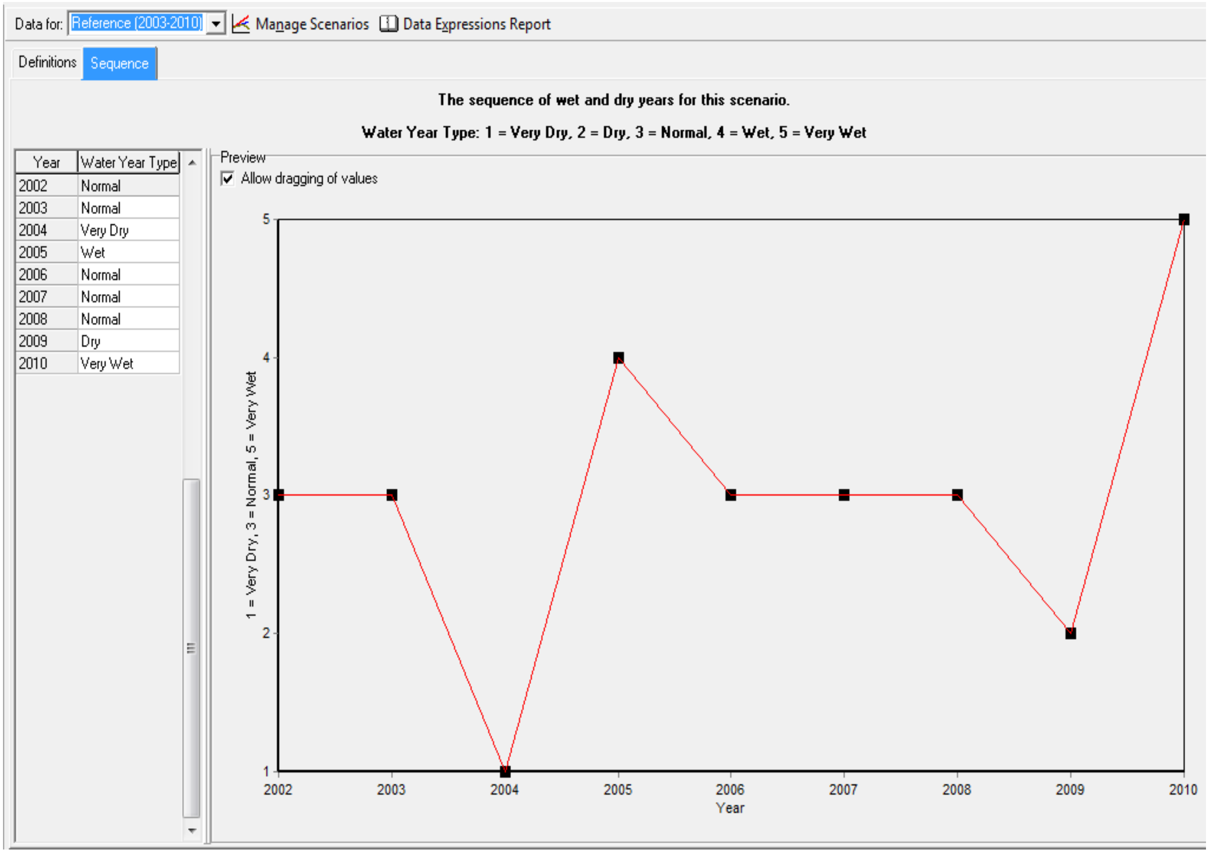

Figure 5.20 Climate sequence for each year including the current year

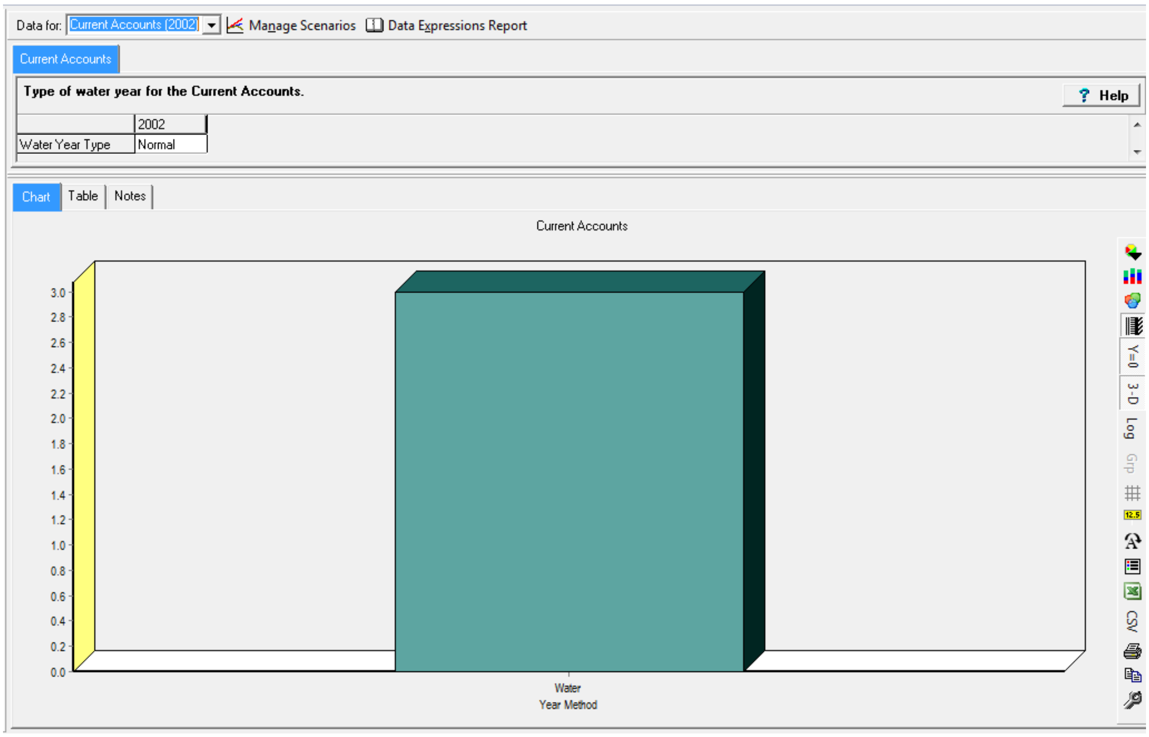

Figure 5.21 Graph generated by WEAP when current account is set as normal.

5.3.10 Set Up the Model to Use the Water Year Method

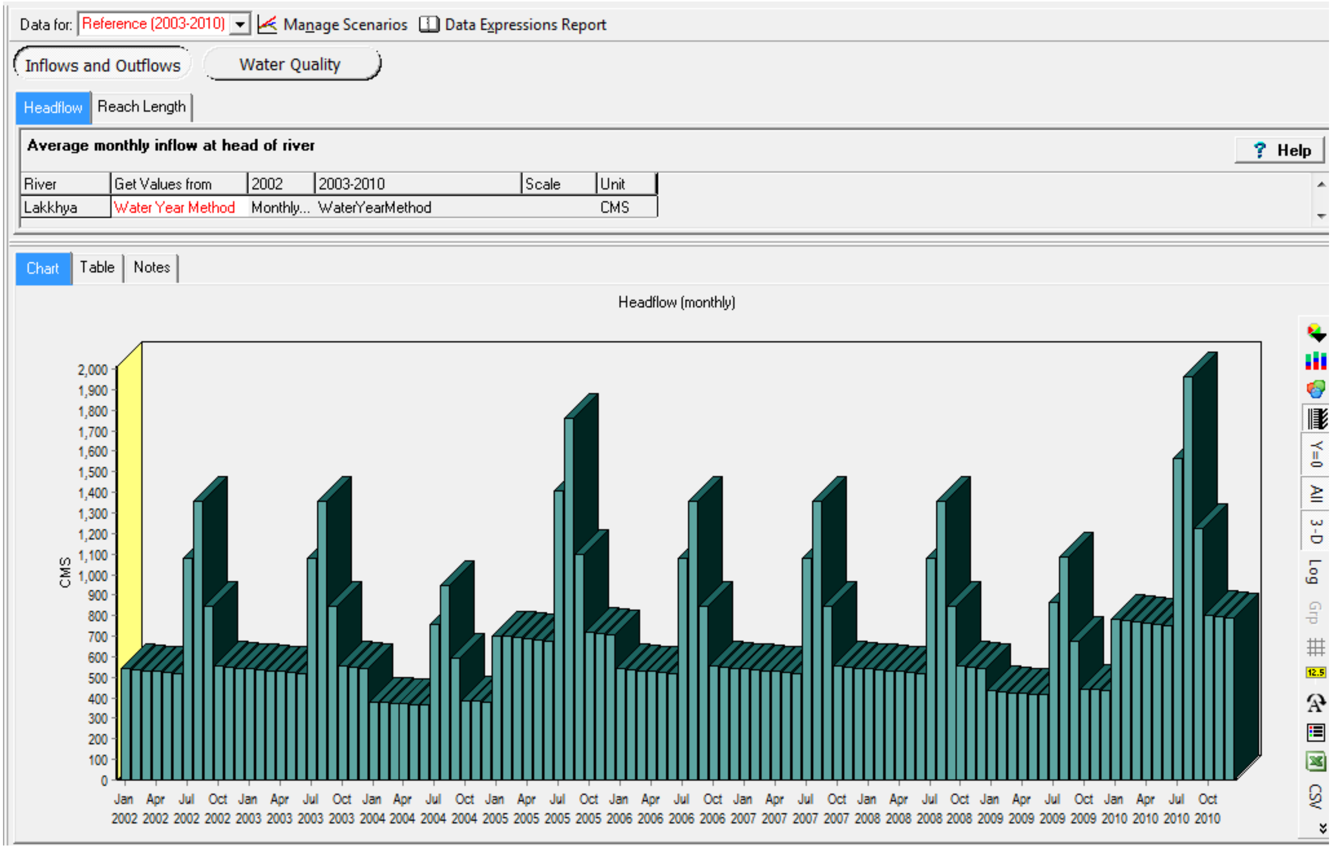

Figure 5.22 Monthly head flow for the water year method of the reference scenario.

5.3.11 Run the Model

The Figure 5.23 simulated by WEAP after running the model depicted that, Demra City “Unmet Demand” for both scenarios is much more erratic using the Water Year Method than assuming a constant head flow to the Main River. In the present case, Unmet Demand varies as the future climate varies.

During years wetter or much wetter than normal (2000, the Current Accounts year), Unmet Demand is actually lower for both scenarios, even with the increased Water Demand for population growth (1.59% for the Reference and 5.0% for the Higher Population Growth scenarios). The increased precipitation, and head flow to the river, mitigates that increased demand in the wetter years.

The opposite occurs in the dry to very dry years, where the unmet demand is exacerbated by the lower precipitation and head flow in the river. This leads to even higher Unmet Demand

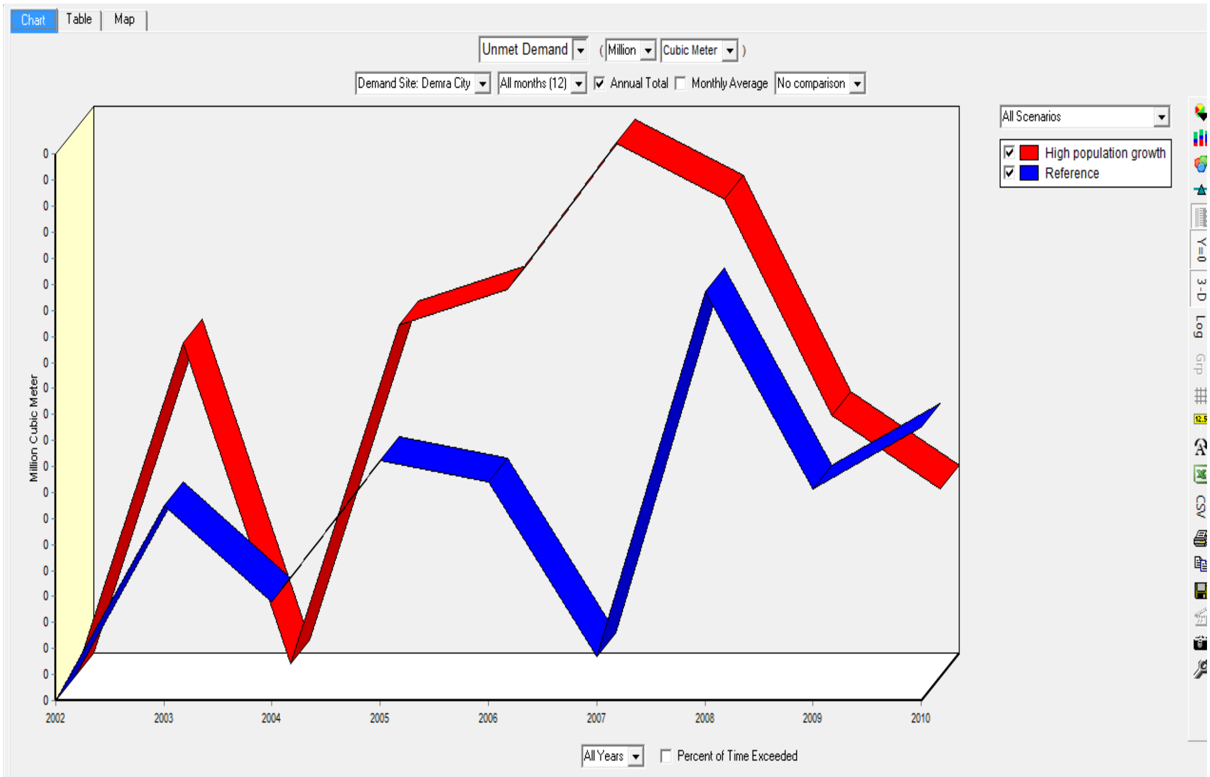

Figure 5.23 Graph showing the unmet demand of two scenarios after incorporating the water year method by running the model

From the graph of Figure 5.23, the comparison of unmet demand for the two scenarios of high population growth rate (5%) and reference scenario (1.59%) has also been done in water year method. The graph depicted that, the unmet demand is increasing from the year 2002 to 2003 as well as it is decreasing from the year 2003 to 2004, for both of the scenarios. That means from the year 2002 to 2004; both of the scenarios have same variation for unmet demand. But from the year 2004 to 2007, the unmet demand is increasing for the High Population Growth Rate scenario. But in case of reference scenario, from the year 2004 to 2006 the unmet demand is increasing. That means up to 2006, the variation is same for the reference scenario as the High Population Growth Rate scenario. But the difference started from the year 2006 to 2007, when the unmet demand is decreasing for the reference scenario but it is increasing for the High Population Growth Rate Scenario. From the year 2007 to 2008 the unmet demand is increasing for Reference scenario while it is decreasing for the High Population Growth Rate Scenario. But from the year 2008 to 2009 the unmet demand is decreasing and again it is increasing from the year 2009 to 2010 for both of the scenarios. As usual, increasing population growth rate will cause higher unmet demand at future, which is easily predictable with numerical amount in million cubic meters. So adequate steps should be taken to meet this demand and assist in future for the sustainable water use and effective water management for all sectors. It can also be used as a branch of IWRM tool to implement successfully in the context of Bangladesh.

5.4 SCENERIO TWO: EXTENDED DRY CLIMATE SEQUENCE

The scenario extended dry climate sequence is defined by taking into accounts the future climate change due to global warming. The problem is more severe for Bangladesh. Impacts of climate change on fresh water systems and their management are mainly due to the observed and projected variations in temperature, evaporation, sea level and precipitations etc. Higher water temperatures, increased precipitation intensity and longer periods of low flows will lead to more pollution, impacts on ecosystems, human health, water system reliability and operating costs. It also affects the function and operation of existing water infrastructure as well as water management practices. So in the modeling of Lakkhya River basin a scenario in extended dry climate sequence have been incorporated and analyzed for future water management of this river basin.

The extended dry climate scenario is developed under two basis-reference scenario where population growth rate is normal as usual 1.59% and the other is high population growth rate where the growth rate is increased from 1.59% to 5%. Previously these two scenarios were developed and analysed only considering the high population growth rate and normal growth rate of population. As increased population is a big problem for Bangladesh along with the climate change problem, this scenario of extended dry climate sequence is also developed and compared with the previous two scenarios. The climate of Bangladesh is changing drastically due to rapid urbanization and increased population. So they are acting as a driving force in water management of Lakkhya River basin. In Figure 5.24 the extended dry climate scenario is defined under the reference scenario.

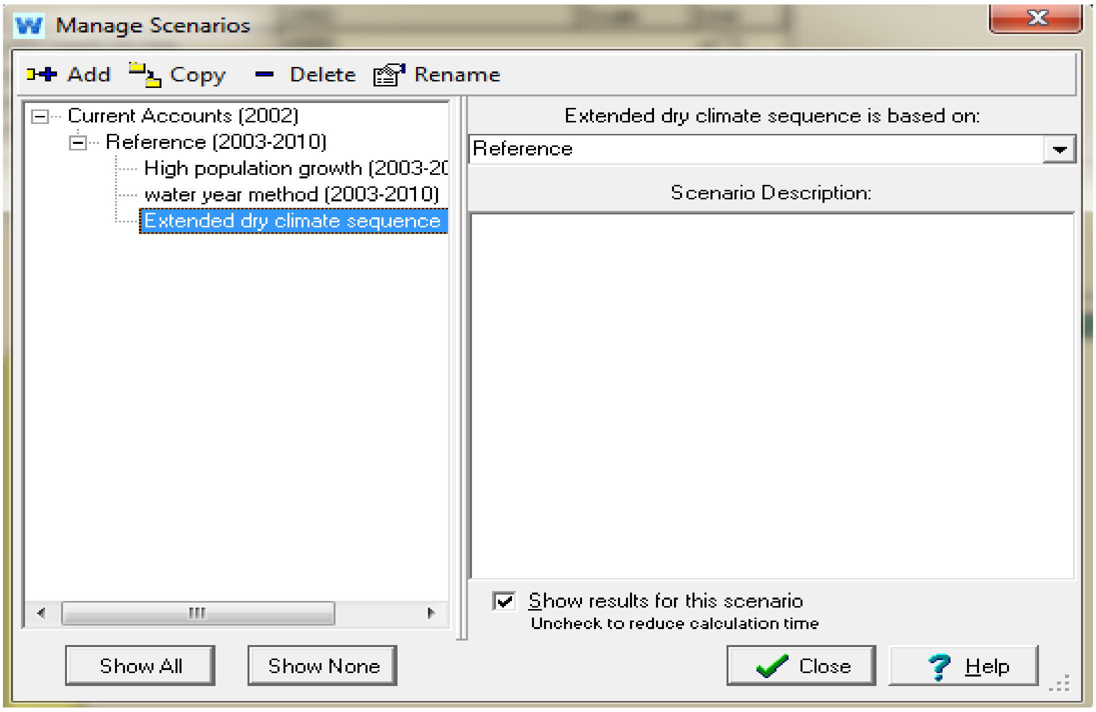

Figure 5.24 Extended dry climate sequence under the reference scenario where the population growth rate is 1.59%.

5.4.1 Change the Climate Sequence of Water Year Method

As the scenario is developed for extended dry climate condition, the climate sequence is defined in Figure 5.25 in the range from normal to very dry. No wet sequence is given here as an input as previous water year method because , the climate is supposed to change severely in future due to GHG emission, rapid urbanization, industrialization and many others factors.

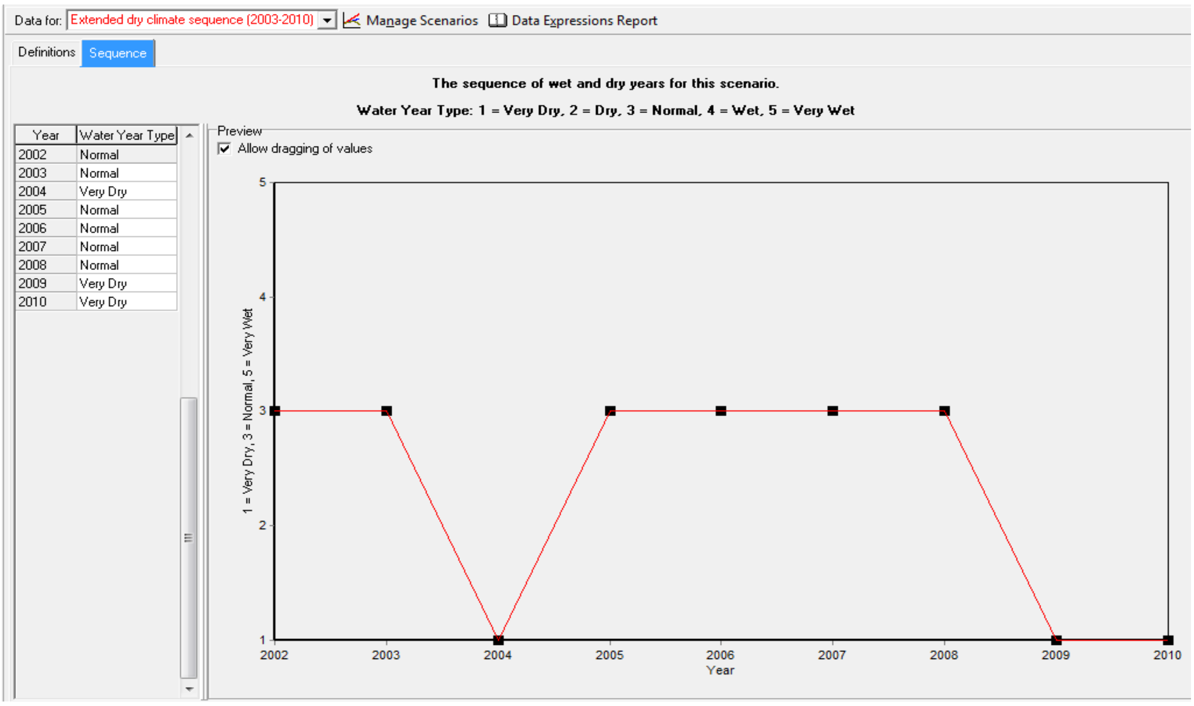

Figure 5.25 Input data for the climate sequence of the water year method in the extended dry climate sequence.

The result and graph after running the model shown in Figure 5.26 indicate that, Demra City "Unmet Demand" for the "Extended Dry Climate Sequence" (new climate sequence and a 1.59 % Population Growth Rate) falls somewhat in between those for the "Reference" scenario (original climate sequence and a 1.59 % Population Growth Rate) and the "High Population Growth" scenario (original climate sequence, but a 5% Population Growth Rate).

5.4.2 Scenario under High Population Growth

Now, changing of the Scenario Inheritance of the "Extended Dry Climate Sequence" by placing it under the "High Population Growth" scenario has been done. So that it inherits the 5% Population Growth Rate of that scenario. It is shown in Figure 5.27.

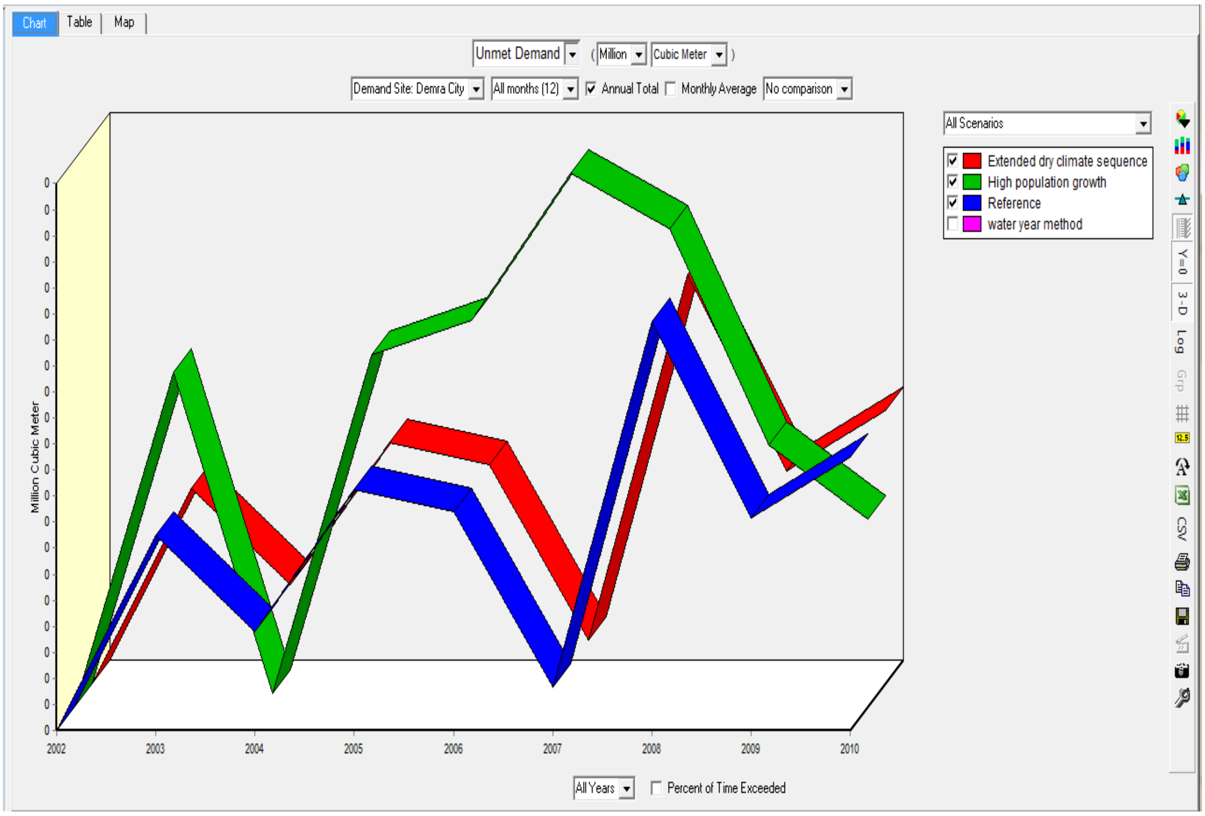

Figure 5.26 Simulated graph showing the relative unmet demand for three reference scenarios in extended dry climate sequence for the reference scenario (1.59%) growth rate.

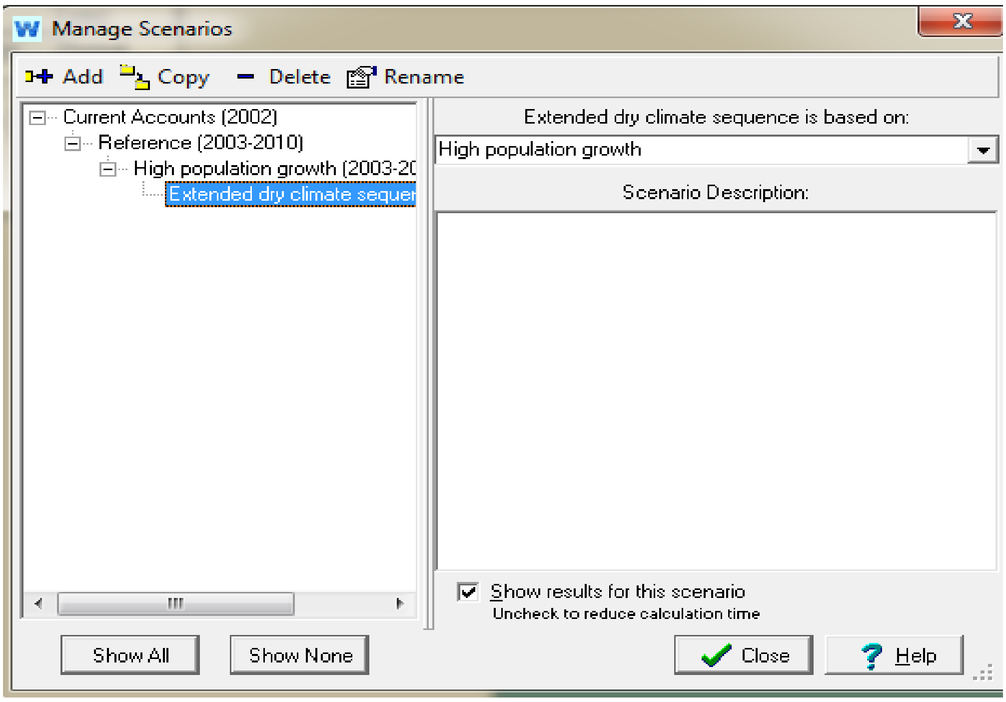

Figure 5.27 Defining the extended dry climate sequence under the high population growth rate scenario where the population growth rate is increased from 1.59% to 5%

5.4.3 Recalculate the Results and Look Again into Unmet Demand for Demra city

The simulated results and graph from WEAP after running the model, is shown in Figure 5.28. From the graph, it is clear that with the higher population growth rate and dryer climate, Unmet Demand increases substantially. This model emphasize that future condition will be more difficult for supplying water to the demand sites. So necessary steps should be taken minimize this unmet demand with a view to implementing efficient water management. Otherwise it will be almost impossible to ensure a sustainable water management for Lakkhya River basin. As the unmet demand will increase in future predicted by WEAP model, other sources of water supply, like ground water storage, rainwater harvesting, recycling of the industrial effluent and then stored them in the water reservoir and again used the recycled water by themselves, will be some effective steps for water management in Demra catchment area. As the effluent from the industries is discharging at river Lakkhya and they hardly use Effluent Treatment Plant (ETP) for the purpose of recycling the effluent, the policy of using their own recycled water by themselves, will make them to use the ETP must as well as it will be helpful to minimize the unmet demand and use the recovered water in other demand sites like agriculture.

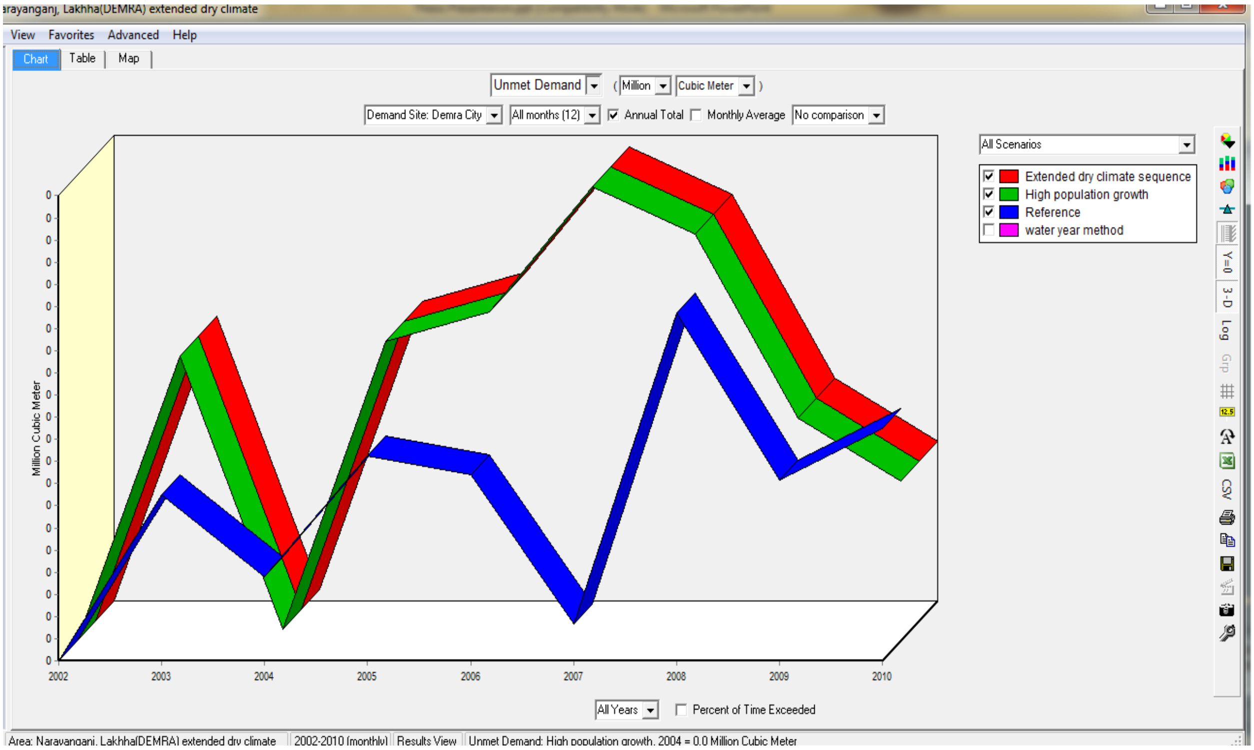

Figure 5.28 Simulated graph showing the relative unmet demand for three reference scenarios in extended dry climate sequence for the high population growth rate (5%).

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CHAPTER VI
CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

The objective of this study was to analyse the applicability and prospects of WEAP as a DSS tool for water demand analysis in Bangladesh and as a case study WEAP was applied to Demra catchment-Lakhya River basin to show how it will assist in policy planning and decision making by performing scenario analysis of the surface water management. As WEAP is not extensively used for decision making at present in Bangladesh, this study is aimed to propose the decision makers for adopting WEAP for assisting in future sustainable water resource management. At present River Basin Management is practiced instead of Integrated Water Resource Management which is not efficient especially for various future uncertainties. This study depicts the significance of implementing IWRM and serves as the foundation of IWRM model in Bangladesh to be continued for future and additional research although having several limitations. To perform the scenario analysis accurate data is required to model the hydrology and water management more precisely. Validation and calibration also depends upon these accurate data. The unavailability of data in Bangladesh made the development and validation of model very difficult during this study. However the comparison between observed streamflow and simulated streamflow and comparison between observed ET and simulated ET shows that the model prediction is close due their same pattern. For instance, in case of streamflow the both the observed and simulated data has their peak value in August.

Water demand varies significantly according to various situations such as population growth, climate change and water usage in agriculture. Unmet water demand will grow dramatically if the existing situation continues. Also the simulated unmet demand is higher for two future uncertainties i.e. high population growth and extended dry climate. The analysis of unmet demand is very significant for adopting intervention measures. As population growth cannot be checked other sectors such as agriculture and industrial should be properly managed. Water pricing, water rationing and water trading between various sectors can be effective. Above all, Bangladesh can successfully develop and manage their water resources by implementing IWRM.

6.2 RECOMMENDATION

The followings are recommended based on the study:

1. The scenarios displayed in this study can be used to bring discussion among various stakeholders involved in water management in the catchment; this will enable understanding of the issues facing the catchment.

2. Storage should be increased in the catchment to safeguard the reserve. The hydrology of the catchment should be modelled using the soil moisture model with availability of more data to confirm the simulations in this study.

3. It is also clear that the catchment is very vulnerable to drought situations if the climatic condition is extreme in the future year as shown in the model.; therefore there is an urgent need to increase storage upstream. Dams and weirs should be constructed along Lakhya River to improve water availability in the lower catchment zones.

4. The connection between the ground water and Lakhya River should be included in the modelling software an important part of the catchment. We can also explore other factors, such as the pollution generated by agriculture, that may strengthen the models and thus planning and management capacities.
5. We have to develop a new cadre of professionals with an integrated vision of water resources planning and management who, in addition to their specific training, will broaden their knowledge of social, environmental, economic and legal issues in order to acquire the appropriate training to implement integrated management for better sustainable development.

6. Increasing water reservoir is necessary as it could be used to store water during excess water year because so far excess water capacity had not occurred.

7. Above all, we should follow integrated water resource management instead of river basin management.

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