Modeling of the Water Supply System in the City of St. John's, Newfoundland

By

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Abstract

Water resources management in the City of St. John's, Newfoundland, is a significant issue because of the intertwined social, economic and environmental concerns. Many sophisticated water management computer models faltered in the past being mathematically obscure and overly ambitious in attempting to optimize solutions to real world problems. The best approach is so; to build a straightforward and flexible tool to assist, not substitute for, the users of the models. In this study, an integrated computer based water management system is developed using water evaluation and planning program (WEAP), to offer a professional and practical tool to study the current and future water supply and demand systems, regarding, but not limited to, the changes in population, industry, agriculture, and regulations in the city. The modeling efforts were based on a comprehensive study on the city and its surrounding areas, the Windsor Lake watershed, nearby reservoirs, water and waste water treatment facilities, and water supply systems, assuming specific conditions with corresponding projections into the future. Available data on the water supply and management systems in St. John's was collected and compiled, covering meteorological, hydrological, environmental, managerial, and social-economic aspects. An integrated water supply database for the city was also developed based on the geographical information system (GIS) and database techniques. The feasibility and capability of the model, developed using WEAP graphical user interface, have been examined through the real-world study on the city. A manifest of this is embodied in the results presented for multiple scenario analyses. The results indicated that the annual unmet demand is predicted as 1.680 x 10^6 m^3, 1.711 x 10^6 m^3, 1.773 x 10^6 m^3, with respect to the reference scenario as 1.586 x 10^6 m^3, and the

cumulative supply requirements are 2563 x 10^6 m^3, 2594 x 10^6 m^3, 2656 x 10^6 m^3, with respect to a reference of 2469 x 10^6 m^3, over the period of 2000-2030 under the three scenarios.

The model developed should evolve into a useful tool in decision making as the interests of jurisdictions considered with increasing awareness and concern on water resources and supply/demand system management as well as its sustainable development under changing environmental conditions.

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Abbreviations

ATLSSM	Across Trophic Level System Simulation Model
BBBP	Bay Bulls Big Pond
CMS	Cubic Meter per Second
DSM	demand-Side Management
ESM	Everglades Screening Model
IGEP	Innovative groundwater Evaluation and Planning
IWRM	Integrated water resources management
FEPS	Flood and Erosion Prediction System
ICWRS	International Commission on Water Resources Systems
IJC	International Joint Commission
IERM	Integrated Ecological Response Model
ILA	International Law Association
PRRISM	Potomac Reservoir and River Simulation Model
SEI	Stockholm Environment Institute.
SFWMM	South Florida Water Management Model
TSS	Total suspended solids
WEAP	Water evaluation And Planning
WL	Windsor Lake
WMA	Washington metropolitan area
WSCU	Water Sector Coordination Unit
WQMA	Water Quality Monitoring Agreement
UNCED	UN Conference on Environment and Development

Chapter 1: Introduction

1.1 Background

The most important and obvious factors that increase the pressures on the available water supplies are population growth and changes in life style, a byproduct of economic development. How to efficiently manage water, a source essential for life, has becomes a critical and necessary function of governments worldwide. Poor management of water could not only result in reduced or imbalanced supplies but also create conflicts of geopolitical nature. In 2000, about 17% of the world's population did not have access to a secure water supply and 40% lacked, otherwise much required, an adequate sanitation (WMDC, 2007).

Water management is defined as an inter-sectoral issue for establishing a holistic and strategic approach for water use owing to its role in all areas of development - health, food, transport, business, etc. In Canada, municipalities are usually responsible for water management such as water supply (both quality and quantity) and wastewater treatment. Meanwhile regional cooperation is of particular importance since water is often a trans-boundary and fragile resource requiring a more resolute political approach including all the areas linked to water management, such as environmental sustainability and pollution control must be adopted. Especially, hydrological boundaries seldom coincide with administrative ones. River basins cross administrative boundaries are appropriate units for operational management but present problems for institutions with different responsibilities. Therefore, integrated water resource management is important. Decision making at the lowest appropriate level needs to be a guiding principle.

This study on the water management (supply and demand) in the City of St. John's, Newfoundland, Canada, is presented as an attempt in the context of foreseeing the effects of an increasing demand, population, booming industry, evolving commercial activities with governmental concerns from the local, provincial, federal, and to international level regarding water conservation and management.

1.2 Water Supply and Demand Systems in the City of St. John's

A review of the available literature and documentation has revealed that there were limited studies performed in the past specifically in the context of examining the water demand situations in Newfoundland and St. John's. Water Resource Atlas of Newfoundland, published by the Water Resources Division, Department of Environmental and Conservation, Government of Newfoundland and Labrador, presented an important source of data for all of Newfoundland (1992). Several sporadic locations were studied. One of the examples was the hydrogeological assessment of Cold Brook, a community in Newfoundland (AMEC 2008). This community relies mainly on both municipal and private groundwater wells for its water supply. The study focused on the possible impact of additional housing on the water supply due to additional septic tanks.

The following studies relate to the Avalon Peninsula, or the St. John's region, Newfoundland:

1) Regional Water Resources Study of the Eastern Avalon Peninsula (1987), Water Resources, Division, Department of Environment, Government of Newfoundland and Labrador, St. John's, Newfoundland.
2) Geology of the St. John's, Area, Report 90-2, Geological Survey Branch, Department of Mines and Energy, Government of Newfoundland and Labrador, (1990).
3) Soils of the Avalon Peninsula, Newfoundland Soil Report (1998), No. 3, Newfoundland Soil Survey, Land Research Branch.
4) Hydrogeology of the Avalon Peninsula (2006), Water Resource Division, Department of environment, Newfoundland Government of and Labradors, John's, Newfoundland.
5) Report No.102515 Aquifer Test Analysis, Drilled Bedrock Wells, Northeast Avalon Arena Site, Torbay NL, Report to Kavanagh and Associates Ltd (2007).

None of the above studies involved the modeling of the Windsor Lake, as a major water system supplying the City of St. John's. A study by the Newfoundland Design Associates in 2007 (NDA, 2007) was the most recent one on the water supply system for the City, as an update to the 1994 St. John's Regional Water Supply Review Study Report (NDAL, 1994). The NDA report detailed the new infrastructure in place since 1994, updated the population projections and the associated water supply and demand comparisons for the region. The report also discussed the requirements concerning upgrades to the existing infrastructure along with the new ones. It was assumed that the total number of occupied dwellings would increase to meet the population demand, while the number of people per occupied dwelling within the region would continue its historical trend, eventually paralleling that of Canada. This report included the data from historical water usage records and projection for per capita water usage trends at a regional scale. The report reviewed the demand for Windsor Lake, Petty Harbour Long Pond, and Bay Bulls Big Pond for the period of 1978 – 2005. The changes to the system were recommended to accommodate the projected demand for cost estimate (NDA 2007). This report also included the projections of demand up to 2035 based on the assumed population growth rate and the supply capacity of Windsor Lake and Broad Cove Watersheds. However, it did not use a modeling tool to provide the examination of scenarios that differ from assumptions made.

Furthermore, groundwater sources are not currently utilized in St. John’s region for drinking water supply unlike other municipalities in Newfoundland. Thus, groundwater management have not been considered in the previous study in the City of St. John’s; however, as a key source of water, consideration of groundwater in an integrated water management system is desired. In fact, there are 597 groundwater wells currently used for domestic purpose outside the municipal boundary (AMEC, 2008) based on self-regulation. These should be counted in the future management of water resources of the city.

1.3 Objectives of the Study

This study aims at developing and evaluating an integrated water supply modeling system for supporting the city's decision making in water resources management. The objective includes the following research tasks:

1) Collection of relevant data and development of a water supply and demand database based on GIS and database techniques;
2) Identification and characterization of the existing problems in water resource and the supply systems in City of St. John's, analysis of different scenarios;
3) Investigations and interviews to formulate the system specifications to find the end users' needs and development preferences;
4) Development of an integrated planning framework based on the Water Evaluation and Planning tool (WEAP); and
5) Preparation of recommendations for the local operational water plans to promote sustainable management.

A flow chart of the study is shown in Figure 1.1. Starting from defining the problem and collecting data on water supply and demand, the WEAP-aided model was developed, under different scenarios, and tested leading to the recommendations for water supply management procedure.

In this study, the WEAP system will be used. This system is simple to build and to use by engineers and decision makers to simulate various scenarios for water supply systems to meet the management requirements. Scenarios can be easily changed by adding, adjusting and dropping components in the WEAP model. The purpose of this study is to apply this tool to help identify and resolve the management problems with the water supply and demand system of the City of St. John’s, Newfoundland. More specifically, this study is expected to support the development of a water evaluation and planning approach by integrating water balance modeling, scenario analysis, and capability assessment.

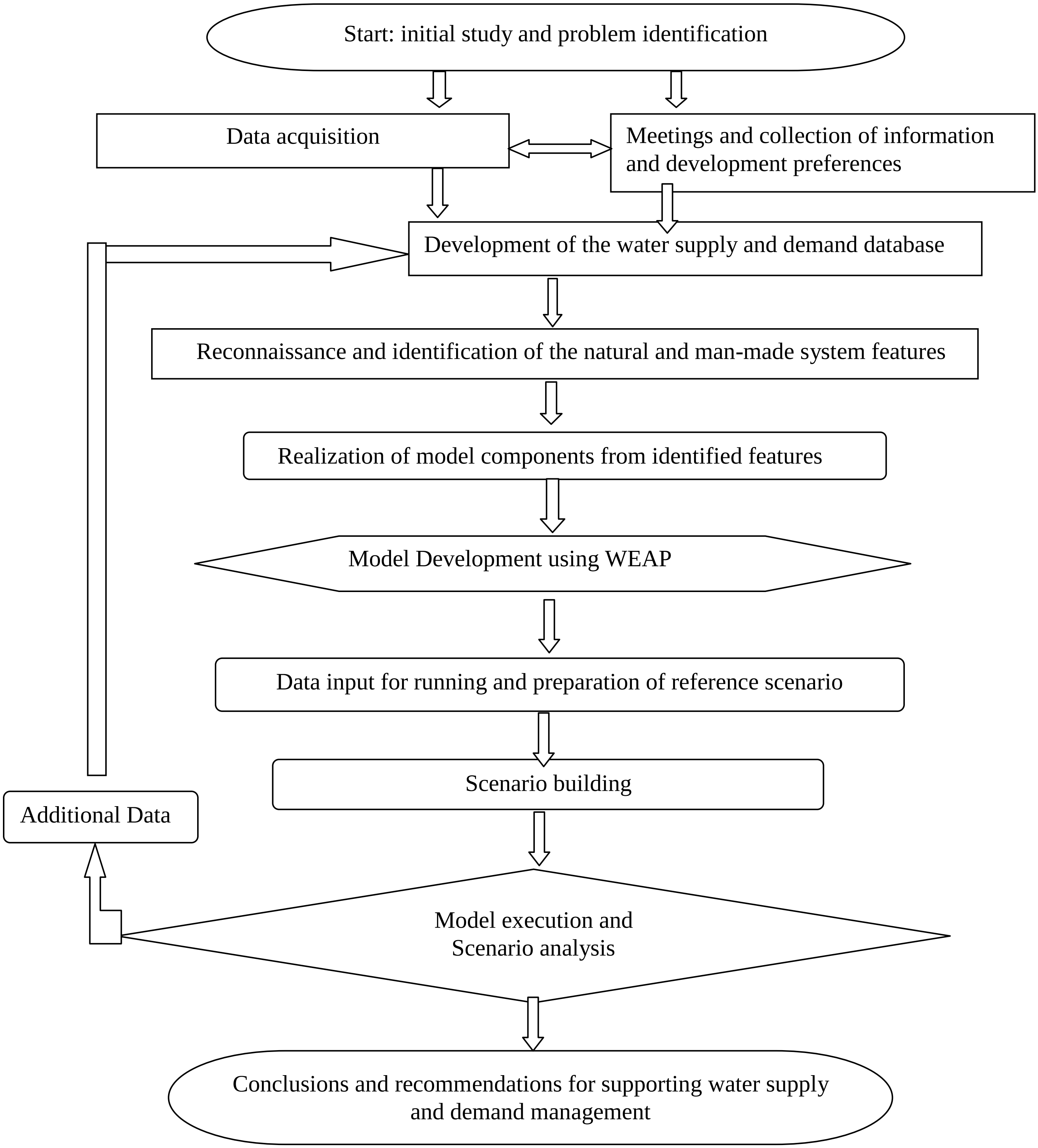

Figure 1.1 Flowchart of the study

1.4 Organization of the Thesis

Chapter one presents the background information for an overall appreciation of the scope and value of the study. It focuses on description of the municipal water management related issues in terms of a comparison with the existing situation in the City of St. John's area before delineating and defining the objectives set for the study. A comprehensive literature review has been provided in Chapter 2. The core of the chapter lies in clarifying and highlighting the importance of integrated approach in water management. This is followed by modeling application leading to evaluating the usefulness of the WEAP in decision making. Further explanation includes how to apply WEAP efficiently and effectively for water resource management and modeling purposes in combination with useful GIS data and information. Chapter 3 focuses on data acquisition and treatment in addition to identification and analysis of the features of natural and man-made water system which have been incorporated in the development of the model. Particularly the development of the water supply and demand database of the City of St. John's is introduced. Chapter 4 is a continuation of the data related aspects described in the previous chapter as it further unfolds the details about the population of the urban area and demographics. Various input parameter for the WEAP model are identified and discussed along with the explanation of the specific model details as key assumptions and corresponding definitions. The modeling results and research findings are also presented, and detailed discussions are provided from the perspective of a comparative scenario analysis. Conclusions and recommendations resulting from the modeling study are presented in Chapter 5.

Chapter 2: Literature Review

This chapter explains previous studies done globally in the field of water resources management, covering the methods used and strategies employed. Different methods have been used in various studies, taking the account of the weather, demography and population and economic situations which can affect and play important role in this kind of study. There is growing awareness in all regions of the world that comprehensive management of water resources is needed, where the fresh water resources are limited.

2.1 Background of Water Resource Management

Water resources include all forms of water from surface water to groundwater. An interesting distinction which can be made is defining water resources as blue and green water. As an example of an improved understanding of hydrology, Falkenmark and Lannerstad (2006) introduced the terminology of blue and green water: the former is the water in rivers, lakes and shallow/unconfined aquifers which is of more concern to the planners and engineers in water resources management; while the latter is the water which is found in the unsaturated zone of the soil and more responsible for food production and sensitive to soil contamination.

Both planning and management in the use of water resources, at all levels from the international to the local, must be carried out effectively and appropriately. Currently, most discussion and analysis of water resource management in the literature is focused on the large scale issues. For example, Postal (1992) proposed three principles to follow in water management under the heading "three E's", equity, ecological integrity and efficiency. By equity every person has an equal right to clean water, i.e. it is a "public good"; by ecological integrities, all water use mustnot harm the environment, thereby reducing access to water by future generations; and by efficiency, the extraction, delivery and waste management should be at the lowest possible cost, consistent with equity.

Duda and El- Ashry (2000) described water resource management as the success of an integrated process, which is measured differently depending on the sectors. The local municipal and governmental bodies measured the success in relation to social benefits that people have; whereas, the private industrial sector measured the success in terms of revenue and profit gained. The authors gave an example on how the lack of regulations from the regulatory bodies on the private sector in the Colorado River caused serious issues in water management.

The word "integration" has been commonly used in the field, meaning that not only conventional engineering considerations are important, but also economics, social and environmental issues should be considered (Griggs 1996). Likewise, this topic has been further studied in the literature (Malano, 1999; Matondo, 2002). In addition, hydrological boundaries seldom coincide with administrative ones. River basins are appropriate units for operational management but present problems for institutions with different responsibilities. Different decisions on water resources management belong at different levels with interactions to each other. An integrated consideration of diverse levels is also important.

2.2 Development History of WRM and IWRM

The terms Integrated Water Resource Management (IWRM) with supporting concepts and methods have been proposed and extensively employed worldwide.

The USA National Water Committee Report (1966) stated that IWRM is the creative and analytical process of: *"(a) hypothesizing sets of possible goals, (b) assembling needed information to develop and systematically analyze alternative actions for attainment of such goals, (c) displaying the information and the consequences of alternative actions in an authoritative manner, (d) devising detailed procedures for carrying out the actions, and (e) recommending courses of actions as an aid to the decision- makers in deciding what set of goals and courses of action to pursue*".

Grigg (1996) suggested that an IWRM plan had to consider the water-related human activities, land use and the environment in an integrated way. Malano (1999) and Matondo (2002) proposed the four principal needs in IWRM:

1) The need to consider various stakeholders in the integration process;
2) The need to consider geographical distribution of these stake holders in the in the integration process;

3) The need to consider social and cost aspects in the integration process; and
4) The need to coordinate the integration process between different levels of the government.

Matondo (2002) discussed the importance and procedures of water resource management plans. The author defined a general appraisal planning as "the broad evaluation of alternative measures for meeting of hypothesized goals and objectives, with recommendations for action plans and programs by specific entities". Implementation planning was defined as "an investigation of a specific structural or non-structural measure, or a system of measures, in sufficient detail to determine whether it will meet established goals, objectives, and criteria". The author further claimed that, to properly design and implement a plan for water resource management, it was necessary to define goals and objectives of what needs to be delivered. This was followed by collection of data about the environmental, social, and cost aspects involved in the process. The development of detailed alternative plans should also be considered in case the main water resource management plan fails. Each alternative plan should have detailed procedures for carrying out the actions. These plans should serve as recommendations to authorities and decision makers and not be treated as obligatory actions. These plans would help provide the higher authorities (usually politicians) with the needed data to make informed decisions. During planning the water management, Matondo (2002) suggested that the engineers and decision makers needed to first consider an overall general multi-sectorial planning, then proceed to a sectorial planning and finally develop a functional planning, through a team of multidisciplinary stakeholders.

Howe and White (1999) thought that WRM should start by planning, then move towards management, since in the absence of planning you might have nothing to manage. Moreover, they defined the integrated water resources planning as "*a process whereby the water utility determines the options that at least cost will provide its customers with the water related services that they demand, rather than the water itself, while maintaining the integrity of the environment*". Similar to the traditional water resource planning, the word integrity in the previous definition means to blend all the human factors into one single integrated protocol.

Many researchers in their publications indicated that stakeholders participation was a key to the success of any IWRMS (e.g., Blackmore, 1995; World Bank, 1993; Ashton et al., 1998; Savenije and Van der Zaag, 1998). The participation could take diverse forms depending on the country where the planning was happening. For example, public hearings have been widely used in developed countries such as USA and Canada. However, the public hearings were not widely used in developing countries. Hence it is obvious that there is a missing link between the methods needed to best utilize the water resources between countries (Matondo, 2002).

2.3 Modeling of Water Resource Systems

In addition to economic, environmental, and social considerations, the use of computer-based models in water-resources development projects is crucial. It must be noted, however, that according to (Loucks, 2008), advanced computer-based models are still based on a lot of implicit information and assumptions embedded in the modeling equations. Hence, the output of any computer-based modeling system should be used as a guidance tool in the overall decision making process and not as a definite set of outcomes that must be followed (Loucks, 2008; Logan 2006). There are numerous examples of the application of water resources models (Friedman 1984, Harou 2009). Here are some examples given by Loucks (2008):

When Loucks (2008) studied the regulations about water discharge of the Great Lakes into the St. Lawrence River, the conflicting objectives were identified. The author applied five models to manage these objectives, which presented a typical approach of water resource systems modeling. They involve:

1) Two models were developed to assess shorelines. The first model was developed by (Lucas 2008), called the Flood and Erosion Prediction System (FEPS), and was used to assess shoreline erosion rates and damage over time. The second model was developed by the International Joint Commission (IJC), called The St. Lawrence River Model, and was used to predict the impact of water levels on existing shoreline-protection works.

2) The Integrated Ecological Response Model (IERM) to estimate how different regulation plans would impact plant and animal species in the eco-systems in Lake Ontario and the St. Lawrence River.

3) Stochastic optimization based policy-generation models to identify and evaluate real-time operation policies and operating policies that could be implemented without periodic modeling.

4) Statistical hydrologic models to generate alternative time series of inflows to the system, which were then used in policy simulations to ensure the reliability, resilience, and robustness of each policy with various time series (up to 5,000 years) to reflect four different climate-change scenarios (Loucks, 2008).

5) Shared-Vision Planning Model to incorporate the results from all the above models for stakeholders and researchers for use on the Internet via an interactive Excel-based program called the Boardroom (Loucks, 2008).

Due to an expected increase in population and economic activity along with an industrial boom, such as in the City of St. John’s metro area with the fast growth of oil and gas industry, many issues related to available water demands and supplies occur. More effective tools for the management of water resource systems are desired with consideration of social and economic factors into the modeling framework by (Loucks, 2008).

2.4 Water Evaluation and Planning Program (WEAP)

2.4.1 The WEAP System

The WEAP system is a widely used modeling tool developed by the U.S. Center of the Stockholm Environmental Institute for Water Resources Planning (SEI, 2009). The WEAP uses an integrated approach to simulate water systems by its policy orientation. It is a computer aided tool that is intended to help human operators perform better planning tasks (Sieber, 2009). It has been used as a forecasting tool that can take input data and simulate water consumption by various sectors of a society. The operators can have different options for the simulation based on the planning strategy. The major features of the WEAP system are listed in Appendix A5.

When applying the WEAP system, users generally need to have a study definition, statistical data of water, water use assumptions, and scenarios of future demand of water. Based on this, scenarios analysis is an integral part of this computerized program. Any scenario analysis will include several questions that need to be answered. Appendix 4 gives details of these questions.

2.4.2 Application of the WEAP System

The WEAP system has been used since 1991 in many cases for modeling large river basins, such as the Olifants River basin in South Africa (Levite et al., 2003) and the Lake Naivasha in Kenya (Alfarra, 2004), and the Volta basin in Ghana (De Condappa et al., 2008). These studies all involved transboundary water resources. They reproduced river flows and water storage in the lakes and/or reservoirs which were sensitive to the rainfall variation, operation of dam hydropower generation, irrigation, population growth and climate change.

The WEAP system has been used worldwide. Two representative cases could be found in the U.S. in the Real Rio Grande / Bravo (Danner et al., 2006) and the Sacramento Basin (Yates et al, 2009). In China, Olusheyi (2006) applied the WEAP to solve a water resource problem in the Heng Shui City in the Fu Dong Pai River basin nearby Beijing. The basin supports a population of about 4 million, of which about 0.7 million are nonfarming related. The basin is bounded by nine rivers mixed with man-made channels, both ancient and recent. There were variable rainfall and frequent flooding events. Population growth scenarios were considered. With growing population and industry, the demand was about to exceed or already exceeded the supply. The study recommended options such as increasing water storage and treatment plant capacities, reusing reservoirs, adjusting water prices, and considering water importation from other sources.

The work presented in this thesis may be one of the first applications of the WEAP in Canada, apart from an earlier study carried out by the International Upper Great Lakes Study Board (2007), which aimed to integrate water availability, water demand, and consumptive loss modeling using the WEAP.

2.5 Application of GIS in Water Resources Management

Over the past decade, the geographical information system (GIS) has been extensively used in various areas that benefit the humanity at large. One of the areas is the planning and management of water resources. The databases of a GIS usually include water related information such as rivers, locations, drainage areas and much more. It is expected that the neat future will even have more revolutionized GIS tools that can help handle more useful data. Loucks et al. (2008) introduced the terminology of “Hydroinformatics” into GIS and its application. The term refers to the use of analytical computer-based techniques for data mining such as artificial neural networks (ANN), support vector machines (SVM), genetic algorithms (GA), and genetic programming. By this way, GIS becomes more efficient in planning and management of water resources.

Chapter 3: Development of a Water Resource Management Database for the City of St. John's

3.1 Introduction

This chapter will highlight salient hydrological features in the City of St. John's including the groundwater situation. This shall help identify factual information to build a data bank for the city since no such study has been accomplished before, in particular for domestic purposes, including where houses are not connected to the water system of the city. Summary of the data gathered in this study with all features such as pumping and treatment stations identified on a Geographic Information System (GIS) map, e.g. as shown in Figure 3.1, is also presented to provide for a better collective appreciation for research as well as other governmental use. This chapter also examines existing situation of the water resources management related policy problems for the City of St. John's, Newfoundland and Labrador.

3.2 Water Resources Management in the City of St. John's

The engineering department of the City of St. John's manages the physical structure including the reservoirs, pumping stations, treatment plant, distribution system, and wastewater treatment plants. Some of these resources are supplied to other municipalities including Mount Pearl and Paradise.

Monitoring groundwater resources (mostly private wells), and water quality of the rivers and lakes is conducted by Water Resources Management Division, Department of Environment and Conservation, Government of Newfoundland and Labrador.

3.3 Water Resource Data Base

The Data collected from Water Resources Management Division, Department of Environment, and Conservation, Government of Newfoundland and Labrador, City of St. John's, Engineering Department, which kindly supplied reports including consultants' reports.

The reports available on the web were also used. The facilities of Map Room of Queen Elizabeth II library at Memorial University provided GIS maps of St. John's study area.

The GIS related database is structured to include the co-ordinates of groundwater wells, the weather stations, water quality monitoring stations, and contort lines. The data for the WEAP model, as detailed in Chapter 4 include water consumption rates for the city, the areas, depths, volumes and reliable yields for the Windsor Lake and Broad Cove watersheds, demands at institutional, industrial and domestic sites, population growth scenarios and monthly precipitation values.

3.3.1 The City of St. John's Area

The area city of St. John's is around 446.04 km^2 (172.22 $mile^2$) (Statistics Canada, 2006 Census), with a population of 100,646 (Statistics Canada, 2006 Census). Its Latitude and Longitude: 47° 37.200' N and: 52° 44.400' W respectively. The Elevation is: 140.50 m.

3.3.2 Annual Precipitation and Temperature

The monthly mean temperature in the area is 5.0°C, ranging from a high of 15.7°C in July to a low of -5.2°C in February. Average annual precipitation in the area is 1,572 mm, of which 80% falls as rainfall and 20% as snowfall. January is typically the wettest month, and July is typically the driest month (Environment Canada, 2008).

The average annual precipitation in the vicinity of the Torbay Road development area is estimated to be 1,510 mm per year. This estimate is based on rainfall records, from the St. John's international Airport from 1942 to 2007(DOE, 1984). Evapotranspiration has been calculated as approximately 86 mm per year thereby leaving approximately, 1424 mm of precipitation available for run off and groundwater recharge. Preliminary studies conducted by the Newfoundland and Labrador Department of Environment on both the Waterford River and Rocky River Basin shave concluded that infiltration is likely to be in the order of 20 to 25 % of the total precipitation (DOE, 1984).

Table 3.1 Mean Monthly Precipitation (mm) in the City of St. John's (DOE, 1984).

Month	Mean Monthly Temperature (°C)	Mean monthly Precipitation (mm)	Infiltration (mm)	Potential Evaporation (mm)	Runoff (mm)
January	- 4.3	150.83	30.17	0	150.83
February	-4.85	139.85	27.97	0.00	139.85
March	-2.53	131.78	26.36	0.00	131.78
April	1.37	117.88	23.58	12.41	105.47
May	5.85	99.08	19.82	47.45	51.63
June	10.72	92.40	18.48	83.40	8.99
July	15.50	86.05	17.21	111.11	25.06
August	15.62	108.76	21.75	102.53	6.23
September	11.99	122.09	24.42	72.21	49.88
October	7.16	149.01	29.80	40.36	108.65
November	3.11	152.18	30.44	17	135.18
December	-1.61	160.53	32.11	0.00	160.53
Annual Total	**-**	**1,510.44**	**302.09**	**486.47**	**1,023.97**

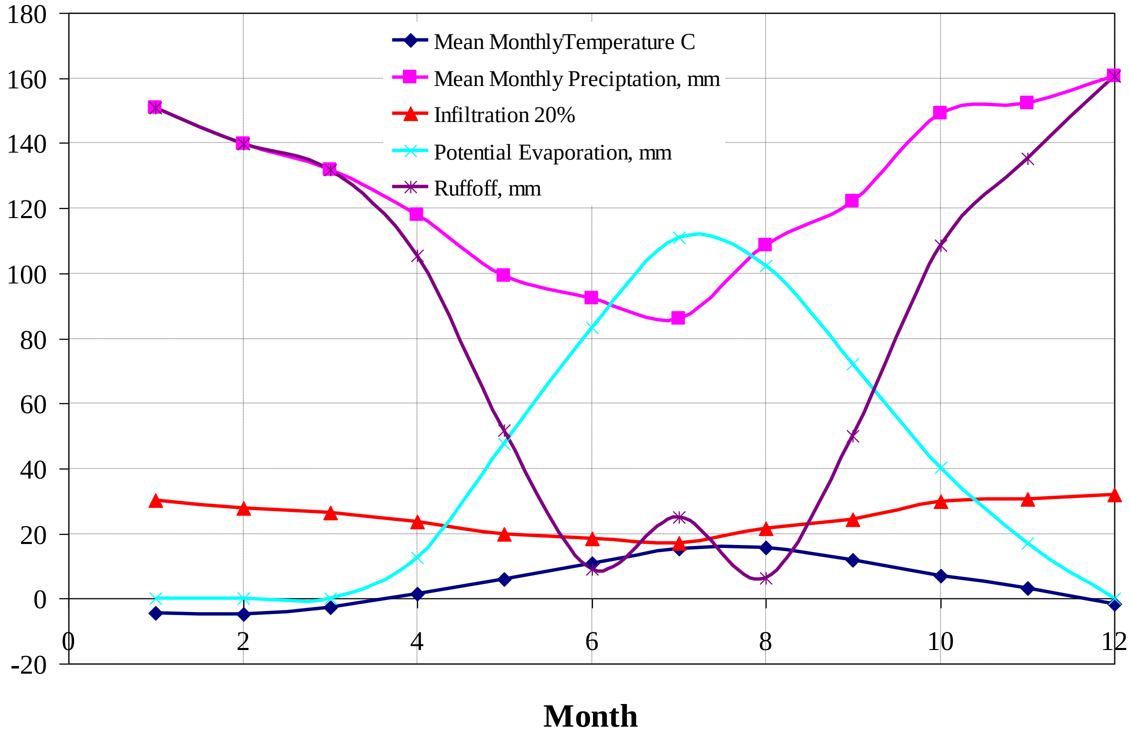

Figure 3.1 Plotting the Mean monthly Precipitation and other data showed in table 3.1 in the City of St. John's

3.3.3 Watershed systems

The City of St. John's gets most of its water supply from Windsor Lake and Bay Bulls Big Pond. There are some domestic wells in the basin. The following is information on watersheds and rivers in the area.

Windsor lake watershed

The Windsor Lake Treatment Plant and underground water storage reservoir is located at Windsor Lake in the City of St. John’s, Newfoundland and Labrador. The use of the lake goes back to 1869. A major upgrade took place in 2003. The construction of the current plant began in late 2006 and was commissioned on February 22, 2007. The reservoir is an underground reinforced concrete tank measuring 43.3 x 81.8 x 7.8 meters.

Bay Bulls Big Pond (BBBP)

BBBP is one of the main drinking water reservoirs for municipal water supply system. This system serves the city and surrounding communities. The BBBP watershed is designated as protected. Water is treated using an ozone process, gas chlorination, and pH adjustment.

3.3.4 Municipal sewage system

Some of the houses in the basin are served by septic systems; however most are served by the municipal sewage system where, until recently, untreated sewage is transported to the St. John's Harbor. There is an outfall in Portugal Cove-St. Phillips that serves 4,701 people. It has a total daily load of 540,000 L/d. Summary of Design Wastewater Concentrations and Loading is show in table 3.2.

Table 3.2 Summary of Design Wastewater Concentrations and Loading

Population			**Ultimate Design** **157,100**
Flows	Average Dry Day (m3/day)		134,800
	Average Dry Day (L/S)		1560
	Peak Design (m3/day)		337000
	Peak Design (L/S)		3900
Concentrations & Loadings	BOD	mg/L	106
		Kg/d	14310
	TTS	mg/L	119
		Kg/d	16065
		mg/L	5.4
	TP	Kg/d	729

Source: City Hall Report (2006)

3.4 Water Supply Systems

The Windsor Lake with the Broad Cove River system is one of the main drinking water reservoirs for the municipal water supply system, is located in the basin headwaters. This system serves the City of St. John's and surrounding communities The Windsor Lake serves a population of approximately 83,000. The Board Cove River is used to augment water yield of the Windsor Lake during low flow periods. The Board Cove River watershed is designated as a protected water supply area by the City of St. John's. Water quality is generally good with relatively low PH. The water quality data is available in (Government of Newfoundland and Labrador-Station #: NF02ZM0020).

Average flow out for Windsor Lake water supply is a 70,000 m^3/day. Treatment consists of screening, gas chlorination, and pH adjustment**.** Portugal Cove-St. Phillips gets its public water supply from Blast Hole Ponds which serves 1,098 people and has gas chlorination and pH adjustment treatment. This water supply is not located in the Broad Cove Brook Basin (Kavanagh and Associates Ltd, 2007).

3.5 Windsor Lake Water Treatment Plant

Windsor Lake Water Treatment Plant is an integral component for the City of St. John's to ensure safe drinking water for all its residents. The treatment train consists of:

1. Alkalinity enhancement through lime addition
2. pH adjustment with carbon dioxide screening
3. Microfiltration using Siemens MEMCOR CMF-S membrane technology Primary UV disinfection for inactivation of Giardia/ Cryptosporidium Secondary disinfection using chlorine.

The facility is highly efficient and discharges minimal waste. Over 99% of the raw water brought into the plant for treatment is supplied as potable water to the City of St. John's. The site also includes an engineered wetland to treat the majority of wastewater from the facility in an environmentally responsible manner. Through the use of various species of trees, shrubs and aquatic plants, the wetland is designed to reduce the total suspended solids (TSS) in the wastewater by as much as 75%. The polished water leaving the wetland will then return to recharge Windsor Lake. This type of Water Treatment Facility is the first one for the province of Newfoundland and Labrador (City of St. John's 1997).

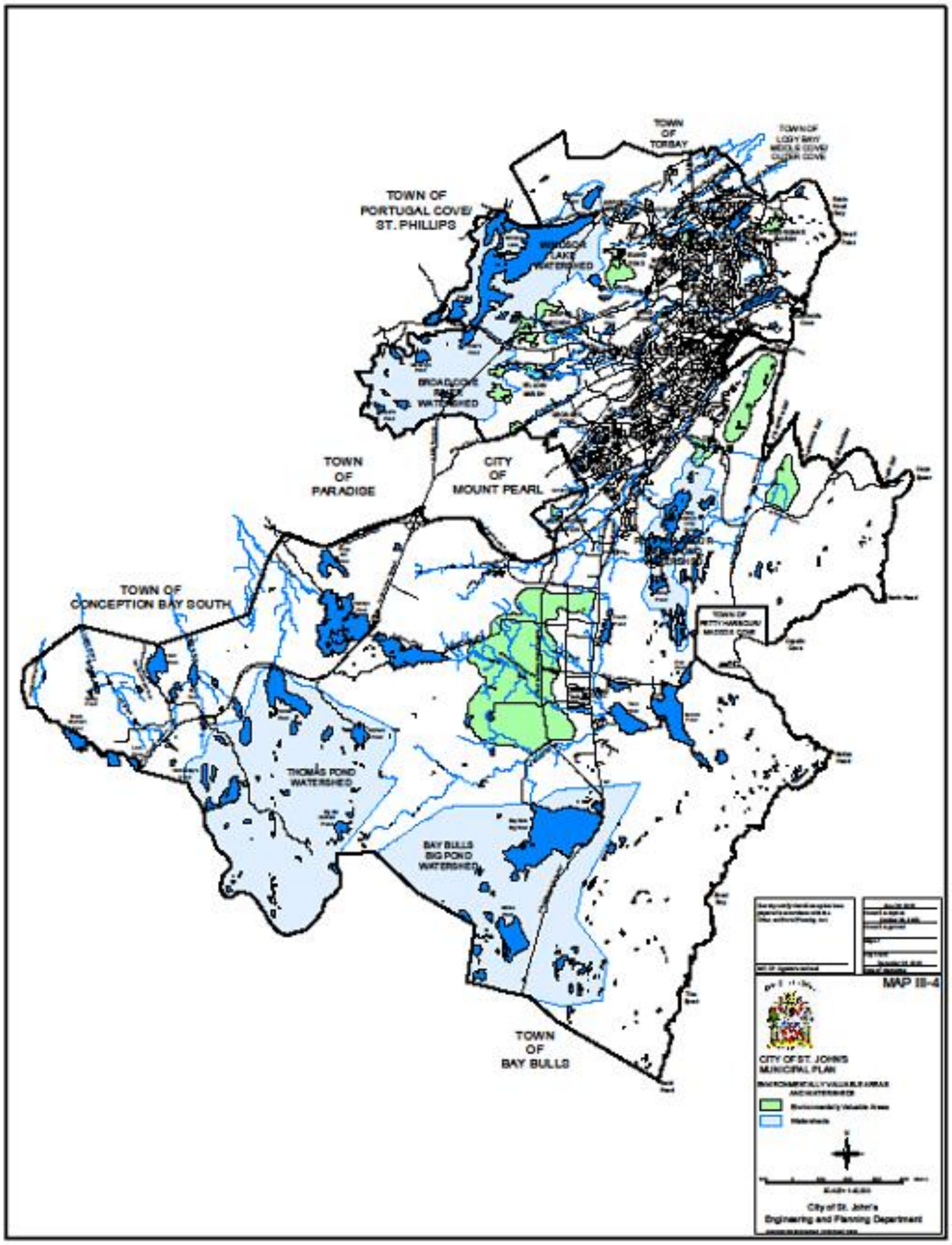

Figure 3.1 Watersheds in the City of St. John's (After City of St. John's, 1996)

Table 3.3 Summary of per Capita Water Use

Service Area	2005 Service Population (estimated)	2005 per Capita Water Use Based on Regression Eq.(L/c/d)	1994 per Capita Water Use Based on Regression Eq.(L/c/d)	Years of Record
Total Area	165,936	820	817	1978-2005
St. John's and Mount Pearl	139,260	836	864	1978-2005
Conception Bay	13,279	576	397	1978-2005
Paradise	10,159	454	485	1978-2005
Portugal Cove and St. Philip's	2,105	338	N/A	1978-2005

Source: City of St. John's, (1996).

3.6 Hydrology and Groundwater

The picture shown in Figure 3.2 (a) contains the topographic map of the City of St. John's area and others Figures 3.2 (b), (c), and (d) are showing the GIS location data. Appendix 3 also gives a table showing partial information of the groundwater wells in the City of St. John's as an example of the water resource management database. For this study, the map has specially been modified by adding various layers of additional information to render, information required, for the user in single map. GIS systems have been used to populate and/merge together various files to incorporate the location of the groundwater wells meteorological or weather stations and water quality stations as shown in the legend. Any ancillary data which might be of interest has been provided in Appendix 2, for the sake of brevity.

3.6.1 Rivers Systems

There are four rivers systems empting to the ocean in the region, the out lets are at the St. John's Harbour, the Quidi Vidi Lake, Petty Harbour, and the Manuel River.

The websites with data on the monitoring stations in the City of St. John's provide useful information on rivers in the area (Environment Canada and the provincial Department of Environment and Conservation).

The Windsor Lake is one of three drinking water sources for the City of St. John's. As noted earlier the Windsor Lake flow is augmented by pumping water from the Broad Cove River on a need basis. Water quality of selected water bodies in the province is monitored under the Canada-Newfoundland Water Quality Monitoring Agreement. Water quality data for rivers of interest is available at the link:

http://www.Canal.gov.nl.ca/root/main/station_details_e.asp?envirodat=NF02ZM0020

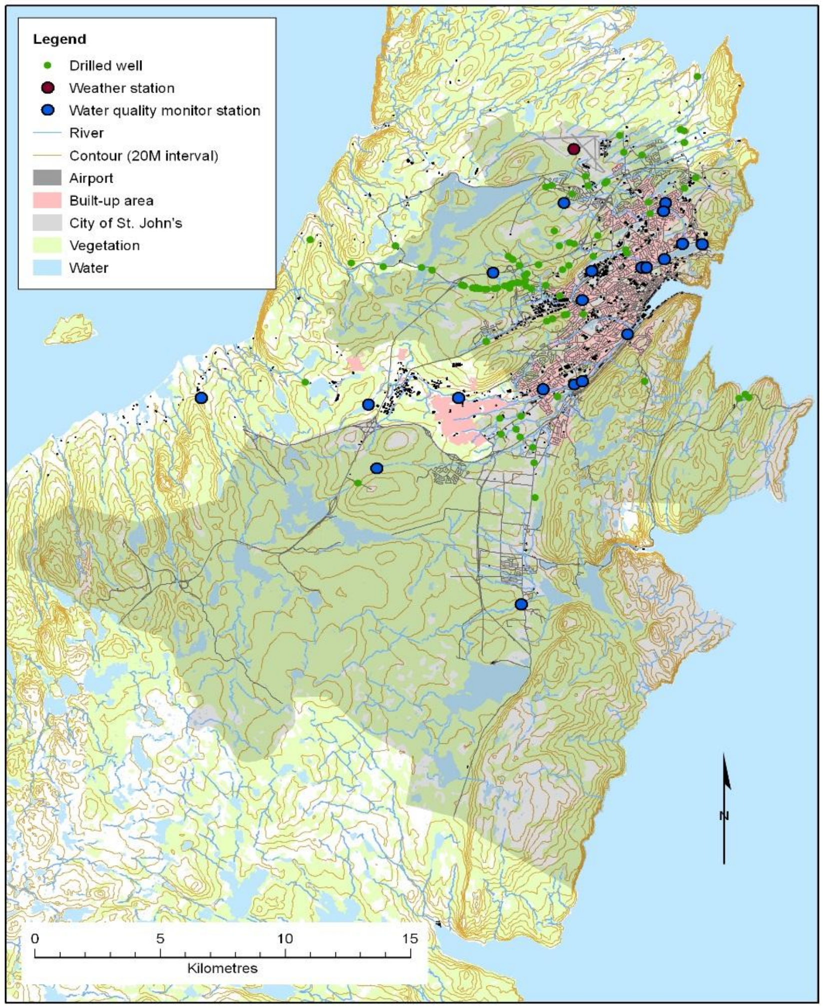

Figure 3.2 (a) Water resources and related features in the metro areas of the City of St. John's

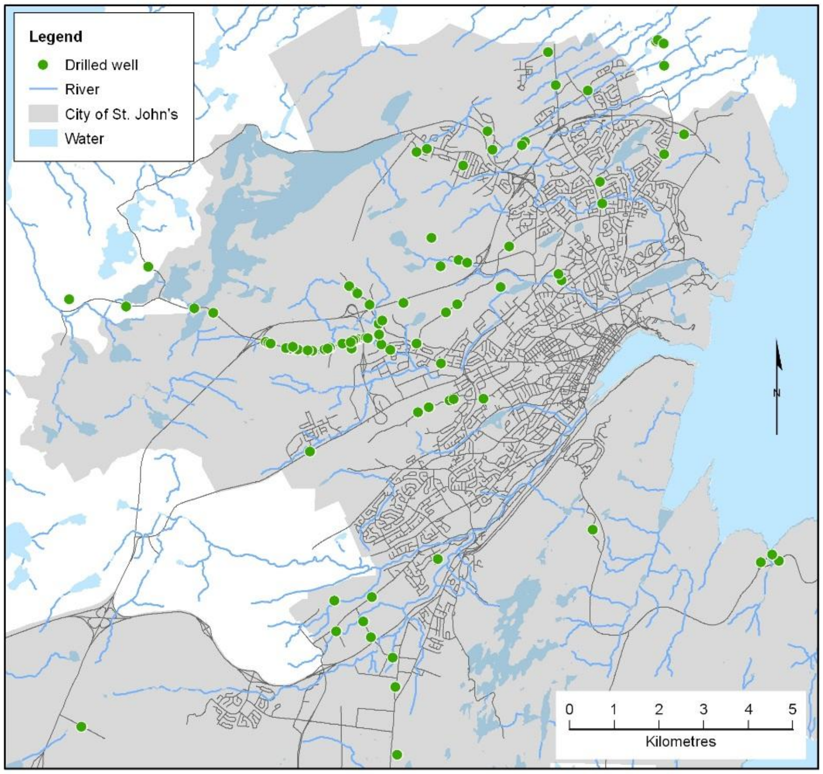

Figure 3.2 (b) Drill Wells in the City of St. John's

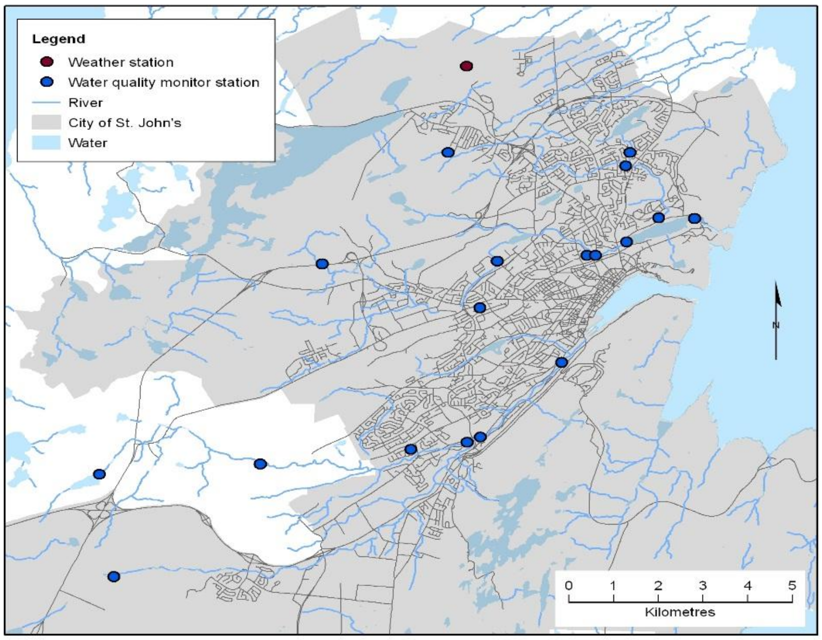

Figure 3.2 (c) Weather and water quality stations in the City of St. John's

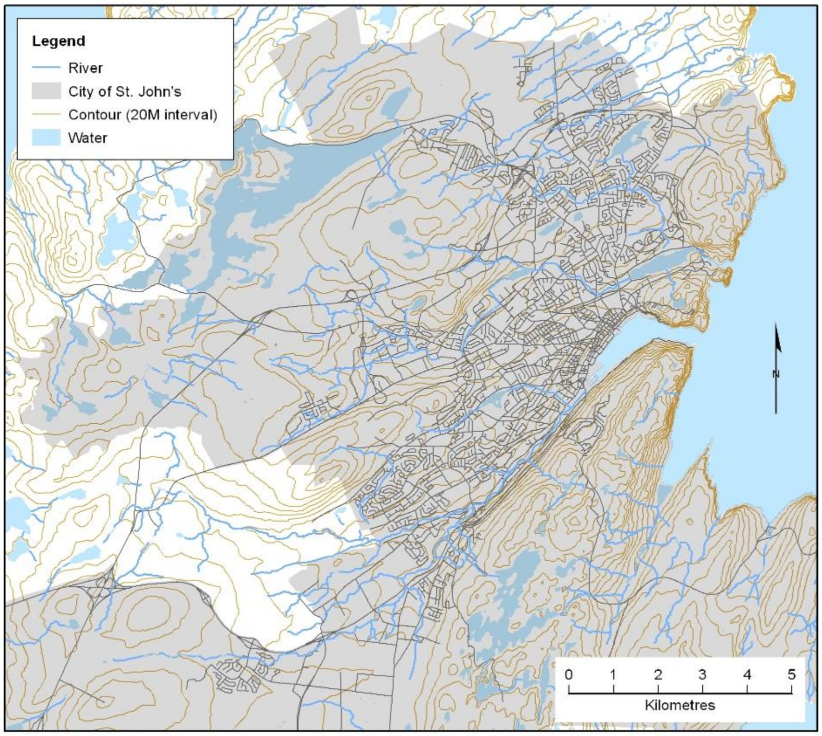

Figure 3.2 (d) Topography and rivers in the City of St. John's

3.6.2 St. John's Harbour System

The Waterford River and Tributaries

The Waterford River basin has two water supplies. The first is Bremigans Pond which is located in the basin headwaters and used as a domestic water supply for the Donovans highways depot. Private Wells are used for domestic purposes in some areas. The Waterford River flows southeast through Mount Pearl to Bowring Park along Topsail Road. Before arriving in Bowring Park many smaller rivers and also ponds have outflows into the river such as Nevilles Pond, Powers Pond, and Flings Brook. In Bowring Park, South Brook joins the Waterford River before the river leaves the Park (Water Quality Station NF02ZM0009).

The Waterford River flows directly alongside Waterford Bridge Road to the Harbour. Before it reaches the harbour out flows from Beaver Pond and Mundy Pond both drain into the Waterford River. Flow and water quality data are collected and available under the Canada-Newfoundland Water Agreements for Various stations operated on rivers within the City of St. John's (Water Quality Station NF02ZM0009).

However, it has recently been decommissioned. Water for the basin population is obtained from the St. John's Regional Water Supply System. Approximately 1/4 of the basin area is utilized for urban and sub-urban development, with housing, commerce, industrial, and etc. There is also a nursery located near the headwaters. The Atlantic Cool Climate Crop Research Centre, located on Brookfield Road, occupies approximately 74 hectares of land, 40 hectares of which are cultivated (Gov. of Newfoundland 2007), (Water Quality Station NF02ZM0009).

Waterford River at Bremigans Pond

The Waterford River at Bremigans Pond is located in Paradise. There is no urban or suburban development around the headwaters is the Trans-Canada Highway (Route 1) and some transmission lines.

South Brook at headwaters

South Brook starts in a marshy area south of Mount Pearl. This marshy area is within the Southlands subdivision.

Mundy Pond

Mundy Pond drains into Waterford River. There is light industry at various locations within this area, and the main of the area contains housing. The data is in (Water Quality Station NF02ZM0009)

3.6.3 The Quidi Vidi Lake System

Georges Pond

Georges Pond is near Signal Hill and drains into the opposite side of the Lake from Virginia River.

Virginia River

The mouth of Rennies River is located at King George V Memorial Park. Bannerman Park, Kelly's Brook Park and Wishing well Park are all located in the basin. There is a bacteriological monitoring and a chemical monitoring station at outlet. Numerous Rivers contribute to Quidi Vidi Lake.

Rennies River

Leary’s Brook joins Big Pond, Left Pond and Middle Pond, which are all located in Pippy Park, and these all from Rennies River. The river, the river then flows through a residential area and then into Quidi Vidi Lake and Quidi Vidi Harbour. The total length from the headwaters to the mouth of the Lake at Quidi Vidi Harbour is 14.7 km (Water Quality Station NF02ZM0009).

Kelly’s Brook at Portugal Cove Road

The headwaters of Kelly’s Brook is located south of Memorial University, and enters Rennies River. It flows through the midst of old St. John's where there is a poor sewage infrastructure. The river is culverted completely until it reaches Portugal Cove Road where it meets up with Rennies River. The distance from the headwaters to the sampling site is approximately 1.7 km.

http://www.canal.gov.nl.ca/root/main/station_details_e.asp?envirodat=NF02ZM0015

Sampling site NF02ZM0144 is the only sampling site on this river. Rennies River and Kellys Brook together drain into Quidi Vidi Lake. Quidi Vidi Lake drains into Quidi Vidi Harbour.

http://www.canal.gov.nl.ca/root/main/station_details_e.asp?envirodat=NF02ZM0177

Leary's Brook

Waters drains from Hummocky Marsh and Yellow Marsh forming Leary's Brook near the Avalon Mall. The river is then flows in a culverled underneath the mall parking lot. Water from the Oxen Pond, located in Pippy Park, also drains into the culverted. The river then flows through a developed area on the way to Long Pond (Water Quality Station NF02ZM0178 Profile).

Leary's Brook is culverted for approximately 0.5 km from the intersection of Prince Phillip Drive and Thorburn Road underground below the Avalon Mall and resurfacing between Kenmount Road and O'Leary Avenue just past the mall. There are storm sewer outfalls, swales and retention ponds constructed along the river. There is constant gravel removal at the intake of the culvert mentioned above and a steel trash rack at culvert inlet was installed. The Health Sciences Complex is located within the basin. The Avalon Mall and most of The O'Leary Industrial Park is located within the basin. Within this Industrial Park and along Kenmount Road there is a light industry. This includes construction and engineering, electrical power, materials handling, manufacturing, wholesale and retail industry for food & beverage, recycling, transport and storage, security and oil and gas business (Water Quality Station NF02ZM0178 Profile).

3.6.4 Petty Harbour System

Raymond Brook flows from Bay Bulls Big Pond and Middle Pond under Route 10 then joins Third Pond, Second Pond and First Pond, and flows into Petty Harbour (Water Quality Station NF02ZM0017 Profile).

Chapter 4: Modeling of the Water Supply System in the City of St. John's

4.1 Overview of the Study Area

As already mentioned, there are several watersheds in the City of St. John's area, in particular the Bay Balls Big Pond watershed is separate source for the watershed of the city of St. John's and mount pearl. The focus for the model in this study is Windsor Lake watershed.

In City of St. John's, rivers are not used for water supply source in both the domestic and industrial sectors. Groundwater use for domestic purposes is limited to only 550 households in total, in suburban areas. The contribution of ground water to the overall supply for the city and/or industry is negligible. The City's supply of groundwater is limited to only 5 households nearby the water quality monitoring station at Barton's Road. Almost all of the water supply comes from Windsor Lake after the treatment. After the treatment, the water is supplied to various regions and sectors. However, whenever required, especially in the case of a decline in the water level of Windsor Lake in the fall, water from the Broad Cove River watershed is pumped to Windsor Lake but never exceeding 20% of the Broad Cove River watershed volume. Figure 4.1 shows a schematic of the demarcated boundary of the city of St. John's area used in modeling the supply and demand of the available water resource using the WEAP software. Each naturally occurring component or feature in the water supply system is defined by a node element in the WEAP environment/interface. The supply and demand sites are modeled as nodes of appropriate type to represent any relevant real life feature. The supply side, thus, includes the Windsor Lake recharged primarily from the Broad Cove river watershed and secondarily from precipitation, and the Water Treatment Plant. The Broad Cove River/watershed and Windsor Lake have been modeled as reservoirs on the supply side. The Atlantic Ocean sink has been modeled as a catchment with runoff to a river. This strategy has been chosen as WEAP is incapable of modeling features such as Lakes and Ocean. The rest of the model elements or features have been modeled by using appropriate nodes as required and suggested in the software instructions. All the nodes are linked by appropriate transmission links in order to ensure the simulated flow of water from the supply side to the demand sites is in compliance with the model restrictions. In principle, each node is linked to a data file to be populated with the data of relevant sort.

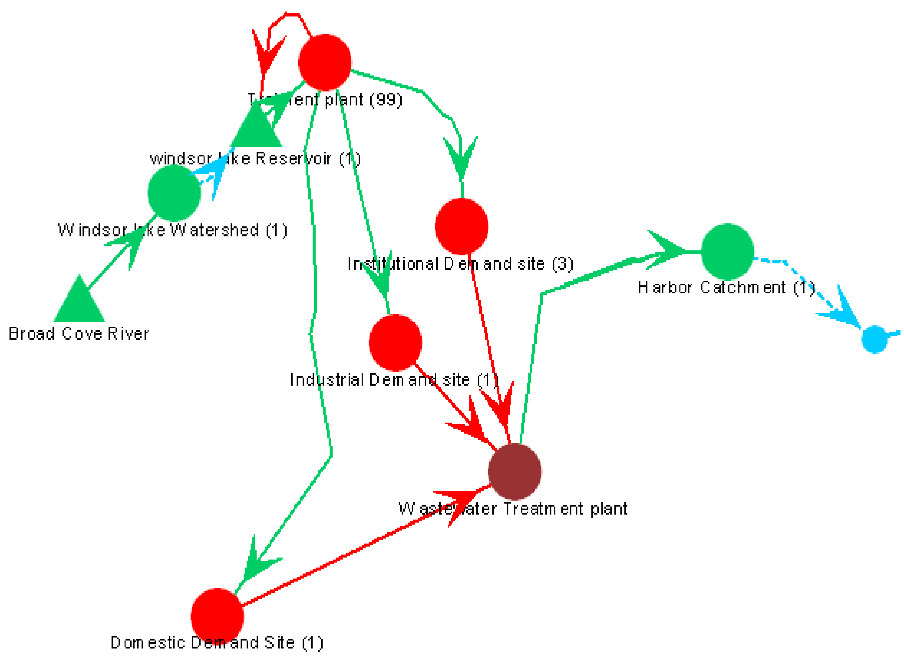

Figure 4.1 Schematic of the City of St. John's Model with various supply, demand and transmission features and data

4.1.1 Land Area and Population

This subsection is extracted from the City of St. John's Climate Change Action Plan 2006. The area of the City of St. John's is 446.04 km^2 (172.22 sq. miles) (Statistics Canada, 2006 Census) while the population of St. John's is approximately 100,646 (Statistics Canada, 2006 Census). This population includes all the individuals irrespective of gender and age, and each individual's contributory interactive effect in relation to water supply and demand is taken as equivalent. Built from the edges of its harbor, residential and commercial properties are scattered throughout the hilly and rocky landscape. As the center for business, research, education and government for the province, St. John's is the second largest metropolitan area in Atlantic Canada and is home to approximately one-third of the province's population. It is a place where old world traditions mingle with 21st century creativity and innovation. From the early days as a commercial trading outpost to the recent offshore oil industry, St. John's has become a thriving, modern city with world-class facilities and services. St. John's is part of a larger of group of municipalities sharing facilities including the Robin Hood Bay Landfill. The landfill is used by the regional group, and while the climate change action plan is only for St. John's, the waste management strategies will also affect the regional group in a positive manner.

4. 1.2 Demographics

The population of St. John's decreased by 2.7% between 1996 and 2001, with an increase in the number of dwellings by 4.0% (Statistics Canada, 2001). Over the last census period

(2001—2006) the population of the City of St. John's increased by 1.5% to 100,646. The population of the St. John's metro area is estimated to have grown by 0.4% in 2007 and now stands at 184,194. The median age of the population in the metro area in 2006 was 38.4 and 83.8% were aged 15 and over. There were 75,860 private dwellings in the St. John's metro area (Gov. of NL, and Statistics Canada, 2006).

As mentioned above, the growth rate of the population of the City of St. John's was recently 1.5%. Based on this three population growth rates have been used in the model as scenarios, 1.5%, 2%, 3%, as low, medium and high rates as shown in Tables 4.1, 4.2 and 4.3 respectively.

Table 4.1 Yearly population estimates for first scenario (Growth rate = .015)

Year	Increment Multiple	Yearly Increment	Population
2000	0	0	100646
2001	0.015	1509.69	102155.7
2002	0.03	3019.38	103665.4
2003	0.045	4529.07	105175.1
2004	0.06	6038.76	106684.8
2005	0.075	7548.45	108194.5
2006	0.09	9058.14	109704.1
2007	0.105	10567.8	111213.8
2008	0.12	12077.5	112723.5
2009	0.135	13587.2	114233.2
2010	0.15	15096.9	115742.9
2011	0.165	16606.6	117252.6
2012	0.18	18116.3	118762.3
2013	0.195	19626	120272
2014	0.21	21135.7	121781.7
2015	0.225	22645.4	123291.4
2016	0.24	24155	124801
2017	0.255	25664.7	126310.7
2018	0.27	27174.4	127820.4
2019	0.285	28684.1	129330.1
2020	0.3	30193.8	130839.8
2021	0.315	31703.5	132349.5
2022	0.33	33213.2	133859.2
2023	0.345	34722.9	135368.9
2024	0.36	36232.6	136878.6
2025	0.375	37742.3	138388.3
2026	0.39	39251.9	139897.9
2027	0.405	40761.6	141407.6
2028	0.42	42271.3	142917.3
2029	0.435	43781	144427
2030	0.45	45290.7	145936.7

Table 4.2 Yearly population estimates for second scenario (Growth rate = .02)

Year	Increment Multiple	Yearly Increment	Population
2000	0	0	100646
2001	0.02	2012.92	102658.92
2002	0.04	4025.84	104671.84
2003	0.06	6038.76	106684.76
2004	0.08	8051.68	108697.68
2005	0.1	10064.6	110710.6
2006	0.12	12077.52	112723.52
2007	0.14	14090.44	114736.44
2008	0.16	16103.36	116749.36
2009	0.18	18116.28	118762.28
2010	0.2	20129.2	120775.2
2011	0.22	22142.12	122788.12
2012	0.24	24155.04	124801.04
2013	0.26	26167.96	126813.96
2014	0.28	28180.88	128826.88
2015	0.3	30193.8	130839.8
2016	0.32	32206.72	132852.72
2017	0.34	34219.64	134865.64
2018	0.36	36232.56	136878.56
2019	0.38	38245.48	138891.48
2020	0.4	40258.4	140904.4
2021	0.42	42271.32	142917.32
2022	0.44	44284.24	144930.24
2023	0.46	46297.16	146943.16
2024	0.48	48310.08	148956.08
2025	0.5	50323	150969
2026	0.52	52335.92	152981.92
2027	0.54	54348.84	154994.84
2028	0.56	56361.76	157007.76
2029	0.58	58374.68	159020.68
2030	0.6	60387.6	161033.6

Table 4.3 Yearly population estimates for third scenario (Growth rate = .03)

Year	Increment Multiple	Yearly Increment	Population
2000	0	0	100646
2001	0.03	3019.38	103665.38
2002	0.06	6038.76	106684.76
2003	0.09	9058.14	109704.14
2004	0.12	12077.52	112723.52
2005	0.15	15096.9	115742.9
2006	0.18	18116.28	118762.28
2007	0.21	21135.66	121781.66
2008	0.24	24155.04	124801.04
2009	0.27	27174.42	127820.42
2010	0.3	30193.8	130839.8
2011	0.33	33213.18	133859.18
2012	0.36	36232.56	136878.56
2013	0.39	39251.94	139897.94
2014	0.42	42271.32	142917.32
2015	0.45	45290.7	145936.7
2016	0.48	48310.08	148956.08
2017	0.51	51329.46	151975.46
2018	0.54	54348.84	154994.84
2019	0.57	57368.22	158014.22
2020	0.6	60387.6	161033.6
2021	0.63	63406.98	164052.98
2022	0.66	66426.36	167072.36
2023	0.69	69445.74	170091.74
2024	0.72	72465.12	173111.12
2025	0.75	75484.5	176130.5
2026	0.78	78503.88	179149.88
2027	0.81	81523.26	182169.26
2028	0.84	84542.64	185188.64
2029	0.87	87562.02	188208.02
2030	0.9	90581.4	191227.4

4.2 Data Acquisitions and Preparation

The Following is an explanation of the data organization and supply and demand features modeled by the WEAP.

4.2.1 Consumption Rate

The consumption rates for each activity shown in **Table 4.4** were assigned to the real consumption input, providing a real picture for each consuming sector. The following table contained the Data provided by the city for current consumption in three demand sectors, which have not changed significantly from 2000 to 2009, with more or less constant population in this period. Scenarios with population growth are examined in this thesis as follows.

Table 4.4 Water Consumption in City of St. John's

activity	Amount*		Water Consumption M^3/year
Domestic**	306	L/day	13,408,563
Institutional**	43,500	L/ha	5,000,000
Commercial/ Industrial**	31,000	L/ha	10,000,000
Total			**28,470,000**

*Source: Windsor lake operation management and City Hall data (2009).
** Data are assumed

Assumptions were made for the use rates for each sector as in table 5.4, based on City hall data and Windsor lake operation .These rates have been assumed to be constant throughout the period modeled. However, changes in use rates (i.e. changes in losses) can be readily introduced in the model, e.g. if improvements to system are envisaged. The total domestic consumption data in the above table was provided by Windsor Lake plant management. The amount of water consumption for commercial, industrial and instructional sites is assumed to be the difference between the overall total consumption and the total of any other known consumption.

4.2.2 Windsor Lake

Windsor Lake and Broad Cove watershed are modeled as nodes in the WEAP; the necessary data is taking from the report of Kavanagh & Associate Limited 1996 and Newfoundland Design Association 2007, where available as in table 4.5, 4.6, 4.7

Table 4.5 Windsor Lake Characteristics

Capacity	33 million gallons per inch of depth
Protected watershed	15 square kilometers
surface area	5 square kilometers
Average daily City consumption	38.5 ML/ day

Source: Windsor lake operation management and City Hall data (2009).

Table 4.6 Windsor Lake and Broad Cove Reservoir s

	Inflow Cubic Meter per Second (CMS)	Storage Capacity (Million M^3)	Initial Storage (Million M^3)
Windsor lake Reservoir	1.6	50	
Broad Cove Reservoir		37.9	10

Source: Windsor lake operation management and City Hall data (2009).

4.3 Parameters in the WEAP

The Software allows for three methods to define the projection of the groundwater and surface water hydrology over the study period as follows:

1) The Water Year Method: It is an in-built model in the WEAP that allows the predictions of hydrological variables based on the analysis of historical inflow data. It uses statistical analysis to identify coefficients, which are used to replace the real data for future projection.
2) Read from File Method: If monthly data on inflows to some or all of the rivers and local supplies are available, then the Read from File Method allows the system to be modeled using this sequence of real inflow data.
3) Expressions: If any equation can explain a physical or evolutionary problem required in the WEAP analysis, this equation can be entered.

4.3.1 Inputs Parameters WEAP

As mentioned before the Windsor Lake and Broad Cove watersheds are modeled as node reservoirs using the data in Table 4.7.

Table 4.7 Broad Cove River reservoir

Watershed	Area (km^2)	Depth (m)	Volume (m^3)	Reliable Yield (m^3)
Broad Cove River*	20.7	1.83	37.9 x10^6	55,500
Windsor Lake	5	10	50,000,000	41,700

*Inflow 18 mil liter daily = 1.6 cubic million liter/second
(Source: Windsor lake operation management (2009).

Annual use rates and priorities have been assigned in the model as in table 4.8 and 4.9

Table 4.8 Demand Site and Catchment

	Annual Activity Level Year 2000 (m^3)	Annual Water Use Rate Year 2000*	Priority**
Treatment Plant	28,470,000	.99	1
Institutional Demand Site	5000,000	.8	1
Industrial Demand Site	10,000,000	.9	1
Domestic Demand site	13,386,000	.75	1

The basin is mostly residential with some light industry and commercial areas.
*Annual use rates: the percentage of consumption by demand
** Priorities: 99 is the highest priority level, 1 is the lowest priority level

Table 4.9 Priority Levels for Demand

Demand Type	Priority Level*
Broad Cove Watershed (local Reservoir)	99
Windsor lake watershed (local Reservoir)	1
Windsor lake reservoir	1
Treatment Plant	99
Intuitional demand site	3
Industrial Demand Site	1

* 99 is the highest priority level, 1 is the lowest priority level.

4.4 Recharge to the Windsor Lake

The main sources of recharge for Windsor Lake Watershed is the creeks, which flow from the other ponds located within the bounds of the watershed (probably not very significant), and the Broad Cove River watershed when being drained towards Windsor Lake, which, in a typical year, accounts for approx. 20 - 25% of the time with the majority of this time in the fall (Sept-Dec). Groundwater and precipitation is a significant factor of regeneration. Historically, the lake levels are closely related to precipitation amounts throughout the year. The lake surface accounts for 1/3 of the entire watershed, so all of that precipitation is directly added to the lake. During the late fall and over the winter, the lake has usually fully rebounded to the full level. In fact, the lake usually overflows its drainage dam over most of the spring season (Apr-May). Past records show that the greater the amount of snowfall during the winter, the longer the lake maintains its full level into the summer.

The water stored in the snow helps to continuously recharge the lake during the usually wet spring when the ground is saturated. If temperatures do not increase too rapidly, there will remain a significant amount of snow within the forests that surround the lake long after when most snow has already melted elsewhere. The fluctuation of water level in WL Pond Lake is presented in the table 4.10 in the period of 2005 to 2009.

Table 4.10 Water levels in the Windsor Lake (inch)

Month	Years			
	2005	**2006**	**2007**	**2008**
Jan	1	3.0	-10.0	-13.0
	0	9.0	-8.0	-12.0
	0	9.0	-6.5	-12.0
	0	8.0	-4.0	-11.0
Feb	1	7.0	-2.0	-7.0
	1	8.0	-1.5	-7.0
	2	8.0	-3.0	-5.0
	10	7.0	-3.0	-1.0
Mar	9	6.0	-3.5	-0.5
	8	6.0	-3.0	0.0
	4	6.0	-3.0	1.0
	9	6.0	-2.0	5.5
	9	3.0	-1.5	5.5
Apr	11	2.5	-0.5	3.5
	12	7.0	-1.5	5.0
	13	10.0	-1.5	9.0
	9	16.5	0.0	8.0
May	7	15.0	1.5	13.0
	6.5	9.0	4.0	13.0
	6	7.0	4.5	11.0
	8.5	5.5	4.5	9.0
June	8.5	4.5	3.0	6.5
	6	2.0	2.0	7.0
	6.5	1.0	0.0	5.0
	4.5	0.5	-3.0	4.5
	3	-3.0	-3.5	2.0
July	1.5	-4.0	-7.5	0.5
	-1	-8.0	-7.0	-3.0
	-3	-10.0	-9.0	-5.5
	-5	-13.5	-10.0	-7.0
Aug	-7.5	-16.0	-12.5	-8.0
	-10	-19.0	-7.5	-9.0
	-13.5	-18.0	-7.5	-8.5
	-16	-21.0	-8.5	-11.0

	-12	-23.0	-11.0	-14.0
Sept	-12.5	-22.5	-14.0	-16.0
	-13.5	-23.25	-17.0	-16.5
	-14	-22.0	-19.5	-19.5
	-12.5	-23.5	-24.0	-23.5
Oct	-14.0	-25.0	-24.5	-26.0
	-14.5	-26.0	-28.0	-29.0
	-10.0	-27.0	-29.0	-31.0
	-10	-27.0	-28.0	-29.0
Nov	-7	-23.5	-29.0	-30.5
	-5.5	-22.0	-30.0	-32.0
	-2.5	-21.0	-25.0	-34.5
	-2.5	-20.0	-25.5	-30
Dec	-2.5	-21.0	-20.5	-22
	-2	-21.0	-15.5	-15
	-0.5	-14.0	-11.0	-6
	2	-12.0	-11.5	-7
	3	-12.5	-13.0	-5

Source: Windsor lake operation management and City Hall data (2009).

4.5 The WEAP Model Key Assumptions

Demand has been loosely divided and defined into three sectors namely domestic, industrial and institutional. The domestic sector represents all the households and the corresponding population, with its contribution in the model a portion of the total consumer population. The rest of the demand or consumer domain, for sake of model development and data use, is bifurcated into industrial and institutional sectors. The industrial sector includes all sorts of production and fabrication units requiring a certain water supply while the institutional sector includes all the public and community entities and services. The waste water from the demand sites is rejected into the harbor in the Atlantic Sea via a well-developed sewerage system. For clarity and appropriate understanding the Figure 4.1 could be examined in connection with the Table presenting the details of various demand and supply side features or model components.

4.6 The WEAP Definitions

4.6.1 Convention and Definition

The parameters used in WEAP are defined as follows. Some have not been used in this thesis. The following definitions below are quoted literally from the WEAP documentation by (Sieber, 2009).

Water Demand

"The requirement at each demand site, before distribution losses, reuse and demand-side management saving are taken into account".

Supply Requirement

"The requirement at each demand site, after distribution losses, reuse and demand-side management saving are taken into account".

Supply delivered

"The amount of water supplied to demand sites, listed either by source (supplies) or by destination (demand sites). When listed by destination, the amounts reported are the actual amounts reaching the demand sites, after subtracting any transmission losses" (WEAP Demand Result).

Unmet Demand

“Amount of each demand site's requirement that is not met. When some demand sites are not getting full coverage, this report is useful in understanding the magnitude of the shortage.” (The WEAP Demand Result)

Coverage

“The percent of each demand site’s requirement (adjusting for distribution losses, reuse and demand-side management savings) that is met, from 0% (no water delivered) to 100% (delivery of full requirement). The coverage report gives a quick assessment of how well demands are being met.” (The WEAP Demand Result)

Demand Site Inflow and Outflow

“The mass balance of all water entering and leaving one or more demand sites. Inflows (from local and river supplies) are represented as positive amounts, outflows (either consumed or routed to wastewater treatment plant, rivers, groundwater nodes and other supplies) as negative amounts.” (The WEAP Demand Result)

In-stream Flow Requirement

“The prescribed minimum flow requirement (given in units of a volumetric flux) for social or environmental purposes.” (The WEAP Demand Result)

Unmet In-stream Flow Requirement

“The different between the in-stream flow requirement and the amount actually delivered.” (The WEAP Demand Result)

In-stream Flow Requirement Coverage

“The ratio of the amount delivered divided by the flow requirement.” (The WEAP Demand Result)

Inflow to Area

“Water entering the system (river head flow, surface water inflows to reaches, ground water recharge, local reservoir inflows, other local supply inflows, and catchment precipitation” (The WEAP Demand Result)

Outflow to Area

“Water leaving the system (consumption at demand sites, catchment evapotranspiration (ET Actual, evaporation on river reaches and reservoirs, losses in transmission links, groundwater and local reservoir overflow, losses in waste treatment, and outflows from the end of rivers and diversions that do not flow into other rivers).” (The WEAP Demand Result)

Rivers

“Stream flow: The stream flow at selected nodes and reaches along a river. You can plot a curve for each point on the river over time (choose Year for the X Axis), or a curve for each month plotted along the river (choose River Nodes and Reaches for the X Axis).” (The WEAP Demand Result)

Stream Flow Relative to Gauge (absolute):

“The absolute difference between simulated stream flow at selected nodes and reaches along a river compared to stream flow gauge data (measured stream flow).” (The WEAP Demand Result)

Stream flow Relative to Gauge (%): "The simulated stream flow expressed as a percent of stream flow indicated by stream flow gauge data (measured stream flow)." (The WEAP Demand Result)

4.7 Model Calibration

The calibration for the model is done by comparing data for a year after that chosen for current account with a projection to that date, this is not possible her as that kind of details is not available for all parameters used. For instance, Precipitation data is available for every year and this can match to measured water level of Windsor Lake and pumping from Braod Cove River watershed 2005-2009. However, that kind of detail was not available for consumption.

4.8 Results & Discussions

The model structure and data outlined in the previous sections have been applied, with results described in the following, in this chapter, out of various types of the WEAP outputs generated, only those have been selected which would best represent the situation under examination or consideration i.e. water supply and demand analysis in relation to population variation. The effect of population changes on domestic demand has been modeled. Commercial, Industrial, and Institution demands have been assumed to be constant, as little or no data on future trends in these sectors are available. However, those components can be easily included, given appropriate data.

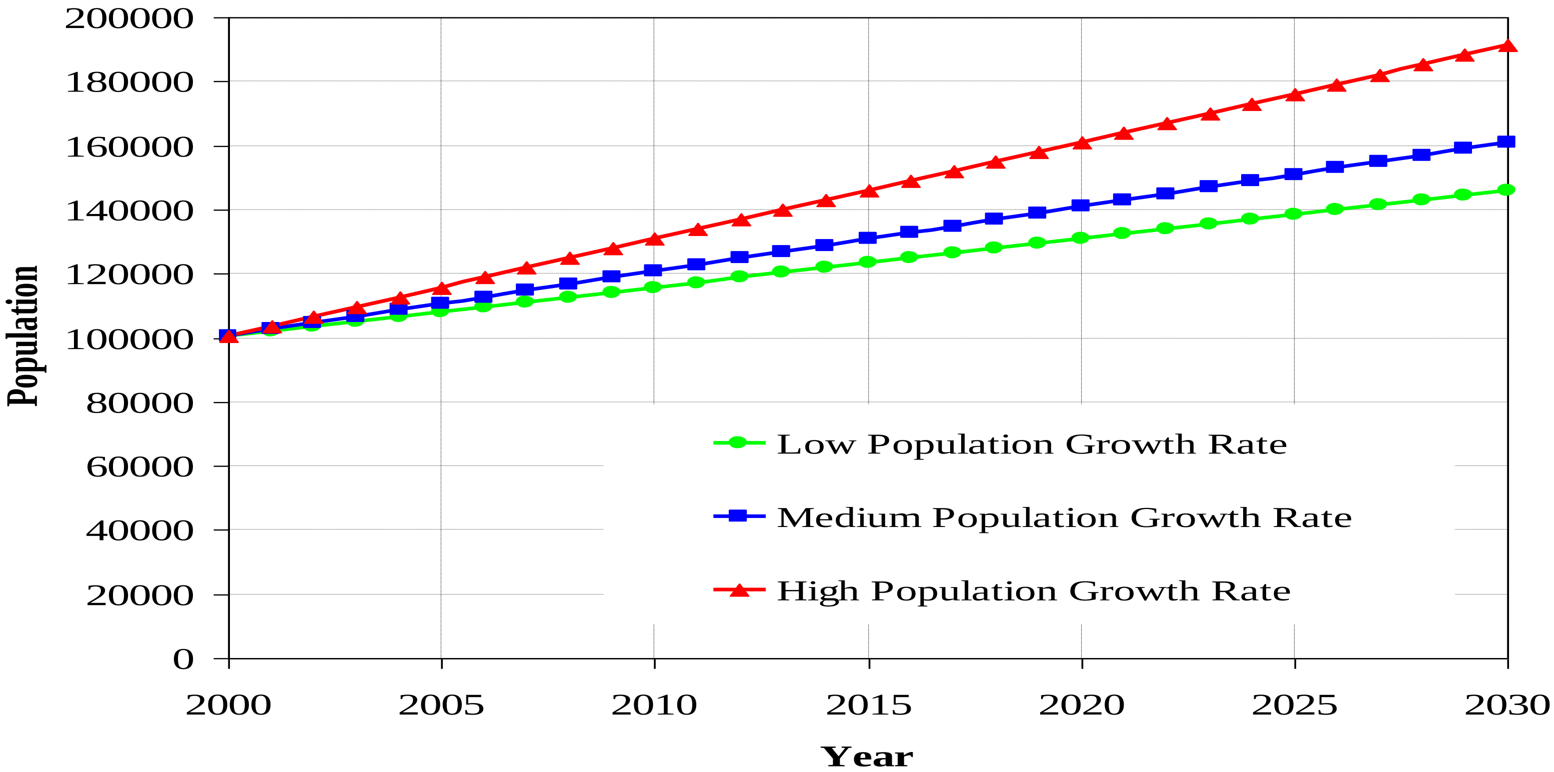

Figure 4.2 Overall unmet yearly demand variation with population growth

Understanding the nature of the seasonal variation in the unmet demand is one important aspect of this analysis. The City of St. John's is already pumping up to 1.8 m^3 daily from Braod Cove River watershed into Windsor Lake at certain time of the year, especially from May to December, meeting such an unmet demand. Figures 4.2 up to Figure 4.4 represent such a variation. Figure 4.1 shows a yearly variation covering the scenario period considered from year 2001 as a current account until 2030. The quantity on the Y-axis has the units thousands of cubic meters. For the curves, identified in the legend, for population growth low, medium and high, the corresponding slopes become steeper for successive scenarios with increasing population growth rates.

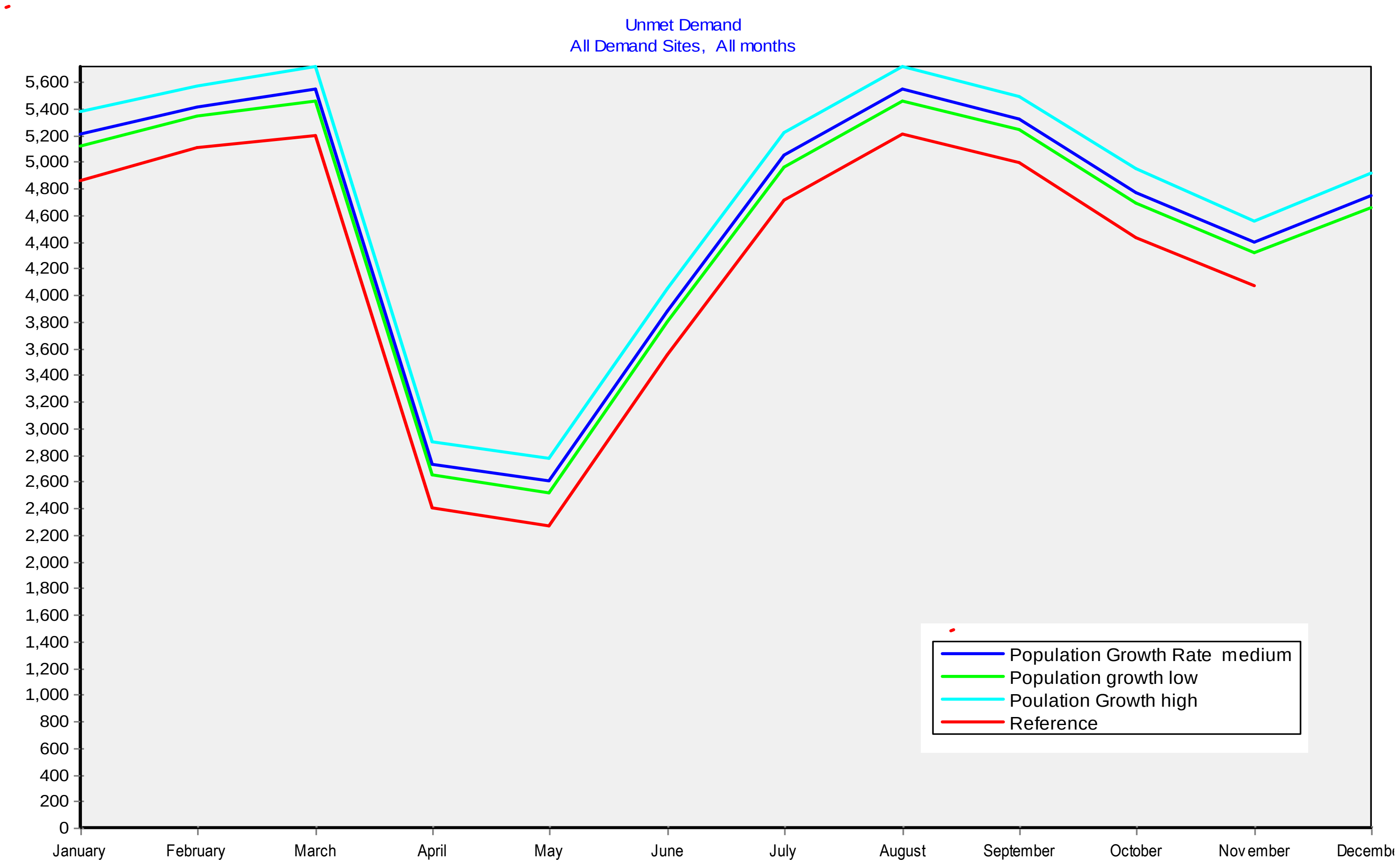

Figure 4.3 Overall monthly unmet demands for all months as an average over thirty years

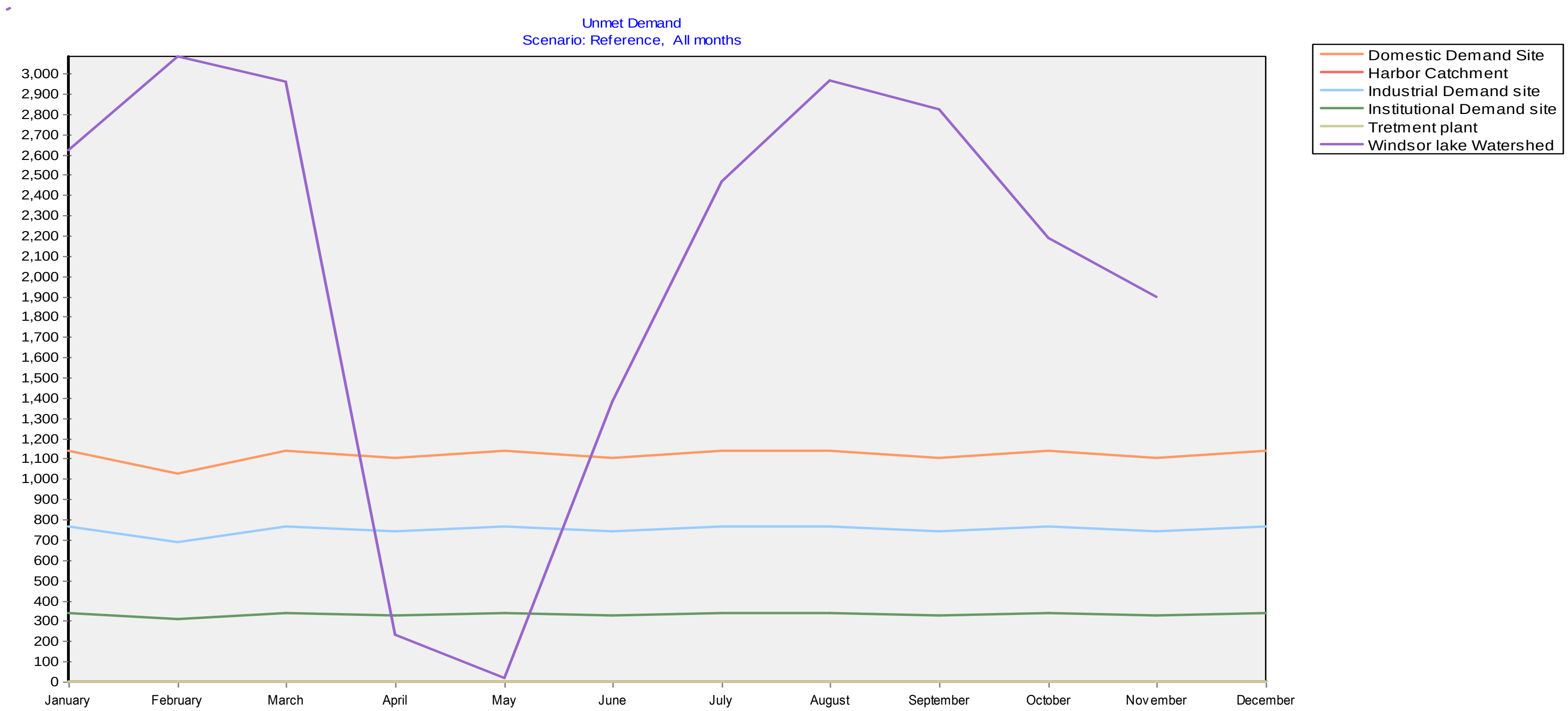

Figure 4.4 Reference Overall unmet demands per sector for all months in a years (2001-2030)

The reference is the current population or zero population growth. Since the population variation chosen in the model is linear; the unmet demand variation also depicts a linear trend, with all other factors unaltered. A closer examination of Figure 4.2 shows that with the an increase in population growth rate the elevation rate of water demand also goes up; furthermore it is clear that the initial difference among the population growth rates, for any given scenario selected for the analysis, might not produce significant effect upon the corresponding variation of unmet demand in short term. However, with the expansion of time horizon, even a slightly higher population growth rate results in a significant increase of the unmet water demand.

Figures (4.3 and 4.4) show similar variation trends from the perspective of a monthly average. Figure 4.3 shows an average over thirty years with per sector over a year in Figure 4.4. In Figure 4.3 a comparison among the unmet demands of all demand sites is drawn, as well as the reference. In Figure 4.4 the difference between three sectors and the monthly varying reference is plotted.

From the information presented in Figures 4.4- 4.7, a similar unmet demand variation of water supplies as a monthly average, within the selected time horizon, with respect to the demand for a particular scenario which is taken as a so-called “datum” or zero. The negative numbers on the Y-axis would represent a surplus, if the supply meets the assumed reference demand. In Figure 4.5 the reference is a low population growth rate; while references of medium and high population growth rates are used in Figures 4.6 and 4.7, respectively. The three figures depict similar patterns, as if the curves have been shifted along the Y-axis. Meanwhile, Figures 4.6 and 4.7 indicate an unmet demand variation that is a monthly variation over the selected time horizon. Figures 4.9 and 4.10 show the similar variation trends on a yearly basis with the time span selected (i.e., yearly comparison of unmet demands with respect to that of any given population scenario).

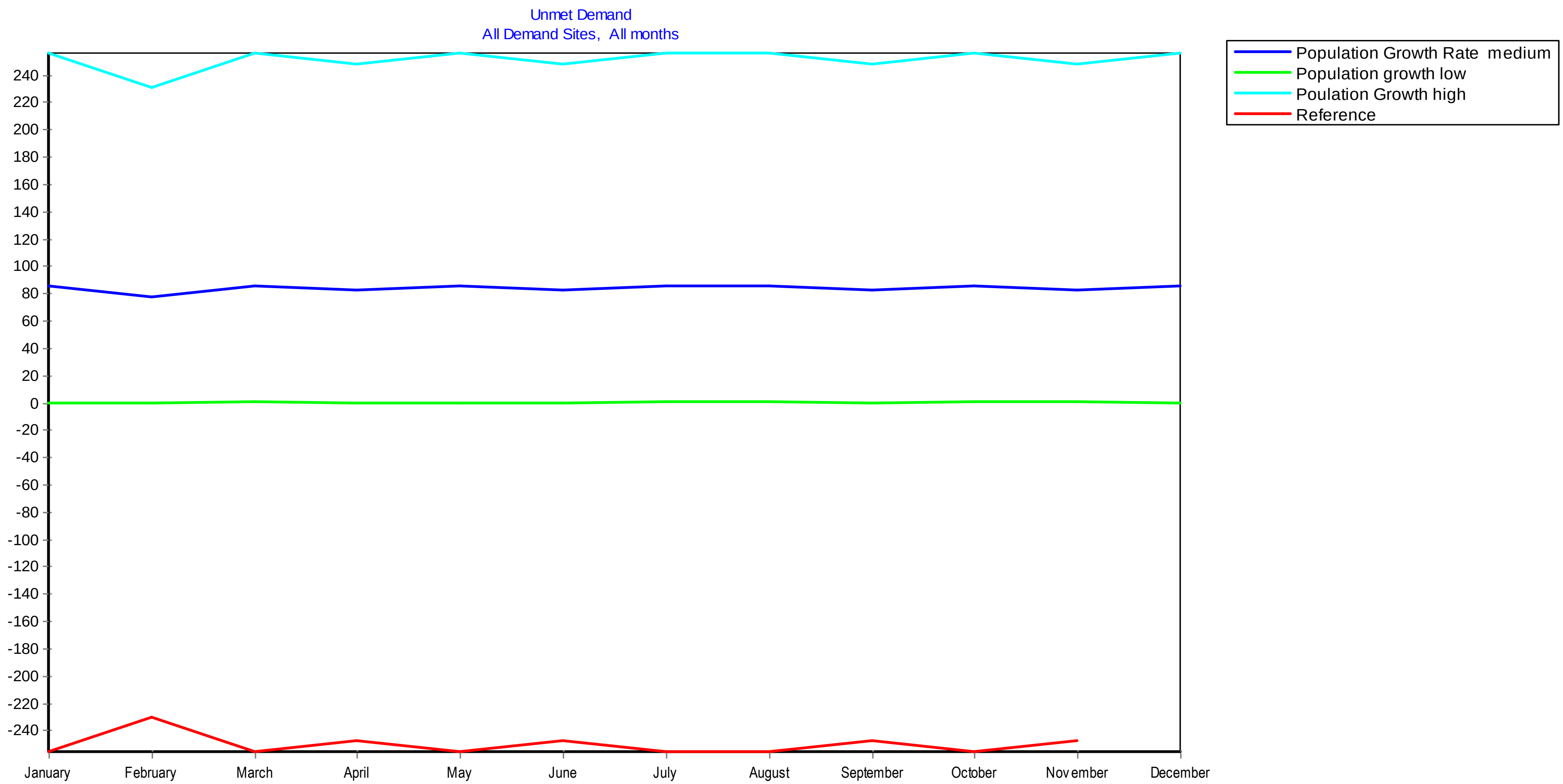

Figure 4.5 Unmet demands for all demand sites with demand at low Population growth as datum.

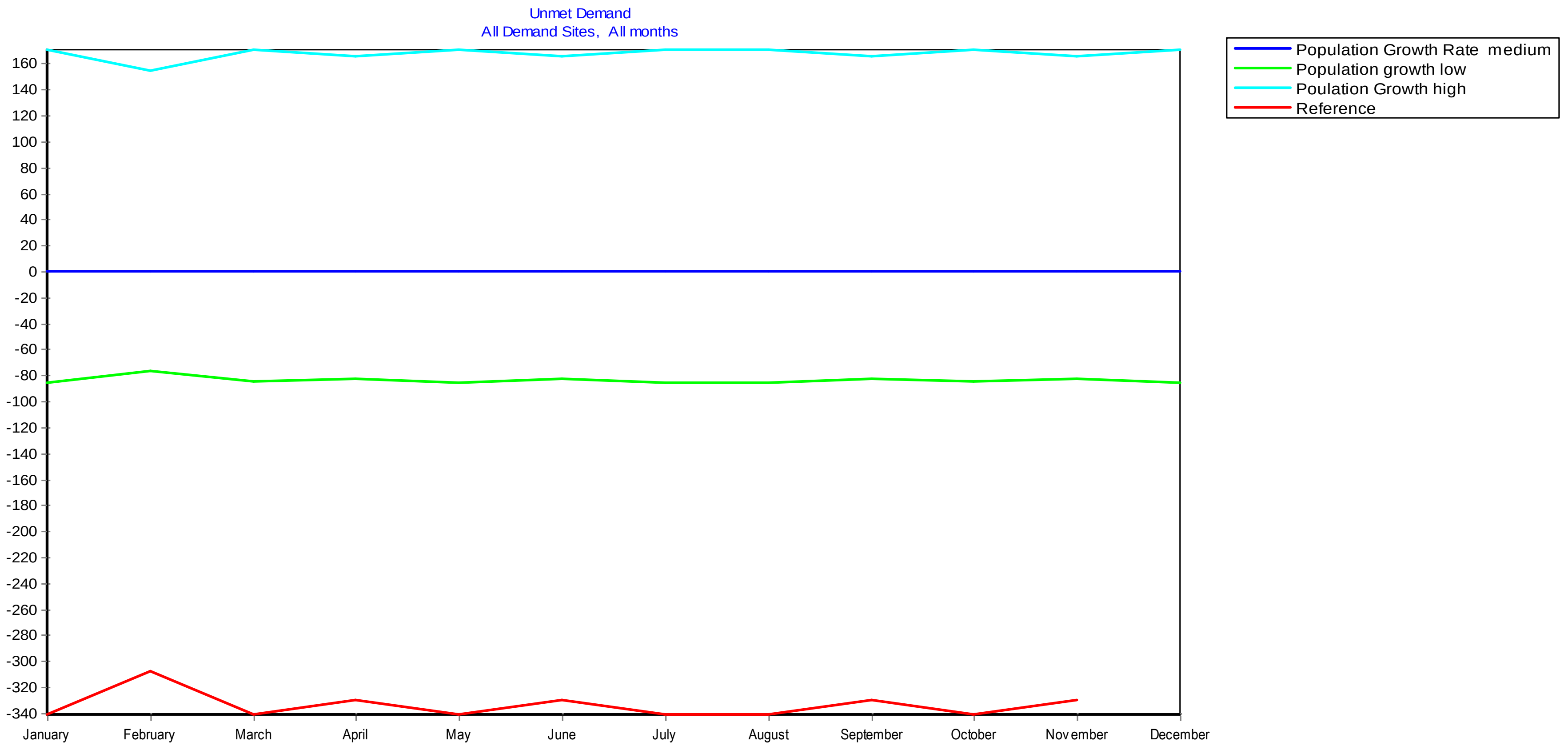

Figure 4.6 Unmet demands for all demand sites with "datum" as unmet demand at low population growth

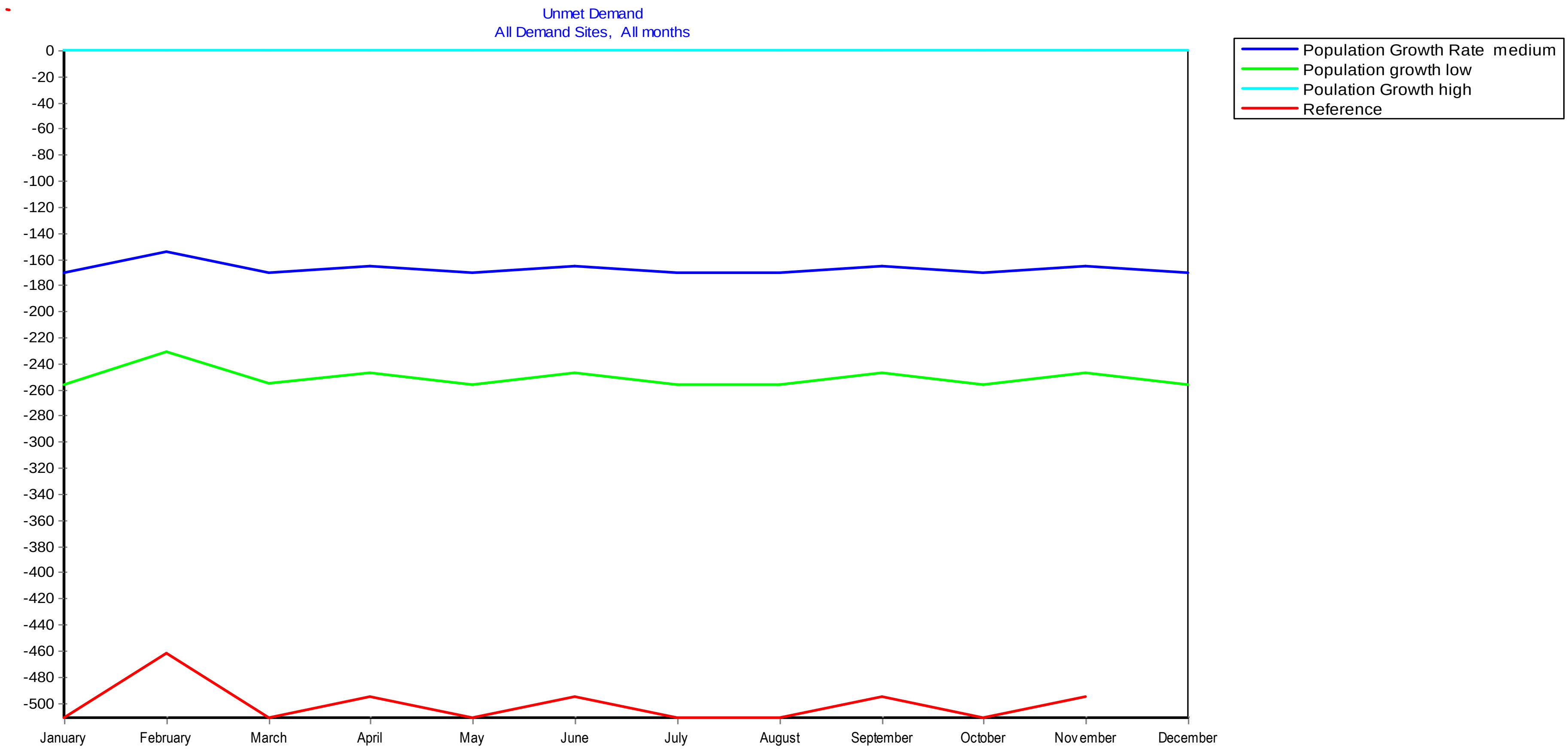

Figure 4.7 Unmet demands for all demand sites with "datum" as unmet demand at high population growth

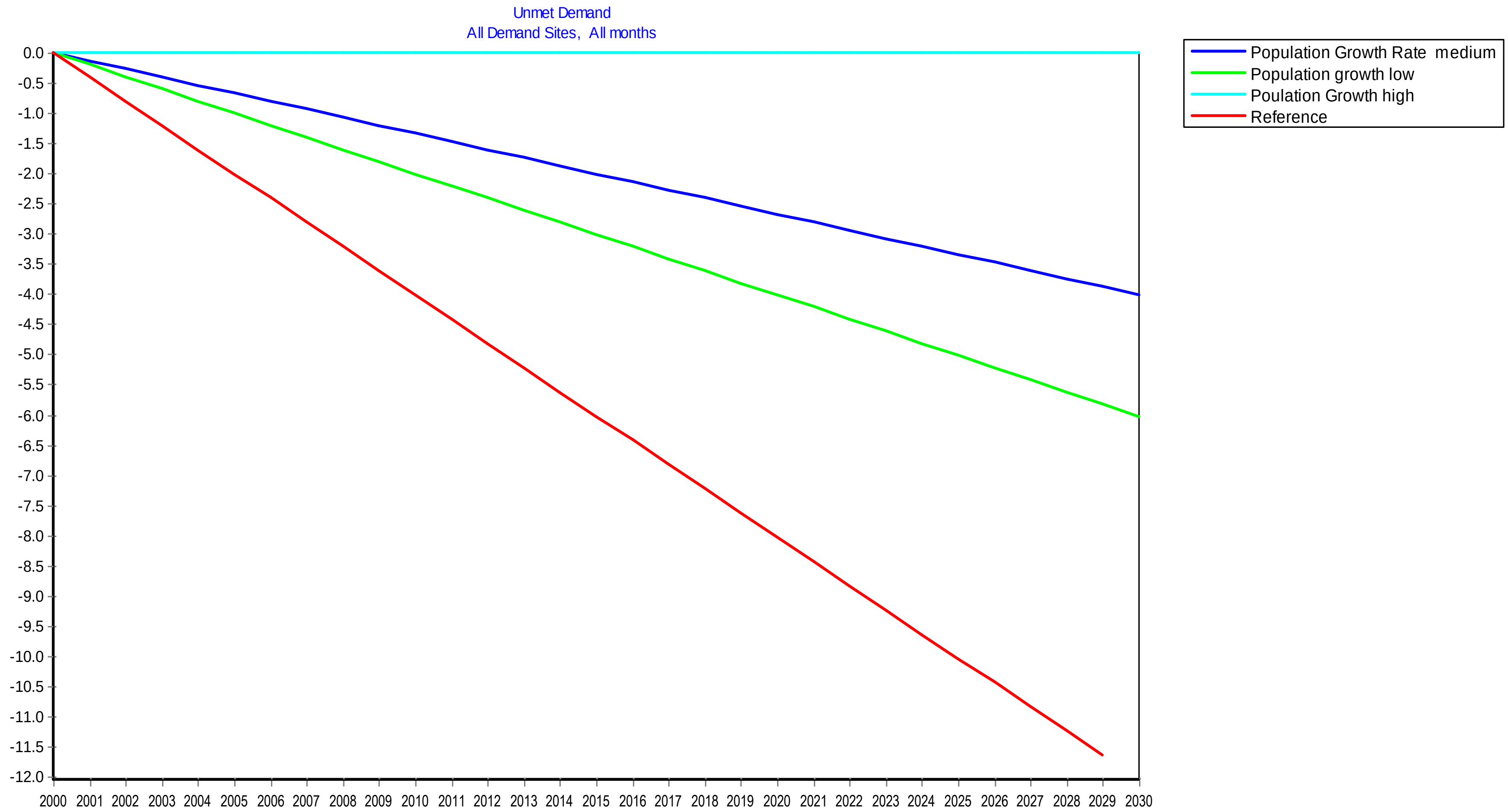

Figure 4.8 Unmet yearly demands for all demand sites with "datum" as unmet demand at high population growth rate

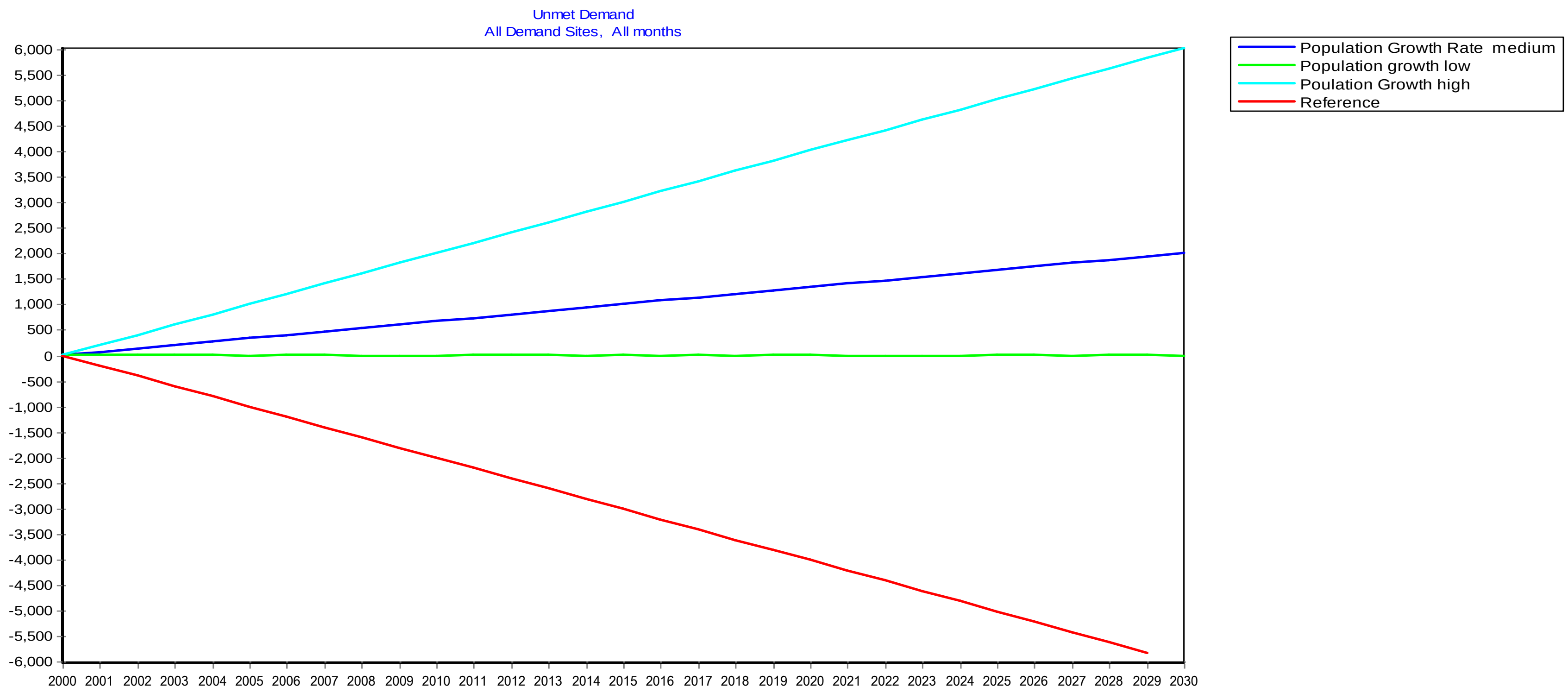

Figure 4.9 Unmet yearly demands for all demand sites with “datum” as unmet demand at medium population growth

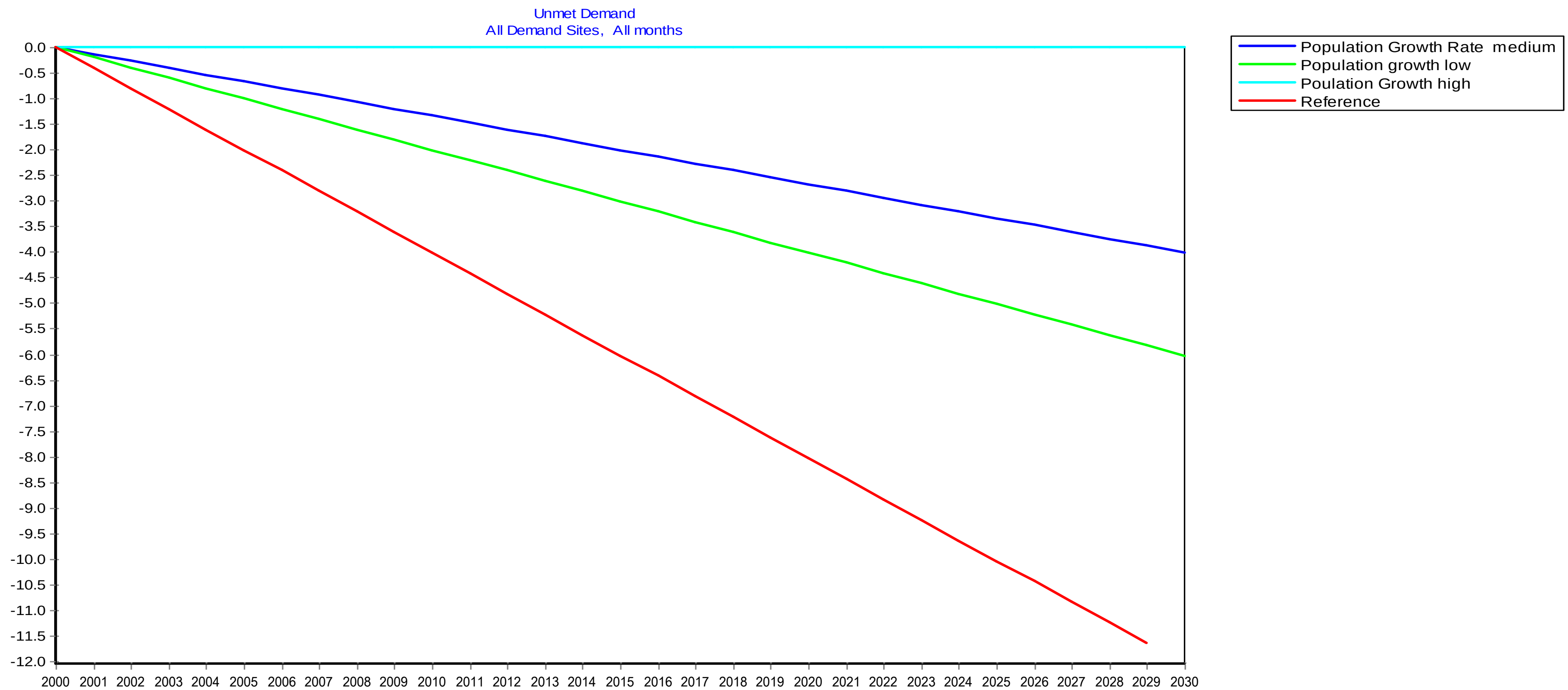

Figure 4.10 Unmet yearly demands for all demand sites with “datum” as unmet demand at high population growth

One of the key purposes of this study is to understand and examine the suitability of the WEAP tool for successful application of its features for the water supply system in St. John's in a broader sense, and to show that it is feasible to apply "what if" scenarios. The results for various scenarios might look insignificant due to the assumptions made and limited available data, but the results are acquired and explained reasonably thoroughly as applied rigorously. It is important that the results should be interpreted and understood in the light of the various "definitions" described in the previous sections. The focus has been on a broad approach rather than examining various features individually. Figures 4.11 to 4.15 present the analysis from the perspective of supply requirements with time. Figures 4.11 shows a supply requirement variation for all scenarios in general as a monthly average for the total period considered, relevant to a reference situation as datum. It is clear as examined in the previous figures from an unmet demand perspective that a population increase would require a corresponding increase in the supply requirement with the requirement being higher in the winter season of various years, as noted in the previous analysis. Figure 4.12 shows the overall variations in supply requirement during the period considered with respect to the reference. It is obvious from the slopes of the curves that the higher the population growth rate the higher the supply requirement with the rate of requirement also climbing for the successive years. The rest of the figures (i.e., Figures 4.12 to 4.14) depict a similar notion of variations in supply requirements but with low, medium and high population growth rates situations taken as datum reference respectively.

As it is observable in Figure 4.15 that if all the supply requirements are supposedly met for a high population growth rate scenario, then there would be surplus supplies for the other scenarios.

More useful and practical way of looking at such figures showing the results in the context of a “what if” situation is to demonstrate that the developed system provides an understanding of the required rates of increase or decrease, in connection whatever ensuing measures be taken, of the supplies with population increase tied with the time.

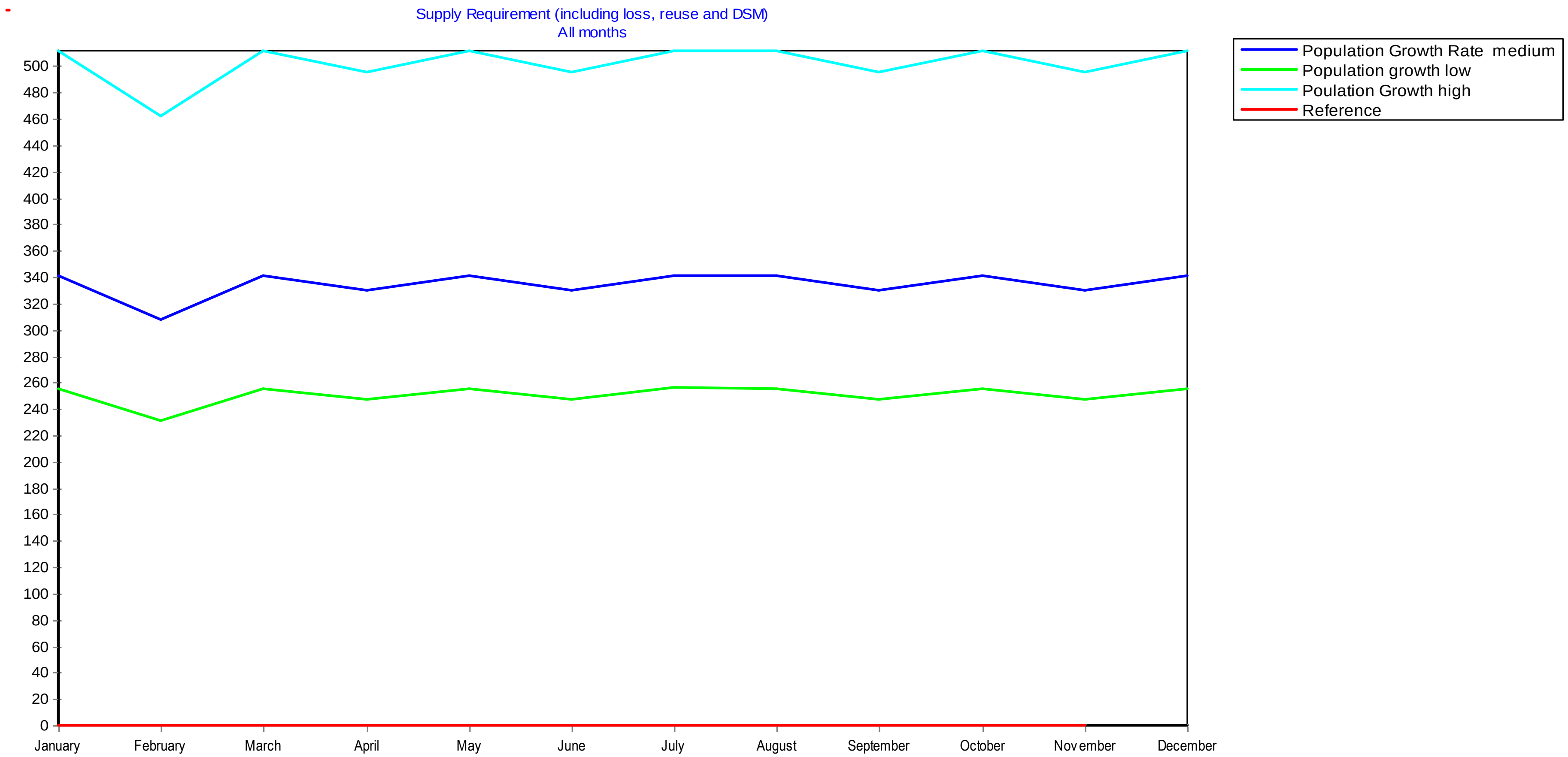

Figure 4.11 Supply requirements overall compared to reference as a monthly average for the year (2001-2030)

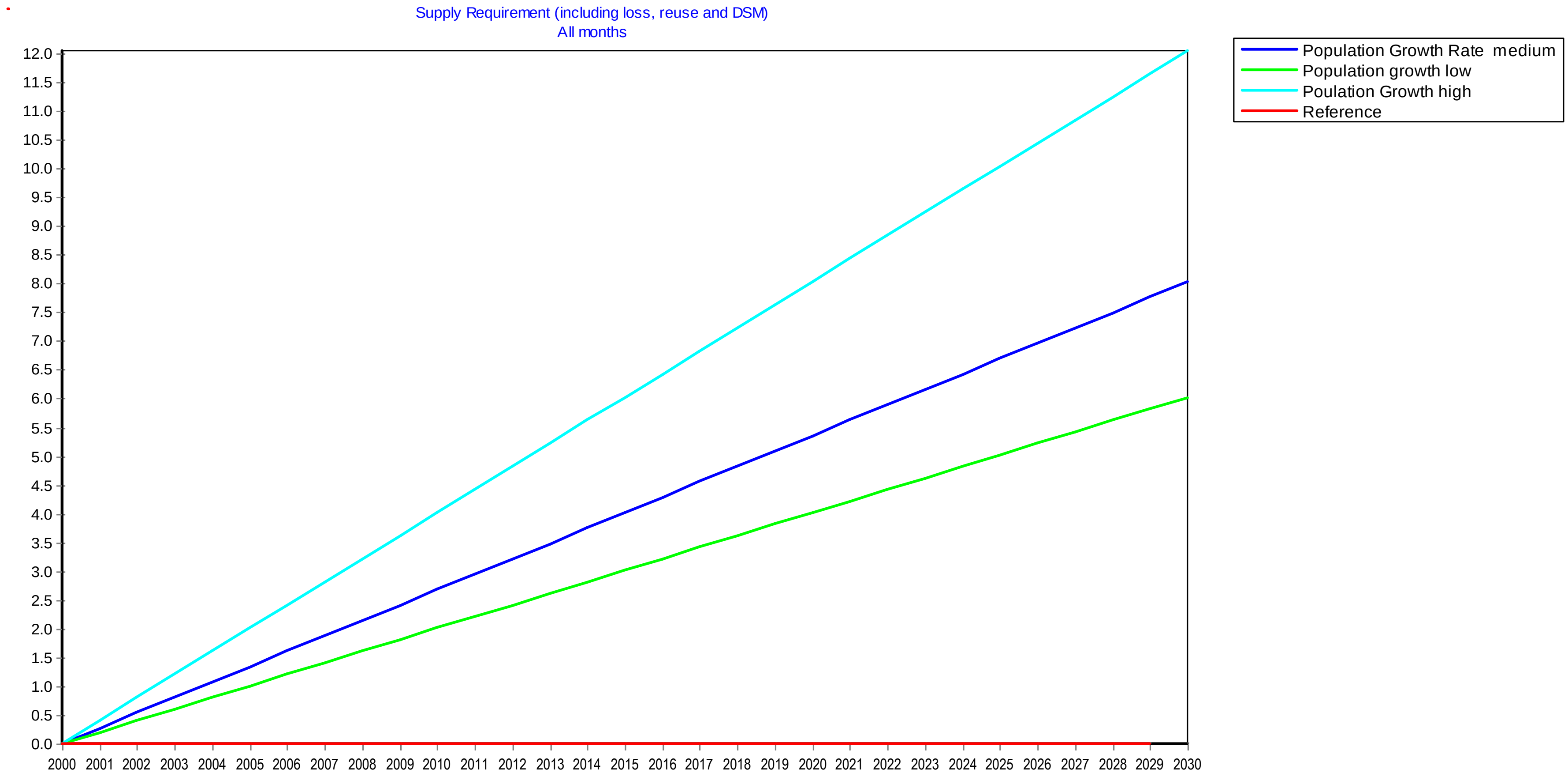

Figure 4.12 Supply requirements variation overall with “datum” as reference situation during the 30 years

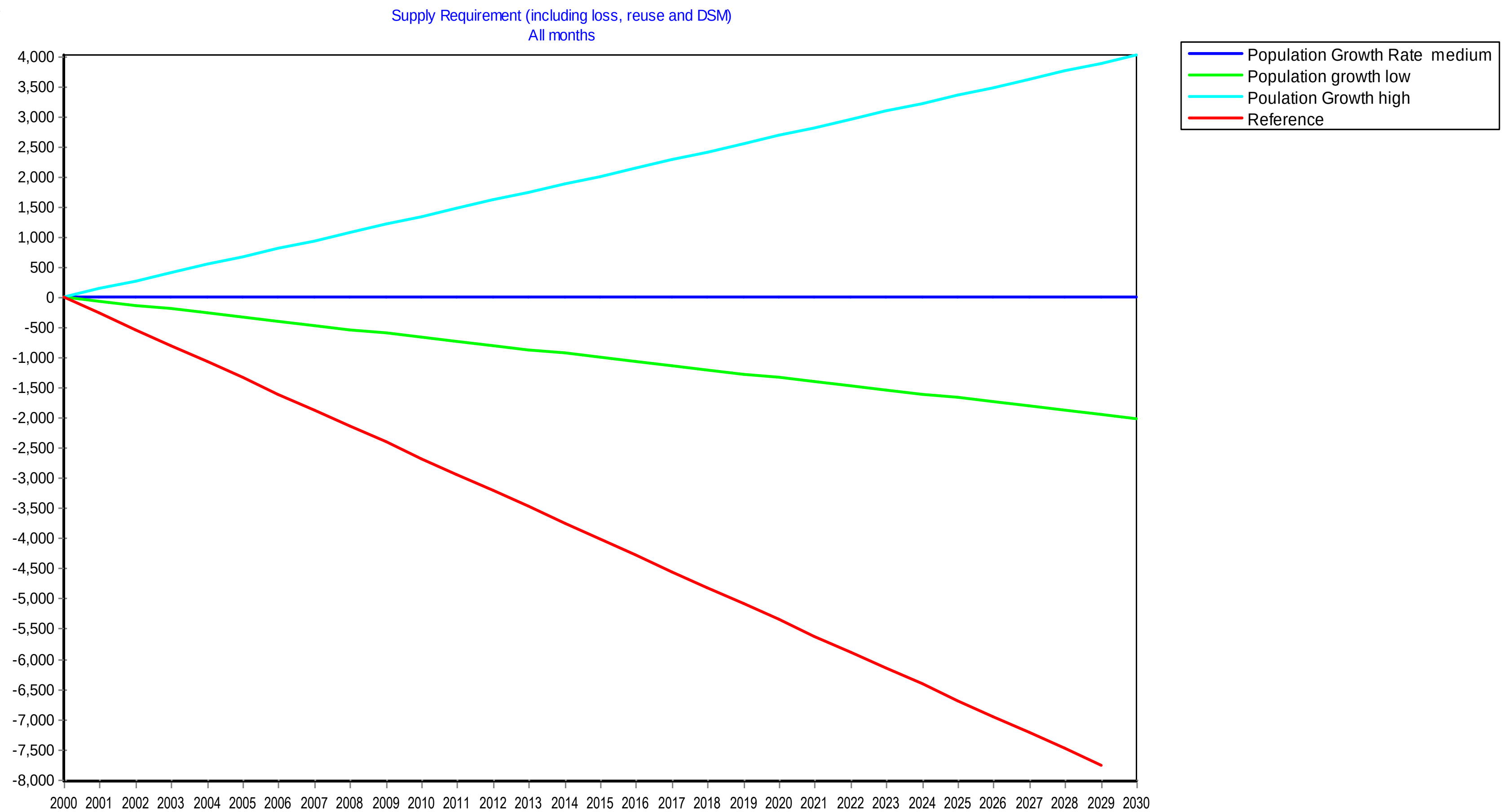

Figure 4.13 Supply requirements variation overall with "datum" as low population growth rate situation during the time span considered

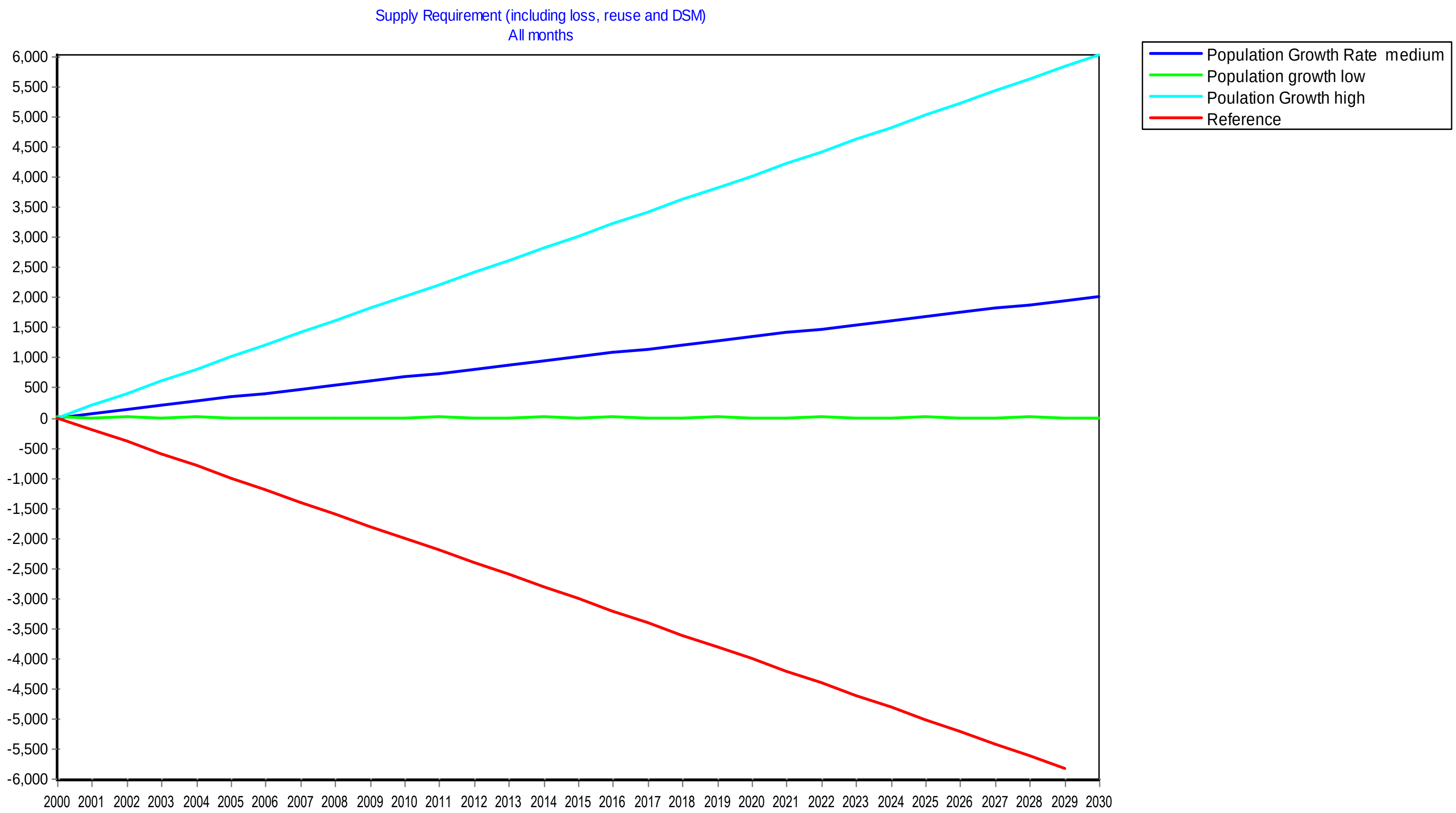

Figure 4.14 Supply requirements variation overall with "datum" as low population growth rate situation during the time span considered

Figure 4.15 Supply requirements variation overall with "datum" as high population growth rate situation

4.9 Model Flexibility

The developed system, based on the WEAP, is a flexible tool for supporting water supply and demand related decision making process. It can be readily changed or expanded for adding or removing nodes, exploring new seniors with different data. This study presents a successful attempt of modeling urban water supply and demand system, focusing on one major watershed and a water treatment plant along with the surrounding serving areas in the city.

An example of an important feature of the model is the choice of priority assigned to demand sites. In previous sections supply and demand were studied with the water treatment plant assigned the priority 99 for seniors for three different population growth rates. This means that the treatment plant capacity is not critical (WEAP Priorities for water allocation).

The WEAP system also gives priorities from 1-99 with 1 is being the highest priority. These priorities largely reflect the importance of the demand sites. This is essential and crucial when there is a deficiency of water, and in this case, it is supposed that the demand site with the highest priority is considered first. For example, if a treatment plant was assigned a priority of 1, the following results are obtained for unmet demand of three population growth scenarios (Figure 4.16).

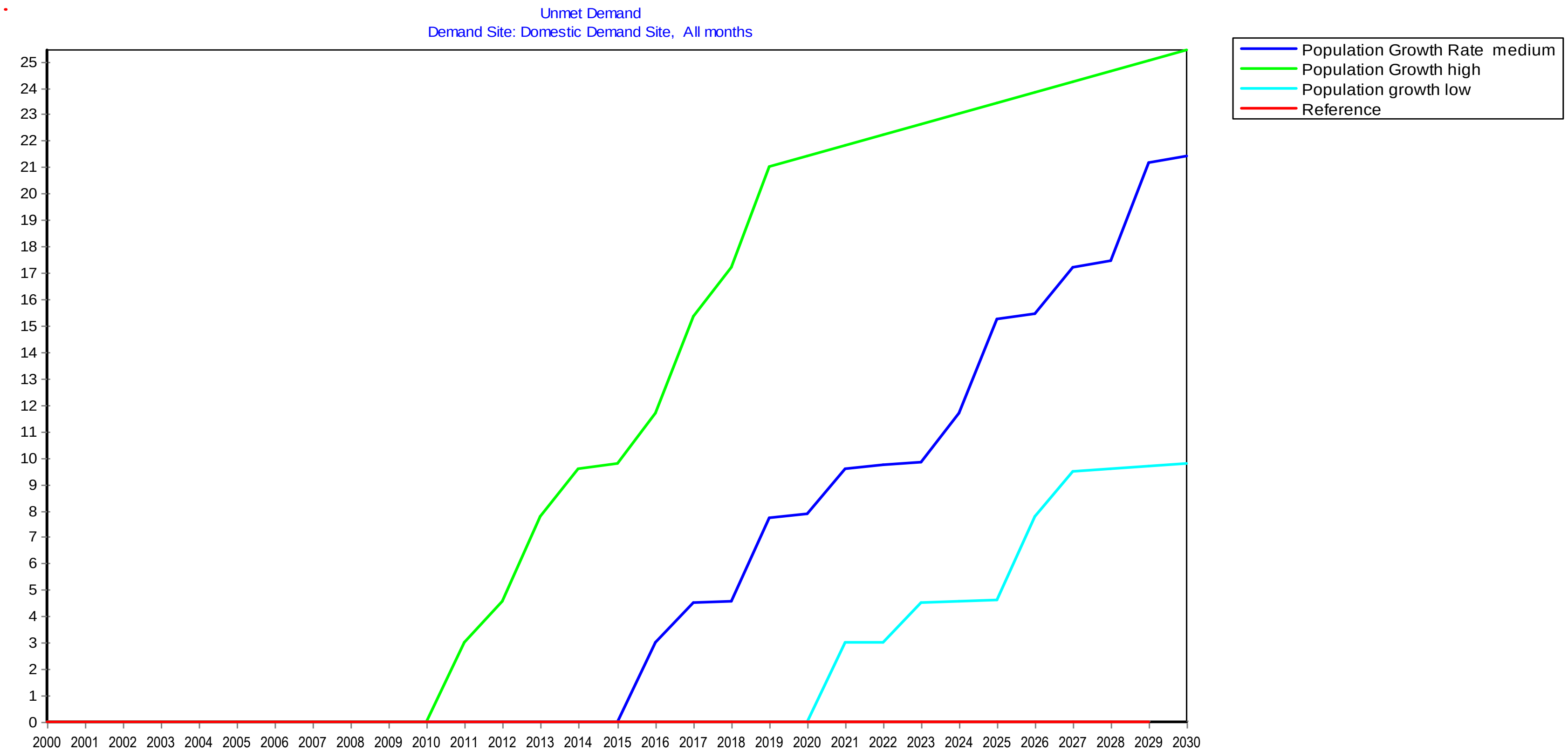

Figure 4.16 Unmet Demands for domestic Demand site (Three scenarios for population growth rates, Starting in 2001(Reference scenario assumes no changes from 2001)

In this figure, it is evident unmet demand will start to occur at a date that depend on the assumed population growth rate. It is obvious that some actions will have to be taken to cope with a growth in population, as well as a likely growth in industry and institutions. The system is demonstrated here to be a flexible and feasible tool which can model differing scenarios with differing assumption and data.

4.10 Modeling Limitations

The developed system can be used for 1) high level planning and strategic analysis at local, national and regional scales; 2) demand management, and regional water allocation. However, this WEAP-based water supply modeling system is not appropriate for supporting: 1) Daily operations and 2) Least-cost optimization of supply and demand Furthermore, the system performance has been impaired at some certain level due to the limited meteorological, hydrological, and social-economic data.

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

In this study, an integrated computer-based water management system was developed based on the water evaluation and planning program (WEAP) to offer a professional and practical tool to study the current and future water supply and demand systems for the city of St. John's, Newfoundland. The proposed system targeted the Windsor Lake watershed and the serving areas of the Windsor Lake Water Treatment Plant of the city.

The modeling efforts were firstly based on a comprehensive study on the city and its surrounding areas, the Windsor Lake watershed, nearby reservoirs, water and waste water treatment facilities, and water supply systems. Available data on the water supply and management systems in St. John's was collected and compiled, covering meteorological, hydrological, environmental, managerial, and social-economic aspects. An integrated water supply database for the city was also developed based on the geographical information system (GIS) and database techniques.

During the modeling of the water supply system, three demands sectors, i.e. domestic, institutional, and industrial, were considered. The three population growth rates selected over a scenario horizon of described by a period from 2000-2030 were 1.5%, 2.0% and 3.0% as a linear increment. The results were presented in terms of unmet demand over time, supply requirement over time and the supply variation in the Windsor Lake over time for various scenarios.

The modeling exercise was a success in terms of the results produced from different scenarios complement each other. It was observed that the unmet demand on a yearly basis would vary linearly with a different monthly average for each year. As an example the cumulative unmet demand over the period of 2000-2030 under the three scenarios was predicted as 1.680 x 10^6 m^3, 1.711 x 10^6 m^3, 1.773 x 10^6 m^3, with respect to for the reference scenario as 1.586 x 10^6 m^3. The yearly variations in the supply requirements of the serviced areas followed a similar pattern. The cumulative supply requirement over the period of 2000-2030 under the three scenarios was estimated as 2563 x10^6 m^3, 2594 x10^6 m^3, 2656 x10^6 m^3, with respect to a reference of 2469 x10^6 $m^{3.}$

With a high population growth rate assumed to have started in 2001, the model predicts unmet demand starting at 2010. With a medium growth rate an unmet demand start at 2015. With a low growth rate there is no unmet demand until 2020. In fact, there has been little population growth between 2001 and 2010, however, as soon as there is significant growth it will be useful to model water supply and demand for planning purposes.

The developed system can be readily expanded by including other watersheds, reservoirs and communities as additional nodes, if appropriate data is available or assumed. The complexity and restrictions in the nature of the water usage have been increasing due to sectoral, regional, or even nationwide competition. Development and application of modeling techniques such as the developed system for managing water recourses efficiently shall become indispensable not only for policy development and decision making in terms of resource allocation but for resolution of water supply and demand conflict.

5.2 Recommendations

This study is an advance of the WEAP, by developing an integrated urban water supply modeling system. The capacity and feasibility of the developed system (and the WEAP) has been tested through the case study in the City of St. John's, which indicates that the system would become an appropriate and powerful water resource management and policy development tool. The study also highlights the importance of recording, management, collection and availability of data in adequate form for efficient performance of such a system for producing suitable results, especially by utilizing GIS and database techniques for supporting water resource management. It is assumed that the same approach can be populated with more features or elements describing more complex situations of water management system in the future, thus providing a useful basic framework which can be developed upon and refined. In specific terms the following recommendations are provided for further improvement and future work:

1) To extend to the Bay Bulls Big Pond watershed and even the whole Avalon for covering the metro area of St. John's, especially the interactions between multiple water treatment plants;

2) To include projections for industrial and institutional growth during water demand modeling;

3) To consider the changes in consumption rates of different sectors due to adoption of water conservation legislations and environmental friendly technologies;

4) To evaluate the effect of urban storm/runoff in modeling water balance especially under changing climatic conditions; and

5) To analyze the uncertainties existing in the water resource management system and quantify the influence on modeling of water supply/demand trend.

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Appendix 1

The WEAP Data Report

Area: The City of St. John's Newfoundland
Current Accounts
Date: 12/13/2009

```
Key Assumptions
  Population Growth Rate low (cap) 100646
  Population Growth Rate medium cap)                100646
  Population Growth Rate high (cap)                100646
Demand Sites and Catchments
  Treatment plant Water Use Annual Activity Level (m^3)
28470000
  Annual Water Use Rate (m^3/m^3)    .99
  Monthly Variation (% share)            Monthly Values(
Jan, 8.633,  Feb, 8.004,  Mar, 8.004,  Apr, 8.004,  May,
8.004,  Jun, 7.824,  Jul, 8.273,  Aug, 8.363,  Sep, 8.723,
Oct, 8.723,  Nov, 8.723,  Dec, 8.723 )
Consumption (%)                             .01
    Priority        Demand Priority              99
  Advanced Method Specify yearly demand and monthly
variation
Institutional Demand site   Water Use
 Annual Activity Level (m^3)                       5000000
 Annual Water Use Rate (m^3/m^3)        .8
 Consumption (%)                        .2
  Priority     Demand Priority            3
Advanced    Method Specify yearly demand and monthly
variation
 Industrial Demand site         Water Use
  Annual Activity Level (m^3)    10000000
Annual Water Use Rate (m^3/m^3)       .9
Consumption (%)                       .1
Priority   Demand Priority             1
Advanced          Method
```

Specify yearly demand and monthly variation

```
Windsor lake Watershed    Land Use
  Area (M^2)                          17700000
```

Climate Precipitation (mm/month)
Monthly Values(Jan, 134.5, Feb, 102.1, Mar, 93.7, Apr, 75.6, May, 98.1, Jun, 102.3, Jul, 117.4, Aug, 122.8, Sep, 122.8, Oct, 130.2, Nov, 120.7, Dec, 126.7)

Temperature (C) Monthly Values(Jan, -6.2, Feb, -7.5, Mar, -3.6, Apr, 2.3, May, 7.4, Jun, 12, Jul, 16.1, Aug, 16.2, Sep, 12.2, Oct, 6.9, Nov, 2.3, Dec, -3)
Latitude 47
Initial Snow (mm) 3220
Irrigation Irrigated Area (%) 100
Lower Threshold (%) 100
Priority Demand Priority 1
Advanced Method
Rainfall Runoff (soil moisture model)
Harbor Catchment Land Use
Area (M^2) 0
Climate Precipitation (mm/month) 290
Latitude 52
Irrigation Irrigated Area (%) 100
Lower Threshold (%) 100
Priority Demand Priority 1
Advanced Method
Rainfall Runoff (soil moisture model)
Domestic Demand Site
Water Use Annual Activity Level (cap) 100646
Annual Water Use Rate (m^3/cap) 133
Consumption (%) 25
Priority Demand Priority 1
Advanced Method
Specify yearly demand and monthly variation
Hydrology
Water Year Method Current Accounts
Normal
Read from File Read from File
Not Specified
Supply and Resources
Linking Demands and Supply
To Treatment plant
From Windsor lake Reservoir
to Institutional Demand site
from Treatment plant
to Industrial Demand site
from Treatment plant
to Windsor lake Watershed

from Broad Cove River
to Harbor Catchment
from Wastewater Treatment plant
to Domestic Demand Site
from Treatment plant

River

Atlantic Ocean Inflows and Outflows
Head flow (CMS); Inflow from Catchment Harbor Catchment
(values not shown in Data View)
Water Quality Model Water Quality? No
Reaches
Below Atlantic Ocean Head flow
Below Catchment Inflow Node 1
Local Reservoirs
Windsor lake Reservoir Physical
Inflow (Million CMS) 1.6
Storage Capacity (Million m^3) 50
Priority Priority 1
Broad Cove River Physical
Storage Capacity (Million m^3) 37.9
Initial Storage (Million m^3) 10
Priority Priority 99

Return Flows

From Treatment plant
To Windsor lake Reservoir
Inflows and Outflows Loss from System (%) 1
from Institutional Demand site
to Wastewater Treatment plant
from Industrial Demand site
to Wastewater Treatment plant
from Domestic Demand Site
to Wastewater Treatment plant
Water Quality
Pollutant Decrease in Return Flows
from Treatment plant
to Windsor lake Reservoir
from Institutional Demand site
to Wastewater Treatment plant
from Windsor lake Watershed
to Windsor lake Reservoir
from Industrial Demand site
to Wastewater Treatment plant
from Domestic Demand Site
to Wastewater Treatment plant
from Harbor Catchment

```
     to Catchment Inflow Node 1
 Wastewater Treatment
    Wastewater Treatment plant
Treatment   Daily Capacity (m^3/day)   134800
Consumption (%)               100
```

Appendix 2:

Canada-Newfoundland Water Quality Monitoring Agreement

Station List

No.	Region	Site Name	Station Number	Latitude	Longitude
1	Eastern	Leary's Brook - Clinch Crescent	NF02ZM0178	47.5725 N	52.7392 W
2	Eastern	Leary's Brook - Outer Ring Road	NF02ZM0184	47.5711 N	52.7914 W
3	Eastern	Manuals River	NF02ZM0294	47.5197 N	52.9447 W
4	Eastern	Mobile River	NF02ZM0018	47.2486 N	52.8447 W
5	Eastern	Mundy Pond - Outlet	NF02ZM0109	47.5611 N	52.7439 W
6	Eastern	Northeast River	NF02ZK0005	47.2731 N	53.8403 W
7	Eastern	Northwest Brook	NF02ZN0002	46.7592 N	53.3903 W
8	Eastern	Nut Brook	NF02ZM0186	47.44 N	52.9728 W
9	Eastern	Pipers Hole River	NF02ZH0001	47.9308 N	54.2736 W
10	Eastern	Quidi Vidi Lake @ Outlet	NF02ZM0015	47.5839 N	52.6808 W
11	Eastern	Rattle Brook - South Branch	NF02ZG0025	47.4511 N	54.855 W
12	Eastern	Raymond Brook	NF02ZM0017	47.4419 N	52.7722 W
13	Eastern	Rennies River - Carnell Drive	NF02ZM0016	47.5778 N	52.7008 W
14	Eastern	Rennies River - Portugal Cove Road	NF02ZM0177	47.5744 N	52.71 W
15	Eastern	Rocky River	NF02ZK0001	47.2272 N	53.5692 W
16	Eastern	Salmonier River	NF02ZN0004	47.1817 N	53.3989 W
17	Eastern	Seal Cove River	NF02ZM0019	46.8453 N	52.9703 W
18	Eastern	South Brook headwaters	NF02ZM0185	47.4936 N	52.8506 W
19	Eastern	South Brook mouth	NF02ZM0176	47.5281 N	52.7467 W
20	Eastern	Spout Cove Brook	NF02ZL0001	47.8122 N	53.1553 W
21	Eastern	Tides Brook	NF02ZG0024	47.1275 N	55.2653 W
22	Eastern	Virginia River - Newfoundland Drive	NF02ZM0180	47.5997 N	52.7006 W
23	Eastern	Virginia River - Guzzwell Drive	NF02ZM0179	47.5964 N	52.7017 W
24	Eastern	Virginia River - headwaters	NF02ZM0098	47.5989 N	52.7547 W
25	Eastern	Virginia River - The Boulevard	NF02ZM0014	47.5839 N	52.6914 W
26	Eastern	Waterford River - Blackhead Road	NF02ZM0181	47.5481 N	52.7192 W
27	Eastern	Waterford River - Bremigans Pond	NF02ZM0182	47.5186 N	52.8558 W
28	Eastern	Waterford River - Brookfield Road	NF02ZM0175	47.5261 N	52.7633 W
29	Eastern	Waterford River - Commonwealth Avenue	NF02ZM0004	47.5219 N	52.8081 W
30	Eastern	Waterford River - Kilbride	NF02ZM0009	47.5294 N	52.7428 W
31	Eastern	Kelly's Brook - Portugal Cove Road	NF02ZM0144	47.8486 N	53.3253 W

Appendix 3:

An Example of the Water Resource Management Database - Groundwater Wells in the City of St. John's

Note: In order to protect the privacy of the well owners, the identifications have been removed.

No.	Well Number	Latitude	Longitude	WELL_DEPTH	DEPTH_WATER_FOUND
1	10105	47.59992222	-52.709536		
2	21273	0	0	73.2	
3	12578	0	0	30.5	
4	12191	0	0	13	27
5	14206	47.54428333	-52.794036	23	
6	12471	0	0	93	23
7	12480	47.54428333	-52.794036	152.5	79
8	12626	47.57411667	-52.777275	68.6	146
9	12665	47.57411667	-52.777275	125	64
10	12682	47.51531111	-52.774619	100	119
11	12683	47.57411667	-52.777275	82	91
12	12702	47.57463611	-52.767222	50	80
13	12707		-52.751139	51.8	46
14	13074	47.57463611	-52.751283	91.4	49
15	13164	47.54428333	-52.794036	55	76
16	13167	47.57463611	-52.767222	80	50
17	13163	47.57463611	-52.767222	134.1	70
	13180		-52.751139	91.4	122
19	13187		-52.751139	61	61
20	13264	47.54428333	-52.794036	140	55
21	13290		-52.751139	84	60
22	13958	0	0	6.4	84
23	14342	0	0	103.6	40
24	14925	0	0	42.7	99
25	10467	47.56531389	-52.788842	49.4	38
26	12200	47.56614167	-52.773611		44
	14606	47.60254722	-52.750464	73.2	35
28	14340	47.59992222	-52.709536	80.2	
29	14167	0	0	121	82
30	14208	0	0	91	61

Appendix 4:

The key questions according to (Sieber 2009) are:

1) What if population growth and economic development patterns change?
2) What if reservoir operating rules are altered?
3) What if groundwater is more fully exploited?
4) What if water conservation is introduced?
5) What if ecosystem requirements are tightened?
6) What if a conjunctive use program is established to store excess surface water in underground aquifers?
7) What if a water recycling program is implemented?
8) What if a more efficient irrigation technique is implemented?
9) What if the mix of agricultural crops changes?
10) What if climate change alters demand and supplies?
11) How does pollution upstream affect downstream water quality?
12) How will land use changes affect runoff?

Appendix 5:

According to Sieber (2009), the major features of the WEAP system include:

- Integrated water resources planning function;
- Built-in models for rainfall runoff and infiltration, evapotranspiration, crop requirements and yields, surface water/groundwater interaction, and in-stream water quality;
- GIS-based, graphical "drag and drop" interface;
- Flexible and expandable data structures;
- Model-building capability with built-in functions;
- User-defined variables and equations;
- Dynamic links to spreadsheets and other models; and
- Embedded linear program solves allocation equations.