An-Najah National University

Faculty of Graduate Studies

Evaluation of Water Resources Management Options in Gaza Strip using WEAP

By

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EVALUATION OF WATER RESOURCES MANAGEMENT OPTIONS IN GAZA STRIP USING WEAP

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To My Father, Abdul Monem Jaradat

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I gratefully acknowledge the help and support by my education supervisors specifically Dr. Anan Jayyousi and Dr. Hafez Shaheen.

إقــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

EVALUATION OF WATER RESOURCES MANAGEMENT OPTIONS IN GAZA STRIP USING WEAP

تقييم الخيارات الإدارية لمصادر المياه في قطاع غزة باستخدام برنامج (WEAP)

اقر بأن ما اشتملت عليه هذه الرسالة، إنما هي نتاج جهدي الخاص، باستثناء ما تمت 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 researchers own work, and has not been submitted elsewhere for any other degree or qualification.

Student's name:	**اسم الطالب:**
Signature:	**التوقيع:**
Date:	**التاريخ:**

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ABSTRACT

The Gaza Strip is facing a challenge of water shortage and the unbalanced municipal water supply-demand situation. The extraction from coastal aquifer is almost twice the available recharge that has resulted in fresh water level decline by 20-30 cm per year (PWA, 2003).

The main objective of this work is provide analysis towards an integrated water resource management (IWRM) for the Gaza Strip using Water Evaluation and Planning software (WEAP). This will be accomplished through evaluating the existing water demand and supply conditions and expected future demand and supply scenarios taking into account the different operating policies and factors that affect demand.

The study methodology consists of five components. First, all needed maps and data are collected and incorporated into the model. Then development of future management scenarios were established. Next, IWRM analysis were conducted. After that, evaluation of water resources management options were provided. Finally, a set of water management recommendations are provided. The WEAP model is used to provide analysis towards building an Integrated Water Resources Management (IWRM) tool for the Gaza Strip as a case study.

Three scenarios have been considered in this work. These scenarios are also in line with those scenarios assumed in water sector strategic planning study and the GLOWA-Jordan River project. Those scenarios are (1)Current State (2) when economy moves on but no development in the political conditions. (3) Independent State with economy moves on. The political aspects and the economic conditions are the key factors in developing water resources management options for Palestine.

The results shows that the gap between demand and supply will grow dramatically if current supply conditions continued, water demand varies significantly according to the assumed future political situation, and underlined the importance role of water management aspects.

And the results shows that the water demand will vary according to three scenarios; the water demand will increase from 201 MCM in scenario 1, to 266 MCM in scenario 2 to 371 MCM in scenario 3 by the year 2020. And the water demand gap will be filled if scenario 3 achieved; it turns out to be zero until year 2018. Even that the gap will be 74 MCM in scenario 2, and 105 MCM in scenario 1.

Also the results revealed that an additional amounts more than 200 MCM is needed to satisfy water needs and development. The results confirmed that

WEAP can be applied as a Decision Support System (DSS) tool for the water resource management in the Gaza Strip.

CHAPTER ONE

INTRODUCTION

1.1 General

Water in the Middle East region is still one of the main causes of conflicts between trans- boundary countries. Part of the Arab-Israeli dispute is the water issue. The lack of available fresh water resources increases the gap towards finding out solutions to the Palestinian Israeli water problems. Both parties are interested in looking for developing non-conventional water resources such as reuse of treated wastewater or desalination to overcome the growth water demand for socio-economic development (Ismail M., 2003).

In Gaza Strip, Palestine, groundwater is the major source for water supply for domestic and agricultural use and it has already been not enough. Rainfall, the main water replenishment source, became insufficient to balance the groundwater system. In year 2002, the available yield of groundwater is about 91 MCM/year while the total abstraction for domestic and agricultural purposes was 153 MCM/year (CAMP, 2000). This result is affecting in a negative way the quality and the quantity of the municipal water that is pumped to the consumers. The average total water production for domestic use was 62 MCM in the year 2002. Only 18% pumped water meet the WHO standards of drinking water, while the other wells have average nitrate concentrations (NO_3) above 45 ppm (Ismail M., 2003). Some agricultural wells have reported Chloride levels in excess of 1200 mg/l (CAMP, 2000).

The Gaza Strip is facing a challenge of water shortage and the unbalanced municipal water supply-demand situation. The extraction from coastal aquifer is almost twice the available recharge that has resulted in fresh water level decline by 20-30 cm/year (PWA, 2003). Seawater intrusion deteriorated the quality of aquifers beside the overuse of fertilizers and pesticides in the agricultural activities. The overall water deficit is estimated at 50-60 MCM/year (CAMP, 2000). This serious problem is accompanied by a rapid growth of population, and inadequate sewerage systems contaminate the groundwater. Securing potable water for domestic use is becoming a heavy target on the PWA (Ismail M., 2003).

The required quantity of drinking water in the urban areas of the Gaza Strip has rapidly increased in recent years as a result of the rapid growth in population. Because the region is essentially semi-arid, with rainfall of about 330mm/yr occurring in only 5 months of the year and high evaporation losses, surface water resources are almost non-existent and the coastal groundwater aquifer is solely relied upon as the source of drinking water. Being a coastal aquifer, adequate recharge and careful management of abstraction are important to prevent the saltwater intrusion problems commonly associated with groundwater mining (Khalaf A., et al., 2006).

1.2 Motivation

A successful management of water requires systematic, comprehensive, and coordinated approaches that will provide decision-relevant information at an affordable cost to water managers. Therefore, to meet the growing information needs of water management and water resources research, efficient modeling techniques are required that have high power for long and short term assessment in order to be able to devise smart decisions (Arafat A., 2007).

In Gaza Strip there is a strong need for integrated water resource management tool in order to evaluate the existing water demand and supply condition and other expected water demand and supply scenarios taking into account the availability of water resources; their quality and quantity, supply and demand sources, climatic changes, socio-economic sides, hydrological and physical characteristics and environmental aspects. The water resource development should meet the needs of the present, without compromising the ability of future generations to meet their own needs, and to ensure a better balance between efficiency, sustainability and equity needs in water allocations.

In this study, WEAP, Water Evaluation and Planning computer software tool which is developed by the Stockholm Environmental Institute is to be applied to compare different options for water management in Gaza Strip.

1.3 The WEAP model

The WEAP tool is a basic mass balance tool where supply is set equal to demand and water is allocated based on user-defined priorities. It has a GIS-based graphical user interface which makes it a good tool for visualizing input data and presenting results of various scenarios to non-technical stakeholders and policy makers.

The WEAP model has a long history of development and use in the water planning arena. The model was first used by Raskin, et al., (1992) and Yates, et al., (2005) to study the Aral Sea water allocation and water management issues (Yates D., et al., 2005). The advancements of WEAP have been based on the premise that at the most basic level, water supply is defined by the amount of precipitation that falls on a watershed or a series of watersheds.

With this supply progressively depleted through natural watershed processes, human demands and interventions, or enhanced through watershed accretions. Thus, WEAP adopts a broad definition of water demand, where the watershed itself is the first point of depletion through evapotranspiration via surface-atmosphere interactions (Mahmood and Hubbard, 2002). In Palestine, WEAP was tested by different researchers and at different scales.

1.4 Research Questions

The following are research key questions:

1. What are the potential water management options for Gaza Strip under different scenarios?

2. What is the best water management option for Gaza Strip under different scenarios?

3. What are the WEAP capabilities to be used as an analysis and Evaluation tool?

1.5 Research Objectives

The main objective of this work is to test different management options using WEAP tool for the Gaza Strip. This will be accomplished through evaluating and analysis of the existing conditions and expected future scenarios taking into account the different operating policies and factors that affect demand such as demand management strategies, alternative supply sources and socio-economic conditions.

The other objective behind this research is to test the capabilities of WEAP tool as water demand management tools and how to apply it for IWRM problems. This will be performed through testing the ability of the tool to respond to different management questions.

1.6 Methodology

To achieve the above mentioned objectives, WEAP tool will be used to build an IWRM tool for the Gaza Strip as a case study. This will be performed after all needed maps and data are collected and incorporated into the WEAP. It should be mentioned here that the main source for the data will be the Coastal Aquifer Management Plan study, 2000.

Based on the above the following are the main steps to be applied:

a) Collection of all data and information needed from national and local agencies especially Palestinian Water Authority data bank (PWA) and the Coastal Aquifer Management Plan study, 2000.

b) Setup the GIS-based data as an input to the tool.

c) Develop future management scenarios related to the population growth, supply and demand changes, socio-economic factors, political agreements and the use of non-conventional water resources.

d) Development of the IWRM tool using WEAP.

e) Evaluation of the tool. Based on the existing conditions, the tool will be evaluated against available present conditions data, to test the ability of the model to reflect existing conditions.

f) Comparative Analysis based of the different scenarios taking into consideration cost and demand management tools will be performed.

g) Based on the above comparative analysis, a set of management practices and recommendations will be developed. The implications and actions needed based on the selected best management practices will be further elaborated.

1.7 Thesis Structure

The general structure of the thesis includes six chapters, chapter one introduces the aim and objective of this study and why it was carried out. Chapter two takes a glance at the study area from different angles (Climatic, Hydrological, ecological, geological, Economic,…). Chapter three includes some of the main articles, studies and research that were needed for this research. Chapter four include the gathering of data from different sources, identifying the data and the process involved and linking the data to build the tool. Chapter five include the build of possible scenarios to run the tool and compute the results, analyze the results from the different scenarios that have been developed and the discussion of this study. Finally, Chapter six summarizes conclusions and recommendations.

CHAPTER TWO

DESCRIPTION OF STUDY AREA

2.1 Location

Gaza strip is located between longitudes 34° 2’’ and 34° 25’’ east and latitudes 31° 16’’ and 31° 45’’ north. The Gaza Strip is confined between the Mediterranean Sea in the west, Egypt in the south and the 1950 Armistice line drawn by Rhodes Agreement of 1949 between the Arab States and Israel. Until 1948, the Gaza Strip was part of Palestine under the British Mandate (Qahman, 2004).

From 1967 until 1994 the Gaza Strip was under Israeli occupation. According to the peace agreement between Israeli and the Palestinian, the Gaza Strip has been under the Palestinian Authority control since May, 1994. Now, the Gaza strip constitutes one unity as the Israeli settlements were removed in 2005. Figure 1 shows Regional setting of Gaza Strip and the neighboring countries.

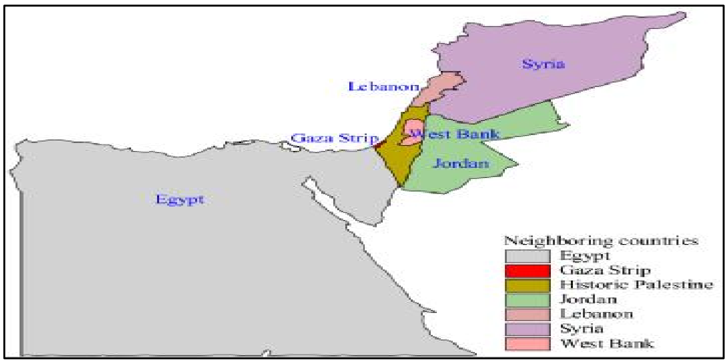


Figure1: Regional setting of Gaza Strip and the neighboring countries(Haj Hamad L., 2007).

2.2 Soil and Topography

The soil in the Gaza Strip is composed mainly of three types, sands, clay and loess. The sandy soil is found along the coastline extending from south to outside the northern border of the Strip, at the form of sand dunes. The thickness of sand fluctuates from two meters to about 50 meters due to the hilly shape of the dunes. Clay soil is found in the north eastern part of the Gaza Strip. Loess soil is found around Wadis, where the approximate thickness reaches about 25 to 30 m (Shaheen S., 2007). The soil map of the Gaza Strip is shown in Figure 2.

As shown in Figure 3, topography is characterized by elongated ridges and depressions, dry streambeds and shifting sand dunes. The ridges and depression generally extend in a NNE-SSW direction, parallel to the coastline. They are narrow and consist primarily of sandstone (Kurkar) (Shaheen S., 2007).

In the south, these features tend to be covered by sand dunes. Land surface elevations range from mean sea level (MSL) to about 110 m above mean sea level (AMSL). The ridges and depressions show considerable vertical relief, in some places up to 60 m. Surface elevations of individual ridges range between 20 m and 90 m AMSL (Shaheen S., 2007).

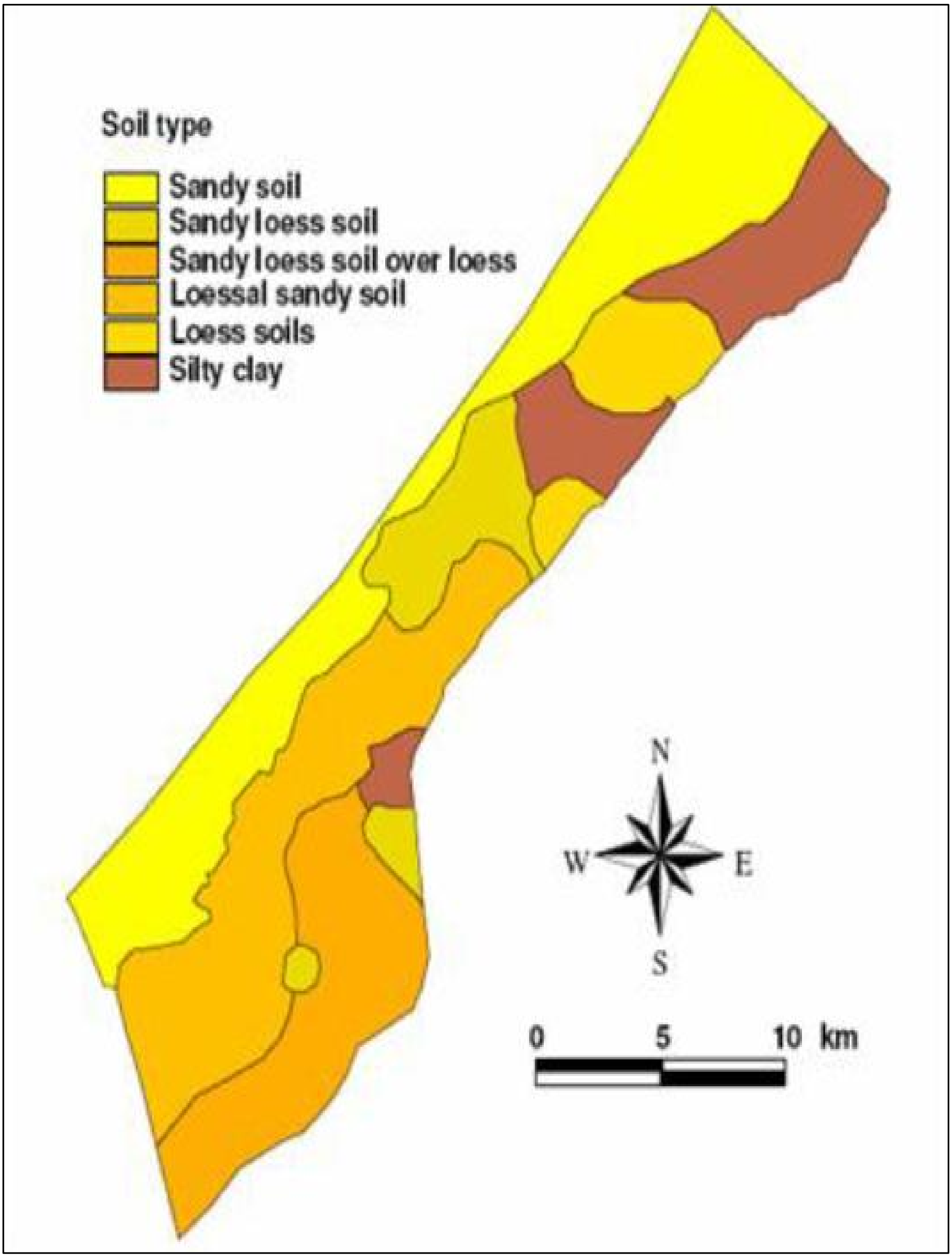


Figure 2: Gaza Strip soil types (Shaheen S., 2007).

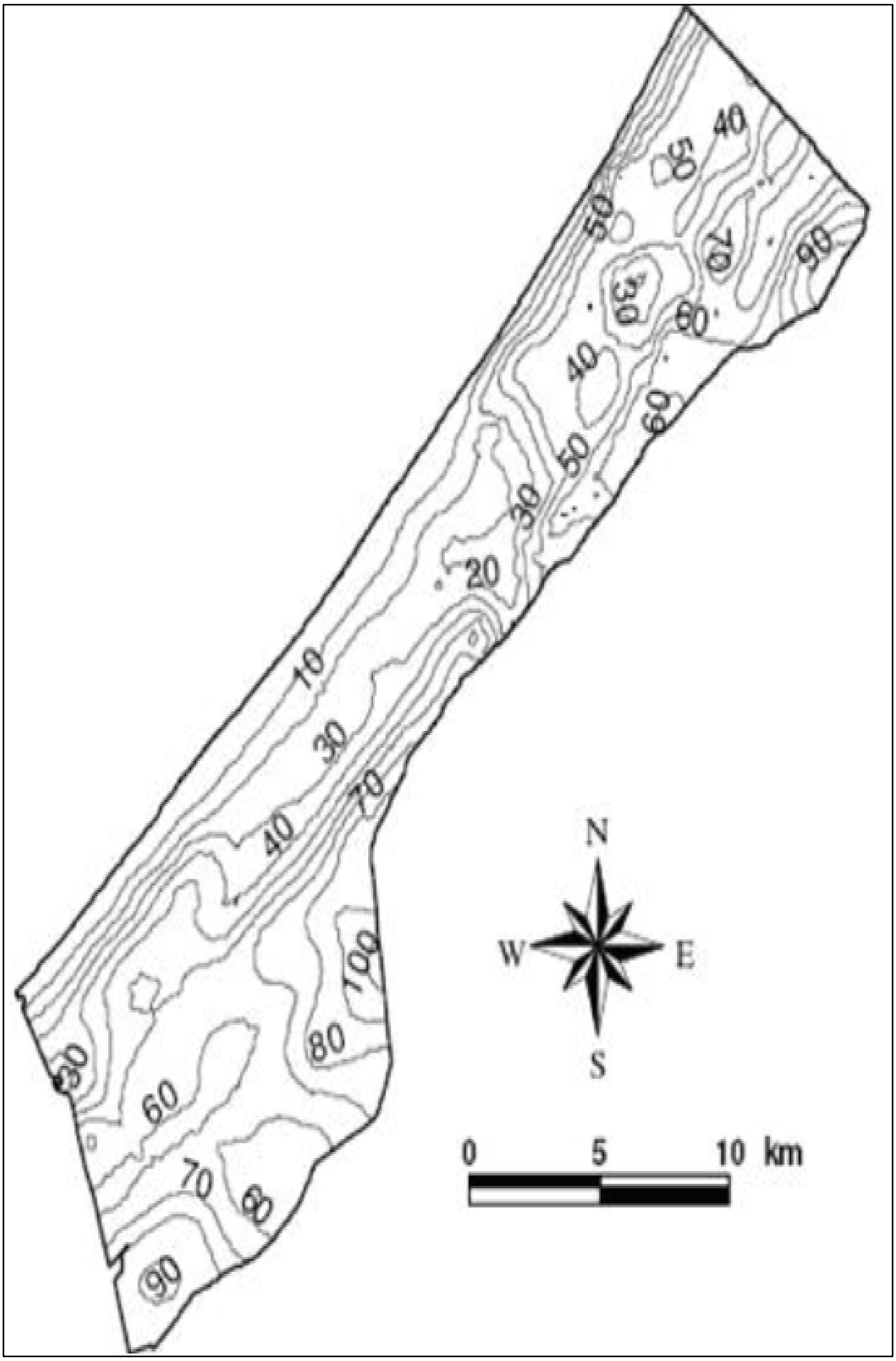


Figure 3: Topography of the Gaza Strip (Shaheen S., 2007).

2.3 Hydrogeology

The hydrogeology of the coastal aquifer consists of one sedimentary basin, the post-Eocene marine clay (Saqiya group). Pleistocene sedimentary deposits of alluvial sands, graded gravel, conglomerates, pebbles and mixed soils constitute the regional hydrological system. Intercalated clay deposits of marine origin separate these deposits, and randomly distributed in the area. Their thickness is decreasing to the east and basically they can be classified as aquitard (Shaheen S., 2007).

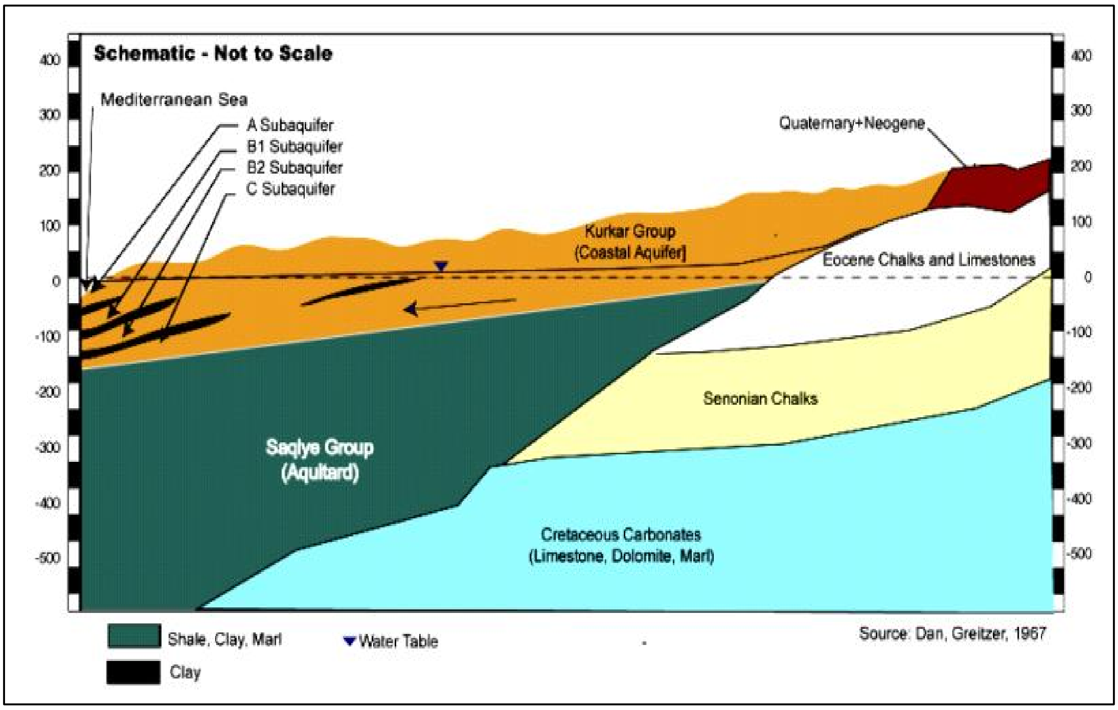
The aquifer is semi-confined with an average thickness of 10 m clay, becoming phreatic 4 km from the sea (Shaheen S., 2007).Schematization of hydrogeological cross section of the Gaza Strip aquifer is shown in Figure4.

Depth to water level is controlled mainly by groundwater elevation and is ranging between 60m- 5m (Aaish, 2000).

2.4 Climate

The Gaza Strip is located in the transitional zone between the arid desert climate of the Sinai Peninsula in Egypt and the temperate and semi-humid Mediterranean climate along the coast. This fact could explain the sharp decrease in rainfall quantities of more than 200 mm/year between Beit-Lahia in the north and Rafah in the South of Gaza Strip (Qahman, 2004).

Figure 5 shows Gaza Strip Governorates.



Source: Dan, Greitzer, 1967

Figure 4: Typical hydrological cross-section of Gaza aquifer (Qahman, 2004)

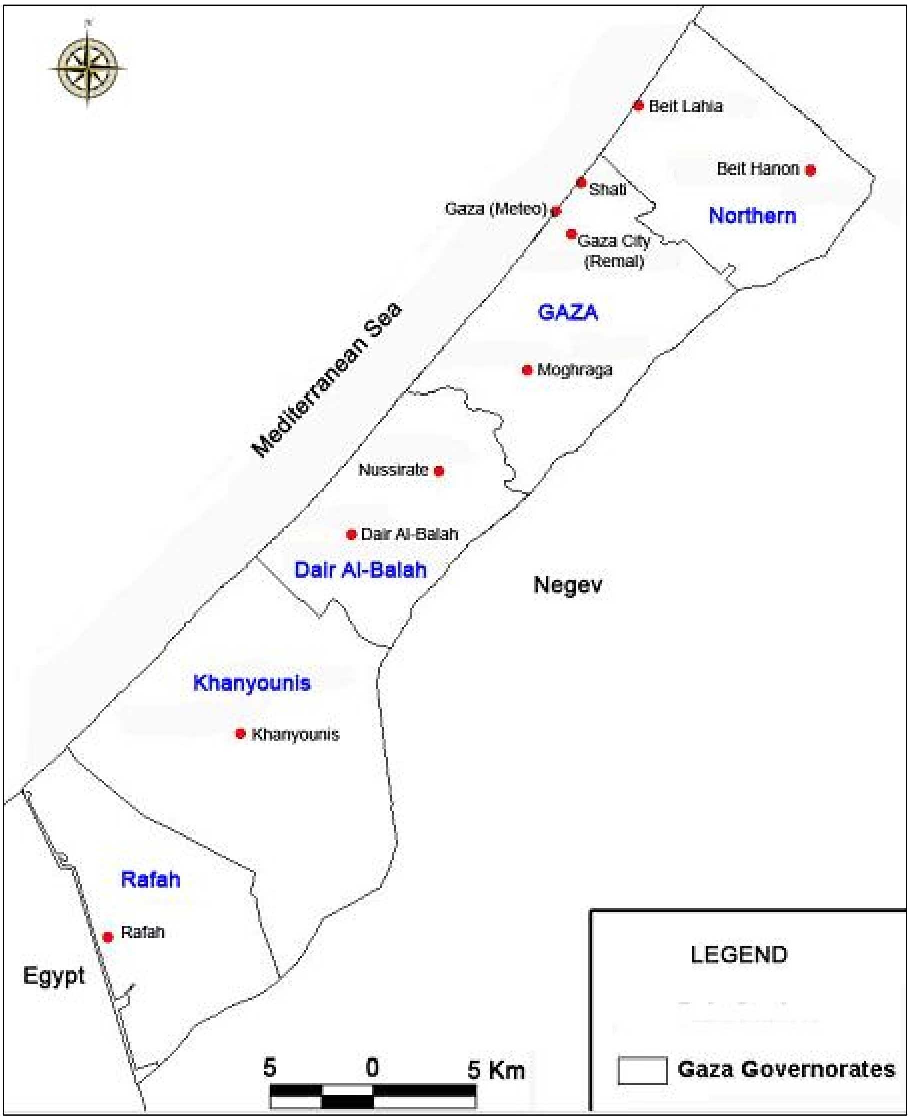


Figure 5: Gaza Strip governorates(Al-Hallaq A. and Abu Elaish B., 2008).

The average daily mean temperature ranges from 25 °C in summer to 13 °C in winter. Average daily maximum temperatures range from 29 °C to 17 °C and minimum temperatures from 21 °C to 9 °C in the summer and winter respectively. The daily relative humidity fluctuates between 65% in the daytime and 85% at night in the summer, and between 60% and 80%

respectively in winter. The mean annual solar radiation amounts to 2200 J/cm^2/day (Qahamn, 2004).

The rainfall data of the Gaza Strip is based on the data collected from 9 rain stations. The average annual rainfall varies from 450 mm/yr in the north to 200 mm/yr in the south of the Gaza Strip. Most of the rainfall occurs in the period from October to March, the rest of the year being completely dry. Precipitation patterns include thunderstorms and rain showers, but only a few days of the wet months are rainy days (Qahman, 2004). Figure 6 shows the observed rainfall depth and normal rainfall depth in Gaza Strip for the year 2006-2007.

There is less aerial variation in evaporation than in rainfall in the Gaza Strip. Evaporation measurements have clearly shown that the long term average open water evaporation for the Gaza Strip is in the order of 1300 mm/yr. Maximum values in the order of 140 mm/month are quoted for summer, while relatively low pan-evaporation values of around 70 mm/month were measured during the months December to January (PWA, 2000).

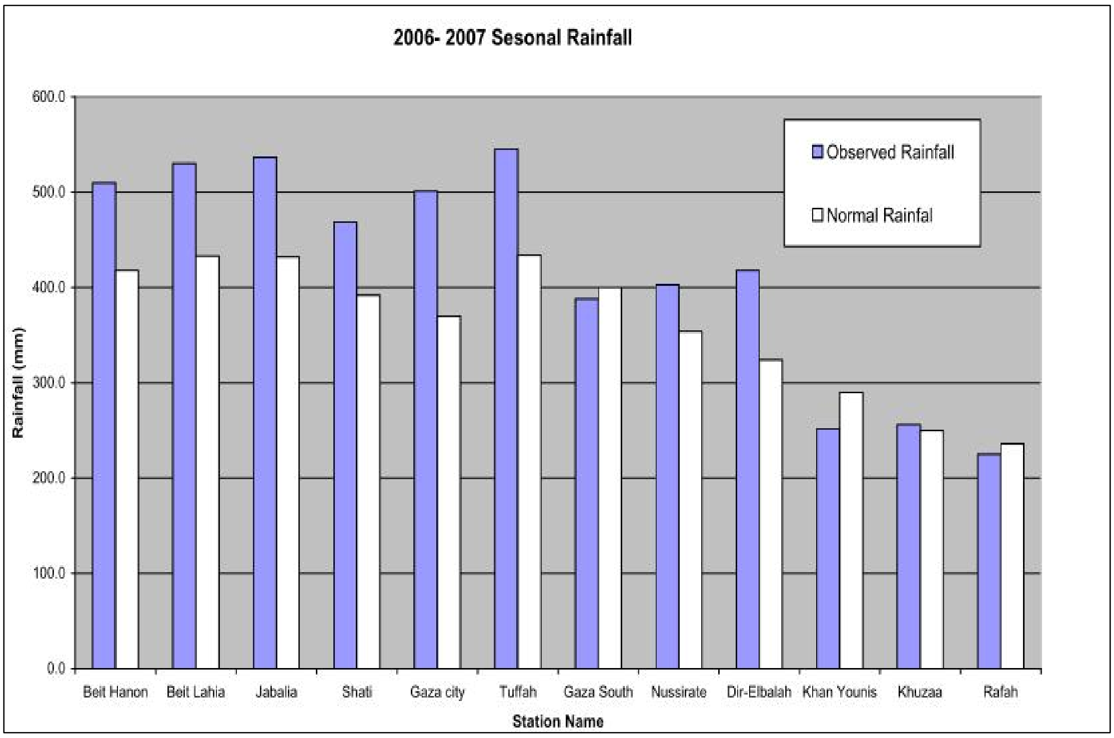


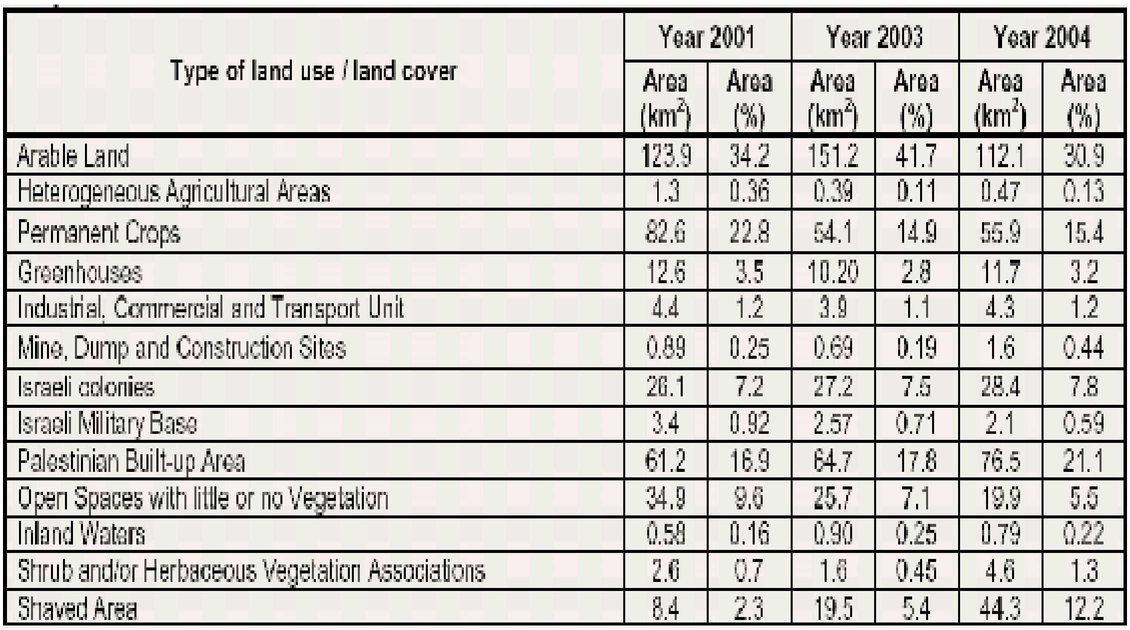
Figure 6: Observed rainfall depth and normal rainfall depth in Gaza Strip for the year 2006-2007 (PWA, 2007).

2.5 Land use

The analysis of the satellite images for the years 2001, 2003 and 2004 was based upon the classification system of CORINE level 2 in order to classify the agricultural land cover in the Gaza Strip, see Figure 7 and Table 1 which classify the total areas of the classified land use / land cover types in the period 2001-2004 by type (Arij, 2005).

The area, in dunums, of developed land in the Gaza Strip was calculated in GIS from the different time series layers. The areas were calculated at Governorate level in the period between 2000 and 2005. The analysis showed that all Governorates have experienced a significant increase in their built-up area especially after 2003. Figure 8 shows Built up areas of the Palestinian localities in the Gaza Strip (Arij, 2005).

Table(1): Land use / land cover changes in the Gaza Strip and percentages of land cover types of the Gaza Strip total area in 2001, 2003 and 2004 (Arij, 2005).



Type of land use / land cover	Year 2001		Year 2003		Year 2004	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Arable Land	123.9	34.2	151.2	41.7	112.1	30.9
Heterogeneous Agricultural Areas	1.3	0.36	0.39	0.11	0.47	0.13
Permanent Crops	82.6	22.8	54.1	14.9	55.9	15.4
Greenhouses	12.6	3.5	10.20	2.8	11.7	3.2
Industrial, Commercial and Transport Unit	4.4	1.2	3.9	1.1	4.3	1.2
Mine, Dump and Construction Sites	0.89	0.25	0.69	0.19	1.6	0.44
Israeli colonies	26.1	7.2	27.2	7.5	28.4	7.8
Israeli Military Base	3.4	0.92	2.57	0.71	2.1	0.59
Palestinian Built-up Area	61.2	16.9	64.7	17.8	76.5	21.1
Open Spaces with little or no Vegetation	34.9	9.6	25.7	7.1	19.9	5.5
Inland Waters	0.58	0.16	0.90	0.25	0.79	0.22
Shrub and/or Herbaceous Vegetation Associations	2.6	0.7	1.6	0.45	4.6	1.3
Shaved Area	8.4	2.3	19.5	5.4	44.3	12.2

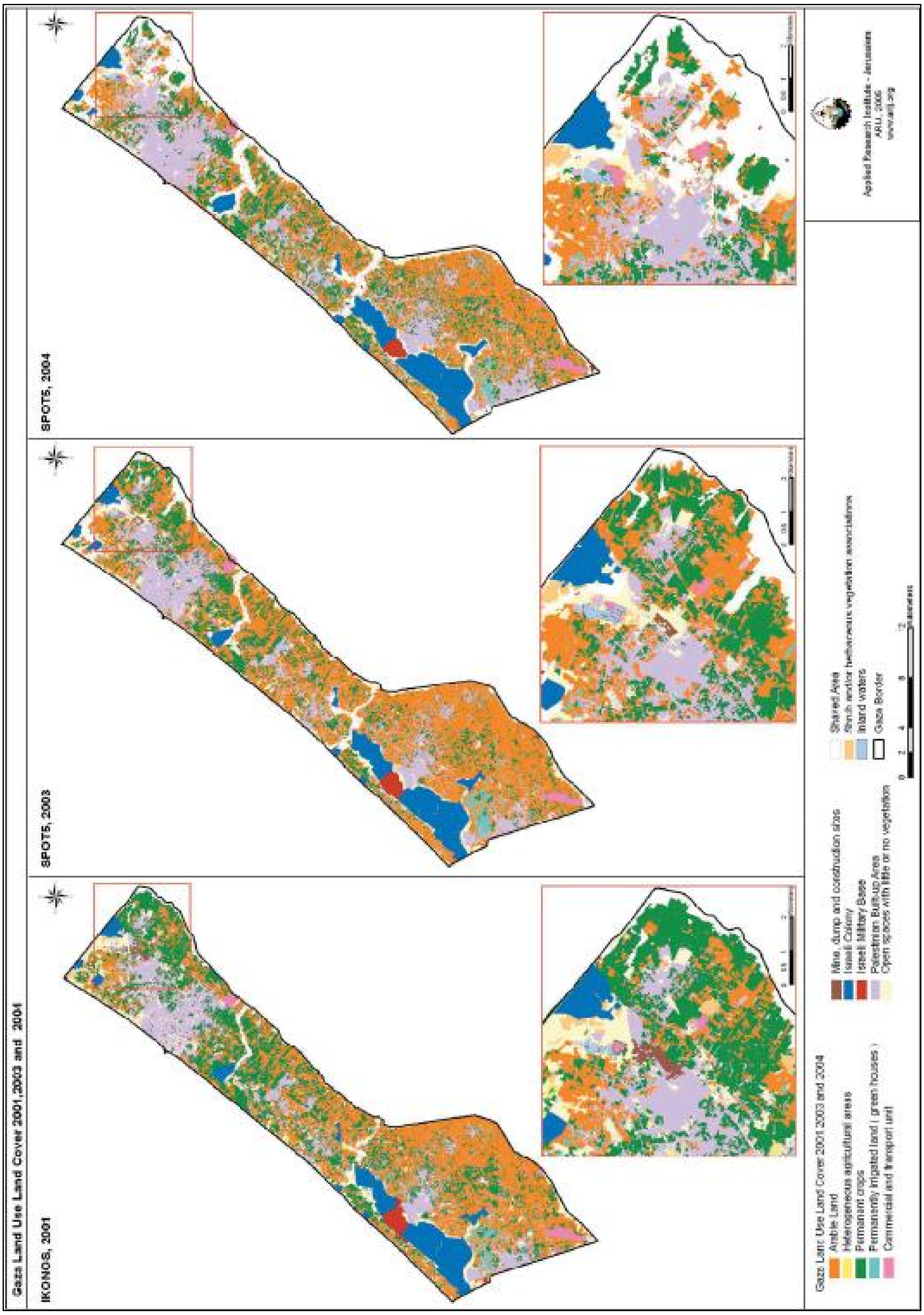


Figure 7: Land use / land cover changes in the Gaza Strip in 2001, 2003 and 2004 as classified from the satellite images (Arij, 2005).

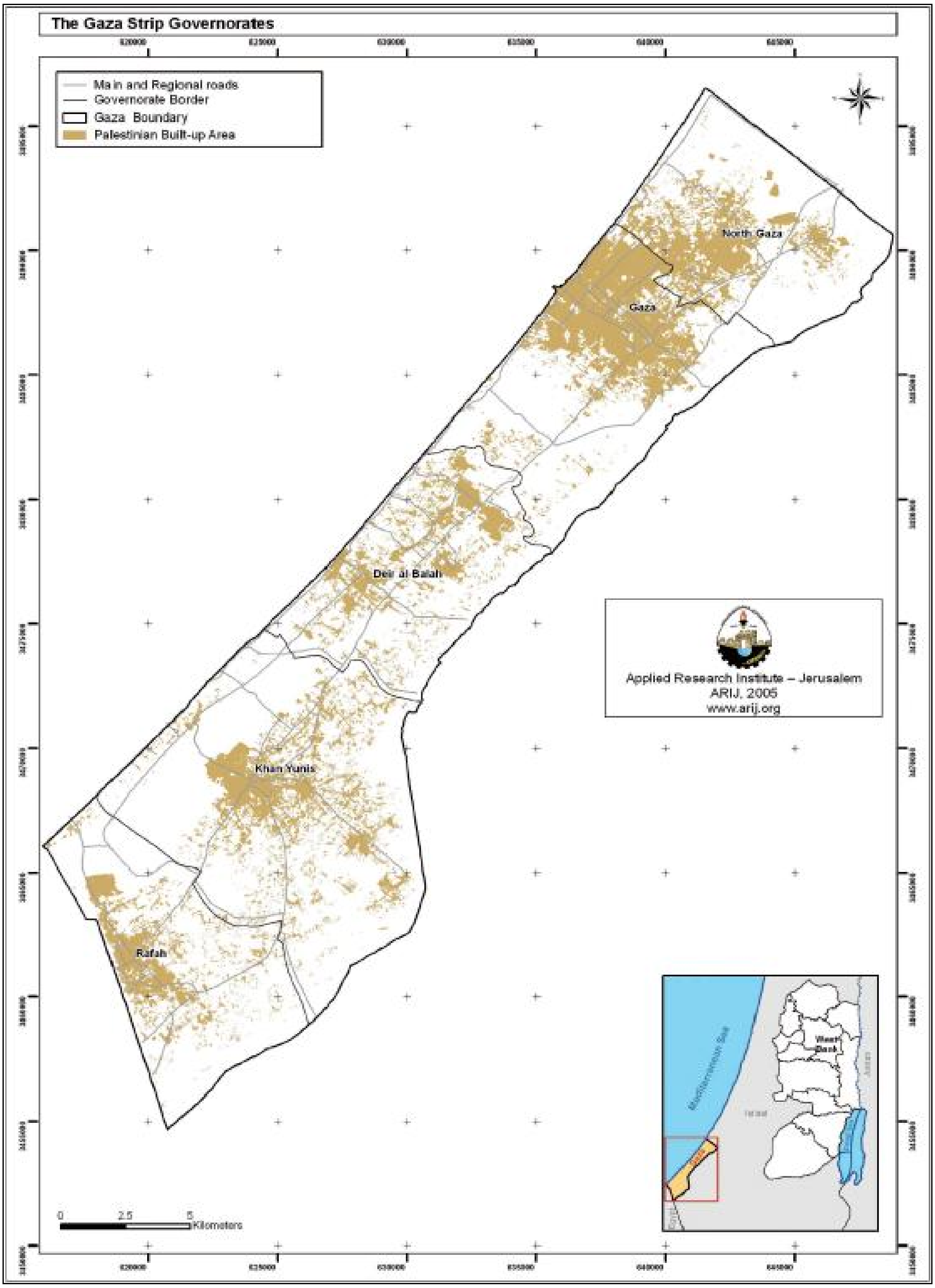


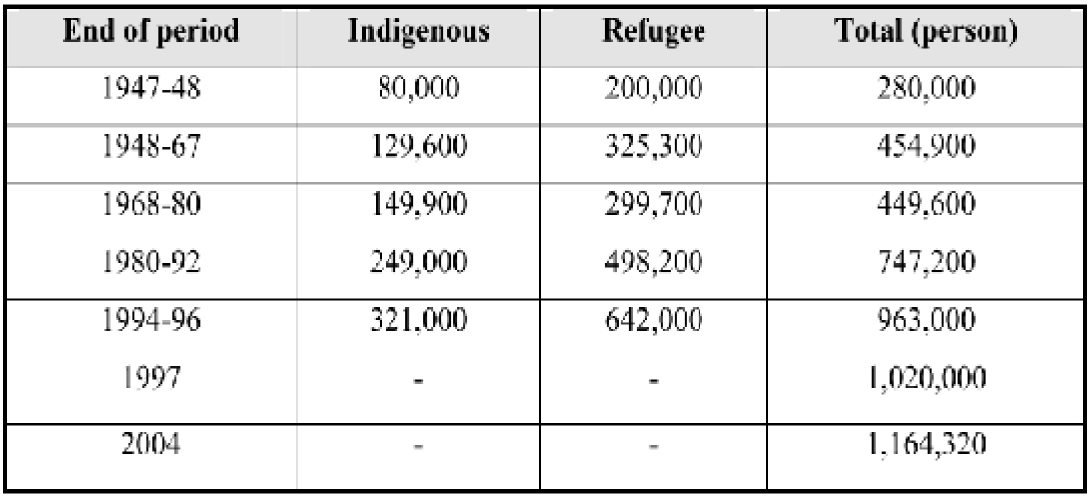
Figure 8: Built up areas of the Palestinian localities in the Gaza Strip (Arij, 2005).

2.6 Population

The estimated population of Palestinians all over the world reached 9.7 millions, by the mid of 2004. The total number of Palestinians in the Diaspora at the mid of year 2004 was 4.9 millions, and the total number of Palestinian beyond the Green Line (inside Israel) is about 1.1 millions (PCBS, 2005). The total number of registered Palestinian refugees in Jordan, Syria, Lebanon, and Palestinian Territories by the end of March, 2005 were 4,255,120 with 961,645 registered refugees (471,555 registered refugees in camps) in the Gaza Strip alone (PCBS, 2005).

According to PCBS census results in 2008, the population of Palestinians in the Gaza Strip was about 1.41 millions. Gaza Governorate was shown to have the second highest population after Hebron Governorate in the West Bank. In the Gaza Strip, the fertility rate is considered high when compared with other countries (PCBS, 2008). Table 2 shows the population change in the Gaza Strip within the period 1947-2004.

Table(2): Population change in the Gaza Strip within the period 1947-2004 (PCBS, 2005).



End of period	Indigenous	Refugee	Total (person)
1947-48	80,000	200,000	280,000
1948-67	129,600	325,300	454,900
1968-80	149,900	299,700	449,600
1980-92	249,000	498,200	747,200
1994-96	321,000	642,000	963,000
1997	-	-	1,020,000
2004	-	-	1,164,320

2.7 Economy and Social Conditions

The socio-economic situation of the Gaza Strip is experiencing various problems resulting from Israeli policies and actions taken against the infrastructure of Gaza. A report produced by the Palestinian Central Bureau of Statistics (PCBS) highlighted the complicated situation of the Gaza Strip during the Israeli withdrawal and revealed that the rate of participation in the labor force for the Gaza Strip had reached 36.5% during the second quarter of year 2005. This is compared to 9.4% participation from females, while the percentage of unemployment persons reached to 30.2%. The average weekly work hours (not including workers in Israel and colonies) reached to 42.0per week, while the average monthly work days reached 24.2 with an average daily wage of 55.8 NIS (PCBS, 2005).

Regarding the poverty indicators in the Gaza Strip under the current situation, the rates continued to be higher in that in the West Bank and in comparison with the period before the Second Intifada began. In 2004, the poverty rate reached 37.2% and 65% according to expenditure and income respectively (PCBS, 2005).

2.8 Gaza Strip Water Resources and Balance

Gaza's water resources are essentially limited to that part of the coastal aquifer that underlies its 360 km^2 area (see Figure 9). The coastal aquifer holds approximately 5000 MCM of groundwater of different quality. However, only 1400 MCM of this is fresh water, with chloride content of less than 500 mg/l. This fresh groundwater typically occurs in the form of lenses that float on the top of the brackish and/or saline groundwater. That means that approximately 70% of the aquifer is brackish or saline water and only 30% is fresh water (Al-Yaqubi A., et al., 2007).

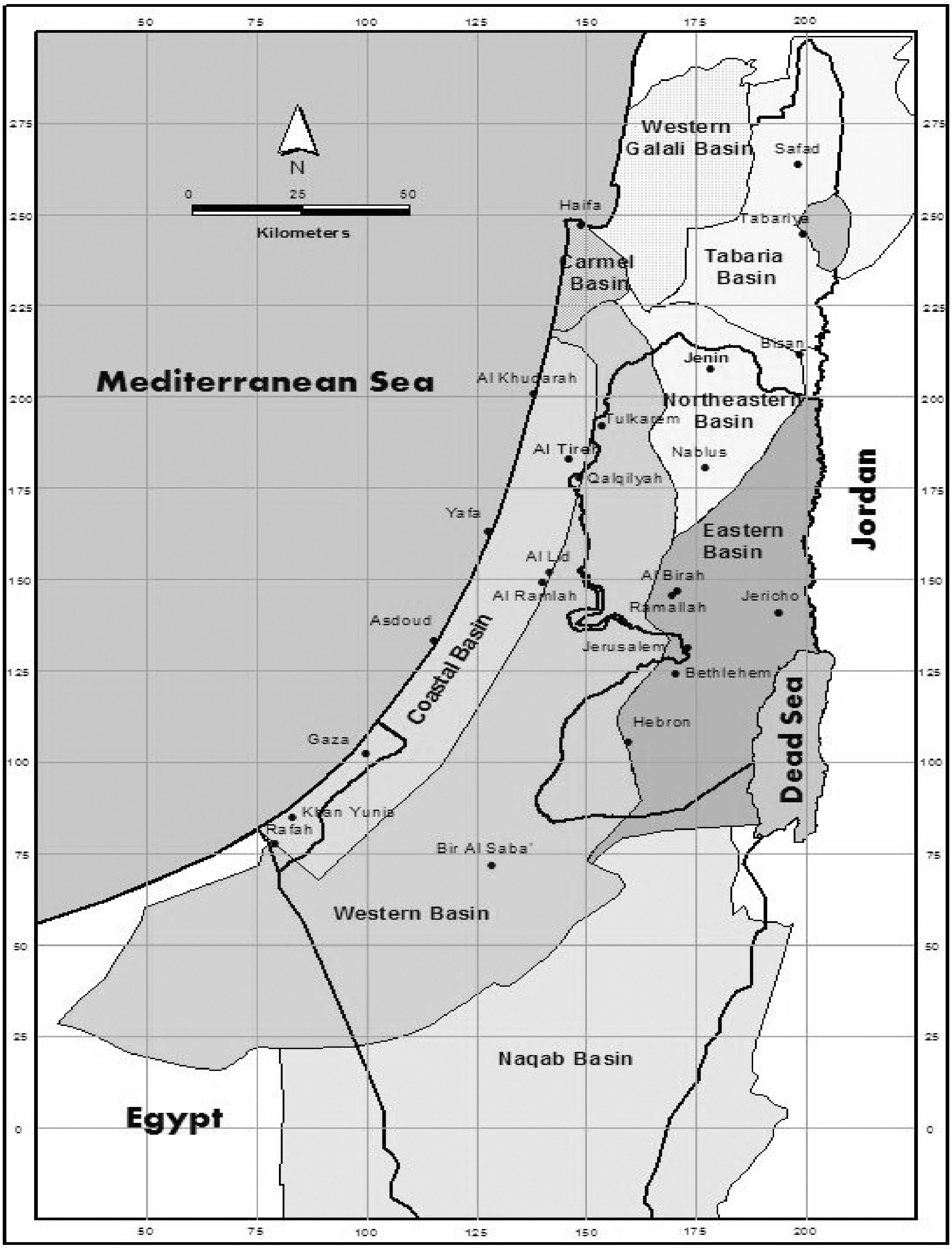


Figure 9: Groundwater basins in Palestine (Al-Yaqubi A., et al, 2007).

The major source of groundwater recharge to the aquifer is rainfall. Rainfall varies from one year to another (from 400 mm/y in the North to about 200 mm/y in the south). The total rainfall recharge to the aquifer is estimated to be approximately 45 MCM/y. The remaining rainwater evaporates or dissipates as run-off during the short periods of heavy rainstorms.

The lateral inflow to the aquifer is estimated at between 10-15 MCM/y. Some recharge is available from the major surface flow (Wadi Gaza). However, Because of the extensive extraction from Wadi Gaza in Israel, this recharge is limited to, at its best, 1.5-2 MCM/y during the 10 or 50 days that the Wadi actually flows in a normal year. As a result, the total fresh water recharge at present is limited to approximately 56.5- 62 MCM/y (PWA, 2000).

The water balance of the Gaza coastal aquifer has been developed based on an estimate of all water inputs and outputs to the aquifer system. The Gaza coastal aquifer is a dynamic system with continuously changing inflow and flows. The present net aquifer balance is negative; thatis, there is a water deficit (Al-Yaqubi A., et al, 2007).

The deficit of 32 MCM / year between total input and output to Gaza aquifer, implying the following adverse consequences:

a) Lowering of the groundwater table.

b) Reduction in availability of fresh groundwater.

c) Increased seawater intrusion and potential intrusion of deep brines.

The net deficit has led to a lowering of the water table in the past 30-40 years and to the inland migration of seawater. Of these two factors, seawater intrusion accounts for a greater fraction of the volume loss, but it is less visible and thus tends to lessen the perception of the worsening aquifer evolution (Al-Yaqubi A., et al, 2007).

The annual deficit in water resources increases annually in addition to the continuous deterioration of the aquifer as a result of seawater intrusion and wastewater discharge. Annual input to the aquifer is expected to increase as a result of on-going desalination projects, in addition to artificial recharge. The annual safe yield of the coastal aquifer is not more than 60 million m^3. Thus, the water available in the aquifer covers only part of the needs, whereas the rest should be secured by other means. According to the PWA plan, the shortage will be eliminated through desalination of brackish water and seawater and through wastewater reuse (H. Baalousha, 2006).

CHAPTER THREE

LITERATURE REVIEW

3.1 Palestinian Water Management

3.1.1 Palestinian Water Sector Challenges

The present situation in the water sector in Palestine and the challenges to be faced are summarized as follows (PWA, 2004):

a) Water resources in the region are extremely scarce, disputed and increasingly costly to develop which is limiting the opportunities for regional transfers. Water resources, particularly in the Gaza Strip, are well above the level of stress due to water scarcity.

b) Water demand is continuously growing due to population growth, economic development, and rising standards of living.

c) Water supply and sanitation services are inefficiently delivered as well as inadequate, in respect of quantity, quality and reliability. Coverage is limited.

d) Tariffs are generally inadequate and many institutions are fragmented.

e) There is insufficient control on water development and consumption and water losses are excessive.

f) There is insufficient maximization of rainwater precipitation before this water is unacceptably polluted or lost to run-off.

g) Wastewater treatment is unavailable, inadequate or not functioning; and wastewater, potentially a significant resource, is not yet satisfactorily reclaimed and utilized.

3.1.2 Palestinian Water Strategy

The following items constitute the main water strategy elements of the Palestinian National Authority (PWA, 2003):

a) All sources of water should be the property of the state.

b) Water has a unique value for humans' survival and health, and all citizens have the right to water of good quality for personal consumptions at cost they can afford.

c) Domestic, industrial and agricultural development and investments must be compatible with the water resource quantity available.

d) Water indeed is an economic commodity; therefore, the damage resulting from the destruction of its usefulness (pollution) should be paid by the party causing the damage (pollution).

e) The development of the water resources of the Palestinian territory must be coordinated on the national level and carried out on the appropriate local level.

f) Water supply must be based on a sustainable development for all available water resources.

g) Public participation in water sector management should be ensured.

h) Water management at all levels should integrate water quality and quantity.

i) Water supply and wastewater management should be integrated at all administrative levels. Consistent water demand management must complement the optimal development of water supply.

j) Protection and pollution control of water resources should be ensured.

k) Conservation and optimum use of water resources should be promoted

3.1.3 The Palestinian National Water Plan (PWA, 2000)

The National Water Plan outlines the direction in which the Palestinian water sector is proposed to develop to the year 2020 and proposes the actions to be taken to achieve these goals. The strategic planning element of the Plan has confirmed the logic for this direction and identified the alternatives, which may have to be considered if assumptions do not materialize as anticipated.

As a strategic plan for the water sector, the plan will be implemented under the direction of the Palestinian Water Authority (PWA) but in close collaboration and co-ordination with other Palestinian stakeholders. It is intended as a dynamic tool to identify, define, and describe an implementation process for the integrated management and development of Palestinian water resources.

The planning approach has been based on estimates of demand for planning horizons up to 2020. These demands have been estimated utilizing internationally recognized standards appropriate to the location and to the development objectives. In accordance with the scarcity of resources in the region, demand management measures and utilization of alternative sources to fresh water have been incorporated wherever appropriate.

The implementation plan has identified projects, which are programmed to achieve the following:

- As a first priority, infrastructure will be expanded to progressively provide quality water service to all domestic consumers reaching an average of 150 L/c/d by the year 2020. Standards of water quality related to WHO criteria and provision within municipal and industrial supplies to meet industrial demand will be met.

- Water exploration and aquifer modeling will be carried out to determine additional quantities of water and sustainable yields.

- Sewer and wastewater treatment facilities will be expanded to safeguard public health, avoid pollution and to utilize water for beneficial purposes.
- Conservation measures such as metering, leakage reduction, and improved agriculture technologies will be implemented to save water.
- Storm water will be channelled to collection facilities for beneficial purposes including agriculture and groundwater recharge and to reduce flooding.
- Reclaimed wastewater, as well as brackish water, will be treated to standards appropriate for the relevant irrigation and for aquifer recharge.

3.1.4 Palestinian Water Sector Strategic Planning Study PECDAR,2000

The strategic plan outlines the direction in which the Palestinian water sector should be developing to the year 2020 and proposes the actions to the year 2020 and proposes the actions to be taken to achieve these goals. The strategic planning process has established the logic for this direction and identified the alternatives, which may have to be considered if assumptions do not materialize as anticipated.

As a strategic plan for the water sector, the plan will be implemented by the PWA in close collaboration and coordination with all Palestinian stakeholders. It is intended as a dynamic tool to identify, define, and describe an implementation process for the integrated management and development of Palestinian water resources. This publication has been structured as a concise document to provide a clear presentation of the vision, objectives and related actions by the various target user groups to accomplish these objectives.

3.1.5 Coastal Aquifer Management Plan (CAMP, 2000)

The main goal of CAMP is to assist PWA to: "Manage the limited capacity coastal aquifer system to exploit fully, in an environmentally safe manner, its utilization as a sustainable source of water supply."

The principal task of CAMP therefore is to prepare an Integrated Aquifer Management Plan whose implementation by Palestinian authorities, principally PWA, will achieve this primary project goal and provide adequate water supply for the Gaza Strip *and* sustain the aquifer for the future. Objectives of CAMP are listed as follows:

Protect the aquifer by control and reduction of extraction for agricultural irrigation.

Ensure the supply of water in quantity and of quality to meet the increasing demands of people (M&I) by increased extraction, pre-treatment, distribution and augmentation of supply.

Recharge the aquifer by collection, treatment and infiltration of wastewater from M&I consumers.

Sustain agriculture by the supply of treated wastewater as the principal source of irrigation water

This calls for the delivery of good-quality water to all households and for collection and recharge of treated wastewater via a system of infiltration basins. Thus, the quantity of good water in the aquifer will be increased, stemming saltwater intrusion in the near-term and reducing it in the future.

It also requires the provision of “new” water to the aquifer system and the reduction of agricultural extraction by some 80 percent from that estimated to occur in 1999. This will be achieved in stages by the desalination of seawater (pending a political solution to the problems of acquiring water rights in the West Bank and piped transfer of water across Israel), and by the distribution of treated wastewater to farmers for irrigation.

Water distribution to the municipal and industrial sector will be by a common system based around a north-south water carrier. All water fed into this carrier will be pre-treated to a level to satisfy the standards of the WHO for drinking water, through treatment facilities as specified in the IAMP. A further benefit of this pre-treatment is that the resulting wastewater to be distributed to farmers will have salinity content lower than that of current agricultural wells in most areas, thus making it more acceptable to farmers.

Municipal wastewater will be collected by sewer systems feeding the three regional wastewater treatment plants to be constructed in stages in the Northern, Central, and Southern parts of the Gaza Strip.

3.2 The Concept of Integrated Water ResourcesManagement

3.2.1 Introduction

Integrated Water Resource Management (IWRM) as a concept allows focusing on the detail of water use practices while stepping back and considering the bigger picture.

The generally accepted definition of sustainable development ‘‘is development which meets the needs of the present, without compromising the ability of future generations to meet their own needs.

Integrated Water Resources Management is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystem (Alfarra A., 2004).

The definition suggests managing things that cannot be managed, such as rainfall; wind and other natural processes; while people’s activities can be managed. Therefore a more suitable definition of Integrated Water

Resources Management would be: managing people’s activities in a manner that pro-motes sustainable development (Alfarra A., 2004).

3.2.2 Water Resources Management Modeling

Modeling of water conditions in a given area is a simplified description of the real system to assist calculations and predictions used to estimate the amount of water that is needed to meet the existing and projected demands under potential availability and demand scenarios, and determine what interventions are necessary, as well as when and where, and their cost. Models can represent the important interdependencies and interactions among the various control structures and users of a water system; in addition they can help identify the decisions that best meet any particular objective and assumptions (Loucks and Beek, 2005).

The two principal approaches to modeling are simulation of water resources behavior based on a set of rules governing water allocations and infrastructure operation; and optimization of allocations based on an objective function and accompanying constraints. Simulation models address what if questions. Their input data define the components of the water system and their configuration and the resulting outputs can identify the variations of multiple system performance indicator values. Simulation works only when there are a relatively few alternatives to be evaluated. Optimization models are based on objective functions of unknown decision variables that are to be maximized or minimized. The constraints of the model contain decision variables that are unknown and parameters whose values are assumed known. Constraints are expressed as equations and inequalities (Loucks and beek, 2005).

3.3 Water Management Decision Support Systems

3.3.1 Introduction

A Decision Support System (DSS) is an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to aid decision makers in solving relatively large, unstructured water resource management problems.

Three main subsystems must be integrated in an interactive manner in a DSS (Orlob G., 1992):

a) A user-interface for dialog generation and managing the interface between the user and the system.

b) A model management subsystem.

c) An information management subsystem.

DSS architecture consists of the following components (see Figure 10):

a) *Data measurement:* the tasks involved in data gathering.

b) *Data processing:* the tasks involved in registration of measurements into databases and their subsequent processing, retrieval, and storage.

c) *Analysis:* the models used to infer the state of the system so that reasonable decision alternatives can be formulated.

d) *Decision support:* the gathering and merging of conclusions from knowledge-based and numerical techniques and the interaction of users with the computer system through an interactive and graphical user interface.

e) *Decision implementation:* the formulation of actions to be implemented in solving a specific problem.

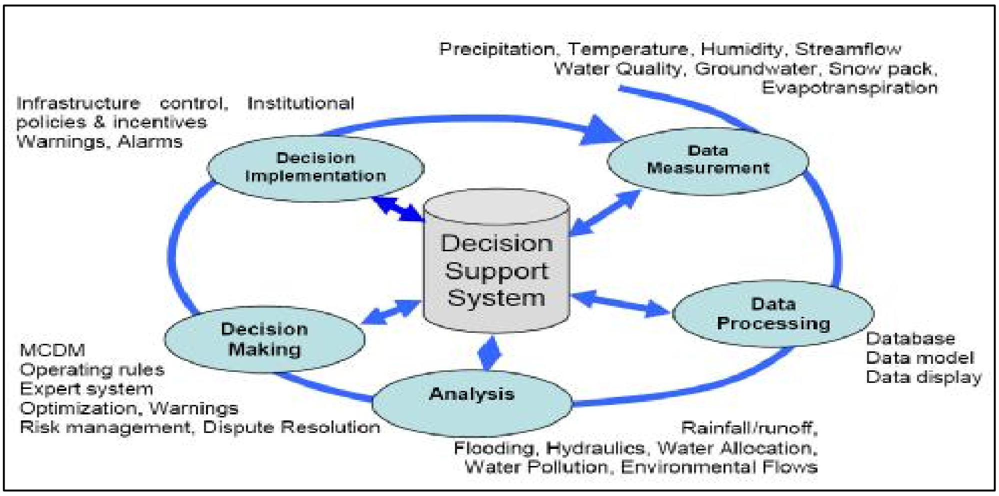


Figure 10: General framework for water resources DSS (Daene C. McKinney, 2004).

3.3.2 Water Allocation Models

Following are some models:

WEAP: The Water Evaluation and Planning System (WEAP) developed by the Stockholm Environment Institute’s Boston Center (Tellus Institute) is a water balance software program that was designed to assist water management decision makers in evaluating water policies and developing sustainable water resource management plans. WEAP operates on basic principles of water balance accounting and links water supplies from rivers, reservoirs and aquifers with water demands, in an integrated system. Designed to be menu driven and user-friendly, WEAP is a policy-oriented software model that uses water balance accounting to simulate user-constructed scenarios. The program is designed to assist water management decision makers through a user friendly menu-driven graphical user interface. WEAP can simulate issues including; sectoral demand analyses, water conservation, water rights, allocation priorities, groundwater withdrawal and recharge, stream flow simulation, reservoir operations, hydropower generation, pollution tracking (fully mixed, limited decay), and project cost/benefit analyses. Groundwater supplies can be included in the WEAP model by specifying a storage capacity, a maximum withdrawal rate and the rate of recharge. Minimum monthly in stream flows can be specified (Raskin, et al., 1992).

Aquarius: Aquarius is a temporal and spatial allocation model for managing water among competing uses. The model is driven by economic efficiency which requires the reallocation of all flows until the net marginal return of all water uses is equal. In the graphical user interface, the components are represented by icons, which can be dragged and dropped from the menu creating instances of the objects on the screen. These can be positioned anywhere on the screen or removed. Once components are placed on the screen, they are linked by river reaches and conveyance structures. The model does not include groundwater or water quality. The model could be used to evaluate net benefits by subtracting costs from benefits in the individual benefit functions. From the model documentation, it is apparent that making significant modifications to the model or its structure would be very difficult (Diaz et al., 1997).

CALSIM: The California Water Resources Simulation Model was developed by the California State Department of Water Resources .The model is used to simulate existing and potential water allocation and reservoir operating policies and constraints that balance water use among competing interests. Policies and priorities are implemented through the use of user-defined weights applied to the flows in the system. Simulation cycles at different temporal scales allow the successive implementation of constraints. The model can simulate the operation of relatively complex environmental requirements and various state and federal regulations (Quinn et al., 2004).

WaterWare: WaterWare is a decision support system based on linked simulation models that utilize data from an embedded GIS, monitoring data including real-time data acquisition, and an expert system. The system uses a multimedia user interface with Internet access, a hybrid GIS with hierarchical map layers, object databases, time series analysis, reporting functions, an embedded expert system for estimation, classification and impact assessment tasks, and a hypermedia help- and explain system. The system integrates the inputs and outputs for a rainfall-runoff model, an irrigation water demand estimation model, a water resources allocation model, a water quality model, and groundwater flows and pollution model (Fedra, 2002).

OASIS: Operational Analysis and Simulation of Integrated Systems developed by Hydrologics, Inc. is a general purpose water simulation model. Simulation is accomplished by solving a linear optimization model subject to a set of goals and constraints for every time step within a planning period. OASIS uses an object-oriented graphical user interface to set up a model, similar to ModSim. A river basin is defined as a network of nodes and arcs using an object-oriented graphical user interface. Oasis uses Microsoft Access for static data storage, and HEC-DSS for time series data. The Operational Control Language (OCL) within the OASIS model allows the user to create rules that are used in the optimization and allows the exchange of data between OASIS and external modules while OASIS is running. OASIS does not handle groundwater or water quality, but external modules can be integrated into OASIS (Randall et al, 1997).

RiverWare: RiverWare is a reservoir and river system operation and planning model. Site specific models can be created in RiverWare using a graphical user interface by selecting reservoir, reach confluence and other objects. Data for each object is either imported from files or input by the user. RiverWare is capable of modeling short-term (hourly to daily) operations and scheduling, mid-term (weekly) operations and planning, and long-term (monthly) policy and planning. Operating policies are created using a constraint editor or a rule-based editor depending on the solution method used. The user constructs an operating policy for a river network and supplies it to the model. RiverWare has the capability of modeling multipurpose reservoir uses consumptive use for water users, and simple groundwater and surface water return flows. Water quality parameters including temperature, total dissolved solids and dissolved oxygen can be modeled in reservoirs and reaches. Reservoirs can be modeled as simple, well-mixed or as a two layer model. Additionally, water quality routing methods are available with or without dispersion (Carron et al., 2000).

Aquatool: Aquatool consists of a series of modules integrated in a system in which a control unit allows the graphical definition of a system scheme, database control, utilization of modules and graphical analysis of results. Modules include: surface and groundwater flow simulation; single- and multi-objective optimization of water resources; hydrologic time series analysis; risk based WRS management. Water quality is not included (Andreu, 2004).

3.4 Water Evaluation and Planning System (WEAP)

3.4.1 Why WEAP?

a) In Palestine, WEAP was tested by different researchers and on different scales like (Haddad et. al., 2006), (Haddad et. al., 2008), (Abu Hantash S., 2007), (Arafat A., 2007) and others, so technical support is available.

b) It was designed to assist water management decision makers in evaluating water polices and developing sustainable water resources management plans through a user friendly menu-driven graphical user interface(GUI) and easy to use, while CALSIM, Aquarius, RiverWare, Water Ware require advanced skills.

c) Relatively straight forward for testing the effects of different water management scenarios. While RiverWare and Aquarius are difficult in entering data.

d) WEAP can simulate issues including; sectoral demand analysis, water conservation, water rights, allocation priorities, groundwater withdrawal and recharge, stream flow simulation, reservoir operations, hydropower generation. Groundwater supplies can be included in the WEAP model by specifying a storage capacity, a maximum withdrawal rate and the rate of recharge. While Aquarius and OASIS does not handle groundwater.

e) WEAP can model water quality by tracking point and non-point source pollution from generation to treatment to its accumulation in surface and underground bodies of water and transport and decay in rivers. While Aquarius and OASIS does not handle water quality.

f) Generate output that can be easily used by data files and spreadsheet files (such as Excel) while in OASIS and Aquarius there are no connection to spreadsheets or databases.

g) Changing input data to model newly proposed scenarios can be readily accomplished. While RiverWare and Aquarius are difficult to make modifications in model structure.

h) Results are easy to view for comparison of different scenarios. While Aquarius and CALSIM does not easy to view and compare results

i) Able to integrate with spatial data stored in GIS. While CALSIM, OASIS, and River Ware are not.

j) WEAP is in widespread use throughout the world, including: Beijing Environmental Master Plan Application System; Water resources study for the Upper Chattahoochee River, Georgia, USA; Water management options in the Olifant River basin, South Africa; the Rio San Juan pilot study, Mexico. Many more examples are available on the SEI website.

k) WEAP is available in many languages while Aquatool is in Spanish.

The result shows that WEAP is a Successful decision support Tool with GIS enabled graphical user interface and with relational databases, visualization techniques, analysis tools and decision logic. Such powerful DSS tool enables managers and decision makers to quickly obtain answers to critical questions and to focus on transparency and accessibility of results. The ever increasing focus on water management requires that scientists, planners, managers and decision makers are able to quickly produce reliable estimates, assess impacts and efficiency of potential strategies.

3.4.2 Principal Capabilities of WEAP

WEAP creates a comprehensive and integrated picture of municipal, industrial and agricultural water use and respective supply sources. The model is useful to systematically identify all users and supply sources by amount and location; to forecast future demand; to compare supply and demand and identify potential shortages; to examine supplies and uses under different scenarios; and to assess the overall adequacy of the water resource for effective water management (William et. al., 1995).

Water Supplies: All surface water supplies, groundwater supplies, and inter basin transfers may be included in the model. Major reservoirs as well as local supply reservoirs are modeled; the amount of water exchanged between a river and adjacent groundwater aquifer are accounted for. Reporting of water supply includes; total supply resources; river, groundwater and local supply sources; evaporation losses from reservoirs, rivers and tributaries; return flow; and surface and groundwater interaction.

Priorities of Water Use: Priorities can be established between competing demands for water along a main river or between local supplies such as streams, local reservoirs and groundwater.

Water Uses: Withdrawals for watertreatment plants, discharges from wastewater treatment plants, return flows, groundwater pumpage, and losses, both in a distribution system and from rivers and reservoirs, are accounted for. Instream flow requirements are also modeled. Reporting of water demands includes: total demand; demand by branch level; demand by sector; demand by geographic area; demand by site; instream demands; and demand by supply source.

Wastewater Treatment Facilities: Wastewater treatment facilities can receive wastewater as return flow from multiple demand sites, temporarily hold it, and then return it to water supply sources.

Comparing Supply and Demand: Comparisons are made at a site specific level such as a water treatment or wastewater treatment plant, or at an aggregate level such as a city or county. Forecasts of future demands may be made in several ways and compared with estimated supplies under drought or other hydrologic conditions.

Mass Balance Reporting: The model can display a mass balance of withdrawals and uses at any river/tributary node, demand site, wastewater treatment facility, and supply source.

Monthly Data: All data used in the program are monthly averages. Supply data can be entered for critical drought periods, individual years, or average conditions.

Tables and Graphs: Supply and use data are displayed as tables or graphs. The graphs available include line charts, pie charts and bar charts. Network diagrams are available to show major rivers and their reservoirs, withdrawals, diversions, confluences, and tributaries. Distribution systems and their supply sources are also shown by a network diagram.

3.5.5 Sample Applications of WEAP

There are many case studies that are supported by WEAP Applications as:

Development of sustainable management option for the West Bank using WEAP: WEAP was applied as a decision support system (DSS) tool for the water resource management in the West Bank. The results obtained showed that water demand varies significantly according to the assumed political situation, and underlined the importance role of water management aspects. Also the results revealed that an additional amount more than 700 MCM is needed to satisfy water needs and development (Abu Hantash S., 2007).

Integrated water resources planning for a water-stressed basin in Palestine: This research focuses on building an IWRM model for Al Far'a catchment using WEAP program. The utility of the analysis to highlight the need for alternative water supplies; to quantify groundwater recharge; to evaluate water conservation and fair water allocation policies (Arafat A., 2007).

GLOWA Jordan River: The GLOWA Jordan River (GLOWA JR) project, a collaboration of Israeli, Palestinian, Jordanian, German and US scientists, provides tools and information to test and assess different scenarios of water resources development and management. WEAP is being used for integration, mapping and visualization of available information for current and future scenario conditions, for regional models as well as detailed local or country models.

WEAP in the Middle East and North Africa: Linking WEAP to MODFLOW and capacity building: In order to help promote integrated water resources planning in the MENA region, SEI is working closely with the Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD, based in Damascus) and the German Federal Institute for Geosciences and Natural Resources (BGR) to build capacity in the use of WEAP. In addition, in order to better address the issues in the arid regions of MENA, particularly those of groundwater, WEAP has been enhanced to dynamically link to MODFLOW, a finite difference groundwater modeling system.

Accounting for Water Supply and Demand: Application of the Computer Program WEAP to the Upper Chattahoochee River Basin: The Hydrologic Engineering Center of the US Army Corps of Engineers, in conjunction with a number of local planning agencies, used WEAP in an analysis of the Upper Chattahoochee River Basin in Georgia. The study modeled the water supply and demand of the water stressed basin and provided federal, state, and local water agencies with a comprehensive look at the total water resource of the watershed. The results were used in resolving interstate conflicts on water allocation.

Israeli/Palestinian Dialogue: WEAP was used to represent alternative water development and allocation scenarios in a process involving both Israeli and Palestinian participants. Results were used in a workshop in which government, academic and stakeholder representatives jointly explored alternatives for water sharing in the region.

CHAPTER FOUR

MODELING DEMAND AND SUPPLY USING WEAP

4.1 Introduction

In the future, available water resources will be subjected to greater pressure in the face of increasing demands. Thus, there is an increasing need to more intensively manage water in order to achieve an increasingly diverse set of water-related social goals (Arafat A., 2007). Since the main objective behind this work is to test different management options using WEAP tool for the Gaza Strip. Therefore, a successful Water management Tool needed to explain variety of options available to Gaza Strip water manager and policy makers to manage future water demand and supply development.

The major steps used in WEAP to generate water management options under different scenarios for the Gaza Strip are:

a) Identification of time frame and system components and configuration.

b) Establishing the current accounts that provide a snapshot of actual water demand resources and supplies for the system.

c) Establishing the reference scenario that represents the changes that are likely to occur in the future, in absence of any new policy measure.

d) Building scenarios based on different sets of future trends and factors that affect demand supply.

e) Evaluating the scenarios with regard to criteria including adequacy of water resources and environmental impacts.

4.2 Model Algorithm

WEAP operates on the basic principle of water balance for every node and link in the system on a monthly time step subject to demand priorities, supply preferences, mass balance and other constraints. Mass balance equations are the foundation of WEAP monthly water accounting: total inflows minus total outflows equal to net change in storage if any. Every node and link in WEAP has a mass balance equation and some have additional equations which constrain their flows (e.g., outflows from an aquifer cannot exceed its maximum withdrawal, link losses are a fraction of flow, etc.) (Abu Hantash S., 2007).

4.3 Establishing the Current Accounts in WEAP

The Current Accounts represent the basic definition of the water system as it currently exists. Establishing Current Accounts requires the user to "calibrate" the system data and assumptions to a point that accurately reflects the observed operation of the system. The Current Accounts are also assumed to be the starting year for all scenarios (WEAP User Guide, 2005).

Establishing the Current Accounts in WEAP represent the core of the simulation process and the basic definition of the water system, as it currently exists. (Haddad et. al., 2008) In this case, the year 2006 is selected as the current year (based on available data for 2006). The model simulation period is taken from 2003 -2020.

4.3.1 Current Water Uses

Existing water uses can be classified to the following:

- Municipal and industrial (domestic, industrial) water demands,
- Agricultural (Irrigation, Livestock) water demands.

Activity Levels are used as a measure of social and economic activity, and the water use rate is the average annual water need per unit of activity.

Domestic demand: the population of Gaza Strip obtained from PCBS is shown in Table 3.

Table(3): Gaza Strip domestic demand sites projection for the year 2006 (PCBS, 2004).

District	**Annual activity**	**growth rate**
North Gaza	278,180	3.3
Gaza	505,702	3.3
Deir Al-Balah	208,716	3.3
Khan yunis	279,853	3.3
Rafah	171,363	3.3
Total	1,443,814	3.3

Agricultural demands are represented by irrigated agricultural areas obtained from PWA, 2007 are shown in Table 4.

Table(4): Gaza Strip agricultural demand areas for the year 2006 (dunums) (PWA, 2007).

District	Irrigated Area (dunums)
North Gaza	17,000
Gaza	14,463
Deir Al-Balah	20,865
Khan yunis	31,511
Rafah	17,765

Industrial demand shares about 6-8 percent of total municipal and industrial demand based on PWA records, 2006.

Livestock demands approximately 2MCM for year 2006 which is equal 2.2% of total agricultural demand based on data from PWA for 2006.

4.3.2 Current Water Needs

Domestic Water needs: Considering drinking water and sanitation needs only suggests that the amount of clean water required to maintain adequate human health is about 100 L/c/d, and 150 L/c/d is necessary to provide for some average acceptable quality of life.

Irrigation Water needs: Irrigation requirements for year 2006 obtained from PWA summarized in Table 5.

Table (5): Gaza Strip irrigation requirements for the year 2006 (m^3/dunum) (PWA, 2007).

District	Area (dunum)	Water requirement
North Gaza	17,000	592
Gaza	14,463	753
Deir Al-Balah	20,865	703
Khan yunis	31,511	841
Rafah	17,765	599

4.4 Potential Water Availability

All available and water resources for now and future, and all resources suggested by Coastal Aquifer Management Plan, Palestinian Water Authority and Palestinian Water Strategic Planning Study without any constrains will be discussed and taken into consideration while developing scenarios.

4.4.1 Groundwater

Gaza’s groundwater resources are mentioned previously in section 2.8.

4.4.2 Surface Water

The surface water system in the Gaza Strip consists of wadis, which only flood during very short periods, except for Wadi Gaza (see Figure 11). Wadi Gaza is the major wadi in the Gaza Strip that originates in the Negev Desert in a catchment area of 3500 km^2 and with an estimated average annual flow of 20-30 MCM/yr. However, rainfall varies significantly from one year to another and thus annual discharge can range from 0 to 100 MCM/yr. In addition, Wadi Gaza at present is diverted by the Israelis towards reservoirs for artificial recharge and irrigation. This means that nowadays, only a little water out of the huge floods may reach the Gaza Strip, if any, due to the Israeli practices. There are two other insignificant wadis in the Gaza Strip, namely Wadi El Salqa in the south and Wadi Beit Hanon in the north, that are almost always dry.

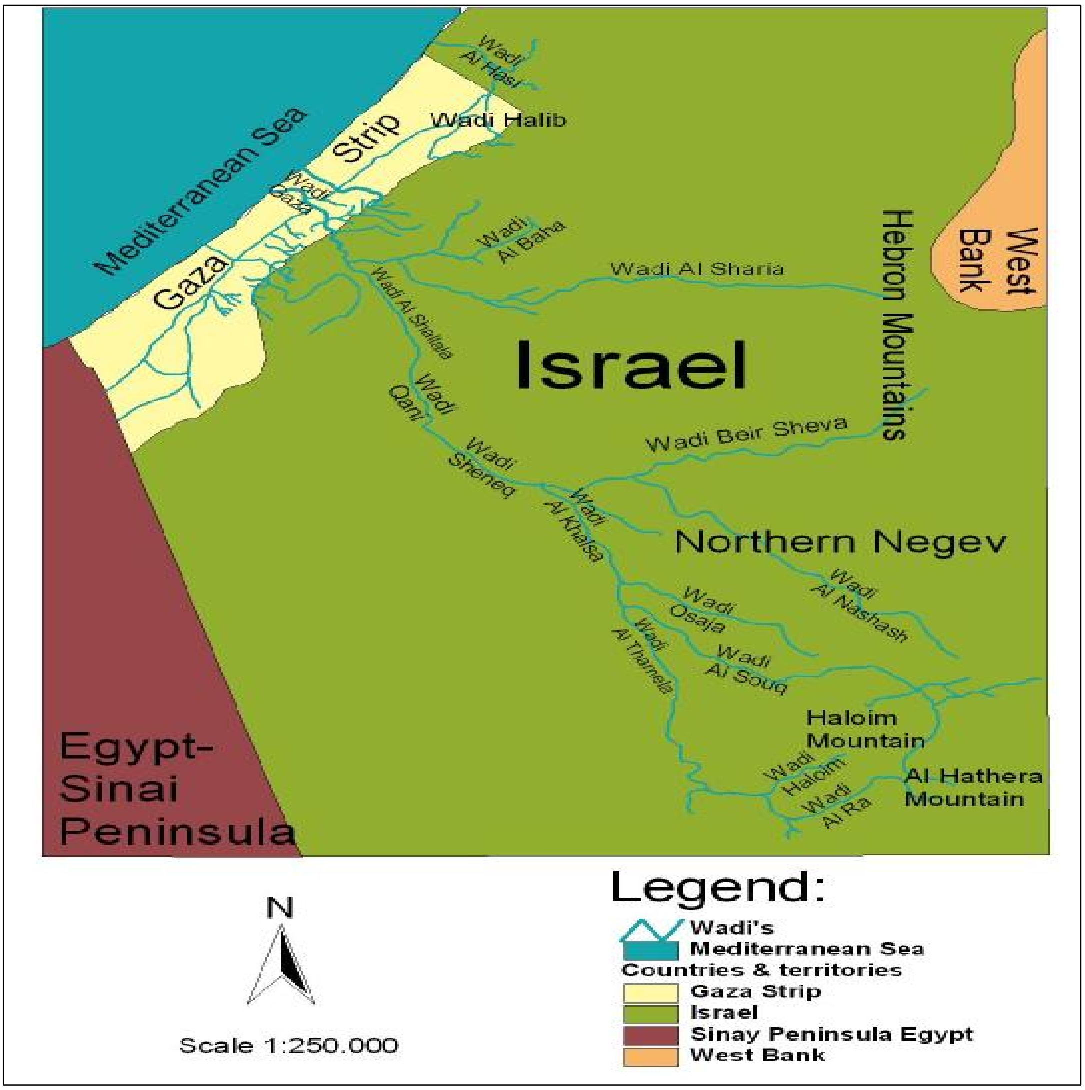


Figure 11: Wadi Gaza and its tributaries (UNDP, 2003).

4.4.3 Mekorot Water

A total amount of 5 MCM from Mekorot water in Israel is agreed to supply the municipalities connections located in the Middle and Khan Younis governorate. Mekorot has two main pipelines running through the Gaza Strip. It supplies some 4 MCM in year 2006 of domestic water to the Gaza region through municipalities and village councils (PWA, 2006).

Additional 5 MCM/yr proposed to be purchased from Mekorot in accordance with the Oslo 2 agreement (CAMP, 2000).

4.4.4 Rainfall Harvesting

Potential rainwater harvesting can be estimated as the total depth of precipitation multiplied by Gaza Strip built up areas. The built up area are which included residential, commercial and a paved and un paved road represents about 16% total area while the amount of rainfall hitting the surface about 88 MCM so the potential volume was estimated at 14 MCM/yr. (Khalaf A., et al., 2006).

4.4.5 Wastewater Reuse

The water waste collected from the whole of the Gaza Strip is fed into three main treatment plants; Beitlahya (North), Gaza and Rafah with total capacity of 20,000, 75,000 and 16,000 m3/day (total of 40 MCM/year) by the year 2010, respectively. Currently, partially treated waste water is discharged to the sea without any significant re-use. As stated in the proposed regional plan for the Gaza Strip (MOP, 2005), the three main treatment plants should be transferred to the eastern border of the Gaza Strip, and should work with treatment technology to produce treated effluent of a quality fit for fruit trees irrigation, according to Ministry of Environmental Affairs standards (RICS, 2007).

Public acceptance of using treated waste water for irrigating agricultural produce is a crucial aspect in ensuring the success of any re-use project. Therefore, a sample of 12 large farm owners with citrus and fruit trees (1500 dunum) were questioned using a questionnaire especially designed to fulfill this purpose. The majority of farmers (10) agreed completely with using the treated effluent; the remainder agreed conditionally, assuming that the general public will not accept the produce which has been irrigated by treated effluent. Marketing the produce is their concern. Most of the farmers show understanding of the water crisis in the Gaza Strip and have attended public awareness workshops (RICS, 2007).

Based on Coastal Aquifer Management Plan the proposed Wastewater treatment plants will product 63 MCM/yr by 2020 which will be used for direct irrigation (CAMP, 2000).

4.4.6 Seawater Desalination

Desalination of brackish and saline water seems to be promising, especially in the absence of any other alternatives in the Gaza Strip. However, using desalination technology as an alternative water supply implies many challenges such as energy cost and environmental aspects. On one hand, reliance on desalination as a source of water supply can solve the growing problem of water shortage in the area and overcome the problem of deterioration of water quality (Baalousha H., 2006).

Based on Coastal Aquifer Management Plan the proposed desalination plants will product 57 MCM/yr by 2020 (CAMP, 2000).

4.4.7 West Bank Mountain Aquifer

Based on Palestinian Water Strategic Planning Study the strategy proposed to construct the necessary infrastructure and transfer 104 MCM/yr of water from West Bank Aquifers regarding to the outcomes of negotiations (PECDAR, 2000).

4.5 Current Water Supply

In Gaza strip, Municipal water demand data comprises water supplied for domestic and industrial use from the following sources are 126 Municipal wells operated by 25 municipalities and PMU-CMWU, 10 UNRWA wells which is operated by UNRWA and Mekorot Water as shown in Figure 12.

The approximate estimation of irrigation water demand based on the quota allowed and the available irrigated lands is about 85.5 MCM/year, with a clear increase of water abstracted for irrigation purposes taking into account the illegal abstraction from more than 4600 agricultural wells (2600 legal wells and more than 2000 illegal wells) distributed all over Gaza Strip (PWA, 2006).

4.5.1 Municipal Water Supply

Municipal water wells production and billed water consumption for different governorates in Gaza strip, are presented in Table 6 below.

Table 6: Municipal well production and consumption in the Gaza Strip governorates for the year 2006 (PWA, 2007).

Governorate	**Population**	**Consumption (MCM)**	**Municipal well production (MCM)**	**Consump. With losses (L/c/d)**	**Consump. Actually provided (L/c/d)**
North Gaza	278,180	9.72	20.76	204	96
Gaza	505,702	17.75	26.7	145	96
Middle	208,716	6.14	10.21	134	81
Khan Younis	279,853	6.39	12.94	127	63
Rafah	171,363	4.31	6.88	110	69
Gaza Strip	**1,443,814**	**44.31**	**76.80**	**144**	**84**

Mekorot water (PWA, 2007): a total amount of 5 MCM from in Israel is agreed to supply the municipalities connections located in the Middle and Khan Younis governorate. Mekorot has two main pipelines running through the Gaza Strip. It supplies some 4 MCM in year 2006 of domestic water to the Gaza region through municipalities and village councils.

In addition it was observed that the yearly municipal water well production is continually increasing.

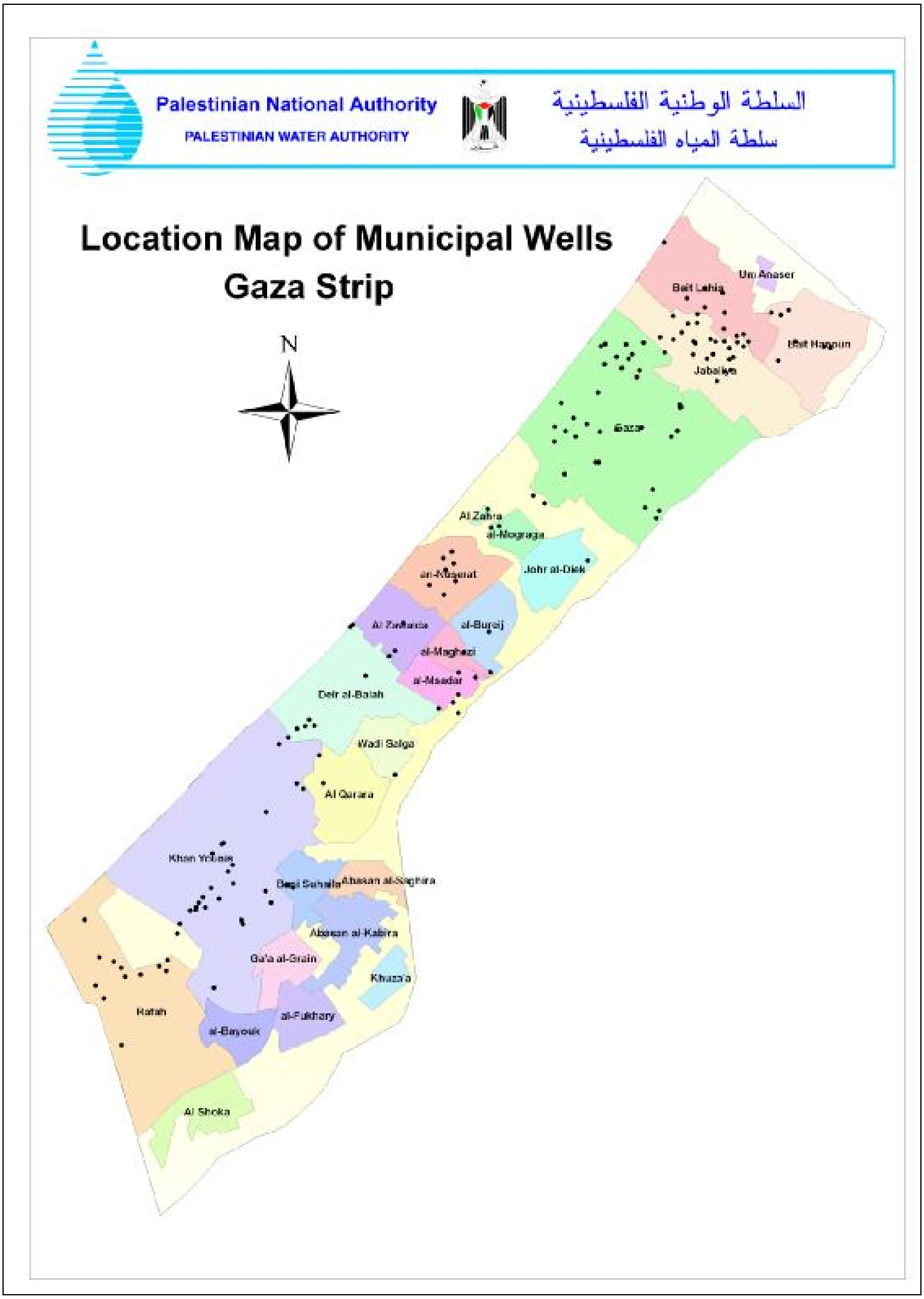


Figure 12: Gaza Strip municipal wells map (PWA, 2007).

4.5.2. Agricultural Water Supply

The approximate estimation of irrigation water demand based on the quota allowed and the available irrigated lands is about 85.5 MCM/year, with a clear increase of water abstracted for irrigation purposes taking into account the illegal abstraction from more than 4600 agricultural wells (2600 legal wells and more than 2000 illegal wells) distributed allover Gaza Strip (PWA, 2007) as shown in Figure 13.

The agricultural water supply comes from Agricultural wells are shown in Table 7 below.

Table 7: Agricultural water supply (MCM/yr) for the year 2006 (PWA, 2007).

Governorate	**Municipal well production (MCM)**
North Gaza	12.0
Gaza	14.6
Middle	18.2
Khan Younis	25.1
Rafah	15.6
Gaza Strip	**85.5**

Livestock water: The appropriate estimation of livestock water demand considered the present number of animals in Gaza Governorates for year 2006 which is equal 2MCM.

The total quantities estimated of agricultural water demand including the livestock are a bout 87.5 MCM/yr.

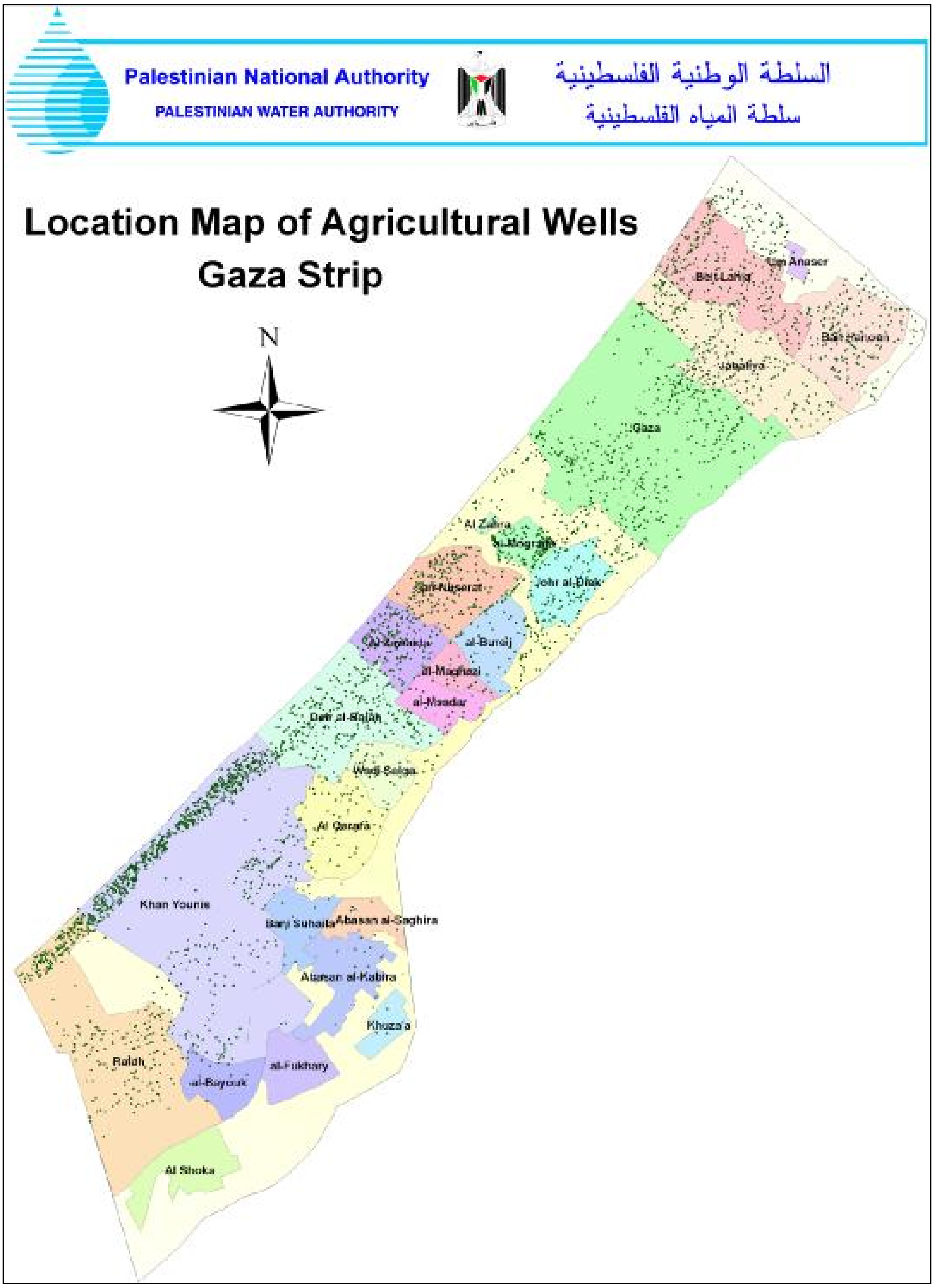


Figure 13: Gaza Strip agricultural wells map (PWA, 2007).

4.6 Water Quality

The main quality problem is the increase in salinity and nitrate content. Nitrate concentration reaches more than 200 mg/l in the northern part of the Gaza Strip and salinity reaches more than 1600 mg/l in the middle and southern parts of the Strip. This deterioration in the quality of water could be related to the unregulated disposal of various forms of waste including domestic industrial solid and liquid and agricultural waste (fertilizers and pesticides) in addition to seawater intrusion in the case of Gaza. PWA reports mentioned that 70% of the Gaza Strip population obtains water with a high salinity and a chloride average of more than 500 mg/l to reach 2500 mg/l. While a large number of drinking water wells contain an average nitrate level of more than 100 mg/l. Moreover, the average water supply per capita in the Strip reaches 86 liters per day; however, most of this water contains high salinity (Ahmed M., 2007), as shown in Figures 14 and 15.

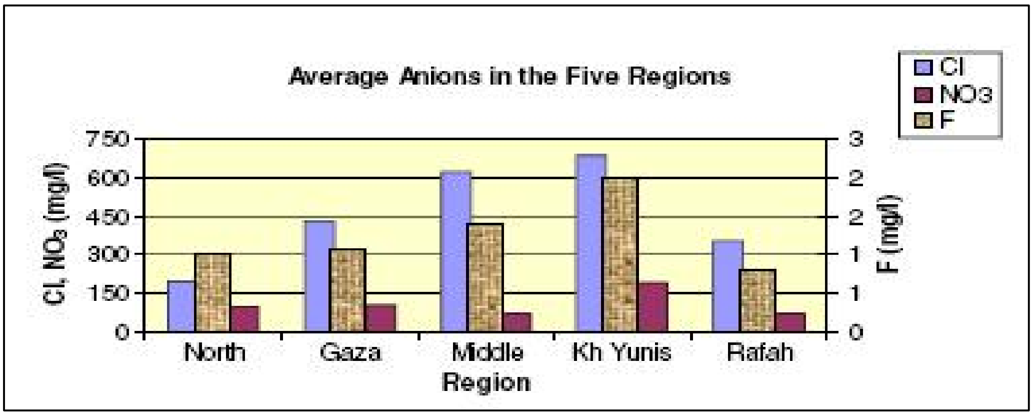


Figure 14: Water quality parameters in Gaza Strip governorates (Shomar B., 2006).

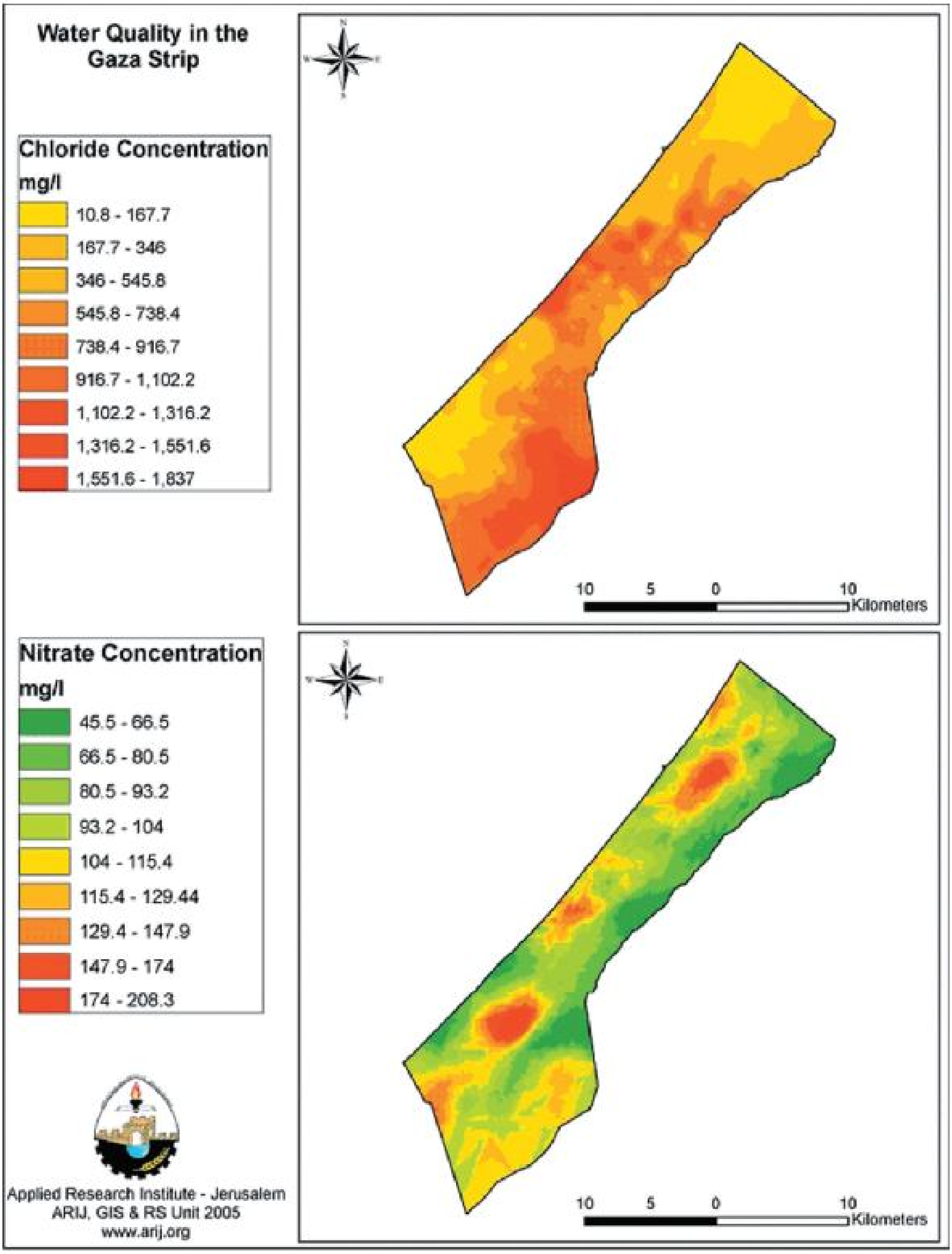


Figure 15: Chloride and Nitrate concentrations in the Gaza Strip (ARIJ,2005).

4.7 Water Distribution System

Transmission links deliver water from surface water, groundwater and other supplies to satisfy demand at demand sites and subject to losses, physical capacity, contractual and other constraints.

More than 90% of the Gaza Strip population is connected to the municipal drinking water network while the other 10% of the rural areas is dependent on private wells (Shomer, 2007), the overall loss of water in the Gaza Strip through the system is estimated at 45% of which 35% is due to physical losses and 10% is due to unregistered connections. (PWA, 2007), Figure 16 shows water network status in Gaza Strip for year 2000.The transmission losses refer to the evaporative and leakage losses as water is carried by canals and conduits to demand sites and catchments.

This loss rate is specified as a percentage of the flow passing through a transmission link. The average estimated loss is due to poor construction, inadequate maintenance, illegal connections and inadequate metering. (Abu Hantash S., 2007).

Table 8 shows these Water Distribution losses for each district.

Table 8: Gaza Strip water distribution losses (PWA, 2007).

District	**Loss Rate (%)**
North Gaza	44
Gaza	40
Deir Al-Balah	42
Khan yunis	52

Figure 16: Water network status for the year 2000 (CAMP, 2000).

4.8 Wastewater facilities

4.8.1 Sewage facilities

Access to sewage facilities at Gaza Strip varies from areas where more than 80% of households are served by well functioning sewage systems to areas where there is no sewage system at all. On average, it is estimated that about 70% of the population is connected to a sewage network as shown in figure 17. Cesspits and boreholes are the alternative waste water disposal systems in the area. All the larger urban centers (except Khan Yunis) are equipped to some extent with a sewage network. Refugee camps with dense populations, like El Nusirat, El Buriej, El Maghazi and El Zawida, don't have any sewage facilities. The only camp connected to sewage system is Jabalia (Alfarra A. and Lubad S., 2004).

Data obtained from a survey conducted by Applied Research Institute (ARIJ) shows that annual quantities generated from houses accounts 80% of total water consumption.

Agricultural wastewater was assumed to be from 15 percent of total irrigated water (Abu Hantash S., 2007). The industrial wastewater quantities produced are estimated to be about 80 percent.

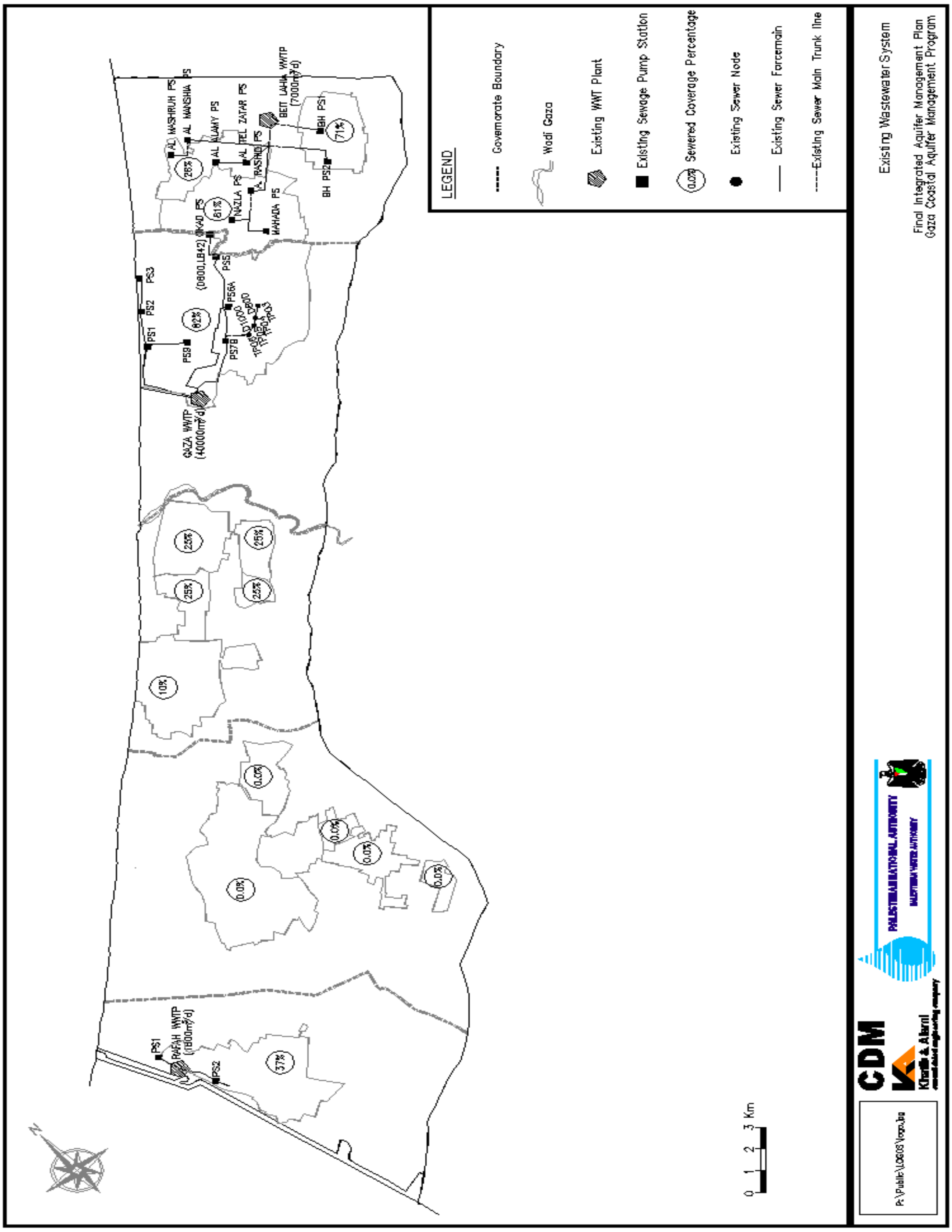


Figure 17: Sewer coverage map for the year 2000 (CAMP, 2000).

4.8.2 Wastewater Treatment Plants

The existing Wastewater Treatment Plants serve only Northern, Gaza and Rafah Governorates. However, not all houses in these Governorates are connected to the sewerage network. Despite that the existing three WWTPs are heavily overloaded as the actual flow far exceeds the design flow. Blocked pipes and flooded manholes are daily events in Gaza Strip. The total capacity of the existing three WWTPs is approximately 20.5 Mm^3/year. The effluent of Northern Governorate plant discharges to the near sand dunes causing many environmental problems to the aquifer and to the neighboring people. Gaza WWTP recharges the aquifer with approximately 3.6 Mm^3 of treated wastewater annually through the infiltration sandy basins and the remaining quantity (11.7 Mm^3) is disposed into the Mediterranean Sea. Rafah plant effluent is discharged into the sea. Clearly, most of wastewater effluent is wasted and causing serious environmental impact (Y. Mogheir et al., 2005). Table 9 show general characteristics Wastewater Treatment Plants in Gaza Strip.

The three Wastewater treatment plants in the Gaza Strip do not function effectively. Approximately 70-80% of the domestic wastewater produced in Gaza is discharged into the environment without treatment, either directly, after collection in cesspits, or through leakage and over loaded treatment plants (UNEP, 2003).

The effluent from the Gaza and Rafah treatment plants is discharged into the Mediterranean, while a substantial quantity of wastewater infiltrates into the ground, contaminating soil and ground water in the area of the Beit Lahia treatment plant (Alfarra A. and Lubad S., 2004). Figure 18 shows Location of Wastewater Treatment Plants in the Gaza Strip.

Table 9: General characteristics of wastewater treatment plants in Gaza Strip (Mogheir Y. et al., 2005).

WWTP	**Type of Treatment**	**Population Served (Capita)**	**Effluent Quantity m^3/d**	**Effluent Disposal Method**
Bait lahia	Primary Sedimentation	250,000	10,000	To sand dunes
	Anaerobic lagoon			
Gaza	Primary Sedimentation	300,000	50,000	Mediterranean Sea
	Anaerobic lagoon			
	Aerobic lagoon			
	Trickling filter			Irrigation

	Secondary Sedimentation			Infiltration
	Drying bed for sludge			
Rafah	Aerated lagoons	80,000	8,000	Mediterranean Sea

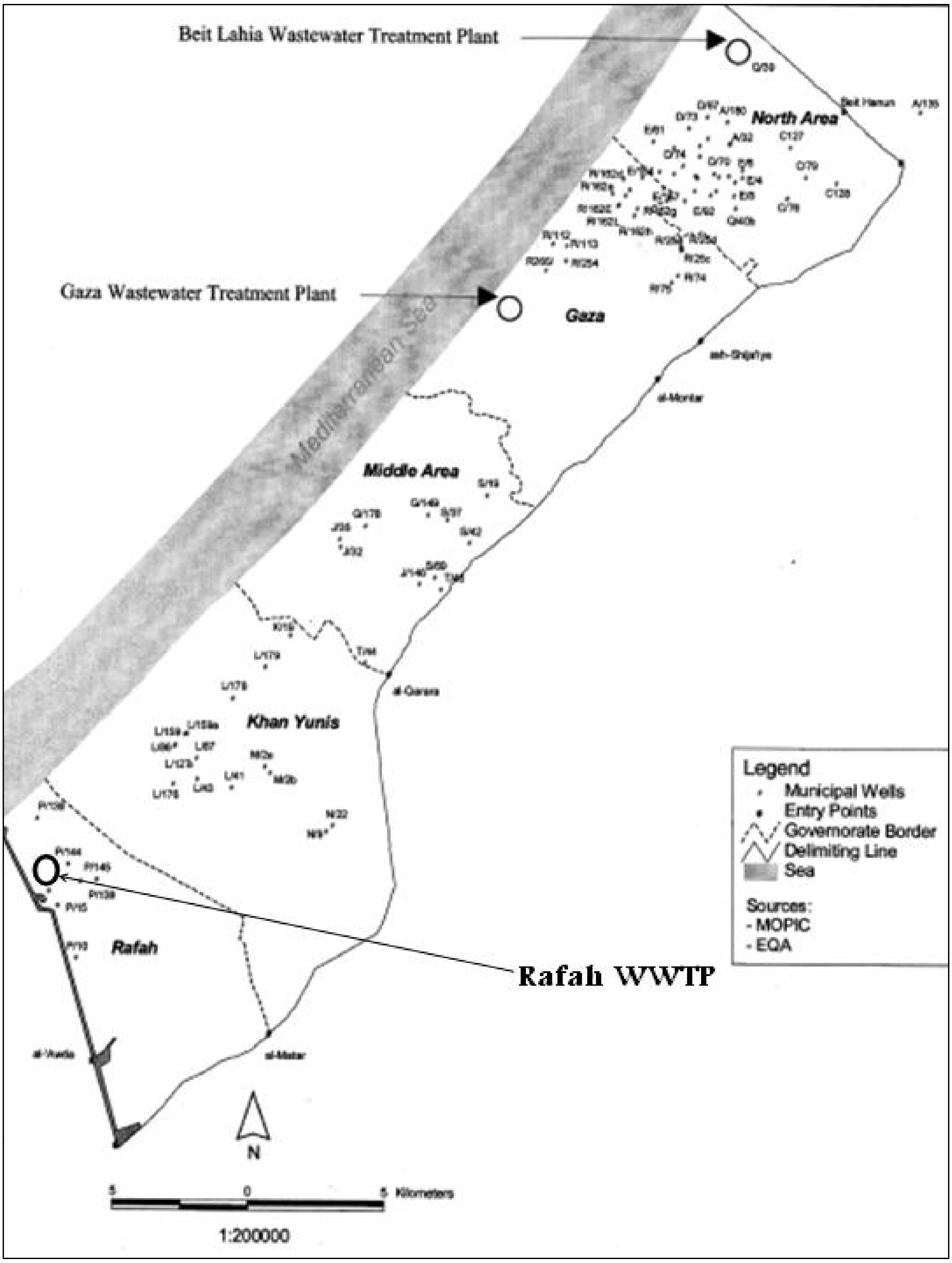


Figure 18: Location of wastewater treatment plants in the Gaza Strip (MOPIC, 2004).

4.9 Desalination Facilities

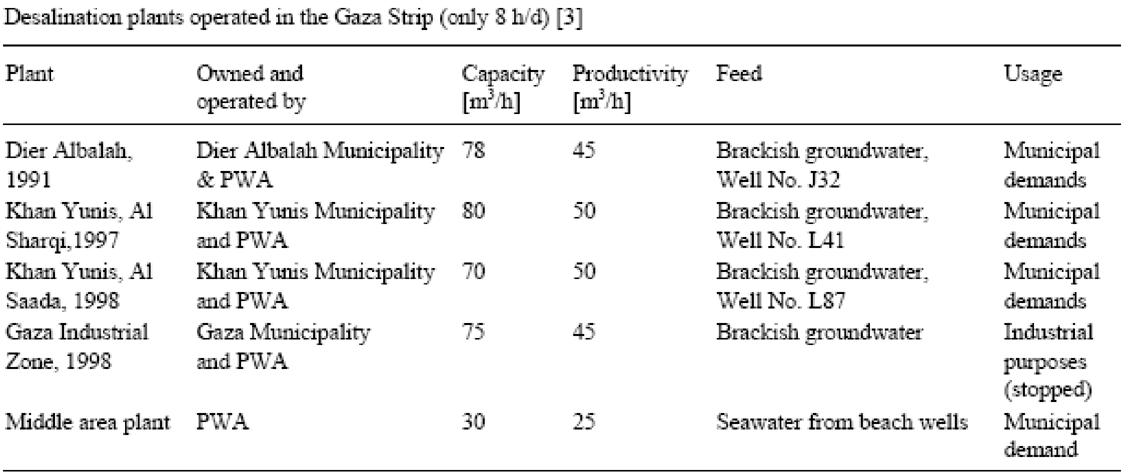
Figure 19 lists all the currently operated desalination plants in the Gaza Strip. The PWA constructed some other plants in cooperation with different municipalities in addition to dozens of small commercial desalination units. These plants are not yet in operation. Figure 19 shows a map of desalination plants in the Gaza Strip. There are two RO desalination plants located in Khan Yunis City: El-Sharqi, built in 1997, and Al-Saada, built in 1998. Both are owned and operated by the PWA and the Khan Yunis Municipality. The capacity of the El-Sharqi plant is 1200 m^3/d and the capacity of the Al-Saada plant is 1560 m^3/d (Baalousha H., 2006).

In the Gaza industrial zone, a RO desalination plant was built in 1998. It uses brackish groundwater as influent and has a capacity of 1080 m^3/d. It is planned that the desalinated water from this plant will be used for industrial purposes in the area and partially for municipal use in the neighborhood. However, due to the political situation, the work in this plant was banned.

There are also two plants that use seawater as influent. The first one is located in the northern part of the Gaza Strip directly at the beach and uses saline water from beach well as a feed. Productivity of this plant is 1200 m^3/d in the first phase and 5000 m^3/d in the final phase. This plant is not yet completed because of the political situation. The second RO desalination plant is located in the middle area of the Gaza Strip with a capacity of 600 m^3/d in the first phase, and 1200 m^3/d in the second phase. Influent of this plant is saline water from wells drilled directly at the beach. The latter plant has been operated while the northern one is not operated yet (Baalousha H., 2006).

There is a plan for a regional desalination plant for the Gaza Strip with a capacity of 60,000 m^3/d in the first phase and 150,000 m^3/d in the second phase. This plant will meet partially the increasing demand of water supply in the area for different purposes. Seawater will be used as a feed for this plant (direct intake) (Baalousha H., 2006).

Nowadays, there are some 18 private desalination plants owned and operated by private investors. The capacity of these plants varies between 20 - 150 m^3/d. These private plants produce a total of about 2000 m^3/d of desalinated water (Baalousha H., 2006). Figure 19 shows general characteristics of desalination plants in Gaza Strip.



Desalination plants operated in the Gaza Strip (only 8 h/d) [3]

Plant	Owned and operated by	Capacity [m^3/h]	Productivity [m^3/h]	Feed	Usage
Dier Albalah, 1991	Dier Albalah Municipality & PWA	78	45	Brackish groundwater, Well No. J32	Municipal demands
Khan Yunis, Al Sharqi,1997	Khan Yunis Municipality and PWA	80	50	Brackish groundwater, Well No. L41	Municipal demands
Khan Yunis, Al Saada, 1998	Khan Yunis Municipality and PWA	70	50	Brackish groundwater, Well No. L87	Municipal demands
Gaza Industrial Zone, 1998	Gaza Municipality and PWA	75	45	Brackish groundwater	Industrial purposes (stopped)
Middle area plant	PWA	30	25	Seawater from beach wells	Municipal demand

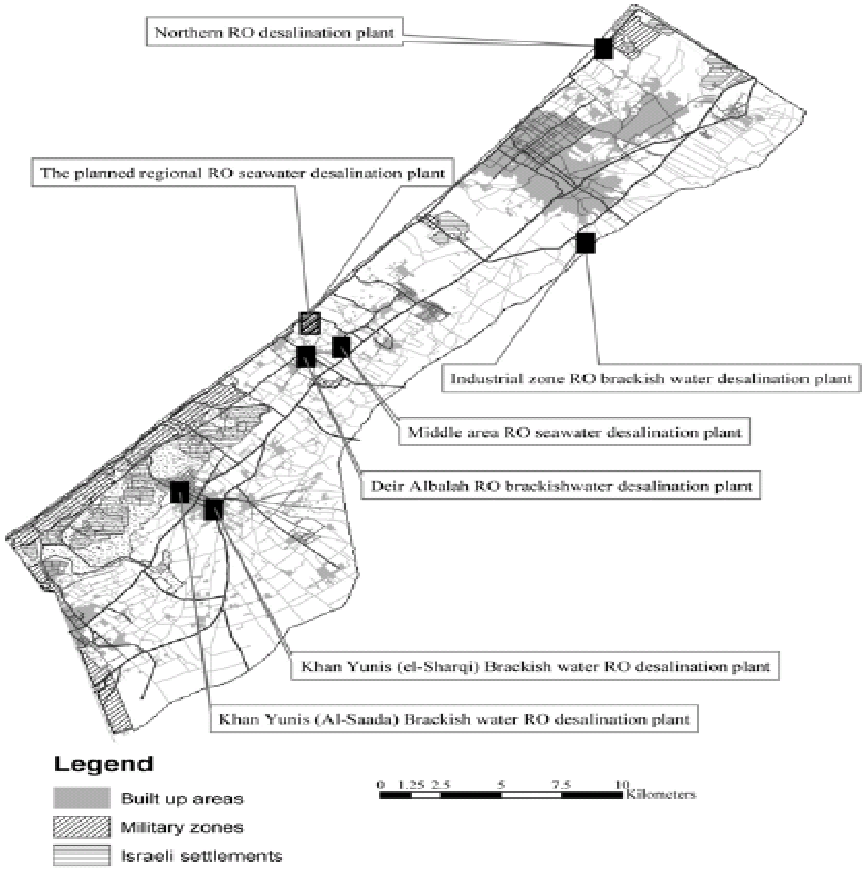


Figure 19: Desalination plants at Gaza Strip (Baalousha H., 2006).

2.10 Water tariff

At present each municipality has its own water tariff structure as shown on Table 10. The most have minimum block rate that has a constant fee regardless of the consumption. Table shows the Water tariff structure for the governorates of Gaza.

Table 10: Gaza Strip governorates water tariff system (CMWU, 2009).

District	Min. Block	Tariff blocks	Tariff (NIS/m3)
North Gaza	30 NIS	Less than 30 m3	1.0
Gaza	6 .0 NIS	Less than10 m3	0.3
Deir Al-Balah	17 NIS	Less than 10 m3	1.7
		More than 10 less than 20 m3	1.8
Khan yunis	23 NIS	Less than 10 m3	1.6
Rafah	20 NIS	Less than 30 m3	1.0

2.11 Input Parameters in WEAP

In order to define the inputs to the WEAP and build up the WEAP model the initial state of each input has to be entered (Current Accounts in WEAP) the current supply and demand data listed in previous sections were entered to be integrated and used inside the WEAP. Water demands were entered as 5 municipal demand sites and 5 agricultural demand sites classified according to Gaza strip governorates. Figure 20 illustrates the input – output for data and Figure 21 illustrates the data entered in WEAP.

Water demands were entered as 5 municipal demand sites and 5 agricultural demand sites classified according to Gaza Strip districts using the Standard Water Use Method.

Supply elements were defined. Data related to groundwater (recharge rates, its initial storage, and the maximum withdrawals allowed according to annual renewal), other supply parameter used in WEAP to represent supplies other than Groundwater such as desalination and Mekorot inflows are entered.

There is a need to tell WEAP how is the demand is satisfied; this was achieved by connecting a supply resource to each demand site through creating a transmission link from the supply nodes to demand site modes. Transmission links carry water from local and river supplies, as well as wastewater from demand sites and wastewater treatment plants, to demand sites, subject to losses and physical capacity, contractual and other constraints.

Primarily, WEAP allocates water according to the demand priority associated with each demand site. The sites with the highest priorities get water first, followed by sites with lower priorities as availability allows.

Each demand site with multiple sources can specify its preference for a source, due to economic, environmental, historical, legal or political reasons, by entering supply preference for each source linked to each demand site.

You can restrict the supply from a source, to model contractual or physical capacity limitations, or merely to match observations by entering the maximum flow volume on transmission link rules/maximum flow volume in WEAP.

The transmission losses refer to the evaporative and leakage losses as water is carried by canals and conduits to demand sites and catchments. This Loss Rate is specified as a percentage of the flow passing through a transmission link.

A return flow link is used to direct the water that is not consumed at demand site to one or more wastewater treatment plants or other supply sources.

Gaza Strip current accounts Conceptual WEAP model is illustrated in Figure 22.

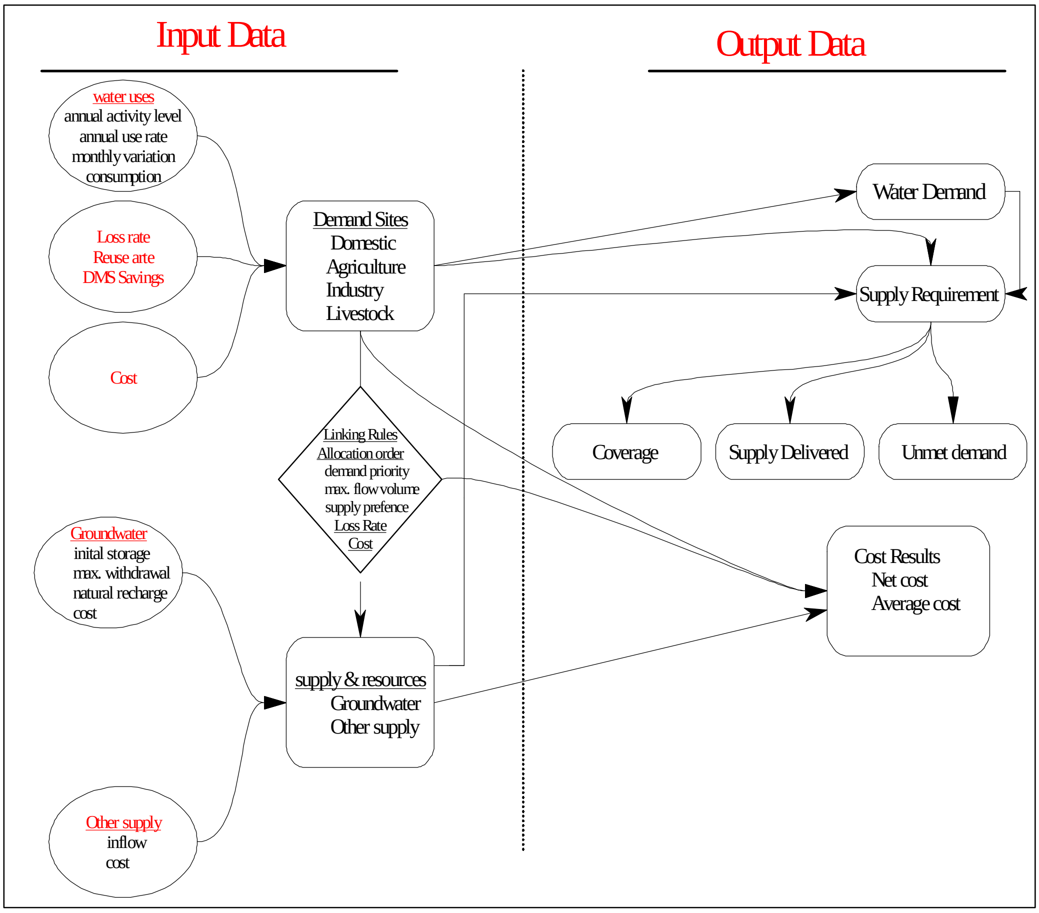


Figure 20: Gaza Strip WEAP input-output data.

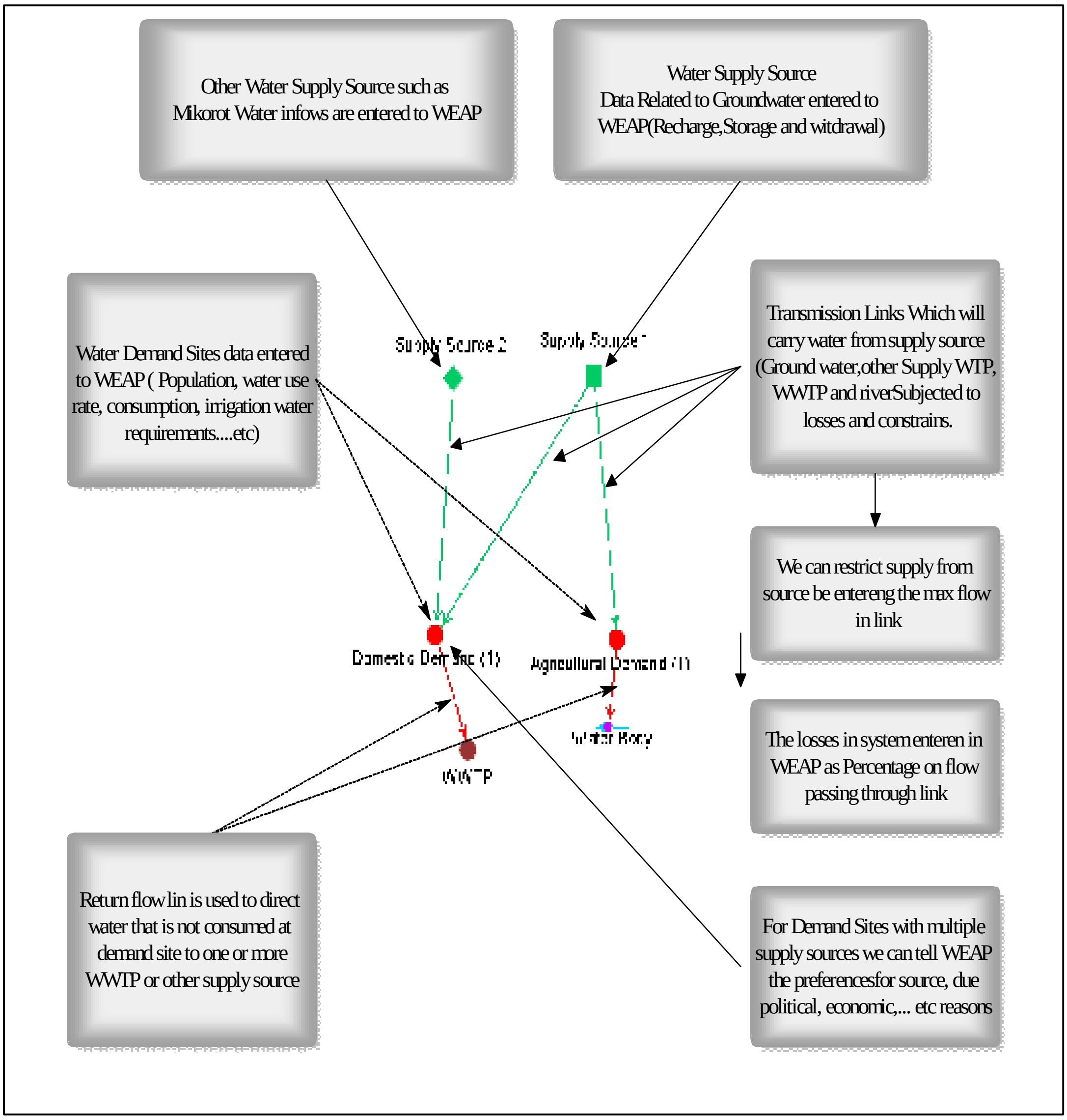


Figure 21: Data entering in WEAP illustration.

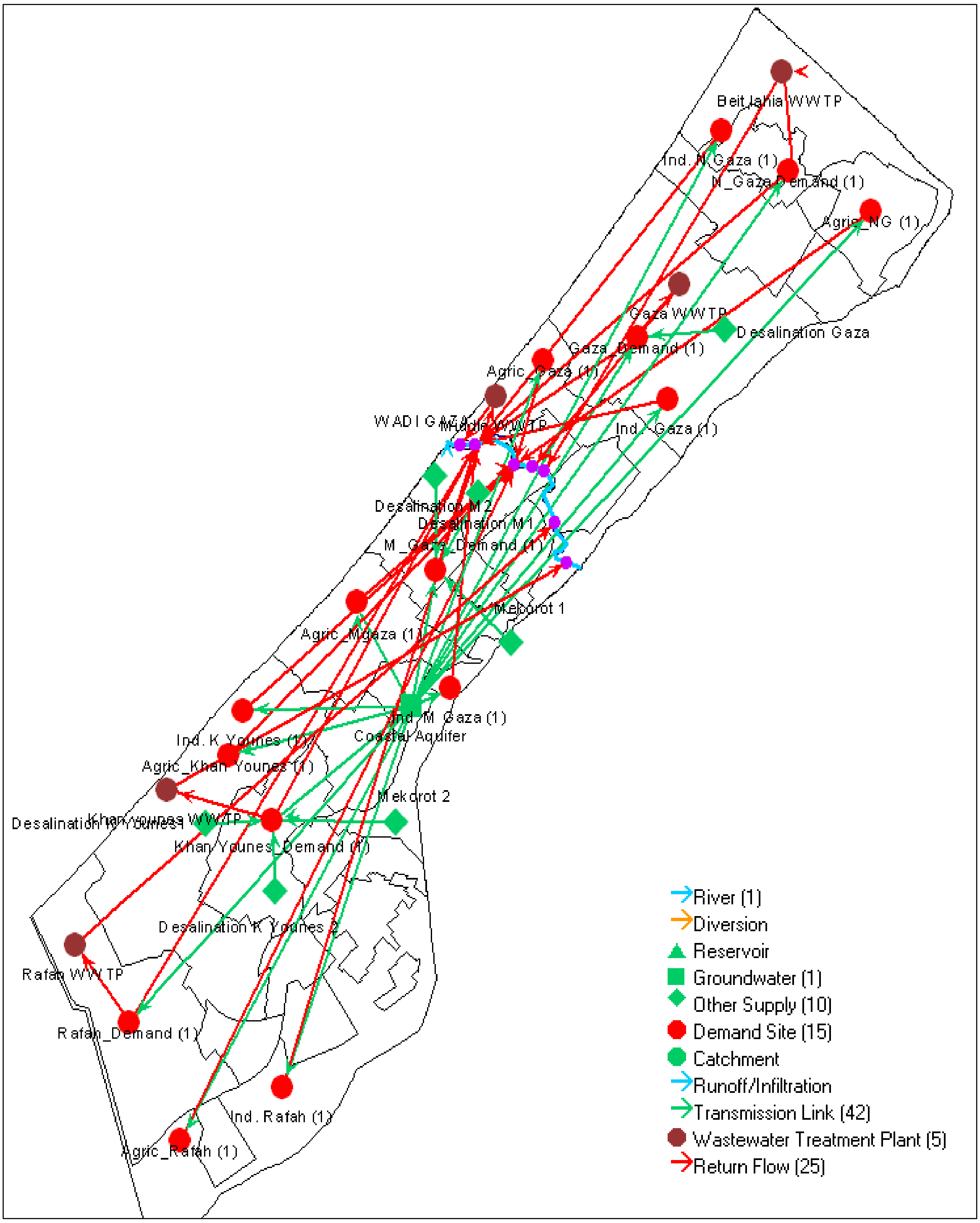


Figure 22: Gaza Strip current accounts conceptual WEAP model.

CHAPTER FIVE

DEVELOPMENT OF SCENARIOS AND RESULTS

5.1 Introduction

At the heart of WEAP is the concept of scenario analysis. Scenarios are self-consistent story-lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions. Using WEAP, scenarios can be built and then compared to assess their impacts. All scenarios start from a common year, for which the model Current Accounts data are established (WEAP user guide, 2005).

The scenarios can address a broad range of "what if" questions, such as: What if population growth and economic development patterns change? What if reservoir operating rules are altered? What if groundwater is more fully exploited? What if water conservation is introduced? What if ecosystem requirements are tightened? What if new sources of water pollution are added? What if a water recycling program is implemented? What if a more efficient irrigation technique is implemented? What if the mix of agricultural crops changes? What if climate change alters the hydrology? (WEAP user guide, 2005).

5.2 Establishing the Reference Scenario

5.2.1 Reference Scenario Input Data

This scenario represents the changes that are likely to occur in the future, in absence of any new policy measure. Base case scenario is with population growth at a rate of 3.3, with existing water allocation and polices and existing irrigation practices.

Future Demand: Existing water consumption will be used to predict future demand. Population increase is the major parameter affecting future water needs, not only for domestic uses, but also for other uses such as industrial use.

Future Supply: Present water supply is limited due to political and economic constrains which cause lack in development of new water resources, water reuse and supply infrastructure, so the supply amount will remain as current.

5.2.2 Reference Scenario Results

WEAP results of Water demand indicate that demand will increase (3.3 % population growth) from 150 MCM in 2006 to 195 MCM for the year 2020 as shown in Figure 23. Projected water demand for different demand sites are shown in Figure 24, which is according to reference scenario.

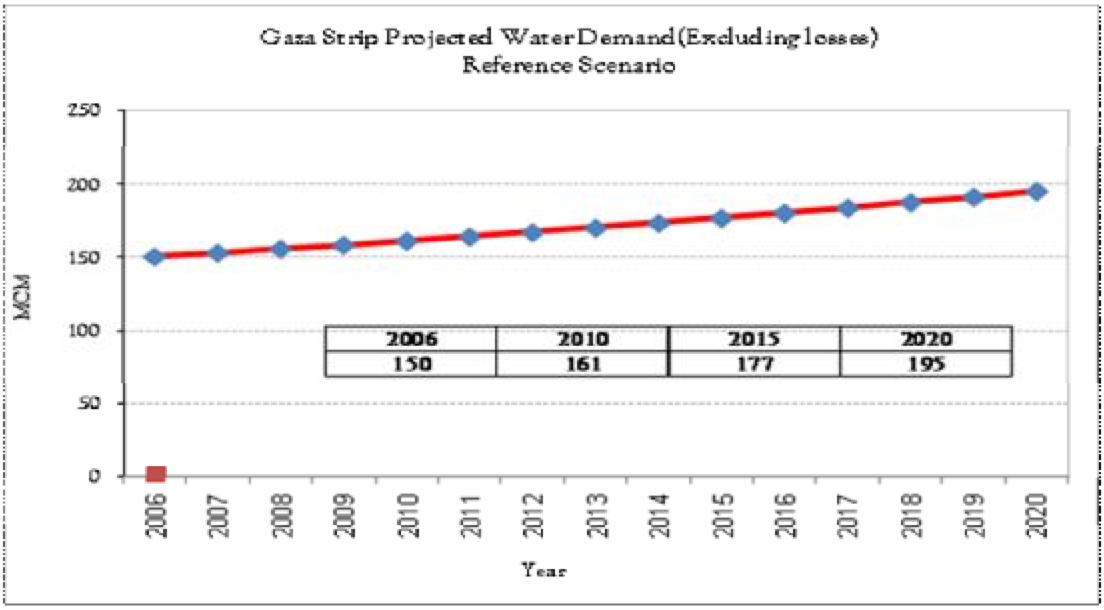


Figure 23: Gaza Strip projected water demand -Reference scenario.

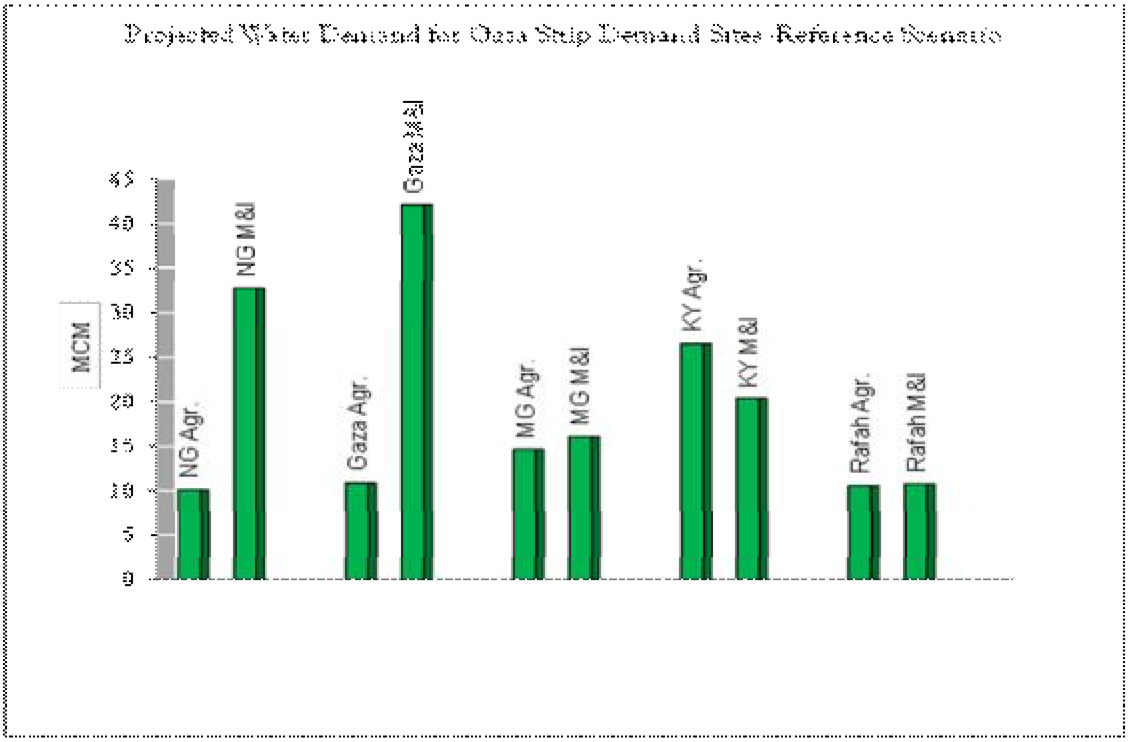


Figure 24: Gaza Strip projected water demand for different demand sites for the year 2020 –Reference scenario.

WEAP results of unmet water demand indicate that it will increase (if no change in water supply) from 54 MCM in 2006 to 99 MCM for the year 2020 as shown in Figures 25 and 26.

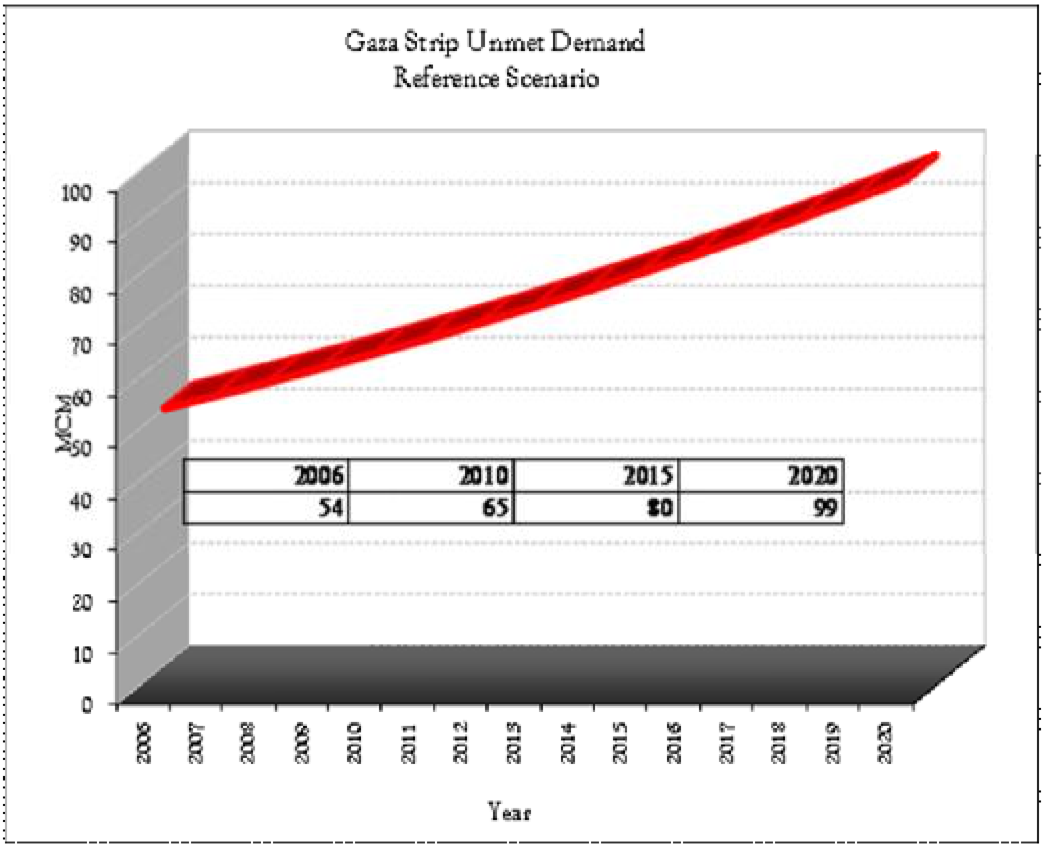


Figure 25: Gaza Strip projected unmet water demand -Reference scenario.

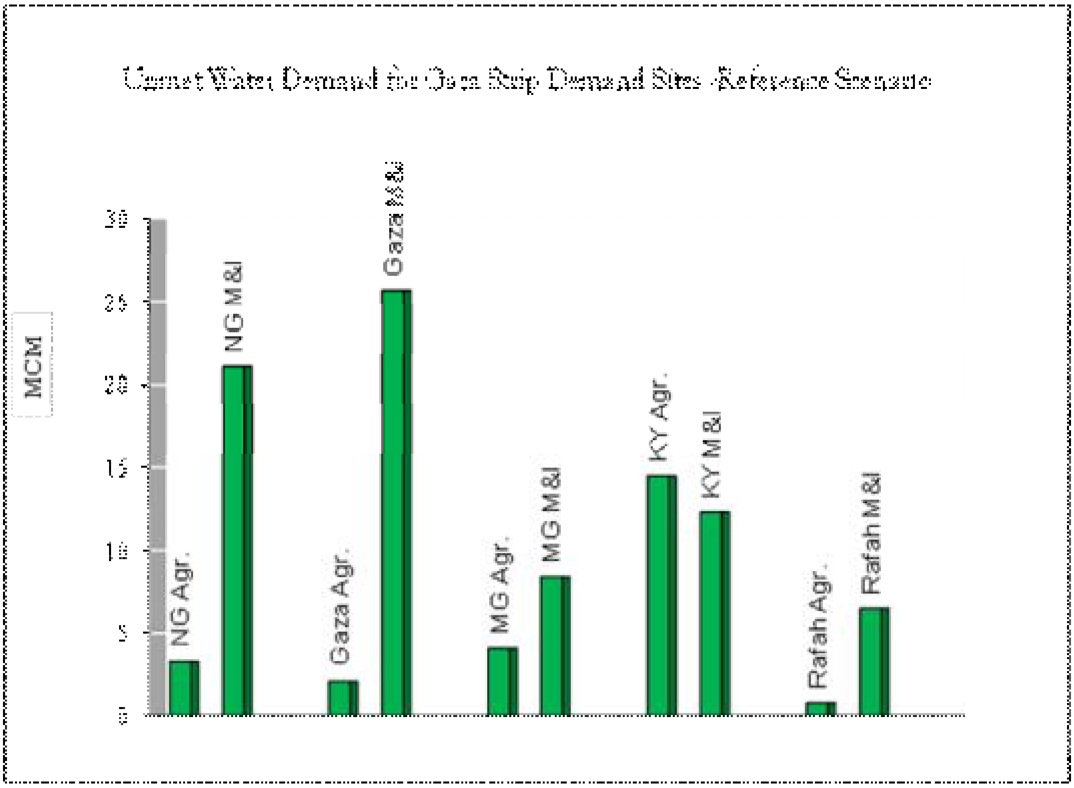


Figure 26: Gaza Strip projected unmet water demand for different demand sites for the year 2020-Reference scenario.

5.3 Water Management Options Development:

Water management concepts used in this study is developed by (Haddad et. al., 2006) and (Abu Hantash S., 2007). The concept uses field survey in order to develop the best management options, by means of a stakeholder questionnaire targeting decision makers, researchers, Academics, and other stakeholders. The questionnaire as shown in Figure 27 below defines eight decisive issues under water management. Those issues are political Constraints, water management, water availability, future expansion, knowledge quality, water quality, data quality and water cost.

Based on the outcome of the stakeholder questionnaire mentioned above, Figure 27 shows decisive Issues used in developing management options which are adopted to be used for the Gaza Strip Case study.

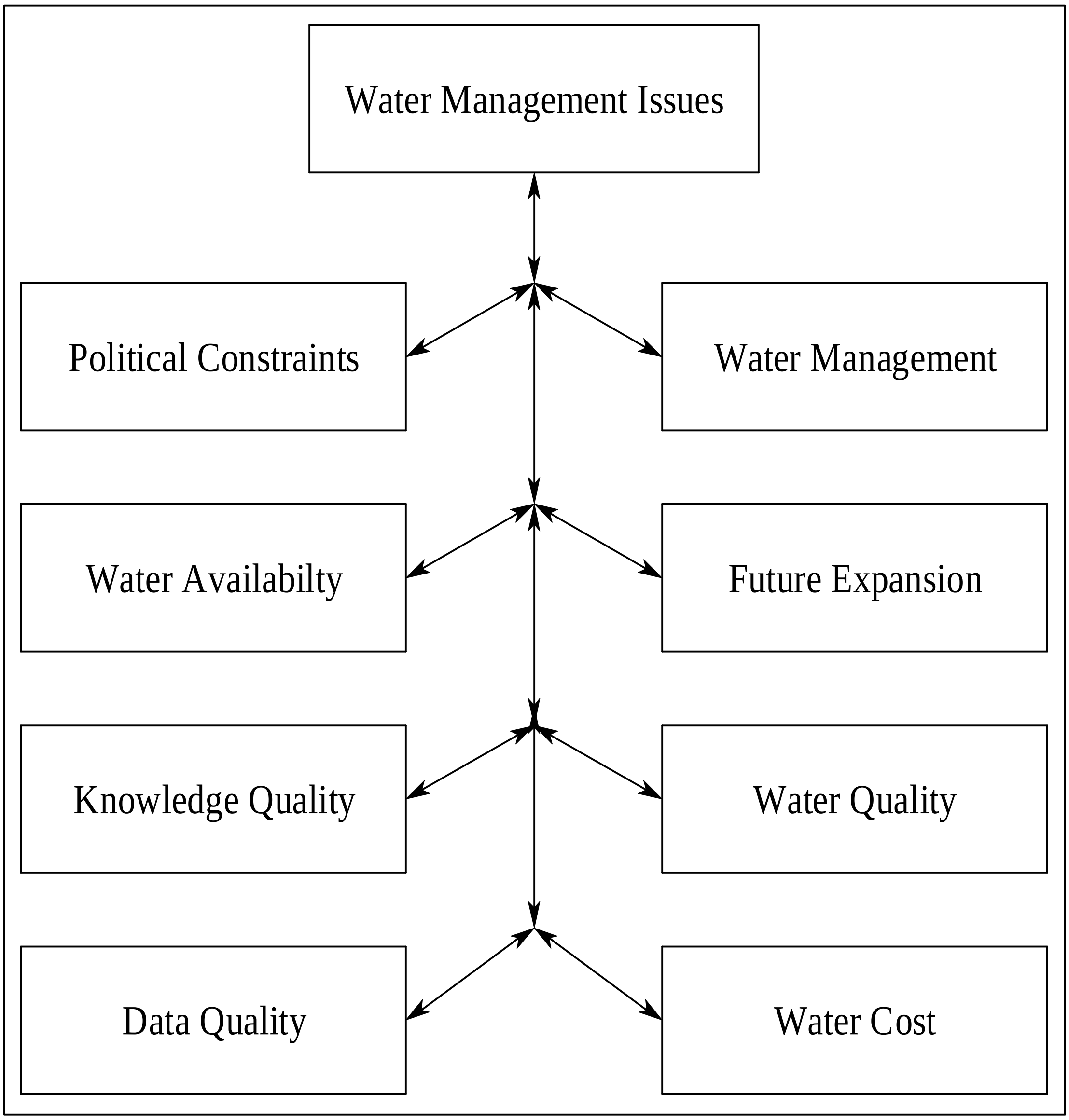


Figure 27: Decisive issues used in developing management options at Palestine (Haddad et al., 2006).

5.4 Pressure, State, Response (PSR) Framework

The PSR framework is based on the fact that human activities exert Pressures on the environment (such as pollution, land use change, or increased demand for water). These result in changes in the State of the environment (e.g. changes in pollutant levels, etc.) which in turn result in Impacts. Society's Response to changes in pressures or state is then with environmental and economic policies or programs intended to prevent, reduce or mitigate the pressures and/or environmental and socio-economic damage that occurred as a result of the original pressures (Bayer E. et al., 1997).

The most widely accepted indicator framework is the “Driving forces-Pressure-State-Impact-Response model” (DPSIR). The DPSIR model is an extension of the PSR (Pressure-State-Response) model, which was developed by Anthony Friend in the 1970s. It defines five indicator categories as shown in Figure 28, within the DPSIR framework (Bayer E. et al., 1997).

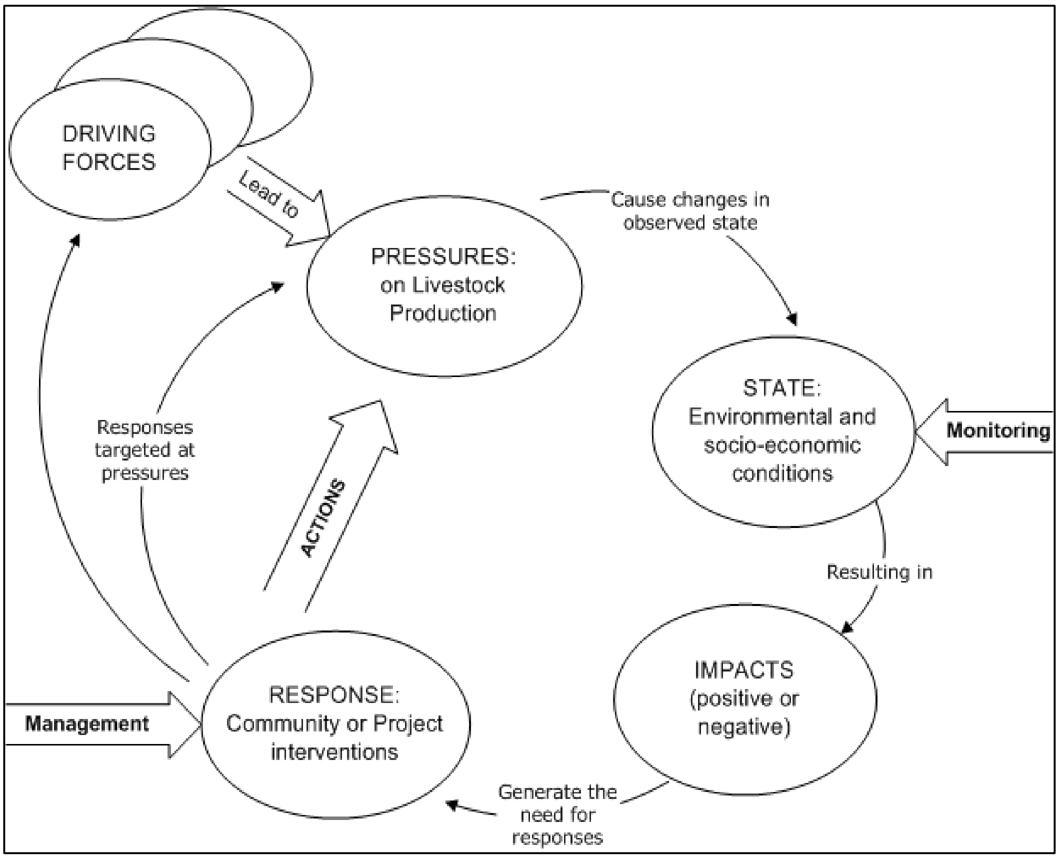


Figure 28: Diagrammatic representation of a Driving force - Pressure - State - Impact - Response (DPSIR) cycle (Lowe Borjeson, 2007).

Driving forces are underlying factors influencing a variety of relevant variables.

Pressure indicators describe the variables that directly cause environmental problems.

State indicators show the current condition of the environment.

Impact indicators describe the ultimate effects of changes of state.

Response indicators demonstrate the efforts of society (i.e. politicians, decision-makers) to solve the problems.

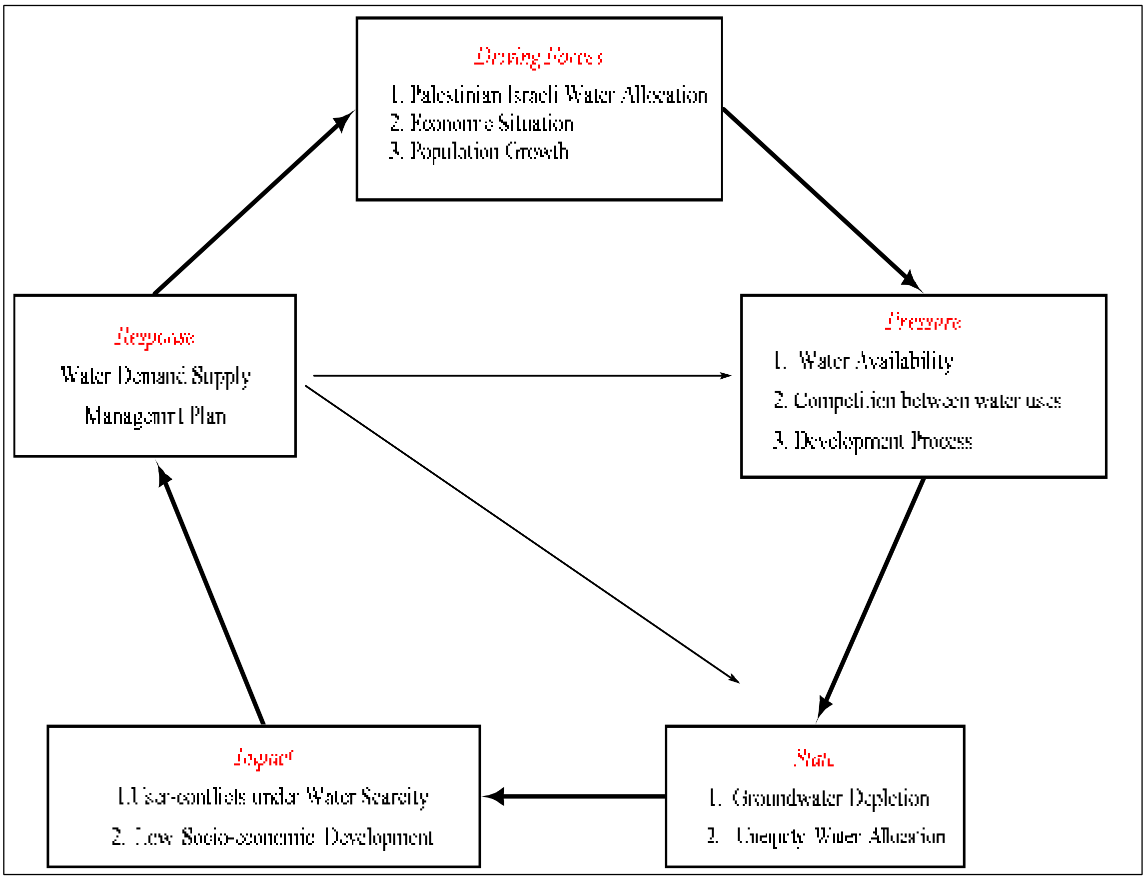


Figure 29: Gaza Strip Driving forces, Pressure, State, Impact, and Response (DPSIR).

The driving forces in Gaza Strip produce a pressure on the quality and quantity of the water resources and deteriorate the state by lowering the groundwater level and influencing the economy. An adequate response to this situation is to develop an integrated water resource management tool for the Gaza Strip. Applying the DPSIR process to the Gaza Strip study area, the following chain was introduced and described as shown in Figure 29 below .

5.5 Future Scenarios, Assumptions and Model Application

5.5.1 Introduction

Based on the outcome of stakeholder questionnaire mentioned previously and according to previous studies in Palestine (GLOWA-Jordan River scenarios, 2009, Abu Hantash S., 2007, Stakeholder questionnaire outcomes mentioned previously) the political aspects and the economic conditions are the key factors in developing water resources management options for Palestine

Accordingly, the following three scenarios have been considered in this work. These scenarios are also in line with those scenarios assumed in water sector strategic planning study and the GLOWA-Jordan River project. Those scenarios are:

Scenario One: Suffering of the Weak & the Environment

(Current State: Economy and political conditions still as current).

Scenario Two: Modest Hopes

(When Economy moves on but no development in the political conditions).

Scenario Three: Willingness and Ability

(Independent State with economy moves on).

5.5.2 Scenario One: Suffering of the Weak & the Environment

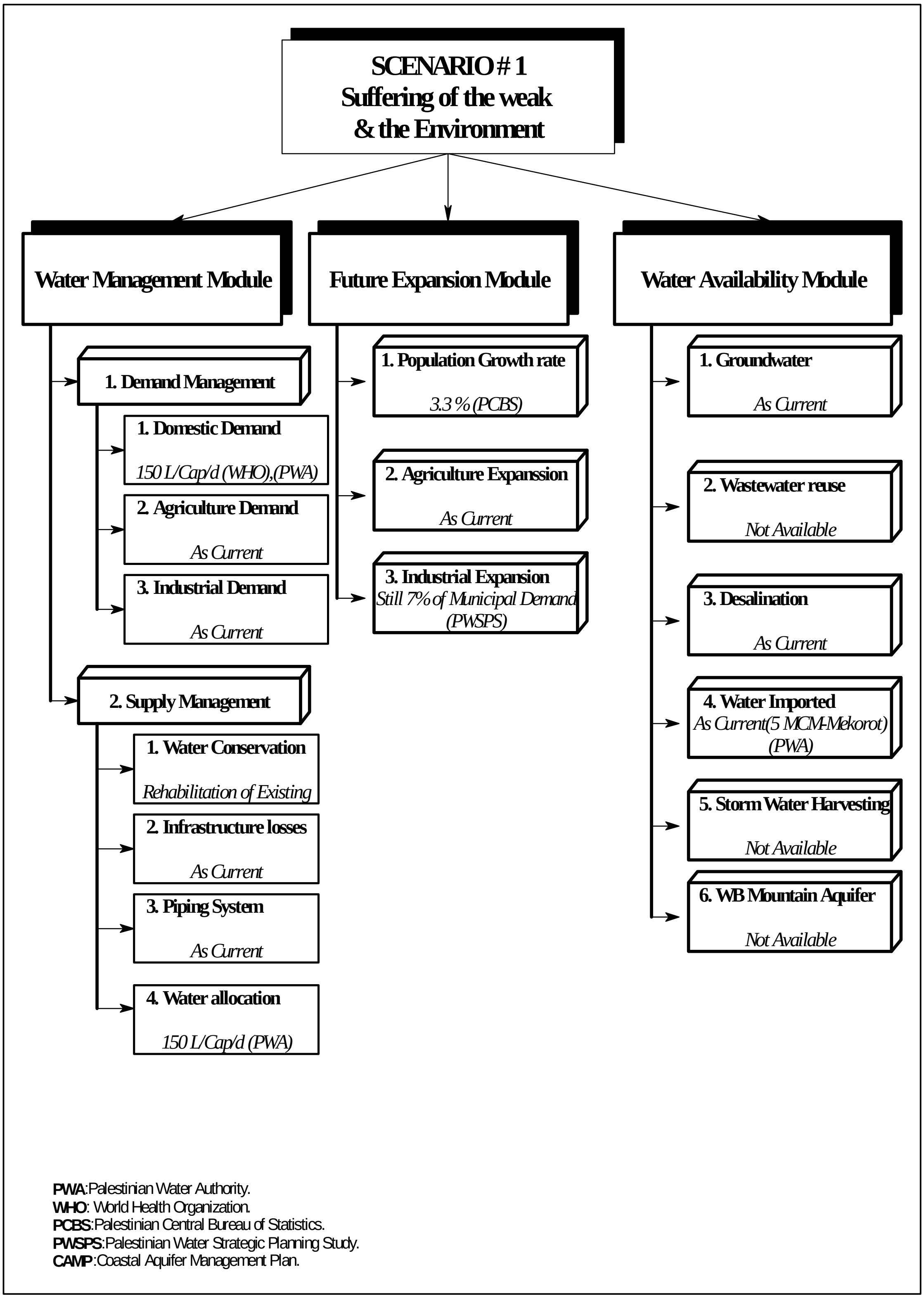
(Current State: Economy and political conditions still as current).

The Suffering of the Weak & the Environment scenario is a worst case scenario in which neither peace nor economic growth can be reached. Unilateral decisions make it impossible to solve the water problem in the region and water becomes increasingly expensive. Agriculture is particularly affected. Donor-funded rural projects fall away because of the political situation and many small farmers give up and move to the growing cities. There is a continuous decline in agricultural area and finally a complete collapse. The overall instability negatively affects investments and ultimately the infrastructure also collapses in many parts of the region. The poor suffer the consequences of a deteriorating environment most, but also the middle class is disappearing (GLOWA, 2009).

Main Assumptions used in this scenario are:

- Domestic demand will be at the average WHO standards 150L/C/d.
- Irrigated areas will remain as current.
- Demand management practices were not considered.
- Population growth rate 3.3%.
- Industrial demand will remain as current 7 % of municipal demand.
- Water available for Gaza Strip still as current.

All assumptions and data used in scenario 1 (with references) are summarized in Figure 30 and Table 11.



PWA:Palestinian Water Authority.
WHO: World Health Organization.
PCBS:Palestinian Central Bureau of Statistics.
PWSPS:Palestinian Water Strategic Planning Study.
CAMP:Coastal Aquifer Management Plan.

Figure 30: Schematic representation of scenario one**.**

5.5.3 Scenario Two: Modest Hopes

(When Economy moves on but no development in the political conditions)

The Modest Hopes scenario assumes that no peace agreement can be reached but that economic prosperity prevails, kindled by international donors. This results in fairly stable conditions in the region. Education, training and capacity building make up for some of the lack of cooperation. High-tech solutions, such as desalination plants and irrigation with properly treated wastewater, make up for the lack of diminishing natural water availability. Agriculture becomes very profitable, but increases the pressure on open land (GLOWA, 2009).

Main Assumptions used in this scenario are:

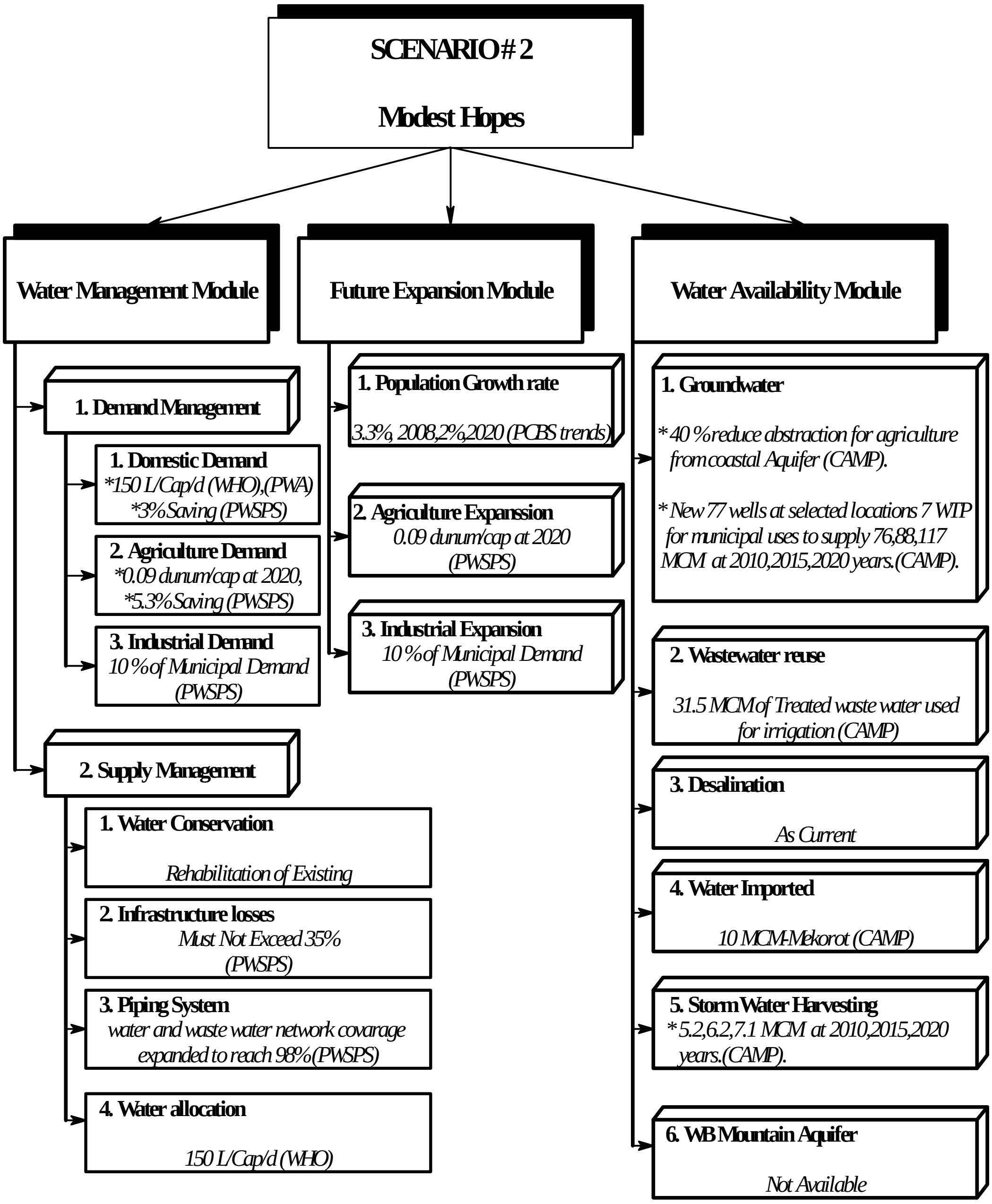
- Municipal demand will be at the average WHO standards 150L/C/d.
- Irrigated areas will be projected to achieve 0.09 dunum/capita.
- Industrial demands will be 10 % of total municipal demand.
- Demand management program will be implemented to save 3% and

5.3 % of Domestic and Agricultural demands respectively.

- Population projections are assumed to be 2.5% (2015) and 2% (2020).

- 40% reduction of abstraction from ground water.
- 32MCM treated waste water and will be used.

All assumptions and data used in scenario 2 (with references) are summarized in Figure 31 and Table 11.



PWA:Palestinian Water Authority.
WHO: World Health Organization.
PCBS:Palestinian Central Bureau of Statistics.
PWSPS:Palestinian Water Strategic Planning Study.
CAMP:Coastal Aquifer Management Plan.

Figure 31: Schematic representation of scenario two.

5.5.4 Scenario Three: Willingness and Ability

(Independent State with economy moves on)

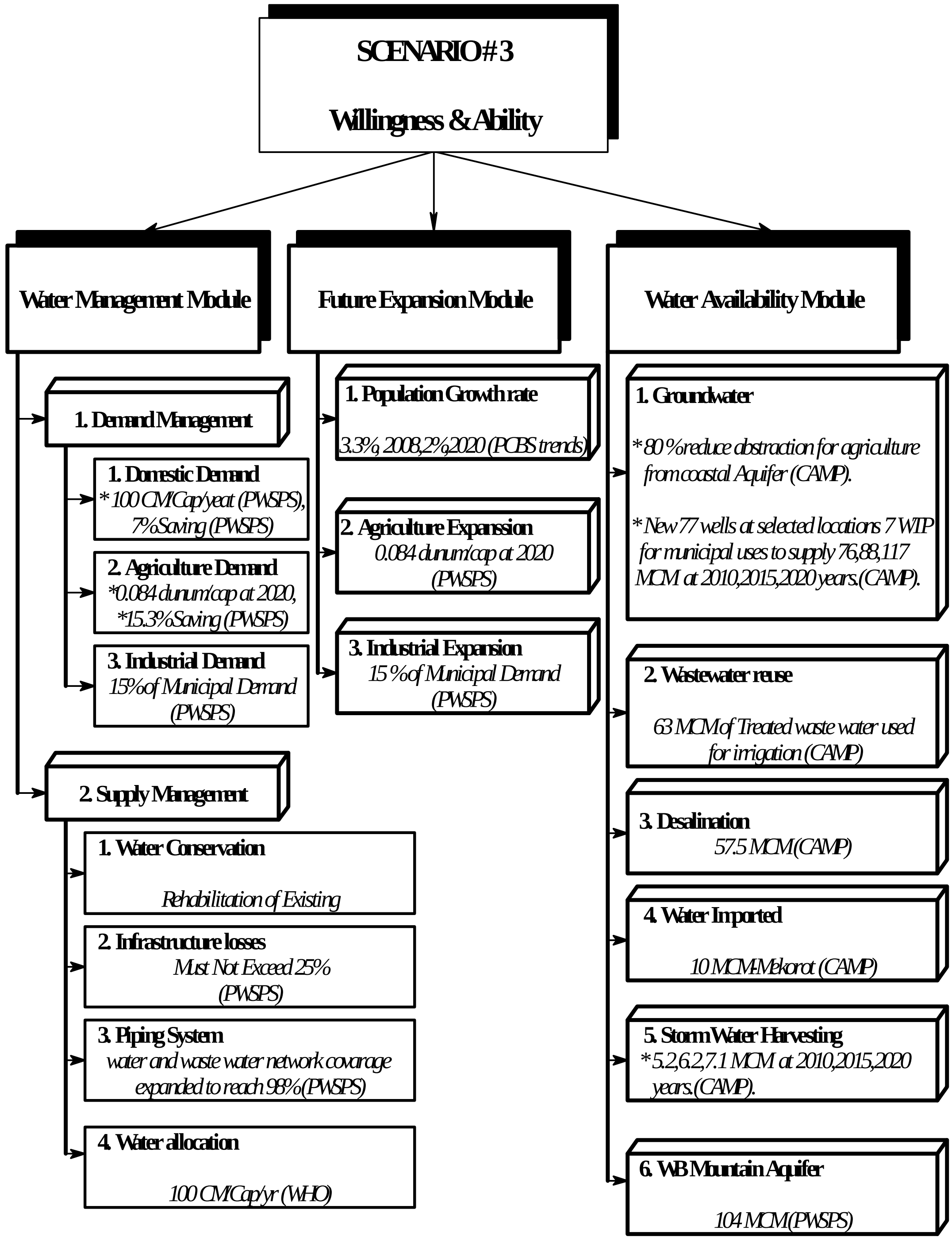
The Willingness & Ability scenario reflects the most optimistic and wished-for scenario in which peace and economic prosperity rein. This means that, the overall water availability can be increased sufficiently through high-tech solutions, such as desalination plants. Innovative industries, including water- and energy-technology industries, are growing fast. Although the pressure on nature increases due to an increasing population and a growing tourist industry, the availability of financial resources and the level of public awareness guarantee a sustainable development of the region (GLOWA, 2009).

Main Assumptions used in this scenario are:

- Municipal demand will be 100 CM/Cap/yr.
- Irrigated areas will be projected to achieve 0.084 dunum/capita .
- Industrial demands will be increased to reach 15 % of municipal demand.
- Demand management program will be implemented to save 7% and 15.3 % of the Domestic and Agricultural demands respectively.

- 63 MCM/yr of treated wastewater will be used for agricultural purposes.
- Population projections are assumed to be 2.5% (2015) and 2% (2020).
- 80% reduction of abstraction from ground water.
- 57.5 MCM from desalination.
- 104 MCM from West Bank.

All assumptions and data used in scenario 3 (with references) are summarized in Figure 32 and Table 11.



PWA: Palestinian Water Authority.
WHO: World Health Organization.
PCBS: Palestinian Central Bureau of Statistics.
PWSPS: Palestinian Water Strategic Planning Study.
CAMP: Coastal Aquifer Management Plan.

Figure 32: Schematic representation of scenario three.

5.5.5. Demand Management Sub Scenarios

To consider demand Management through its different measures, two additional sub scenarios were assumed, scenario 2 and 3 with demand management saving are as follows:

<u>For Scenario 2</u>:

1) **Saving 3% (Domestic):** due to rehabilitation of wells to improve their efficiency, adaption of graduated tariff system and rehabilitation of distribution networks**.**
2) **Saving 5.3% (Agriculture**): due to the expansion of drip irrigation and other modern irrigation system.

<u>For Scenario 3</u>:

1) **Saving 7% (Domestic):** due to rehabilitation of wells to improve their efficiency, adaption of graduated tariff system and rehabilitation of distribution networks and recycling water in the industrial sector.
2) **Saving 15% (Agriculture):** due to the expansion of drop irrigation, other modern irrigation system, reducing the irrigation of citrus, balance between production and importation of agricultural products and rehabilitation of traditional surface irrigation systems.

Table 11 below summarizes the data for the different scenarios under different proposed management modules while Figure 33 shows Gaza Strip future conceptual WEAP model.

Table(11): Assumptions and data used in the three scenarios.

Scenario	**Suffering of the**	**Modest Hopes**	**Willingness & Ability**
1. Water management Module			
1.1 Demand management			
Domestic demand	Min 150 L/C/d	Demand savings 3	Demand savings 7
Agriculture demand	As current*	Demand savings 5.3	Demand savings 15.3
Industrial demand	As current *(7%)	+3 % of total municipal demand (10%)	+8 % of total municipal demand (15%)
1.2 Supply management			
Water conservation	Rehabilitation of the existing	Rehabilitation of the existing	Rehabilitation of the existing
Infrastructure losses	As current*	must not exceed 35 %	must not exceed 25 %
Water allocation	150 L/C/d	150 L/C/d	100 CM/C/yr
Piping system	Water network coverage 100%	Water network coverage 100%	Water network coverage 100%
2. Future Expansion Module			

2.1. Population growth rate	3.3%	3% (2010), 2.5% (2010-2015), 2%(2020)	3% (2010), 2.5% (2010-2015), 2%(2020)
2.2. Agriculture expansion	As current*	0.09 dunum/c/yr	0.084 dunum/c/yr
2.3. Industrial expansion	As current*	+ 3% of municipal	+8% of municipal
3. Water availability module			
3.1. Groundwater	As current*	* 88 MCM (2015), 117 MCM (2020). *40 % reduction of abstraction	*88 MCM (2015), 117 MCM (2020). *80 % reduction of abstraction
3.2.Wastewater reuse	N/A	31.5 MCM of treated water will be used for irrigation	63 MCM of treated water will be used for irrigation
3.3.Desalination	As current*	As current*	57.5 MCM /yr
3.4. Water Imported	As current*	Additional 5 MCM from	Additional 5 MCM
3.5. Storm Water harvesting	N/A	(2010,5.2MCM)	(2010,5.2MCM)
3.6. WB Mountain Aquifer	N/A	N/A	104 MCM/yr from
***As Current: discussed at section 4.4 previously.**			

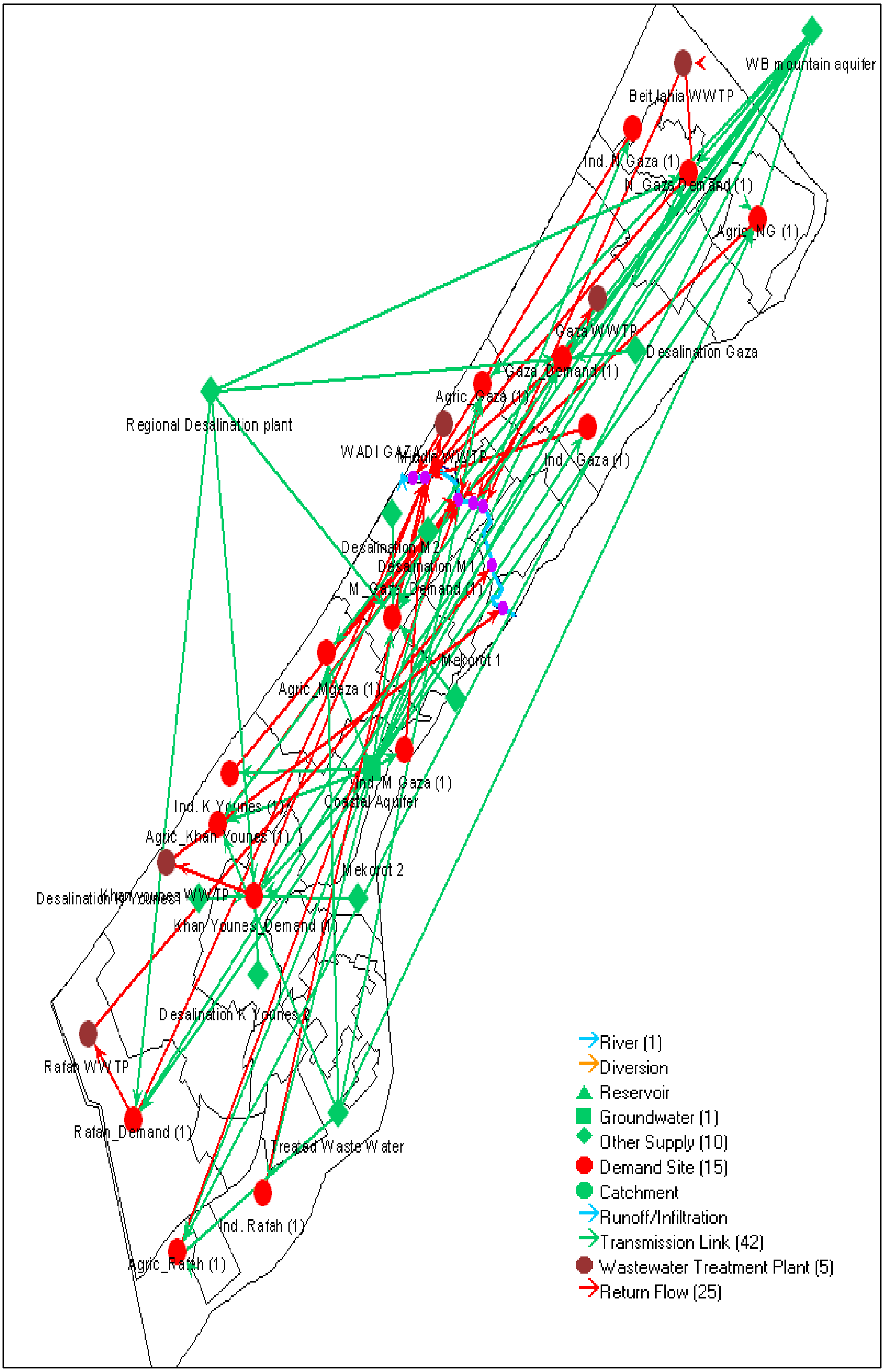


Figure 33: Gaza Strip future accounts conceptual WEAP model.

5.6. Simulation Results and Discussion

The results obtained from various WEAP runs on the impact of the three scenarios, two sub scenarios and four water management modules in addition to water cost estimate were summarized and discussed in this section.

5.6.1. Water Management Module

Table 11, Figures 30, 31 and 32 shows the assumptions of the different water management modules. These main assumptions can be summarized in the following:

Scenario One:

- Domestic demand will be at the average WHO standards 150L/C/d.
- Irrigated areas will remain as current.
- Industrial demand will remain as current.
- Demand management practices and wastewater treatment and reuse, desalination, farming practices change, West Bank aquifer water and others were not considered due to economy.

Scenario Two:

- Municipal demand will be at the average WHO standards 150L/C/d.
- Irrigated areas will be projected to achieve 0.09 dunum/cap at the end of 2020 to secure the per capita basic food needs.
- Industrial demands will be increased to reach 10 % of total municipal demand.
- Demand management program will be implemented to save 3% and 5.3 % of Domestic and Agricultural demands respectively.
- Water and wastewater network coverage will be expanded to reach 100%.
- 32 MCM/yr of treated wastewater will be used for agricultural purposes.

Scenario Three:

- Municipal demand will be 100 CM/Cap/yr.
- Irrigated areas will be projected to achieve 0.084 dunum/cap at the end of 2020 to secure the per capita basic food needs.
- Industrial demands will be increased to reach 15 % of total municipal demand.

- Demand management program will be implemented to save 7% and 15.3 % of the Domestic and Agricultural demands respectively.

- Water and wastewater network coverage will be expanded to reach 100%.
- 63 MCM/yr of treated wastewater will be used for agricultural purposes.

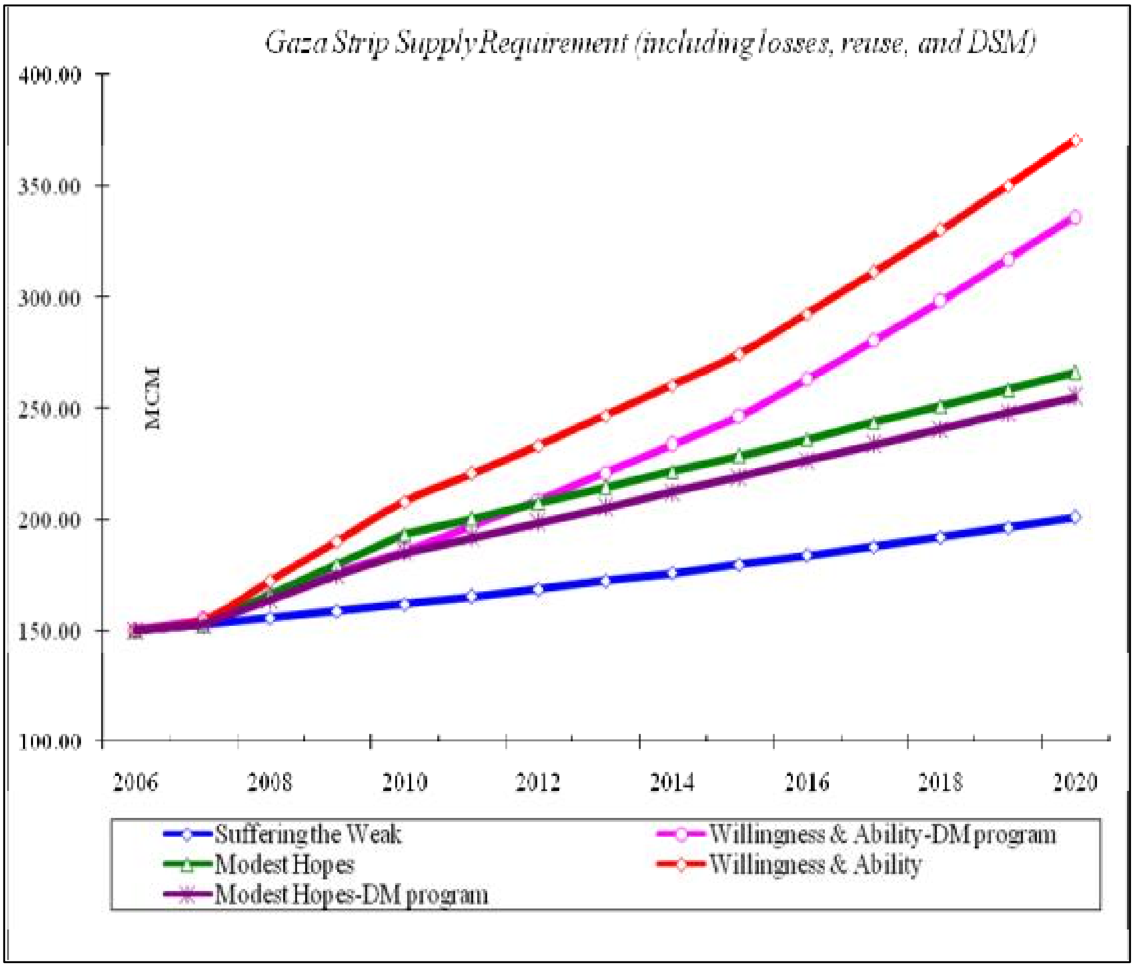


Figure 34: Predicted supply requirements (MCM) for different scenarios.

Applying water management program, the supply requirements will be decreased from 371 MCM to 336 MCM (10.5 % reduction) in scenario 3 and from 266 MCM to 255MCM (4.5 % reduction) in scenario 2. This result emphasizes the role of water management program in the future as shown in Figure 34.

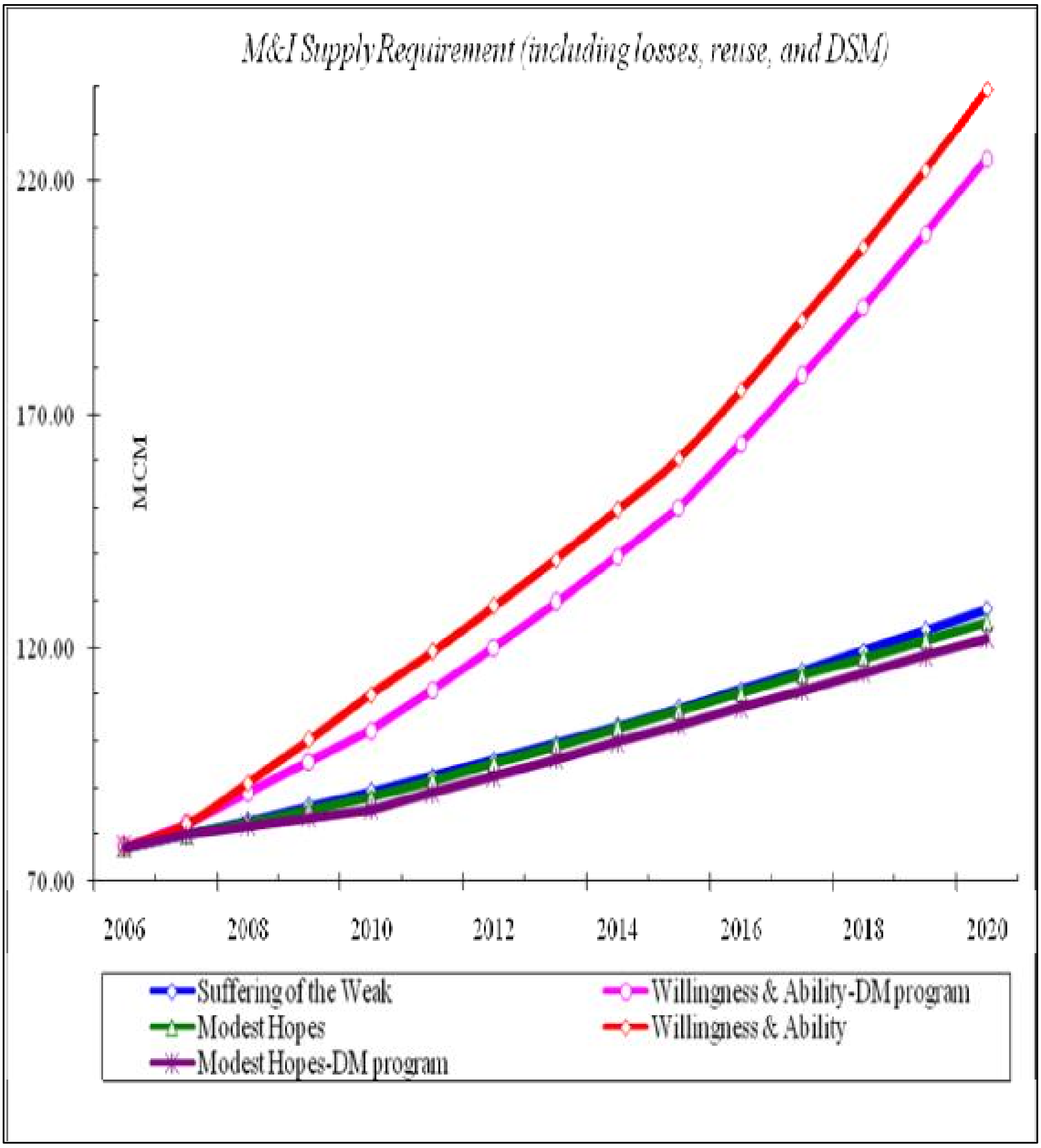


Figure 35: Municipal and Industrial (M&I) supply requirements (MCM) for different scenarios.

The effect of applying water management program will save 4MCM at the municipal and industrial (M&I) sector and 15MCM at Agricultural sector in scenario 2, while 8MCM and 20MCM will be saved in scenario 3 as shown in Figures 35 and 36.

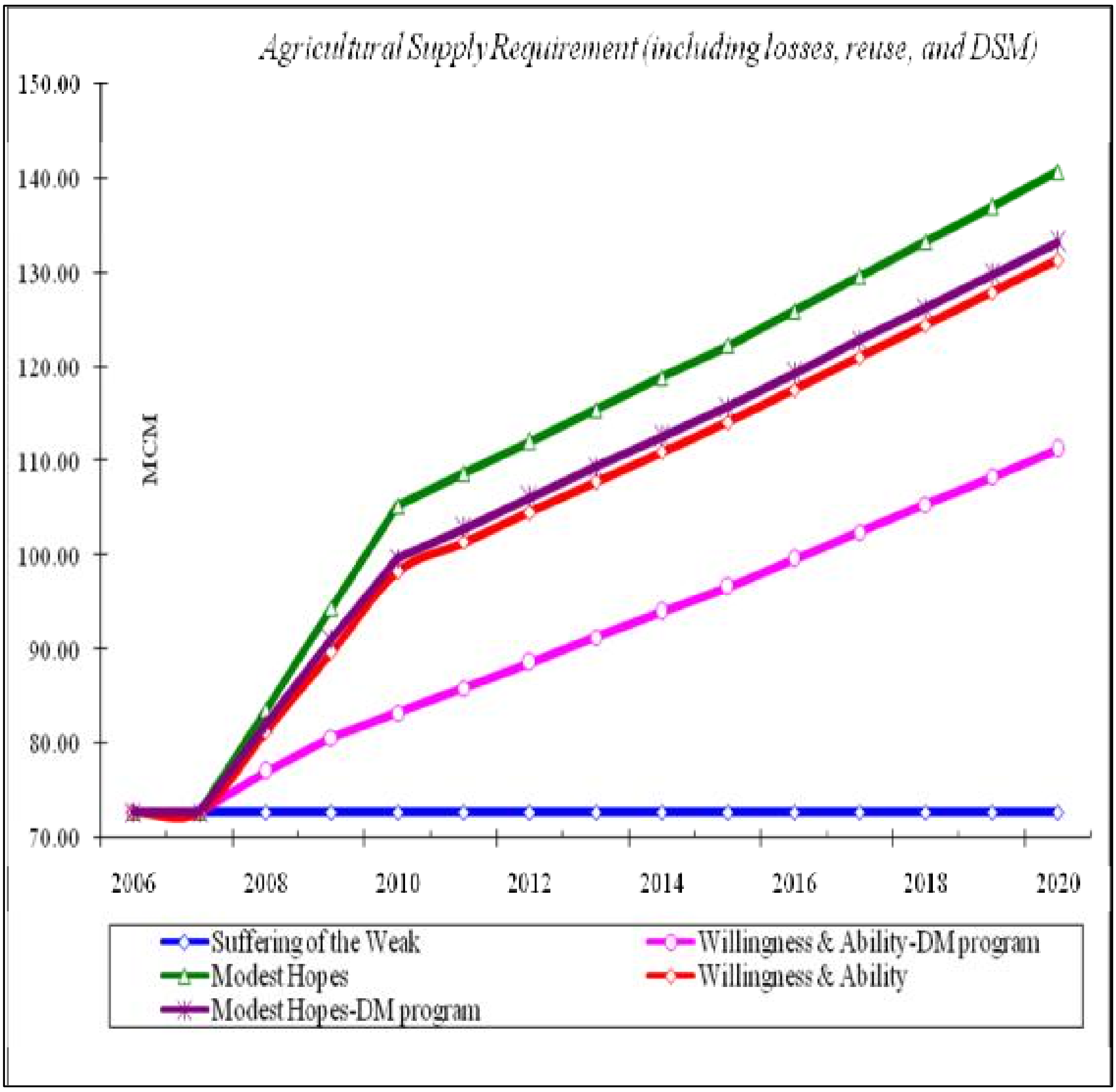


Figure 36: Agricultural supply requirements (MCM) for different scenarios.

Water consumption is the actual amount of water that is delivered to demand sites after subtracting losses, the applying of water management program can save water as much as 31 MCM/ yr by 2020 in scenario three and no saving in scenario 2 ; as shown in Figure 37 below.

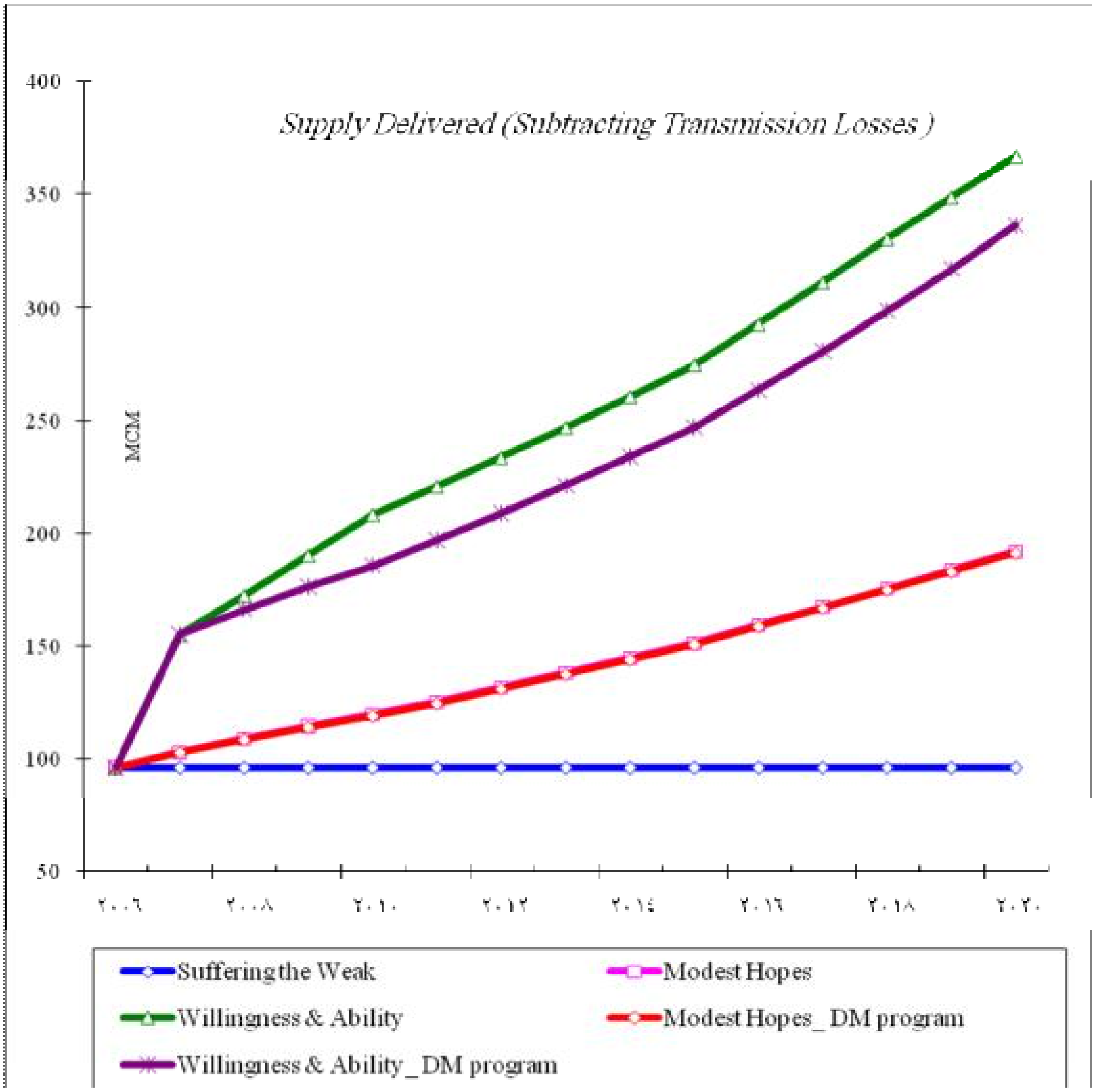


Figure 37: Supply delivered (MCM) for different scenarios.

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As shown in Figure 37, the supply delivered from groundwater and wastewater reuse will be major sources of water by the year 2020 with 31 MCM and 146 MCM respectively in scenario 2, while the main sources of water at scenario 3 will be desalination, West Bank aquifers and wastewater reuse within the period until the year 2020 as shown in Figures 38 and 39 respectively.

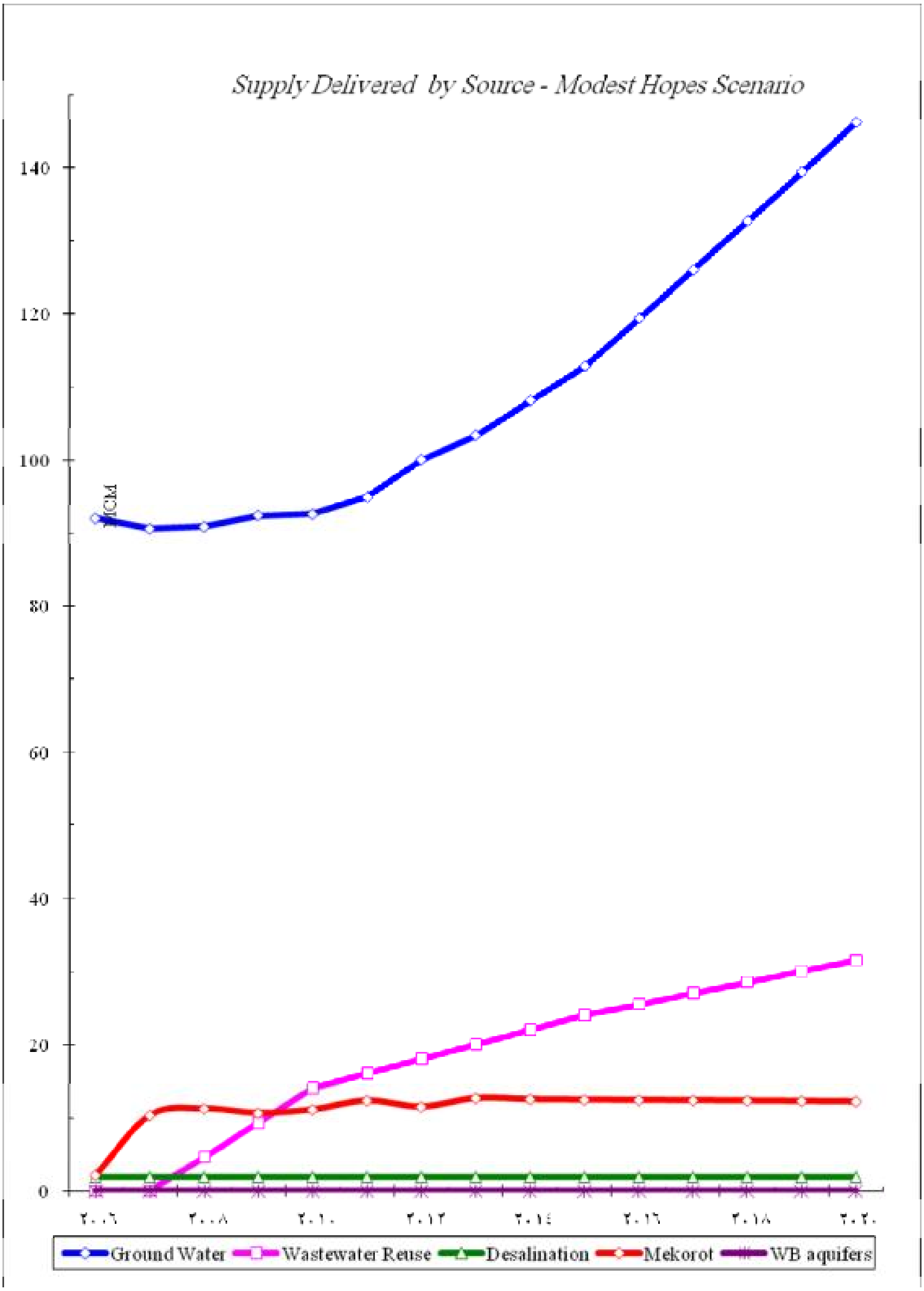

Figure 38: Supply delivered by source (MCM) for scenario 2.

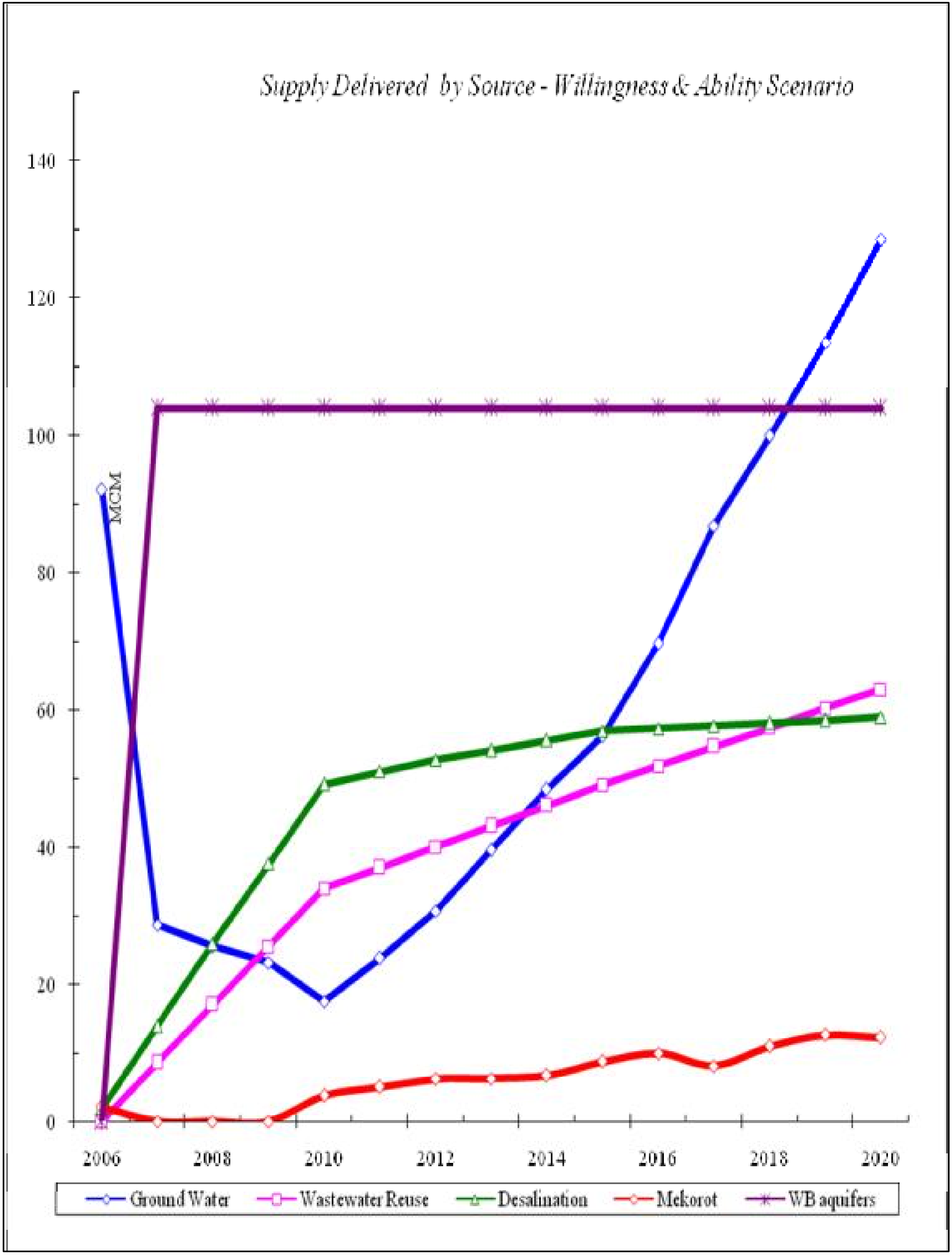

Figure 39: Supply delivered by source (MCM) for scenario 3.

5.6.2. Future Expansion Module

Table 11, Figures 30, 31 and 32 shows the assumptions of the different water management modules. These main assumptions can be summarized in the following:

Scenario One:

- Population growth rate 3.3%
- Domestic demand will be at WHO standards (150 L/C/d). The aim is to provide a sustainable and reliable amount to secure health.
- Irrigated areas will remain as current
- Industrial demand will remain as current 7 % of municipal demand.

Scenario Two:

- Population projections are assumed to be 3% (2010), 2.5% (2015) and 2% (2020) to reflect the improvement in the level of living.
- Municipal demand will be at the average WHO standards 150L/C/d.
- Irrigated areas will be projected to achieve 0.09 dunum/cap at the end of 2020 to secure the per capita basic food needs.
- Industrial demand will be increased to reach 10% of total municipal demand to achieve some reasonable level of economic development.

Scenario Three:

- Population projections are assumed to be 3% (2010), 2.5% (2015) and 2% (2020) to reflect the improvement in the level of living.

- Municipal demand will be 100 CM/C/Yr.

- Irrigated areas will be projected to achieve 0.084 dunum/cap at the end of 2020 to secure the per capita basic food needs.

- Industrial demand will be increased to reach 15% of total municipal demand to achieve some reasonable level of economic development.

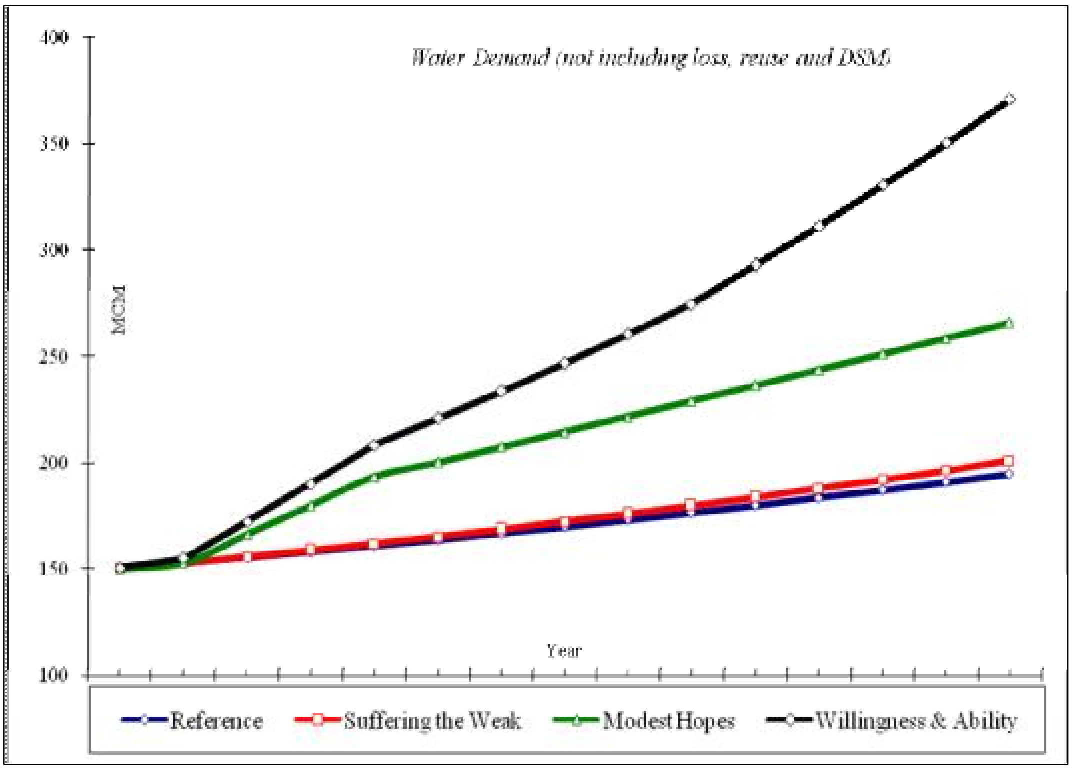

Figure 40: Predicted water demand (MCM) under different scenarios.

Simulation predicted water demand will vary according to three scenarios as shown in Figure 40; the water demand will increase from 201 MCM in scenario 1, to 266 MCM in scenario 2 to 371 MCM in scenario 3 by the year 2020.

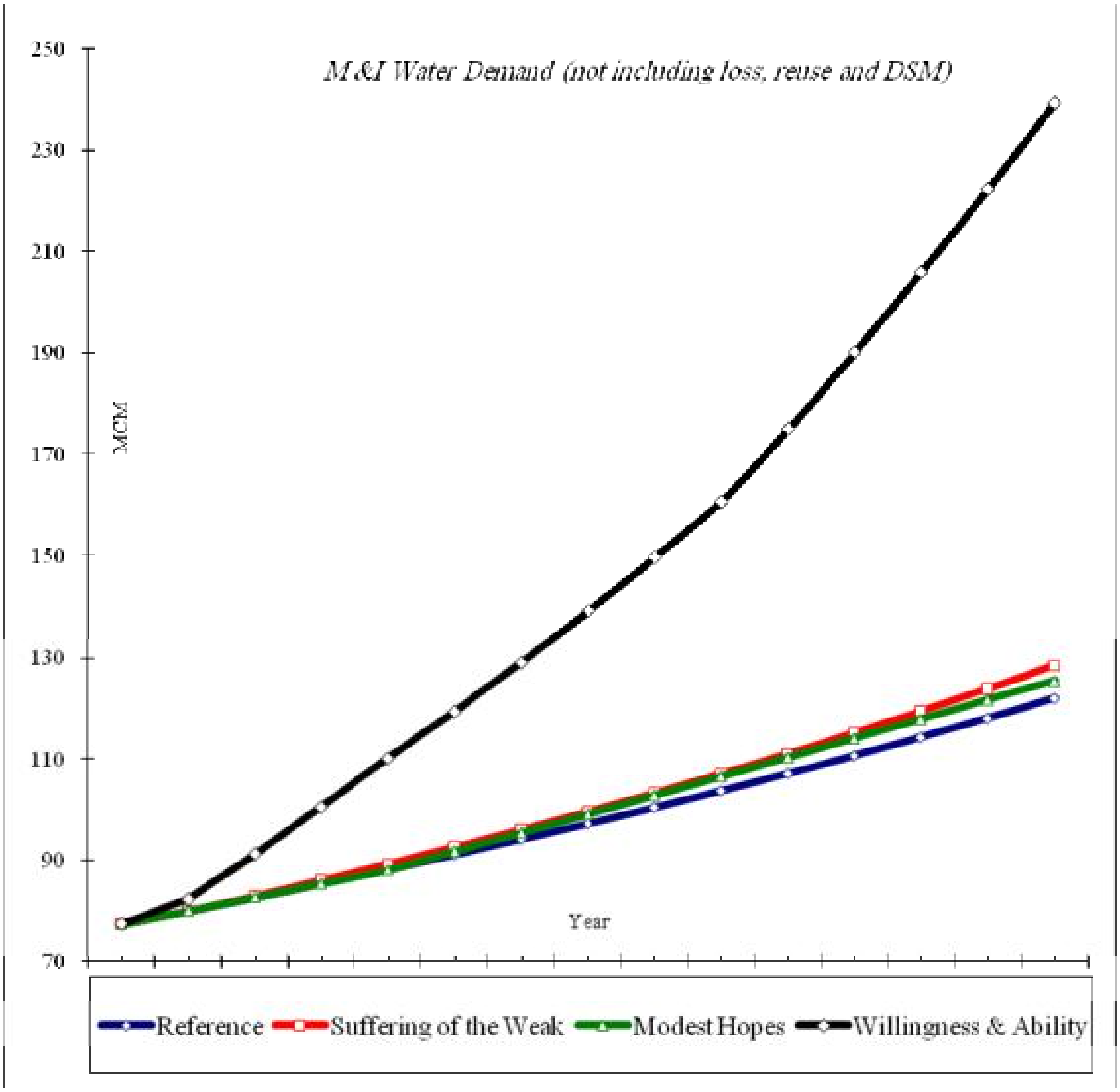

Figure 41: M&I water demand (MCM) under different scenarios.

Figures 41 and 42 shows that M&I water demand will be 128MCM, 126 MCM and 239 MCM for the three scenarios respectively by the year 2020, while the Agricultural water demand will be 73MCM, 141 MCM and 131 MCM for the three scenarios respectively by the year 2020.

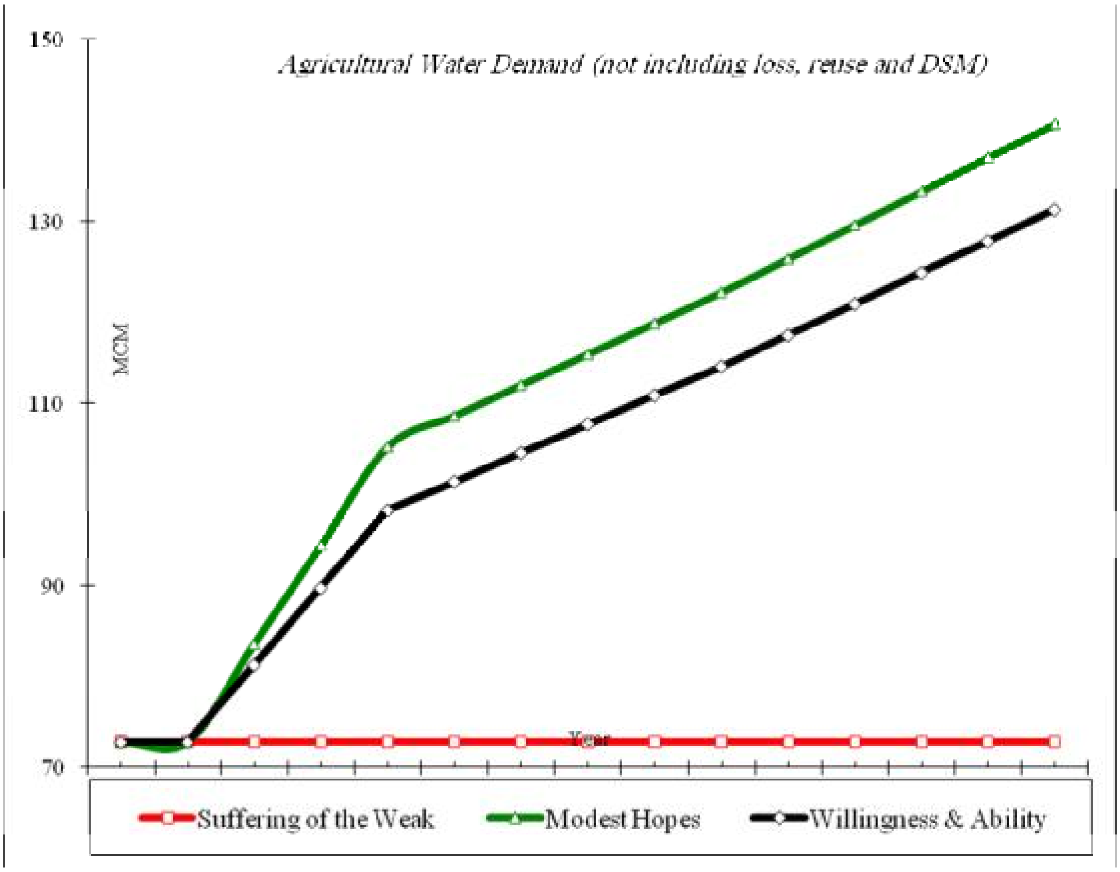

Figure 42: Agricultural water demand (MCM) under different scenarios.

Table 12 shows the predicted water demand and water available for three scenarios by the year 2020. So there is significant relation between water availability module and future expansion module that are affected by political constraints module.

Table(12): Predicted water demand and water available (MCM).

SCENARIO	Scenario 1: Suffering of the Weak	Scenario 2: Modest Hopes	Scenario 3: Willingness & Ability
Water Demand	**201**	**266**	**371**
Water Available	**161**	**161**	**359**

5.6.3. Water Availability Module

Table 11, Figures 30, 31 and 32 shows the assumptions of the different water management modules. These main assumptions can be summarized in the following:

Scenario One:

- Water available for Gaza Strip will remain as current.

Scenario Two:

- 40% reduction of abstraction from ground water, New 77 wells at selected locations, 7 Water treatment plants to supply 76 MCM, 88 MCM and 117 MCM at the years 2010, 2015 and 2020 respectively.

- 32MCM treated waste water and 5MCM from Mekorot will be used.

- Desalination will remain as current.

Scenario Three:

- 80% reduction of abstraction from ground water, New 77 wells at selected locations, 7 Water treatment plants to supply 76 MCM, 88 MCM and 117 MCM at the years 2010, 2015 and 2020 respectively.
- 63 MCM treated water and 5MCM from Mekorot.
- 57.5 MCM from desalination and 104 MCM fro West Bank.

The unmet demand for the three scenarios is presented in Figure 43. The water demand gap will be filled if the willingness and ability scenario achieved; it turns out to be zero until year 2018. Even that the gap will be 74 MCM in scenario 2, and 105 MCM in scenario 1.

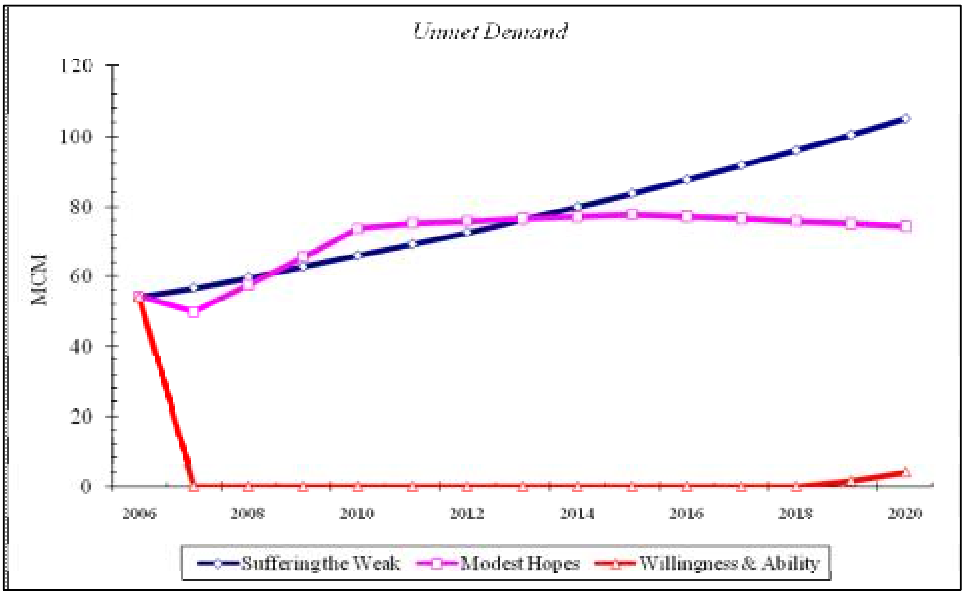

Figure 43: Predicted unmet water demand (MCM) under different scenarios.

Figures 44 and 45 shows that municipal and industrial (M&I) unmet water demand will be 80MCM, 23 MCM and 2 MCM for the three scenarios respectively by the year 2020, while the Agricultural unmet water demand will be 25MCM, 51 MCM and 1.5 MCM for the three scenarios respectively by the year 2020.

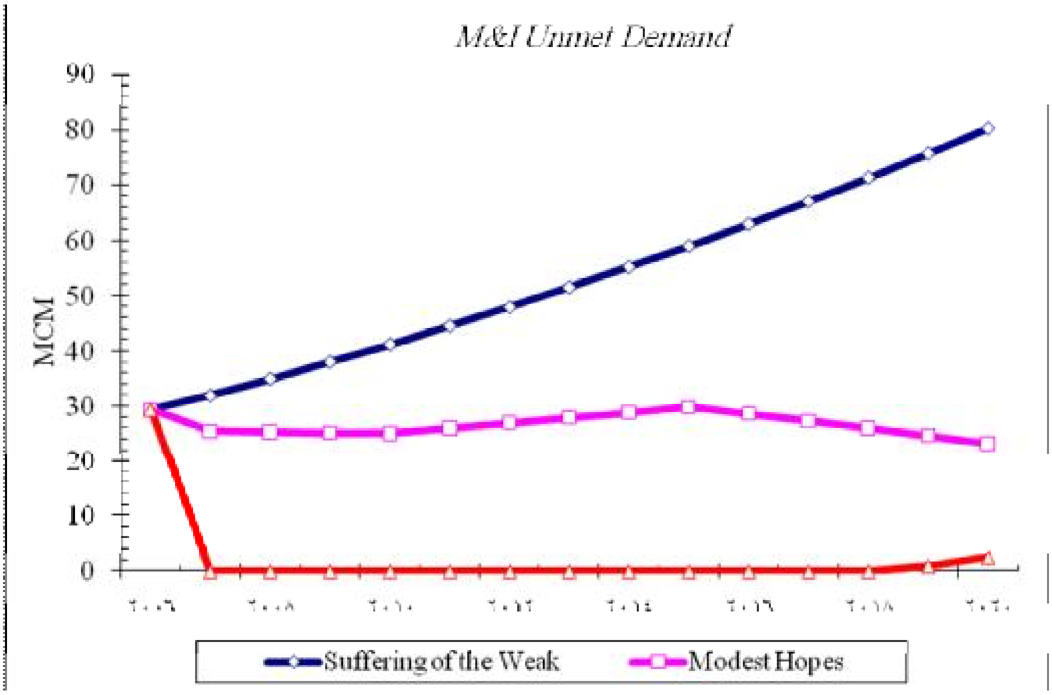

Figure 44: M&I unmet water Demand (MCM) under different scenarios.

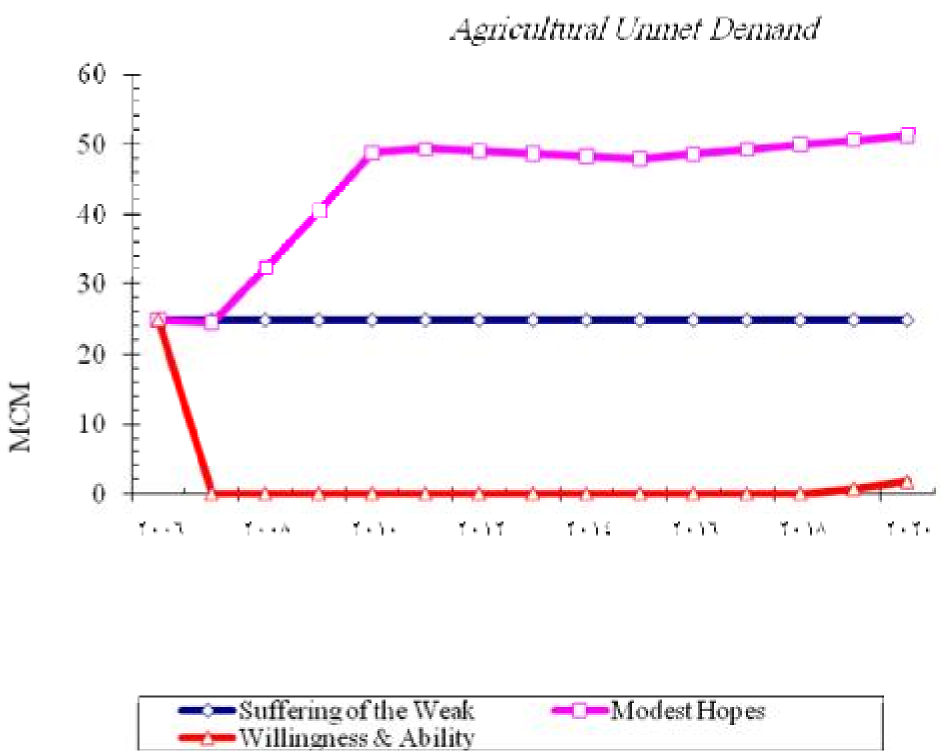

Figure 45: Agricultural unmet water demand (MCM) under different scenarios.

5.6.4. Political Constraints Module

Under this module, the simulation runs were conducted for different possible water resources taking into consideration the Coastal Aquifer Management Plan and Palestinian Water Strategic Planning Study. Table 13 shows the predicted unmet water demand for the three scenarios.

Table(13): Predicted unmet demand (MCM) under the different scenarios and modules. **(+ : Positive effect)**

SCENARIO / MODULE	Scenario 1: Suffering the Weak	Scenario 2: Modest Hopes	Scenario 3: Willingness & Ability
Political Constraints	**105**	**74**	**4**
Water Management	**105**	**64**	**0**
Future Expansion	**105**	+	+
Water Availability	**105**	+	+

As Shown in Table 13, there exist significant and direct relation between the political situation and water availability. The unmet water demand will vary from 4 MCM in scenario 3, to 74 MCM in scenario 2 to 105 MCM in scenario 1. As political situation improves the economic situation will be improved and water availability will increase.

In scenarios 2 and 3, water availability and future expansion modules have significant positive effects on the unmet demand. Water demand management module has significant effects in reducing unmet demand in all scenarios.

Table 14 emphasized the significant role of water management in saving water and reducing water demand based on political situation. Water availability and future expansion plays an important role.

Table(14): Predicted water supply requirements (MCM).

SCENARIO	Scenario 1: Suffering of the	Scenario 2: Modest Hopes	Scenario 3: Willingness &
Political Constraints	201	266	371
Water Management	201	255	336
Future Expansion	+	+	+
Water Availability	+	+	+

(+ : Positive effect)

5.5.6. Water Cost Estimates

One of the components in water management is the price of water for different users. The main element in price estimates is the cost of producing water from different potential sources. For that cost estimates of water under different scenarios and for the different sectors have been performed.

Table 15 shows capital, operating and maintenance unit water costs form different sources.

All cost estimates are based on the available cost estimates in the Water Sector Strategic Planning Study (WSSPS) and Palestinian Water Authority records for the year 2003. Table 15 shows a summary of the estimated unit costs (Capital, operating and maintenance) for the different water sources.

Table (15): Capital, operating and maintenance unit water costs (NIS /m^3)

Water Source	Capital Cost (NIS/m^3)	Operation and Maintenance Cost
Mekorot Water	1.56	2.121
Desalination	1.09	2.80
West Bank Aquifers	0.80	0.76
Ground Water	1.57	0.62
Wastewater Reuse	5.17	3.61

Results show that the average operational and maintenance unit water cost will increases from 1.15 NIS to 1.58 NIS and 1.61 NIS for scenarios 2 & 3 respectively as shown in Figure 46 and Table 16 below.

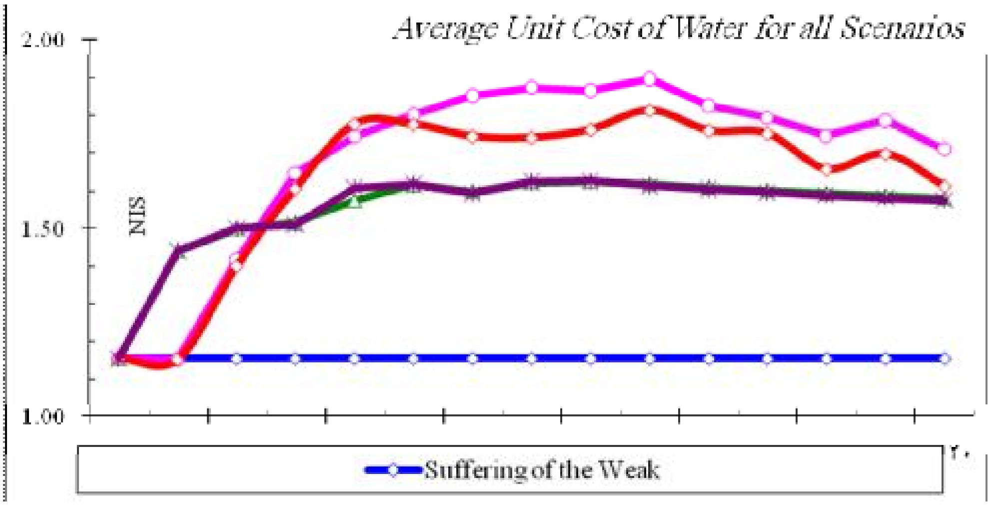

Figure 46: Average operation and Maintenance unit water costs (NIS /m^3) under different scenarios.

Table 16: Operational and maintenance unit water costs (NIS/m^3) under different scenarios for the year 2020.

Scenario	Water unit cost (NIS/m^3)
Suffering of the weak	1.15
Modest Hopes	1.58
Modest Hopes-DM	1.58
Willingness and Ability	1.61
Willingness and Ability-DM	1.71

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Based on the outcome of this work, the following concluding remarks can be stated:

- Water demand varies significantly according to the assumed political situation.
- Water management aspects are significant especially under willingness and ability scenarios.
- Unmet water demand will grow dramatically if the existing situation continues.
- Full Water Resources management is possible under the willingness and ability scenario along with water management programs. Water resource management cannot take place properly if the existing situation continues.
- Available water resources cannot meet the continuous increase in demand without employment of non-conventional water resources (such as desalination and waste water reuse). And agricultural dependence on fresh water sources must be reduced.
- Additional 63 MCM/yr from treated waste water should be developed to reduce the gap between supply and demand and to reduce the abstraction from polluted coastal aquifer.

- Additional 58 MCM/yr from seawater desalination should be developed to satisfy domestic needs and reduce the abstraction from coastal aquifer to achieve reasonable level of living by the year 2020.

- Desalination of seawater is a must in the Gaza Strip to allow natural recharge overtime to restore and cleanse the aquifer pollution and salinity until 2020.

- Additional 104 MCM/yr should be transferred to Gaza Strip from West bank Aquifers by the year 2020 to achieve reasonable level of living.

- WEAP tool provides a comprehensive picture of the forecast of future demand for water of available supplies under different scenarios.

- WEAP is potentially a useful tool for rapid assessment of water allocation decision in Gaza Strip, in Particular to locate where the problems are likely to occur.

- WEAP facilitating dialogue among the various stakeholders with an interest in water management in Gaza Strip.

- WEAP can be used to follow-up actions are being undertaken in water sector.

- WEAP tool allows decision makers and planners the opportunity of checking the impact of future water sector decisions, and gives meaningful and useful results for decision makers and all stakeholders.

6.2. Future recommendations

Based on the concepts developed and results concluded throughout this work, the following recommendations might be considered for future:

- IWRM is necessary in solving water crisis , to achieve that water resources management tools and models must be created, updated and all possible scenarios must be set to assist decision makers.

- The agriculture sector, which is the highest water consumer in Gaza Strip, should be managed through the more efficient use of water, through adopting new crop patterns and utilization of alternative water resources (treated wastewater). And generalize modern irrigation and conservation techniques in the irrigated agriculture.

- The implementation of already established polices, strategies and Plans regarding water management especially Coastal Aquifer Management Plan and Palestinian Water Strategic Planning study must be a major goal.

- As stated in the Palestinian National Water Plan, priority must be given to meet the increasing needs of the domestic purpose through efficient water resources management.
- Intensive education campaigns and public awareness should be extended and provided to aware the public and farmers about the water value.
- Licensing, metering of wells and introduction of an appropriate tariff are matter of urgency to improve water conservation and controlling the abstraction.
- Coordination between all related institutions should continued and accelerated to implement the needed projects for new water resource in Gaza Strip.
- The support of regional and international levels in playing a major role in solving political and water problems and protecting Palestinian water rights is a must.
- The study serves as the foundation of WRM model to be continued for additional researches.
- Gaza Strip is a good example for similar studies in all neighboring countries which have similar natural conditions. The results and conclusions of water management could be imitated in these similar areas.

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جامعة النجاح الوطنية
كلية الدراسات العليا

تقييم الخيارات الإدارية لمصادر المياه في قطاع غزة باستخدام برنامج (WEAP)

إعداد
نور الدين عبد المنعم محمد جرادات

إشراف
د. حافظ شاهين
د. عنان جيوسي

قدمت هذه الأطروحة استكمالاً لمتطلبات درجة الماجستير في هندسة المياه والبيئة بكلية الدراسات العليا، جامعة النجاح الوطنية، نابلس، فلسطين
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تقييم الخيارات الإدارية لمصادر المياه في قطاع غزة
باستخدام برنامج (WEAP)

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الملخص

يواجه قطاع غزة تحديا في الوضع المائي من حيث نقص المياه و عدم الاتزان بين طلب وتزويد المياه. كما ان كمية المياه الجوفية المسحوبة من الحوض الساحلي تعادل ضعف التغذية لهذا الحوض مما يؤدي إلى انخفاض منسوب المياه الجوفية العذبة من 20-30 سم سنويا(سلطة المياه الفلسطينية، 2003).

ان الهدف الرئيسي وراء هذا العمل هو التحليل باتجاه تطوير نظام متكامل لإدارة الموارد المائية في قطاع غزة باستخدام برنامج WEAP. وسيتحقق ذلك من خلال تقييم الأوضاع القائمة من حيث الطلب والتزود بالمياه وكذلك السيناريوهات المستقبلية المتوقعة أخذين بعين الاعتبار السياسات والعوامل المختلفة التي تؤثر على طلب المياه.

تكونت منهجية الدراسة من خمسة عناصر وهي: (1) جمع البيانات والخرائط اللازمة وادخالها الى برنامج(WEAP) (2) استنباط العوامل المهمة والمؤثرة في القرارات الإدارية لمصادر المياه (3) تحليل كافة العوامل والخيارات المؤثرة باستخدام برنامج (WEAP)(4) تقييم هذه الخيارات والعوامل المؤثرة استنادا إلى الظروف الحالية والمستقبلية (5) وضع مجموعة من التوصيات لادارة المياه في قطاع غزة كحالة دراسية.

ثلاثة سيناريوهات للحالة السياسية والاقتصادية المستقبلية تم اخذها بعين الاعتبار، وهذه السيناريوهات تم اخذها بالتوازي مع السناريوهات المستقبلية المتوقعة من دراسة التخطيط الاستراتيجة لقطاع المياه وكذلك سيناريوهات مشروع GLOWA– نهر الاردن، وهذه السيناريوهات هي: (1) بقاء الوضع الحالي كما هو (2) تحسن الوضع الاقتصادي مع بقاء الوضع السياسي كما هو الان(3) وجود دولة مستقلة وتحسن في الوضع الاقتصادي. حيث ان الوضع السياسي والاقتصادي هي العوامل المؤثرة على تطوير الخيارات الادارية لتطوير مصادرالمياه في فلسطين.

تظهر النتائج أن الفجوة بين التزويد والطلب على المياه ستنمو بشكل كبير إذا استمرت الظروف الحالية كما هي. كما وخلصت الدراسة الى ان الطلب على المياه يختلف اختلافا كبيرا وفقا للوضع السياسي المستقبلي المفترض.

كما وتشير النتائج الى ان الطلب على المياه يعتمد عل السيناريو المستقبلي، حيث سيزداد الطلب في سنة 2020 من 201 مليون متر مكعب في السيناريو الاول الى 266 مليون متر مكعب في السناريو الثاني ليصل الى 371 مليون متر مكعب في السيناريو الثالث . كما ان الفجوة بين التزويد والطلب على المياه سوف تسد حتى سنة 2020 اذا تحقق السيناريو الثالث، بينما ستكون هناك فجوة تقدر ب 74 مليون متر مكعب اذا تحقق السيناريو الثاني لتزداد الى 105 مليون متر مكعب اذا تحقق السيناريو الاول.

وأظهرت النتائج أيضا أن هناك حاجة لتطوير أكثر من 200 مليون متر مكعب لتلبية الاحتياجات المستقبلية من المياه ز.كما وأكدت النتائج على أنه يمكن تطبيق WEAP كنموذج داعم ومساعد لمتخذي القرار وكذلك لاستخدامه كأداة لإدارة الموارد المائية في قطاع غزة.