An-Najah National University
Faculty of Graduate Studies

EVALUATION OF URBAN WATER SUPPLY OPTIONS USING WEAP: THE CASE OF NABLUS CITY

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DEDICATION

To my husband and my parents for their encouragement and support

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الإقــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

EVALUATION OF URBAN WATER SUPPLY OPTIONS USING WEAP: THE CASE OF NABLUS CITY

أقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء مـــا تمــت الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أية درجة علمية أو بحث علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's name: **اسم الطالبة:**

Signature: **التوقيع:**

Date: **التاريخ:**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX TABLES AND FIGURES

ABBREVIATIONS

Symbols	Definition
WEAP	Water Evaluation And Planing
PCBS	Palestinian Central Bureau of Statistics
m^3	Cubic Meter
mcm	Million Cubic Meter
L	Liter
m^3/m	Cubic Meter Per Month
l/c-d	Liter Per Capita Per Day
m^3/h	Cubic Meter Per Hour
$m^3/year$	Cubic Meter Per Year
DSS	Decision Support System
IWRM	Integrated Water Resources Management
WWTP	Wastewater Treatment Plant

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ABSTRACT

Palestinians undergo the problem of insufficient water which emerges largely from the fact that the Israelis do not allow the Palestinians a full control of their water resources. In addition to this restriction, the Palestinians are not permitted to pump out sufficient quantities from the aquifers. This has led to water shortage and thus the majority of the major cities and communities in the West Bank encounter challenges and difficulties in water allocation and management. The City of Nablus is an example of such a situation since it suffers from water shortage and difficulties in distributing water to all users at sufficient quantities.

This work utilizes the Water Evaluation And Planning Tool (WEAP) in assessing the management options the Municipality of Nablus is considering for dealing with the on-going water crisis in the City of Nablus.

The study methodology consists of three components: data gathering; knowledge acquisition on WEAP and its applications; and WEAP modeling that aided to evaluate water resources management options for Nablus City.

The results show that the unmet water demand will continue to increase over the coming years. This is mainly due to the increase in population with limited water resources. Therefore, securing additional water supplies becomes an essential issue to meet the increase in water demand. The most effective option for the period 2009-2025 is the construction of Sabastia well that leads the lowest unmet water demand during this period. The development of new groundwater wells is very efficient in covering the unmet water demand. In this option the unmet water demand will start to decrease when adding the first well in 2015, and more decrease in 2020, 2025, and 2035 when the second, the third, and the fourth wells are constructed. The decrease in 2025 in the unmet water demand is more than Sabastia well option, so in this period this option becomes more effective than Sabastia well option. The option of using stormwater harvesting gives satisfactory results in decreasing the unmet water demand better than the options of spring rehabilitations and the reduction in water leakage which gives a small decrease in the unmet water demand. Improving the water-related infrastructure of the City to decrease the water leakage is crucial in mitigating the water shortage.

CHAPTER ONE

INTRODUCTION

1.1 General Background

Palestine like many other Middle Eastern countries undergoes water shortage problem. West Bank and Gaza Strip suffer from a chronic water shortage, preventing sustained economic growth and damaging the environment and the Palestinians health sector. The large variations in rainfall and limited surface water resources has led to a widespread scarcity of fresh water resources in the region, resulting in heavy reliance on groundwater as a major source for various uses. The contribution of surface water to the overall water balance is limited and marginal (Mogheir et al., 2005).

The sources of water in the West Bank are the renewable water of the mountain aquifer that rises and outcrops in the West Bank but extends across and below the territories of historic Palestine. The groundwater recharge in the West Bank is from the direct infiltration of rainwater through fractured rocks and porous soils. The overall average recharge in the West Bank is estimated to be 679 mcm/year, while in Gaza it is estimated at 45 mcm/year (Mogheir et al., 2005).

The extent of the problem that the Palestinians undergo emerges largely from the fact that the Israelis do not allow the Palestinians a full control of their water resources. In addition to this restriction, the Palestinians are not permitted to pump out sufficient quantities. This has led to water shortage and thus the majority of the major cities and communities in the West Bank undergo challenges and difficulties in water allocation and management.

The City of Nablus is an example of such a situation since it suffers from water shortage and difficulties in distribution of water to all users at sufficient quantities. Many future scenarios were proposed and under such scenarios many management options were highlighted. As a first step, it is essential to evaluate the existing conditions related to the water supply system in the City of Nablus, then assess the effectiveness of management options in mitigating the on-going water crisis. As such, this work comes in line with the objective of evaluating the efficacy of the proposed management options under potential future scenarios. The Water Evaluation And Planning Tool (WEAP) (http://www.weap21.org/index.asp, accessed on July 6, 2008) was utilized in this regard.

1.2 Importance of the Study

Nablus City like many other Middle Eastern cities undergoes water shortage problems that need to be addressed and solved. The Municipality of Nablus serves more than 170,000 inhabitants (PBCS, 2007) including the four refugee camps which are Balata, Old Askar, New Askar and Ein Beit El Ma. In addition, few surrounding villages are supplied with water by Nablus Municipality. These villages are Asira Ashamaliya, Zawata, Deir Sharaf, Al-Badan, Al-Juneid, Faraa, and Talluza through the Water Supply and Sanitation Department. As a first step for solving the on-going problem, an assessment of the current situation should be considered to find out the ramifications. This assessment is carried out by developing a supply-demand model using WEAP. Thereafter, this WEAP model will be utilized to assess and evaluate the outcome of the different options.

WEAP is a powerful tool for water planning and management. WEAP incorporates water supply in the context of demand-side issues, and provides a practical tool for water resources planning. WEAP is distinguished by its integrated approach to simulating water systems.

The importance of the study emerges from the following facts:

1. This is the first time WEAP will be developed and utilized at city level for the assessment of urban water management;
2. The Municipality of Nablus has absolutely no tool to assess the efficacy or the outcome of the proposed management options; and
3. The experience gained from carrying out this research can be further extended to other urban centers in the West Bank.

1.2 Description of the study area

The City of Nablus is one of the major Palestinian cities. It is located in the middle of the northern part of the West Bank (see Figure 1).

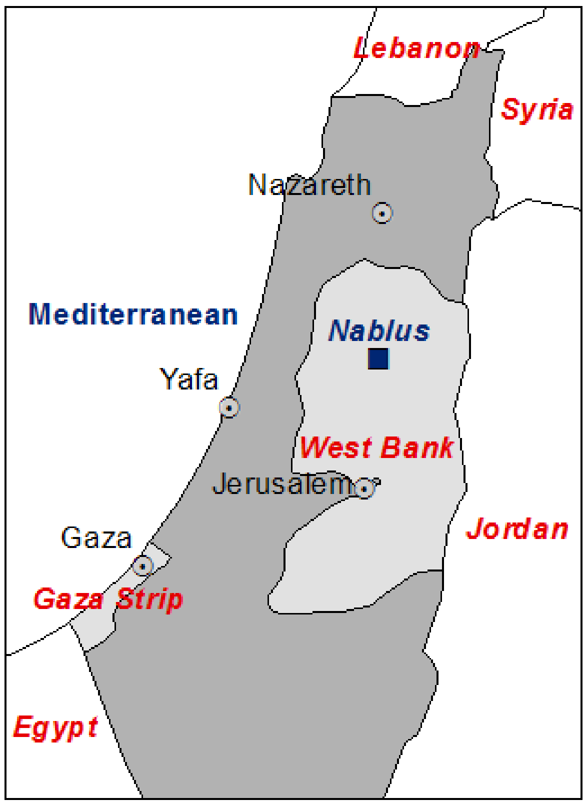

Figure 1. Location of the City of Nablus

As shown in Figure 2, the city is located between two mountains; Eibal (940 m amsl) in the north and Gerizim (881 m amsl) in the south.

Figure 2. The two mountains of the City of Nablus

The city has an area of about 28.5 km^2 (http://ar.wikipedia.org, accessed on June 10, 2008) and has a population of approximately 156,992 inhabitants (PCBS, 2007) including the four refugee camps.

Nablus has hot dry summers and moderate rainy winters. The maximum average temperature in the year is during the month of August, which is 29.4 °C while the minimum average temperature is 6.2 °C during the month of January (http://www.nablus.org, accessed on June 15, 2008).
Rainfall in Nablus is limited to the winter and spring months from October to May. The total annual mean rainfall is approximately 660 mm with a range from 350 to 1200 mm as shown in Figure 3.

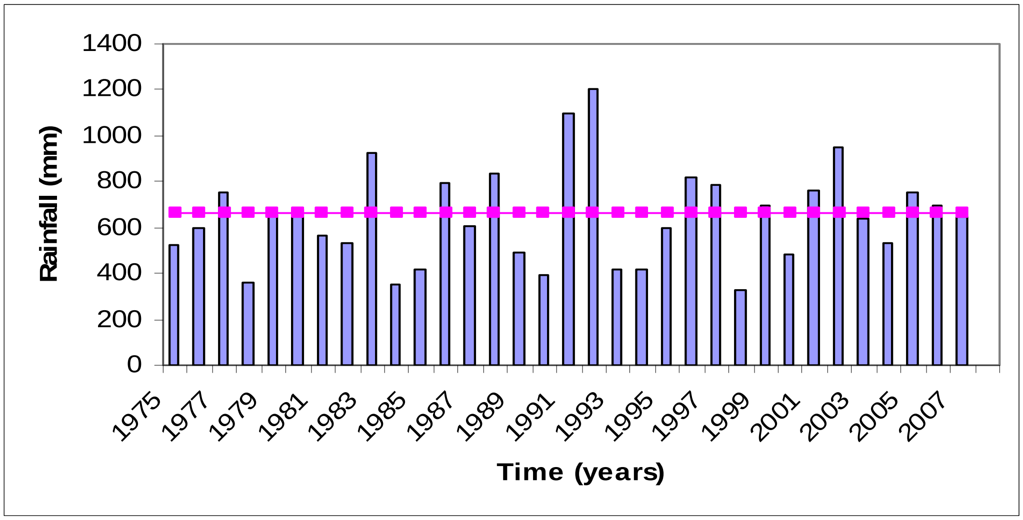

Figure 3. The annual and the annual average rainfalls of Nablus City for the period from 1975 to 2007 (**The meterological station of Nablus, 2008**)

The mean annual relative humidity of Nablus City is 62%. The minimum value of humidity is 50.72% in May, while the maximum humidity is 67% is usually reported in December (http://www.nablus.org, accessed on June 15, 2008).

Groundwater is the sole source of water in Nablus City. The Municipality utilizes four deep groundwater wells located outside the city. These wells cover an average of about 80% of the present supply (according to the Municipality of Nablus). In addition, five major springs located within the city boundaries are utilized. The average yield rates of the wells and springs of Nablus City are depicted in Figure 4. Additional information related to the existing water infrastructure and supply procedure is given in Chapter 3.

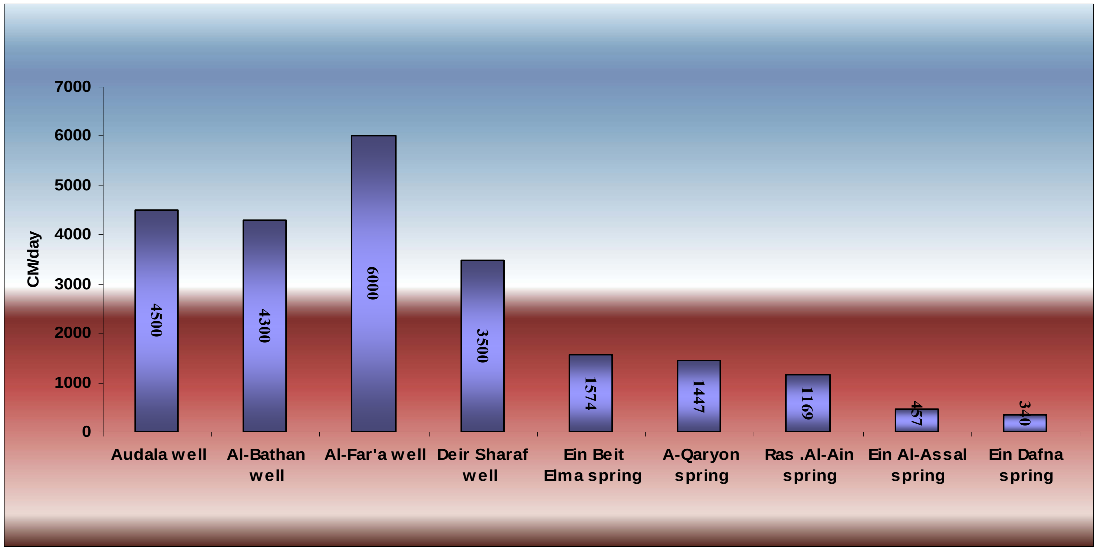

Figure 4. The average yield of water sources in Nablus City (Lahmeyer and Setec, 2004)

1.4 Research motivations

The research is motivated by the following issues:

1. The importance of understanding the extent of the existing problems in the water sector of the City of Nablus;
2. Nablus City is expanding very fast and assessing the potential solutions for the water supply problems is vital;
3. Decision makers lack a tool that can aid them in the planning and management of the water sector and WEAP is a tool that provides instant answers to raised planning inquiries.

The following are the main deficiencies in the water sector of the City of Nablus that motivate carrying out the work furnished in this thesis (Lahmeyer and Setec,2004):

- Insufficient water resources especially during summer time;

Undersized distribution network where 2 and 3 inch pipes are mostly used to provide water for wide and extended areas resulting in high head losses. However, recently there were replacements of some undersized pipes and this led to decrease the water losses. Replacements included a 14-inch transmission link between Deir Sharaf well and Ein Beit Elma reservoir, and replacement of Rafidia area network by higher diameter pipes.

- High water losses from the network;
- Lack of proper bedding of pipes that are close to the surface. This results in frequent pipe bursts and damages due to traffic;
- Heavy reliance on continuous direct pumping into large sections of the pipe network with widely differing elevations. This generates excessive head in low areas and sites close to the pumping stations. But there will be restructuring and optimization of the main system, aiming at water loss reduction and operation efficiency by using the available water resources focusing on defining pressure zones where the pressure is not to exceed 10 bars at lowest points and 3 bars at highest points (Lahmeyer and Setec,2005.
- Negative pressure as a result ofthe intermittent supply operation and risk of contamination with sewage and pollutants.

1.5 Research main objective

The main objective of the thesis is to evaluate the existing conditions related to the water supply system in the City of Nablus and to assess the long-term impacts of the proposed management options under potential driving scenarios using WEAP.

1.6 Why WEAP?

WEAP was chosen in this research due to the following reasons:

- Recently, WEAP received a great deal of attention where it is being applied at national and international levels;
- WEAP can be used at different levels spatially and temporarily;
- Its capabilities promote using it as a decision support system (DSS);
- Easy to use;
- The developers of WEAP can provide technical help;
- Public domain for academic use; and
- Capable to simulate conveniently hydrology, groundwater utilization, and wastewater treatment.

1.7 Methodology

The research methodology is comprised of three main phases as shown in Figure 5. The first phase includes data collection mainly from Nablus Municipality, Water and Environmental Studies Institute at An-Najah National University, relevant reports and studies, and information from the internet. Interviews and meetings with the engineers of the Department of Water Supply and Sanitation at Nablus Municipality were carried out especially to comprehend the existing situation and to gain an understanding regarding the management plans intended to mitigate the on-going water-related problems. In addition to the above, literature review was carried out regarding WEAP and its past applications. As such, reports and journal articles were reviewed.

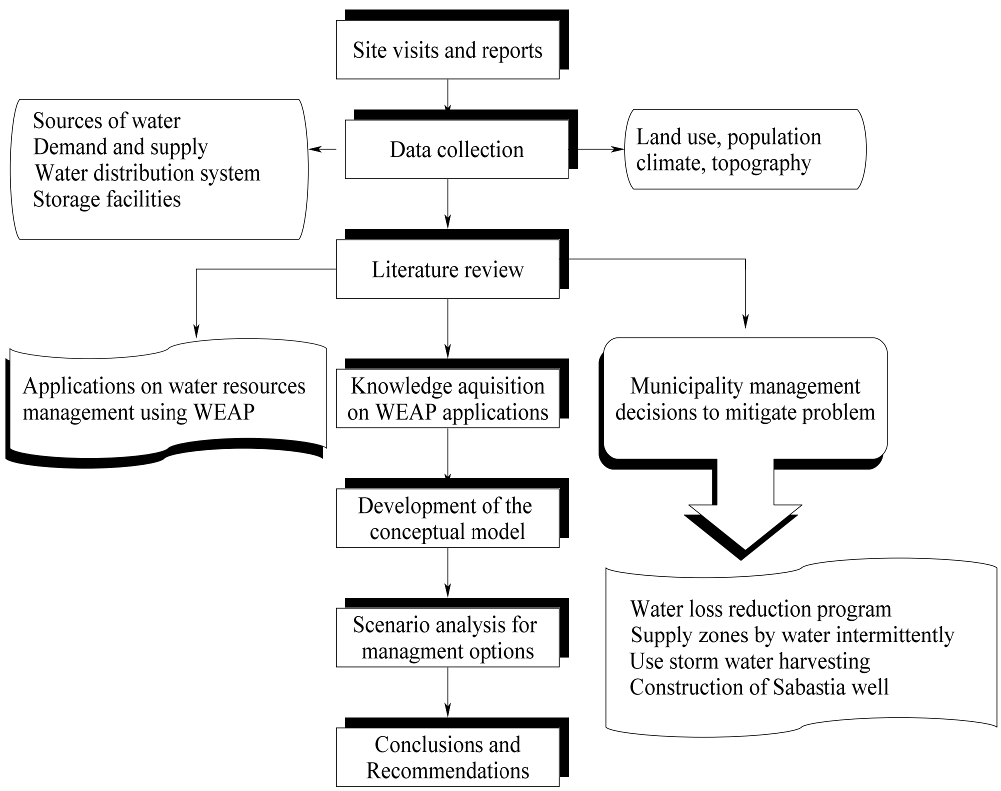

Figure 5. Depiction of research methodology

The second phase implies knowledge acquisition on WEAP and its applications. The training manual accompanying WEAP was used to improve and direct my skills in using WEAP and to get acquainted regarding WEAP main functionalities.

The third phase entails the development of the conceptual model using WEAP. The conceptual model matches the existing conditions. Potential scenarios were proposed and were utilized in the research to explore the outcomes that correspond to the different applicable management options. As such, the planning and management alternatives were conceptualized (adapted from the Department of Water Supply and Sanitation of the Municipality of Nablus) and were later processed using WEAP.

1.8 Thesis outline

The general structure of the thesis goes as follows. Chapter II furnishes related literature review for WEAP past applications. Chapter III describes modeling demand and supply using WEAP corresponding to the existing conditions. Chapter IV demonstrates WEAP-based assessment of the different management options that correspond to the potential scenarios. In Chapter V, the conclusions and recommendations based on WEAP outcomes are furnished.

CHAPTER TWO
LITERATURE REVIEW

2.1 General

Planning, developing, and managing water resources to ensure adequate, inexpensive and sustainable supplies and quality of water for both humans and natural ecosystems can only be successful if such activities address the causal socio-economic factors, such as inadequate education, population pressures and poverty (Loucks and Beek, 2005).

Water management must be undertaken using an integrated approach that can achieve social equity, sustainable environment, and the economic efficiency which makes the identification and implementation of effective solutions much easier and improves the efficiency in water use (Global Water Partnership, 2004).

In the following sections, a brief description of WEAP is provided and review of available past studies that utilized WEAP is furnished.

2.2 Water Evaluation And Planning System (WEAP)

WEAP is a computer tool for integrated water resources planning. WEAP was created in 1988, and is continuously being updated by the Stockholm Environment Institute, Boston, US, with the aim to be a flexible, integrated, and transparent planning tool for evaluating the sustainability of current water demand and supply patterns and exploring alternative long-range scenarios.It provides a comprehensive, flexible and user-friendly framework for policy analysis and a system for maintaining water demand and supply information.

As a forecasting tool, WEAP simulates water demand, supply, flows and storage. WEAP operates on the basic principle of water balance and can be applied to municipal and agricultural systems, a single watershed or complex trans-boundary river basin systems. Moreover, WEAP can simulate a broad range of natural and engineered components of these systems, including rainfall-runoff, baseflow, and groundwater recharge from precipitation; demand analyses; water conservation; water rights and allocation priorities, reservoir operations; pollution tracking and water quality.

As such, WEAP is an effective tool for examining alternative water development and management options. Scenarios are used to explore the model with an enormous range of "what if" questions, such as: what if population growth and economic development patterns change? What if reservoir operating rules are altered?

In this study WEAP forecasted water demand for the year 2035 in Nablus City, after providing information like population, population growth rate, annual use rate and consumption. WEAP simulates unmet demand according to supply sources under different management options and corresponding scenarios.

WEAP applications generally include several steps:

- Study definition: The time frame, spatial boundaries, and system components are established.
- Current accounts: Actual water demand, pollution loads, and available resources and supplies for the system.
- Scenarios and options: A set of alternative assumptions about future impacts of policies, costs, and climate (on water demand and supply, hydrology, and pollution) can be explored.
- Evaluation: The scenarios are evaluated with regard to water sufficiency, costs and benefits.

2.3 WEAP Applications

Lévit et al. (2003) developed water demand management scenarios in a water-stressed basin in South Africa using WEAP. This study was done for the water resources of the Olifants River Basin which is almost fully allocated. It flows from the highly populated and industrialized Gauteng Proven to Mozambique. To get a rapid and simple understanding of water balance at different levels in the basin and equity needs in water allocation, the study was done using WEAP model as a mean of addressing water allocation question in water stressed river basin. The use of WEAP allowed the simulation and analysis of various water allocation scenarios, by representing the system in terms of its various sources of supply (rivers, groundwater), water demand sights, reservoirs (location, capacity, operation), and the major water users. For each user, the activity level, the water demand, and return flow were introduced. Water demand management options can be included in WEAP either at specific sites (for example, by studying the possibilities for saving water by individual users) or globally. The study chose to consider the effect of the overall efforts of all users. Three options of water demand management were included in WEAP (at 10%, 20%, and 30% of saving water by users). The simulation results demonstrate that with no water demand management efforts, the requirements of up to 15 users would not be met. Moreover, for certain users, even extreme water demand management efforts (30% of saving water) would not be enough. This is possibly a consequence of their position in the basin, on the other hand, at certain other locations; limited efforts appear to be sufficient to meet local requirements.

Using WEAP, Alfarra (2004) developed an IWRM model that can help to better understand the situation in the whole catchments and identify where problems do exist. The system of uncoordinated water resources management in the basin of Lake Naivasha in Kenya cannot sustain the ever increasing water needs of the various expanding sectors. Such increase in water needs include the increased water demand throughout the region because of the increase in human population, which causes a strain on agricultural production, larger flower farms, industrial and other sectors. This may lead to the dry up of Lake Naivasha during droughts. The WEAP model shows that the main problem in the area is caused by a number of identified water uses in agricultural sector. According to the study, water is misused by over-irrigation in fodder, grass, vegetable farming, and flower farm. Scenarios were built (reference, water year, water demand and supply, water balance, net evaporation scenarios, etc) and then the analysis of the results of the scenarios was carried out. Modeling demand and supply helped to observe and understand a wide long-term vision of the problem.

Assaf and Saadeh (2006) used WEAP for the development of an integrated decision support system for water quality control in the upper Litani basin. The study was developed to control water quality in the upper Litani basin in Lebanon due to the current practices of discharging untreated sewage into the river causing wide-scale pollution. A decision support system (DSS) was developed using WEAP to help decision makers and other stakeholders assess alternative water quality control policy options to mitigate water pollution in the river. It was used to assess water quality conditions under three scenarios; the reference scenario where no water quality measures are introduced, another one considers adoption of an environmental master plan (the Council for Development and Reconstruction (CDR) plan), which is the construction of seven secondary wastewater treatment plants to serve seventy five towns, and the third scenario represents small scope plan which is the construction of six secondary wastewater treatment plants to serve eleven towns. The three selected scenarios were run against three hydrological records representing low, average and high river flows. The three scenarios were assessed only in terms of the Biochemical Oxygen Demand (BOD) using WEAP. The results showed that the CDR plan is effective in improving water quality.

Charlotte et al. (2006) used WEAP in the Rio Grande/Bravo Basin. The Rio Grande/Bravo basin is located in North America between two riparian nations, the United States and Mexico. This river basin is currently considered a water scarce area with less than 500 m^3 per person per year of available water. Throughout decades, there has been a lot of population growth in the basin, with population expected to double. The study describes the basin-wide WEAP model that was constructed to help evaluate stakeholder driven scenarios to more effectively manage these highly stressed water resources. The goal of study project was to create a hydrologic model that can be calibrated in the future. A Rainfall Runoff Soil Moisture model that allows for the characterization of land use and soil type impacts to hydrological processes was utilized. Evapotranspiration, surface runoff, sub-surface runoff and deep percolation were computed. Demands and supply, river, groundwater, local reservoirs, and return flows were all linked. The results show a good approximation to both annual and monthly flows. The model could be useful in generating inflows to the basin under various sequences of future precipitation.

Abu Hantash (2007) used WEAP for the development of sustainable management options for the water resources of the West Bank. The study considered different scenarios to ensure adequate, sustainable supplies and qualities of water. These scenarios are: (1) current state of occupation and closure scenario which includes: water management module ([i] demand management: domestic, industrial, and irrigated area as current, [ii] water conservation: improving infrastructure to decrease losses down to < 30%, [iii]-supply management), future expansion module (based on population growth, industrial demand, irrigated areas, domestic as current), water availability module, water cost module, water quality module, knowledge quality module, (2) consolidate state when peace process moves on scenario: domestic, industrial, and irrigated area demand was increased, improving infrastructure to decrease losses to <25%, supply management include additional annual supply of 70-80 mcm from GW, water availability module development of additional 80 mcm, no increase in water cost module, for water quality module municipal have wastewater collection, for knowledge quality module: education awareness, (3) independent state of Palestine scenario**:** increase user awareness to save water and protect it from pollution, improving_infrastructure to decrease losses to <20%, Palestinian will gain their water rights and will develop all their needs, future expansion module: based on regional equity between Palestinian and Israelis, industrial demand projected to reach 13% of municipal water, irrigated areas will achieve the land requirement for national consumption needs 0.14 donum/capita, development of Palestinian needs from aquifers, Jordan river, treated water, wadis, cistern, collected wastewater used in agriculture, increase education to decrease water demand**.** WEAP output showed that management cannot take place properly if the existing situation continues, and implementation of water resource management aspects can take place only when peace process move on.

Arafat (2008) used WEAP software to build an IWRM model on Al-Faria catchment, and to examine alternative water development and management strategies. Different scenarios for Al-Faria watershed were investigated. The impact of these scenarios were evaluated. These Scenarios were (1) “Do-no-thing Scenario” shows the reference scenario that reflects the existing conditions. (2) Suggestion to establish wastewater treatment plant (WWTP) in the catchment to reuse water from agricultural and domestic sites. (3) Wadi Al-Faria watershed is threatened by rapid population growth in the city of Nablus and several refugee camps. (4) well known that the new techniques can save about 30% of the irrigation water through the reduction of water losses by conveyance system as well as evaporation from soil surface. From the suggested scenarios, it was shown that all of them are successful to control and manage the water consumption in the region, but the most effective scenario is to use new techniques in agriculture.

To conclude, WEAP was used usefully in water demand management, developing integrated decision support system to control water quality in basins, developing IWRM models to identify the water allocation problems between users and thus to identify where is the misuse of water, and development of sustainable management options for water resources.

CHAPTER THREE
MODELING WATER SUPPLY AND DEMAND FOR NABLUS CITY USING WEAP

3.1 Introduction

All people, whatever their stage of development and their social and economic conditions, have the right to have an access to drinking water in quantities and of a quality that suffice their basic needs (UN,1977).

Currently, the City of Nablus is suffering from a shortage of water and insufficient resources. Since twelve years, no new resources were developed to meet the increasing demand that accompany the population growth and urbanization until recently a new groundwater well (Sabastia well) was drilled for the utilization of the City of Nablus and the neighboring villages.

Water shortage in the City of Nablus can be attributed to the following:

1. Demand exceeds supply due to the increase of population without increasing the water quantity or developing new water resources,
2. The municipality is not permitted by the Israelis to dig new wells,
3. Losses of water from the distribution system due to the deficiencies in the existing system that uses pipe diameters less than the required, due to the aged pipes in many locations, and due to the poor maintenance and excessive pressure heads,
4. The expansion of the city exceeded the planning expectations. Several none residential sites were developed very rapidly and became full of residents. This situation has exacerbated the problem of water in the city as additional water infrastructure is needed. This

in turn increases the cost of construction and the cost of pumping for elevated and remote areas.

3.2 Water Supply in Nablus City

Water supply in the city comes from the springs located within the city boundaries and from the groundwater wells located outside the city boundaries (see Table 1). The Water Supply and Sanitation Department (WSSD) of Nablus Municipality operates four groundwater wells located outside the city's boundaries and these are Audala, Al-Badan, Al-Far'a, and Deir Sharaf wells, and utilizes five major springs and these are Ein Beit Elma, Al-Qaryon, Ras Al-Ain, Ein Al-Asal, and Ein Dafna springs for supplying water for all water-using sectors inside the city and for some villages and camps. Figure 6 shows the location of the water sources. The springs of the city derive their water from the rain that fall on the two mountains located inside the city. Therefore, there are fluctuations in spring yield from month to month, season to season, and year to year. This variability relies largely on the groundwater recharge which in turn depends on the total rainfall and level of urbanization.

Inside the City of Nablus, there are twelve operating storage reservoirs that are fed from wells and springs , tow of them are out of order (see Figure 7 below, Figure 1 in appendix B). These reservoirs vary in size and date of construction (see Table 2). All storage reservoirs are combined with the pumping stations. There are ten pumping stations distributed throughout the city and provide water to the different service zones (see Figure 7).

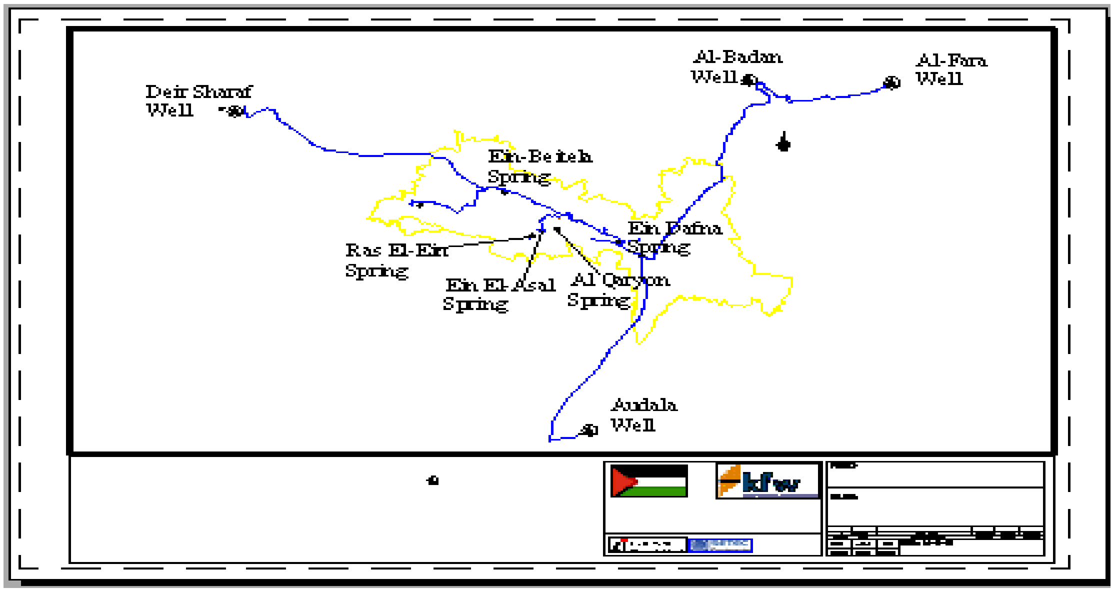

Figure 6. Location of the water sources of the City of Nablus
(Lahmeyer and Setec, 2004)

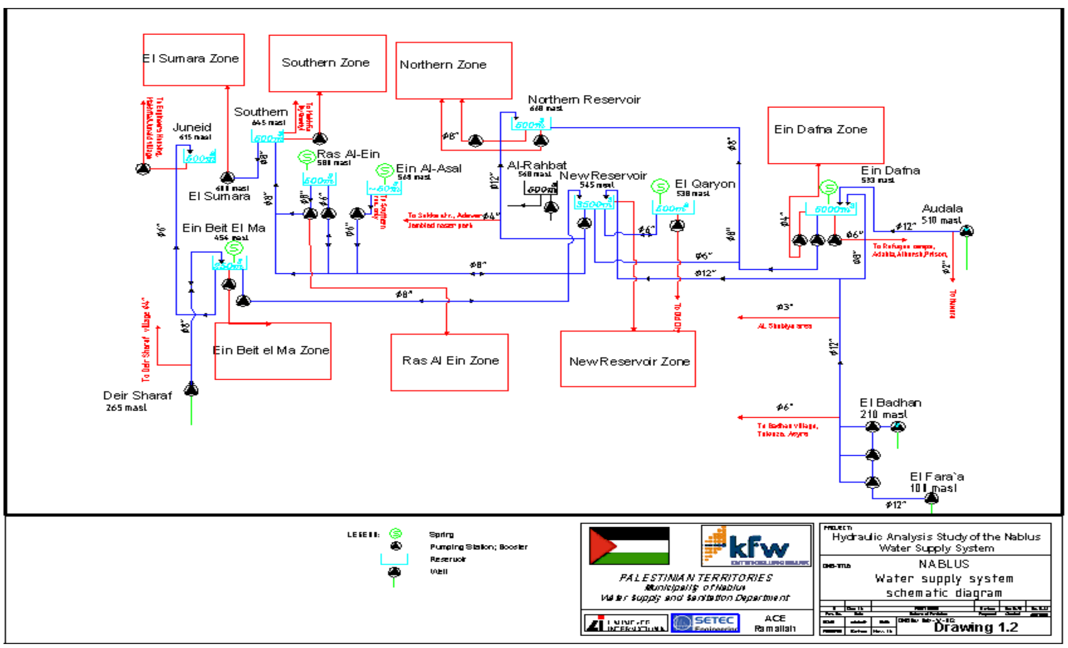

Figure 7. A schematic that shows reservoirs and pumping stations
(Lahmeyer and Setec, 2004)

Table 1: Wells and springs of Nablus Municipality

Name	Average yield(m^3/d)	Elevation m (asl)	Coordinates		location
			x	y	
Audala well	4500	510	175200	173350	8km far, south east of city
Al-Bathan well	4300	210	185610	179900	10km far east of Nablus
Al-Far'a well	6000	100	185700	182700	4km far east of Bathan well
Deir Sharaf well	3500	265	184650	166170	8km far west Nablus
Ein Beit Elma spring	1574	454	173487	181846	
A-Qaryon spring	1447	538	174836	180542	
Ras Al-Ain spring	1169	580	174344	180292	
Ein Al-Assal spring	457	563	174399	180391	
Ein Dafna spring	340	531	176426	179998	
Total m^3/d	23287				

(Lahmeyer and Setec, 2004)

Table 2: The storage reservoirs of Nablus Municipality

Reservoir	Capacity m^3	Elevation m (asl)	Year of construction	Condition
Ein Dafna	5000	531	1979	Very good
New Reservoir	3500	459	1995	Very good
Northern	500	668	1958	poor
Southern	500	645	1956	moderate
Ras Al-Ein	500	580	1953	fair
Ein Al-Assal	50	563	1952	Very poor
Qaryon	500	538	1935	moderate
Juneid	500	615	2000	Very good
Ein Beit Elma	250	454	1960	poor
Total	**11300**			
Al Worash	2000			
Al-Horsh	150	675		Out of order
Al-Rahbat	500	568	1956	Out of order

(Lahmeyer and Setec, 2004)

3.3 Water Distribution System

The water distribution network of the city consists of about 270 km of water pipes ranging in diameter from 2 to 12 inches. Recently, a 14-inch transmission link was constructed between Deir Sharaf well and Ein Beit Elma reservoir.

The existing distribution system consists of a variety of pipe types: steel, cast iron, ductile iron, and galvanized steel. Lately, the polypropylene and HDPE pipes were used (Lahmeyer and Setec, 2004). The unaccounted for water is currently about 31% (http://www.nablus.org, accessed on Jan 8, 2009).

Nablus network supplies water to nine service zones as shown in Figure 8. The zones are supplied by water intermittently by a group of skilled water staff who is managing the system mainly by using controlling valves in order to supply all customers at least twice a week in winter time and almost once a week during summer time. This depends mainly on the experience and the understanding of the duration that every zone needs to get its need of water by simply filling up all the roof tanks (see Table 1 in Appendix A).

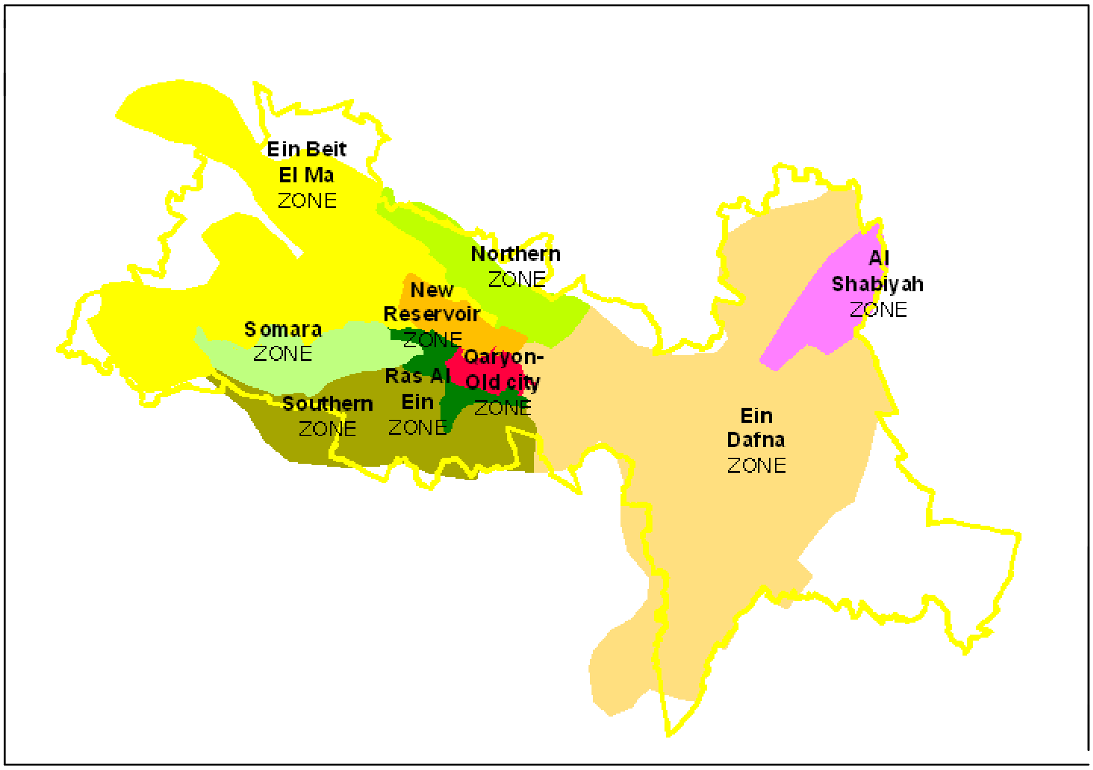

Figure 8. Supplied zones of Nablus City **(Lahmeyer and Setec, 2004)**

3.4 Water Quality

According to the Chemical analysis carried out by the Water and Environmental Studies Institute at An-Najah University, the groundwater quality of Nablus City is accepted for drinking water.

Table 2 in Appendix A summarizes the results of the chemical analysis performed in September 2006 for the wells and springs utilized by the Water Supply and Sanitation Department (Almasri, 2008). Upon examining the concentrations of the different parameters, it can be concluded that all the concentrations are below the maximum contaminant level and thus water is suitable for drinking purposes without a need for treatment.

Chlorination is the sole method of water disinfection. In general, chlorine is injected directly into the main supply at well locations (since villages receive their water immediately from the wells) or by mixing with water in the reservoirs of the pumping stations (see Figure 9).

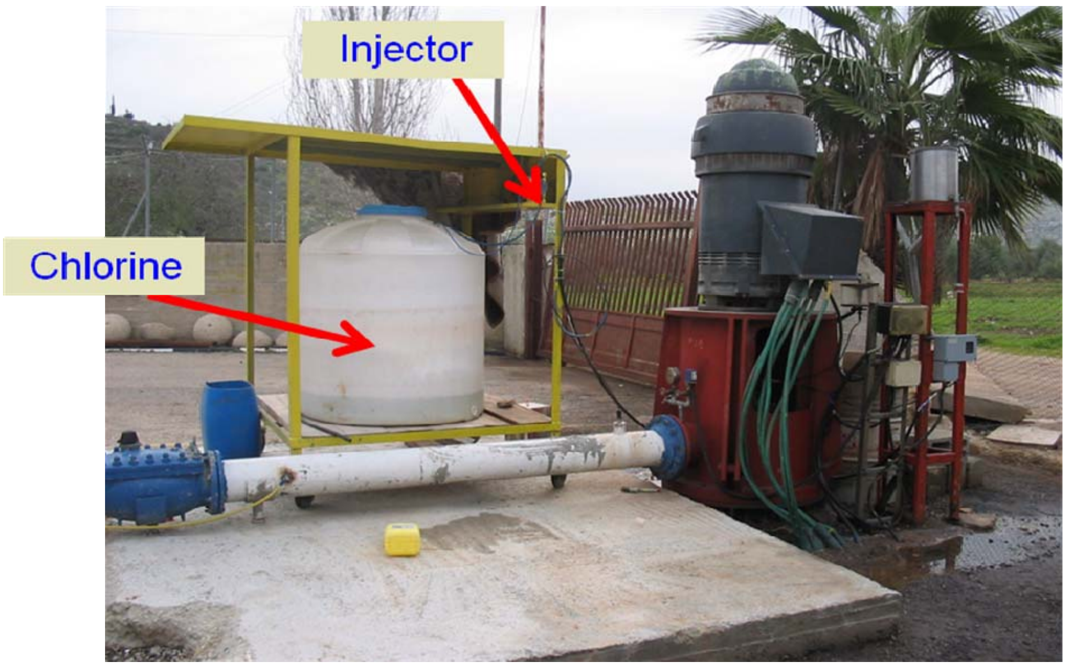

Figure 9. Chlorination tank and injector at Deir Sharaf well.

3.5 Unaccounted for water

The water distribution network of Nablus City encounters a high percentage of unaccounted for water. Figure 10 shows the percentage of unaccounted for water from 1997 to 2007 while Figure 11 shows the difference between water production and water sold where this difference indicates the unaccounted for water.

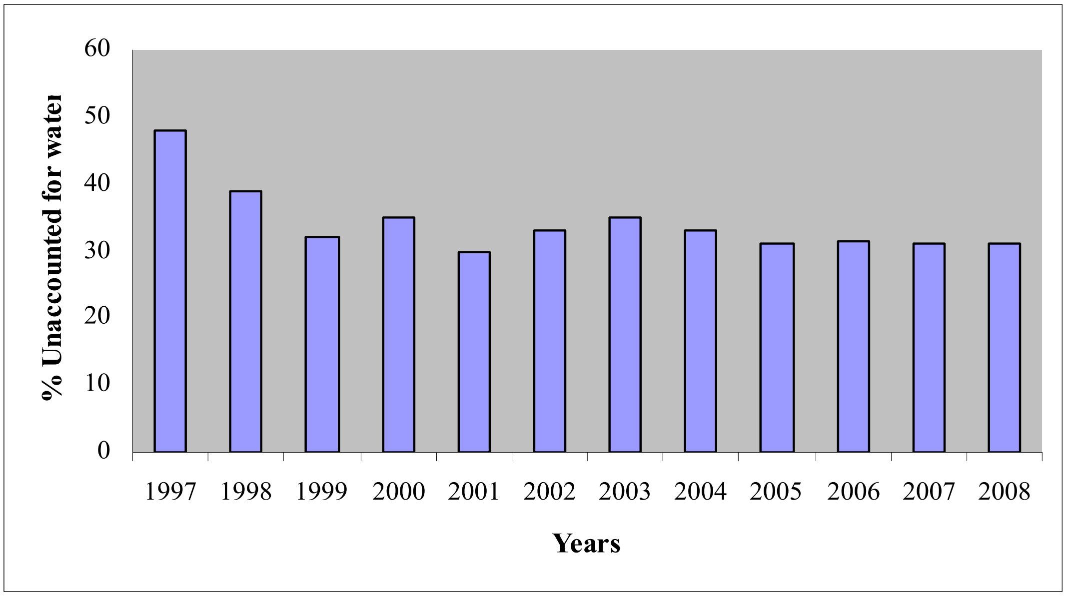

Figure 10. Percentage of unaccounted for water
(http://www.nablus.org, accessed on Jan 8, 2009).

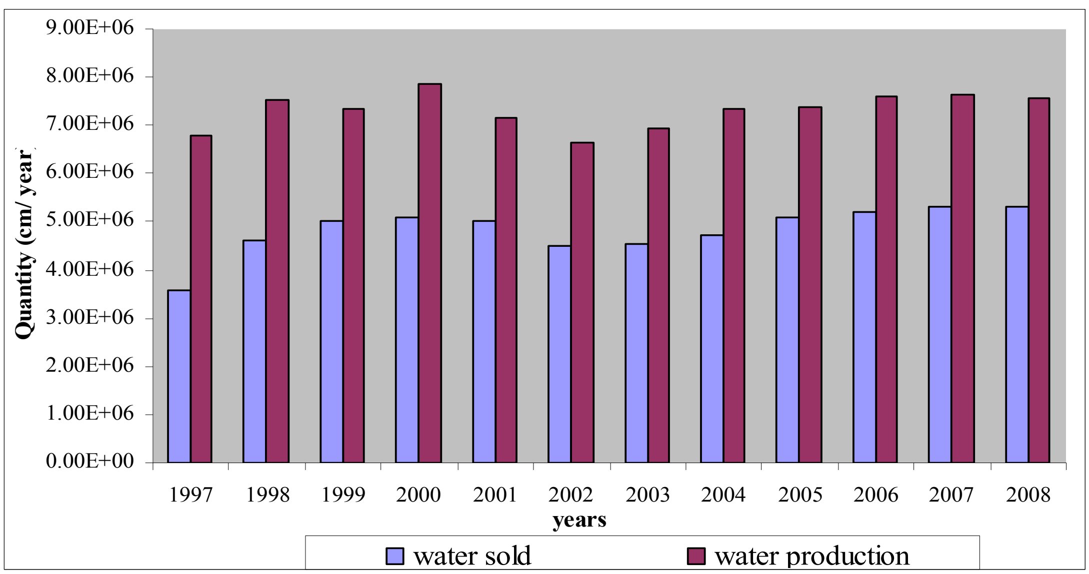

Figure 11. Water Production and water sold
(http://www.nablus.org, accessed on Jan 8, 2009).

Unaccounted for water is divided into: (1) physical losses which is called leakage. It varies spatially from location to location throughout the network depending on the age of the pipe, pressure magnitudes and proximity to the water source. Water leakage is attributed mainly to the following reasons: (i) the aged water distribution network, and the pipes diameter which is less than the required (ii) the improper linkage of houses and supplied units to the network especially for the old places, (iii) the incorrect and wrong burial of the network pipes, (iv) the failures and faults in the bulk meters located in the pumping stations. (2) Non-physical water losses which are called apparent losses, attributed mainly to the following reasons: (i) mistakes in reading meters due to the poor conditions of the household meters, and the low sensitivity of these meters to low flow rates, (ii) water thievery, and (iii) unpaid consumed quantities for example quantities for the public facilities, mosques and worship houses, schools, fire station and the slaughterhouse**.**

3.6 Water Demand and Consumption

Water demand increases with time due mainly to population growth. Therefore, new water resources ought to be developed in order to meet the increasing water demand at present and in future.

According to the Inception Report "Hydraulic Analysis Study of the Nablus Water Supply System" the potential unmet water demand in the future considering an annual growth rate of 3.5% is shown in Figure 12. This figure shows the projected average annual domestic and non-domestic water demand in the years 2005, 2015, and 2025, and the available water production and deficit of water with population growth Apparently, the unmet water demand (demand minus water availability) increases over time.

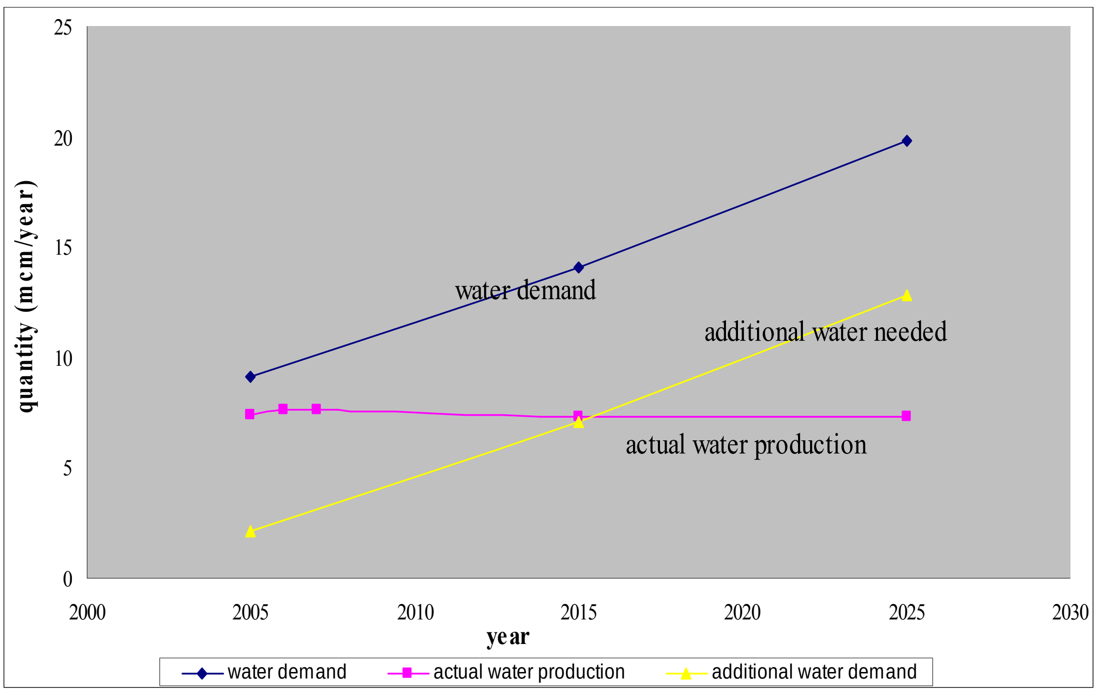

Figure 12. Water demand, water production and unmet water demand

The average per capita daily water consumption is 50 liters for villages and refugee camps and 70 liters within the city boundaries (Lahmeyer and SETEC, 2004). However, the daily water consumption varies throughout the year. For example, Figure 13 shows the average per capita daily water consumption for the years 2006 and 2007 for the Old City of Nablus. This consumption rate is below the recommended limit of the World Health

Organization (WHO) of 150 L/c-d, (http://wedc.lboro.ac.uk/WHO_Technical_Notesaccessed on Jan 11, 2009). The figure shows that the daily water consumption varies throughout the year according to climate variation from season to season, very low water consumption in winter months, but rises during summer months due to the increase in water use in bathing, cleaning, and irrigation. Also, there is a variation in water consumption from one area in the city to another, which reflects the socio-economic conditions.

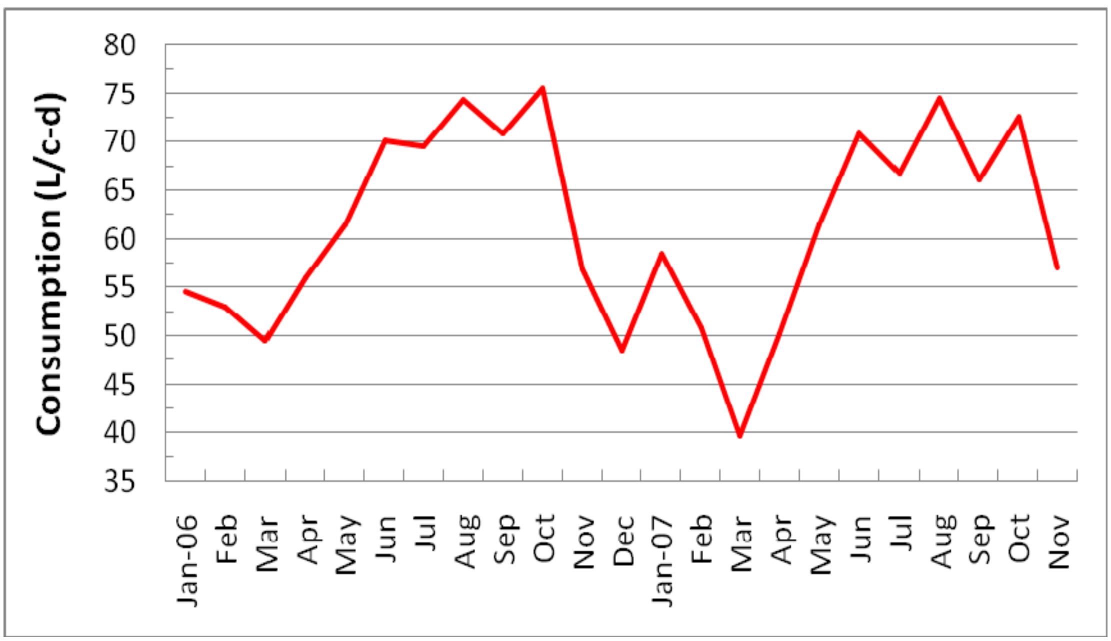

Figure 13. Average per capita daily water consumption for the years 2006 and 2007 for the Old City of Nablus **(Almasri, 2008)**

3.7 City Expansion

City expansion is characterized mainly by the increase in the built-up areas and the increase in pavements. Due to the rural-urban migration and the natural increase in population, utilizing an existing supply system or a distribution network to provide water to an extended area will result in an increase in headlosses and energy cost, especially in areas that are of high altitudes with reference to the pumping stations. In addition, urbanization has a potential negative impact on the groundwater recharge collected by the spring catchment areas. Therefore, urbanization may lead to a decline in the spring yield on the long term (figure 2 in Appendix B shows the expected expansion areas according to "Hydraulic Analysis Study of Nablus Water Supply System" Inception Report) .

3.8 Nablus City WEAP Model

The assessment model was constructed using WEAP, which operates on the basic principle of water balance for every node and link in the system subject to demand priorities and supply preferences.

Figure 14 shows Nablus WEAP model which consists of nine demand sites represented by the red circles (nodes) and eight water supply sources. The supply sources are seven reservoirs represented by green triangles and one more supply for Almasaken Al shabiyah area represented by a green square. Demand sites are connected to the water sources by transmission links (the green lines). The wastewater outflows from demand sites are represented by return flow links (the red lines) that lead to the receiving bodies (wadis).

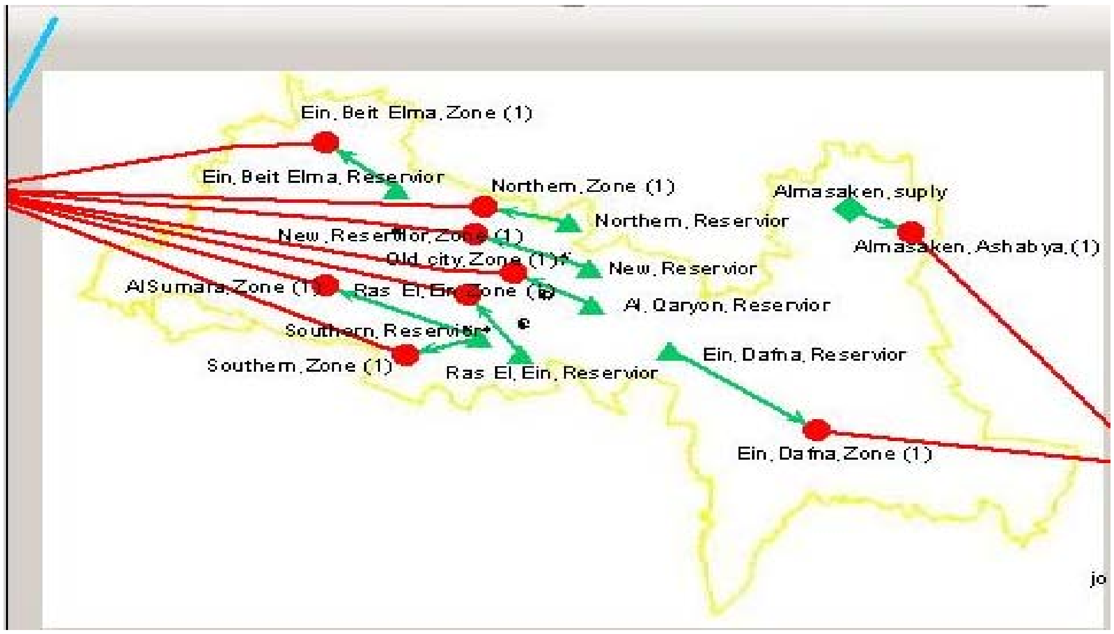

Figure 14. **Nablus City WEAP model**

3.8.1 Establishing the Current Accounts in WEAP

The current accounts represent the basic definition of the water system as it currently exists. In our case, the model simulation period is taken from 2008 to 2035, and the year 2008 was selected as the current year. The first step in this work was the development of WEAP schematic that shows all components needed in the model (water resources which are reservoirs that are connected to the demand sites by transmission links, in addition to return flow links). The data used in the model were for the year 2008, by defining the water uses in each demand site and for each user, the population or the number of devices, the population growth rate, and the per capita water use rate were defined, also monthly inflow and storage capacity for reservoirs were considered. Then four scenarios were proposed to explore the model under six management options, and finally WEAP outcomes were assessed.

Identifying current water uses: Existing water uses that are used in WEAP model can be classified as follow:

- Residential
- Health care
- Schools
- Institutions
- Industrial (only from Ein Dafna, because of the location of industrial zone)

Activity levels are used to describe the demand sites. if the demand site represents a residential site or a school, then the activity level is the number of people. If it is a health care center, then the activity level is the number of beds. For other institutions it is the number of buildings. Water use rate is the average annual water need per unit of activity.

Demand in WEAP: The demand represents the amount of water needed by the demand site for its water use. The demand for water is calculated as follows:

Total demand = Total activity level × Water use rate…………………….... (1)

Supply Elements: These elements will be defined by the main reservoirs; Ein Dafna, New, Northern, Alqaryon, Ras Elein, Southern, and Ein Beit Elma Reservoirs. These reservoirs are fed by springs and wells as shown in Figure 7. For Ashabya Zone, it gets its water needs directly from the main line of Albadan well.

The monthly inflow, storage capacity, and net evaporation for each reservoir (which is zero because they are closed) were defined. Table 3 in Appendix A shows the monthly pumping amounts to the several zones which were used in the model as monthly inflow to the reservoirs.

Supply and preference: If a demand site is connected to more than one supply source, choices for supply where a specific supply is preferred to be used firstly may be ranked using supply preferences.

Transmission links: There is a need to connect supply sources to each demand site in WEAP model to satisfy the demand through creating a transmission link from supply nodes to demand sites to satisfy final demand at the demand sites. These transmission links are subject to losses that are about 31% (http://www.nablus.org, accessed on Jan 8, 2009). As such, the total amount delivered to the demand site equals the amount withdrawn from the source minus the losses.

Return flow links: These links are used to transmit wastewater from demand sites to destinations such as wastewater treatment plants or receiving water bodies.

Priorities for water allocation: Competing demand sites allocate water according to their demand priorities. These priorities are useful during a water shortage where sites with higher priorities are satisfied as fully as possible before lower priority sites are considered.

3.8.2 WEAP Input Parameters

In order to build up the WEAP model, the current supply and demand data were entered to WEAP model. Table 4 in appendix A and Figure 15 show the demand data entry table in WEAP).

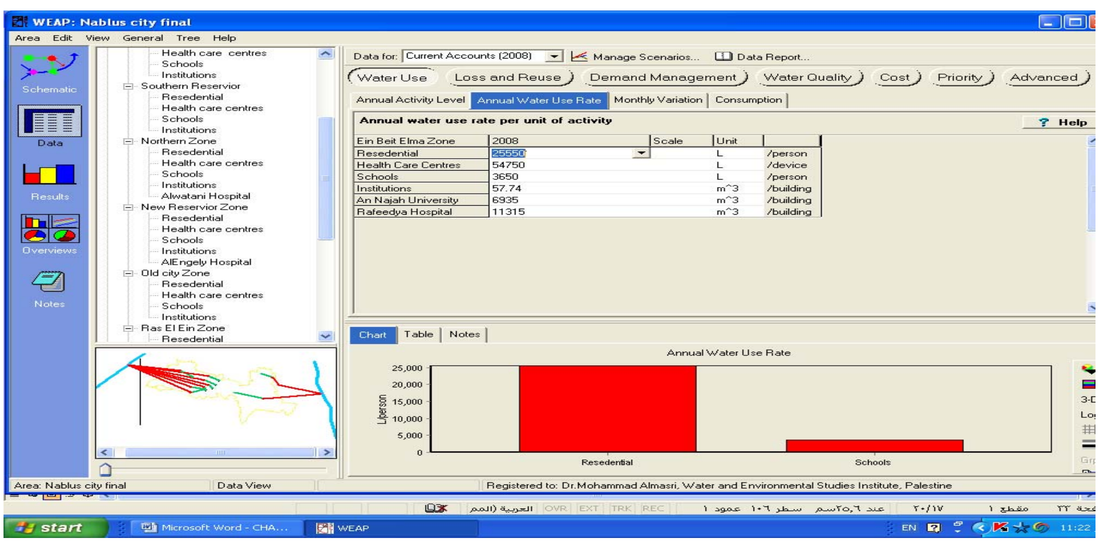

Figure 15. **Demand data entry table**

CHAPTER FOUR

ANALYSIS OF SCENARIOS AND MANAGEMENT OPTIONS

4.1 Introduction

In this chapter, the assessment of the different management options that correspond to scenarios will be demonstrated using WEAP model. Scenarios were built using WEAP, and then their impacts on water supply and unmet water demands in the city were assessed. Figure 16 shows the proposed management options for the different scenarios that were assessed using the developed WEAP model.

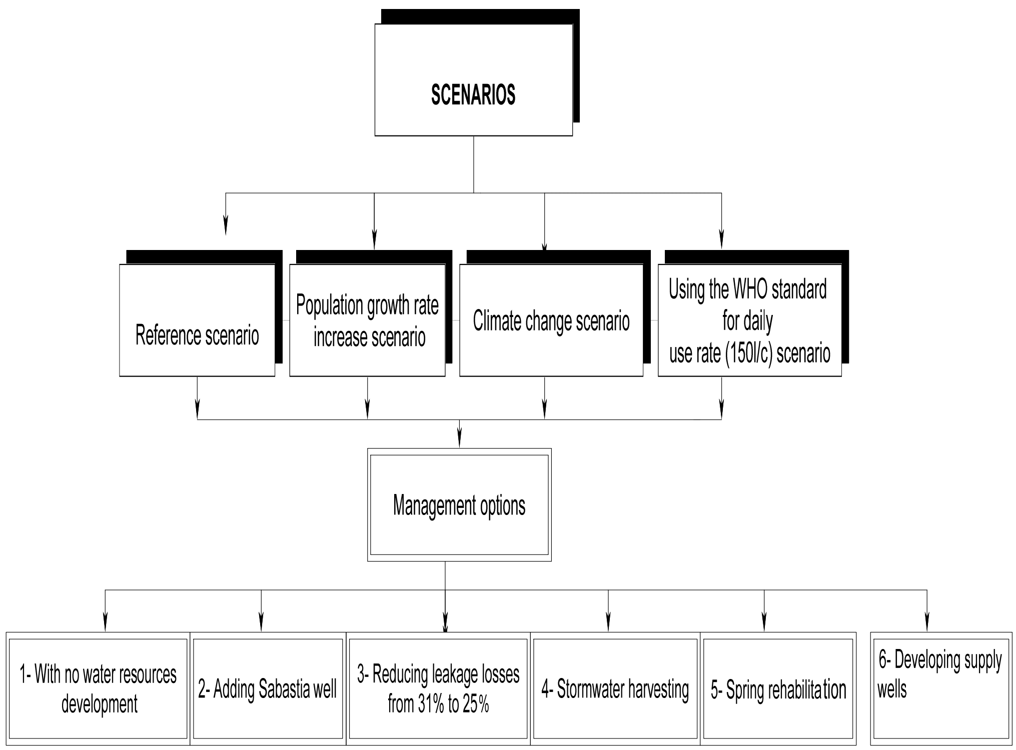

Figure 16. The scenarios and the management options for the City of Nablus as assessed by the WEAP model

The following sections illustrate these scenarios and the corresponding management options along with the assessment carried out using WEAP.

4.2 Scenarios

Four main scenarios were considered in the assessment:

- Scenario 1 (Reference scenario): This scenario represents the current system conditions with its water supplies (reservoirs) and demand sites (with population, annual use rates). It starts from a common year for which the model current accounts data are established. In this study, the current year is 2008. This scenario represents the changes that are likely to occur in future under conditions depicted in Figure 17.

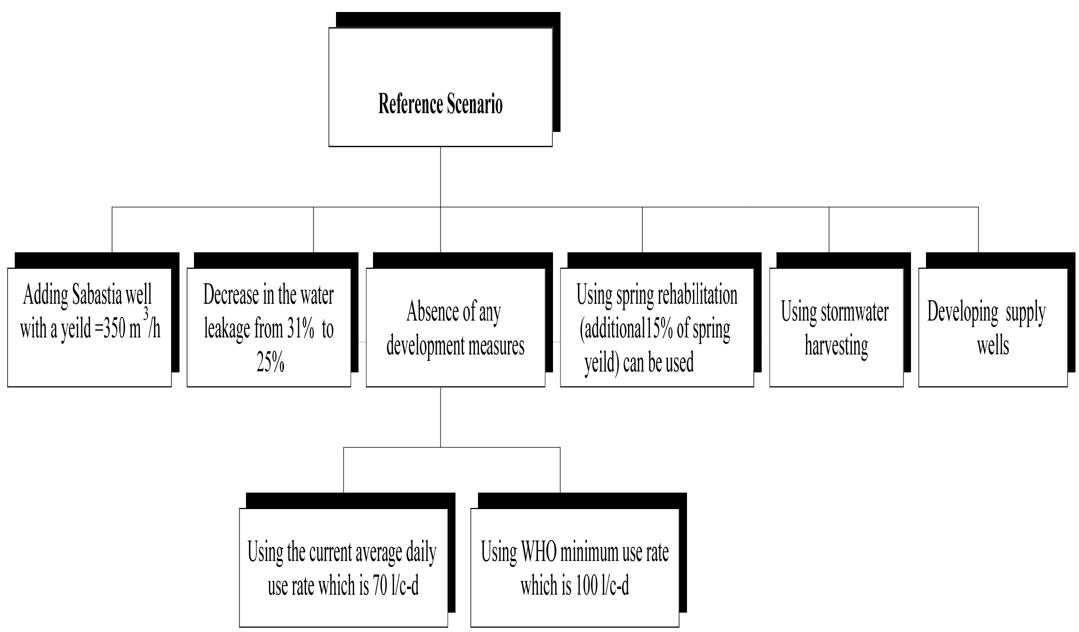

Figure 17. Reference Scenario and Corresponding Management Options

- Scenario 2: Population growth increases more than 2.6% to be 3%. This increase is due to the assumption of improving the city conditions (economic and political conditions) which encourages people who immigrate to another city or country to return to the city. In addition, the placement of people from villages to the city is another cause to the increase in population growth.

- Scenario 3: Climate change which is the change in magnitude of a single climate parameter such as temperature. The assumption that there will be a decline in the yield of the water resources can be attributed to the potential impact of climate variability which may lead to a decline in spring and well yield and groundwater recharge below the average values (Almasri, 2008). In this scenario the effect of climate change on water resources and the yield, and how this change will affect water supply and the unmet water demand were considered.
- Scenario 4: This scenario uses the WHO standard for daily use rate which is 150 l/c-d. Thus, this scenario shows how is the unmet demand will increase under the existing conditions and management options.

4.3 Management Option

4.3.1. Key Factors

The key factors that have significant effects on developing water resources and the formulation of the management options under different scenarios are:

1- Political constraints: this is represented by the Israeli restrictions on all the development schemes of existing and new water resources for the City of Nablus. For example, difficulties to lay new pipes or replacement of existing transmission lines that connect groundwater wells with their reservoirs. This is an apparent problem when these transmission lines are located partly outside Nablus City behind the check-points. In addition, the obstructions to get a license to dig a new well, which takes several years of negotiations. Even if the license is granted, there will be restrictions on the well depth and thus well productivity.

2- Financial constraints: Since the available funds for water resources development are scarce and depends on external donations, the choices for water supply alternatives will be restricted in magnitudes to these funds. For example, there is a water leakage reduction project in Nablus network in which there will be a replacement of the old pipes by new ones with higher diameters. This project is funded by KFW. There is a lot of projects which need funds to implement, like a wastewater treatment plant in the east of Nablus, separation of the wastewater from stormwater, construction of reservoirs to save the unused water from springs in winter months.

3- Socio–Economic Aspects: Water resources development should go beyond the mere allocation of certain quantities of water concerned with the quality of life for people, in addition, although water is available it cannot be afforded to pay for it.

4.3.2 Management Options

The following are the management options that are proposed by the Municipality of Nablus:

- Developing a new groundwater well in Sabastia (Sabastia well): There will be an additional quantity of water supply due to the construction of the new well with a yield of 350 m^3/h, 250 m^3/h for the city and 100 m^3/h for the neighboring villages (personal communications, Eng. Areej Kittaneh, Nablus Municipality).It is funded by Arab Fund for Economic Development in cooperation and partnership with Palestinian Water Authority (see Figure 18). In this option additional quantity of 50 m^3/hr from Rujeib well will be added.

Figure 18. Sabastia Well during construction

- Reduction in water leakage: by improving the water infrastructure, the unaccounted for water rates will be reduced and losses will drop to 25% in this option.
- Storm water harvesting: The City of Nablus utilizes a combined system for wastewater and stormwater collection. The estimated volume of urban stormwater is approximately 2-4 mcm/yr (Lahmeyer and Setec, 2004) which is completely lost through the two major drainage systems of the city. This situation deprives the city from the potential reuse of the collected stormwater. Recently and when carrying out new construction and rehabilitation works for the sewerage system, the WSSD started to separate between the wastewater and stormwater collection systems.
- Rehabilitation of springs: Based on the estimates furnished in the "Hydraulic Analysis Study of the Nablus Water Supply System" . Additional water quantities can be obtained from the city springs once rehabilitated. This implies an additional amount of water of about 15% of springs' yield that can be utilized for domestic purposes. Spring rehabilitation implies storing the lost water from springs during winter months.
- Wastewater reuse: The increase in demand for the limited raw water resources has led to the proposals of reusing treated wastewater in agricultural production, industrial cooling, landscape watering and recharges to aquifers. This in turn will be on the expense of reducing the use of fresh water in these applications and thus more fresh water

can be used to supply for potable water needs. Wastewater in the City of Nablus is being disposed of without treatment. After leaving the two main outfall points (in the east and west), untreated wastewater flows in open channels (wadis) as shown in Figure 19. Recently, an approval was given for the construction of Wastewater treatment plant (WWTP) in the western part of Nablus, which receives wastewater daily inflows of about 6000 m^3 according to the Sewerage Project Nablus West Report 2. The effluent standards will be determined to be: BOD5 20 mg/l, SS 30 mg/l, N (total nitrogen) 50 mg/l (Lahmeyer, 2007). The effluent of treated wastewater will be used for agricultural irrigation in the nearby villages. This option will not be used in this study since it needs advanced treatments to use for public services in the city.

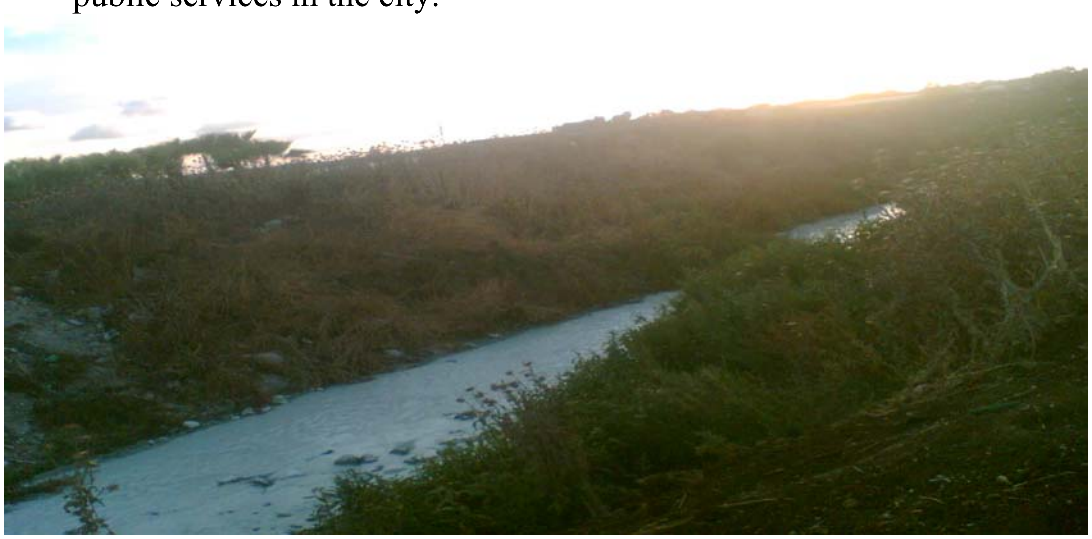

Figure 19. Wadi Zeimer

- Developing new groundwater wells: Based on different hydrological studies (for instance, the "Hydraulic Analysis Study of the Nablus Water Supply System") additional eight new wells can be developed to supply Nablus with additional water quantities. The proposed wells can provide some 9.3 mcm/yr. The potential new wells are shown in Figure 20 (Table 5 in Appendix A).

  But this option is not realistic and still not applicable because the municipality cannot construct all these wells at once and there will be Israeli restrictions and financial constraints. This study consider the development of four wells at different time steps: By using Deir Sharaf N 3 which will start at the year 2015 with a yield of 1.1 mcm/year, using Deir Sharaf N 4 which starts in the year of 2020 with an annual yield of 1.8 mcm, using Yutma N 1 which starts in the year of 2025 with an annual yield of 1.5 mcm/year, and finally using Yutma N 2 with a yield of 1.5 mcm/year and starts in the year 2030.

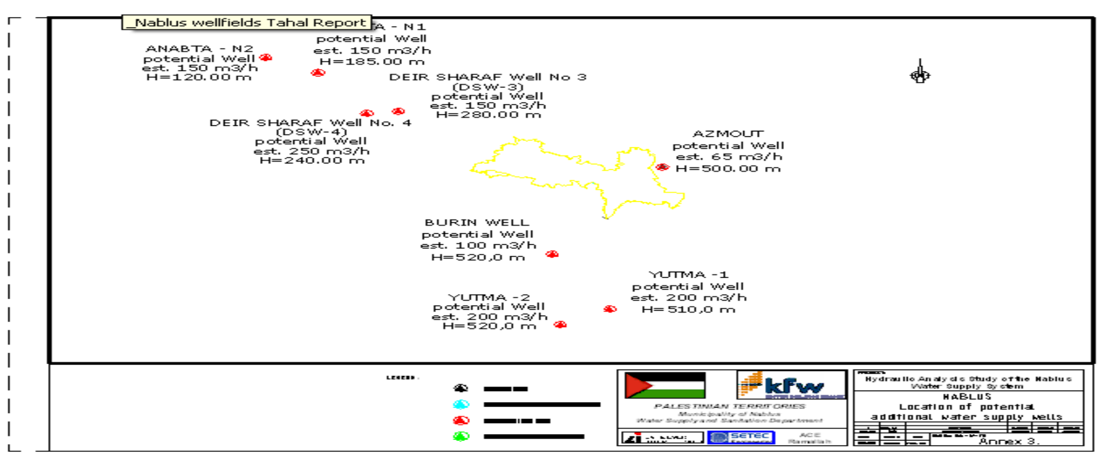

Figure 20. Potential new wells locations **(Lahmeyer and SETEC, 2004)**

Table 3 summarizes the proposed future scenarios and the management options.

Table 3: Summary of future scenarios and management options

Scenarios	**Description**		
Population increase	In this scenario, the impact of increasing the population growth rate to be 3% on water demand, and the unmet water demand, was assessed under potential management options, using the minimum standard for daily use rate which is 100 l/c-d.		
	Management options		Description
	1	With no water supply development	The impact of population growth increase on water demand, and the unmet water demand, with no new water resources were developed
	2	Construction of Sabastia well	The impact of increasing the amount of water supplied by adding Sabastia well 300 m^3/h (250 m^3 from sabastia+50m^3 from Rujeib)
	3	Rehabilitation of springs	The impact of additional 15% of springs yield (202025 m^3/year) that can be utilized for domestic purposes will be evaluated
	4	Reduction in water leakage	The impact of decreasing the water leakage to 25% instead of 31% on the unmet water demand
	5	Stormwater harvesting	The impact of increasing the amount of water supplied by adding the amount of stormwater harvesting, which can be used in public services and it is estimated to be 2 mcm/year

	6	Construction of additional supplied wells	The impact of increasing the amount of water supplied by construction: 1- Deir Sharaf well N 3 with yield 1.1 mcm/year (from 2015-2035) 2- Deir Sharaf N 4 well with yield 1.8 mcm/year (from 2020-2035). 3- Yutma N 1 with yield 1.5 mcm/year (from 2025-2035). 4- Yutma N 2 with yield 1.5 mcm/year (from 2030-2035). (These wells will feed all reservoirs in the model)
Climate change	Considering the negative impacts of climate change accompanied with declining rates in water resources replenishment due to decrease in rainfall amounts and the increase in water demand due to increase in temperatures, using the minimum standard for daily use rate which is 100 l/c-d, the assumption of declining 20% of the water sources yield		
	1	With no water supply development	The impact of declining of wells and springs yield, which is assumed to be 20% of its average yield on the unmet water demand. No new water resources development are considered
	2	Construction of Sabastia well	The impact of adding Sabastia well which in turn will be affected by climate change, which leads to a decline in its yield to be 240 m^3/h
	3	Rehabilitation of springs	The impact of reduction the amount of springs rehabilitation which is declined 20% estimated to be 0.161 mcm/year

	4	Reduction in water leakage	The impact of decreasing the water leakage to 25% on the unmet water demand under climate change condition
	5	Stormwater harvesting	The impact of reduction the amount of stormwater harvesting which is declined 20% estimated to be 1.6 mcm/year
	6	Construction of additional supplied wells	The impact of climate change on the yield of the proposed new wells which will decline 20%: 1- The yield of Deir Sharaf well N 3 will be 0.88 mcm/year 2- Deir Sharaf N 4 well with yield 1.44 mcm/year. 3- Yutma N 1 with yield 1.2mcm/year. 4-Yutma N 2 with yield 1.2 mcm/year
Using WHO daily use rate standard	In this scenario, the standard of WHO for capita daily use rate, which is 150 l/c-d will be used to evaluate the existing supply systems and management options.		
		Management options	Description
	1	With no water supply development	The impact of increasing the daily water use rate to be 150 l/cd on water demand, and the unmet water demand, with no water resources development.
	2	Construction of Sabastia well	The impact of increasing the amount of water supplied by adding Sabastia well on the unmet water demand with increasing in water demand
	3	Rehabilitation of springs	The impact of additional 15% of springs yield (202025 m^3/year) that can be utilized for domestic purposes on unmet water demand

			will be evaluated
	4	Reduction in water leakage	The impact of decreasing the water leakage to 25% on the unmet water demand under the increase of water use rate
	5	Stormwater harvesting	The impact of increasing the amount of water supplied by adding the amount of stormwater harvesting which is estimated to be 2 mcm/year, under the increase of water use rate.
	6	Construction of additional supplied wells	The impact of increasing the amount of water supplied by construction Deir Sharaf well N 3 , Deir Sharaf well N 4 , Yutma N 1 ,Yutma N 2 on the unmet water demand, under the increase of water use rate.

4.4 Results

WEAP was applied to assess all the proposed scenarios and recommended management options. A summary of sample results is provided in Tables 4.1, 4.2, 4.3, and 4.4. WEAP provides the results in charts (See Figures 21 and 22) or in tables, which include all demand sites (including all users: residential, health care centers, schools, institutions), and can show the results for every user in each demand site (for example see Table 6 in Appendix A, which shows the estimated water demand for the residential uses in Ein beit elma zone). .

Tables (7, 8, 9, and 10) in Appendix A show the outcomes of the different management options related to the different scenarios. These tables show the water demand and the unmet water demand in each year of the simulation period which increase with time for every zone. For example, in Table 7 the water demand in 2011 when 100 l/c.d is considered equals 6.74 mcm, and the unmet water demand when no water resources development is 2.94 mcm, 1 .13 mcm when Sabastia well is considered, 2.66 when water leakage is reduced, 1.56 mcm for stormwater harvesting, 2.8 mcm for spring rehabilitation, and 2.94 mcm for the option of developing new well. .

Summary of sample results for different scenarios and management options

Table 4.1: Reference Scenario

Reference Scenario									
		Water demand (mcm)				**Unmet water demand (mcm)**			
Management options		**2010**	**2015**	**2025**	**2035**	**2010**	**2015**	**2025**	**2035**
1	With no water supply development using 70 l/cd	4.74	5.35	6.84	8.76	1.327	1.789	3.39	4.896
	With no water supply development using 100 l/cd	6.58	7.44	9.54	12.26	2.789	3.621	5.645	8.265
2	Construction of Sabastia well					0.976	1.808	3.832	6.452
3	Reduction in water leakage					2.540	3.313	5.337	7.95
4	Stormwater harvesting					1.409	2.24	4.265	6.88
5	Rehabilitation of springs					2.65	3.48	5.506	8.126
6	Development of new wells					2.789	2.862	2.609	4.194

Table 4.2: Population growth increase scenario

Population growth increases									
		Water demand (mcm)				**Unmet water demand (mcm)**			
Management options		**2010**	**2015**	**2025**	**2035**	**2010**	**2015**	**2025**	**2035**
1	With no water supply development using 100 l/cd	6.69	7.72	10.27	13.70	2.905	3.887	6.345	9.64
2	Construction of Sabastia well					1.09	2.073	4.53	7.835
3	Reduction in water leakage					2.63	3.578	6.036	9.34
4	Stormwater harvesting					1.525	2.508	4.969	8.27
5	Rehabilitation of springs					2.765	3.747	6.205	9.509
6	Development of new wells					2.905	3.128	3.916	6.391

Table 4.3: Climate change scenario

Climate change scenario									
		Water demand (mcm)				**Unmet water demand (mcm)**			
Management options		**2010**	**2015**	**2025**	**2035**	**2010**	**2015**	**2025**	**2035**
1	With no water supply development using 100 l/cd	6.58	7.44	9.54	12.26	3.498	4.33	6.354	8.974
2	Construction of Sabastia well					2.047	2.88	4.904	7.524
3	Reduction in water leakage					3.252	4.084	6.108	8.728
4	Stormwater harvesting					2.394	3.226	5.25	7.870
5	Rehabilitation of springs					3.287	4.219	6.24	8.863
6	Development of new wells					3.498	3.845	3.925	5.7179

Table 4.4: Adopting the WHO daily use rate standard scenario

Using WHO daily use rate standard									
		Water demand (mcm)				**Unmet water demand (mcm)**			
Management options		**2010**	**2015**	**2025**	**2035**	**2010**	**2015**	**2025**	**2035**
1	With no water supply development using 100 l/cd	9.663	10.95	14.07	18.12	5.758	6.997	10.009	13.906
2	Construction of Sabastia well					3.945	5.184	8.196	12.092
3	Reduction in water leakage					5.45	6.689	9.700	13.597
4	Stormwater harvesting					4.378	5.617	8.629	12.526
5	Rehabilitation of springs					5.619	6.858	9.869	13.766
6	Development of new wells					5.758	6.238	6.97	9.835

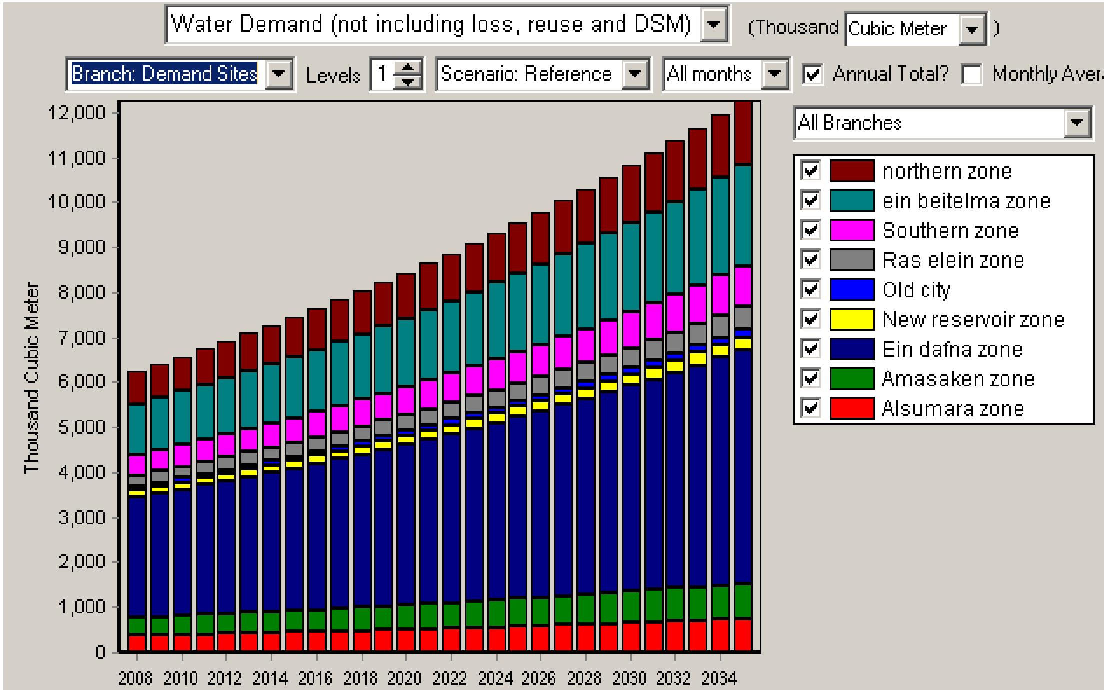

Figure 21. Projected water demand for using 100 l/c-d scenario

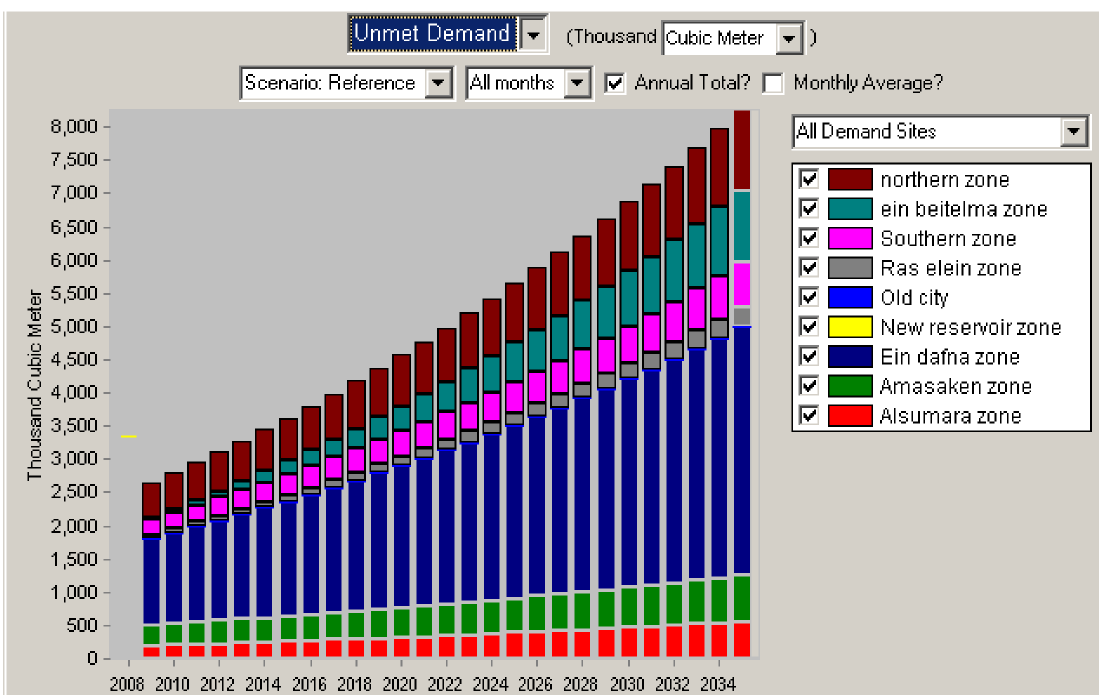

Figure 22. Unmet water demand when using 100 l/c-d scenario

4.5 Discussion of results

- WEAP estimates the water demand and the unmet water demand for every zone alone taking in consideration the amount of supplied water to every zone, then adds the water demand or the unmet water demand for all zones together at the end of every year.
- The reference scenario WEAP results indicate the following:

  1- The total water demand will increase from 4.738 mcm in 2010 to 8.768 mcm by the end of 2035 when using the current average use rate of 70 l/c-d. This increase is due to population growth only. However, if the use rate reaches the minimum standard of WHO which is 100 l/c-d, then the amount of water demand will increase by 1.84 mcm to be 6.579 mcm in 2010 and by 3.49 mcm to be 12.26 mcm in 2035. The amount of unmet water demand will increase by 1.46 mcm to be 2.78 mcm in 2010, while for the year 2035 it will increase 3.37 mcm to be 8.26 mcm.

  This is illustrated in Figures 28 and 29

  2- The per capita water availability will decrease to become approximately 37 l/c-d at the end of the year 2035 if the available water remains the same and no new water resources will be developed (see figure 23).This decrease is due to the increase in water demand that accompany population increase with the same water available.

  3- The decrease in the amounts of the unmet water demand when using the different management options are as summarized in Table 5, which show the amount that every management option will decrease the unmet water demand.

4- Figures 24, 25, 26, and 27 show the unmet water demand for the different management options under the different scenarios. The most effective option for the period 2009-2025 is the construction of Sabastia well that gives the lowest unmet water demand during this period , and from the year 2025 until 2035 is the development of new groundwater wells since this will be more efficient in covering the unmet water demand. In this option the unmet water demand will start to decrease about 0.759 mcm when adding the first well in 2015, in 2020 the second well will be added then the unmet water demand will continue to decrease by an amount of 2 mcm until 2025 where the third well will be added that will decrease the unmet water demand to 3.036 mcm until 2030. The decrease here is more than Sabastia well option decrease, so in this period this option becomes more effective than Sabastia well option. The last well will be added in 2030, and then the unmet water demand will decrease by 4.07 mcm. The option of using stormwater harvesting gives satisfactory results in decreasing the unmet water demand better than the options of spring rehabilitations and the reduction in water leakage which give small decrease amount in unmet water demand.

- For the increase in population growth rate by 0.4%, the water demand increases by an amount of 0.12 mcm in the year 2010, and by an amount of 1.435 mcm in the year 2035.

- Using 150 l/c daily use rate scenario and when comparing the water demand for the different daily use rates in the year 2010 (see Figure 28) we got the following estimates:

  70 l/c-d = 4.74 mcm

  100 l/c-d = 6.579 mcm

  150 l/c-d = 9.663 mcm

  The water demand when using 150 l/c-d has increased by an amount of 4.9 mcm when using 70 l/c-d and 3.08 mcm when using 100 l/c-d. Also the unmet water demand increased by an amount of 4.43 mcm when using 70 l/c-d, and by an amount 2.97 mcm when using 100 l/c-d (see Figure 29).

- The connections between reservoirs are not possible in WEAP. This makes it impossible to transmit the surplus water between reservoirs and thus the unmet water demand cannot be possibly reduced. To overcome this problem, I tried to consider all demand sites as one demand site and all water sources as one source (by adding all water quantity available together). Tables 11, 12, 13, and 14 in Appendix A show the actual final unmet water demand in the City of Nablus

Table 5: The decrease in the unmet water demand for the different management options

Reference, Population growth increase, and Using WHO daily use rate standard scenarios		Decrease in unmet water demand (mcm)			
Management options		**2010**	**2015**	**2025**	**2035**
1	Construction of Sabastia well	1.813	1.813	1.813	1.813
2	Reduction in water leakage	0.308	0.308	0.308	0.308
3	Stormwater harvesting	1.38	1.38	1.38	1.38
4	Rehabilitation of springs	0.14	0.14	0.14	0.14
5	Development of new wells	0	0.759	3.036	4.071
Climate change scenario					
1	Construction of Sabastia well	1.4506	1.4506	1.4506	1.4506
2	Reduction in water leakage	0.246	0.246	0.246	0.246
3	Stormwater harvesting	1.104	1.104	1.104	1.104
4	Rehabilitation of springs	0.112	0.112	0.112	0.112
5	Development of new wells	0	0.607	2.429	3.257

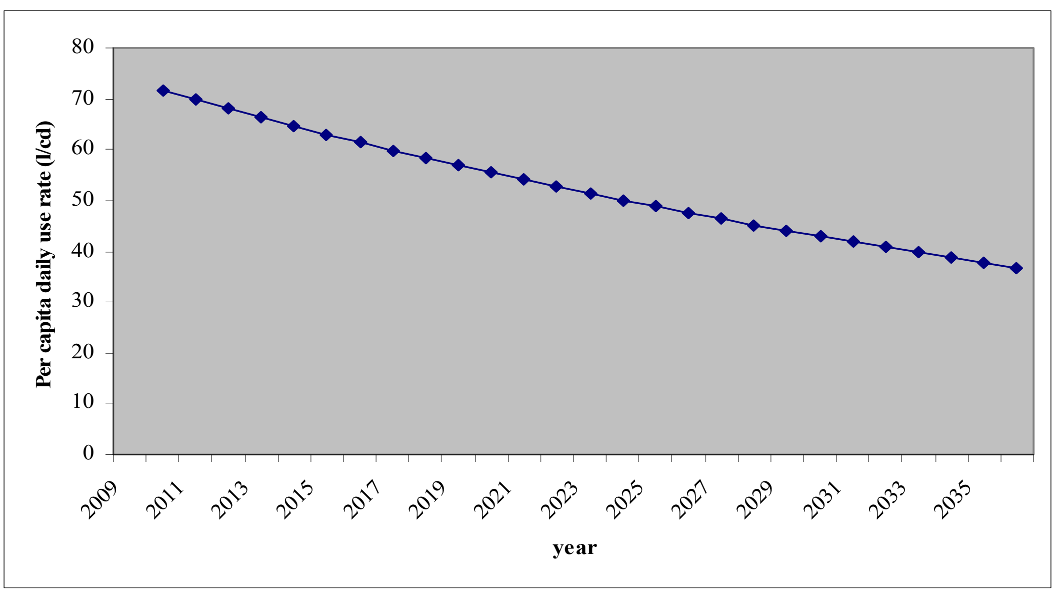

Figure 23. Average yearly per capita daily water use rate

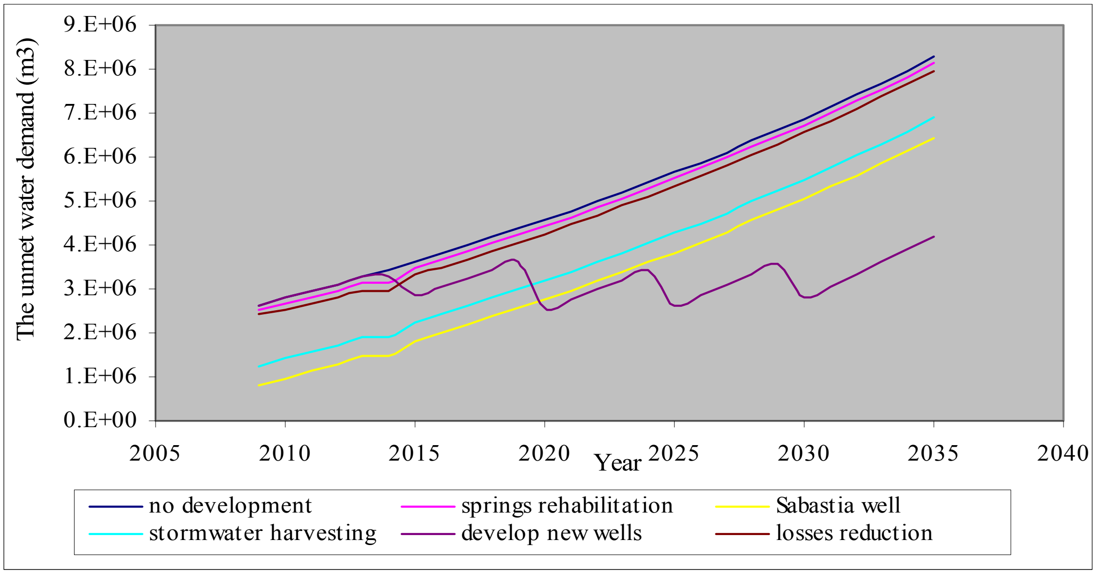

Figure 24. The unmet water demand under the reference scenario for the different management options

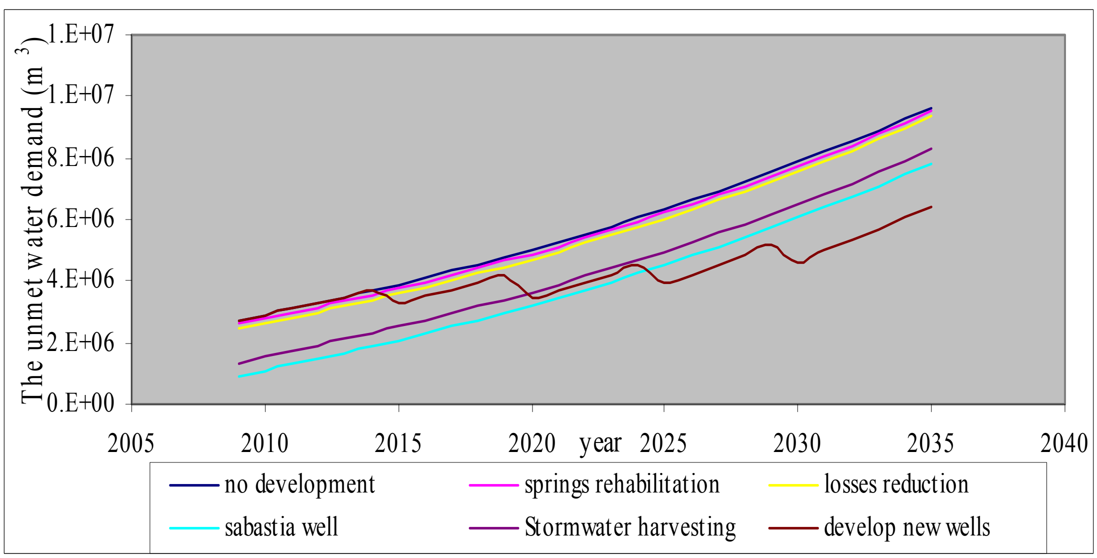

Figure 25. The unmet water demand under the population growth rate scenario for the different management options

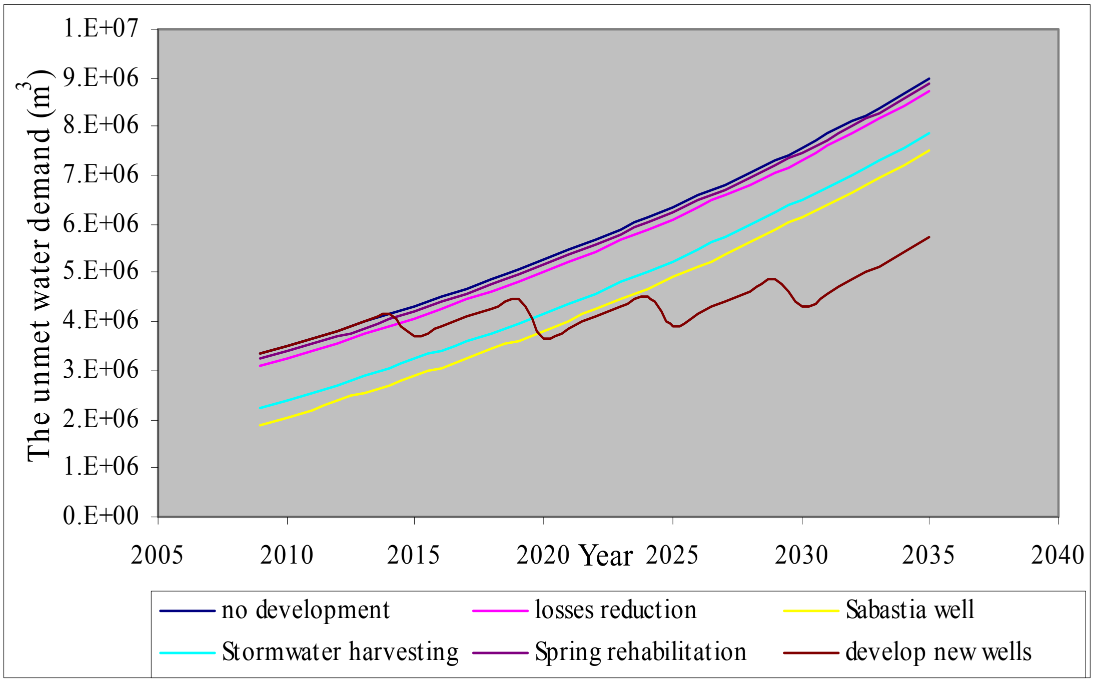

Figure 26. The unmet water demand under climate change scenario for the different management options

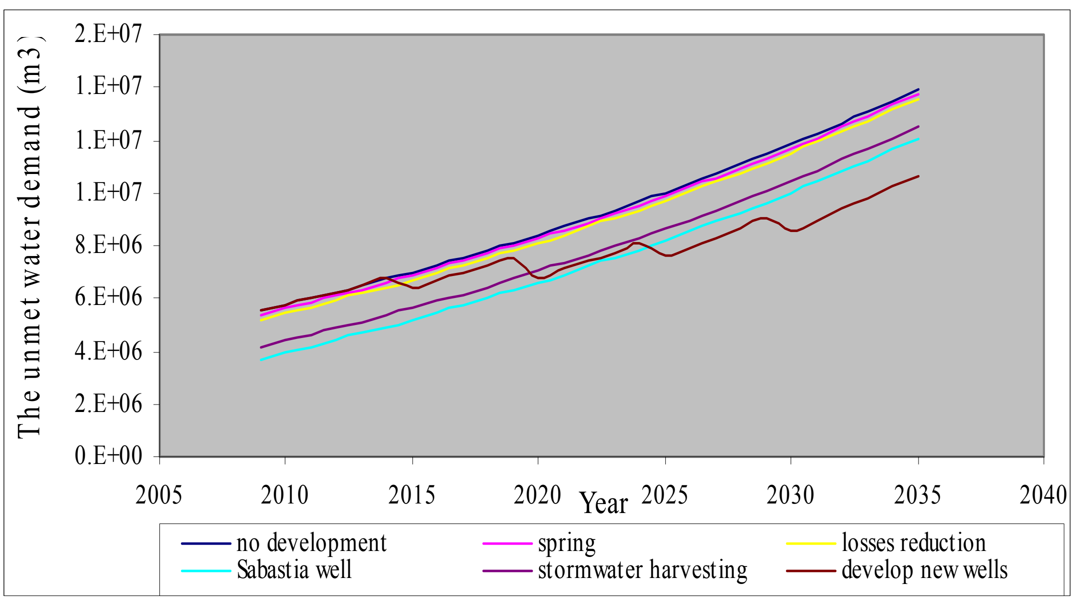

Figure 27. The unmet water demand under 150 l/c-d scenario for the different management options

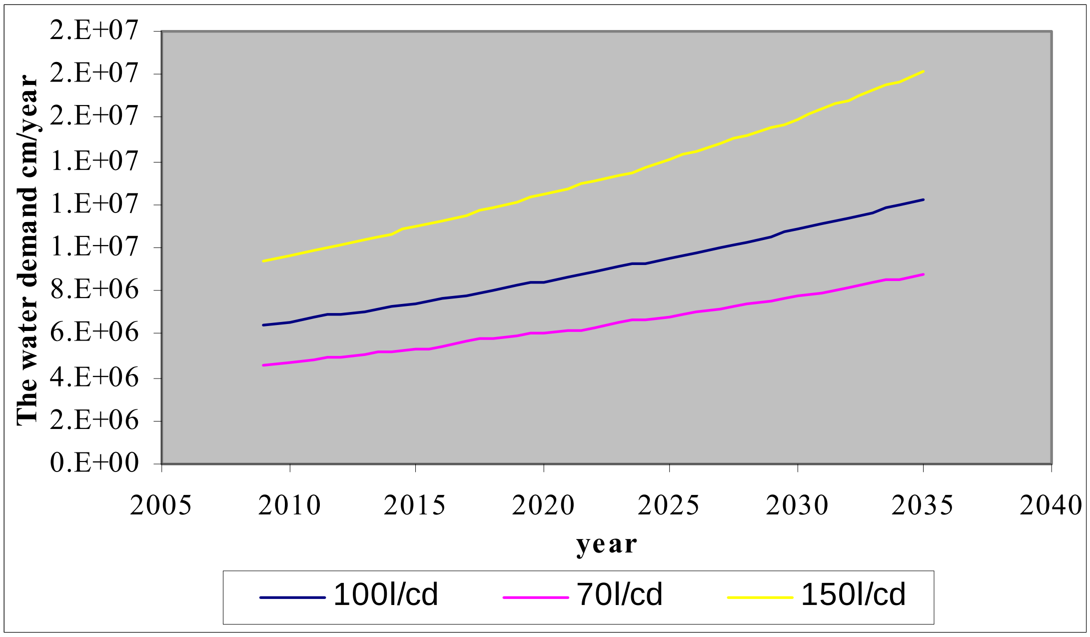

Figure 28. Water demand for 70 l/c-d, 100 l/c-d, and 150 l/c-d use rate

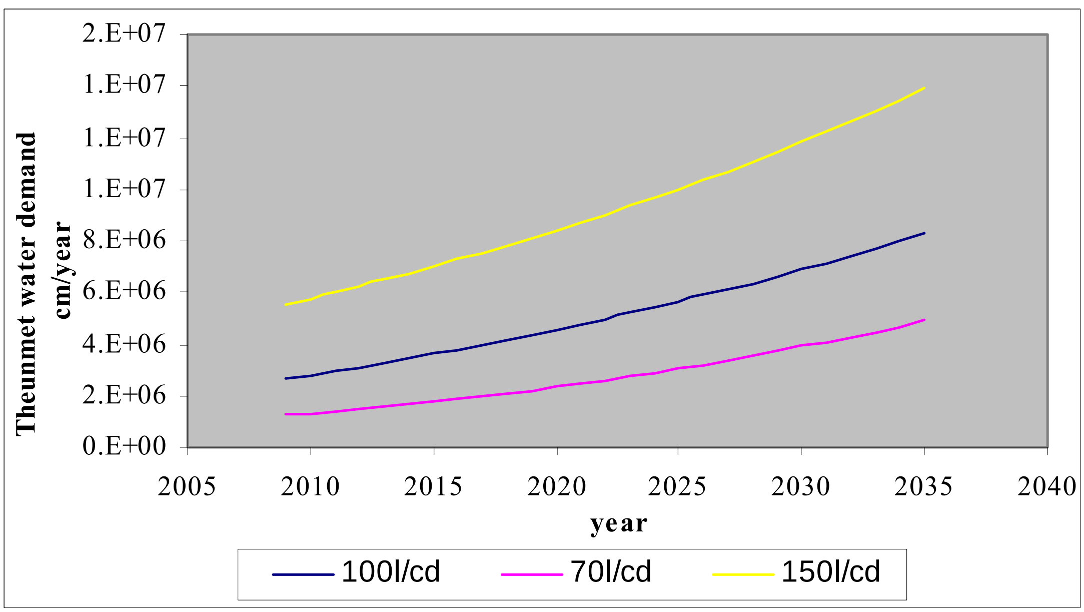

Figure 29. The unmet water demand for 70l/c-d, 100l/c-d, and 150l/c-d use rate

CHAPTER F IVE

CONCLUSIONS AND RECOMMENDATIONS

The following are the main conclusions and recommendations:

5.1 Conclusions

1. The results show that the unmet water demand will continue to increase over the coming years. This is mainly due to the increase in population with limited water resources. Therefore, securing additional water supplies becomes an essential issue to meet the increase in water demand.
2. The per capita water availability will decrease to reach approximately 37 l/c-d by the end of the year 2035 if the available water remains the same and no new water resources are developed.
3. The development of additional groundwater wells for water supply is an influential option especially for the period from 2025 to 2035. The option of using Sabastia well, will be an efficient option till the year of 2025. Stormwater harvesting gives satisfactory results. Improving the water-related infrastructure of the city to decrease the water losses is crucial in mitigating the water shortage problem.
4. WEAP has many shortcomings that I did experience such as:
    i. The connections between reservoirs are not possible in WEAP. This makes it impossible to transmit the surplus water between reservoirs and thus the unmet water demand cannot be reduced possible.
    ii. No connections can be made between groundwater wells and reservoirs.

iii. Assessment of all options simultaneously cannot be carried out.

5.2 Recommendations

1. Since this is the first time to use WEAP at the city level, additional work should follow in this regard by other researchers in order to address all the outstanding issues including carrying out economic analysis.
2. To better improve the outcome of this work, stakeholder involvement should be considered when executing similar work.
3. It is highly recommended that Nablus Municipality has a better and well-arranged database that summarizes and contains all the information regarding water use rates for the different sectors in the city.
4. Since the deteriorated infrastructure is responsible for water leakage, it is highly recommended to carry out rehabilitation activities.
5. The Municipality of Nablus should continue working on public awareness campaigns, though people are consuming an average amount of water way less than the WHO standards. This is just to urge people to adapt to water availability.
6. It is highly recommended to continue the current work taking into consideration:

   i) Pressure zoning that Nablus Municipality is executing nowadays.

   ii) Mixing of scenarios or part of scenarios.

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APPENDIX A

Tables

Table 1: pumping hours for areas

pumping station	summer days	winter days
Alein station		
Rafidya	15.5hrs/4days	9hrs/2days
Almreij	14hrs/4days	9hrs/2days
Junblat alqadeem	13.5hrs/4days	7hrs/2days
Junblat aljadeed	11hrs/4days	7hrs/2days
Alein camp	9hrs/2days	5hrs/2days
Asira street	16hrs/4days	10hrs/2days
Zawata	18hrs/4days	8hrs/2days
Almaajeen	10hrs/4days	8hrs/2days
Aljneid	7.5hrs/4days	5hrs/2days
Ras el ein station		
Ras elein	6hrs/4+days	3hrs/2days
Albasha	10hrs/4days	6hrs/2days
Abu obaida	10hrs/4days	6hrs/2days
Southern station		
Altaawon	9hrs/4days	6hrs/2days
Alshinar	9hrs/4days	6hrs/2days
Tell	17hrs/4days	11hrs/2days
new Fatayer	11hrs/4days	8hrs/2days
Ein Dafna station		
Alquds street	21hrs/4days	12hrs/2days
Amman street	21hrs/4days	12hrs/2days
Iraq altayeh	17hrs/4days	9hrs/2days
Khalet alamod	14hrs/4days	8hrs/2days
Salah alddeen	11hrs/4days	8hrs/2days
Adahyeh	17hrs/4days	9hrs/2days
Balata Camp	13hrs/4days	7hrs/2days
Old+new Askar camp	15hrs/4days	8hrs/2days
Khalet aleman alsoflya	8hrs/4days	5hrs/2days
Sumara station		
Almakhfya	17hrs/4days	12hrs/2days
15street,almtalleh	14hrs/4days	9hrs/2days
Northern station		
Imad eddin,Beiker	14hrs/4days	8hrs/2days
Khalet aleman alolwyeh	17hrs/4days	11hrs/2days
Albalad	20hrs/4days	10hrs/2days
New reservior		
Assekkeh	15hrs/4days	9hrs/2days
Aqaryon station	8hrs/4days	5hrs/2days
Deir Sharaf	9hrs/4days	7hrs/2days
Almasaken ashabya	20hrs/4days	10hrs/2days

Table 2. Chemical analysis of the main water sources of the City of Nablus.

Water Source	PH	Turb idty(NTU	NO3 mg/l	SO4 mg/l	PO4 mg/l	F mg/l	Cl mg/l	HC O3 mg/l	CaC O3 mg/l	TDS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l
Odala well	7.3	0.17	16.8	8	0.0	0.15	49.9	220	222.	340	59.5	18	21	1.7
Alfar'a well	7.4	0.79	15.8	8	0.00	0.38	89	260	274.	450	78	19.4	36	1.6
AlBadan well	7.24	0.31	13	10	0.01	0.23	69	240	252.	390	65	22	28	1.5
Alqaryoon	7.16	0.15	19.5	6	0.0	0.15	45	190	191.	290	57	12	19.5	1.9
Deir sharaf well	7.35	0.15	16.7	11.5	0.01	0.34	43	240	221.	350	59	18	25.5	1.7
Ein Beit Elma	7.27	0.18	36	10	0.0	0.14	71	220	242.	390	65	19.4	32	2.7
Ein Defna	7.5	0.16	24	8	0.06	0.1	59.9	220	216.	350	62	15	35	1.5
Ein Al-Asal	7.46	0.16	14.1	8	0.01	0.12	39.9	165	167.	260	43	14.5	21	0.38
Ras Al Ein	7.58	0.16	15	7	0.00	0.14	32	180	176.	258	51	12	17	0.4

Table 3: amount of pumping m^3/month

pumping station	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Ein beitelma station	120656	107939	122018	154971	153649	145280	146640	164736	145752	137135	137900	130400
Ras el ein station	16368	73080	42780	37440	25296	15840	15624	14880	12600	12960	13320	16368
Southern station	29997	29997	34188	38236	27747	24812	24812	24812	24812	24812	29997	29997
Ein Dafna station	145455	100833	124340	161840	181240	202200	202240	202142	198060	200552	186700	174948
Sumara station	28911	28911	27161	25665	19771	19433	19433	19433	19433	19433	28911	28911
Northern station	32222	32222	32165	28043	29084	22971	22971	22971	22971	22971	32222	32222
New reservior	95642	98642	102642	108475	115650	120038	135993	130493	125862	110685	105685	101360
Alqaryon station	23808	78509	71424	45720	38539.2	33840	32944	30600	30504	25300	18760	0
Al masaken Alshabya	9209	9389	8382	9792	10574	10176	12558	13398	13388	13661	11552	9700

Table 4: Demand sites in WEAP model

Demand sites	unit	Activity level	Annual use rate m^3/c/year
Ein Beit Elma Zone			
Residential areas	No.people	27228	36.5
Health care centers	No. beds	86	54.75
Schools	No.people	5794	3.65
Institutions	No.points	600	40.9
Rafeedya hospital	No.points	1	11315
Najah University	No.points	1	6935
Ras Elein Zone			
Residential areas	No.people	6303	36.5
Health care centers	No. beds	11	54.75
Schools	No.people	329	3.65
Institutions	No.points	123	40.9
Southern Reservoir Zone			
Residential areas	No.people	11132	36.5
Health care centers	No. beds	26	54.75
Schools	No.people	2225	3.65
Institutions	No.points	216	40.9
Ein Dafna Zone			
Residential areas	No.people	62188	36.5
Health care centers	No. beds	184	54.75
Schools	No.people	10302	3.65
Institutions	No.points	1383	40.9
Industrial uses	No.points	1	112739
Sumara Zone			
Residential areas	No.people	9107	36.5
Health care centers	No. beds	0	54.75

Schools	No.people	1673	3.65
Institutions	No.points	39	40.9
Najah University	No.points	1	8030
Northern Reservoir Zone			
Residential areas	No.people	17527	36.5
Health care centers	No. beds	152	54.75
Schools	No.people	3824	3.65
Institutions	No.points	344	40.9
Al watani Hospital	No.points	1	9855
New Reservoir Zone			
Residential areas	No.people	3496	36.5
Health care centers	No. beds	5	54.75
Schools	No.people	699	3.65
Institutions	No.points	48	40.9
Al Engely Hospital	No.points	1	5110
Al Qaryon Zone			
Residential areas	No.people	2003	36.5
Health care centers	No. beds	6	54.75
Schools	No.people	400	3.65
Institutions	No.points	97	40.9
AlMasaken+Askar Albalad			
Residential areas	No.people	9615	36.5
Health care centers	No. beds	38	54.75
Schools	No.people	1923	3.65
Institutions	No.points	243	40.9

Table 5: The potential wells that can be used to supply Nablus City

name	coordinates	Elevation m asl	Drilling depth m	Aquifer basin	Expectd pumping rate (m^3/hr)	Expected pumping hours (m^3/hr)	Expected pumpage (Mcm/yr)
Deir Sharaf well N3	166.35/186.2	280	900	Northeasten	150	7300	1.1
Deir Sharaf well N4	164.75/186.0	240	800	Northeasten	250	7300	1.8
Anabta well N1	162.3/189.65	185	850	Western	150	7300	1.1
Anabta well N1	159.65/191.00	120	750	Western	150	7300	1.1
Azmout	179.6/181.4	500	400	Northeasten	65	7300	0.5
Burin	174.1/173.4	520	700	Northeasten	100	7300	0.7
Yutma1	177.0/168.5	510	500		200	7300	1.5
Yutm2	174.5/167.1	520	550		200	7300	1.5

Table 6: The estimated water demand for the residential uses in ein beit elma zone

year	Water demand (m3)
2009	787543.7904
2010	812745.1917
2011	838753.0378
2012	865593.135
2013	893292.1153
2014	921877.463
2015	951377.5418
2016	981821.6232
2017	1013239.915
2018	1045663.592
2019	1079124.827
2020	1113656.822
2021	1149293.84
2022	1186071.243
2023	1224025.523
2024	1263194.34
2025	1303616.558
2026	1345332.288
2027	1388382.921
2028	1432811.175
2029	1478661.133
2030	1525978.289
2031	1574809.594
2032	1625203.501
2033	1677210.013
2034	1730880.734
2035	1786268.917

Table 7. Reference scenario results

year	2009	2010	2011	2012	2013	2014	2015	2016	2017
Water demand(70l/cd)	4624931	4738133	4854299	4973508	5095840	5221375	5350199	5482398	5618060
Water demand(100l/cd)	6419797	6579665	6743711	6912044	7084778	7262026	7443907	7630542	7822056
The unmet water demand under management options									
No supply development(70l/cd)	1243625	1327083	1412726	1500612	1591492	1689243	1789554	1892492	1998127
No supply development(100l/cd)	2635539	2789479	2947442	3109533	3275860	3446535	3621671	3801385	3985796
Construction Sabastia well	822219	976159	1134122	1296213	1462540	1462540	1808351	1988065	2172476
Reduction inwater leakage	2416077	2540616	2668408	2801216	2967543	2967543	3313354	3493068	3677479
Stormwater harvesting	1255539	1409479	1567442	1729533	1895860	1895860	2241671	2421385	2605796
Rehabilitation of springs	2519822	2650082	2808044	2970135	3136463	3136463	3482274	3661987	3846399
Development of new wells	2635539	2789479	2947442	3109533	3275860	3275860	2862671	3042385	3226796
year	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Water demand(70l/cd)	5757277	5900140	6046747	6197195	6351586	6510022	6672609	6839458	7010680
Water demand(100l/cd)	8018576	8220233	8427163	8639502	8857392	9080979	9310412	9545843	9787431
The unmet water demand under management options									
No supply development(70l/cd)	2106527	2217767	2331921	2449064	2569656	2722211	2878763	3039417	3204282
No supply development(100l/cd)	4175028	4369206	4568461	4772925	4982734	5198028	5418951	5645651	5878278
Construction Sabastia well	2361708	2555886	2755141	2959605	3169414	3384708	3605631	3832331	4064958
Reduction inwater leakage	3866711	4060889	4260144	4464608	4674417	4889711	5110634	5337334	5569960
Stormwater harvesting	2795028	2989206	3188461	3392925	3602734	3818028	4038951	4265651	4498278
Rehabilitation of springs	4035631	4229809	4429064	4633527	4843337	5058631	5279554	5506253	5738880
Development of new wells	3416028	3610206	2567461	2771925	2981734	3197028	3417951	2609651	2842278
year	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Water demand(70l/cd)	7186389	7366703	7551743	7741634	7936503	8136480	8341699	8552299	8768421
Water demand(100l/cd)	1E+07	1E+07	1.1E+07	1.1E+07	1.1E+07	1.1E+07	1.2E+07	1.2E+07	1.2E+07
The unmet water demand under management options									
No supply development(70l/cd)	3373467	3547087	3725258	3908098	4095731	4288283	4485883	4688663	4896760
No supply development(100l/cd)	6116987	6361938	6613295	6871224	7135899	7407495	7686194	7972183	8265651
Construction Sabastia well	4303667	4548618	4799975	5057904	5322579	5594175	5872874	6158863	6452331
Reduction inwater leakage	5808670	6053621	6304978	6562907	6827582	7099178	7377877	7663865	7957333
Stormwater harvesting	4736987	4981938	5233295	5491224	5755899	6027495	6306194	6592183	6885651
Rehabilitation of springs	5977590	6222541	6473898	6731827	6996502	7268098	7546797	7832785	8126253
Development of new wells	3080987	3325938	3577295	2800224	3064899	3336495	3615194	3901183	4194651

Table 8: Population growth increase scenario results

year	2009	2010	2011	2012	2013	2014	2015	2016	2017
Water demand	6513205	6699692	6891773	7089616	7293395	7503288	7719477	7942151	8171506
The unmet water demand under management options									
No supply development	2725494	2905068	3090029	3280539	3476765	3678877	3887052	4101473	4322326
Construction Sabastia well	912174	1091748	1276709	1467219	1663445	1865557	2073732	2288153	2509006
Reduction inwater leakage	2488943	2634246	2783908	2972222	3168447	3370560	3578735	3793156	4014009
Stormwater harvesting	1345960	1525669	1710774	1901436	2097823	2300106	2508463	2723075	2944131
Rehabilitation of springs	2592687	2765671	2950632	3141142	3337367	3539479	3747655	3962076	4182929
Development of new wells	2725494	2905068	3090029	3280539	3476765	3678877	3128052	3342473	3563326
year	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Water demand	8407742	8651065	8901687	9159828	9425713	9699575	9981653	1E+07	1.1E+07
The unmet water demand under management options									
no supply development	4549805	4784109	5025441	5274014	5530043	5793754	6065375	6345146	6633309
Construction Sabastia well	2736485	2970789	3212121	3460694	3716723	3980434	4252055	4531826	4819989
Reduction inwater leakage	4241488	4475791	4717124	4965696	5221726	5485436	5757058	6036829	6324992
Stormwater harvesting	3171823	3406353	3647924	3896748	4153043	4417033	4688949	4969030	5257521
Rehabilitation of springs	4410408	4644711	4886044	5134616	5390646	5654356	5925978	6205748	6493912
Development of new wells	3790805	4025109	3024441	3273014	3529043	3792754	4064375	3916146	4204309
year	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Water demand	1.1E+07	1.1E+07	1.2E+07	1.2E+07	1.2E+07	1.3E+07	1.3E+07	1.3E+07	1.4E+07
The unmet water demand under management options									
no supply development	6930118	7235830	7550715	7875045	8209106	8553188	8907593	9272630	9648618
Construction Sabastia well	5116798	5422510	5737395	6061725	6395786	6739868	7094273	7459310	7835298
Reduction inwater leakage	6621800	6927513	7242397	7566728	7900788	8244871	8599276	8964312	9340301
Stormwater harvesting	5554673	5860748	6176013	6500744	6835225	7179750	7534619	7900144	8276644
Rehabilitation of springs	6790720	7096433	7411317	7735648	8069708	8413791	8768195	9133232	9509220
Development of new wells	5E+06	4806830	5121715	4618045	4952106	5296188	5650593	6015630	6391618

Table 9. Climate change Scenario results

year	2009	2010	2011	2012	2013	2014	2015	2016	2017
Water demand	6419797	6579665	6743711	6912044	7084778	7262026	7443907	7630542	7822056
The unmet water demand under management options									
No supply development	3344669	3498609	3656571	3818662	3984990	4155665	4330801	4510515	4694926
Construction Sabastia well	1894013	2047953	2205915	2368006	2534334	2705009	2880145	3059859	3244270
Reduction inwater leakage	3098015	3251955	3409918	3572009	3738336	3909011	4084147	4263861	4448272
Stormwater harvesting	2240669	2394609	2552571	2714662	2880990	3051665	3226801	3406515	3590926
Rehabilitation of springs	3233151	3387091	3545053	3707145	3873472	4044147	4219283	4398997	4583408
Development of new wells	3344669	3498609	3656571	3818662	3984990	4155665	3845041	4024755	4209166
year	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Water demand	8018576	8220233	8427163	8639502	8857392	9080979	9310412	9545843	9787431
The unmet water demand under management options									
no supply development	4884158	5078336	5277591	5482055	5691864	5907158	6128081	6354781	6587407
Construction Sabastia well	3433502	3627680	3826935	4031399	4241208	4456502	4677425	4904125	5136751
Reduction inwater leakage	4637504	4831682	5030937	5235401	5445210	5660504	5881427	6108127	6340754
Stormwater harvesting	3780158	3974336	4173591	4378055	4587864	4803158	5024081	5250781	5483407
Rehabilitation of springs	4772640	4966818	5166073	5370537	5580346	5795640	6016563	6243263	6475889
Development of new wells	4276958	4471136	3676791	3881255	4091064	4306358	4527281	3925981	4158607
year	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Water demand	1E+07	1E+07	1.1E+07	1.1E+07	1.1E+07	1.1E+07	1.2E+07	1.2E+07	1.2E+07
The unmet water demand under management options									
no supply development	6826117	7071068	7322425	7580354	7845029	8116625	8395324	8681312	8974780
Construction Sabastia well	5375461	5620412	5871769	6129698	6394373	6665969	6944668	7230656	7524124
Reduction inwater leakage	6579463	6824414	7075771	7333700	7598375	7869971	8148670	8434659	8728127
Stormwater harvesting	5722117	5967068	6218425	6476354	6741029	7012625	7291324	7577312	7870780
Rehabilitation of springs	6714599	6959550	7210907	7468836	7733511	8005107	8283806	8569794	8863262
Development of new wells	4397317	4642268	4893625	4323554	4588229	4859825	5138524	5424512	5717980

Table 10. Using WHO standard use rate

year	2009	2010	2011	2012	2013	2014	2015	2016	2017
Water demand	9424961	9662963	9907175	10157759	10414880	10678711	10949426	11227205	11512232
The unmet water demand under the management options									
No water supply development	5529496	5758678	5993840	6235137	6482731	6736784	6997466	7264951	7539415
Construction of Sabastia well	3716176	3945358	4180520	4421817	4669411	4923464	5184146	5451631	5726095
Reduction in water leakage	5221178	5450361	5685523	5926820	6174413	6428467	6689149	6956634	7231098
Stormwater harvesting	4149496	4378678	4613840	4855137	5102731	5356784	5617466	5884951	6159415
Rehabilitation of springs	5390098	5619281	5854442	6095740	6343333	6597387	6858069	7125553	7400017
Development of new wells	5529496	5758678	5993840	6235137	6482731	6736784	6238466	6505951	6780415

year	2018	2019	2020	2021	2022	2023	2024	2025	2026
Water demand	11804697	12104793	12412721	12728684	13052894	13385564	13726916	14077176	14436578
The unmet water demand under management options									
No water supply development	7821041	8110016	8406531	8710785	9022978	9343319	9672020	10009299	10355381
Construction Sabastia well	6007721	6296696	6593211	6897465	7209658	7529999	7858700	8195979	8542061
Reduction inwater leakage	7512724	7801698	8098214	8402468	8714661	9035002	9363702	9700982	10047063
Stormwater harvesting	6441041	6730016	7026531	7330785	7642978	7963319	8292020	8629299	8975381
Rehabilitation of springs	7681643	7970618	8267134	8571387	8883581	9203922	9532622	9869902	10215983
Development of new wells	7062041	7351016	6405531	6709785	7021978	7342319	7671020	6973299	7319381

year	2027	2028	2029	2030	2031	2032	2033	2034	2035
Water demand	14805361	15183768	15572052	15970471	16379290	16798779	17229218	17670894	18124099
The unmet water demand under The management options									
No water supply development	10710495	11074877	11448770	11832422	12226088	12630029	13044514	13469818	13906225
Construction of Sabastia well	8897175	9261557	9635450	10019102	10412768	10816709	11231194	11656498	12092905
Reduction in water leakage	10402177	10766560	11140453	11524105	11917770	12321712	12736197	13161501	13597908
Stormwater harvesting	9330495	9694877	10068770	10452422	10846088	11250029	11664514	12089818	12526225
Rehabilitation of springs	10571097	10935480	11309373	11693025	12086690	12490631	12905117	13330421	13766828
Development of new wells	7674495	8038877	8412770	7761422	8155088	8559029	8973514	9398818	9835225

Table 11: Reference Scenario results considering one demand site and one water source

Reference Scenario									
		Water demand (mcm)				**Unmet water demand (mcm)**			
Management options		**2010**	**2015**	**2025**	**2035**	**2010**	**2015**	**2025**	**2035**
1	With no water supply development using 70 l/cd	4.738	5.35	6.839	8.768	0.00	0.575	2.064	3.993
	With no water supply development using 100 l/cd	6.579	7.44	9.54	12.26	1.804	2.665	4.765	7.4854
2	Construction of Sabastia well					0.008	0.852	2. 95	5.672
3	Reduction in water leakage					1.389	2.25	4.35	7.07
4	Stormwater harvesting					0.424	1.285	3.385	6.105
5	Rehabilitation of springs					1.665	2.526	4.626	7.3460
6	Development of new wells					1.804	1.906	1.729	3.415

Table 12: Population growth increase scenario results considering one demand site and one water source

Population growth increases									
		Water demand (mcm)				**Unmet water demand (mcm)**			
Management options		**2010**	**2015**	**2025**	**2035**	**2010**	**2015**	**2025**	**2035**
1	With no water supply development using 100 l/cd	6.699	7.719	10.27	13.702	1.924	2.944	5.495	8.927
2	Construction of Sabastia well					0.111	1.131	3.682	7.114
3	Reduction in water leakage					1.509	2.529	5.080	8.512
4	Stormwater harvesting					0.544	1.564	4.115	7.547
5	Rehabilitation of springs					1.785	2.805	5.356	8.788
6	Development of new wells					1.165	2.185	2.459	4.857

Table 13: Climate change scenario results considering one demand site and one water source

Climate change scenario									
		Water demand (mcm)				**Unmet water demand (mcm)**			
Management options		**2010**	**2015**	**2025**	**2035**	**2010**	**2015**	**2025**	**2035**
1	With no water supply development using 100 l/cd	6.579	7.44	9.54	12.26	2.759	3.620	5.720	8.4403
2	Construction of Sabastia well					1.308	2.169	4.269	6.9896
3	Reduction in water leakage					2.427	3.288	5.388	8.1081
4	Stormwater harvesting					1.655	2.516	4.616	7.3363
5	Rehabilitation of springs					2.647	3.508	5.608	8.3288
6	Development of new wells					2.759	3.013	3.291	5.184

Table 14: Using WHO daily use rate standard scenario results considering one demand site and one water source

Using WHO daily use rate standard									
		Water demand (mcm)				**Unmet water demand (mcm)**			
Management options		**2010**	**2015**	**2025**	**2035**	**2010**	**2015**	**2025**	**2035**
1	With no water supply development using 100 l/cd	9.66	10.95	14.07	18.12	4.885	6.175	9.2954	13.345
2	Construction of Sabastia well					3.072	4.362	7.4821	11.532
3	Reduction in water leakage					4.470	5.760	8.8801	12.930
4	Stormwater harvesting					3.505	4.795	7.9153	11.965
5	Rehabilitation of springs					4.746	6.036	9.1560	13.206
6	Development of new wells					4.885	5.416	6.2594	9.275

APPENDIX B

FIGURES

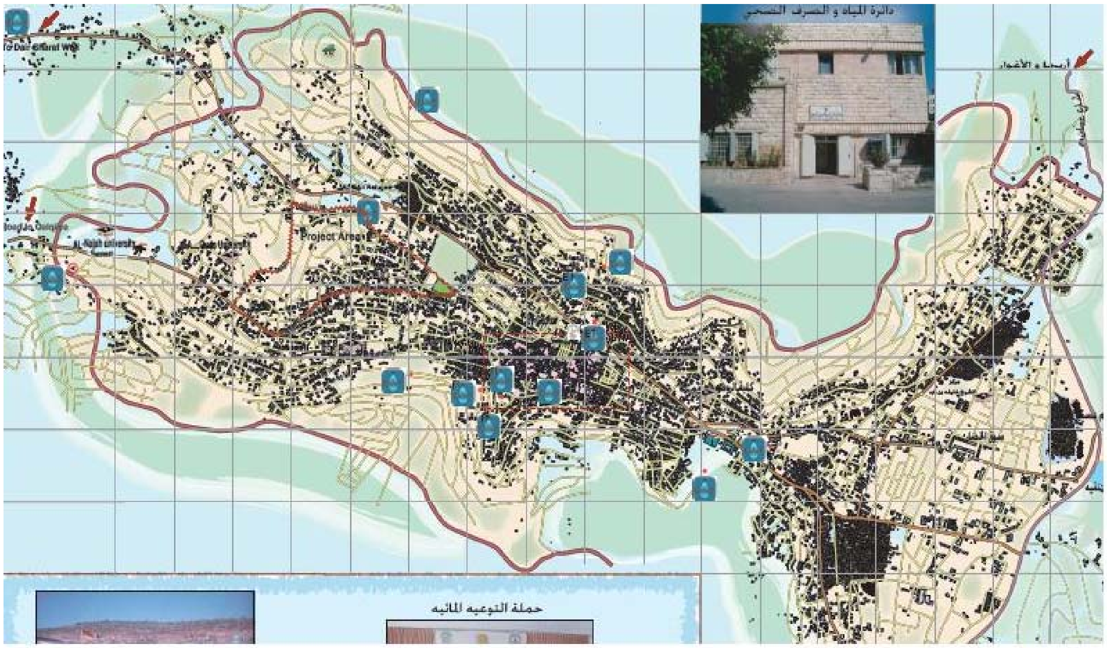

Figure 1: shows pumping stations and reservoirs

Aljunied Pumping Station

Ein Beit Elma Pumping Station , and Reservoir

Deir Sharaf Pumping station

Ein Dafna Pumping Station

Northern Pumping Station and Reservoir

Southern Pumping Station and Reservoir

Ras Elein Pumping Station and Reservoir

Alsumara Pumping Station

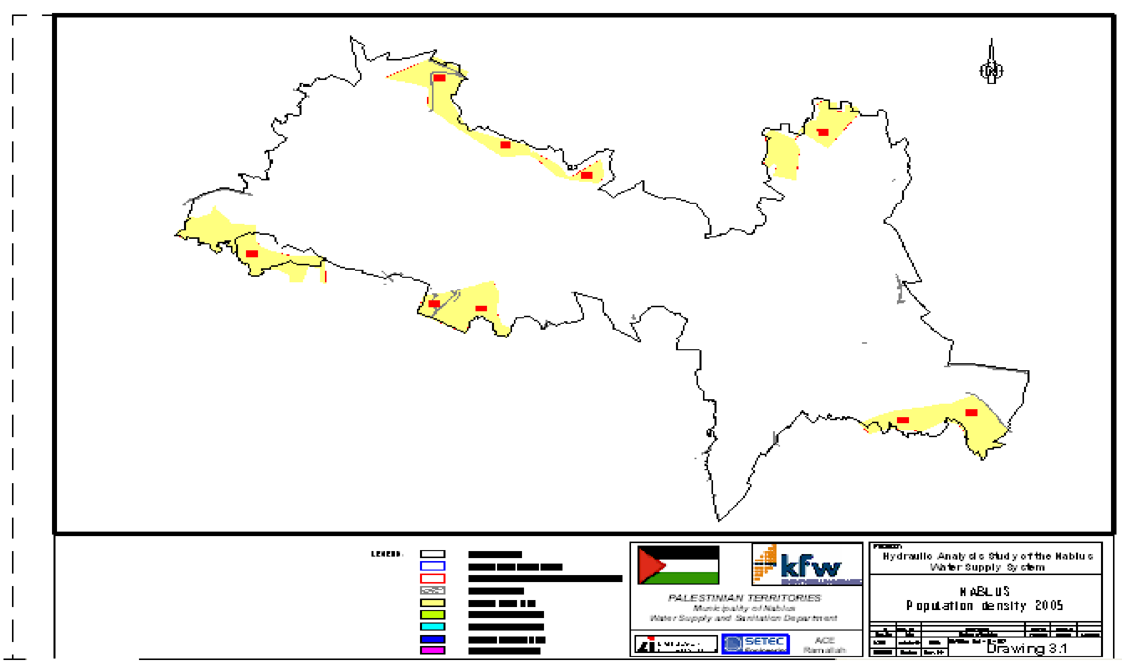

Figure 2 : The expected expansion area in Nablus City

جامعة النجاح الوطنية
كلية الدراسات العليا

تقييم إدارة التزود للمياه في مدينة نابلس باستخدام برنامج (WEAP)

إعداد
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إشراف
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قدمت هذه الأطروحة استكمالا لمتطلبات درجة الماجستير في هندسة المياه و البيئة بكلية الدراسات العليا، جامعة النجاح الوطنية، نابلس، فلسطين

2009

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الملخص

يعاني الفلسطينيون من نقص حاد لمصادر المياه نتيجة للقيود التي فرضها الاحتلال الإسرائيلي على الفلسطينيين والتي تعوق دون تطوير مصادر جديدة و تحد من توفر المياه للفلسطينيين. و تفتقر الضفة الغربية لبنية تحتية جيدة لتوفير المياه مما تسبب في فقدان كميات كبيرة من المياه بالإضافة إلى عدم توفر الدعم المالي لمشاريع جديدة، بالتالي بعض المدن الرئيسية في الضفة الغربية كمدينة نابلس تعاني من مشكلة في توزيع المياه إلى المستهلكين بكميات كافية.

تم استخدام برنامج WEAP في هذه الدراسة لتقييم الخيارات لدى بلدية نابلس لتقليل الفجوة بين الطلب والتزود. تكونت منهجية الدراسة مما يلي: (1) جمع البيانات اللازمة (2) التدريب على برنامج (WEAP) و تطبيقاته (3) نمذجة نظام مصادر المياه في مدينة نابلس باستخدام برنامج (WEAP) بهدف محاكاة الواقع لدراسة و تقييم الخيارات المختلفة .

تشير النتائج التي حصلنا عليها أن الطلب على المياه يتزايد بتزايد عدد السكان على مدى سنوات الدراسة، وإذا استمر الوضع الحالي بوجود نفس كميات المياه فان الفجوة بين مقدار التزود و الطلب على المياه سوف تزداد اتساعا. لذا تطوير مصادر إضافية أصبحت حاجة ملحة لمواجهة الطلب المتزايد للمياه، و أيضا استغلال الحصاد المائي و تحسين البنية التحتية للمدينة لتقليل الفاقد من المياه من الأمور المهمة لتقليل الفجوة بين التزود و الطلب.