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Developing A GIS And Hydrological Modeling Approach For Sustainable Water Resources Management In The West Bank -- Palestine

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DEVELOPING A GIS AND HYDROLOGICAL MODELING APPROACH

FOR SUSTAINABLE WATER RESOURCES MANAGEMENT

IN THE WEST BANK – PALESTINE

by

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GRADUATE COMMITTEE APPROVAL

of a dissertation submitted by

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ABSTRACT

DEVELOPING A GIS AND HYDROLOGICAL MODELING APPROACH
FOR SUSTAINABLE WATER RESOURCES MANAGEMENT
IN THE WEST BANK – PALESTINE

Walid W. Sabbah

Department of Civil and Environmental Engineering

Doctor of Philosophy

This research deals with setting up a GIS and hydrological modeling based approach for sustainable water resources management in the West Bank of Palestine.

This water sustainability approach took into consideration the water balance, the social, the economic, the demographic, the environmental, and the institutional components in order to enhance and promote the sustainable development in Palestine, both on the short and long runs.

To evaluate the water balance component, a methodology was introduced to create the Water Sustainability Map (WSM). Since the groundwater is currently the only accessible water source by the Palestinians, the WSM is represented by the Aquifer

Sustainable Yield (ASY) which is equivalent to the annual renewable recharge of the various aquifer formations in the West Bank. The ASY was determined by integrating the watershed boundaries derived from the Digital Elevation Model (DEM) with the available hydrological and meteorological data by using GIS. This GIS based approach was used to create the rainfall, evapo-transpiration, and runoff coverages by interpolating their values from the measured parameters. The total estimated ASY using this GIS approach was 679.7 MCM/Yr. which constituted the upper limit for the overall water use in all assumed future water demand scenarios.

This approach fulfilled the demographic, social, and economic water sustainability components by proposing water demand scenarios for the period from 2005 to 2025 based on the gradual increase of population and their per capita water use, the available water infrastructure, and based on the value of water where priority was given to the household water use.

This approach fulfilled the environmental dimension of water sustainability by studying the water quality and identifying the locations with high pollution indicators for various water use purposes and recommending ways to prevent the environmental degradation and groundwater pollution.

This approach fulfilled the institutional dimension of water sustainability by reviewing the current institutions dealing with water management and distribution, recommending options to enhance their efficiency, and finally by proposing some options to save additional water in the West Bank.

Keywords: approach, GIS, **m**odeling, sustainability**, h**ydrology, water balance, water supply, water demand scenario, institutional water management, optimal water use.

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I want to begin expressing my appreciation and maximum thanks to my beloved wife; Hilda, who supported me through my years of study to get where I am now, getting my degree. I also would like to mention the most wonderful part of my life; my children: Sondos, Serrien, and Wajeeh for understanding the times I needed to be away from them in order to accomplish this mission.

This appreciation extends also to our families in Palestine that believed in me and in my work and are optimistic that this research will make a difference and will help build a new brick in the wall of the mutual understanding for the conflict and complications they have been living in since decades.

I am very thankful and appreciative to Dr. Miller, who is my committee chair, for his supervision, encouragement, and financial support which helped me accomplish my research and fulfill my doctorate degree.

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CHAPTER ONE

INTRODUCTION

Water resources have played an important role in shaping the geopolitical boundaries of Palestine since the beginning of the twentieth century. Although water resources of Palestine are scarce due to hydrological and other natural and physical characteristics, the abnormal political conditions due to the Israeli occupation of the West Bank and Gaza Strip since 1967 have further complicated the water situation.

1.1 Study Area

In this research, the study area includes the West Bank (WB) of Palestine, which has an overall area of approximately 5822 km^2, of which 5632 km^2 is land area and 190 km^2 is the area of the Palestinian portion of the Dead Sea (Applied Research Institute, 2000). Figure 1-1 shows the regional location map of the study area. Although the West Bank is located downstream from the Jordan River Basin, the Palestinians have no access to its water since the Six-Day War in 1967. Before 1967, the Palestinian farmers in the western Jordan Valley pumped their agricultural water directly from the Jordan River. After 1967, Israel declared all the areas adjacent to the Jordan River as a closed military area, and all groundwater wells and pumps along the Jordan River were confiscated. Since the beginning of the Israeli occupation, groundwater has been the only accessible

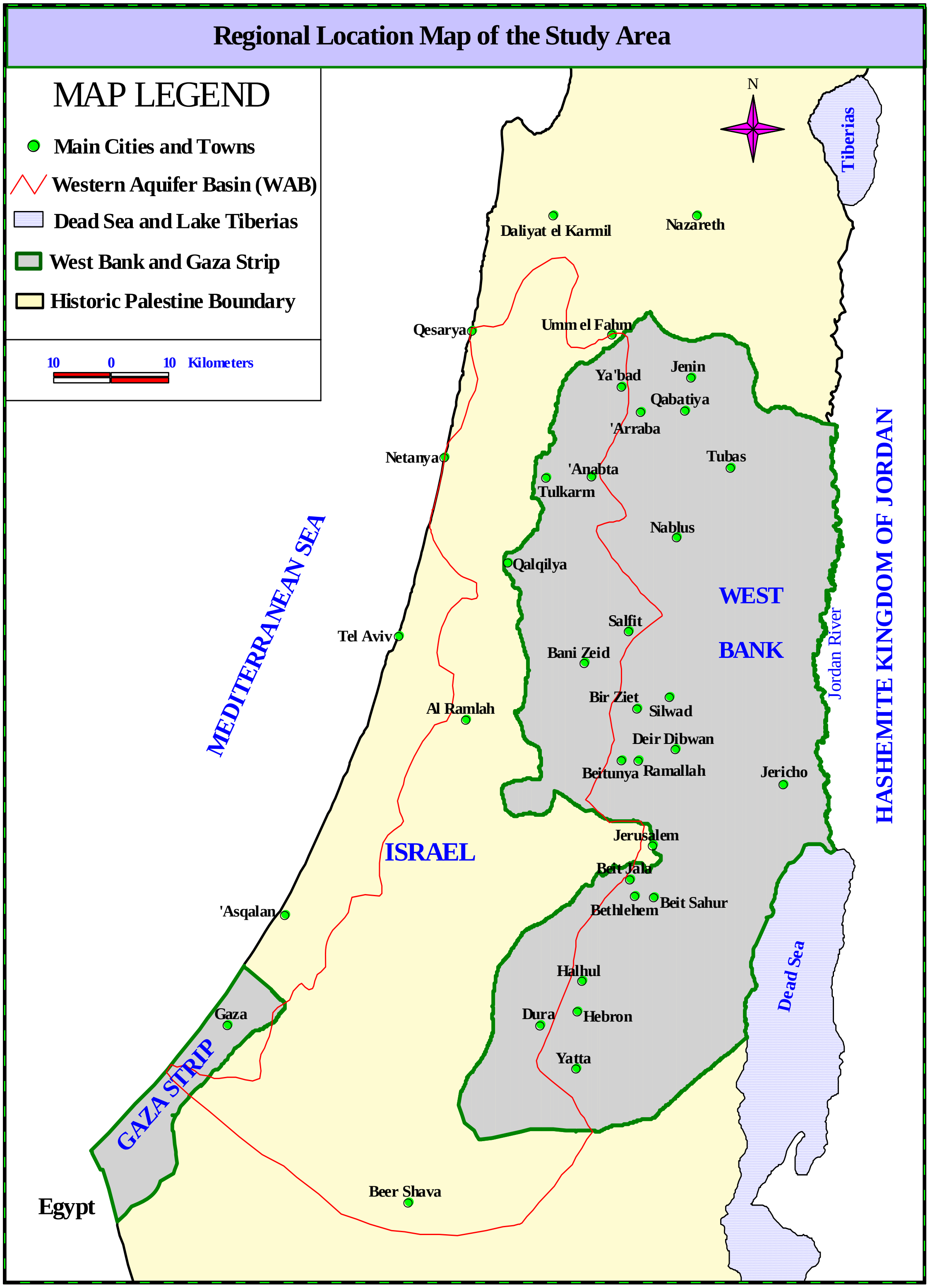

Figure 1-1: The Regional Location Map Of The Study Area

source of water for Palestinians living in the West Bank. Not all communities of the West Bank have access to the groundwater, so they have to develop simple rain water harvesting tools in the form of agricultural ponds and/or cisterns which collect the rain water from the roofs of their houses (Isaac and Sabbah, 1998). Since the Israeli occupation, Palestinians must obtain permits from the Israeli Government to drill any new wells or to rehabilitate any existing ones. For each permit granted by Israel to drill a new well, the Israeli Government limits the pumping quota. That quota cannot be exceeded without pre-authorization, which is rarely given.

1.2 Research Objectives & Methodology

Due to the long-term Israeli occupation and the abnormal political status in the West Bank and Gaza Strip since 1967, the number of surface and groundwater management studies by Palestinian researchers and hydrologists has been limited. None of these Palestinian water management studies dealt with the technical aspects of the various aquifer basins. All the Israeli water related data for these basins are classified and so a very limited number of water research studies done by the Israeli hydrologists are public. Most of their water resources management research is written in the Hebrew language and/or published in the form of internal reports for use within the Israeli institutions dealing with such types of water research.

The main goal of this research study is to develop an integrated GIS and hydrological modeling based approach for Sustainable Water Resources Management in the West Bank-Palestine. This research uses various GIS and spatial modeling softwares such as ArcView, ArcGIS, MapInfo, Vertical Mapper, Surfer, the Watershed Modeling System

(WMS), and the Groundwater Modeling System (GMS) to study and evaluate the spatial variation of key water related issues.

The traditional definition of sustainable water resources management is the status of using the water resource so that the resource is not depleted or permanently damaged. This research uses a more comprehensive definition of sustainable water management which includes the equitable, environmental, social, and economic sustainability aspects. Equitable sustainability ensures that all people have fair access to a good and sufficient water supply. Environmental sustainability means that the use of water should not cause environmental degradation and/or harm the other water users sharing the same water resource. Based on this definition, sustainable water management maintains the dynamic equilibrium of the hydrological system. Social sustainability means that the water management system must support the social cohesion of the people by providing equitable chances of access to water for future generations. Economic sustainability means that all water management activities must ensure that water will be used for the best possible economic benefit according to its value. By taking into consideration all the above mentioned aspects of sustainable water management, this research enhances the contribution water to human beings and their quality of life in the West Bank (Orthofer et al, 2001).

This study has the following objectives:

1. Conduct a survey and literature review of the natural, hydrological, and hydro-geopolitical status of Palestinian water resources. This review will include a

background on the available water resources (both surface and groundwater) and the previous and current status of water use and management in Palestine.

2. Perform a watershed analysis for various watersheds of the West Bank to:
    a. Delineate drainage patterns and surface water flow directions from topographic data.
    b. Derive watersheds and sub-watersheds and compute their geometric characteristics.
    c. Propose the best locations for hydro-metric stations to measure stream flow runoff and other meteorological parameters in the various derived watersheds.
3. Conduct a 10-year (1990/91-1999/2000) water balance study for the West Bank watersheds.
    a. Create the annual depth of rainfall and convert it to GIS grid coverage.
    b. Estimate the 10-year average annual depth and volume of reference evapotranspiration (ET_0) and crop evapotranspiration (ET_c) based on the available meteorological and crop data and convert it into GIS grid coverage.
    c. Create the annual depth and volume of runoff and convert it into GIS grid coverage. Runoff values will be taken from measurements by hydrometric stations within and around the West Bank.
    d. Create the annual depth and volume of Recharge/Infiltration using the general mass balance equation:

$$\text{Precipitation} = ET_c + \text{Runoff} + \text{Infiltration/Recharge} \qquad (1\text{-}1)$$

4. Evaluate the quantitative and qualitative aspects of groundwater resources. This will be done as follows:

a. Review the geological structures, the hydro-stratigraphy, and the geological outcrops (recharge areas) of various groundwater basins and their aquifers. This is required to compute the recharge for various basins and their aquifers based on the coverage maps created in the objective category #3 above.

b. Compare the estimated groundwater recharge with the total groundwater extraction and spring flow discharge to study the sustainability of various basins and their aquifers.

c. Create a contour map for the groundwater elevation of the main aquifer system to identify the groundwater flow patterns.

d. Set up a numerical groundwater flow model for the Western Aquifer Basin (WAB) as a case study on the West Bank aquifer basins. Although 60 percent of the WAB's area is located out of the West Bank border (within the Israeli area), we have to deal with the whole basin in order to understand the groundwater flow regime and manage the groundwater resources. The model will be calibrated for steady state conditions in an attempt to test the best conceptual model and boundary conditions, sources and sinks, groundwater flow direction, head gradient distribution, the overall flow budget, and the optimal values of hydraulic conductivity and recharge that can minimize the difference between the observed and computed heads. The current available observations inadequate to calibrate the model for transient conditions. Once the political atmosphere between the Palestinian Authority and Israel becomes better and enough confidence is built so the hydrological data exchange agreed upon within the context of the OSLO I & II agreements (1993, 1995, respectively) is re-activated, this model could be updated to include transient flow and pollution transport models for long-term forecasting.

5. Study water supply and demands by:

   a. Classifying the current (as of the year 2002; the newest available data) Palestinian water use for various purposes and identify the sources and quantities of water consumption for each purpose (groundwater, surface water, purchased from Mekorot Israeli water company, etc).

   b. Identifying the efficiency of the current water supply for various purposes in terms of the percentage of the actual water quantities being used by consumers. The water consumption equals the water supply minus the total losses.

   c. Proposing scenarios of water demand for the three main water use sectors for the period 2005-2025. Three scenarios were proposed using the water supply for the year 2002 as a baseline. The three proposed scenarios are:

      - The Low Scenario for household, irrigation, and industrial water sectors. For the household water demand, this scenario considers the natural growth of the population of the West Bank, the coming of 250,000 visitors a year until the year 2025 to stay in the West Bank during the summer months (June-August), and the return of 250,000 returnees by the year 2025. For the irrigation water sector, this scenario assumes that the irrigated areas are increased from the current areas of 10500 hectares to 25000 hectares by the year 2025. For the industrial water sector, this scenario assumes that the growth rate of the water demand for industry will be increased from the current rate of 1.5% to 3% during the period (2005-2025).

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- ❖ The Medium Scenario for household, irrigation, and industrial water sectors. For the household water demand, this scenario considers the natural growth of the population of the West Bank, the coming of 500,000 visitors a year until the year 2025 to stay in the West Bank during the summer months (June-August), and the return of 500,000 returnees by the year 2025. For the irrigation water sector, this scenario assumes that the irrigated areas are increased from the current areas of 10500 hectares to 27500 hectares by the year 2025. For the industrial water sector, this scenario assumes that the growth rate of the water demand for industry will be increased from the current rate of 1.5% to 4% during the period (2005-2025).
- ❖ The High Scenario for household, irrigation, and industrial water sectors. For the household water demand, this scenario considers the natural growth of the population of the West Bank, the coming of 750,000 visitors a year until the year 2025 to stay in the West Bank during the summer months (June-August), and the return of 750,000 returnees by the year 2025. For the irrigation water sector, this scenario assumes that the irrigated areas are increased from the current areas of 10500 hectares to 30000 hectares by the year 2025. For the industrial water sector, this scenario assumes that the growth rate of the water demand for industry will be increased from the current rate of 1.5% to 5% during the period (2005-2025).

6. Propose better methods for institutional water management and optimization of water use by:
    a. Reviewing and assessing the current water management institutions in the West Bank.
    b. Recommending an alternative institutional structure that can manage the water more efficiently in order to achieve the water sustainability.
    c. Recommending options for optimizing the water use and making more water available to meet the requirements of water demand for the various purposes. These optimization options could include, but are not limited to, small-scale cisterns and water harvesting tools, irrigation water management, continuous maintenance of water networks and other related water storage facilities, and rehabilitation of springs and groundwater wells.

Figures 1-2 shows the methodology used in this study for evaluating the sustainability of water resources which took the various water management components into consideration. The main component of this sustainable water resources management study includes the water balance which could be considered as the bank cash account that could be used for certain planned business. The water balance estimation and the creation of the Water Sustainability Map (WSM) represented by the Aquifer Sustainable Yield (ASY) is the key issue for sustainable water resources management under the various assumed water use scenarios in the West Bank. The other water management components dealt with during this research study include the environmental, land use, demography and population, socio-economic, and institutional components.

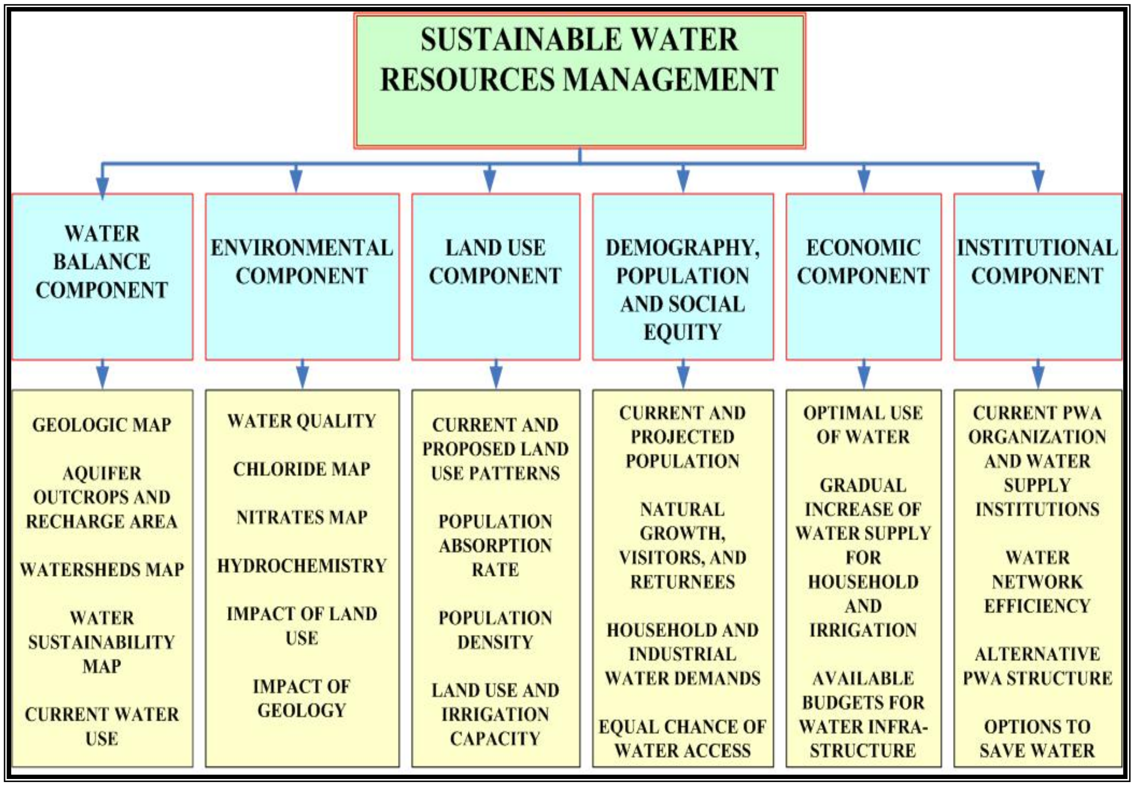


Figure 1-2: Proposed Methodology For Evaluating Sustainable Water Resources Management

1.3 Anticipated Benefits of the Study

- This pilot study could be a solid reference to any future groundwater and environmental studies in the West Bank and Gaza Strip.
- This research would be the first to deal with identifying the surface water balance for various derived watersheds. This could help water managers and decision makers to make the right decisions at the right time to better manage the Palestinian water resources in the West Bank.
- This research would be the first to deal with the technical aspects of water use optimization required for more efficient management of the Palestinian water resources in the West Bank.

- The results of this research study could help Palestinian technical and official teams for final status peace negotiations with Israel on the water related issues (as proposed within the context of OSLO agreements and the newly proposed Road Map) to better understand the hydrological situation, flow patterns, groundwater budget, and the spatial extent of the various aquifer basins.
- The groundwater flow models could be the base for any future water modeling studies. For example, setting up a pollution transport model or a geochemical model representing the dissolution of the aquifer's rock forming minerals as groundwater flows from the recharge (upstream) to the discharge areas (downstream) depends mainly on a calibrated groundwater flow model.
- The Palestinian Water Authority (PWA) could benefit from this research to formulate a National Palestinian Water Resources Master Plan.

1.4 Dissertation Overview

The first chapter provides a definition of the study area and its various names used in the literature. It also provides a description of the objectives of the research study, the anticipated benefits, an overview of how the rest of the dissertation is organized, and the main sources of the hydrological data used in this research.

Chapter two provides a hydro-political background of water resources in the historic Palestine in general and in the West Bank in particular.

Chapter three deals with the surface water resources and the evaluation of the elements of the surface water balance for various watersheds of the West Bank. It also shows the derivation of various watersheds and their stream drainage patterns from digital elevation data.

Chapter four identifies the groundwater resources including the hydro-geological settings, the hydro-stratigraphic classification, the identification of recharge areas and rates of recharge for various aquifer basins, and the identification of water quality in the West Bank.

Chapter five shows the development of a groundwater flow model for the Western Aquifer Basin (WAB) by creating the conceptual model, converting it to a numerical groundwater flow model, and calibrating the numerical model against a set of representative measured head and flow observations under steady state conditions to identify the groundwater flow patterns and the groundwater flow budget.

Chapter six deals with the water supply and demand for various purposes, including the current water supply and the water use efficiency as of the year 2002 (the latest year with available data). It also includes three projection scenarios of water demand for each water use sector for the period (2005-2025). The water use sectors used in these scenarios include the household, the agricultural, and the industrial sectors.

Chapter seven reviews and assesses of the current water management institutions in the West Bank. It provides an alternative institutional structure required to manage the

Palestinian water resources more efficiently. It also provides options for optimizing the water use in an attempt to bridge the gap between the water supply and the demand.

Chapter eight provides conclusions, recommendations, research contributions, and suggestions for future research.

1.5 Sources of Data

Files and Archives of the Palestinian Water Authority Hydrological Database

- Palestinian Central Bureau of Statistics (PCBS)
- Palestinian Ministry of Agriculture.
- Palestinian Ministry of Transport, Meteorological Department
- Rofe and Raffety Reports on Geology and Hydrogeology of the West Bank
- Research centers of the Palestinian Academic Universities
- Israeli Sources such as the Hydrological Services, Meteorological Services, the Institute for Petroleum Research and Geophysics, the Geological Survey, and the Land Survey of Israel.

CHAPTER TWO

HYDRO-POLITICAL BACKGROUND

Historic Palestine (pre-1948) is located on the eastern coast of the Mediterranean Sea with an area of 27,000 square kilometers. It is bordered by the Hashemite Kingdom of Jordan and Syria on the east, Egypt and the Mediterranean on the west, Gulf of Aqaba on the south, and Lebanon on the north (Figure 1-1). Palestine occupies a unique geographical, historical and religious importance for the whole world. It links Asia with Africa and many civilizations originated there. It is also considered a holy place by many of the major world religions. As a result, Palestine is home to a long-running Middle Eastern conflict.

In 1917, under the pressure of the Zionist movement, Balfour, the British foreign minister, issued a declaration, holding his name, which declared the right of the Jews to establish their homeland in Palestine. Since the Jewish population of Palestine at that time was not greater than 10% of the total population of Palestine, a political conflict started between the Arabs (mainly the Palestinians) and the Jews which is still active today. This chapter will give a hydro-political history of Palestine's water resources in various time stages since the beginning of the twentieth century until now.

2.1 Water Politics During the Period 1917-1948

The Balfour Declaration of 1917 encouraged the Zionist Movement to begin hiring engineers, hydrologists and other water and agricultural experts to conduct multi-disciplinary research on Palestine to explore its natural resources of which the land and water were the key issues. In addition, the Zionist Movement started organizing intensive Jewish immigration to Palestine in order to balance the demographic status between the Arabs and the Jews.

After the end of World War I and the collapse of the Ottoman Empire, many Arab and Jewish leaders started keen competition and negotiations with the two main powers who won the war (France and Great Britain) in an attempt to control the Arab territories which were a part of the collapsed Ottoman Empire.

In 1920, France and Britain organized a peace conference in Paris involving one Arab delegation and one Jewish delegation. The Arab delegation didn't include Palestinian representatives (Trottier, 1999). The Jewish delegation focused on Palestine and gave the subject of water a high priority in their proposals for the borders of Palestine. Their main proposal submitted to the conference was to include the entire Jordan River Basin within the borders of Palestine to ensure free access to the water of the Jordan River (Garfinkle, 1992).

In 1922, Britain declared the "Mandate of Palestine", in which two of the three tributaries of the Jordan River were excluded to be within the borders of Syria and Lebanon which became a part of the French Mandate. The British Mandate imposed some rules to organize Jewish immigration to Palestine mainly based on the agricultural absorptive capacity of that territory (Reichman, 1997). Later in the 1940's, the Zionists used water as a key factor for determining the absorptive capacity of their future Jewish State (Trottier, 1999). During the British Mandate, the Zionist Movement increased the intensity of the Jewish immigrations to Palestine in an attempt to get more advantage of the friendship with the new mandating power and to balance the population percentages there. Table 2.1 shows the statistics of the population of Palestine in 1922 and 1944 which illustrates the intensity of the Jewish immigration during that period. In the 22 years (1922-1944) of the British Mandate of Palestine, the Jewish population increased from 11% into 33% of the total population of Palestine, while the Arabs decreased from 89 percent into 67 percent.

Table 2-1: The Population Statistics Of Palestine From 1922 To 1944

Palestine Population	**1922**	**1944**
Jews	83,794	553,600
Arabs	673,388	1,144,370
Total	757,182	1,697,970
% Jews	11	33
% Arabs	89	67

Source: ARIJ, 2000

In November 1947, the United Nations (UN) Security Council met to discuss the problem of Palestine and they adopted the UN Resolution #181 which mandated the partitioning of Palestine into two states: the Palestinian Arab State and the Jewish State to be established on the land of historic Palestine according to the map shown in Figure 2-1.

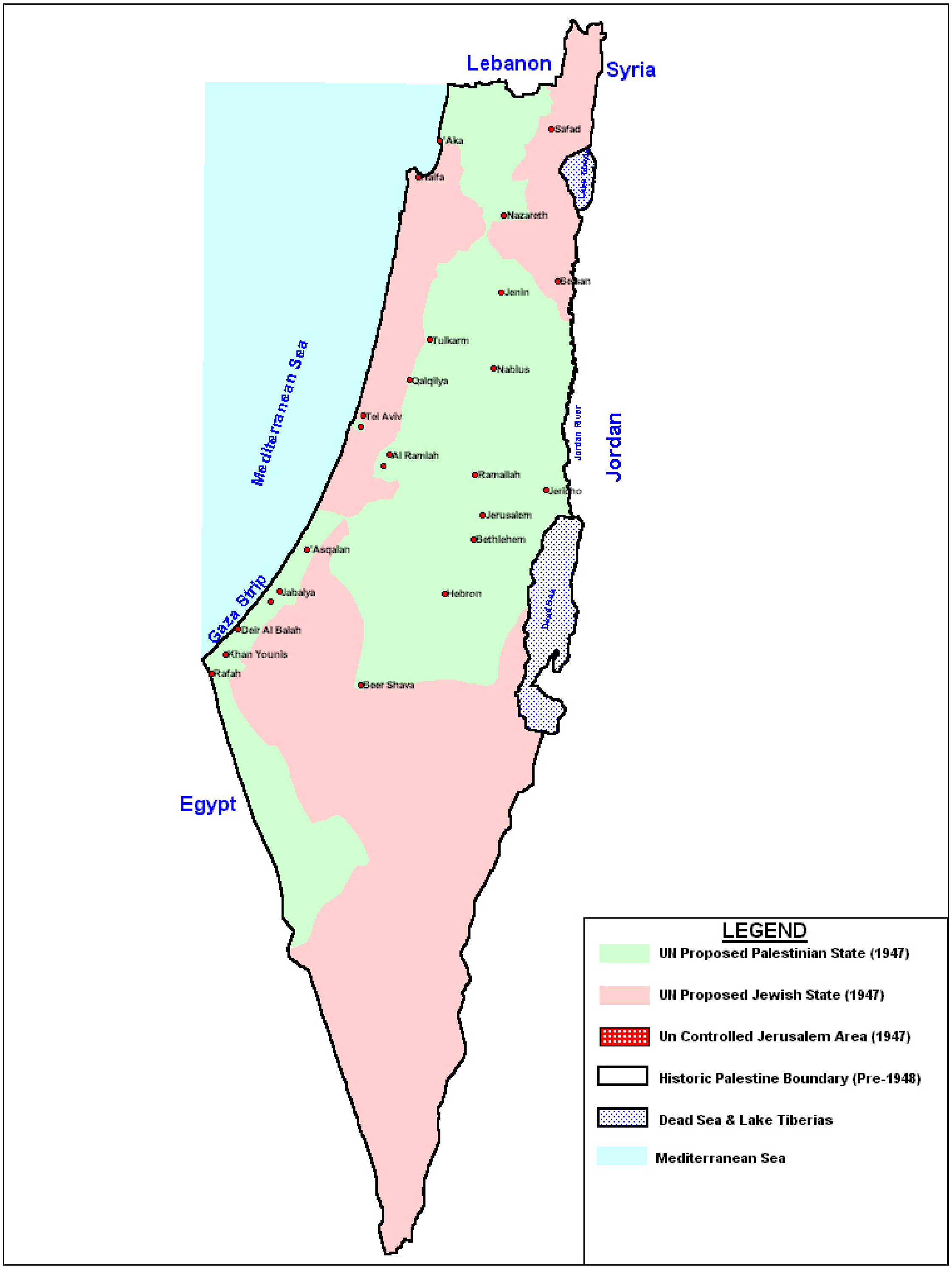


Figure 2-1: The United Nations Partition Plan Of Palestine (Resolution #181, 1947)
(Modified From ARIJ (2000))

Although the ratio of the Palestinian population to the Jewish population was two to one, the Arab State was given 43% of the Mandate area of Palestine and the Jewish State was given 56%. The other 1% which represents Jerusalem and Bethlehem cities was to be controlled by the UN (international) due to their religious importance. The resolution gave Britain a maximum period of eight months to be completely withdrawn from Palestine and the Arab and Jewish states were to be established two months later (i.e. by October 1st, 1948). The Arab countries surrounding Palestine denied the UN resolution, believing that it was not a fair resolution. Britain terminated their Mandate four months early and left the area uncontrolled. That led to the 1948 war which occurred between the Jews and the neighboring Arab countries and determined the political fate of Palestine. The Jewish militia won the war and they declared the establishment of Israel on May 15th, 1948 over an area of 78% of the Mandate area of Palestine. The newly established Jewish state took 22% more area than what they were given according to the UN resolution #181 concerning the partitioning of Palestine. The Palestinians were left with 22% of the Mandate area.

2.2 Water Politics During the Period 1948-1967

During the 1948 war and after the establishment of Israel, 800 thousand Palestinians were forced to leave the Palestinian land taken by Israel and became refugees in the remaining part of the Palestinian land and the surrounding Arab countries. The other 22 percent of the Mandate area of Palestine represents what is currently known as the West Bank and Gaza Strip.

Since most of the Palestinians were forced to leave their country, the Arab states decided to let the adjacent Arab countries temporarily administer the remaining Palestinian areas until reaching a just and permanent solution of the Palestinian problem. As a result, the West Bank fell under the Jordanian administration while the Gaza Strip fell under the Egyptian administration. From a water resources point of view, Israel was able to control the downstream of the Jordan River, including Lake Tiberias, while two out of the three main tributaries draining to the Jordan River were still located out of Palestine. They were in Syria and Lebanon, which remained under the French Mandate. That was against what the Jewish delegation had submitted for the Paris conference of peace held in 1920 in which their proposal for the Jewish State in Palestine included the entire Jordan River Basin to be located within the political boundary of Palestine.

Soon after its establishment, Israel initiated a 7-year project in 1953 aimed at diverting the water of the Jordan River at the Banat Yacoub Bridge in the de-militarized zone between Israel and Syria and conveying water into the Israeli coastal cities and finally to the Negev desert through the so called National Water Carrier. Syria objected to the project and so the United States imposed economic sanctions against Israel which resulted in a temporary freeze of that project.

In the 1950's, several plans were suggested to allocate the water of the Jordan River between different riparian countries. The most important among the different plans was the Johnston Plan suggested by the United States in 1953 which sought to satisfy the minimum requirements of riparian Arab states as well as Israel. That plan, named after the American engineer Eric Johnston who implemented the water plan prepared by Charles Main under the direct supervision of the Tennessee Valley Authority, was a combination of the previously suggested plans. The new plan included water distribution quotas for the Jordan Valley Basin, estimated at 1,213 MCM annually, among the riparian states (Palestinian Encyclopedia Committee, 1984). The plan was not well received by either Israel or the Arab States. Consequently, Arab riparian countries proposed the Arab Technical Committee plan alternative while Israel proposed the Cotton Plan alternative for dividing their water shares. Table 2-2 shows a summary of the various proposed plans for dividing the water of the Jordan River Basin.

Table 2-2: The Development Of The Johnston Plan, 1953-1955

State	Johnston (1953)	Arab Technical (1954)	Cotton (1954)	Revised Johnston (1955)
	MCM/Yr	*MCM/Yr*	*MCM/Yr*	*MCM/Yr*
Jordan/Palestine	774	861	575	720
Syria	45	132	30	123
Lebanon	-	35	451	35
Sub-total	819	1028	1056	887
Israel	394	200	1290	450
Total	1213	1228	2346	1337

In 1955, the Johnston Plan was revised which raised the quota of Israel to 450 MCM/Yr and decreased the Jordan's quota to 720 MCM/Yr. This was more acceptable to Israel but was rejected by the Arab countries. Finally, none of the above mentioned plans was accepted by the different riparian countries and each country proceeded independently.

In 1958, Israel re-initiated the National Water Carrier project after shifting the diversion point to a new location at the northwest corner of Lake Tiberias and replaced the Seven-Year plan with a Ten-Year plan. Figure 2-2 shows the current situation of the Israeli National Water Carrier and the related infrastructure. The new Israeli diversion project was carefully designed in accordance with Israel's water allocation according to the Revised Johnston Plan. The Arab reaction to Israel's National Water Carrier was to build dams on tributaries of the Jordan and Yarmouk Rivers draining into Lake Tiberias to reduce the water flow to Israel by 35 percent.

In 1965, Syria began building dams to divert water from the Banias and Dan tributaries of the Jordan River in the Golan Heights. Israel, as a riparian state of the Jordan Basin, considered that an aggressive action in regard to its water resources and sent fighter planes that destroyed the Syrian engineering work sites.

Based on the Johnston Plan, the Palestinian water rights in the Jordan River were included in the Jordan’s allocation due to the Jordanian administration of the West Bank. In 1966, Jordan was able to construct the East Ghore Canal (currently known as King Abdallah Canal) to use their quota from the basin proposed by Johnston’s Plan and plans were being prepared to construct the Western Ghore Canal to provide the West Bank with 150 MCM/Yr from the Jordan River.

After the establishment of Israel in 1948, it launched intensive research & hydrological studies which indicated the hydrological importance of the West Bank. The outcome of the hydrological research indicated that the West Bank represents a source for natural replenishment of three major renewable Palestinian aquifer basins

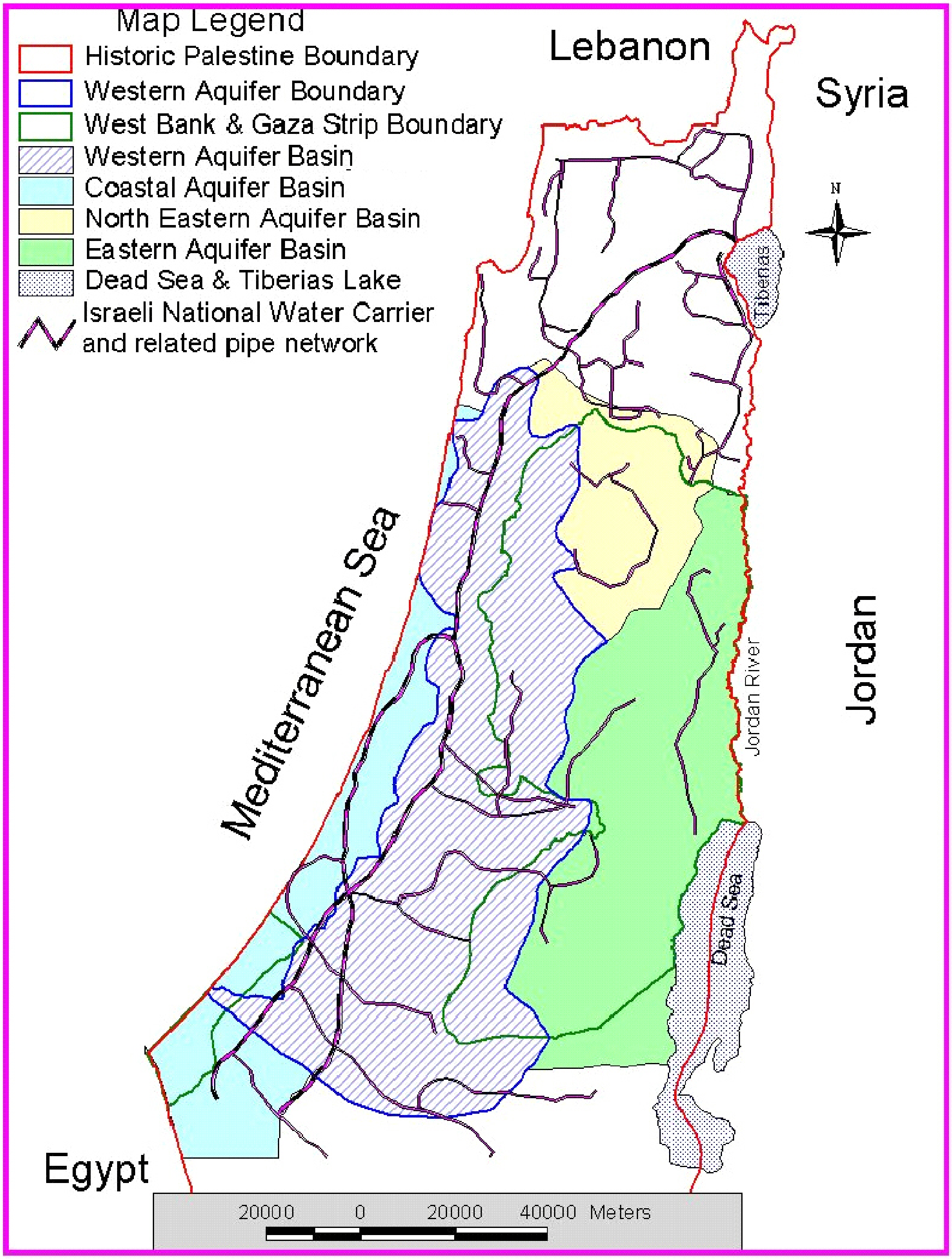


Figure 2-2: The Israeli National Water Carrier And Related Network Infrastructure (Modified From ARIJ (2000))

that can produce around 600-700 MCM/Yr of groundwater (Eastern, Western and Northeastern Basin Aquifers). Due to these hydrological findings, Israel initiated intensive drilling projects to extract groundwater in locations very close to the 1967 border between the West Bank and Israel.

In order to develop the irrigated agricultural sector in the West Bank, the Jordanian administration granted the Palestinian private sector a great number of licenses to drill new groundwater wells in the West Bank. Most of these wells are shallow (100-150 meters deep) and mainly used for agricultural purposes. Due to the absence of enough public wells used for drinking purposes, most Palestinian communities, who have no access to such public wells, obtained their water for household purposes from these private agricultural wells. Due to the economic hardship of the Palestinian private owners of these agricultural wells and the limited technology available in Jordan at that time for drilling deep wells, most wells were shallow (100-150 meters deep). This resulted in over-exploiting of the West Bank shallow and surficial aquifers, while the deeper aquifers were kept safe.

2.3 Water Politics and Conflict During the Period 1967-1993

After the Six Day War in 1967, Israel occupied the West Bank, the Gaza Strip and the Golan Heights, vastly expanding its control over surface water of the Jordan River Basin and groundwater resources in the whole area, including the West Bank.

Soon after the Israeli occupation of the West Bank (including East Jerusalem) and Gaza Strip, Israel imposed a number of military orders by which it could comprehensively control Palestinian water sources, water installations, drilling of wells, prices, and quantities allowable for use by Palestinian inhabitants and farmers in the West Bank. Israel imposed strict rules on the exploitation of water and at the same time retained the traditional ownership system. On August 15th, 1967, the Israeli military commander issued Order No. 92, in which water was considered as a strategic resource. This order was followed by numerous other orders aimed at making basic changes in the water laws and regulations in force in the West Bank. Under Military Order No. 158 of 1967, it is not permissible for any person to set up, assemble, possess, or operate a water installation unless a license has been obtained from the area commander. This order applies to all wells and irrigation installations. The area commander can refuse to grant any license without giving a reason. These orders were followed by numerous military orders to achieve complete control over the Palestinian water resources.

Beginning in 1967, Israel started establishing new Israeli settlements and constructing deep groundwater wells in the West Bank to serve the settlements with water. As of 2002, the total number of settlement wells was 38, most of which are tapping the deep unexploited aquifers several hundreds of meters deep with a total production of 65 MCM/Yr (PWA, 2003). From 1967 through 1994, Israeli authorities prevented the Palestinians from drilling any wells for agricultural and industrial purposes, while they gave permission to drill only five wells for municipal and drinking purposes. They put an upper limit of 36 MCM/yr for the Palestinians to use for agricultural purposes. The Palestinians had to develop their own water management structures such as the low-scale water harvesting cisterns and agricultural ponds from the limited winter storm flood waters (Isaac and Sabbah, 1998).

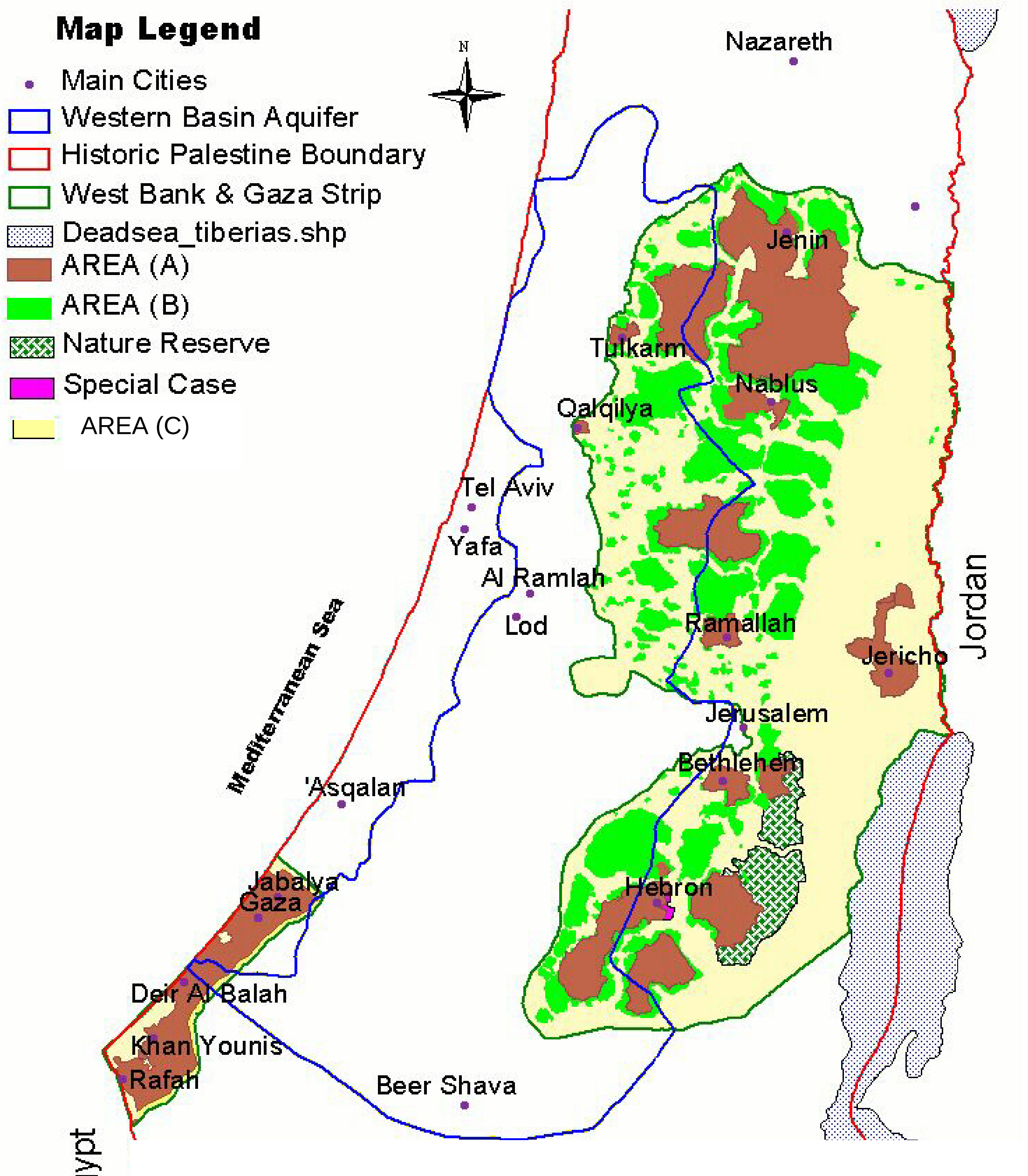
2.4 Water Politics (October 1993-September 2000)

On October 30, 1991, the Madrid Peace Conference was held between Israel and the Arab countries (including Palestinians of the West Bank and Gaza Strip) under the sponsorship of the former Soviet Union and the United States of America in an attempt to resolve the Arab-Israeli conflict. The basis for establishing peace was the United Nations Security Council Resolutions No. 242 and No. 338. The main Arab countries that participated in the conference were Palestine (under the umbrella of Jordan), Jordan, Syria, Lebanon and Egypt. That conference launched both bilateral and multilateral negotiations among the participating parties.

The Declaration of Principles (DOP) signed on September 13, 1993 in Washington D.C between the Palestinian Liberation Organization (P.L.O.) and Israel was implemented by another agreement known as the OSLO I Agreement signed on May 4th, 1994. That agreement carries different names such as the Gaza-Jericho First Agreement and the Cairo Agreement. The agreement resulted in the formation of the Palestinian National Authority (PNA) for the first time in recent Palestinian history to govern Jericho City and 70% of Gaza Strip as a transitional phase that would lead to further control of other areas of the West Bank and Gaza Strip. That was an interim agreement for five years (May 4th, 1994 -- May 4th, 1999) until both sides agreed on the final status of the West Bank (including East Jerusalem) and Gaza Strip. The negotiations for the final status of the West Bank and Gaza Strip were supposed to start by the beginning of the third year of this interim agreement (May 4th, 1996). The DOP and OSLO I agreements identified excepted five issues from the bilateral tract of negotiations and discussed later on in the final status negotiations. They are water resources, Israeli settlements, political borders, Jerusalem, and Palestinian refugees.

OSLO II Agreement was signed between Israel and the PNA in Washington D. C. on September 28th, 1995. This agreement dealt mainly with further re-deployment of Israeli authorities from more Palestinian areas and transferring of responsibilities in these areas to the PNA. That agreement classified the West Bank into areas A, B, and C based on the responsibility and control; Area A to be controlled by PNA, Area B to be mutually controlled by PNA (to be responsible for Palestinian civil affairs) and Israel (to be responsible for security issues), while controlling area C is the full responsibility of Israel. Several agreements and memoranda were signed between Israel and the PNA since 1995 for implementing the OSLO II agreement of further Israeli re-deployments from Palestinian lands. The last re-deployment agreement was Sharm Esh Sheikh (Phase III) signed on March 2000. As of September 2000 and after the implementation of all signed re-deployment agreements, Area A constituted 18.2% of the West Bank and 70% of Gaza Strip, Area B constituted 21.8% of the West Bank and no area in Gaza Strip, While area C constituted 60% of the West Bank and 30% of Gaza Strip. Figure 2-3 shows the development of OSLO map and the various A, B, and C areas (as of May 2000 after implementing the various Palestinian-Israeli agreements and memoranda).

Within the context of the OSLO II interim agreement (OSLO II Accord, 1995), water and sewage related issues were identified through Article 40 which permitted the Palestinians to establish the Palestinian Water Authority (PWA).



Area ID	West Bank Areas		Gaza Strip Areas	
	(km²)	*(%)*	*(km²)*	*(%)*
Area A	**1234**	**21.2**	**255**	**70**
Area B	**1094**	**18.8**	***DNE**	**DNE**
Area C	**3492**	**60**	**110**	**30**
Total Area	**5820**	**100**	**365**	**100**

*DNE: Area B does not exist

Figure 2-3: The OSLO Map Of The West Bank And Gaza Strip (As Of May 2000)
(Modified From The ARIJ (2000))

The responsibility of PWA is to deal with all water and sewage related issues in the West Bank and Gaza Strip. The Joint Water Committee (JWC) was also established within the context of Article 40 which consists of members from both Israeli and Palestinian sides to discuss all water related issues in the West Bank and Gaza Strip and ensuring that the PWA continues to implement the interim agreement. The problem in Article 40 of OSLO II Agreement is that the Palestinians are given the right to use limited water quantities only after approval from the Israeli side and the Palestinians have no any sovereignty over their national water resources. In addition, the water use must be coordinated with Israel through the JWC. Within that agreement, both sides agreed that the immediate and critical Palestinian water need during the interim period (May 1994-May 1999) are 28.8 million cubic meters per year (MCM/Yr) for drinking purposes and another 50 MCM/Yr for other water use purposes. All the above mentioned water needs during the interim period (78.8 MCM/Yr) are to be taken from the Eastern Aquifer Basin and other sources to be agreed upon within the JWC. Article 40 specified that the 28.8 MCM/Yr for drinking purposes was to be obtained by constructing new wells. However, licensing of any new wells should be submitted to the Israelis through the JWC to be approved by Israeli officials which normally takes a very long time, and is often refused.

The other problem in Article 40 is that there is no evidence that the Eastern Aquifer Basin can provide such large quantities of water with good quality. The JWC has nominated members of both sides (Israel and PNA) to deal with routine field measurements for groundwater wells in the West Bank during the interim period. Article 40 stated the necessity of transferring all the hydrological data on the

Palestinian water resources in the West Bank and Gaza Strip during the period (1967-1994) to the PWA. Israel gave the PWA large amounts of hand written historical data including water level measurements in wells, well pumping, discharge of springs and partial analysis of water quality data. The PWA started and is still continuing to establish and archive that data in the form of a Comprehensive National Hydrological Database. Unfortunately, the transferred data didn't include borehole data such as well logs, well construction details, and hydraulic properties.

2.5 The Current Political Status (September 2000 – Current)

Two months after the failure of the two week tri-lateral American-Israeli-Palestinian Peace Rally held in Camp David in July 2000 to reach a final, just, and permanent peace agreement between the PNA and Israel, a large-scale "Palestinian Uprising" started in the West Bank and Gaza Strip against the Israeli occupation in September 2000. The Israeli government responded to that popular Palestinian uprising militarily by re-occupying the previously mentioned OSLO II areas A and B (Figure 2.3) of the West Bank and a great part of Gaza Strip.

The water and sewage facilities were severely damaged by this current conflict. The Israeli occupation army has demolished many groundwater wells as well as water and sewage networks. Monitoring has been stopped for all wells, reservoirs, and networks due to the military closures by Israelis.

In March 2002, the United Nations Security Council met to find a solution in order to stop the mounting violence and to obtain a ceasefire between Israel and the Palestinian Authority. The Security Council adopted resolution #1397 which called for the establishment of a Palestinian state that can live side by side with the State of Israel within secure and recognized borders.

In March 2002, The Arab League summit proposed a peace initiative which called for full Israeli withdrawal from all the territories occupied since June 4, 1967 including the West Bank, Gaza Strip, Syrian Golan Heights, as well as the remaining occupied Lebanese territories in the south of Lebanon. It also called for the end of violence between Israel and the Palestinian Authority by establishment of a Palestinian independent state on the West Bank (including East Jerusalem) and Gaza Strip based on the borders of June 4, 1967. That Arab initiative also addressed the acceptance of Israel as a neighbor which can live peacefully with all Arab Countries in the region after reaching a comprehensive peace treaty between the Arab Countries and Israel.

In June 2002, the President of the United States gave a speech which dealt with the USA vision towards resolving the ongoing Israeli-Palestinian conflict by establishing an Independent Democratic Palestinian State side by side with Israel that will be able to survive. In July 2002, that USA vision for peace was welcomed and accepted by Russia, the European Union, and the United Nations who formed with the USA a group called "The Quartet" which began to shape an international policy toward the resolution of the Israeli-Palestinian conflict. In September 2002, the Quartet issued a draft proposal of the so called "Road Map" based on the principles of peace mentioned in the USA vision of peace. The main goal of that road map is to end the Israeli-Palestinian conflict and the 1967 Israeli occupation of the West Bank and Gaza Strip based on the outcomes of the "Madrid Peace Conference", the principles of "Land for Peace", the United Nations Resolutions #242 (1967), 338 (1973) and 1397 (2002), the previous signed agreements between the PNA and Israel, and the peace initiative proposed by the Arab League summit conference held in Beirut in March 2002. The road map was subjected to several revisions after taking the comments of the PNA, Israel, Jordan, Egypt, Saudi Arabia, and other countries supporting the peace process in order to be applicable by the main intended parties.

As of November 2002, Israel completed the first phase of the so called "Separation Wall" which was justified by the Israeli government under the claim that this will provide a buffer zone to prevent the Palestinian militia from entering Israel. Figure 2-4 shows the map for the completed phase of that wall in the northwestern part of the West Bank. The area of this preventive wall buffer zone is about 86.5 km^2 and it is completely located within the study area. Twenty nine groundwater wells, that produce 4.5 MCM/Yr, are entirely located within that zone. The wells were effectively confiscated, meaning their Palestinian owners have no more access to their land and water there. The figure also shows how intensive the groundwater wells are on the western, within the wall, and on the eastern sides of the wall which indicates the hydrological importance of the aquifers there.

On April 30, 2003, the official text of the latest version of the road map which was developed and approved by the Quartet was announced and published by the US Department of State with the date of May 1, 2003. The main goal of the new version of the road map is to achieve a final and comprehensive settlement of the Israeli-Palestinian conflict by 2005. This road map established a more realistic timeline for implementation; it involves the following phases:

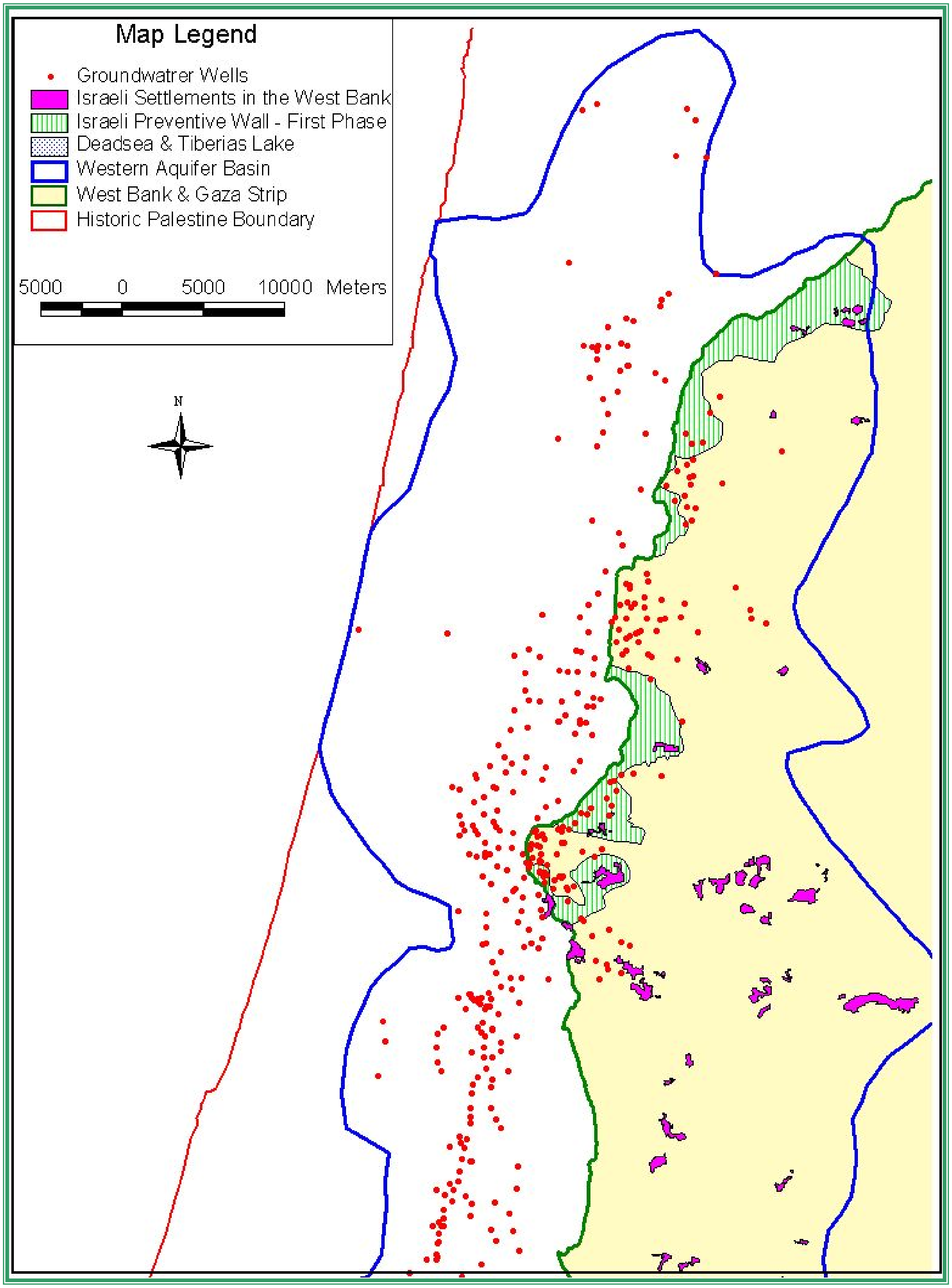


Figure 2-4: The Completed Map Of The First Phase Of The Separation Wall In The Northwestern Part Of The West Bank (Modified From PASSIA Website, 2003)

Phase I (till the end of May 2003) which calls for unconditional cessation of violence, normalizing the Palestinian life, re-building the Palestinian institutions, and the resumption of the Israeli-Palestinian security cooperation to restore the bridges of confidence between both sides. The main goal is to restore the political status that existed before September 28, 2000 by the withdrawal of Israel from the Palestinian main cities re-occupied after March 2002.

Phase II (June 2003-December 2003) which calls for establishing an independent Palestinian State with temporary borders and attributes of sovereignty.

Phase III (2004-2005) which calls for a permanent status agreement to end the Israeli-Palestinian conflict by the end of the year 2005, based on all UN Security Council resolutions and previous agreements related to that conflict.

The permanent status peace agreement should include the issues of the borders, Jerusalem, Israeli colonies, the refugees, and the water resources. These five issues were classified as the final status issues of OSLO interim agreements.

Based on the above mentioned requirements for achieving permanent peace, water resources play a very important role in any future solution of the Israeli-Palestinian conflict. For example, water is the key issue when discussing the problem of Palestinian refugees.

Continuous updating for this study is needed in order to be consistent with the elements of the permanent status when the peace agreement is finally reached.

CHAPTER THREE

HYDROLOGY AND WATER BALANCE EVALUATION

The water resources of the West Bank come mainly from natural rainfall. The hydrologic cycle of the West Bank shows that natural rain falls on the West Bank during winter months (from October to April with most from December to February), with values ranging from less than 100 in the Jordan Valley and the Dead Sea to more than 700 in the northwestern part of the West Bank. Once this rainfall reaches the ground surface, it flows in the form of three major components.

- The first component represents that portion of rainfall which is consumed by soil and the vegetation cover and is then evaporated either directly or through plant tissues (transpiration). This combined water consumption process is referred to as Evapo-transpiration which consumes the greatest portion of natural rainfall.
- The second component represents that portion of rainfall which flows on the ground surface through streams in the form of flood runoff.
- The third component represents that portion of rainfall which percolates deep through the soils and rock strata to recharge the groundwater aquifers.

In addition to the above three measurable components, there are some other minor losses which are hard to measure such as initial abstraction, subsurface flow and depression storage. Rainfall, evapo-transpiration, runoff, and infiltration/groundwater recharge are the major hydrological parameters to be measured and/or estimated when studying the annual water balance. The overall goal of this chapter is to develop an applicable technique for water balance estimation to derive the Water Sustainability Map (WSM) based on the available meteorological, hydrological and physical characters of the drainage basins and the stream flow patterns in the West Bank of Palestine. That was conducted by deriving the watershed boundaries and their drainage system using the digital elevation data to evaluate the various water balance parameters for the various created watersheds of the West Bank during the 10-Year period (1990/91-1999/00).

3.1 Literature Review

The only hydrological and geological studies dealing with surface water and the evaluation of water balance of the West Bank were executed during the Jordanian administration of the West Bank before 1967. Rofe & Raffety (1963-1965) were contracted by the Central Water Authority of Jordan to conduct a two-year hydrological and geological study of the West Bank in which various elements of the surface water budget were identified. In that two-year-study, Rofe & Raffety installed several hydrometric and evaporation stations in the West Bank and they used the meteorological data measured by these newly installed stations recorded during the 1963/64 and 1964/65 hydrologic years. According to their study, the total estimated annual rainfall volume was 2895 MCM/Yr in the year 1963/64 and 2707 MCM/Yr in the year 1964/65. The total runoff was estimated to be 64 MCM/Yr in the year 1963/64 and 60 MCM/Yr in the year 1964/65 or 2.2 % of the rainfall. The potential evaporation was estimated by the Penman method using the data provided by twelve climatic stations over the two-year period (1963/64 and 1964/65). The average estimated potential evaporation was 2000

MCM/Yr (69.1% of rainfall) in the year 1963/64 and 1810 MCM/Yr (66.9% of rainfall) in the year 1964/65. Groundwater recharge was estimated to range from 713.3 MCM/Yr (24.6% of rainfall) into 802.8 MCM/Yr (28.7% of rainfall) in the year 1963/64, while ranging from 725.8 MCM/Yr (26.8% of rainfall) into 810.4 MCM/Yr (30.9% of rainfall) in the year 1964/65. No studies have been done since 1967 to delineate and analyze the various watersheds of the West Bank and/or to update the water balance study.

3.2 Surface Water Resources

Surface water is that water which flows n the form of rivers and streams or the water which is captured by seasonal reservoirs. Surface water flowing in streams may include flood flow water and base flow water. The base flow is the contribution of groundwater in feeding surface drainage basins through springs. Surface runoff depends mainly on the quantity and duration of rainfall during the wet seasons.

3.2.1 The Jordan River

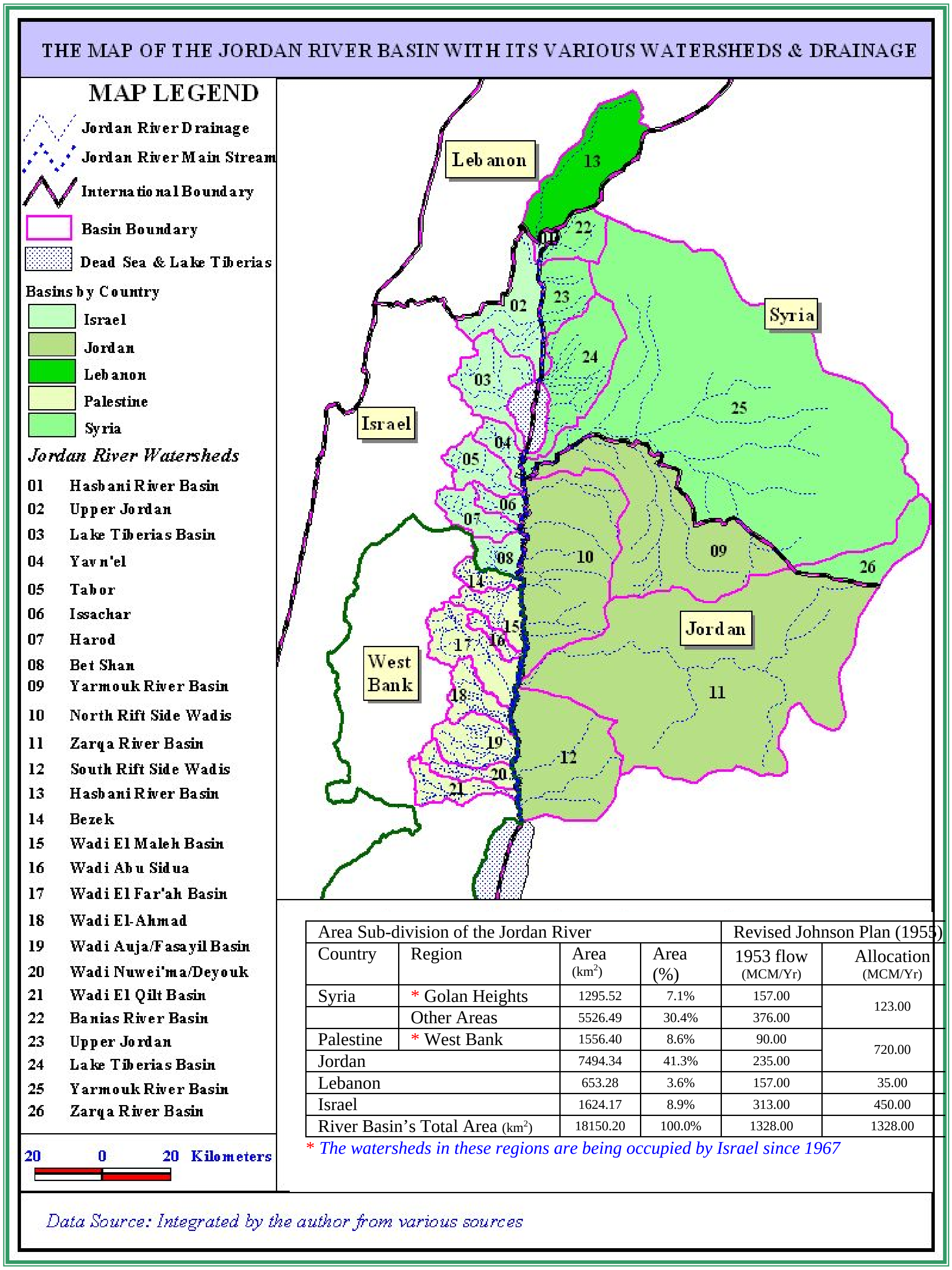
The Jordan River is the only river which can be used as a source of surface water in the West Bank, if a just agreement is reached concerning the allocation of its water among various partners. Compared with international rivers, this source is a very small one that discharges, for example, only 1.5% of the Nile's discharge.

The Jordan River is 360 kilometers long with a surface catchment area of about 18300 km^2 of which 2833 km^2 lie upstream of Lake Tiberias outlet. The eastern catchment area downstream of Lake Tiberias is about 13027 km^2, while the western catchment is about 2344 km^2. The average annual flow of this river is about 1287 MCM

(Johnston Plan, 1955). The Jordan River originates from three main springs: the Hasbani (157 MCM/Yr) in Lebanon, the Dan (258 MCM/Yr) in Israel, and the Banias (157 MCM/Yr) in the Golan Heights, to form the Upper Jordan River basin. The water of this basin flows southward towards the Lake Tiberias. The riparian countries of the Jordan River are Lebanon, Syria, Israel, Palestine, and Jordan. Figure 3-1 shows the map of the Jordan River Basin.

The average annual precipitation in the Upper Jordan and Lake Tiberias is 1600 mm/Yr and 800 mm/Yr, respectively. The Jordan River becomes progressively more saline and the water is less usable towards the Dead Sea.

In the 1950's, all the Jordan River water used to drain into the Dead Sea. The absence of an agreement to divide the Jordan River's water among various riparian countries pushed each country to act unilaterally to get its share. That unilateral action resulted in an unfair water usage of the Jordan River basin by various riparian countries. In the 1950's and before the diversion of the Jordan River by the various riparian countries, the Jordan River was draining 1287 MCM/Yr into the Dead Sea. Recent studies estimate that the average flow in the Upper Jordan River is currently about 1300 MCM/Yr, which is very close to its flow in the 1950's reported by Johnston Plan but of which only 13% (169 MCM/Yr) reaches the Dead Sea. The other 87% is being consumed by the upstream riparian countries as follows: 47% (611 MCM/Yr) by Israel, 22% by Jordan (286 MCM/Yr), 16% by Syria (208 MCM/Yr), and 2% (26 MCM/Yr) by Lebanon (Al-Weshah, 2000). Since 1967, the Palestinians of the West Bank have been denied their access to the Jordan River due to the Israeli declaration that the Palestinian area adjacent to the Jordan River be a closed military area.



Area Sub-division of the Jordan River				Revised Johnson Plan (1955)	
Country	Region	Area (km^2)	Area (%)	1953 flow (MCM/Yr)	Allocation (MCM/Yr)
Syria	* Golan Heights	1295.52	7.1%	157.00	123.00
	Other Areas	5526.49	30.4%	376.00	
Palestine	* West Bank	1556.40	8.6%	90.00	720.00
Jordan		7494.34	41.3%	235.00	
Lebanon		653.28	3.6%	157.00	35.00
Israel		1624.17	8.9%	313.00	450.00
River Basin's Total Area (km^2)		18150.20	100.0%	1328.00	1328.00

** The watersheds in these regions are being occupied by Israel since 1967*

Figure 3-1: The Watersheds And Drainage System Of The Jordan River Basin

3.2.2 The Dead Sea

As described above, the Dead Sea is a closed lake which represents the sink for the whole Jordan River drainage basin. It is a unique surface water body since it is located at the lowest point on earth and it is one of the richest seas with salts in the world; where its salinity is about 345 grams per liter which is 10 times greater than the salinity of the oceans (Abed, 1985). So, the Dead Sea has an economical, historical, and environmental significance as well as possesses a unique ecosystem and cultural heritage (Al-Weshah, 2000).

The Dead Sea can be divided into two basins; the deep wide northern basin and the southern shallow basin which are separated by a peninsula called the Lisan (Abed, 1985). In the late 1950's, the water level of the Dead Sea was 395 meters below mean sea level with a total surface area of about 1000 km^2 (Abed, 1985). The northern basin had an area of 757 km^2 and a maximum water depth of 400 meters, while the southern basin had an area of 240 km^2 with a maximum depth of 10 meters (Abed, 1985). In 1982, the level of the Dead Sea water was 400.5 meters below mean sea level and its total surface area was about 800 km^2 (the northern basin's area is about 740 km^2 and the southern basin's area is about 60 km^2) (Abed, 1985). The Arab Potash Company (APC) reported that the water level of the Dead Sea was 410.9 meters below mean sea level with a total surface area of about 645 km^2 as of February 1998 (APC, 1998). The Dead Sea is a shared surface water body among Palestine, Jordan, and Israel. The Palestinian portion of its surface area is about 190 km^2, but currently, the Palestinians have no access to its water due to the military closure by Israel since 1967 (Isaac & Sabbah, 1998). This means that during 40 years (1958-1998), the surface area of the Dead Sea decreased by 1% per year and its water level decreased by 0.4 meters per year.

This shrinkage of the Dead Sea is due to the diversion of the Jordan River's water and related west and east streams by upstream riparian users as well as due to the industrial activities of the potash mining by Israel on the western shore and by Jordan on the eastern shore of the Dead Sea. The potash mining activities and other historical changes on the Dead Sea have increased the evaporation depth rate which represents a serious risk to its ecosystem (Eco-Peace, 1996).

In order to stop the deterioration of the ecosystem and to restore the water level of the Dead Sea as it was in the 1950s (395 meters below mean sea level), several scenarios were suggested such as the Med-Dead and the Red-Dead canals to convey water from the Mediterranean or the Red Sea to the Dead Sea, respectively. Al-Weshah (2000) submitted a paper about the Dead Sea water balance in which he evaluated the Red Sea-Dead Sea Canal (RSDSC) project to be implemented within the context of the peace treaty between Israel and Jordan in order to provide sustainable freshwater and to halt the decline in the Dead Sea level. In one of his scenarios to connect the water of the Red Sea to the Dead Sea, Al-Weshah assumed a diversion capacity of 70 m^3/s which showed that the Dead Sea will be restored to its 1950's level (395 meters below mean sea level) in about 40 years.

3.2.3 Flood Water Runoff

Surface flood runoff in the West Bank is mostly intermittent and probably only occurs when the rainfall exceeds 50 mm in one day or 70 mm on two consecutive days.

Such surface water runoff has not been measured or estimated since 1967. It is also hard to measure due to the mixing with base flow coming from the springs draining into the main streams of the West Bank. Runoff has not been utilized or controlled on a large scale by Palestinians of the West Bank. Low-scale utilization of such surface water is being practiced in some villages by constructing cisterns to fulfill their municipal needs, especially in villages that have no other water sources. Some farmers use low-scale open ponds for irrigation. Streams flowing from the west towards the Jordan Valley recharge shallow aquifers such as Wadi el Qilt, Auja and Wadi el Far'ah (Assaf, 1993). High priority must be given to the construction of small- and large-scale dams to collect flood water to be used for various purposes. This study will help in evaluating the annual total flood flow runoff in the West Bank.

3.3 Hydro-Meteorological and Climatic Characteristics

The hydro-meteorological and climatic characteristics of the West Bank are strongly dependent on many physical features such as topography, geology, soil structure, etc.

3.3.1 Topography and Physiographic Regions

A 25-meter topographic contour map produced by the Land Survey of Israel was used as an elevation reference for the West Bank. The highest point in the West Bank is 1020 meters above mean sea level to the north of Hebron city, while the lowest elevation is 375 meters below mean sea level at the northeast tip of the Dead Sea. Figure 3-2 shows the sub-division of the West Bank into four physiographic (geomorphologic) regions of hydrologic meaning based on the digital elevation data.

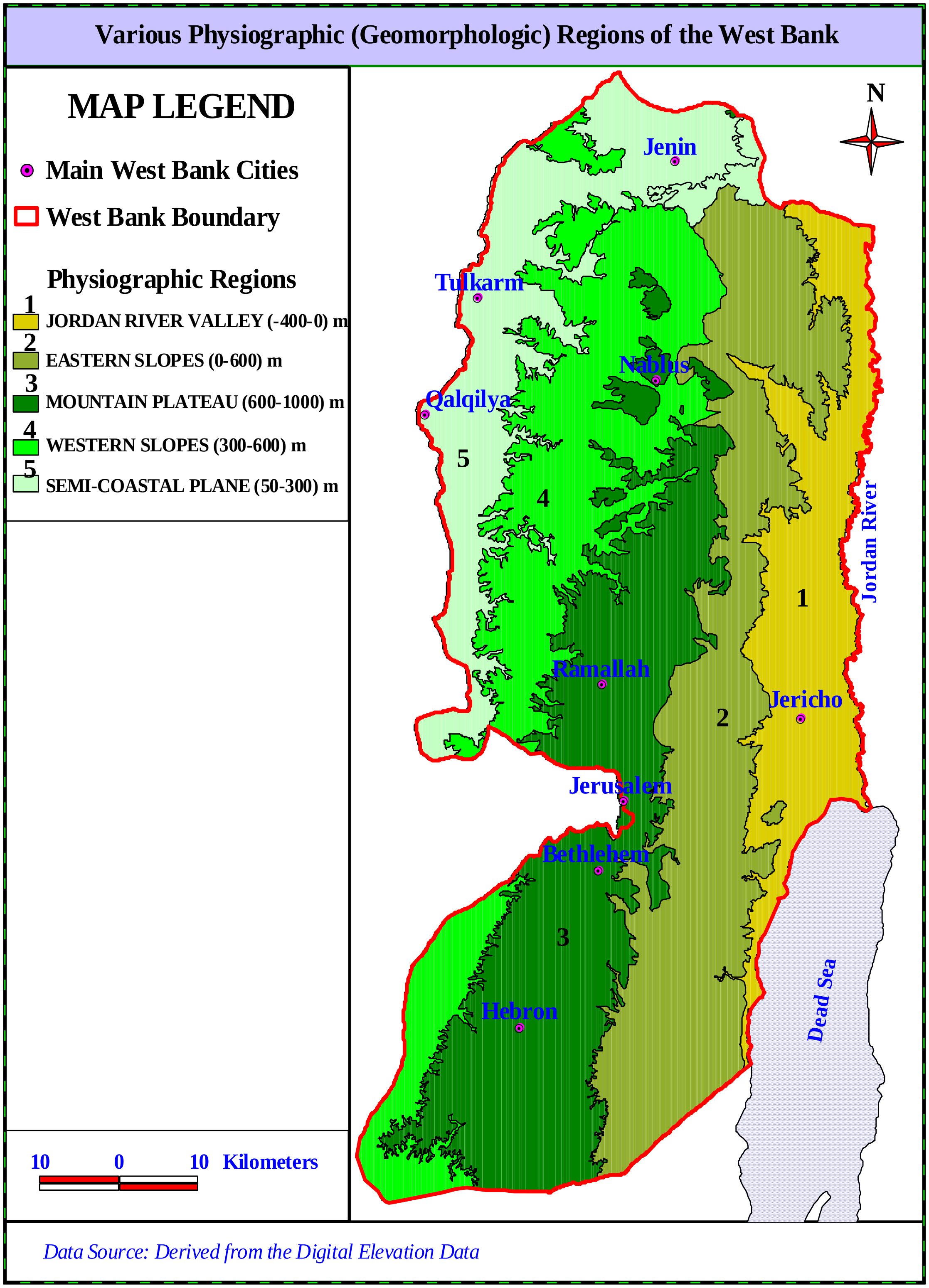


Figure 3-2: The Various Physiographic Regions Of The West Bank

These regions are:

1. The Mountainous Region which includes the mountain belts of Hebron, Jerusalem, and Nablus that represent the zones of natural recharge for various aquifers of the West Bank.

    - Hebron Mountains which have an elevation ranging between 750 to 950 meters above mean sea level with an average elevation of 850 meters above mean sea level and the highest point is at 1020 meters above mean sea level. Despite the high elevation of these mountains, they are devoid vegetation relative to the other mountain areas in the West Bank. This is due to the closeness of the Hebron Mountains to the Negev Desert in the south and the Dead Sea in the east, where arid conditions prevail (Isaac & Sabbah, 1998).
    - Jerusalem Mountains which extend from the south of the Nablus Mountains passing through the Ramallah Mountains into the north of the Hebron Mountains. The regional watershed line passes through the summits of these mountains. The highest point is located at an elevation of 1016 meters above mean sea level (Isaac & Sabbah, 1998).
    - Nablus Mountains which extend from Marj Ben Amer in the north to the north of Jerusalem Mountains in the south. The highest elevation point is 940 meters above mean sea level at Ebal Mountain. The regional water divide separating the western and eastern basins in the West Bank coincides with the summits of these mountains. The eastern slopes of the Nablus Mountains, which extends into the Jordan Valley, are characterized

by steep slopes that contribute to forming major springs such as Badan and Far'ah Springs (Isaac & Sabbah, 1998).

2. The Foothill Region (Western & Eastern Slopes) which is overlain by impervious rocks that represents the confined portion of the aquifer. The Foothill Region is characterized by gentle slopes with an elevation ranging from 100 meters to 500 meters above mean sea level. The western slopes have an elevation ranging from 250 meters into 500 meters above mean sea level, while the eastern slopes range between 100 meters and 250 meters above mean sea level.

3. The Jordan Valley Region where the basin drops down from 100 meters above mean sea level to 349 meters below sea level. The Jordan Valley is located between the Jordan River and the eastern slopes, with elevations ranging between 349 meters below mean sea level and 100 meters above mean sea level. Its widest point in the West Bank reaches 16 kilometers and is located in the northern part of the valley, while it narrows gradually to 7 kilometers in the south. The Jordan River, which is 95 kilometers long in the West Bank and runs from north to south, represents the eastern boundary of the Jordan Valley region and it constitutes the political border between the West Bank and the Hashemite Kingdom of Jordan. There are also several major streams draining both flood flows and base flows into the Jordan Valley such as Wadi En-Nar, Wadi El-Qilt, Wadi El-Auja, Wadi El-Maleh, Wadi El-Far'ah and Wadi El Ahmar (Isaac & Sabbah, 1998).

4. Semi-Coastal Region which represents the major portions of the Tulkarm and Qalqilya districts in the northern parts of the West Bank. The elevation of this region ranges from 40 meters above mean sea level in Qalqilya city to 500 meters near Rummana village to the northwest of Jenin City (ARIJ, 1996).

3.3.2 Climate

The majority of the West Bank area has the climatic characteristics of the Mediterranean zone with winter rain and summer drought. The Lower Jordan Valley has a different transitional climate with dry and extremely desert conditions in the Dead Sea region. Rainfall is limited to the winter and spring months (mostly between November and April), while summer is completely dry. Although uncommon, snow and hail may occur anywhere in the West Bank especially in the highlands and mountainous regions. The mountainous areas in the West Bank which extend from the north to the south serve as a barrier to the passage of moist air coming from the Mediterranean Sea. The marine influence reaches the whole entire areas of the Tulkarm and Jenin districts as well as the western edges of the Nablus, Ramallah, Jerusalem, Bethlehem and Hebron districts. However, it does not go deep into these districts due to the presence of mountains that shield the wind.

To the south of Jerusalem, the marine influence decreases because the Mediterranean shore bends to the southwest which increases the distance between the sea and the West Bank. In the north, there are no hills to block the sea winds, so the marine influence passes easily across the open lands of Marj Ben Amer Plain, the plain between the Jordan Valley and the coast, and reaches all the way to the Jordan Valley. This explains the increased quantity of rain in the northern Jordan Valley despite the fact that most of it is below mean sea level.

The climate of the West Bank, especially in the south, is influenced by the vast nearby deserts of the Negev and Wadi Araba. During spring and early summer, desert storms move through with hot winds full of sand and dust which increase the temperature and decrease the humidity. This type of wind is called in Arabic the *khamaseen.*

3.3.3 Meteorological Stations

Various types of meteorological stations are required to measure the short term weather and climatic parameters. According to the installation and control of these stations, three historical periods are discussed:

- The Jordanian Administration of the West Bank (1948-1967): five agricultural weather stations were installed to record data for agricultural purposes including rainfall, temperature, humidity, wind speed, and sunshine. These stations were located in El Arroub, Maythalun, Beit Qad (currently known as Jenin station), Tulkarm (Al-Hussein Agricultural School), and Al Far'a. Another three meteorological stations were established by the Jordanian Ministry of Transportation; these are the Jerusalem, Hebron and Jericho meteorological stations. These meteorological stations made full observations and had records of rainfall, evaporation, relative humidity, sunshine, wind direction and speed, maximum and minimum temperatures and air pressure. In addition, 100 more traditional rain gauges were installed at schools, mosques, and other places to measure rainfall. Within the Rofe & Raffety study (1963-1965), 12 hydrometric gauge stations were installed to measure the flood flow runoff on their streams.

- ❖ The Israeli Administration (1967-1993): only one additional meteorological station was installed in the city of Nablus. They kept 5 hydrometric stations of the 12 stations installed by Jordan before 1967, while they ignored the remaining ones. They also ignored 30 rain gauges of those traditional stations installed before 1967.

- ❖ The Palestinian Authority Administration (1993-current): All the previous stations and pre-measured data were transferred to the Palestinian Authority. There is much inaccuracy in these data for several reasons such as: lack of experienced technicians to measure and record the meteorological data from their gauge stations and lack of responsible persons to work with the technicians to monitor their accuracy. There are gaps in the data resulting from political instability especially when curfews and strikes were imposed by Israel which prevent the workers from traveling to collect such on-site data. After 1994, four electronic weather stations were installed at Tulkram, Bir Zeit, Ramallah and Bethlehem Cities of the West Bank. These electronic stations are measuring all meteorological parameters every half-hour. The current number and classification of working meteorological stations in the West Bank is: 70 traditional rain gauges, 13 weather stations, and 5 hydrometric stations.

3.3.4 Meteorological Parameters

Fifteen meteorological stations have been used to measure seven meteorological parameters in the study area. Five of these stations are located out of the West Bank boundary. Table 3-1 shows the 10-year minimum, maximum, and average monthly measured meteorological data including maximum and minimum temperature, relative humidity, wind speed, sunshine hours, and solar radiation for 15 meteorological stations (10 stations are located inside the West Bank, while the other 5 stations are outside but close to the West Bank boundary). The table also shows the average monthly estimated reference evaporation. The stations of Nablus, Jerusalem, and Hebron represent the mountainous region, the stations of Jericho and Far'ah represent the Jordan Valley region, while the stations of Tulkarm and Jenin represent the semi-coastal region of the West Bank. The six meteorological parameters are temperature, sunshine and solar radiation, wind speed, relative humidity, Precipitation, and evaporation.

3.3.4.1 Temperature

Temperatures in the West Bank vary according to the geographical position, altitude, and exposure to the marine influences. A rise in summer temperature increases the vapor pressure on the leaf and soil surfaces, but it has much less effect on the vapor pressure of the atmosphere. The hottest month of the year in the West Bank is August where there is a sharp difference in vapor pressure between the leaf and soil surfaces from one side and the atmosphere from the other side, so evaporation increases. Plants and soils are warmer than the atmosphere on bright and clear days which increases the rate of evaporation.

Table 3-1: Extreme Values Of Various Meteorological Parameters In The West Bank.
(10-Year Average; 1990/91-1999/00)

Station	Extreme	Measured Parameters							Calculated
		Max Temp	Min Temp	Humidity	Wind Speed	Sun Shine	Solar Radiation	Rainfall	ET_0
	Values	(°C)	(°C)	(%)	(km/d)	(Hours)	($MJ/m^2/d$)	(mm/month)	
AL ARROUB	Minimum	12.40	4.40	54.50	122.20	6.30	10.70	0.00	47.12
	Maximum	30.30	16.40	78.80	261.60	11.90	27.80	156.20	177.01
	Average/Total	22.38	10.54	67.84	173.05	8.88	19.33	638.89	1335.80
BETHLEHEM	Minimum	13.03	6.16	22.22	142.41	5.05	10.31	0.00	44.64
	Maximum	33.13	21.61	89.89	362.59	12.52	28.85	129.71	270.32
	Average/Total	23.88	14.40	59.59	235.33	8.86	19.53	510.37	1665.03
FAR'AH	Minimum	19.70	9.29	43.43	52.52	5.76	10.49	0.00	50.35
	Maximum	39.79	24.44	73.73	165.64	11.82	27.65	58.20	233.77
	Average/Total	30.49	17.15	58.66	107.57	8.79	19.24	242.25	1553.04
HEBRON	Minimum	10.40	4.04	48.78	195.94	4.75	9.22	0.00	48.05
	Maximum	27.47	17.17	74.94	310.07	11.01	25.36	146.89	177.63
	Average/Total	20.09	11.24	62.32	244.08	7.87	18.13	611.74	1381.69
JENIN	Minimum	17.60	6.90	39.40	131.30	5.40	9.50	0.00	51.77
	Maximum	34.50	21.30	84.80	235.30	11.40	27.10	105.72	212.66
	Average/Total	27.33	13.65	67.84	190.48	8.18	18.30	456.02	1566.55
JERICHO	Minimum	17.39	6.47	48.48	167.76	4.45	8.51	0.00	58.90
	Maximum	36.18	20.62	75.50	382.89	11.42	26.71	40.65	282.10
	Average/Total	27.86	13.72	60.76	287.95	8.17	18.27	166.00	1979.50
JERUSALEM	Minimum	11.51	6.16	45.45	314.11	5.05	10.29	0.00	64.17
	Maximum	28.89	19.19	67.67	493.89	12.52	28.85	135.60	243.97
	Average/Total	21.40	13.27	57.65	419.91	8.86	19.52	571.94	1824.76
NABLUS	Minimum	13.23	6.26	51.51	185.84	4.75	9.13	0.00	51.77
	Maximum	29.69	19.70	67.67	301.99	11.01	25.28	143.53	194.37
	Average/Total	22.56	13.42	61.11	239.54	7.89	18.03	646.44	1504.39
RAMALLAH	Minimum	17.57	1.21	57.57	200.99	5.05	10.24	0.00	62.31
	Maximum	37.88	17.68	77.77	296.94	12.52	28.84	160.18	234.05
	Average/Total	28.01	9.28	71.04	232.13	8.86	19.48	700.29	1736.35
TULKARM	Minimum	13.53	8.69	62.62	63.63	5.25	9.57	0.00	41.23
	Maximum	29.90	22.93	76.76	104.03	10.40	25.72	153.14	154.38
	Average/Total	22.51	15.76	70.36	82.06	7.63	17.67	611.82	1144.10

Source: Integrated from the Palestinian Meteorological Department (2001) and the Meteorological Services of Israel (2001)

The Jordan Valley, which is located to the east of the highlands of the West Bank benefits from the north western winds that moderate the temperature in the rest of the West Bank (Isaac & Sabbah, 1998).

Temperatures below the freezing point are registered nearly every winter in the mountainous regions of the West Bank where -3^{o}C is the minimum value of temperature registered in the Hebron Mountains in January. The minimum temperature in Jericho is -1^{o}C registered in December and January (PWA, 2003). In the Semi-coastal regions, the freezing temperatures are very rare. The 10-year average values of maximum and minimum daily temperatures are shown in Table 3-1 and Appendix A.

3.3.4.2 Sunshine and Solar Radiation

The amount of solar radiation received in the West Bank differs from one place to another. The solar radiation raises the leaf temperatures above that of the surrounding air and hence increases the evapo-transpiration rate. The temperature of leaves in the shade is approximately equal to the air temperature, while the leaf temperatures in the sunlight are 5 ^{o}C to 10 ^{o}C greater than the air temperature. The amount of radiation decreases toward the west due to the cloud cover between the hills and the coastal plain. The Jordan Valley (Jericho) has the highest solar radiation in the West Bank. In the winter months, the cloud cover reduces the solar radiation, thus reducing the potential evaporation rate (Isaac and Sabbah, 1998). The 10-year average values of daily sunshine hours and solar radiation are shown in Table 3-1 and Appendix A.

3.3.4.3 Wind Speed

The prevailing winds in the West Bank travel from the southwest to the northeast. In summer, the high pressure over the Mediterranean and the low continental pressure to the east create a strong pressure gradient across the West Bank. This difference in pressures causes a cooler wind movement from the Mediterranean into the West Bank. The reduction of the pressure gradient at night causes diurnal fluctuations in the wind speed because the winds blow from the land to the sea at night and reverse their direction during the day. In winter, there are depressions moving from the Eurasian area of high pressure, centered in Russia, and from the North Atlantic high pressure area, centered in

North Africa, passing through the Mediterranean low pressure area into the West Bank. The incoming storms bring winds saturated with moisture from the southwest and west as a result of their passage over the Mediterranean Sea. Dry sand-filled wind usually blows over the West Bank between April and June as a result of low barometric pressure over the deserts of Libya and/or Egypt. This type of wind is called the *khamaseen* which is characterized by low humidity, high temperature, and hazy atmosphere with dust coming from the desert region. Such dry winds tend to increase the evapo-transpiration (Isaac and Sabbah, 1998). The 10-year average daily wind speed is shown in Table 3-1 and Appendix A.

3.3.4.4 Relative Humidity

The 10-year average daily relative humidity is about 61% in Jericho (Jordan Valley), while it is 61%, 57%, and 62% in the mountainous regions of Nablus, Jerusalem, and Hebron, respectively. In the semi-coastal area of Tulkarm, the 10-year average daily relative humidity is 70.3% which is the highest among the other districts of the West Bank due to the humid sea breezes coming from the Mediterranean and passing there. On *khamaseen* days, the relative humidity may drop below 30% where the lowest value occurs in May. The low humidity can enhance evapo-transpiration due to the differences in the vapor pressure between the leaves of plants and the atmosphere (Isaac and Sabbah, 1998). The detailed 10-year average values of daily relative humidity are shown in Table 3-1 and Appendix A.

3.3.4.5 Precipitation

The precipitation in the West Bank changes abruptly with the autumn shift from the arid summer to the storms of winter. In the winter, depressions passing from the west to the east over the Mediterranean bring westerly rain-bearing winds. The mountains of the West Bank force the moist air upwards which leads to higher values of rainfall over the hilly regions. The eastern and south-eastern slopes of the southern part of the West Bank Mountains receive lower quantities of rainfall due to the rain shadow where the air flows warm downhill and so rainfall ceases. The absence of mountains in the northern part of the Jordan Valley allows the Mediterranean winds to flow across the Marj Ben Amer Plain and then into the Jordan Valley where rain is deposited. Despite its low altitude, this part of the Jordan Valley receives more rainfall than other parts (Isaac and Sabbah, 1998).

The Precipitation decreases from the north to south since the northern part of the West Bank is closer to the usual track of storms coming from the northwest. The annual average rainfall increased from less than 100 mm/Yr near the Dead Sea to 700 mm/Yr in the northwestern parts of the West Bank. The long term annual average rainfall decreases from 210 mm/Yr in the Northern Jordan Valley to 144 mm/Yr in Jericho (southern Jordan Valley) and finally drops to 100 mm/Yr on the Dead Sea shore. Although the monthly and annual rainfall data are available for longer period (30-40 years) in the West Bank, the 10-year average monthly rainfall is used in this study because the other hydro-meteorological data are only available for the 10-Year period (1990/91-1999/00).

Figure 3-3 shows a comparison between the long term average annual rainfall for the period 1967/68 to 1999/00 and the 10-Year average annual rainfall for the period 1990/91 to 1999/00.

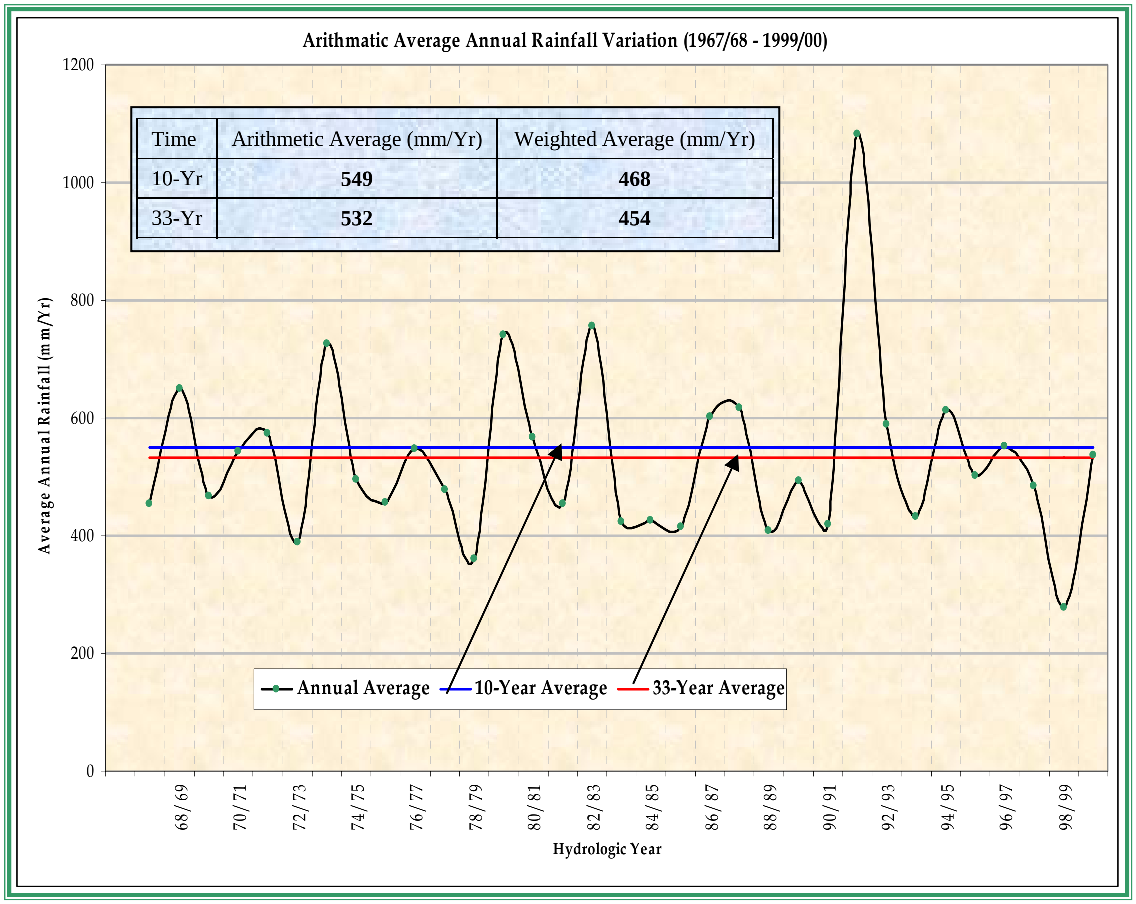


Figure 3-3: A Comparison Between The 10-Year Average And The 33-Year Average Annual Rainfall Variation For The West Bank

As shown in this Figure and the accompanied Tables, the following notes can be observed:

- ❖ The curve of rainfall variation is based on arithmetic annual rainfall average for the 61 stations used in this study.

- 10-Yr average annual rainfall is a little bit less than the 33-Yr average due to the exceptional high rainfall in the year 91/92.
- The Arithmetic Average for 10-Year Rainfall was 549 mm/Yr, while it was 532 mm/Yr for the 33-Yr Rainfall.
- The Weighted Average Based on Isohyetal Areas for the 10-Year Rainfall was 468 mm/Yr, while it was 454 mm/Yr for the 33-Yr Rainfall. This shows that the 33-Year average rainfall constitutes about 97% of the 33-Year average rainfall.
- The estimated water balance volumes for both the 10-Yr and 33-Yr were based on the weighted averages based on the isohyetal areas.

Based on Table 3-1 and Appendix A, Figures 3-4 and 3-5 were created to show the variation of the 10-year average monthly rainfall and the variation of the annual rainfall for the meteorological stations of the main cities of the West Bank, respectively.

As shown in Figure 3-5, the 10-year (1990/91–1999/00) annual weighted average of rainfall in various areas of the West Bank is 486 mm/Yr. All stations except Jericho and Far'ah recorded rainfall values greater than 800 mm/Yr in 1991/92 (wet year) which is about double the amount of the average rainfall.

The rainy season in the West Bank starts in October and continues to the end of May with some frequent exceptions. Almost 70% of the annual rainfall occurs between November and February with December and January as the rainiest months in the west and January and February are the rainiest months in the east part of the West Bank.

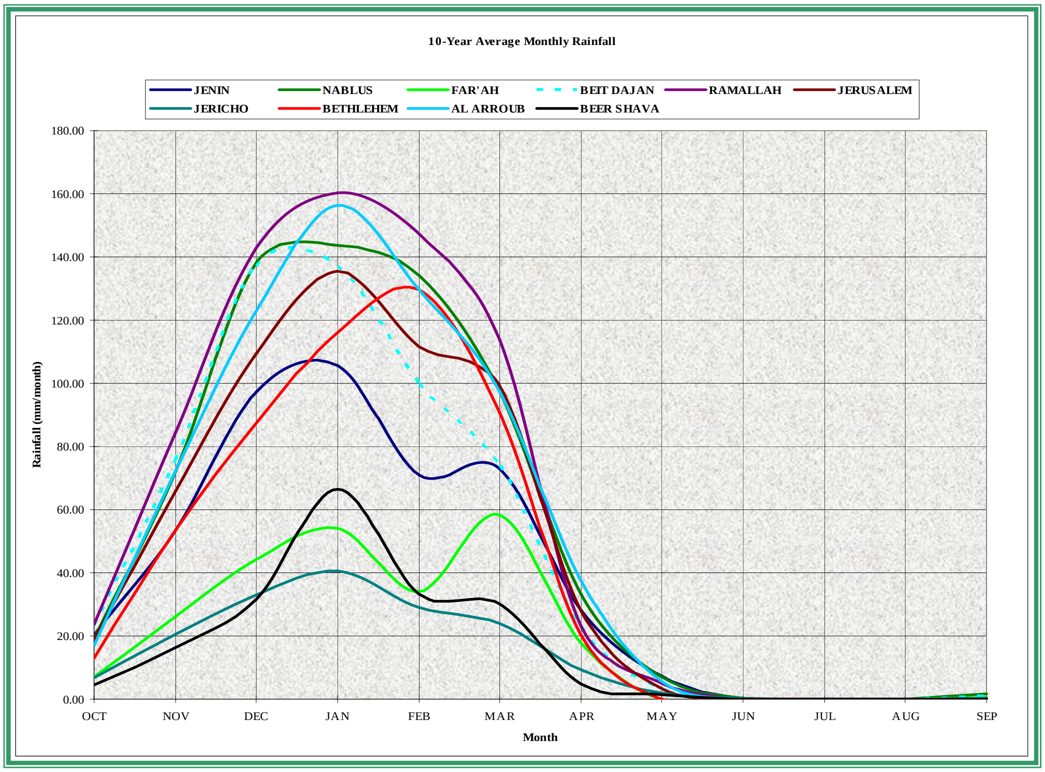


Figure 3-4: The 10-Year Average Monthly Rainfall For The Main West Bank Cities

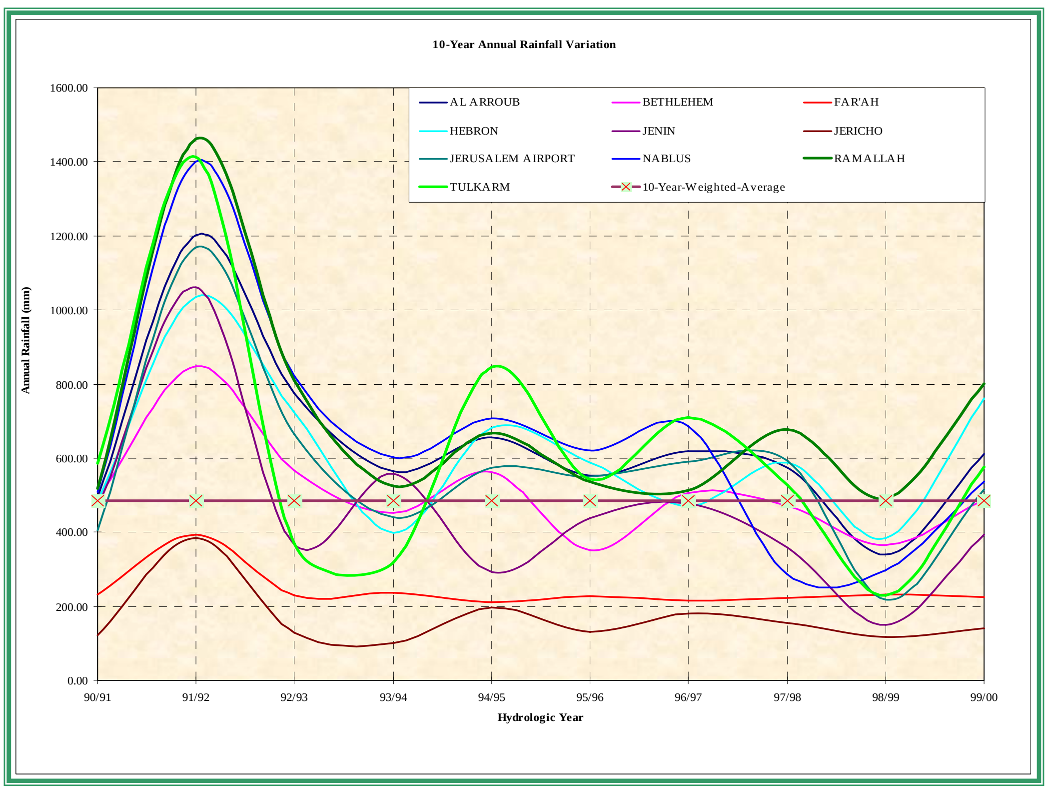


Figure 3-5: The 10-Year Variation Of Annual Rainfall In The Main West Bank Cities

The Precipitation usually deceases in March and April, while it is very rare in May and September. No rainfall occurs in June, July, and August (Figure 3-3). The least monthly rain occurred in Jericho in October with the maximum values didn't exceed 40 mm.

Snowfall is normally limited to the higher parts of the West Bank Mountains. For Example, Jerusalem has an average of two days of snowfall per year which usually falls in January or February. No data are available on the amount of dew that forms in the West Bank. The dew is more prevalent in the semi-coastal region which provides a limited amount of moisture even during the dry summer.

3.3.4.6 Evaporation

Evaporation in the West Bank is high, especially in summer, as a result of high temperatures, intensive solar radiation, and low humidity. Evaporation measurements are not available in the West Bank. The reference evapo-transpiration was estimated in this study using the Modified Penman-Montieth method based on the previous available meteorological measurements.

The 10-year average annual estimated reference evapo-transpiration (ET_0) rates are 1504.39 mm, 1824.76 mm, and 1381.69 mm in the mountainous regions of Nablus, Jerusalem, and Hebron, respectively, while it is about 1979.50 mm in Jericho. The 10-year average monthly evaporation is shown in Table 3-1 and Appendix A. Figure 3-6 shows the variation of the average monthly estimated reference evapo-transpiration (ET_0) for the main cities of the West Bank.

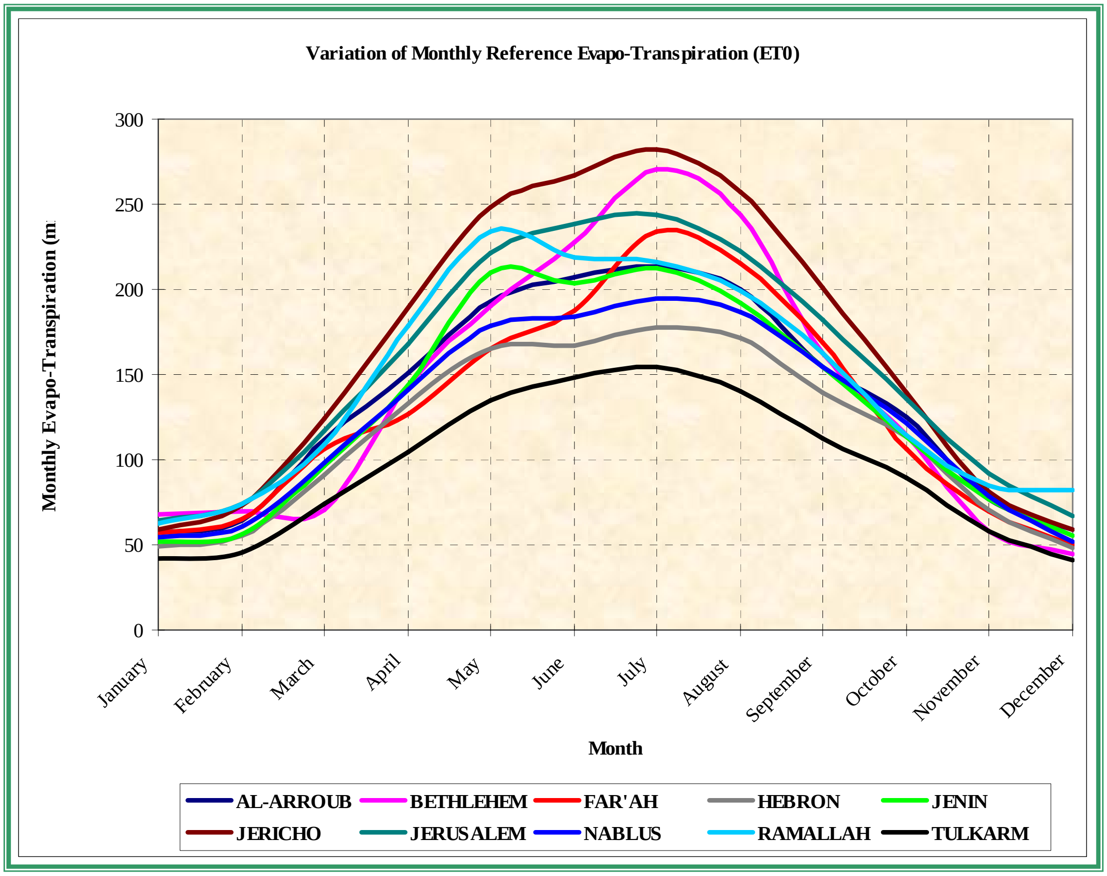


Figure 3-6: Variation Of The Average Monthly Reference Evapo-Transpiration For The Main Cities Of The West Bank.

As shown in Figure 3-6, the evapo-transpiration is concentrated in the months of May through August with the maximum occurred in July. The highest evapo-transpiration was recorded at Jericho station, while the lowest value was recorded at Tulkarm station.

The high values of evaporation in the June-August period are attributed to the high temperature, the low relative humidity, the high solar radiation, and the absence of precipitation in these months.

3.4 Water Balance Evaluation

Based on the available data and GIS Software, spatial modeling was used to evaluate the various elements of the water balance using the following general mass balance equation in terms of spatial GIS-based grid coverage:

$$P - ET_c - R - I = 0 \quad \textbf{(3-1)}$$

Where, P Precipitation/Rainfall Coverage

ET_c Evapo-Transpiration Coverage

R Runoff Coverage (Rainfall Excess)

I Infiltration/Recharge Coverage

This spatial modeling approach is based on interpolating the data of each hydro-meteorological parameter of equation 3-1 into grid coverages and solving for the missing grid coverage which is recharge coverage in this case. The recharge coverage is assumed to be the same as the infiltration coverage since the rainwater directly percolates into the aquifers through their outcrops. In order to conduct the water balance study using this approach, spatial boundaries and various hydro-meteorological data are required. Figure 3-7 shows the flowchart of the spatial modeling approach used for this water balance evaluation.

This spatial approach is very good for getting the accurate results for the rainfall, evapo-transpiration, and runoff. But the recharge could most probably be over-estimated due to the fact the general mass balance equation 3-1 ignored some other minor losses such as the water responsible for moisturizing the soil before the water finally percolates deeper to recharge the groundwater. Thus, if more data on the other minor losses becomes available, this modeling approach could be used to update the estimated groundwater recharge and so the Water Sustainability Map could be more accurate and reliable. This approach is valid for any future application which could be done by just changing the input data fed into the model as shown in Figure 3-7.

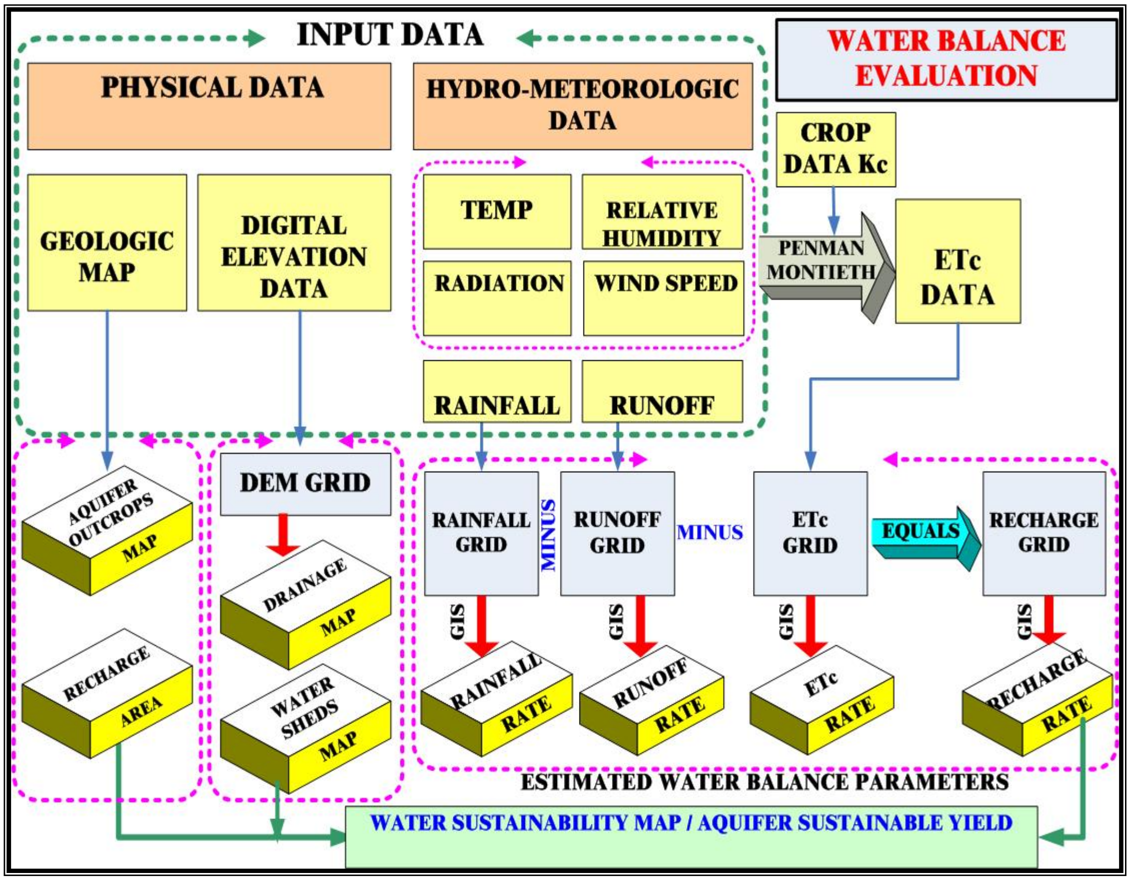


Figure 3-7: The Flowchart Of The Spatial Modeling Approach Used For Estimating The Water Balance And For Creating The Water Sustainability MapOf The West Bank

3.4.1 Spatial Model Boundaries

Since the watersheds are very large and their drainage systems are very coarse, as available in the literature, there is a need to create more detailed drainage systems and sub-watersheds to accurately evaluate the water balance parameters in the West Bank.

In order to identify the spatial model boundaries, several 25-meter interval topographic contour maps of the West Bank were scanned and geo-referenced, and their topographic contours digitized using MapInfo Professional Software. The digitized contour lines were then converted into data file (xyz text points) which were in turn used to create the Triangular Irregular Network (TIN) and the 100-meter resolution Digital Elevation Model (DEM) using the Watershed Modeling System (WMS).

3.4.1.1 Delineation of Drainage System from the DEM

The WMS was used to delineate the detailed drainage system from the created DEM using a threshold value of 0.5 squared kilometers. The created drainage was then converted into feature coverage and exported into ArcView GIS shape file. Figure 3-8 shows the subdivision of the known drainage and watersheds with the created drainage and sub-watersheds and their stream outlets.

3.4.1.2 Derivation of Watersheds and Sub-watersheds from the DEM

The created DEM was used to derive the boundaries and the geometry of all watersheds and sub-watersheds of the West Bank. Fourteen known watersheds were digitized from the maps of the Hydrological Services of Israel (1994) and Rofe & Raffety (1963-1965) which were then used as a base to derive 72 sub-watersheds. Only 58 (4674.8 km^2 which represents 83% of the total area of the West Bank) out of the 72 created watersheds have their stream outlets inside the West Bank, while the other 14 watersheds (957.5 km^2 which represents 17% of the total area of the West Bank) are draining their surface water out of the West Bank boundary (within Israel) This means that the stream flow can only be measured for the 83% of the West Bank's area.

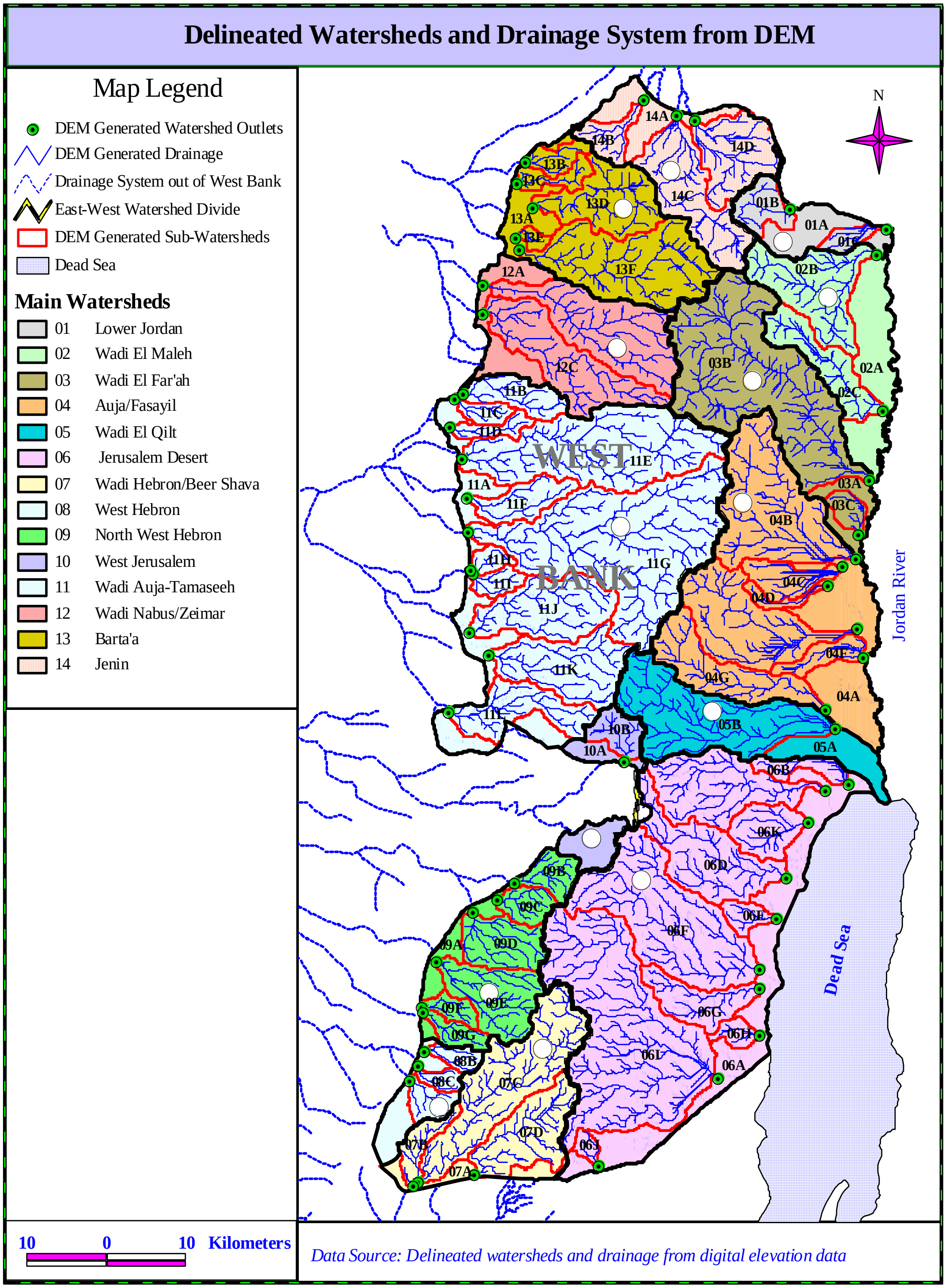


Figure 3-8: Delineated Watersheds And Drainage System From DEM

This study indicates that there is great need to install at least 58 hydrometric stations at the stream outlets of the created sub-watersheds as shown in Figure 3-8 in order to measure the stream water runoff on an hourly or daily basis. These stations should be able to measure the rainfall and other hydro-meteorological data every 5, 30, 60, 120, 180 minutes, respectively, in order to conduct more detailed hydrological research modeling studies in the West Bank. The detailed measurements could be used to create the Intensity-Duration- Frequency (IDF) curves of rainfall that have many valuable applications in hydrological research.

The general sequence of this spatial modeling approach is to create one grid coverage for each water balance parameter within the boundary of the West Bank (5632 km^2) which in turn will be clipped based on the created watersheds, groundwater basins and their outcropped aquifers using the geo-processing tools embedded within ArcView Software.

3.4.2 Hydro-Meteorological Data Requirements

Because there are not enough hydro-meteorological stations, a number of stations located out of the West Bank boundary were included in this study to get a better spatial distribution of the created grid coverage of the various water balance parameters. Figure 3-9 shows the location and classification of various types of hydro-meteorological stations which are used in this study. The climatic data used in this research were shown in Appendix A with the raw data taken from the Palestinian Water Authority, The Palestinian Department of Meteorology, the Hydrological Services of Israel, and the Meteorological Services of Israel.

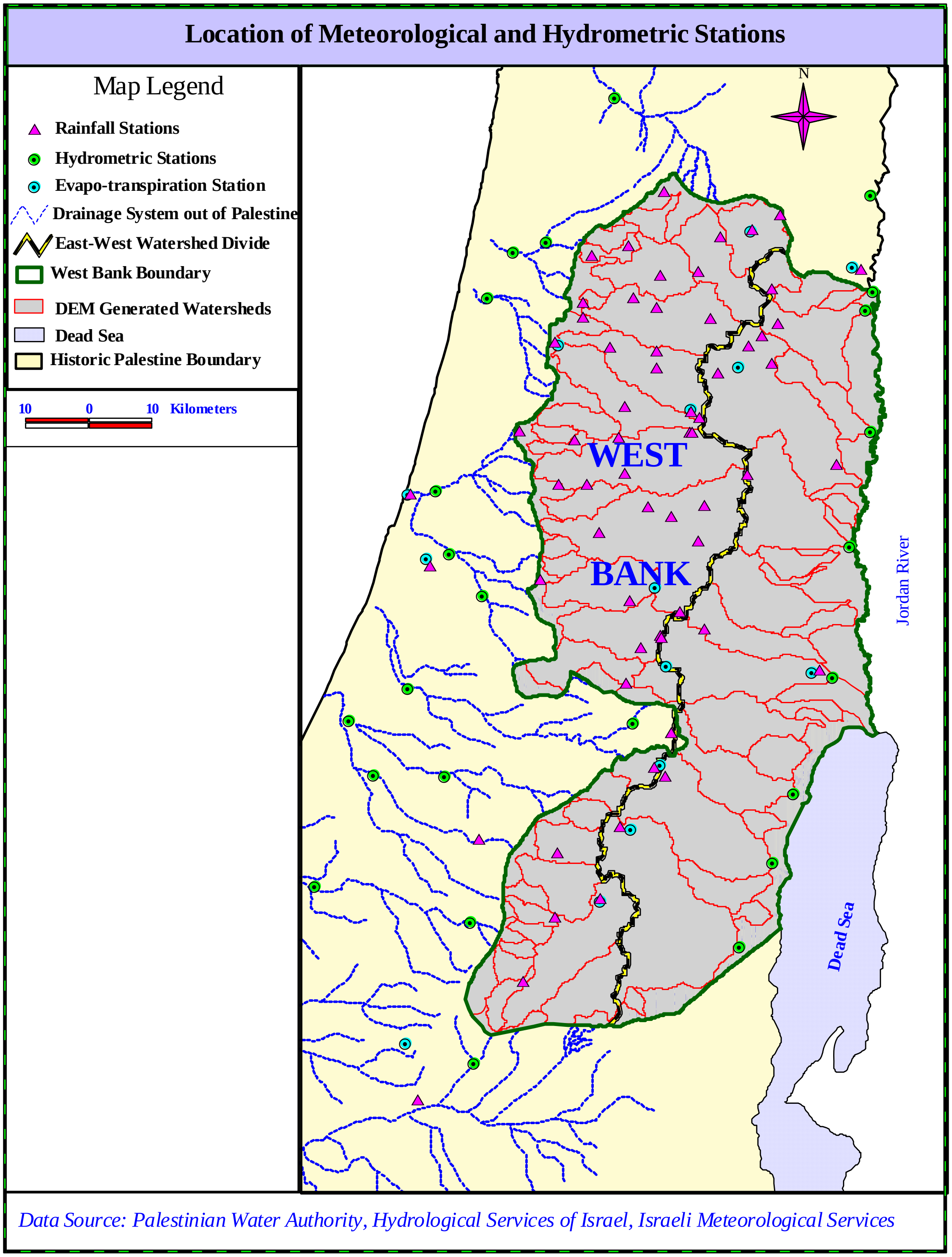


Figure 3-9: Location Of Meteorological And Hydrometric Stations Used In The Study

3.5 Spatial Modeling Application

This section shows the application of the spatial model to create various grids for the water balance parameters within the West Bank boundary based on the available hydro-meteorological data. As mentioned earlier, the main goal of this spatial model is to estimate the rate and volume of various water balance parameters for the West Bank aquifers and surface watersheds. This spatial modeling approach is mainly based on interpolating grids from point stations with known geographic locations (with XY data) that measure the hydro-meteorological data. The grids were then used to create contour maps of various water balance parameters in order to estimate the annual volume of the maps using the Isohyetal method. For more reliability, the estimated results were compared to the Theissen Polygons method results which ware used for estimating the annual volumes of water balance parameters. The various water balance parameters were estimated based on two regions; the West Bank region and the recharge outcrops of the West Bank Aquifers.

Figure 3-10 shows the recharge and non-recharge areas of the West Bank as derived from the digitized geologic map. From Figure 3-10, the recharge and non-recharge areas of the West Bank were estimated using the ArcView GIS Software to be 4356.89 km^2 and 1275.4 km^2, respectively. Thus the recharge area constitutes about 77% of the West Bank area where the rainfall is directly recharging the aquifer through their outcrops. Another method should be developed to estimate the water balance for the non-recharge (aquitards) area which constitutes about 23% of the West Bank area. The fate of rain water which falls on that aquitard area could be evaporated, flow in streams in the form of runoff. A small portion of that water could be percolated into the underlying aquifers.

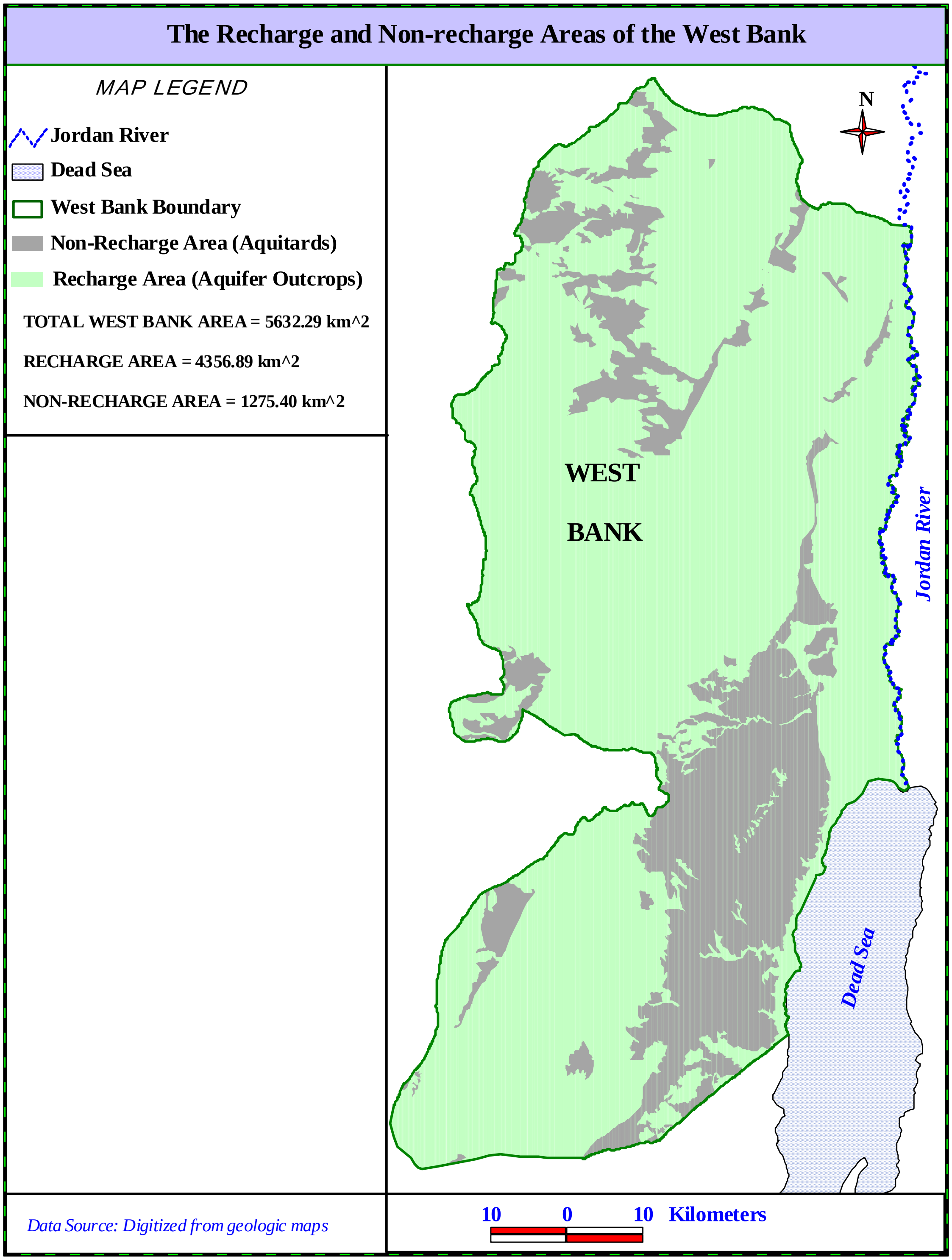


Figure 3-10: The Recharge And Non-Recharge Areas Of The West Bank As Derived From The Digitized Geologic Maps

3.5.1 Creating the Rainfall Coverage

All types of hydro-meteorological stations measure the rainfall amounts. Rainfall data are the most reliable data among the other water balance parameters where the monthly and the annual rainfall data are available for 61 stations over the 10-year period (from 1990/91 to 1999/00). Although the records of rainfall for the 61 stations located in study area are available for 33 years (19967/68-1999/00), this study is conducted for the latest 10 years (1990/91-1999/00) with available meteorological data. The 10-Year rainfall average was a little higher than the 33-Year rainfall average due to the exceptional rainfall in the year 1991/92 which had an average rainfall greater than 1000 mm/Yr.

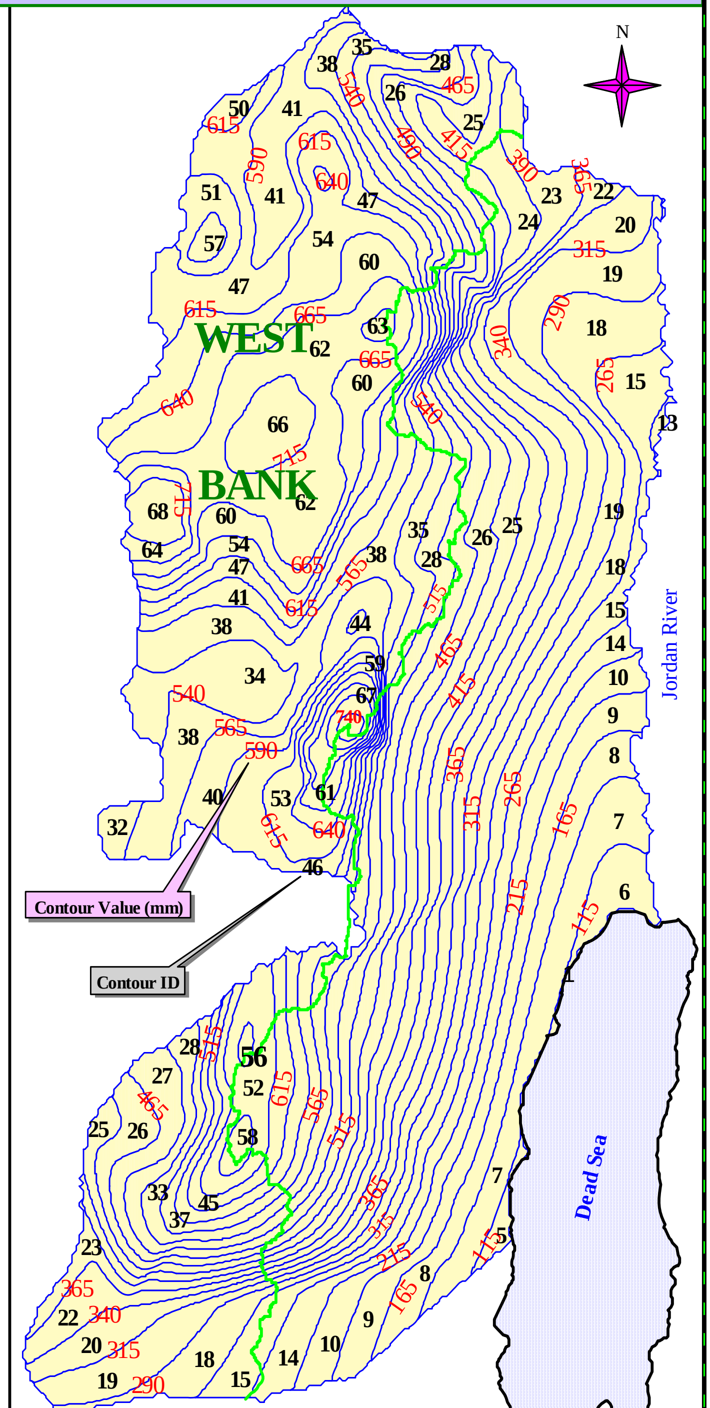
In evaluating the volume of rainfall, two methods were used these are; the Theissen Polygon and the Isohyetal methods. The isohyetal method was assumed to give better results because it takes the spatial distribution property of rainfall into consideration.

The 10-year average annual rainfall was interpolated for the 61 stations to create the average annual rainfall grid coverage based on X and Y locations of stations. The grid used for the interpolation of the average annual measured rainfall values has a grid cell size of (100 m x 100 m).

Figure 3-11 shows the 10-year average isohyetal contour map and the details of rainfall estimation with a total rainfall volume of 2508.3 MCM/Yr and a weighted annual average of 445.3 mm/Yr in the West Bank. Figure 3-12 shows the 10-year average rainfall using the Theissen Polygons method with a total estimated rainfall volume of 2571.41 MCM/Yr and a weighted annual average of 456.5 mm/Yr in the West Bank.

Estimation of Rainfall Volume Using the Isohyetal Method

ID	LOWER	UPPER	AREA	VOLUME
	mm/yr	mm/yr	km^2	MCM
1	95	115	0.05	0.01
2	95	115	0.17	0.02
3	95	115	0.22	0.02
4	95	115	0.87	0.09
5	95	115	14.33	1.50
6	95	115	44.89	4.71
7	115	140	148.12	18.89
8	140	165	133.73	20.39
9	165	190	140.77	24.99
10	190	215	139.81	28.31
11	215	240	0.12	0.03
12	215	240	0.18	0.04
13	215	240	4.24	0.97
14	215	240	138.90	31.60
15	240	265	206.61	52.17
16	265	290	0.09	0.03
17	265	290	0.33	0.09
18	265	290	266.18	73.86
19	290	315	280.86	84.96
20	315	340	238.86	78.23
21	340	365	0.63	0.22
22	340	365	207.02	72.97
23	365	390	215.36	81.30
24	390	415	208.07	83.75
25	415	440	212.67	90.92
26	440	465	215.05	97.31
27	465	490	224.40	107.15
28	490	515	201.32	101.16
29	515	540	0.02	0.01
30	515	540	0.21	0.11
31	515	540	1.28	0.67
32	515	540	16.43	8.67
33	515	540	69.13	36.46
34	515	540	94.36	49.78
35	515	540	109.07	57.53
36	540	565	0.01	0.01
37	540	565	64.16	35.45
38	540	565	264.31	146.31
39	565	590	58.93	34.03
40	565	590	92.52	53.43
41	565	590	183.87	106.18
42	590	615	0.01	0.01
43	590	615	0.28	0.17
44	590	615	2.38	1.43
45	590	615	60.14	36.23
46	590	615	78.38	47.22
47	590	615	218.45	131.62
48	615	640	0.01	0.00
49	615	640	0.01	0.01
50	615	640	13.79	8.65
51	615	640	38.33	24.05
52	615	640	76.86	48.23
53	615	640	51.05	32.03
54	615	640	206.84	129.79
55	640	665	2.78	1.82
56	640	665	4.84	3.16
57	640	665	11.51	7.51
58	640	665	12.15	7.93
59	640	665	24.97	16.29
60	640	665	203.99	133.11
61	665	690	21.25	14.40
62	665	690	251.71	170.53
63	690	715	7.44	5.23
64	690	715	24.39	17.13
65	690	715	18.23	12.81
66	690	715	57.30	40.25
67	715	740	11.50	8.37
68	715	740	30.41	22.12
69	740	753	5.17	3.86
Total			5632.29	2508.29



10 0 10 Kilometers

East-West Watershed Divide

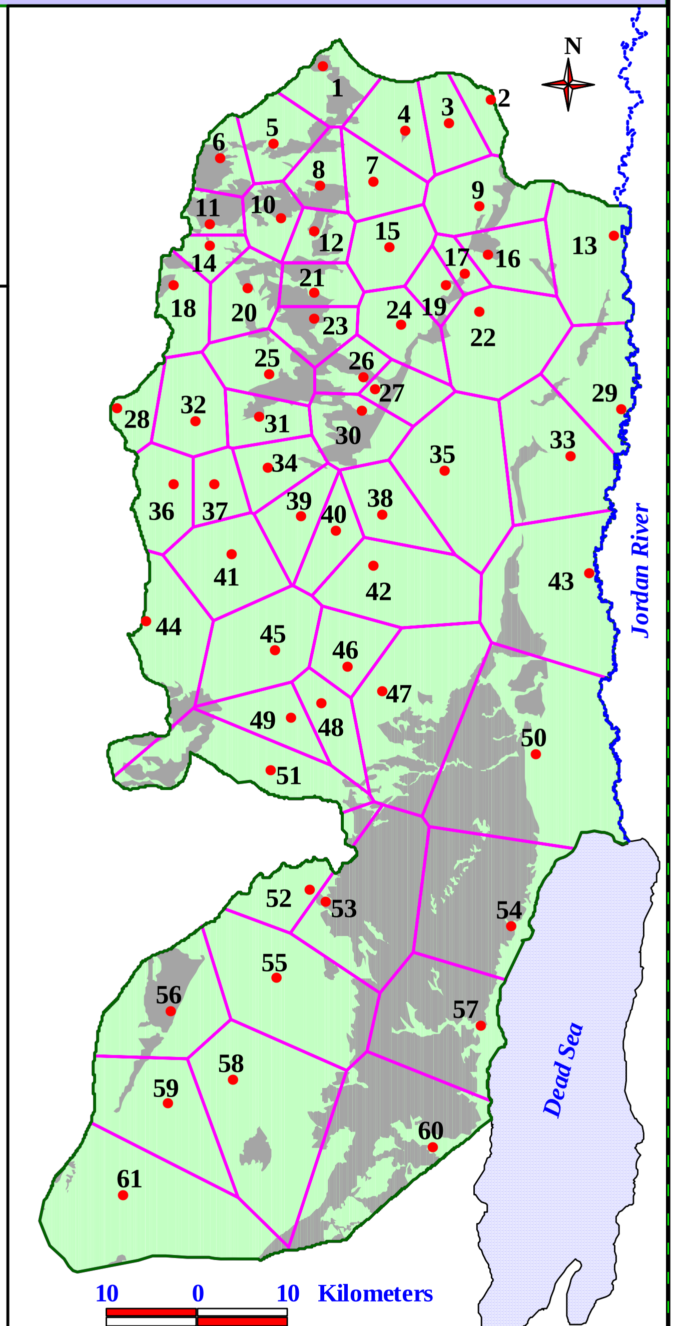
Data Source: Interpolated from rainfall data of the PWA and Meteorological Services of Israel

Figure 3-11: Estimation Of Rainfall Volume For The West Bank Area Using The Isohyetal Method

Rainfall Estimation Using Theissen Polygons Method

MAP LEGEND

- Rainfall Stations & their ID's
- Jordan River
- Dead Sea
- West Bank Boundary
- Rainfall Theissen Polygons
- Non-Recharge Area (Aquitards)
- Recharge Area (Aquifer Outcrops)



ID	RAINFALL mm/yr	AREA km^2	VOLUME MCM
1	560.1	55.02	30.82
2	385.5	23.46	9.04
3	441.7	51.37	22.69
4	419.9	63.80	26.79
5	577.9	59.80	34.56
6	608.8	39.55	24.08
7	544.3	56.68	30.85
8	641.0	42.75	27.40
9	414.5	83.54	34.63
10	576.5	41.49	23.92
11	639.6	28.69	18.35
12	626.5	36.94	23.14
13	315.0	112.54	35.45
14	655.6	26.08	17.10
15	630.4	64.48	40.65
16	406.2	60.06	24.40
17	471.6	19.91	9.39
18	602.5	49.95	30.09
19	460.0	28.54	13.13
20	605.0	61.36	37.12
21	638.4	39.80	25.41
22	323.7	128.99	41.75
23	674.5	43.39	29.27
24	656.1	66.13	43.39
25	693.0	67.33	46.66
26	642.5	34.16	21.95
27	614.0	40.99	25.17
28	616.0	30.23	18.62
29	237.5	93.73	22.26
30	627.0	65.82	41.27
31	707.0	44.58	31.52
32	662.4	73.97	49.00
33	321.7	145.29	46.74
34	678.0	50.49	34.23
35	486.2	168.08	81.72
36	736.1	63.78	46.95
37	657.3	40.83	26.84
38	542.0	66.88	36.25
39	675.4	53.64	36.23
40	576.7	45.40	26.18
41	574.5	97.40	55.95
42	572.2	129.34	74.01
43	246.0	197.58	48.60
44	538.7	107.30	57.80
45	536.7	115.80	62.15
46	753.3	57.40	43.24
47	474.5	203.08	96.36
48	700.0	51.19	35.83
49	627.8	56.12	35.23
50	163.5	345.50	56.49
51	612.8	131.00	80.28
52	538.0	62.58	33.67
53	507.9	174.49	88.62
54	136.0	184.92	25.15
55	610.0	193.37	117.96
56	471.8	133.02	62.76
57	139.0	161.18	22.40
58	600.0	238.32	142.99
59	535.5	135.53	72.57
60	135.2	237.51	32.11
61	328.7	250.13	82.22
Total		**5632.29**	**2571.41**

Data Source: Integrated from rainfall data of the Palestinian Water Authority

Figure 3-12: Estimation Of Rainfall Volume For The West Bank Area Using The Theissen Polygon Method

3.5.2 Creating the Evapo-transpiration Coverage

The most difficult part in this study is to estimate the evoptranspiration (ET). In order to estimate evapotranspiration, the Penman-Montieth method was used after modification by the Food & Agriculture Organization (FAO) of the United Nations. The FAO modified the Penman-Montieth method and developed the CROPWAT software to estimate the reference crop evapotranspiration (ET_0). The Penman-Monteith equation can be used both for 24-hour calculations of reference evapotranspiration as well as for monthly mean data. The Modified Penman-Monteith equation can be simplified as follows:

$$ET_0 = \frac{0.408\delta(R_n - G) + U_2(e_a - e_d)\gamma \dfrac{900}{T+273}}{\delta + \gamma(1 + 0.34U_2)} \qquad \textbf{(3-2)}$$

where:

- ET_o : reference crop evapo-transpiration (mm/d)
- R_n : net radiation at the crop surface ($MJ/m^2/d$)
- G : soil heat flux ($MJ/m^2/d$)
- T : average air temperature (^0C)
- U_2 : wind speed measured at 2 m height (m/s)
- (e_a-e_d) : vapor pressure deficit (kPa)
- * : slope of the vapor pressure curve ($kPa/^0C$)
- γ : psychrometric constant ($kPa/^0C$)
- 900 : conversion factor

The actual crop evapotranspiration (ET_c) can then be calculated using the equation:

$$ET_c = K_c * ET_0 \qquad (3\text{-}3)$$

where, K_c is the crop coefficient which varies from crop to another and from growth stage to another for the same crop.

The reference crop evapo-transpiration (ET_0) was estimated for 15 meteorological stations using equation 3-2 which is embedded in CROPWAT Software. Five of these stations are located out of the boundary of the West Bank and were used to give a better spatial distribution to represent the various regions of the study area. As seen in equations 3-2 and 3-3 above, such estimation needs various weather and crop data such as sunshine duration, minimum and maximum temperature, wind speed, longitude and latitude, crop coefficient, and others. The crop coefficient (K_c) for each station was estimated based on the average K_c value for the 20 most dominant crops planted in the district where the meteorological station is located. K_c values for various crops in the study area were taken from the FAO published irrigation paper (FAO, 1977) on evaluation of crop water requirements.

Since this study is dealing with evaluating the water balance derived from the natural rainfall, the following two assumptions were made in estimating the monthly and annual ET_c values:

1. The ET_c was assumed to equal zero for the months with zero rainfall since the study is dealing with evaluating the water balance derived from the natural rainfall in the study area.
2. When the estimated monthly ET_c is greater than the monthly rainfall, the ET_c value is assumed to be equal to the rainfall of that month which means that 100% of the rainfall is evaporated.

Table 3-2 shows the summary of the long term estimated annual ET_c for the 15 stations representing the study area. In order to apply the spatial modeling approach, the estimated ET_c values shown in Table 3-2 were interpolated into grid coverage with (100 m x 100 m) grid cell size for the study area. Contour maps were derived from the interpolated grid in order to estimate the ET_c volume. Figure 3-13 shows the 10-year average ET_c contour map and the details of ET_c estimation with a total ET_c volume of 1607 MCM/Yr and a weighted annual average of 285.3 mm in the West Bank. Figure 3-14 shows the 10-year average ET_c using the Theissen Polygons method with a total estimated ET_c volume of 1683.08 MCM/Yr and a weighted annual average of 298.8 mm in the West Bank.

Table 3-2: Estimated Annual Crop Evapo-Transpiration (ETc) Measured In mm For Various Meteorological Stations Of The Study Area (10-Year Average; 1990/91-1999/00)*

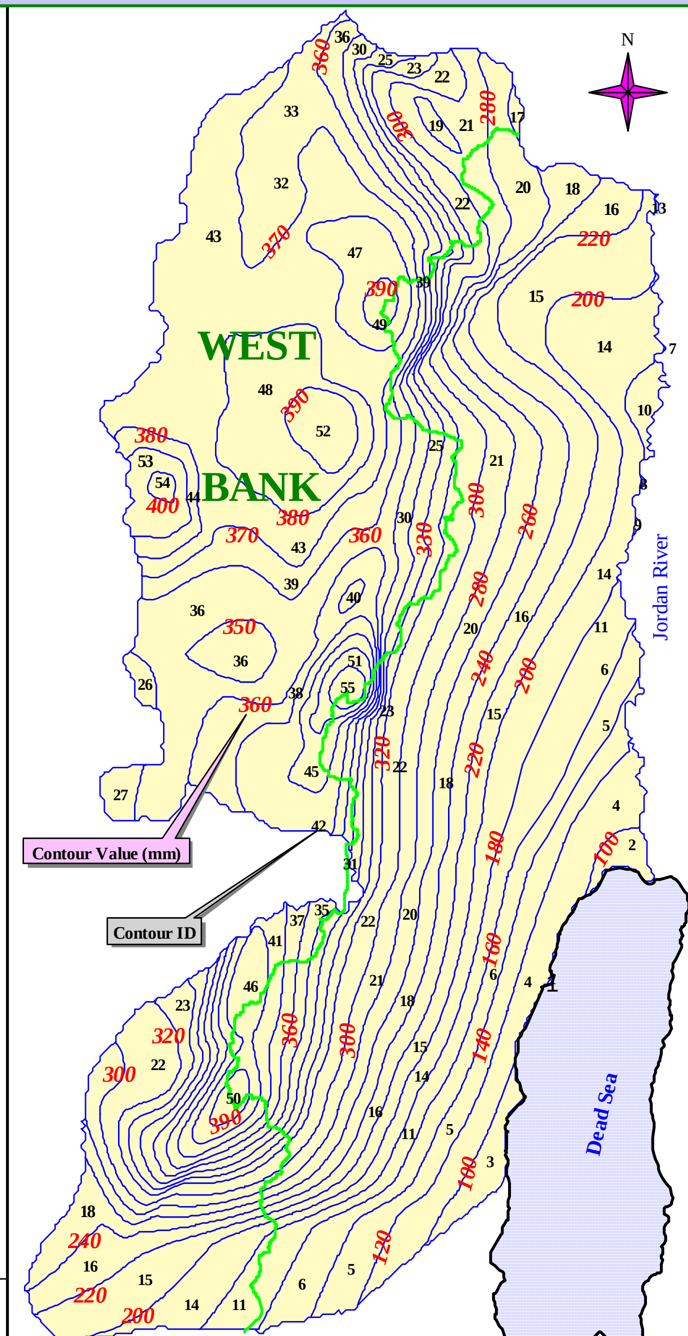
ID	STATION	X	Y	Rainfall	ET_c	ET_c/Rain
1	JENIN	183217.62	208305.28	456.02	300.00	65.8%
2	TIRAT ZVI	199215.67	202805.94	353.77	240.00	67.8%
3	TULKARM	153103.61	190606.93	611.82	378.00	61.8%
4	NABLUS	173826.25	180634.26	646.44	320.00	49.5%
5	FAR'AH	196627.43	172125.51	242.25	200.13	82.6%
6	TEL AVIV	129465.44	167437.10	568.95	382.00	67.1%
7	BEIT DAJAN	132260.13	157467.40	573.73	356.00	62.1%
8	RAMALLAH	169260.10	145225.18	700.29	387.00	55.3%
9	JERUSALEM	170054.65	140799.11	571.94	379.00	66.3%
10	JERICHO	192770.78	139717.27	166.00	140.62	84.7%
11	BETHLEHEM	169800.00	123700.00	510.37	300.00	58.8%
12	AL ARROUB	164361.69	115351.30	638.89	368.00	57.6%
13	HEBRON	159606.61	104290.16	611.74	310.00	50.7%
14	GAZA SHORE	94997.92	101237.06	445.58	255.90	57.4%
15	BEER SHEVA	129126.97	82235.69	188.82	167.91	88.9%

***** *The estimated annual ET_c is much greater than what is shown in this table, but since this study is dealing with the ET_c originated from the natural annual renewable rainfall, this table is modified based on the assumption that the monthly ET_c will never exceed the monthly rainfall (For more details, see Appendix A).*

Appendix A shows the required monthly climatic data taken from 15 meteorological stations, the estimated monthly reference evapo-transpiration (ET_0), and the estimated monthly crop evapo-transpiration (ET_c) which are estimated using the FAO CROPWAT method for the West Bank. Appendix A also shows the adjusted ET_c summary based on the assumption that ET_c will not exceed the rainfall in any month for each station.

Estimation of ETc Volume Using the Isohyetal Method

ID	LOWER mm/yr	UPPER mm/yr	AREA km^2	Volume MCM
1	80	100	0.31	0.03
2	80	100	21.31	1.92
3	80	100	40.16	3.61
4	100	120	190.32	20.94
5	120	140	184.70	24.01
6	140	160	189.46	28.42
7	160	180	0.09	0.01
8	160	180	0.32	0.05
9	160	180	0.63	0.11
10	160	180	20.99	3.57
11	160	180	190.53	32.39
12	180	200	0.08	0.02
13	180	200	0.28	0.05
14	180	200	338.81	64.37
15	200	220	374.98	78.75
16	220	240	305.39	70.24
17	240	260	4.94	1.23
18	240	260	274.35	68.59
19	260	280	9.60	2.59
20	260	280	271.46	73.29
21	280	300	310.38	90.01
22	300	320	325.88	101.02
23	320	330	158.89	51.64
24	330	340	57.15	19.14
25	330	340	86.17	28.87
26	340	350	11.31	3.90
27	340	350	18.71	6.46
28	340	350	40.05	13.82
29	340	350	53.63	18.50
30	340	350	86.26	29.76
31	350	360	0.08	0.03
32	350	360	0.29	0.10
33	350	360	0.75	0.26
34	350	360	0.89	0.31
35	350	360	55.24	19.61
36	350	360	327.78	116.36
37	360	370	55.01	20.08
38	360	370	111.18	40.58
39	360	370	251.33	91.73
40	370	380	4.64	1.74
41	370	380	61.55	23.08
42	370	380	100.26	37.60
43	370	380	560.33	210.30
44	380	390	34.88	13.43
45	380	390	39.42	15.18
46	380	390	57.28	22.05
47	380	390	78.63	30.27
48	380	390	173.98	66.98
49	390	400	13.39	5.29
50	390	400	13.79	5.45
51	390	400	18.92	7.47
52	390	400	44.80	17.69
53	390	400	42.59	16.82
54	400	407	6.77	2.73
55	400	407	11.40	4.60
Total			5632.29	1607.08

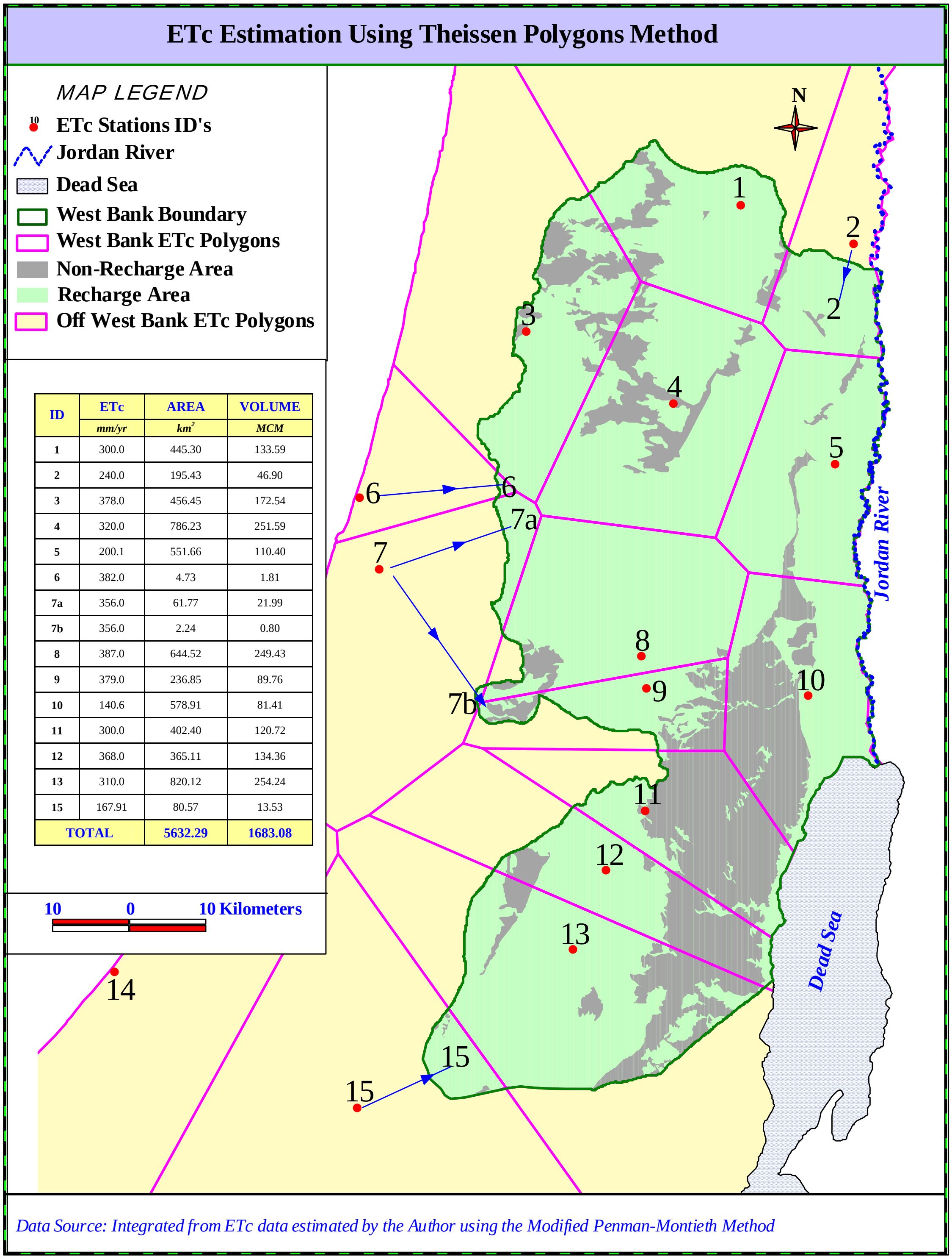


East-West Watershed Divide

10 0 10 Kilometers

Source: Estimated ETc based on the climatic data and the crop Characteristics

Figure 3-13: Estimation Of Evapo-Transpiration (ET_c) Volume For The West Bank Area Using The Isohyetal Method



ID	ETc	AREA	VOLUME
	mm/yr	km²	MCM
1	300.0	445.30	133.59
2	240.0	195.43	46.90
3	378.0	456.45	172.54
4	320.0	786.23	251.59
5	200.1	551.66	110.40
6	382.0	4.73	1.81
7a	356.0	61.77	21.99
7b	356.0	2.24	0.80
8	387.0	644.52	249.43
9	379.0	236.85	89.76
10	140.6	578.91	81.41
11	300.0	402.40	120.72
12	368.0	365.11	134.36
13	310.0	820.12	254.24
15	167.91	80.57	13.53
TOTAL		5632.29	1683.08

Figure 3-14: Estimation Of ET_c Volume For The West Bank Area Using The Theissen Polygon Method

3.5.3 Creating the Runoff Coverage

As discussed earlier in this chapter, there are no functioning hydrometric stations in the West Bank. In 1998, the Hydrological Services of Israel submitted an internal water report which included a map showing the long term runoff coefficient (1967/68 – 1995/96) for 26 streams within and around the study area. Eight streams are located within the West Bank boundary, while the other 18 streams are located within the Israeli boundary. The 10-Year rainfall average for the 26 stream points was multiplied by the runoff coefficient to get the 10-Year runoff values for the study area.

Figure 3-15 shows the location map of the 26 stream measurements and their long term runoff coefficients. In order to get the runoff coverage for the West Bank, all the estimated runoff depths were interpolated with (500 m x 500 m) grid cell size to get the contour map coverage for runoff. Also, the Theissen Polygon method was used to map the runoff polygons and clip the portion of the polygons which is located within the West Bank boundary.

Figure 3-16 shows the 10-year average runoff contour map and the details of runoff estimation with a total runoff volume of 78.61 MCM/Yr and a weighted annual average of 14 mm/Yr in the West Bank. Figure 3-17 shows the 10-year average runoff using the Theissen Polygons method with a total estimated runoff volume of 73.28 MCM/Yr and a weighted annual average of 13 mm/Yr in the West Bank.

In the future, this flood runoff which is usually mixed with the base flow that comes from springs in the winter months and could be used for water harvesting by capturing the water behind dams to increase the upper water sustainability limit in the West Bank.

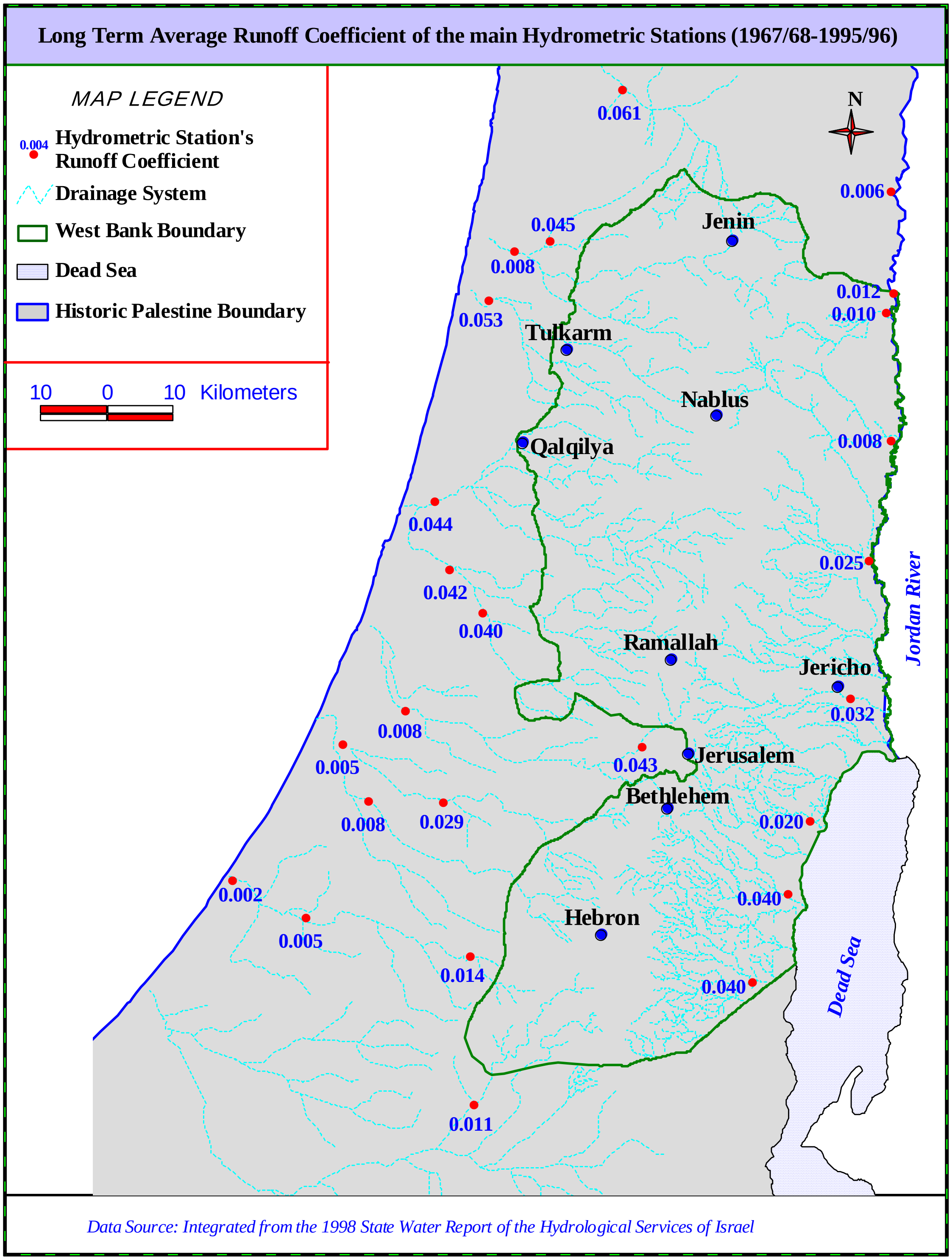
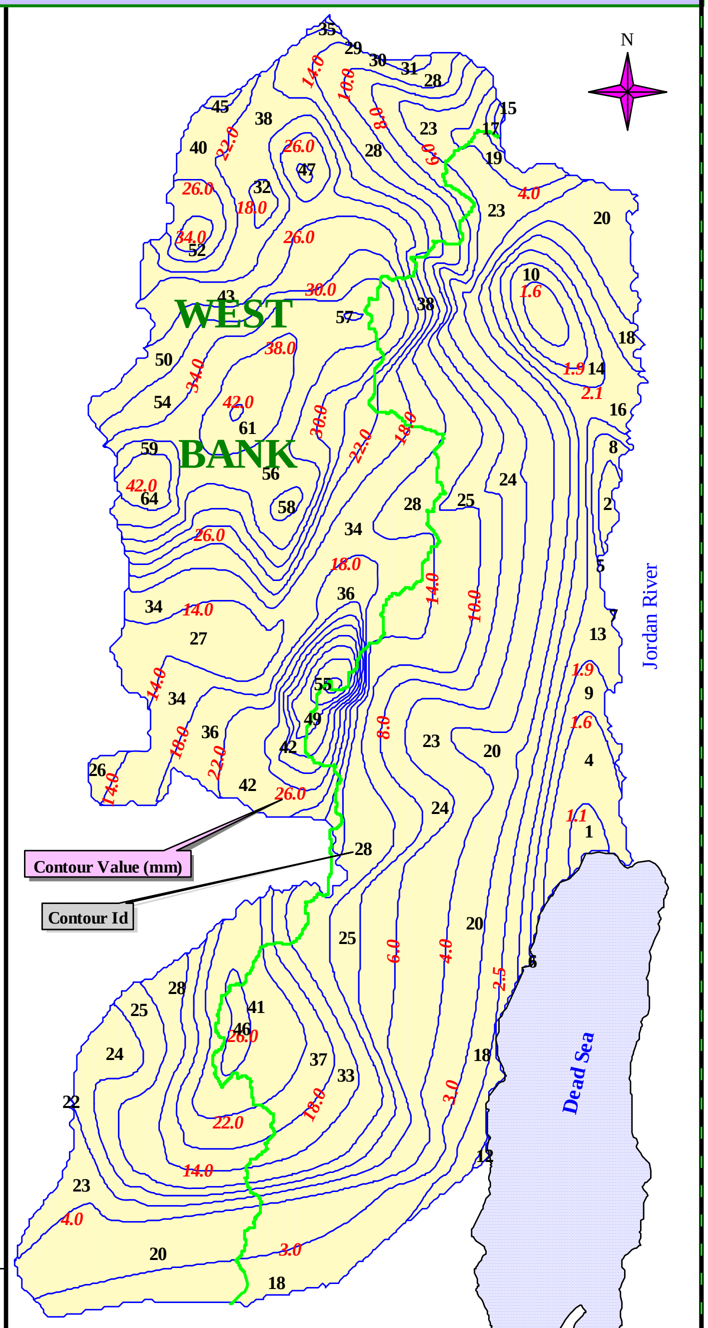


Figure 3-15: The Long Term Average Runoff Coefficient Of The Main Hydrometric Stations (1967/68-1995/96)

Estimation of Runoff Volume Using the Isohyetal Method

ID	LOWER mm/yr	UPPER mm/yr	AREA km^2	Volume MCM
1	0.9	1.1	17.76	0.017
2	1.1	1.6	13.00	0.018
3	1.1	1.6	20.65	0.028
4	1.1	1.6	78.59	0.106
5	1.6	1.9	0.20	0.000
6	1.6	1.9	0.28	0.000
7	1.6	1.9	0.29	0.001
8	1.6	1.9	16.25	0.028
9	1.6	1.9	46.21	0.080
10	1.6	1.9	36.42	0.063
11	1.9	2.1	0.13	0.000
12	1.9	2.1	1.98	0.004
13	1.9	2.1	82.72	0.163
14	1.9	2.1	38.82	0.077
15	2.1	2.5	2.09	0.005
16	2.1	2.5	187.56	0.431
17	2.5	3.0	4.57	0.013
18	2.5	3.0	340.07	0.935
19	3.0	4.0	29.95	0.105
20	3.0	4.0	528.39	1.849
21	4.0	6.0	0.02	0.000
22	4.0	6.0	0.05	0.000
23	4.0	6.0	511.35	2.557
24	6.0	8.0	375.39	2.628
25	8.0	10.0	329.08	2.982
26	10.0	14.0	12.13	0.146
27	10.0	14.0	108.17	1.298
28	10.0	14.0	509.73	6.117
29	14.0	18.0	0.01	0.000
30	14.0	18.0	0.05	0.001
31	14.0	18.0	4.87	0.078
32	14.0	18.0	9.46	0.151
33	14.0	18.0	124.09	1.985
34	14.0	18.0	386.65	6.186
35	18.0	22.0	2.28	0.046
36	18.0	22.0	98.33	1.967
37	18.0	22.0	116.86	2.337
38	18.0	22.0	221.19	4.424
39	22.0	26.0	0.39	0.009
40	22.0	26.0	62.29	1.495
41	22.0	26.0	139.64	3.351
42	22.0	26.0	82.95	1.991
43	22.0	26.0	174.17	4.180
44	26.0	30.0	0.02	0.001
45	26.0	30.0	3.82	0.107
46	26.0	30.0	20.39	0.571
47	26.0	30.0	23.08	0.646
48	26.0	30.0	32.21	0.902
49	26.0	30.0	32.45	0.909
50	26.0	30.0	173.96	4.871
51	30.0	34.0	2.03	0.065
52	30.0	34.0	9.69	0.310
53	30.0	34.0	23.11	0.739
54	30.0	34.0	172.41	5.517
55	34.0	38.0	21.02	0.757
56	34.0	38.0	231.53	8.335
57	38.0	42.0	1.03	0.041
58	38.0	42.0	7.39	0.296
59	38.0	42.0	28.21	1.128
60	38.0	42.0	19.09	0.764
61	38.0	42.0	74.04	2.962
62	42.0	46.0	1.56	0.069
63	42.0	46.0	12.15	0.535
64	42.0	46.0	26.09	1.148
65	46.0	46.8	1.90	0.088
Total			5632.29	78.61

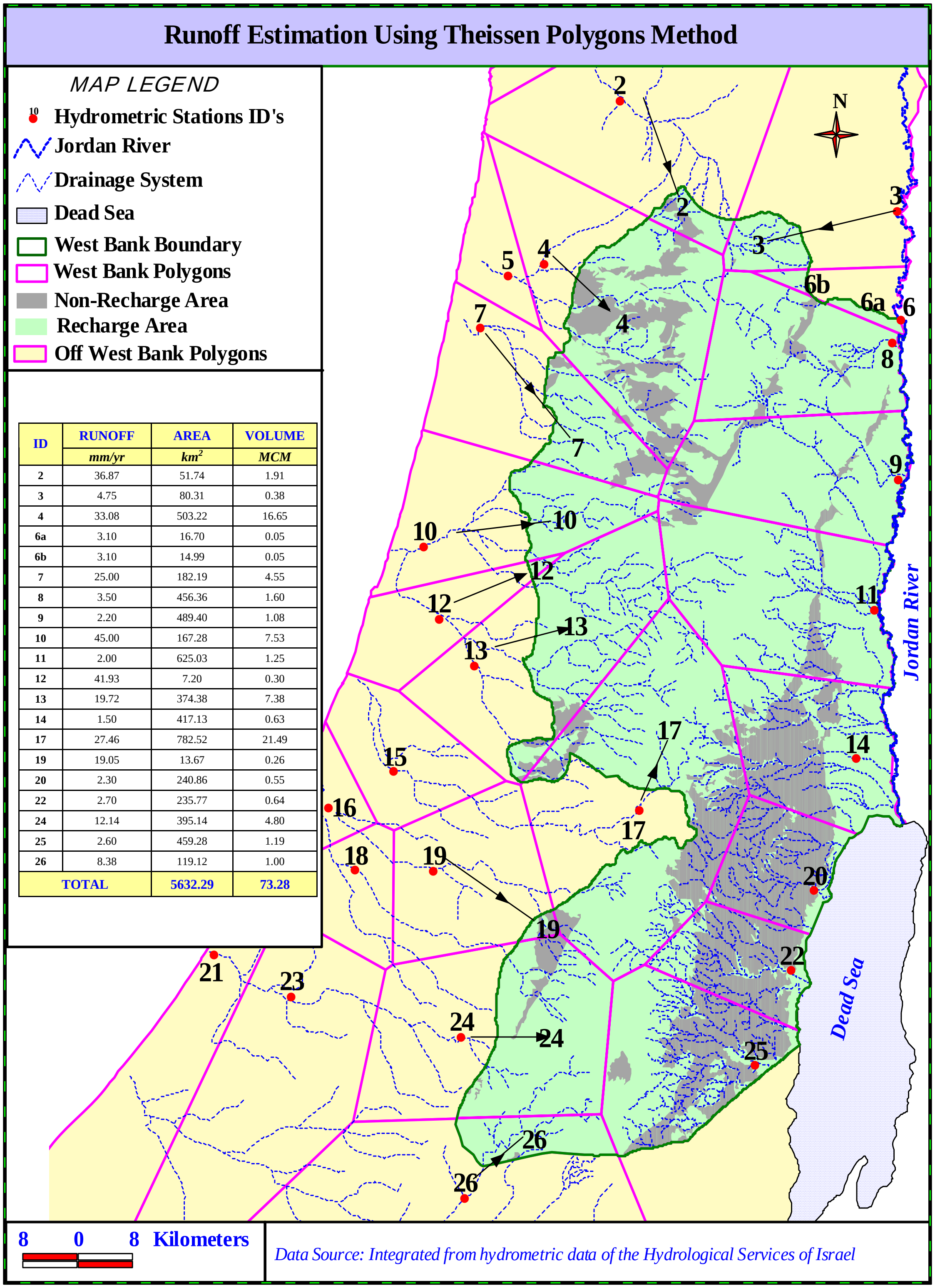


East-West Watershed Divide

10 0 10 Kilometers

Data Source: Interpolated from runoff measurements of the hydrometric stations conducted by the Hydrological Services of Israel (Long term average; 1967-1996)

Figure 3-16: Estimation Of Runoff Volume For The West Bank Area Using The Isohyetal Method



ID	RUNOFF mm/yr	AREA km²	VOLUME MCM
2	36.87	51.74	1.91
3	4.75	80.31	0.38
4	33.08	503.22	16.65
6a	3.10	16.70	0.05
6b	3.10	14.99	0.05
7	25.00	182.19	4.55
8	3.50	456.36	1.60
9	2.20	489.40	1.08
10	45.00	167.28	7.53
11	2.00	625.03	1.25
12	41.93	7.20	0.30
13	19.72	374.38	7.38
14	1.50	417.13	0.63
17	27.46	782.52	21.49
19	19.05	13.67	0.26
20	2.30	240.86	0.55
22	2.70	235.77	0.64
24	12.14	395.14	4.80
25	2.60	459.28	1.19
26	8.38	119.12	1.00
TOTAL		5632.29	73.28

Figure 3-17: Estimation Of Runoff Volume For The West Bank Area Using The Theissen Polygon Method

3.5.4 GIS Geo-Processing Tools and the Derivation of the Recharge Coverage

With all grids required for estimating the recharge/infiltration coverage created, the various GIS geo-processing tools and simple algebra were used to estimate the missing grid coverage and then the contour map of recharge was created based on Equation 3-1. The same process was also applied using the Theissen Polygon method. Two geo-processing actions were used to create the recharge coverage; these are the GIS Intersection Theme and Dissolve Theme tools. Figure 3-18 shows the derivation of the recharge coverage by applying the geo-processing tools on the created contour maps, while Figure 3-19 shows the derivation of the recharge coverage by applying the geo-processing tools on the created Theissen Polygons. Figure 3-20 shows the 10-year average recharge contour map and the details of recharge estimation with a total recharge volume of 822.6 MCM/Yr and a weighted annual average of 146.05 mm in the West Bank.

Figure 3-21 shows the 10-year average recharge using the Theissen Polygons method with a total estimated recharge volume of 815.05 MCM/Yr and a weighted annual average of 144.71 mm in the West Bank.

All the above mentioned created coverages and the water balance estimations are conducted for the whole West Bank area. Given the fact that not all the aquifers of the West Bank are outcropped (the aquifers' outcrops constitute 77% of the total area of the West Bank, while the aquitards' outcrops constitute the other 23% of its total area) as shown previously in Figure 3-10, the above estimated recharge should be adjusted to just include the aquifers' recharge. In order to setup a water resources management and planning program, only the recharge of the outcropped aquifers should be considered.

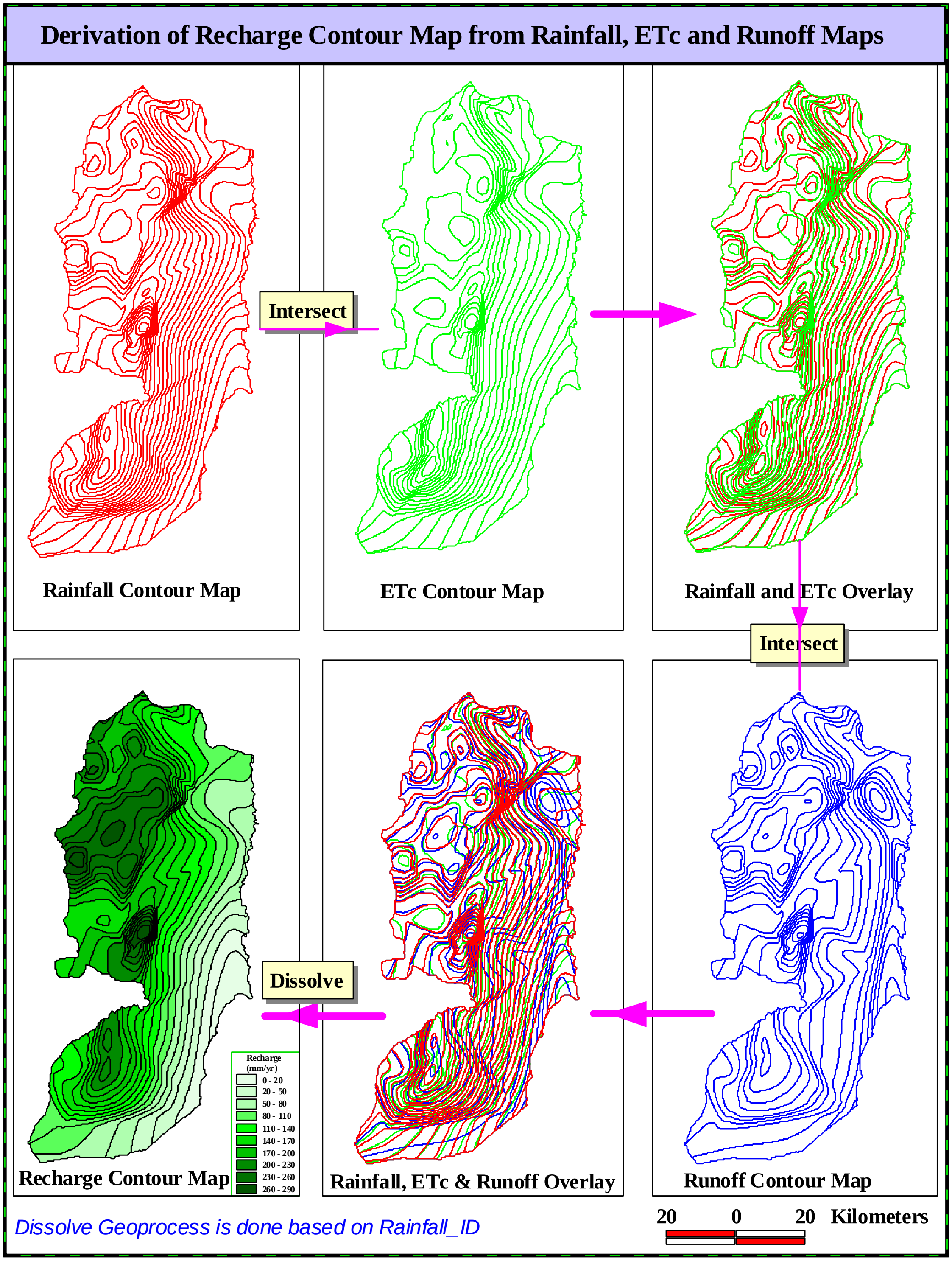


Figure 3-18: Derivation Of Recharge Contour Map From Rainfall, Etc And Runoff Maps

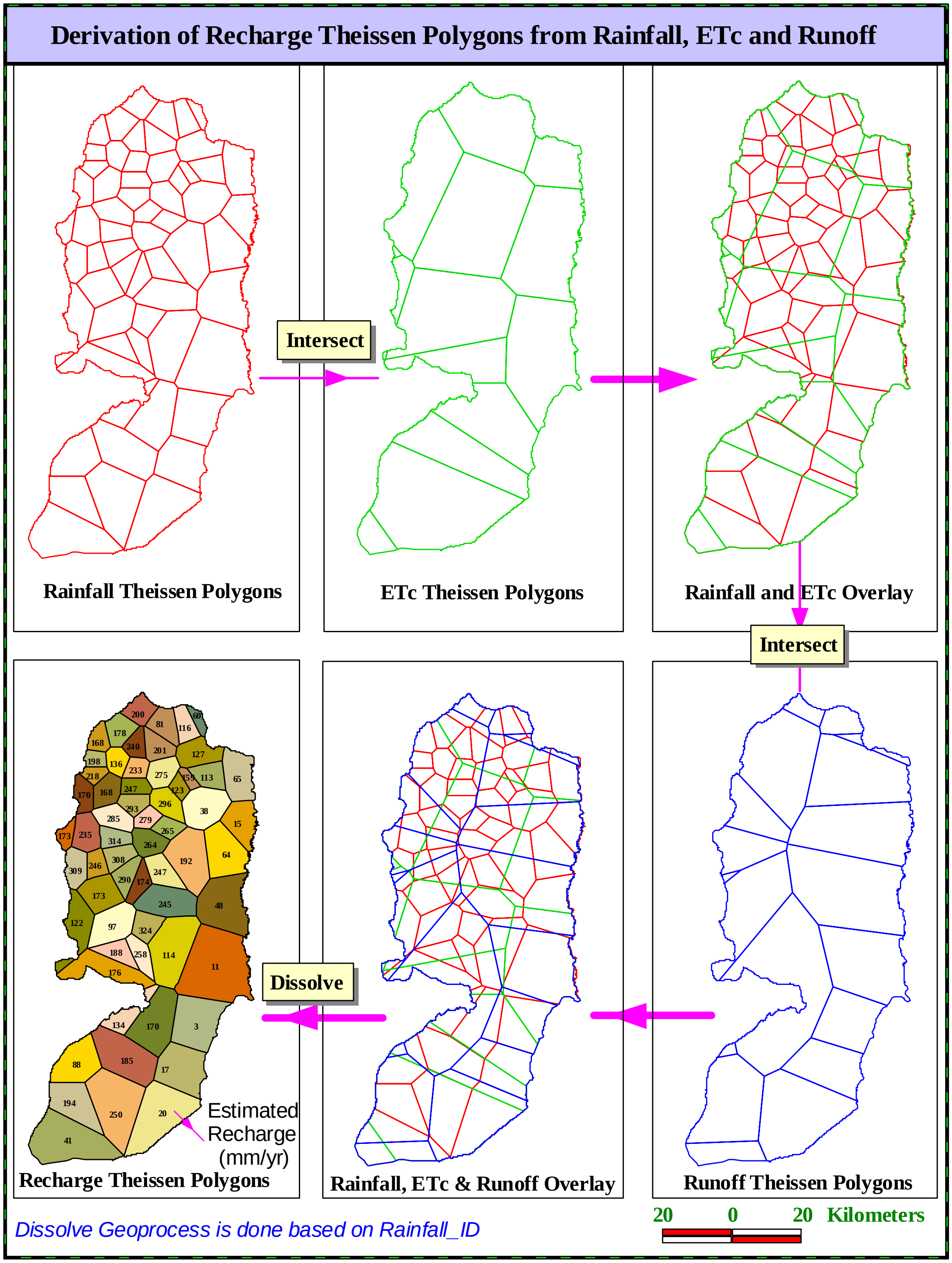
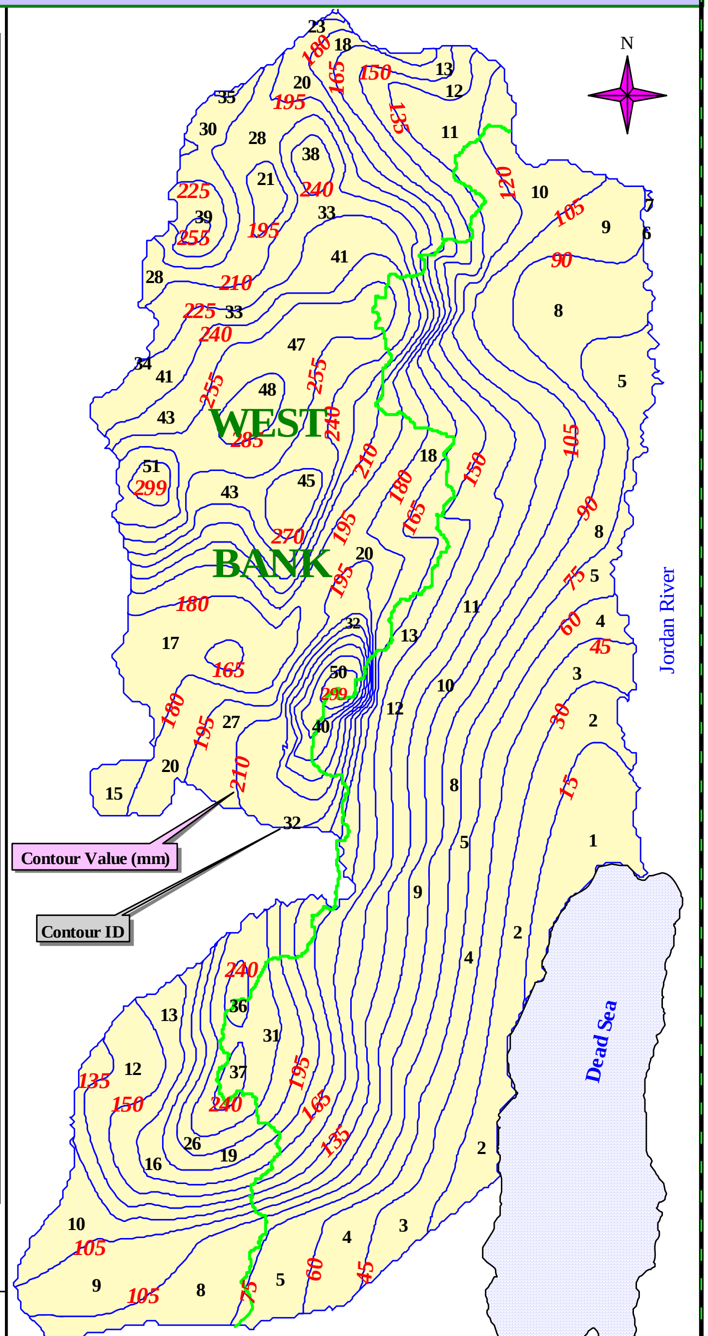


Figure 3-19: Derivation Of Recharge Theissen Polygons From Rainfall, ETc And Runoff Theissen Polygons Using The Various GIS Geo-Processing Tools (units are in mm/yr)

Estimation of Recharge Volume Using the Isohyetal Method

ID	LOWER mm/yr	UPPER mm/yr	AREA km^2	Volume1 MCM
1	0	15	127.60	0.960
2	15	30	193.66	4.357
3	30	45	202.99	7.612
4	45	60	207.59	10.898
5	60	75	283.53	19.138
6	75	90	0.14	0.012
7	75	90	1.19	0.098
8	75	90	414.41	34.189
9	90	105	397.76	38.782
10	105	120	360.02	40.502
11	120	135	332.59	42.406
12	135	150	339.00	48.307
13	150	165	8.77	1.381
14	150	165	313.77	49.100
15	165	180	23.59	4.069
16	165	180	97.22	16.770
17	165	180	140.87	24.300
18	165	180	158.61	27.361
19	180	195	19.63	3.680
20	180	195	80.21	15.040
21	180	195	284.84	53.407
22	195	210	0.01	0.002
23	195	210	0.06	0.011
24	195	210	1.28	0.260
25	195	210	1.76	0.357
26	195	210	76.88	15.567
27	195	210	87.52	17.723
28	195	210	213.22	43.177
29	210	225	0.13	0.028
30	210	225	0.19	0.042
31	210	225	59.34	12.906
32	210	225	97.56	21.220
33	210	225	76.85	16.715
34	210	225	171.05	37.203
35	225	240	1.63	0.378
36	225	240	12.31	2.862
37	225	240	13.05	3.035
38	225	240	17.58	4.087
39	225	240	29.79	6.927
40	225	240	28.33	6.587
41	225	240	190.40	44.268
42	240	255	4.90	1.212
43	240	255	22.89	5.665
44	240	255	202.64	50.153
45	255	270	28.92	7.591
46	255	270	20.56	5.398
47	255	270	181.40	47.616
48	270	285	16.14	4.479
49	270	285	31.84	8.835
50	270	285	31.12	8.636
51	285	299	10.55	3.084
52	285	299	14.40	4.207
Total			5632.29	822.60



East-West Watershed Divide

10 0 10 Kilometers

Data Source: Recharge is estimated from the interpolated grids of rainfall, ETc and runoff.

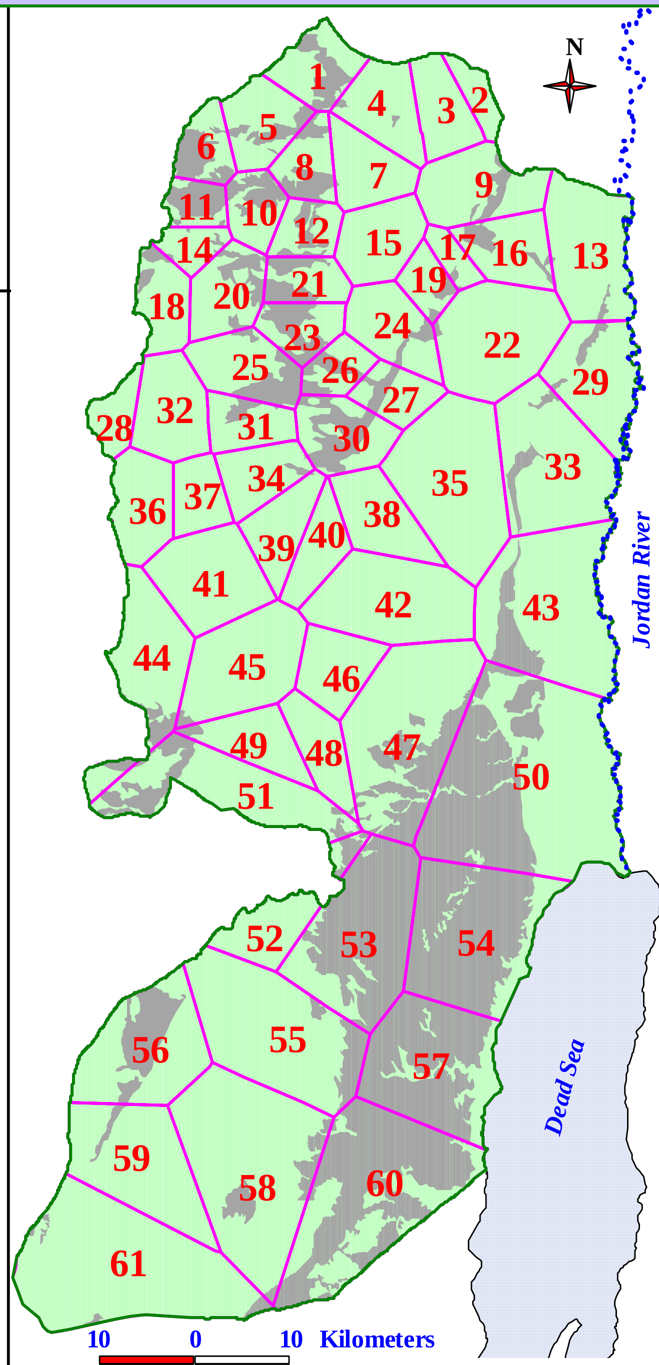
Figure 3-20: Estimation Of Recharge Volume For The West Bank Area Using The Isohyetal Method (This recharge looks higher than the actual value because it is estimated based on the assumption that no minor losses will occur during the percolation of rainfall into the groundwater aquifers)

Recharge Estimation Using Theissen Polygons Method

MAP LEGEND

- 13 Recharge Polygon ID
- Jordan River
- Dead Sea
- West Bank Boundary
- Rainfall Theissen Polygons
- Non-Recharge Area (Aquitards)
- Recharge Area (Aquifer Outcrops)

ID	RAINFALL	AREA	VOLUME
	mm/yr	km^2	MCM
1	199.65	55.02	10.99
2	60.38	23.46	1.42
3	115.67	51.37	5.94
4	81.41	63.80	5.19
5	178.28	59.80	10.66
6	167.80	39.55	6.64
7	201.37	56.68	11.41
8	240.19	42.75	10.27
9	127.18	83.54	10.62
10	136.11	41.49	5.65
11	198.02	28.69	5.68
12	232.59	36.94	8.59
13	64.84	112.54	7.30
14	217.89	26.08	5.68
15	275.38	64.48	17.76
16	112.51	60.06	6.76
17	159.24	19.91	3.17
18	169.96	49.95	8.49
19	123.46	28.54	3.52
20	168.24	61.36	10.32
21	247.46	39.80	9.85
22	52.05	128.99	6.71
23	293.36	43.39	12.73
24	295.67	66.13	19.55
25	284.92	67.33	19.18
26	279.21	34.16	9.54
27	265.43	40.99	10.88
28	172.89	30.23	5.23
29	28.82	93.73	2.70
30	264.39	65.82	17.40
31	313.93	44.58	14.00
32	235.19	73.97	17.40
33	77.70	145.29	11.29
34	307.55	50.49	15.53
35	206.01	168.08	34.63
36	309.15	63.78	19.72
37	245.73	40.83	10.03
38	246.77	66.88	16.50
39	290.33	53.64	15.57
40	174.43	45.40	7.92
41	172.69	97.40	16.82
42	258.98	129.34	33.50
43	62.36	197.58	12.32
44	121.70	107.30	13.06
45	97.44	115.80	11.28
46	323.65	57.40	18.58
47	128.08	203.08	26.01
48	257.85	51.19	13.20
49	188.28	56.12	10.57
50	25.24	345.50	8.72
51	176.29	131.00	23.09
52	134.47	62.58	8.42
53	169.77	174.49	29.62
54	16.66	184.92	3.08
55	184.72	193.37	35.72
56	88.14	133.02	11.72
57	16.75	161.18	2.70
58	249.91	238.32	59.56
59	193.54	135.53	26.23
60	19.97	237.51	4.74
61	54.74	250.13	13.69
Total		5632.29	815.05



Data Source: Integrated from rainfall, ETc, and Runoff Theissen Polygon themes by using the GIS geoprocessing tools

Figure 3-21: Estimation Of Recharge Volume For The West Bank Area Using The Theissen Polygon Method (This recharge looks higher than the actual value because it is estimated based on the assumption that no minor losses will occur during the percolation of rainfall into the groundwater aquifers)

The Clip Theme GIS Geo-processing tool was used to quantify the various water balance parameters both for the recharge (aquifer outcrops) and non-recharge areas (aquitard outcrops) of the West Bank. Table 3-3 shows a summary which compares the results of such clipping for the estimated water balance of the entire West Bank area, the non-recharge area as well as for the recharge area of the West Bank using both the Isoheytal and the Theissen Polygon methods.

Table 3-3: A Comparison Summary of the Estimated Water Balance Volumes for the West Bank using the Isohyetal Method

Estimated Water Balance for the Entire West Bank [1]								
Parameter	Area	Theissen Polygons Method			Isohyetal Method			
		Volume	Weighted Depth	% Rain	Volume	Weighted Depth	% Rain
	km^2	*MCM/Yr*	*mm/yr*		*MCM/Yr*	*mm/yr*	
Rainfall	5632.29	2571.41	456.5	100.0	2508.29	445.3	100.0
ETC	5632.29	1683.08	298.8	65.5	1607.08	285.3	64.1
Runoff	5632.29	73.28	13.0	2.8	78.61	14.0	3.1
Recharge	5632.29	815.05	144.71	31.7	822.60	146.05	32.8
Estimated Water Balance for the Outcrops of the Aquitards of the West Bank								
Parameter	Area	Theissen Polygons Method			Isohyetal Method		
		Volume	Weighted Depth	% Rain	Volume	Weighted Depth	% Rain
	km^2	*MCM/Yr*	*mm/yr*		*MCM/Yr*	*mm/yr*	
Rainfall	1275.40	498.26	390.7	100.0	467.55	366.6	100.0
ETC	1275.40	346.33	271.5	69.5	311.27	244.1	66.6
Runoff	1275.40	11.92	9.3	2.4	13.37	10.5	2.9
Recharge	1275.40	140.01	109.78	28.1	142.91	112.05	30.6
Estimated Water Balance for the Outcrops of the Aquifers of the West Bank							
Parameter	Area	Theissen Polygons Method			Isohyetal Method		
		Volume	Weighted Depth	% Rain	Volume	Weighted Depth	% Rain
	km^2	*MCM/Yr*	*mm/yr*		*MCM/Yr*	*mm/yr*	
Rainfall	4356.89	2073.15	475.8	100.0	2040.75	468.4	100.0
ETC	4356.89	1336.75	306.8	64.5	1295.81	297.4	63.5
Runoff	4356.89	61.36	14.1	3.0	65.24	15.0	3.2
Recharge	4356.89	675.04	154.94	32.6	679.69	156.00	33.3

[1] This recharge looks higher than the actual value because it is estimated based on the assumption that no minor losses will occur during the percolation of rainfall into the groundwater aquifers

Table 3-3 shows that although the total estimated recharge volume for the entire West Bank using the isohyetal method was 822.6 MCM/Yr, only 679.69 MCM/Yr is recharging the West Bank aquifers, while the other volume of 142.91 MCM/Yr is recharging the aquitard formations (non-recharge area). On the other hand, Table 3-3 shows that although the total estimated recharge volume for the entire West Bank using the Theissen Polygon method was 815.05 MCM/Yr, only 675.04 MCM/Yr is recharging the West Bank aquifers, while the other volume of 140.01 MCM/Yr is recharging the aquitard formations (non-recharge area). As seen in Table 3-3, both methods of estimation gave very close results.

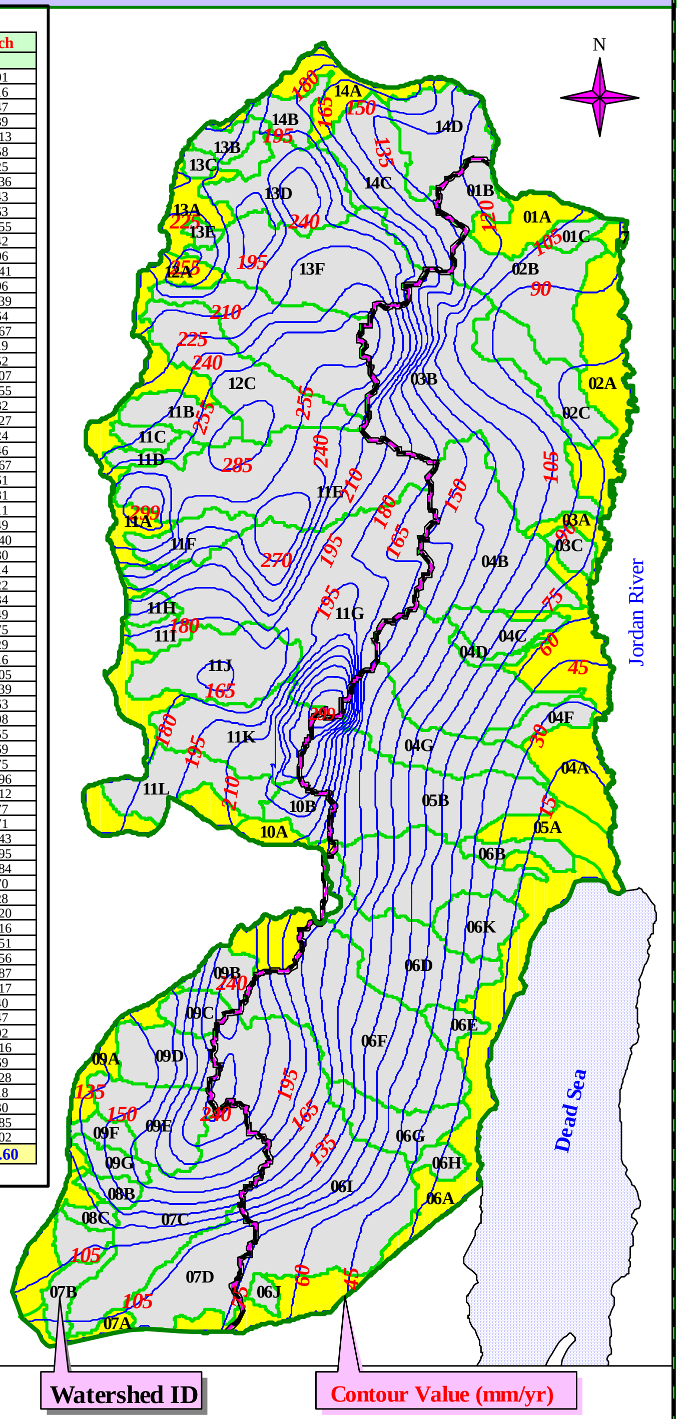
The created watersheds were overlain by the recharge contour map and the resulted overlay was subjected to the GIS Intersection Theme and then to the Dissolve Theme tools to get the various water balance parameters for the various watersheds. Figure 3-22 shows the resulting map of the various estimated water balance parameters for various watersheds as a result of GIS overlay, Intersect Theme, and Dissolve Theme.

As shown in Figure 3-22, the Watershed IDs 1 through 6 are draining surface water to the east towards the Jordan River and the Dead Sea, while those IDs 7 through 14 are draining surface water to the west towards the Mediterranean Sea. The 14 yellow highlighted watersheds shown in Figure 3-22 are not complete watersheds because they either have no stream outlets or their stream outlets are out of the West Bank boundary. These watersheds are either draining surface water off the West Bank inside Israel or they drain to the Jordan River and the Dead Sea. These areas could not be included in any water resources management program. The total area of these watersheds is about 949.82 km^2 which constitutes 17% of the total West Bank area.

Table 3-4 shows a summary of the estimated water balance for the eastern and western watersheds as well as for the watersheds draining surface water out of the West Bank boundary and those draining water within the West Bank boundary.

Derivation of Water Balance for the Various Watersheds using GIS tools

ID	Area	Rain	ETc	Runoff	Rech
	(km^2)	(MCM/Yr)			
01A	55.12	19.58	13.34	0.22	6.01
01B	35.30	14.19	9.86	0.17	4.16
01C	14.86	4.97	3.45	0.05	1.47
02A	109.35	29.31	20.64	0.28	8.39
02B	112.70	37.02	25.55	0.34	11.13
02C	69.26	19.35	13.63	0.14	5.58
03A	28.62	7.95	5.63	0.07	2.25
03B	318.50	137.31	88.49	3.46	45.36
03C	17.23	4.97	3.50	0.04	1.43
04A	134.11	24.35	19.44	0.28	4.63
04B	182.71	74.77	49.59	1.63	23.55
04C	36.47	12.03	8.36	0.26	3.42
04D	11.59	3.79	2.64	0.09	1.06
04E	136.35	49.69	33.95	1.33	14.41
04F	27.53	5.28	4.24	0.07	0.96
04G	95.71	35.82	24.66	0.78	10.39
05A	49.15	6.40	5.68	0.08	0.64
05B	182.48	74.15	49.37	2.10	22.67
06A	187.26	26.28	20.66	0.43	5.19
06B	24.04	3.89	3.31	0.06	0.52
06C	118.99	40.53	28.63	0.83	11.07
06D	114.86	38.16	26.91	0.69	10.55
06E	18.12	3.66	2.77	0.07	0.82
06F	220.10	85.57	57.22	2.09	26.27
06G	56.98	14.54	9.85	0.45	4.24
06H	14.37	2.03	1.53	0.04	0.46
06I	356.00	135.42	86.06	4.69	44.67
06J	8.95	2.05	1.41	0.03	0.61
06K	47.91	9.46	7.50	0.15	1.81
07A	26.91	6.94	4.76	0.07	2.11
07B	26.22	8.45	5.87	0.09	2.49
07C	171.37	74.28	47.94	1.94	24.40
07D	90.04	25.39	17.27	0.32	7.80
08A	38.24	13.38	9.08	0.16	4.14
08B	15.51	7.07	4.71	0.14	2.22
08C	11.67	4.43	3.02	0.06	1.34
08D	22.78	8.07	5.48	0.10	2.49
09A	36.47	15.31	10.29	0.27	4.75
09B	29.70	18.00	11.04	0.67	6.29
09C	26.30	15.11	9.45	0.50	5.16
09D	59.36	30.61	19.78	0.78	10.05
09E	81.29	44.07	28.52	1.16	14.39
09F	17.43	8.40	5.61	0.17	2.63
09G	20.26	9.80	6.53	0.20	3.08
10A	17.80	10.33	6.39	0.39	3.55
10B	35.53	19.93	12.65	0.59	6.69
10C	30.05	18.83	11.30	0.78	6.75
11A	114.16	65.28	39.77	2.55	22.96
11B	44.36	29.53	16.88	1.52	11.12
11C	15.32	10.05	5.79	0.49	3.77
11D	18.40	12.38	7.02	0.65	4.71
11E	231.67	152.34	88.54	7.37	56.43
11F	43.79	29.20	16.77	1.48	10.95
11G	345.21	203.43	124.94	7.65	70.84
11H	13.69	7.93	4.97	0.26	2.70
11I	17.92	9.97	6.41	0.28	3.28
11J	105.61	56.96	37.37	1.38	18.20
11K	107.85	65.87	40.14	2.58	23.16
11L	74.17	42.77	26.81	1.44	14.51
12A	57.10	34.83	20.75	1.52	12.56
12B	143.98	94.20	54.83	4.50	34.87
12C	122.95	81.36	47.17	4.01	30.17
13A	40.06	23.86	14.48	0.98	8.40
13B	21.19	12.77	7.82	0.48	4.47
13C	21.47	12.69	8.30	0.47	3.92
13D	92.16	55.78	34.48	2.15	19.16
13E	7.39	4.69	2.79	0.21	1.69
13F	169.85	105.50	63.96	4.26	37.28
14A	55.47	28.23	18.30	0.75	9.18
14B	28.31	16.08	10.29	0.49	5.30
14C	114.43	55.85	36.74	1.26	17.85
14D	84.23	35.80	24.22	0.56	11.02
Sum	5632.29	2508.29	1607.08	78.61	822.60



Recharge Contour Line

Watershed Boundary

East-West Watershed Divide

Off West Bank Stream Outlets

9 0 9 18 Kilometers

Figure 3-22: Derivation Of The Estimated Water Balance For Various Watersheds Using The GIS Overlay, Intersect Theme, And Dissolve Theme.
(This recharge looks higher than the actual value because it is estimated based on the assumption that no minor losses will occur during the percolation of rainfall into the groundwater aquifers).

Table 3-4 [1]: A Summary Of The Estimated Water Balance For The Eastern And Western Watersheds And For The Watersheds With Stream Outlets Off- And In- The West Bank Boundary

WATERSHED_ID	AREA	RAINFALL	ET_C	RUNOFF	RECHARGE	ET_C	RUN	RECH
	(km^2)	(MCM/Yr)	(MCM/Yr)	(MCM/Yr)	(MCM/Yr)	(%)	(%)	(%)
TOTAL WEST BANK	5632.29	2508.29	1607.08	78.61	822.60	64.07	3.13	32.80
EASTERN WATERSHEDS	2784.63	922.53	627.85	20.94	273.74	68.06	2.27	29.67
WESTERN WATERSHEDS	2847.66	1585.76	979.23	57.67	548.86	61.75	3.64	34.61
OFF WEST BANK OUTLETS	949.82	467.55	311.27	13.37	142.91	66.57	2.86	30.57
IN WEST BANK OUTLETS	4682.46	2040.75	1295.81	65.24	679.69	63.50	3.20	33.31

[1] This recharge looks higher than the actual value because it is estimated based on the assumption that no minor losses will occur during the percolation of rainfall into the groundwater aquifers

Although the eastern watersheds and the western watersheds have roughly the same area, the ratio of the various estimated water balance parameters between the eastern to the western watersheds is around one third. That indicates how much more important the western watersheds are in any future Palestinian water resources management and planning and in any negotiations with Israel on the final status of the Palestinian water resources.

Table 3-4 shows that the estimated ET_c, runoff, and recharge coefficients as a percentage of rainfall in various areas of the West Bank. These ET_c, runoff, and recharge coefficients are ranging from 61% to 68 %, 2.2% to 3.6%, 29% to 35%, respectively.

In addition to the classification of water balance estimations for the various created watersheds, the GIS geo-processing tools were used to derive the water balance on the aquifer by aquifer basis for various groundwater basins of the West Bank and the results are given in the next chapter (Chapter 4).

CHAPTER FOUR

GROUNDWATER RESOURCES MANAGEMENT

The main goal of this chapter is to evaluate the quantitative and qualitative aspects of groundwater resources of the West Bank in terms of water resources management (See the Objective Category #4 and its related specific objectives as is mentioned in Chapter One).

4.1 Literature Review

The first published water research studies in Palestine were done by the Irrigation Service of the British Department of Land Settlement during the British Mandate of Palestine in 1947. That study was published in the form of three volumes which included the "Water Measurements" in Palestine for the periods "Prior to 1944", 1944-1945", and "1945-1946".

The most important and comprehensive groundwater study conducted during the Jordanian administration was executed by a British Consulting Company called Rofe & Raffety through a contract with the Central Water Authority of Jordan. That was a three-year study (1963-1965) including geology and hydrogeology of the West Bank (Rofe & Raffety, 1963 &1965). Different geological and hydro-geological columnar and cross sections were prepared to represent the hydro-stratigraphic units of different aquifers. About 65 detailed colored geological maps (10 km x 10 km, with a scale of 1:20,000) were prepared covering the West Bank region. The nomenclature of stratigraphic classification used by that study is still being used by the Palestinian and Jordanian Hydrogeologists.

The Hydrology Division of the Natural Resources Authority of Jordan (1966) submitted a technical paper which reviewed the flow discharge, the names, the locations, and the coordinates of 240 springs whose discharges were being measured before 1965 in the West Bank. The total number of flowing springs and seeps in the West Bank at that time was 900.

Herzalla (1973) published a report on the groundwater resources of the Jordan Valley which was mainly based on the Rofe & Raffety study mentioned earlier. That report made a comparison between the Jordanian Jordan Valley on the east of the Jordan River and the Palestinian Jordan Valley on the west. Among the main recommendations of that study was to set up a groundwater management program to overcome the overdraft situation since most well fields were overexploited and saline. That program involved a ban on new extraction wells, exploration of new fresh water fields, and controlling the surface water floods of the major side wadis.

Awartani (1992) submitted a report which reviewed the locations, names, coordinates, and the pumping quota of the groundwater wells in the West Bank and Gaza Strip. That study covered those wells which are owned by the Palestinians as well as those which are controlled by the Israeli occupation authorities.

The United Nations (1992) submitted a report on the water resources of the occupied Palestinian territory which included two main sections. The first section dealt with the Jordan River Basin and the groundwater resources involving the occupied Palestinian territories and introduced the major Israeli projects which divert these water resources. The second section focused on the effects wich the Israeli annexation, land, and settlement policies have had on the Palestinian water economy.

Fleischer, Gelberman, and Wolff (1993) submitted a report in which they introduced isobach maps of for various aquifers of the Judea Group.

After the signature of the OSLO Peace Agreement between Israel and the Palestinian Authority in 1993-94, several joint Israeli-Palestinian research projects were launched to deal with proposing different mechanisms to manage and control the shared aquifers. The Palestine Consultancy Group (PCG) and the Hebrew University of Jerusalem (HUJ) (1994a, 1994b, 1996) organized three joint Israeli-Palestinian workshops entitled: "Joint Management of Shared Aquifers" and the Proceedings of these workshops were published in three volumes (I, II, and III). The aim of the workshops was to propose the best way to maintain the sustainability of various shared Israeli-Palestinian aquifers and protect them from deterioration and over pumping.

Lonergan and Brooks (1994) submitted a book entitled: "Watershed, The Role of Fresh Water in the Israeli-Palestinian Conflict". That book reviews the "three crises" of water: the water quantity crisis, which is economic in character; the water quality crisis, which is ecological; and the geo-strategic crisis, which is political. The authors conclude with a set of regional options and policy recommendations. The analysis is limited primarily to the Israeli-Palestinian conflict, but Syrian and Jordanian interests are also treated on occasion.

Gvirtzman (1994) published a paper entitled: “Groundwater Allocation in Judea and Samaria” within the proceedings of the First Israeli-Palestinian International Academic Conference held in Zurich in December 1992. In that paper, he tried to analyze the rights of Palestinians and Israelis in the West Bank Aquifer System based on natural and hydrological aspects as well as on historical issues. His final conclusion was that the actual water needs of the communities that depend on shared waters take precedence over the natural properties of that shared basin, i.e. the priority is usually given to the past and existing water use.

Owiwi, Isaac, and Sabbah (1995) submitted a technical paper on the application of GIS in water resources management in the international symposium organized by Birzeit University and the IHE. The main issue of that paper was introducing an up-to-date GIS methodology to deal with managing the hydrological data which was transferred from Israel to the Palestinian Water Authority within the context of the signed Interim Peace Agreement.

Nuseibeh and Nasser Eddin (1995) have submitted a report on the Palestinian Fresh Water Springs which included the spring names, coordinates, and monthly and bimonthly flow discharge during the period (1970-1994). The number of submitted springs with flow rate exceeding 0.1 liter per second was 114. The 25-Year (1970-1994) average annual flow discharge of these springs was estimated to be 52 MCM/Yr (Isaac and Sabbah, 1998).

Baida et. al. (1995) submitted an internal report entitled: "Characterization and reduction of uncertainty in planning the exploitation and development of groundwater sources in the Cenomanian aquifer in the regions of Jerusalem and the hill range". An earlier report by Tahal investigated the possibility of enhancing the pumpage in the reported area. This report checks the effect of uncertainty in the various parameters of the flow simulation model on the reliability of increased pumping levels. It was found that the possible pumpage is highly sensitive to changes in the levels of rainfall, of transmissivity in the pumped areas, and to changes in the boundary conditions of the model. The results of the study are expressed in terms of the expected availability of the increased pumping capacity as a function of time. It was found that this expectancy will decline in the course of time and will ultimately stabilize at a level lower than the installed pumping capacity.

Rosenthal and Weinberger (1995) submitted an internal report entitled: "Evolution of the hydro-geochemistry of groundwater in the Kurnub Group and its impact on groundwater quality in the southern part of the Western Aquifer Basin". In that report geochemical models were used to identify possible relationships between the chemical composition of the water and the mineral composition of the aquiferous rocks. The chemical reactions between the two phases were found adequate to explain the lithological composition and the facial changes in the different parts of the Kurnub Group. The processes along the flow paths include dissolution, precipitation, degassing, ion exchange as well as mixing of waters. Salinization of the fresh groundwater in the southern flank of the Western Aquifer Basin is explained by mixing with invading Kurnub Group waters.

Avisar (1996) submitted a paper entitled: “The impact of pollutants from anthropogenic sources within a hydrologically sensitive area - Wadi Rabba Watershed - upon groundwater quality”. The catchment area of Wadi Rabba is situated on outcrops of the Western Aquifer Basin. The study was carried out to investigate the influence of anthropogenic pollutants, mainly industrial effluents and urban sewage in the Wadi Rabba catchment area, upon the quality of the underlying groundwater. The study included chemical and bacteriological analyses of the effluents and of the water in surrounding wells. Isotopic analyses of uranium, tritium and radiocarbon content in some of the wells were also made to study the age of the groundwater. These analyses together with stratigraphic cross sections were used to identify the sources of the groundwater. The study revealed local effects of pollution sources on adjacent wells. However, no evidence was found for the effect of pollutant sources over aquiferous outcrops on wells lying downstream due to the differences between the stratigraphic unit and hydraulic characteristics of the outcrops.

Sabbah and Isaac (1996) submitted a paper which evaluated the water resources of the Ramallah district in the West Bank, Palestine. That paper highlighted the available groundwater resources, the groundwater flow pattern as well as the water quality identification. It also showed a comparison between the water consumed by the Palestinians from one side and the Israeli settlers on the other side within the Ramallah District.

The Hydrological Services of Israel (1999) submitted their internal annual hydrologic report which was written in the Hebrew language. That report included some data on the groundwater level, the pumping quantities, concentration of chloride and nitrate for the various Israeli and Palestinian groundwater basins during the period 1970 through 1998. These data don't correspond to single wells but report cells representing well fields based on different areas of groundwater recharge.

The Hydrological Services of Israel (1994) submitted the 1994 Hydrological Yearbook of Israel which was used in this study to get data on all hydrometric network stations operating in streams, reservoirs, Lake Tiberias, the Dead Sea, and at springs. The above report is written mainly in Hebrew with some key legends in English. Some data used in this study were extracted from these reports.

The Applied Research Institute of Jerusalem (2000) had submitted the Atlas of Palestine which includes a chapter on water with the general maps of the drainage systems and the groundwater basins and locations of wells and springs in the West Bank and Gaza Strip.

The most important current groundwater study conducted in Palestine is the United States Agency for International Development (USAID) funded project initiated on July 1st, 1996. That project was a multi-phase, multi-task, multi-disciplinary, water resources project in the West Bank and Gaza Strip aimed at implementing the water-related aspects of the OSLO agreements (1993-1995) signed between the P.L.O. and Israel. The first phase of that project was conducted by the American companies Camp Dresser & McKee (CDM) and Morganti. CDM/Morganti (1996-1998) created a groundwater flow model to study the Sustainable Yield of the Eastern Aquifer Basin (EAB) in the West Bank and submitted their results in 1998 in the form of a final report. The main findings of that model were:

- The total estimated recharge was 197.3 MCM/Yr
- Confined aquifers have a transmissivity ranging from 400 m^2/day to 300,000 m^2/day, while storativity ranges from 0.1 to 1.
- Unconfined aquifers have a specific yield ranging from 1 to 20%
- The flow pattern is very complex and structurally controlled.

The second phase (1998-2002) of the USAID project was conducted by CH2MHILL which finalized the second phase of the model on the Eastern Aquifer Basin but the author has been unable to get a copy of that report yet.

The third phase (2000-2003) was approved by USAID in January 2000 for a three year period to be conducted by CH2MHILL. That phase is dealing with identification of groundwater flow as well as groundwater quality modeling for the northeastern part of the West Bank. The author has not been informed if they published the results of that study yet.

4.2 Geology And Hydrogeology

Understanding the geology, hydrogeology, and hydro-stratigraphy represents the key issues in groundwater research studies aimed at managing the groundwater resources.

4.2.1 Geological History

By the end of the Precambrian era (the time when the earth was created), an ancient ocean existed, the Tethys, approximately in the present location of Mediterranean. It is believed that most of the detritus that resulted from erosion of

Precambrian sediments were carried off into the Tethys. The Tethys invaded and flooded Palestine several times during the geologic history in the form of sea transgression.

In the Paleozoic era, Palestine was invaded by five major transgressions of the Tethys. At the end of this era, substantial sea regression occurred and desert conditions dominated in the country.

In the Mesozoic era, the major geologic formations in the study area were deposited in the form of sedimentary rocks. The largest sea transgression, both in duration and extent, was that of the Middle and Upper Cretaceous which resulted in the formation of the rocks outcropped on the hills of the West Bank of Palestine. In the Cenomanian and Turonian ages of the Upper Cretaceous, thick strata of limestone and dolomite with intercalations of marls were dominated.

In the Cenozoic era, particularly during the Eocene, the study area was characterized by the deposition of Chalks and Nummulitic Limestone. The Lower Miocene, during which simple fold structures were created, is considered the principal stage of mountain-building in the study area. At that time, the structural faults and folds (anticlines, synclines, and monoclines structures) began to appear, together with the uplifting forces producing the West Bank Mountains which are occupying the upstream and the recharge area of the West Bank and some parts of Israel. Shallow environments, inland lakes and transitional continental conditions dominated throughout the Pliocene. In the Pleistocene, most of the present mantle rock and soils of the West Bank were formed (Rofe & Raffety, 1963-1965, Blake & Goldschmidt, 1947).

4.2.2 Structural Geology

The structural geology deals with the various structures which deform the earth crust. Two main structures are the most important in structural geology; these are the structural faults and folds. The structural fault means the fracture in the rock or rock formation into two blocks which are moving in opposite direction to each other which may be vertical, horizontal or a combination of both. If the fault plane is inclined, one of the two blocks on either side of the fault plane is called the hanging wall and the other is known as the footwall. The hanging wall is the surface of the block of rock located above the inclined fault plane, while the footwall is the block of rock located below the inclined fault plane. In some cases, a fault system occurs on two ends of a rock block to form a trench-like structure called a graben which exists in several places of the West Bank. The Dead Sea Jordan Valley is a good example. There are various types of faults such as normal faults, strike-slip faults, grabens, horsts, etc. Figure 4-1 shows a schematic fault structure, with the hanging wall and the footwalls, which forms a graben special structure.

According to the Continental Drift Hypothesis in geology, the West Bank in particular, and Palestine in general was affected by the development of huge geologic structures since it is located within the great Afro-Arabian Shield which had drifted northwards and narrowed the ancient Tethys Sea to the present Mediterranean. As a result of such drifting, the Arabian shield detached from the African Shield along two lines; the Red Sea-Gulf of Suez line and the Aqaba-Wadi Araba-Dead Sea-Jordan Valley line which then extended northwards to Tiberias Lake (Sea of Galilee), Lebanon, Syria and Turkey (Rofe & Raffety, 1963-1965, Blake & Goldschmidt, 1947).

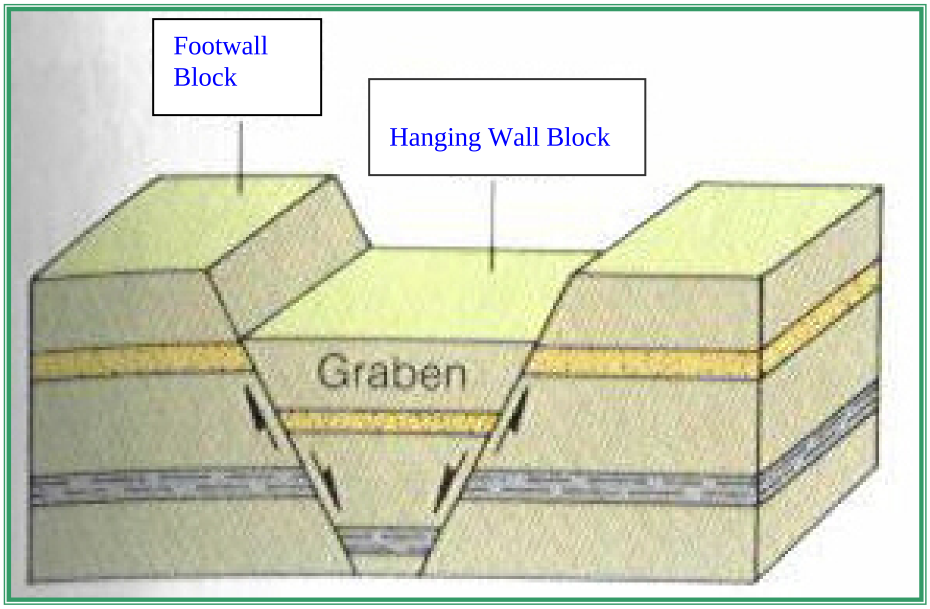


Figure 4-1: Schematic Fault Structure Which Forms A Graben Structure (After Skinner And Porter, 1987) (Similar To The Dead Sea Depression)

Fruend and Garfunkel (1980) submitted a paper on the evolution of the Dead Sea depression in which they explained the relative horizontal motion of two tectonic plates on the east (Arabian Peninsula Plate) and west (Palestine Plate) of the Dead Sea as a result of a great structural fault where the western plate moved to the south and the eastern one moved to the north. Combined with the horizontal displacement, there was a vertical relative movement of the two tectonic plates due to a system of steeply dipping strike slip faults that formed what is known geologically as a graben. Frued Garfunkel also submitted the regional structural map of Palestine with the main geologic transform plate boundary along the Gulf of Aqaba, the Tiberias Lake and the

Dead Sea as shown in Figure 4-2. Fruend and Garfunkel also submitted a geologic cross-section across the Dead Sea depression which shows the formation of thick sediments in the depression and the graben geologic structure affected by structural faults as shown in Figure 4-3.

The mountainous region of the West Bank constitutes a relatively large symmetrical anticline, on which extensive secondary structures of different ages were formed. Figure 4-4 shows a schematic representation of the West Bank by a symmetrical anticline.

Figure 4-5 shows a schematic geological cross section which extends from the Mediterranean Sea on the west to the Jordan River on the east.

From the hydro-geological point of view, such extensive structural patterns affecting the study area controls the groundwater and surface water flow patterns and makes the West Bank a very good recharge area of the various aquifer systems. Also the highly faulted rock formations, which may reach several kilometers in some areas, increase the possibility of hydraulic connection between the various aquifer formations. For example, most springs of the West Bank formed within structural fault zones where the fault acts as a water barrier which transfers water from the affected aquifer formation to the ground surface. On the other hand, some drilling experiments in the West Bank showed that the groundwater wells have higher yield potential in areas with highly structural fault intersections. Combined with the topography of the area, the land forms and drainage patterns are highly determined by the geologic structures.

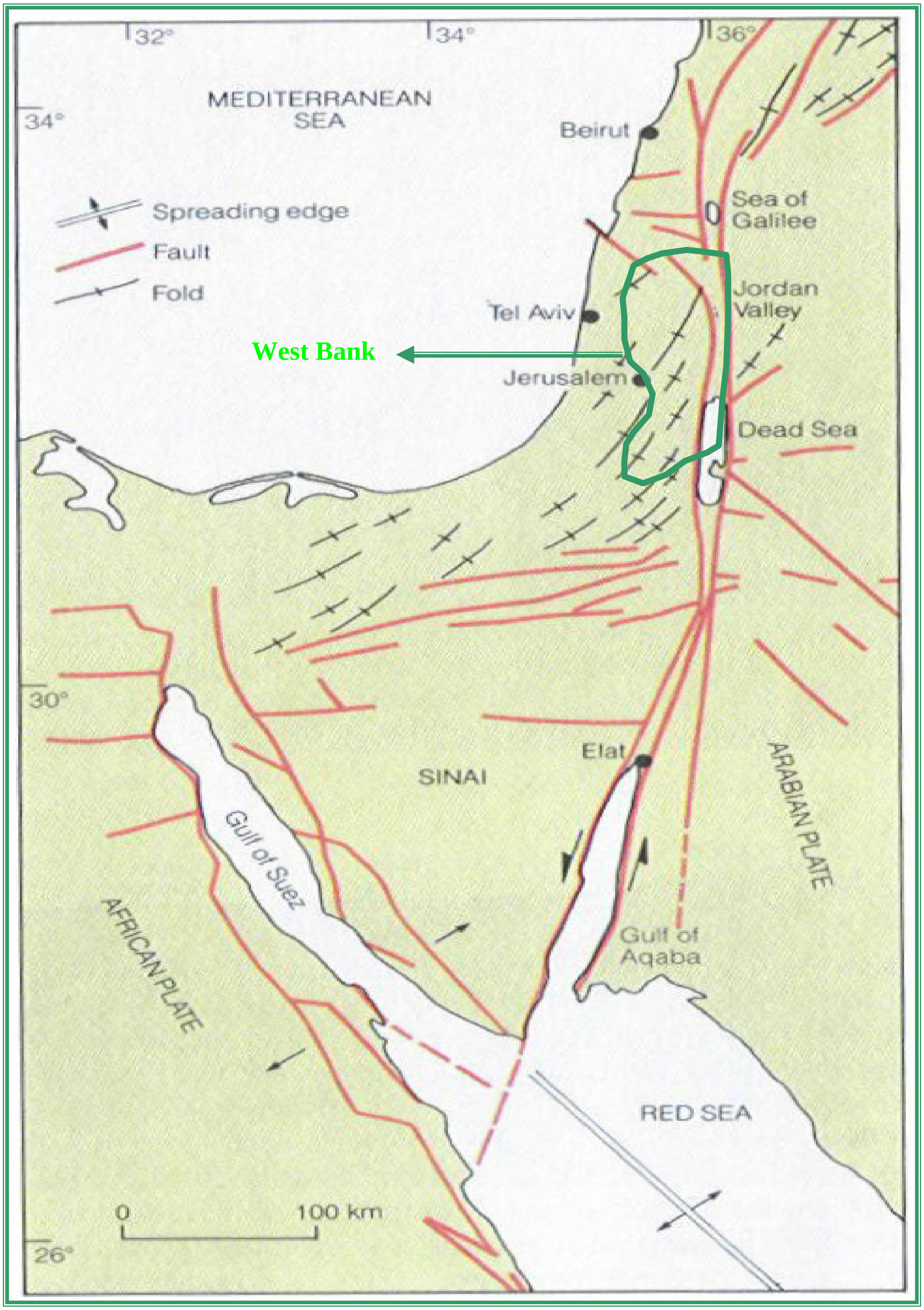


Figure 4-2: The Regional Structural Map Of The West Bank/Palestine Within The Plate Tectonics Theory (Modified From Frued And Garfunkel, 1980)

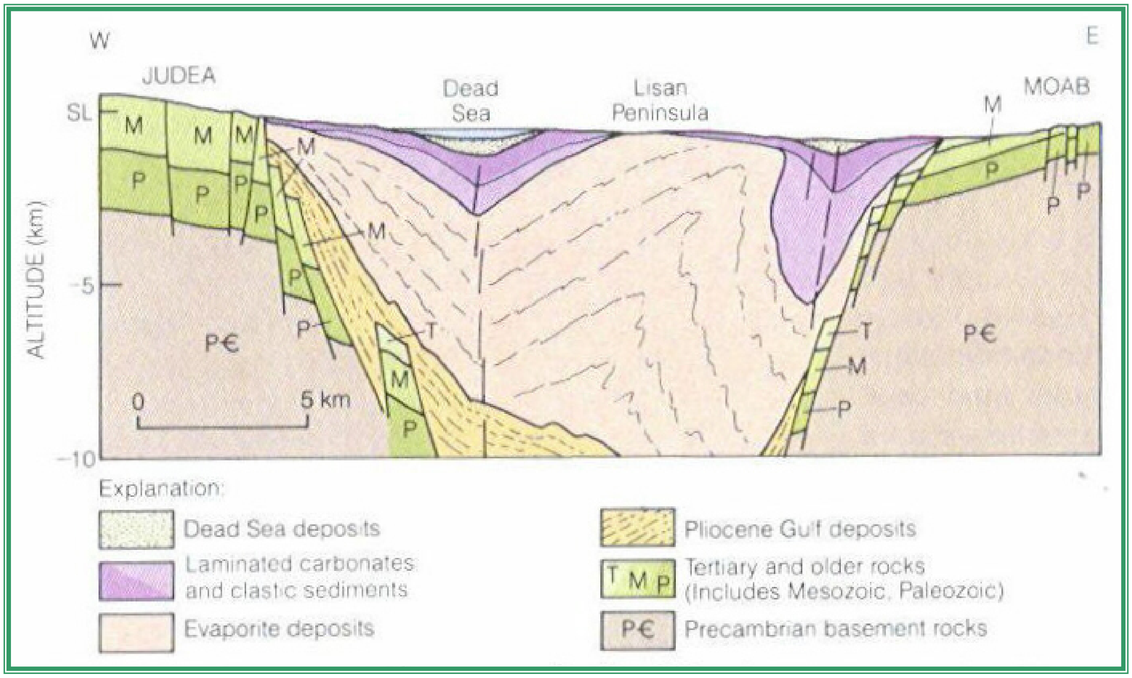


Figure 4-3: Geological Cross-Section Across The Dead Sea Depression And The Graben Geologic Structure (After Fruend And Garfunkel, 1980)

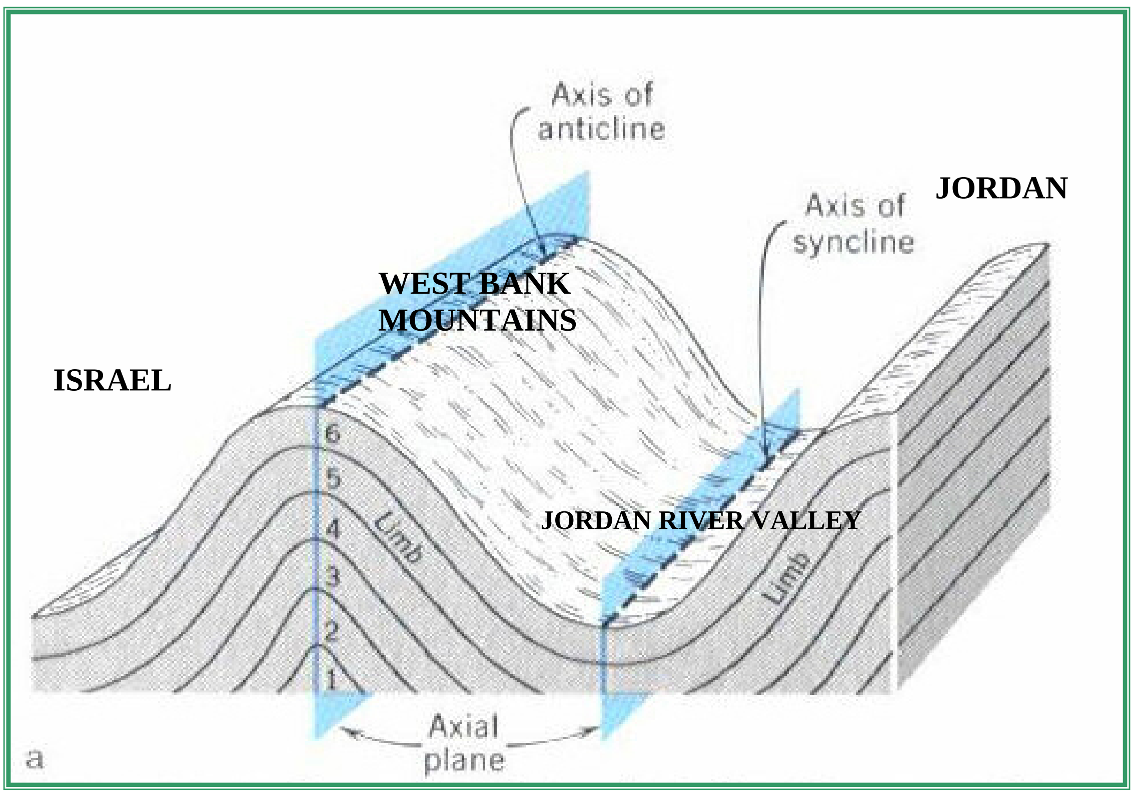
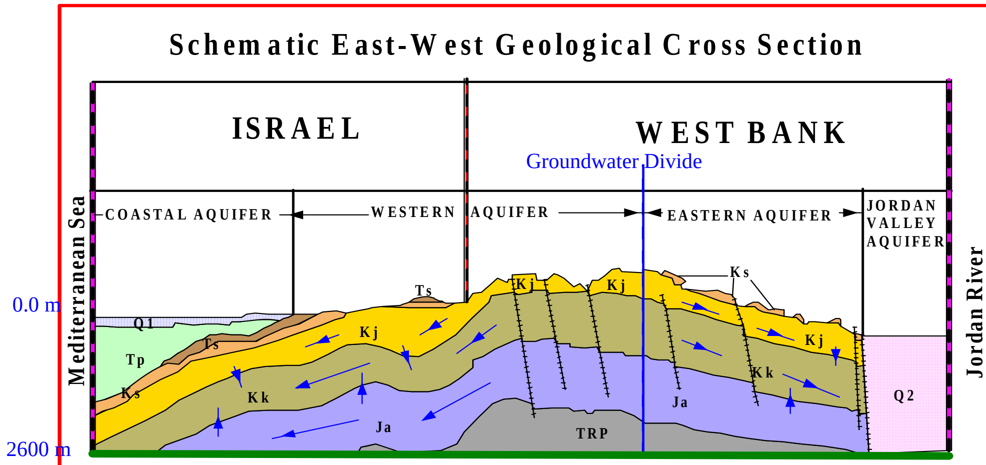


Figure 4-4: Schematic Representation Of The West Bank By A Symmetrical Structural Anticline (*Modified From Skinner And Porter, 1987*)



ID	Israeli Group	Palestinian Group
TRP	Negev & Yam Suf Group	Triassic Group
Ja	Arad Group	Jurassic Group
Kk	Kurnub Group	Kurnub Group
Kj	Judea Group	Ajlun Group
Tp	Saqiya Group	Belqa-Beida Group
Q1	Kurkar Group	Lisan Group
Q2	Jordan Valley Group	Alluvium Group
Ts	Saqiya & Advat Group	Belqa-Beida Group
Ks	Mount Scopus Group	Belqa-Abu Dis Group

Figure 4-5: A Schematic East-West Geological Cross Section (Adapted From Geological Survey Of Israel, 2000)

The predominant feature in the West Bank is the considerable contrast in elevation between the uplands (West Bank Mountains), with an altitude of up to 1000 meters above mean sea level, and the great depth of the Jordan Rift Valley, with a depth of 400 meters below mean sea level. The crest axial line extending from the mountains of Hebron, Jerusalem, Ramallah, and Nablus is parallel to the Jordan Rift Valley in the east of the West Bank. The horizontal distance between the axial line and Jordan River is about 30-40 kilometers. This indicates a steep overall topographic gradient of about 1:20 to the east of the West Bank Mountains and at some locations the gradient is much steeper. For example, the gradient is about 1:90 in Jericho area.

As was mentioned earlier, the West Bank area is affected by intensive structural patterns where the major folds are accompanied by a great number of faults, joints and fractures which make it unique from a geological and hydrological point of view. In addition to the main regional geological structure of the Jordan Rift-Dead Sea Depression, Figure 4-6 shows the hydro-geologic classification of the outcropped geologic formations and major geologic structures affecting the West Bank. According to that figure, there are seven major anticlines, one major monocline, and 10 major faults affecting the West Bank and controlling the flow pattern of groundwater and surface watersheds and their drainage systems.

4.2.3 Hydro-geology and Litho-Stratigraphy

The main aquifer system in the West Bank is of the Albian-Turonian geologic time (Cretaceous age). That aquifer is mainly composed of karstic and permeable limestone and dolomite inter-bedded with argillaceous formations of lower permeability which separate the upper and lower parts of the Judea Group creating two sub-aquifers. Because the study area is located in two political regions; Israel and the West Bank, three sources of geological literature were used: Palestinian, Jordanian (Jordan administered the West Bank from 1949 to 1967), and Israeli. As a result, several terminologies were used. In this section, I integrated the terminologies from all different literature sources in such a format to be acceptable by the three countries' researchers and Hydro-geologists

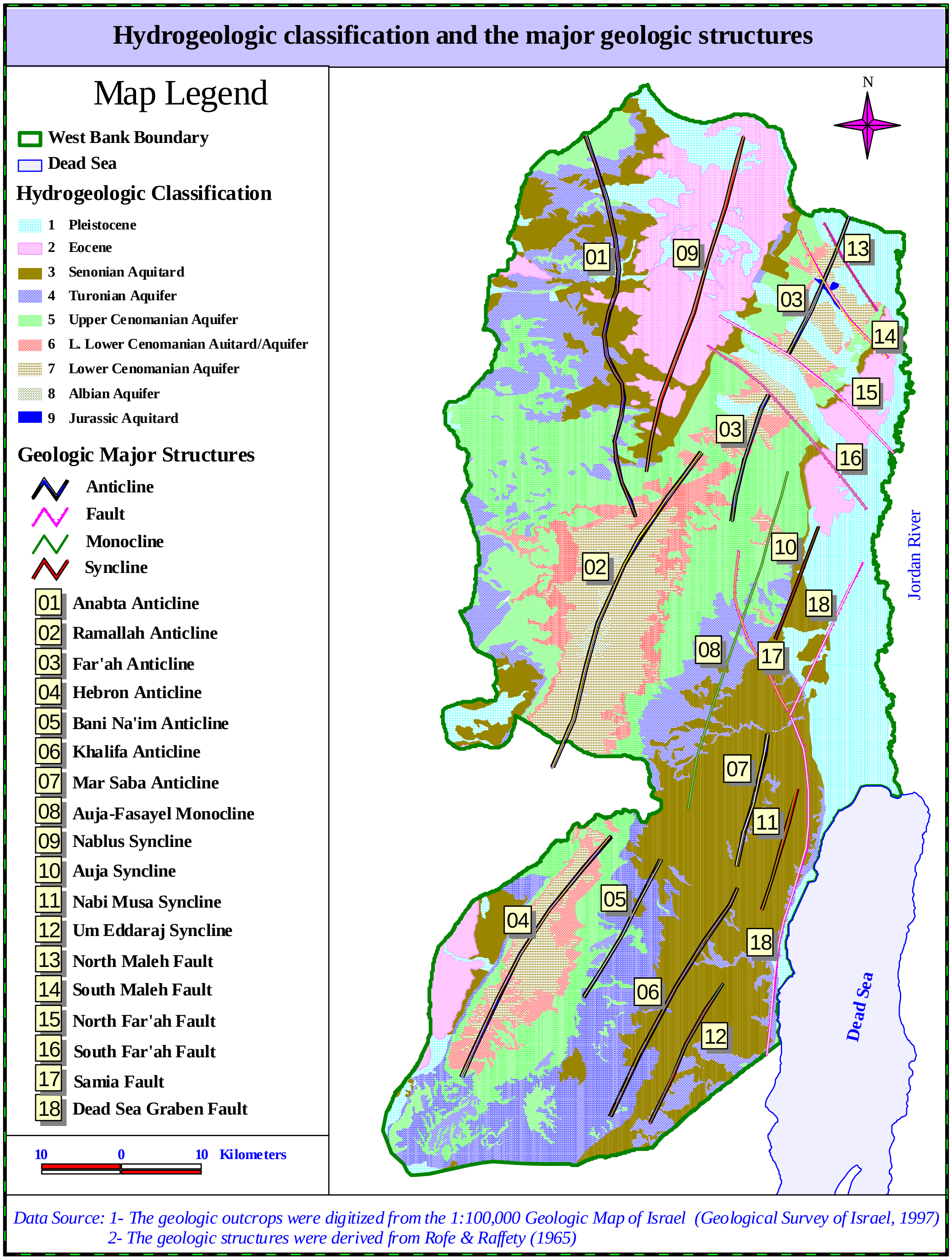


Figure 4-6: Hydro-Geologic Classification Of The Outcropped Geologic Formations And The Major Geologic Structures Of The West Bank

Table 4-1 shows the hydro-stratigraphic column and the classification of the main geologic formations in the study area (Rofe & Raffety (1963-1965), Fleischer, Gelberman, and Wolff (1993), Geological Survey of Israel (1990-2002)). The thicknesses of the geologic formations shown in Table 4-1 are the typical thicknesses which generally mean the average formation's thickness if it wasn't affected by erosion or other weathering processes. So, it may range from zero (in places of outcropping due to erosion and geological structuring) to a much greater thickness than the typical thickness in other places with higher sedimentation rate. In order to know the exact thicknesses of geologic formations in the study area, one must prepare columnar stratigraphic sections in specific locations which show good outcropping. Figure 4-7 shows a columnar stratigraphic section for the Ramallah area which represents the mountainous area of the West Bank where the Upper Cretaceous formations are exposed while the other newer formations (Tertiary and Quaternary formations) were eroded.

Figure 4-8 shows a columnar stratigraphic section for the Bet Shan area which represents the Jordan Valley area where the Tertiary and Quaternary formations are outcropped.

Figure 4-9 shows a columnar stratigraphic section for the Nablus area which represents the northern part of the West Bank. All these columnar stratigraphic sections were prepared by the Geological Survey of Israel.

Table 4-1 Hydro-Stratigraphic Column And The Classification Of The Main Geologic Formations In The Study Area

GEOLOGICAL TIME SCALE					PALESTINIAN / JORDANIAN TERMINOLOGY				ISRAELI TERMINOLOGY						LITHOLOGY	HYDROSTRATIGRAHY
ERA	SYSTEM		EPOCH		GROUP	FORMATION		SYMBOL	GROUP	FORMATION			SYMBOL	SYMBOL	THICKNESS (m)	
CENOZOIC	QUATERNARY			HOLOCENE	RECENT	ALLUVIUM & GRAVELS		Qnv/Qhg	SHAHAF GROUP			MUDS & SANDS	QRD	Al	0 - 20	SOIL COVER
				PLEISTOCENE	COASTAL	COASTAL FORMATION		Qpl	KURKAR GROUP			HEFER FORMATION(COASTAL BASIN)	QK	Qh	50 - 150	COASTAL AQUIFER
					LISAN	LISAN FORMATION		Ll	DEAD SEA GROUP			LISAN & NAHARAYIM FORMATION	Ql	Ql	0 - 50	AQUITARD
	TERTIARY	NEOGENE		PLIOCENE	BEIDA	BEIDA FORMATION		Tpb	SAQIYA GROUP			YAFO FORMATION	P	Ny	10 - 30	AQUIFER/AQUITARD (90 - 275 m)
				MIOCENE								MAHQIM FORMATION	M	Nm	0 - 20	
												ZIQLAG/ZIQIM FORMATION		Nz	0 - 20	
		PALEOGENE		OLIGOCENE	BELQA	JENIN SUB SERIES		Te				BET GUVRIN FORMATION	OL	EOb	30 - 50	
				EOCENE					ADVAT GROUP			MARESHA FORMATION	E	Em	20 - 40	
												ADULAM FORMATION		Ea	30 - 55	
				PALEOCENE		ABU DIS FORMATION		Kaa	Mt. SCOPUS GROUP			TAQIYE FORMATION	PA	Tt	120 - 150	AQUITARD (320 - 515 m)
MESOZOIC	CRETACEOUS	UPPER CRETACEOUS		SENONIAN								GHAREB FORMATION	MA	Kug	50 - 75	
												MISHASH FORMATION	CA	Kumi	40 - 60	
												MENUHA FORMATION	SC	Kum	50 - 70	
				TURONIAN	AJLUN	JERUSALEM FORMATION		Kij	JUDEA GROUP			DALIYAMINA FORMATION	T	Kub	60 - 100	
				UPPER CENOMANIAN		BETHLEHEM FORMATION		Kcb		UPPER NEGBA FTN		VERADIM FORMATION	C3	Kuv	30 - 60	UPPER AQUIFER (240 - 300 m)
												KFAR SHA'UL FORMATION	C2	Kuks	70 - 120	
			UPPER	LOWER CENOMANIAN		HEBRON FORMATION		Kch				AMMINADAV FORMATION	C2	Kua	80 - 105	
			LOWER	LOWER CENOMANIAN		YATTA FORMATION		Kcy		LOWER NEGBA FTN		MOZA FORMATION	C2	Kumo	10 - 20	AQUIFER/AQUITARD (70 - 155 m)
												BEIT MEIR FORMATION	C2 C2	Kubm	60 - 135	
		LOWER CRETACEOUS		UPPER ALBIAN		UPPER BEIT KAHIL FORMATION		KcuBk		UPPER TALME YAFE FTN	YAQUR FORMATION	KESALON FORMATION	C1	Kuke	30 - 50	LOWER AQUIFER (300 - 450 m)
												SOREQ FORMATION		Kus	90 - 150	
						LOWER BEIT KAHIL FORMATION		KclBk				GIV'AT YE'ARIM FTN		Kugy	60 - 90	
												KEFIRA FORMATION	LC	Kk	120 - 160	
				LOWER ALBIAN	KURNUB	KOBAR FORMATION	QATANA FORMATION	Klkq	KURNUB GROUP	LOWER TALME YAFE FTN	YAKHINI FORMATION	QATANA FORMATION	LC	Klq	40 - 50	
							EIN QINYA FORMATION	Klkeq				EIN QINYA FORMATION	LC	Kle	50 - 60	AQUITARD (170 - 210 m)
							TAMMUN FORMATION	Klkt				TAMMUN FORMATION	LC	Kt	80 - 100	

Source: Adapted from Rofe & Raffety (1963-1965), Geological Survey of Israel, (1997-2002), Fleischer, Gelberman, and Wolff (1993).

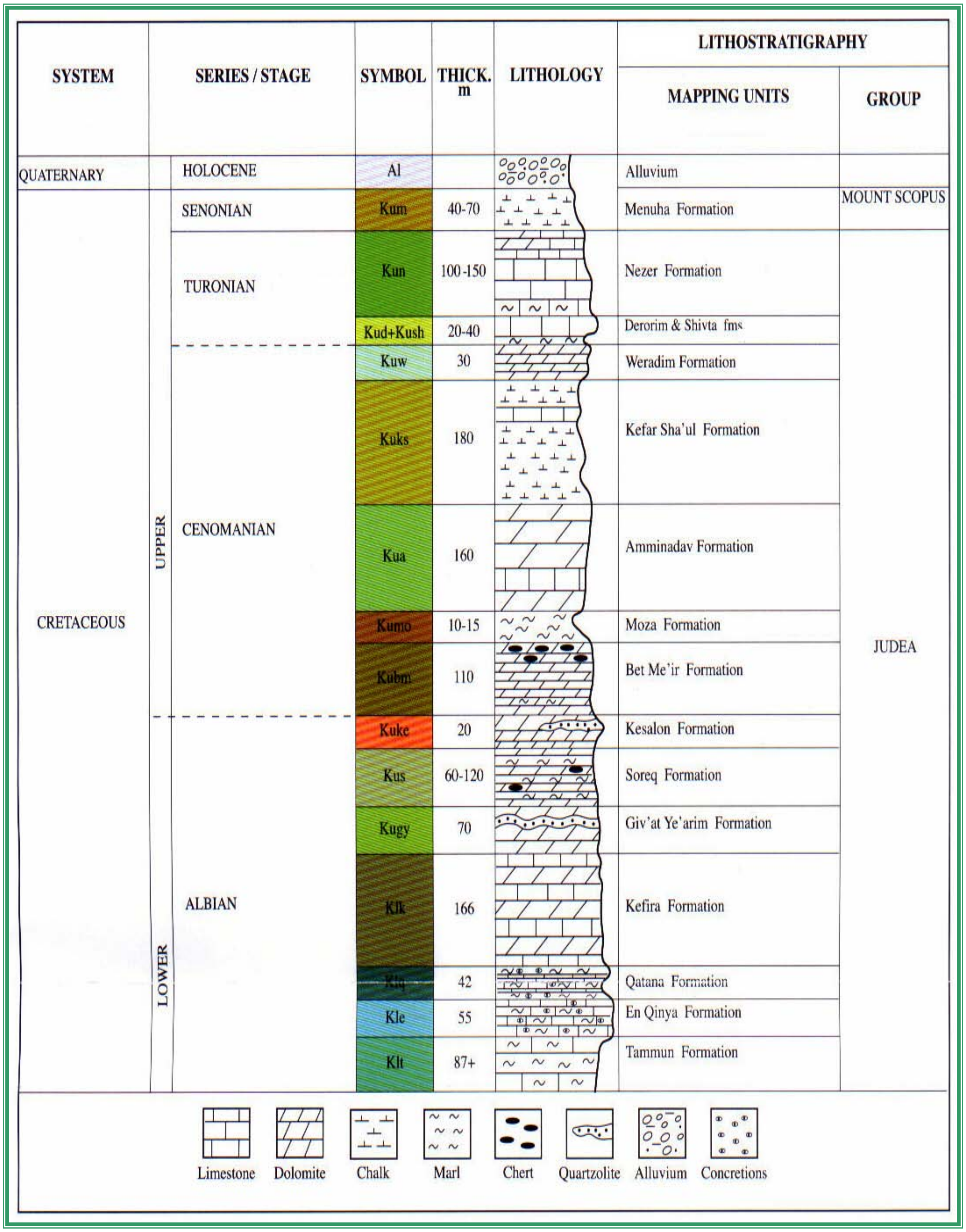


Figure 4-7: Ideal Columnar Stratigraphic Section For Ramallah Area
(Adapted from Shachnai, 2000)

The following sections review the main geologic groups and formations from the oldest to youngest, their lithologic description, typical thicknesses and hydro-geologic classification in the study area.

4.2.3.1 Lower Cretaceous System

Although the Lower Cretaceous is of Berriasian to Albian age which has an approximate thickness of 500 meters, we are not dealing in this study with stratigraphic units older than the Albian age. Two geologic groups of the Albian age represent the Lower Cretaceous in the study area: the upper portion of the Kurnub Group (this is the common name used by Palestinian, Jordanian, and Israeli geologists), and the lower portion of Ajlun Group. The Ajlun Group is used by Jordanian/Palestinian geologists and it is equivalent to the Judea Group in Israeli terminology.

The upper portion of the Kurnub group has a thickness ranging from 170 to 210 meters which consists mainly of limestone, marl, and chert concretions. The main geologic formation of that group is named by the Palestinians as the Kobar Formation which is in turn subdivided into three more specific formations; these are Tammun, Ein Qinya, and Qatana formations from oldest to youngest, respectively. In Israeli terminology, they used Yakhini Formation instead of Kobar Formation.

The Israeli geologists defined one more formation, the Talme Yafe Formation, which replaces both the Yakhini Formation and the overlying Yagur Formation in some places of the study area (See Table 4-1).

The lower portion of Ajlun Group constituting the upper part of the Albian Lower Cretaceous is subdivided by Palestinian/Jordanian geologists into two main formations:

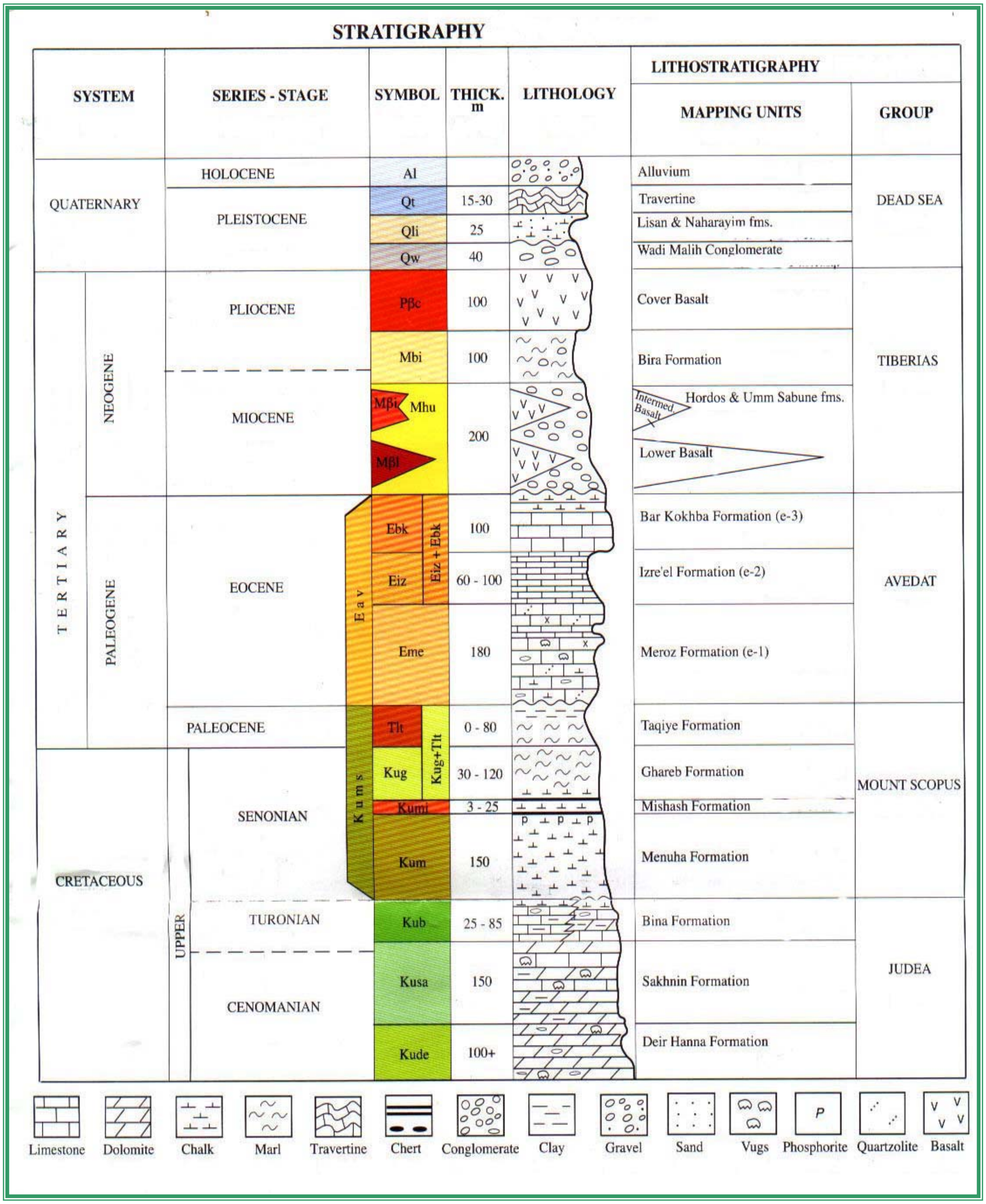


Figure 4-8: Ideal Columnar Stratigraphic Section For Bet Shan Area
(Adapted from Hatzor, 2000)

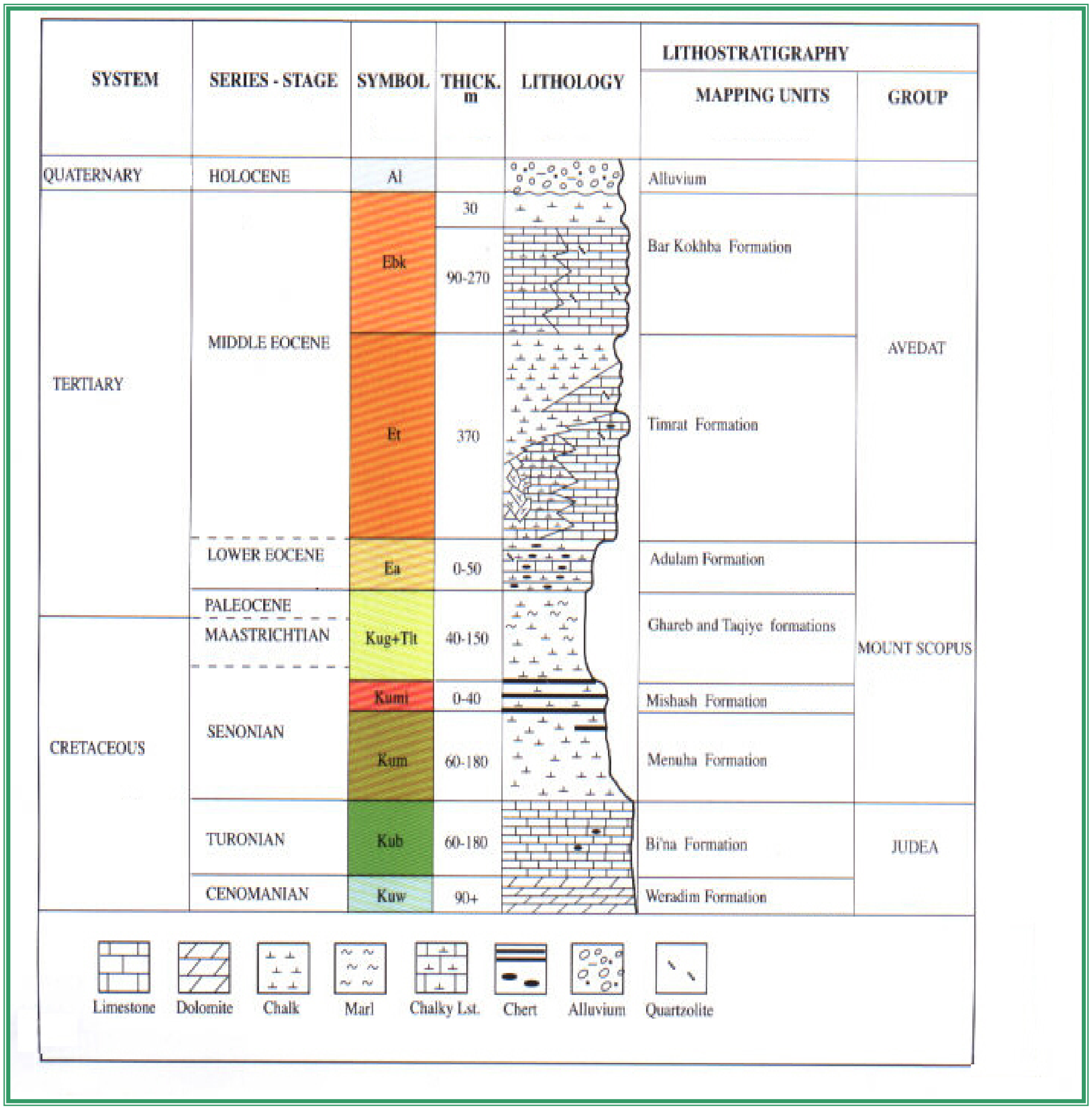


Figure 4-9: Ideal Columnar Stratigraphic Section For Nablus Area (Adapted from Cook, 2000)

Lower Beit Kahil and Upper Beit Kahil which are both equivalent to Yagur Formation (Israeli Terminology). The Lower Beit Kahil Formation which consists of 180-250 meters of alternations of limestone and dolomite with some limited quartzite is equivalent to the Kefira and Giv’at Ye’arim Formations (Israeli Terminology). The base of this formation is marked by thick, massive, iron-stained limestone. It consists of sandy marls and shales into thin-bedded porcellanous limestone with shale, silt and marl containing glauconite. The Upper Beit Kahil Formation which consists of 120-200 meters of limestone and dolomite with marl and some chert is equivalent to the Soreq and Kesalon Formations (Israeli Terminology) (See Table 4-1).

In terms of conceptual and hydrological modeling, the Kobar/Yakhini Formation represents the aquitard lower boundary while the Yagur Formation (the Lower and Upper Beit Kahil Formations) represents the lower aquifer to be modeled in the study area. The Lower Aquifer in the study area (Yagur Formation) has a typical thickness ranging from 300 meters into 450 meters. This formation is outcropped upstream somewhere between the Hebron and Jerusalem mountains which reduces the aquifer thickness to much less than 300 meters. This aquifer formation is tapped by a limited number of wells in the study area and it could be a potential groundwater source in the future. The model developed in this study can be used to highlight such a potential.

4.2.3.2 Upper Cretaceous System

The Upper Cretaceous, with an approximate total thickness of 470 to 740 meters, consists of the upper part of the Ajlun Group (the upper part of Judea Group too) and the lower part of the Belqa Group (the lower part of the Mt. Scopus Group) with Cenomanian to Senonian geologic age. The Upper Cretaceous system constitutes the major aquifer in the region which is normally referred to as the Cenomanian-Turonian Aquifer. The Upper Cretaceous system consists of the following geologic formations, from oldest to youngest (See Table 4-1):

Yatta Formation (Lower Cenomanian)

The Yatta Formation consists of chalky limestone, dolomite, chert, marl and calcareous karstic limestone. The thickness of the formation ranges between 70 and 155 meters. This formation is considered hydro-stratigraphically as an aquitard that separates the underlying Albian Aquifer from the overlying Cenomanian-Turonian Aquifer. The upper most 10 to 20 meters acts as an aquifer. There are also other locations where the Yatta Formation acts as an aquifer, thus merging the upper and lower aquifers in one aquifer. The Yatta Formation is subdivided by Israeli geologists into the Beit Meir (60-135 meters aquitard) and Moza Formations (10-20 meters aquifer) (See Table 4-1).

Hebron Formation (Lower Cenomanian)

The Hebron Formation outcrops in the west and southwest region of the northern half of the West Bank. The formation shows a considerable number of variations. It consists of limestone, dolomitic and chalky limestone that changes laterally to marly limestone, dolomitic limestone, marl and massive dolomite. The formation thickness ranges between 80 and 105 meters and its rocks are characterized by karstification and strong jointing that make it an excellent aquifer. In some places, infiltration of rainwater is restricted by marly limestone and Nari cover. This formation is equivalent to the Ammindav Formation in the Israeli terminology (See Table 4-1).

Bethlehem Formation (Upper Cenomanian)

The Bethlehem Formation is exposed on the flanks of the Anabta Anticline. There are other exposures in the bottoms of wadis and on the tops of hills. Its thickness in the study area ranges from 100 meters into 180 meters except in areas of outcropping which reduce such thickness to zero. The formation consists of dolomite, limestone, chalky marl, marly chalk and chalky limestone. Lithological facies of this formation change from south to north. In the north they show aquifer characteristics, while in the south, they are considered to be a confining aquiclude. It is equivalent to the Kfar Sha'ul and Werdim Formations in Israeli terminology (See Table 4-1).

Jerusalem Formation (Turonian)

The Jerusalem Formation is exposed in the west along the axial area of the Anabta Anticline flank. It is less variable in lithology and thickness than the other formations. Its thickness ranges between 60 and 100 meters and consists of alternating well-bedded limestone, chalky limestone and some marl. Hydrogeologically, this formation can be considered to be good aquifer. It is equivalent to the Daliya/Bina Formation in Israeli terminology (See Table 4-1).

The Hebron, Bethlehem, and Jerusalem Formations are usually considered, from a hydrogeological point of view, as a single system of aquifers bounded below by the Yatta Aquitard and the Cenomanian-Turonian Aquifer. This aquifer represents the upper aquifer of the Western Aquifer Basin under study. The Upper Aquifer is more important than the lower one since 95% of groundwater extraction and spring flow discharge from the western basin passes through this aquifer.

In the Israeli terminology, the Negba Formation which is in turn subdivided into five more specific formations (Beit Meir, Moza, Amminadav, Kfar Sha'ul and Weradim formations) is equivalent to the Yatta, Hebron, and Bethlehem Formations. So, the Israeli terms Negba and Bina/Daliya Formations together compose the Upper Aquifer to be modeled.

Lower Abu Dis Formation (Senonian age)

The Abu Dis Formation represents the lower part of the Belqa Group which is equivalent to the Mt. Scopus Group in the Israeli terminology. The Lower part of the Abu Dis Formation is of Senonian age and is composed of Chalk, Marl and Chert with a thickness ranging from 140 meters in 205 meters. The Senonian Abu Dis Formation is further subdivided by Israeli geologists into three specific formations: the Menuha (Chalk), Meshash (Chert), and Ghareb (Chalk and Marl) formations (See Table 4-1). Hydrologically, the Senonian Chalk is confining the underlying Cenomanian-Turonian Aquifer.

4.2.3.3 <u>Tertiary System</u>

This system is composed of three formations: Upper Abu Dis Formation, the Jenin Sub-series, and the Beida Formation (See Table 4-1):

Upper Abu Dis Formation (Paleocene age)

This formation is equivalent to the Taqiye Formation in the Israeli terminology and is mainly composed of shale and clay rocks. The Paleocene part of Abu Dis Formation has a thickness ranging from 120 meters into 150 meters.

The Jenin Sub-series (Eocene-Oligocene)

The Jenin Sub-series is composed of Chalk, Chert and Nummulites. This sub-series varies greatly in thickness which ranges from zero in the Upper Cretaceous outcrops in the upstream portion of the study area into 145 meters in Israel. To the northeast of the study area (Specifically in Nablus and Jenin areas), this sub-series has a thickness that exceed 500 meters which forms an the Eocene Aquifer is of very good aquifer potential. This sub-series is equivalent to the Advat Group and the lower part of the Saqiya Group. Furthermore, Israeli geologists subdivided the equivalent groups of such sub-series into three formations: the Adulam, Maresha, and Bet Guvrin Formations.

The Beida Formation (Miocene-Pliocene)

The Beida Formation is composed of a mixture of limestone, shale, clay, anhydrite, gravel, conglomerates, chalk and marl. The Israeli equivalent to the Beida Formation is the Saqiya Group with a total thickness ranging from 10 to 70 meters. That group is in turn subdivided by Israeli geologists into three more formations: the Ziqlag, Mavqiim, and Yafo Formations.

The combination of the Abu Dis Formation, the Jenin Sub-series, and the Beida Formation in the study area constitute one aquitard unit with a total thickness greater than 500 meters and in some places downstream the thickness exceeds 1000 meters. The aquitard separates the overlying Coastal Aquifer from the underlying Upper Aquifer (Cenomanian-Turonian Aquifer) in the downstream portion of the study area. In the places of Cenomanian-Turonian outcropping in the West Bank region, there are no such Tertiary Formations.

4.2.3.4 Quaternary System

This system is composed of three formations: the Lisan Formation, the Coastal Plain Formation and the Alluvium Formation.

Lisan Formation (Pleistocene)

The Lisan Formation is exposed along the Rift Valley and extends from Lake Tiberias in the north to about 40 km south of the Dead Sea. Lithologically, it is composed of marl and chalk that consists of thin layers of gypsum and limestone, forming alternating light and dark bands. Fine laminations indicate annual calm deposition. Alternation of dark and light colors indicates seasonal sedimentation. The formation is of variable thickness and becomes more gravely at the margins, while it becomes more calcareous and thick away from the margins. This formation is equivalent to the Kurkar formation of the coastal plain area. This formation has a thickness ranging from 0-50 meters with an average thickness of 25 meters.

Coastal Plain Formation (Pleistocene)

The Coastal Plain Formation is also called the Kurkar Formation which mainly composed of gravel, sands and shales with variable thickness ranging from 50 meters to 150 meters. It constitutes a very good aquifer that provides Israel and the Gaza Strip with about 400 MCM/Yr for different purposes. This means that this aquifer has a potential capacity close to the capacity of the aquifer under study. This formation is equivalent to the Kurkar Group (Hefer Formation) in the Israeli terminology (See Table 4-1).

Alluvium Formation (Holocene)

This formation is mainly composed of alluvial and gravel fans with some mud, soils and sands with a small thickness ranging from zero to twenty meters. The alluvium is generally unconsolidated where it is formed of laminated marls with occasional sands.

The nature of alluvial deposits is affected by the nature of the rock from which they are derived. Alluvial deposits derived from limestone have a red color and those derived from sandstone are sandy. Gravel fans are widely distributed in the study area, especially in the small valleys and streams. The Alluvium Formation plays an important role in recharging the Coastal Aquifer Basin. The Shahaf Group (Mud & Sand Formation) is the equivalent to the Alluvium Formation in Israeli terminology (See Table 4-1).

4.3 The Groundwater Flow Patterns, Groundwater Basins And Their Aquifers

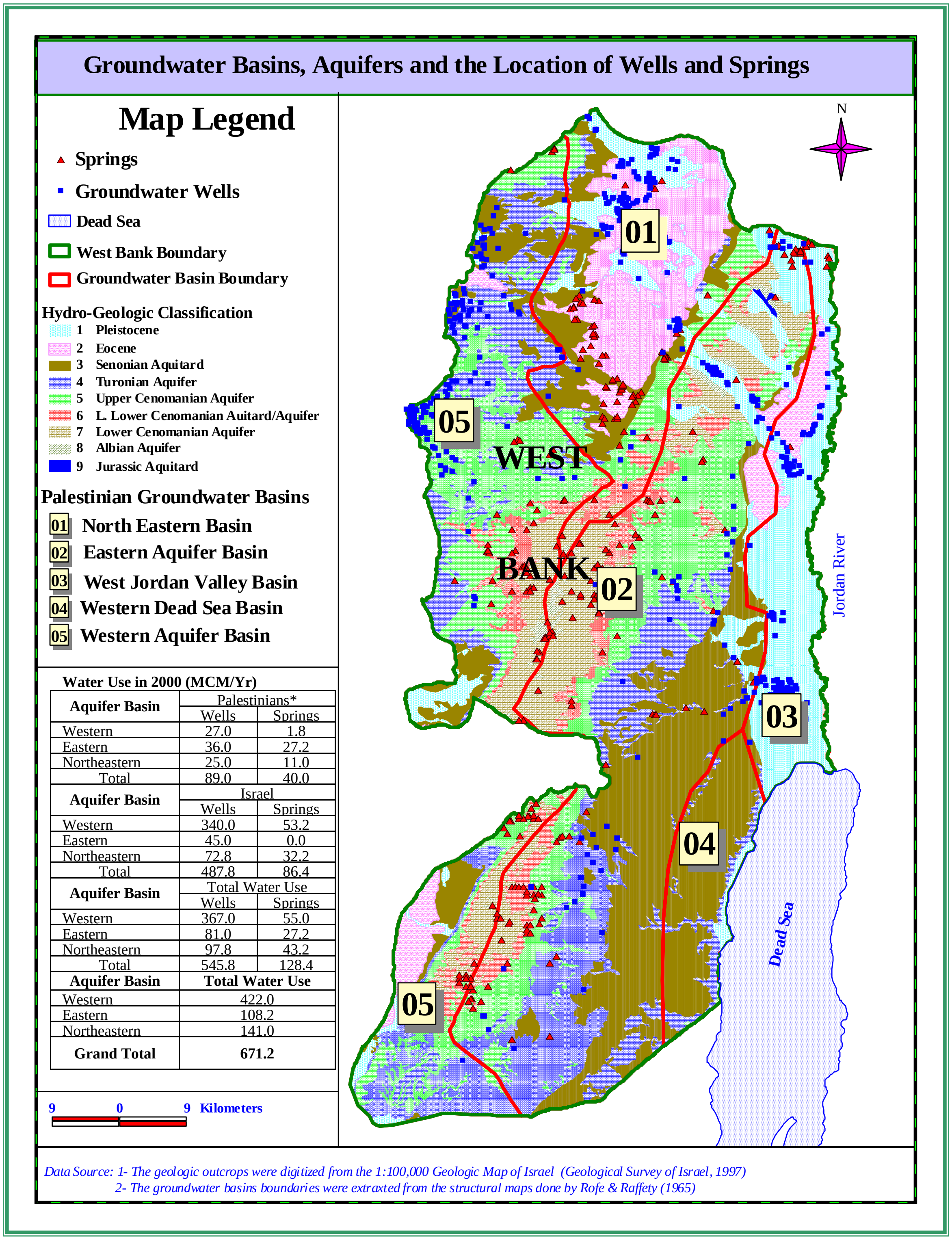
The groundwater in the West Bank flows in three main directions, to the east, to the northeast, and to the west, thus forming three main groundwater basins (referred to as Aquifer Basins in this study) each of which is in turn subdivided into sub-basins. In addition to the Western Aquifer Basin (WAB) and the Northeastern Aquifer Basin (NEAB), some Palestinian and Israeli hydro-geologists are sub-dividing the Eastern Aquifer Basin (EAB) into three smaller sub-basins which are; the Eastern Aquifer Basin (less in area than the overall eastern aquifer basin), the Jordan Valley Floor Aquifer Basin (JVFAB), and the Dead Sea Aquifer Basin (DSAB). In this study, the three main aquifer basins (the Western, the Eastern, and the Northeastern basins) are used.

The aquifer basins are recharged directly from the natural rainfall on the outcropped geologic formations in the West Bank Mountains, forming the phreatic portion, while the major storage areas are in the confined portions which either flows west towards the Israeli underground and the Mediterranean, or flows east towards the Jordan Valley and the Dead Sea. In the Nablus-Jenin areas, the flow goes to the northeast. Figure 4-10 shows the distribution of the groundwater basins, the exposed aquifers, the location of wells and springs, and the water quantities used in the year 1999/2000 from the three main aquifer basins of the West Bank.

4.3.1 The Western Aquifer Basin (WAB)

The Western Aquifer Basin is currently the major groundwater source underlying the West Bank and Israel. It extends from the anticlinal axis of the West Bank Mountains of the Nablus, Ramallah, Jerusalem, and Hebron in the west to the Mediterranean in the west. The WAB aquifers are unconfined in the upstream portion at elevations that may reach 1000 meters above mean sea level, while it is confined in the downstream potion at an elevation of zero above mean sea level. The water quality of the WAB water is very good except for some springs which drain saline water such as the Yarkon and Taninim spring in Israel. The main recharge comes from the West Bank Mountains and their western slopes in the winter seasons. In section 4.5, the 10-Year average (90/91-99/00) annual recharge for the WAB was estimated to be 336.6 MCM/Yr which is assumed to represent the Aquifer Sustainable Yield (ASY) of the WAB aquifers. The groundwater utilization from the various aquifers of the WAB changes from one year to another where the extracted groundwater had exceeded the estimated ASY of the WAB aquifers during the past 10 years.

As shown in Figure 4-10, the 1999/00 groundwater extraction from the WAB was about 367 MCM/Yr of which about 340 MCM/Yr was used by Israel and 27 MCM/Yr



Water Use in 2000 (MCM/Yr)

Aquifer Basin	Palestinians*	
	Wells	Springs
Western	27.0	1.8
Eastern	36.0	27.2
Northeastern	25.0	11.0
Total	89.0	40.0
Aquifer Basin	Israel	
	Wells	Springs
Western	340.0	53.2
Eastern	45.0	0.0
Northeastern	72.8	32.2
Total	487.8	86.4
Aquifer Basin	Total Water Use	
	Wells	Springs
Western	367.0	55.0
Eastern	81.0	27.2
Northeastern	97.8	43.2
Total	545.8	128.4
Aquifer Basin	**Total Water Use**	
Western	422.0	
Eastern	108.2	
Northeastern	141.0	
Grand Total	**671.2**	

Figure 4-10: The Distribution Of Groundwater Basins, The Exposed Aquifers, And The Locations Of Wells And Springs In The West Bank

was used by Palestinians in the West Bank. In addition, several freely flowing springs discharged about 55 MCM/Yr of which 1.8 MCM/Yr was used by the Palestinians of the West Bank and 53.2 MCM/Yr was used by Israel from the two main springs; the Yarkon and the Taninim springs (Israeli Hydrological Services, 2001 and PWA, 2001).

4.3.2 The Eastern Aquifer Basin (EAB)

The Eastern Aquifer Basin (EAB) is completely located and underlying the West Bank i.e. both its recharge and discharge areas are completely located within the West Bank boundary. It extends from the crests of the West Bank Mountains on the west to the Jordan River and the Dead Sea on the east. The aquifer sustainable yield (ASY) of the EAB aquifers was estimated in section 4.5 to be about 202 MCM/yr. The 1999/00 groundwater extraction from this basin was about 81 MCM/yr of which 36 MCM/yr was used by the Palestinians and 45 MCM/yr was used by Israel. The springs of this basin were responsible for discharging another 42.2 MCM/yr with good water quality of which about 28.2 MCM/yr was used by the Palestinians and 14 MCM/yr was used by Israel (Israeli Hydrological Services and PWA, 2001). In addition to the good quality spring water, there is about 45-80 MCM/Yr of saline water discharged by the EAB on the western shore of the Dead Sea.

4.3.3 The Northeastern Aquifer Basin (NEAB)

The Northeastern Aquifer Basin is underlying the northeastern part of the West Bank (underlies the Nablus and Jenin governorates, and the western part of Tubas governorate) and extends under an Israeli area in the Northern Jordan Valley and Betshan area. The estimated 10-Year average sustainable yield of the NEAB is about 141 MCM/Yr. The

1999/00 groundwater extraction from this basin was about 97.8 MCM/yr of which 25 MCM/yr was used by the Palestinians and 72.8 MCM/yr was used by Israel. The springs of this basin were responsible for discharging another 43.2 MCM/yr of which 11 MCM/yr was used by the Palestinians and 32.2 MCM/yr was used by Israel (PWA, 2003).

In order to identify the groundwater flow pattern in various basins, the depth to water table which was being measured on monthly or bi-monthly basis by the Palestinian Water Authority (PWA) for about 163 wells and the static water levels were calculated. Figure 4-11 shows a contour map for the static water levels of the Cenomanian-Turonian Aquifer, which is the main Aquifer in the West Bank. The map of Figure 4-11 shows also the groundwater flow directions. One part of the groundwater flows towards the east and southeast forming the Eastern Aquifer Basin (EAB). A second part flows to the west and northwest forming the Western Aquifer Basin (WAB). A third part flows to the northeast forming the Northeastern Aquifer Basin (NEAB). The figure shows that in some places the groundwater flows in a direction different or opposite to the direction which it really should flow. That is due to the fact that this map is computed based on interpolation techniques which don't take the geological lithology and structures as well as the topography into consideration.

4.4 Groundwater Resources Availability

The groundwater resources of the West Bank consist of both groundwater wells and springs. Figure 4-10 also shows the location map of all the groundwater wells and the major springs in various districts of the West Bank.

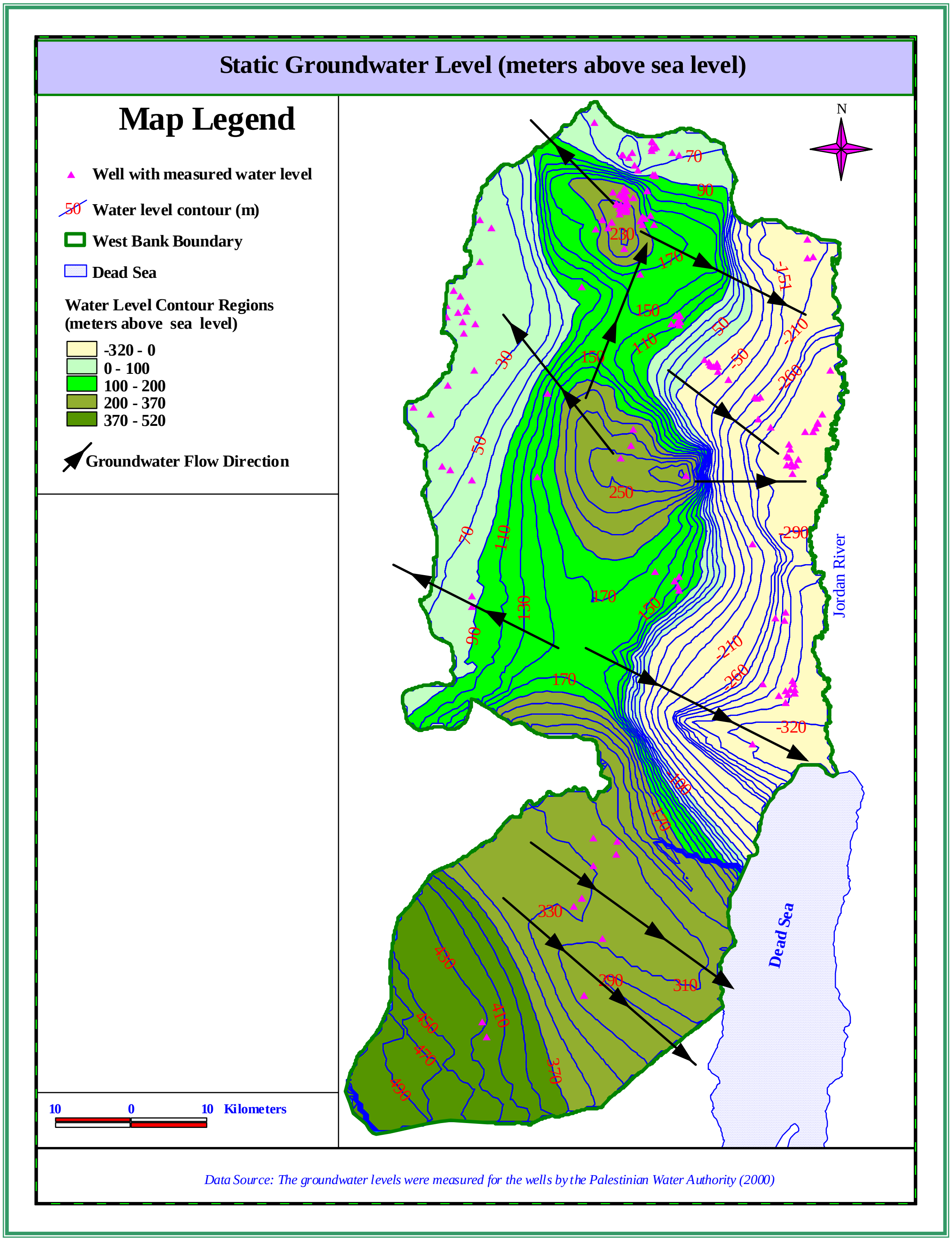


Figure 4-11: Static Groundwater Level In The Groundwater Wells Of The West Bank
(Interpolated from elevation of groundwater above sea level measured by the PWA)

4.4.1 Groundwater Wells

Currently there are about 550 groundwater wells in the West Bank, but some of them are not pumping due to their old infra-structure. These are no longer functioning because and their rehabilitation needs a permit from Israel which can't be obtained easily. The water level in some other wells is so low that the pumps can't reach the water

The current number of working wells is about 370, of which 53 wells are being used for drinking purposes and 323 wells are being used for irrigation (PWA, 2003). The irrigation wells are owned by the private Palestinian sector, while the drinking wells are publicly owned by the Palestinian Water Authority (PWA), the Jerusalem Water Undertaking (JWU), the West Bank Water Department (WBWD), and the Palestinian municipalities and the local councils. As shown in Figure 4-10, the total water use from the West Bank aquifers is about 134.3 MCM/Yr of which 89 MCM/Yr was extracted from wells and 45.3 MCM/Yr was used from the major springs. Another 36 MCM/Yr of water is usually purchased from external sources (such as Mekorot) or from public springs or from private irrigation wells (PWA, 2003). In addition to the Palestinian wells, there are 36 wells owned by the Israeli settlements established in the West Bank after 1967 which produce about 50 MCM/Yr (PWA, 2003).

4.4.2 Springs

There are more than 500 springs and seeps in the West Bank. The number of springs which are subjected to flow measurements on a regular basis by the Palestinian Water Authority is 114. These springs have a minimum flow discharge of 0.1 liters per second. These springs discharge flow in two general directions, east and west. These 114 springs are distributed through 10 spring systems based on their watersheds; each system is subdivided into several groups. Six spring systems with 79 springs discharge their flow to the east towards the Jordan Valley and the Dead Sea and to the northeast towards Betshan area in Israel, while another 4 spring systems with 35 springs discharge their flow to the west. The long term average annual flow discharge of the fresh water springs draining within the West Bank boundary is about 55 MCM/Yr (Isaac and Sabbah, 1998).

The Palestinian water use from the wells and springs within the various aquifer basins of the West Bank in the year 2000 are shown in Figure 4-10.

More details on the water supply and consumption from these sources will be discussed in more detail later in Chapter Six.

4.5 Water Balance And Groundwater Sustainability

The 10-year (1990/91-1999/00) water balance was estimated for the West Bank using a GIS spatial modeling approach. In this section, the water balance results of that approach have been integrated using the GIS geo-processing tools to identify the water balance for the various groundwater basins and their aquifers and aquitards. In chapter three, the water balance was estimated for the whole West Bank region including the outcrops of the various aquifers and aquitards. What is really required is to classify the water balance parameters by the main aquifers and the aquitards as well in order to be used for formulating water resources planning, management and sustainability programs.

Since the recharge coverage was already derived from the rainfall, ETc and the runoff coverages by the Intersect Theme and the Dissolve Theme geo-processes, it includes the values of these water balance parameters in its table of attributes for each derived recharge zone. In this chapter, the water balance was derived based on intersecting the estimated recharge coverage with both the groundwater basins coverage and the coverage of the outcropped geologic formations.

Figure 4-12 shows the derived water balance for the various groundwater basins and their outcropped aquifers and aquitards. Table 4-2 shows the classification of the water balance from the derived coverage of Figure 4-12 for the study area. The table shows that the total groundwater recharge for the West Bank aquifer is about 679 MCM/Yr, while the other 143 MCM/Yr goes to the aquitards of which a part could percolate into the underlying aquifers and indirectly recharge the aquifers. Table 4-2 also shows that the West Bank aquifers could be classified into three systems as follows:

- ❖ The Shallow Aquifer System which consists of the Eocene and the Pleistocene aquifers with a total groundwater recharge of about 163 MCM/Yr. This system is mainly responsible for providing water for the communities located within the boundaries of the NEAB such as the Jenin and Nablus districts.
- ❖ The Upper Aquifer System which consists of the Upper Cenomanian and the Turonian aquifers in terms of geologic age. This system is composed of limestone and dolomite carbonate rock formations which is mainly subdivided between the eastern and the western aquifer basins. The total estimated groundwater recharge of this aquifer is about 364 MCM/Yr.
- ❖ The Lower Aquifer System which consists of two aquifers; the Albian and the Lower Cenomanian aquifers. The total estimated annual groundwater recharge of this system is about 153 MCM/Yr.

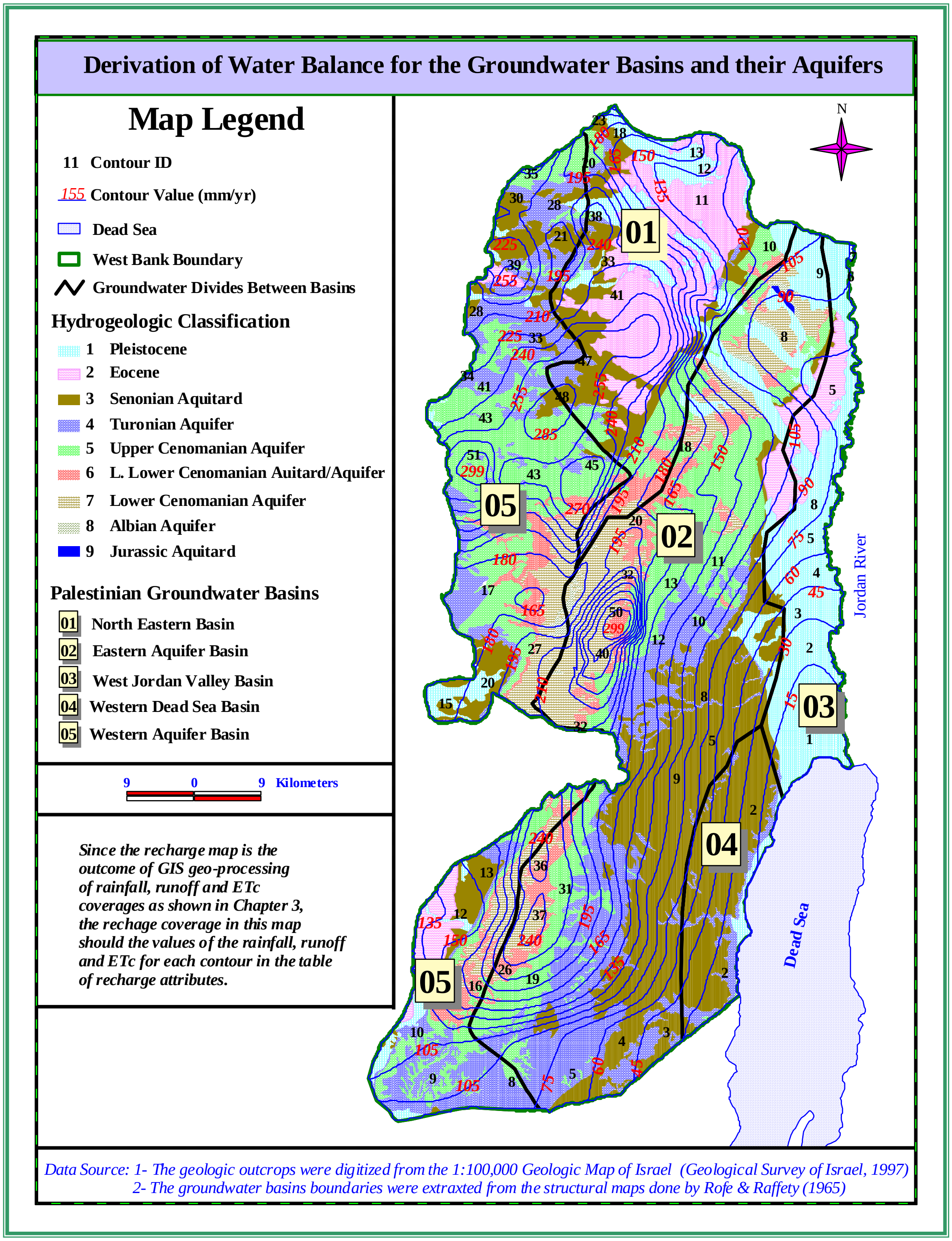


Figure 4-12: Derivation Of The Estimated Water Balance For The Groundwater Basins And Their Aquifers In The West Bank

Table 4-2 [1]**:** Classification Of The Estimated Water Balance By Groundwater Basins And The Geologic Outcrops Of The Various Aquifers Of The West Bank

ID	AQUIFER NAME	EASTERN AQUIFER BASIN				WESTERN AQUIFER BASIN			
		Rainfall	ETC	Runoff	Recharge	Rainfall	ETC	Runoff	Recharge
		MCM/Yr	*MCM/Yr*	*MCM/Yr*	*MCM/Yr*	*MCM/Yr*	*MCM/Yr*	*MCM/Yr*	*MCM/Yr*
1	**PLEISTOCENE AQUIFER**	118.75	88.45	1.37	28.92	44.10	28.86	1.09	14.16
2	**EOCENE AQUIFER**	28.60	19.94	0.30	8.41	41.93	28.00	0.86	13.12
3	**SENONIAN AQUITARD**	194.70	139.23	3.98	51.49	131.79	83.61	4.24	44.11
4	**TURONIAN AQUIFER**	141.99	92.78	3.75	44.05	289.62	182.52	9.76	98.44
5	**UPPER CENOMANIAN AQUIFER**	172.51	110.50	5.02	56.92	424.55	257.58	17.10	149.56
6	**U. LOWER CENOMANIAN AQUIFER**	117.86	73.21	4.12	40.58	110.28	70.19	3.45	36.70
7	**L. LOWER CENOMANIAN AQUIFER**	63.07	39.08	2.25	21.75	87.39	56.35	2.48	28.62
8	**ALBIAN AQUIFER**	6.56	4.34	0.14	2.09	5.70	3.68	0.17	1.87
9	**JURASSIC AQUITARD**	0.69	0.48	0.01	0.20	0	0	0	0
TOTAL WEST BANK AREA		**844.71**	**568.02**	**20.94**	**254.41**	**1135.37**	**710.78**	**39.15**	**386.59**
TOTAL WEST BANK AQUIFER OUTCROPS		**638.63**	**418.49**	**16.50**	**202.13**	**988.18**	**617.80**	**34.96**	**336.64**

** the U. and L. in aquifers #6 and #7 means Upper and Lower, respectively*

ID	AQUIFER NAME	NORTH-EASTERN AQUIFER BASIN				SUMMARY TOTAL			
		Rainfall	ETC	Runoff	Recharge	Rainfall	ETC	Runoff	Recharge
		MCM/Yr	*MCM/Yr*	*MCM/Yr*	*MCM/Yr*	*MCM/Yr*	*MCM/Yr*	*MCM/Yr*	*MCM/Yr*
1	**PLEISTOCENE AQUIFER**	81.95	52.69	2.26	26.96	**244.80**	**170.00**	**4.72**	**70.04**
2	**EOCENE AQUIFER**	207.59	128.9	7.29	71.56	**278.13**	**176.84**	**8.45**	**93.09**
3	**SENONIAN AQUITARD**	114.12	68.75	4.73	40.62	**440.61**	**291.59**	**12.95**	**136.22**
4	**TURONIAN AQUIFER**	27.52	16.56	1.17	9.78	**459.12**	**291.87**	**14.69**	**152.27**
5	**UPPER CENOMANIAN AQUIFER**	62.43	39.49	1.97	21.03	**659.49**	**407.57**	**24.09**	**227.51**
6	**U. LOWER CENOMANIAN AQUIFER**	12.09	7.47	0.44	4.19	**240.23**	**150.87**	**8.01**	**81.48**
7	**L. LOWER CENOMANIAN AQUIFER**	21.81	13.98	0.62	7.2	**172.27**	**109.40**	**5.35**	**57.58**
8	**ALBIAN AQUIFER**	0.72	0.45	0.03	0.25	**12.98**	**8.47**	**0.34**	**4.20**
9	**JURASSIC AQUITARD**	0	0	0	0	**0.69**	**0.48**	**0.01**	**0.20**
TOTAL WEST BANK AREA		**528.2**	**328.3**	**18.5**	**181.6**	**2508.31**	**1607.09**	**78.61**	**822.59**
TOTAL WEST BANK AQUIFER OUTCROPS		**414.1**	**259.5**	**13.77**	**141**	**2040.91**	**1295.81**	**65.23**	**679.73**

[1] The recharge looks higher than the actual value because it is estimated based on the assumption that no minor losses will occur during the percolation of rainfall into the groundwater aquifers

Table 4-2 classifies the estimated annual recharge for the various basins as follows:

- The Eastern Aquifer Basin (EAB) is recharged by about 202.1 MCM/Yr. This recharge value also includes the Jordan Valley Floor and the Dead Sea sub-basins.
- The Western Aquifer Basin (WAB) is recharged by about 336.6 MCM/Yr.
- The North-Eastern Aquifer Basin (NEAB) is recharged by about 141 MCM/Yr.

In order to achieve the groundwater resources sustainability, the total long term water use from any aquifer or groundwater basin should not exceed, in any way, the natural long term groundwater recharge. In addition, to achieve the sustainability in the shared groundwater basins, such groundwater use should not harm the other partner, as in the case of the Palestinian-Israeli situation. By comparing the results of the estimated natural groundwater recharge (Table 4-2) with the total annual groundwater use (Figure 4-10), it can be noted that the total water use in the year 2000 was 671 MCM/Yr, while the total annual recharge was about 679.7 MCM/Yr. So, if it is assumed that the only recharge of the shared Palestinian-Israeli groundwater basins comes from the West Bank, a good water resources sustainability plan should be designed to prevent such over-pumping and restore the safe hydrological situation. In the case of this study and other similar studies of the shared water resources, international co-operation is required to overcome the problem in water sustainability.

4.6 Groundwater Quality

In addition to water quantity and groundwater flow pattern, the groundwater quality is very important to determine suitability of the water for various water use purposes.

During the time period (1995-1998) the author, who acted as the project leader for a three-year project on the water resources and irrigated agriculture in the West Bank, had sampled 225 wells and 25 springs to identify the physical and chemical parameters of the West Bank groundwater resources for various purposes. On site physical measurements were conducted for that water samples which then subjected to routine laboratory analysis for the major cations and anions. The onsite physical measurements included the electric conductivity, the pH, and temperature. The routine chemical analysis included the major ions of Calcium (Ca^{++}), Magnesium (Mg^{++}), Sodium (Na^{+}), and Potassium (K^{+}), Bicarbonates (HCO_3^{-}), Sulfates (SO_4^{--}), Chloride (Cl^{-}), and Nitrates (NO_3^{-}) (Isaac and Sabbah, 1998). Fifteen representative water samples were selected from that punch of samples to give an idea about the water quality trends in the study area. Of these samples, 10 samples were representing the wells and 5 samples were representing the springs.

Table 4-3 shows the results of the measured physical and chemical water quality parameters for the fifteen representative water samples.

Table 4-1: The Physical And Chemical Water Quality Parameters For 15 Selected Water Samples (Isaac and Sabbah, 1998)

NO.	Source Name	District	EC	Temp	pH	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{--}	Cl^{-}	NO_3^{-}
			µS/cm	^{0}C		(milli equivalents/liter)							
1	Abdul Fattah Majjad	Qalqilya	566	22.2	6.9	3.79	3.87	0.91	0.03	7.22	0.91	0.98	0.10
2	Abdul Lateef Mur'eb	Tulkarm	586	22.8	7.0	1.90	1.97	1.26	0.08	4.01	0.54	0.73	0.16
3	ADSP Al Wad Well	Jericho	440	23.3	7.3	6.79	11.68	28.06	1.82	10.68	5.28	37.24	0.08
4	Al Auja Spring	Jericho	386	22.8	8.3	1.50	1.65	1.74	0.05	4.36	0.51	0.20	0.04
5	Al Bathan No.1	Nablus	203	21.7	7.3	2.15	3.29	0.74	0.03	4.98	0.65	0.89	0.03
6	Al Delbeh Spring	Nablus	448	22.4	7.3	2.75	0.74	1.04	0.03	3.35	0.47	0.88	0.06
7	Al Far'a Spring	Nablus	144	23.3	7.5	2.99	1.32	1.04	0.05	4.35	0.56	0.66	0.06
8	Al Matweh Spring	Nablus	509	21.2	7.2	3.64	2.39	1.31	0.31	5.98	0.80	1.15	0.18
9	Arrabeh Well	Jenin	268	24.1	7.1	2.50	3.62	0.74	0.08	5.90	0.73	0.63	0.06
10	Ein Al Sultan Spring	Jericho	445	22.2	7.3	1.85	1.81	1.87	0.05	5.01	0.58	0.22	0.07
11	Ghaleb El Ahed	Jenin	1258	22.7	6.8	5.99	4.20	5.74	0.15	9.85	1.74	5.79	0.16
12	Hamdallah H. Abdu	Nablus	1640	24.9	7.0	6.44	3.62	14.44	0.61	8.72	2.73	15.94	0.14
13	Kufr Zibad Well	Qalqilya	569	24.0	7.1	5.44	3.37	0.74	0.08	8.53	1.02	0.71	0.06
14	Ref'at al Faris	Nablus	562	22.6	6.8	5.34	1.15	1.04	0.03	6.15	0.80	1.02	0.13
15	Zubaida AL Said	Tulkarm	467	23.1	7.0	4.79	2.80	1.04	0.03	7.46	0.92	0.86	0.08

Figure 4-13 shows the presentation of the electric conductivity data on columnar bar diagram for the fifteen representative samples. Figure 4-14 shows the presentation of the major ions on a horizontal bar diagram with the anions given negative values to identify the hydro-chemical water types.

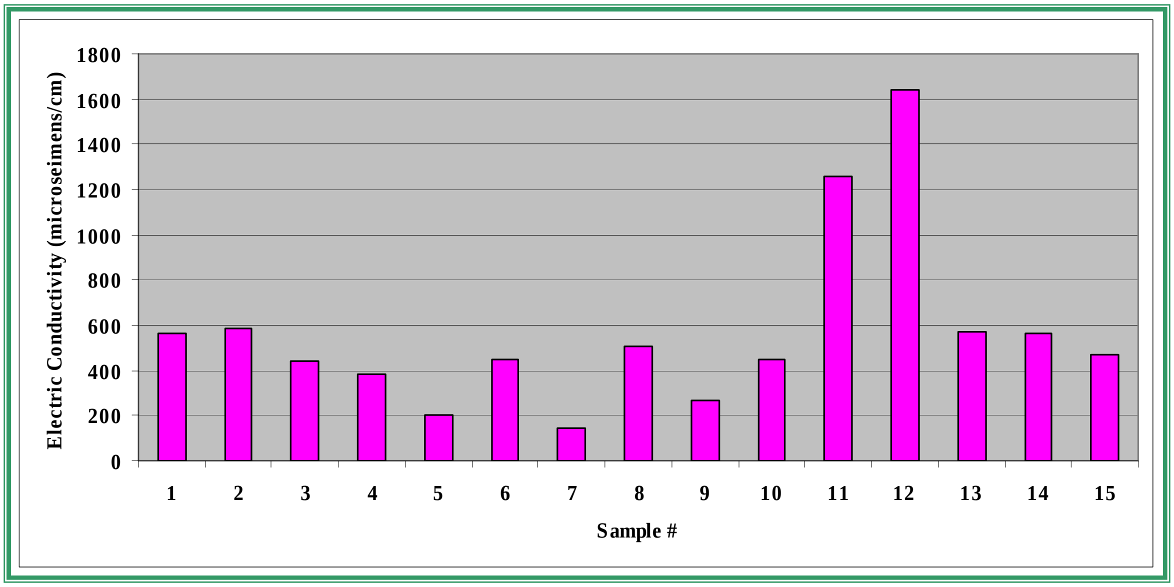


Figure 4-13: Presentation Of Electric Conductivity For The 15 Selected Water Samples

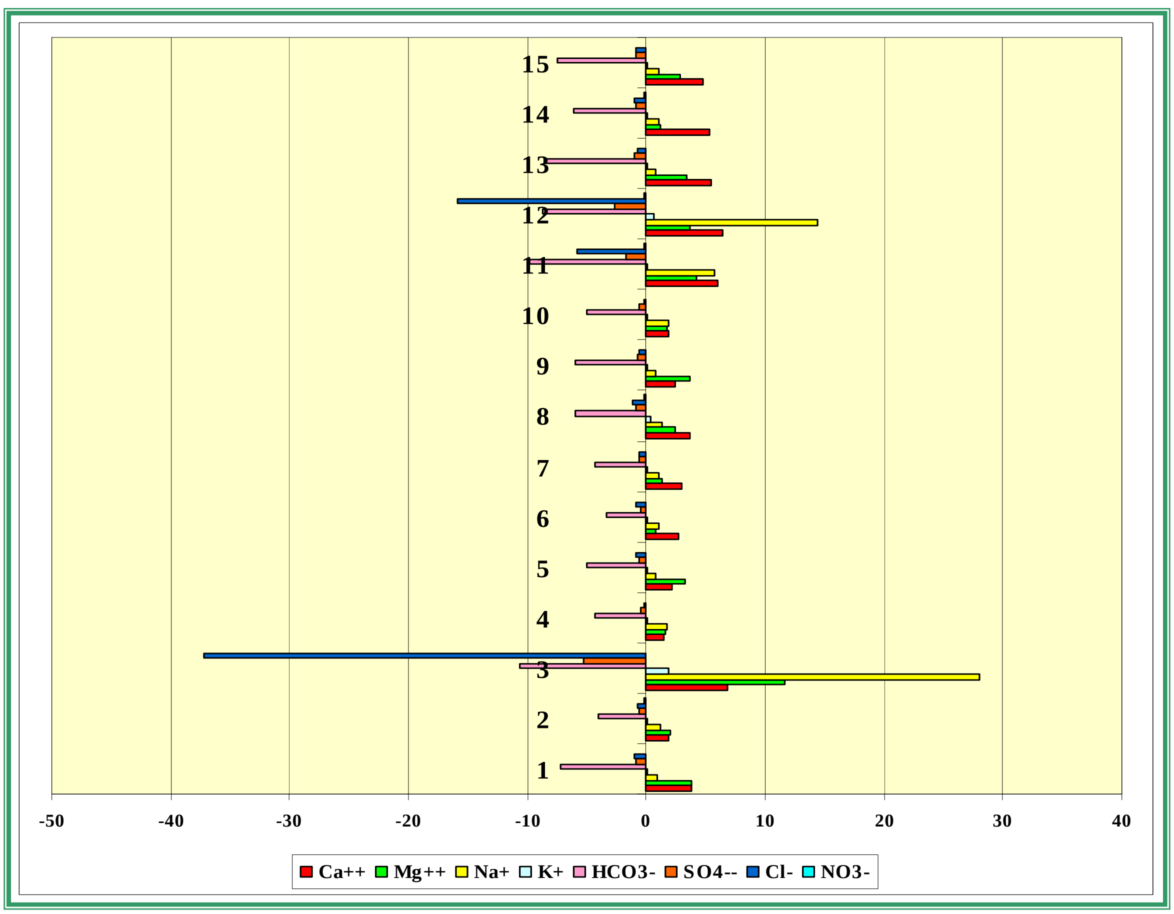


Figure 4-14: Presentation Of Hydro-chemical Data On Horizontal Bar Diagram

As shown in Table 4-3 and Figure 4-13, the highest value of the electric conductivity was recorder for Jericho representative well, then the Jenin representative well. The electric conductivity is a salinity indicator which means that high electric conductivity is attributed to high salinity and high value of total dissolved solids. The two wells of high values of electric conductivity are not good for drinking and caution should be taken when using that source in irrigation. The pH and temperature are within the acceptable limits for all water use purposes.

As shown in Figure 4-14, three water types exist. These water types are:

- Ca^{++}/HCO_3^- water type where Calcium (Ca^{++}) is the predominant cation and the Bicarbonate (HCO_3^-) is the predominant anion in nine of the tested water samples. This water type is attributed to the Calcite which is one of the main constituents of the West Bank carbonate aquifers.
- Mg^{++}/HCO_3^- water type where Magnesium (Mg^{++}) is the predominant cation and the Bicarbonate (HCO_3^-) is the predominant anion in five of the tested water samples. This water type is attributed to dolomite which is one of the main constituents of the West Bank carbonate aquifers.
- Na^+/Cl^- water type where Sodium (Na^+) is the predominant cation and the Chloride (Cl^-) is the predominant anion in one of the tested water samples for a well located in Jericho. This water type indicates that the wells of Jericho are tapping the shallow Pleistocene aquifer which is composed of sand stone and marl with intercalations of Gypsum, Halite, and Anhydrite. The Gypsum, Halite, and Anhydrite were deposited during the formation of the Lisan Lake which was extending from north of the Tiberias Lake into south of the Dead Sea.

Partial chemical analysis for Chloride and Nitrate was performed on 261 wells and 35 springs by the PWA in 1998 (PWA, 2003). Appendix B shows the Chloride and Nitrates for these 296 wells and springs.

Figures 4-15 and 4-16 show the spatial distribution maps of Chloride and Nitrates in groundwater by using the PWA data.

Figure 4-15 shows that the highest values of Chloride concentration are located in the Jordan Valley area. According to the Jordanian Standards for drinking water, the red region is not acceptable for drinking. Figure 4-15 also shows that most wells in the Jordan Valley including Jericho are located in this region

Figure 4-16 shows that the Nitrates concentration exceeding the acceptable limits for drinking purposes whereas there in no restriction on water use for irrigation purposes. The regions with Nitrates greater than 45 ppm are located in the urban centers such as Jenin, Tulkarm, Tubas, Qalqiliya, Jerusalem, and Bethlehem cities due to the sewage leakage in that areas.

For the groundwater quality to be sustainable in that regions, high care should be taken by maintaining, rehabilitating, and installing new sewage networks in order to minimize the leakage and to protect the groundwater from such pollutants.

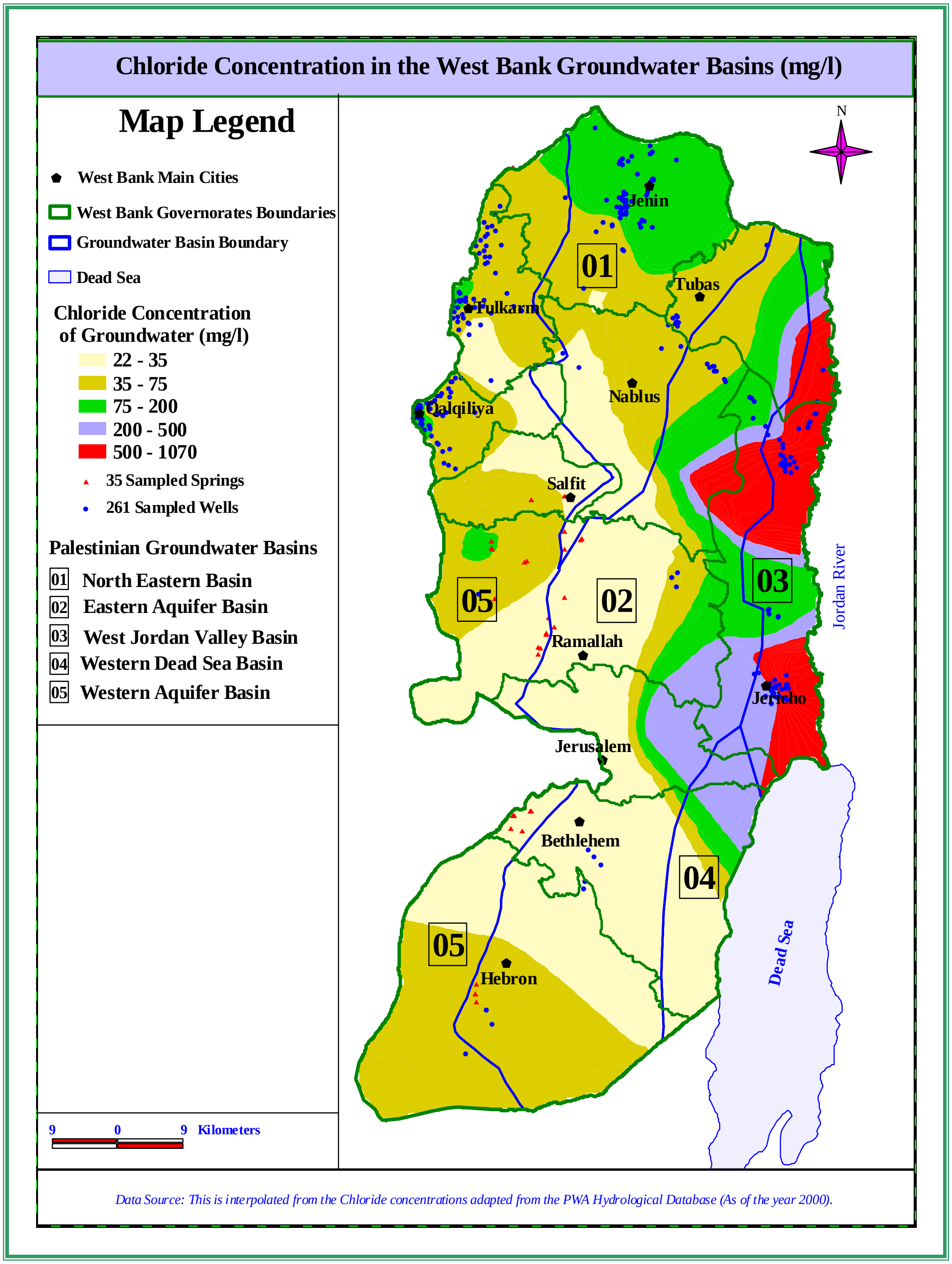


Figure 4-15: Spatial Map Showing The Distribution Of Chloride In Groundwater In The West Bank

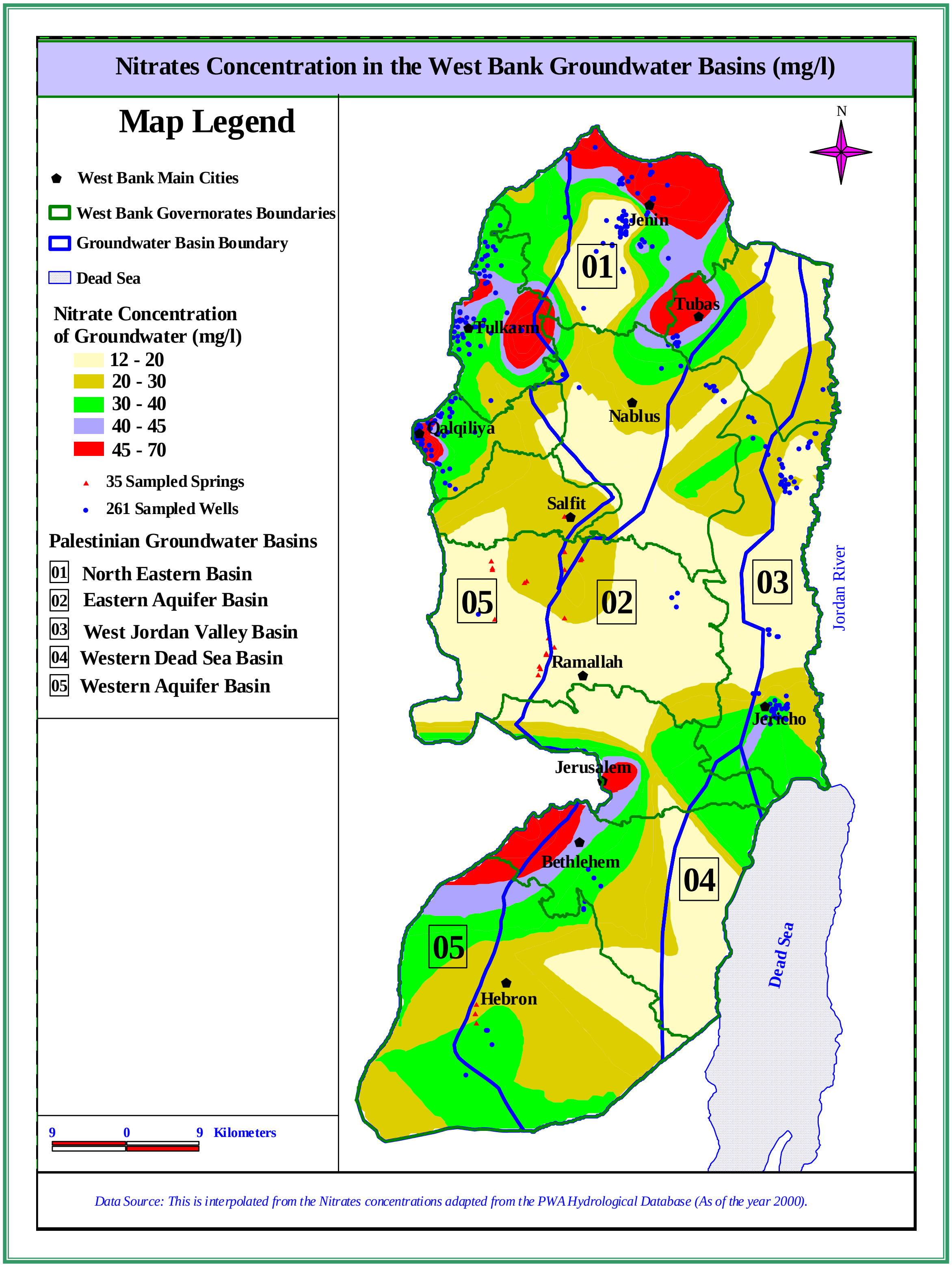


Figure 4-16: Spatial Map Showing The Distribution Of Nitrates In Groundwater In The West Bank

CHAPTER FIVE

GROUNDWATER FLOW MODELING OF THE WESTERN AQUIFER BASIN

Groundwater modeling techniques are new useful tools in studying groundwater management. The primary goal of this research was to build a conceptual model for the Western Aquifer Basin (WAB) and to convert it into a numerical flow model that could be calibrated for both the steady state and the transient conditions to check the degree of match between the simulated and the measured heads or flows. The anticipated outcome of that model was to simulate the groundwater flow and to study the hydraulic response of the aquifers composing the model under assumed groundwater usage scenarios. Figure 5-1 shows the location map of the WAB.

Six-months after starting that research, a wave of violence started in the Palestine-Israel area (the area under study) at the beginning of the year 2001which resulted in deterioration of confidence between the PNA and Israel. As a result, all the peace agreements and memoranda of understanding that were signed during the 1993-2000 period were frozen. The water resources issues were negatively affected by that political situation because the track of hydrological data exchange, which was included within the context of the OSLO I and II agreements, had been frozen. Thus getting a complete set of hydrological data on the WAB became the most challenging and complicated effort.

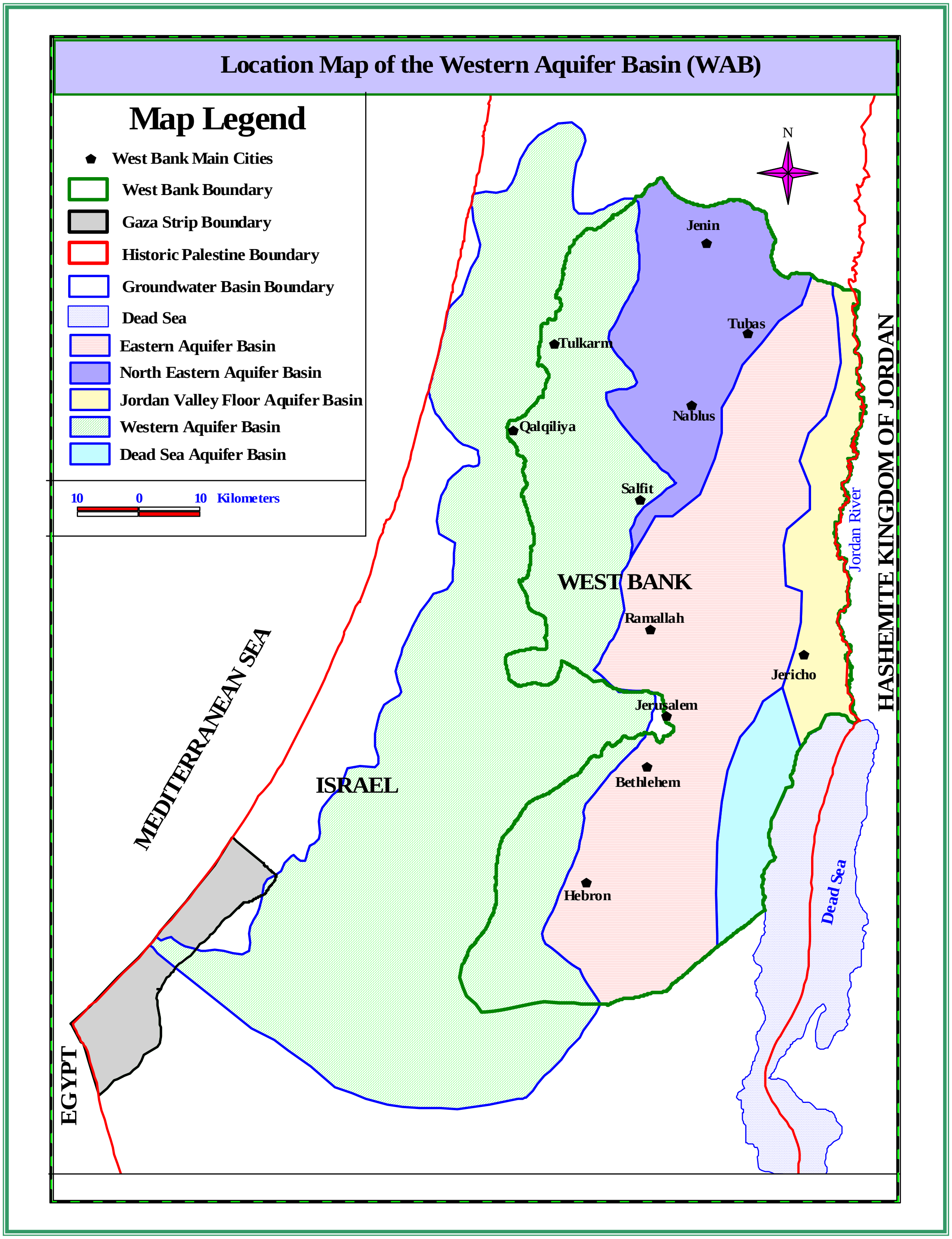


Figure 5-1: The Location Map Of The Western Aquifer Basin (WAB)

On the Palestinian portion of the WAB (Figure 5-1), the author was able to get enough time-series hydrological and meteorological data from the various Palestinian institutions listed in Chapter One, especially from the Palestinian Water Authority (PWA).

On the Israeli portion of the WAB, which constitutes about 60% of its area, insufficient data were obtained that could help setup a useful calibrated groundwater flow model for transient conditions that could be used for long term forecasting of the groundwater flow patterns and the water balance under an assumed water pumping scenarios.

The above mentioned complexities in getting enough hydrological data led the author to restrict this research study for the time being to the steady state groundwater flow model rather than the transient groundwater flow model. This means that the work on the transient groundwater flow model will be delayed for the time being until more reliable and enough hydrological data becomes available to the author to build a more useful model.

Based on these changes, the author modified the objectives of his research study to be more fruitful and professional. The currently modified research focuses on integrating the Water Resources Management Plan for the West Bank. Within this modified research study, the author has included the steady state groundwater flow model of the WAB as a case study to be the first step on the way of a more comprehensive groundwater management models. The main components of this steady state groundwater flow model include an excellent conceptual model and a well calibrated numerical groundwater flow model for steady state conditions.

5.1 The Study Area

The WAB has an area of 5500 km^2 which emerges from the mountains of the West Bank in the east and extends westward towards the Mediterranean Sea (Figure 5-1). It has two natural spring outlets which are the Auja and Tamaseeh springs located in the downstream portion within the Israeli boundaries. In the Israeli literature these springs are known as the Yarkon and Taninim springs which are the Hebrew translations from their original Arabic names (Auja and Tamaseeh). Also the Israeli literature is naming the WAB after the names of these two springs as the "Yarkon-Taninim Aquifer". Another common Israeli name for WAB is the "Judea Group Aquifer" since the Judea Group is the main geologic formation constituting this groundwater basin. The WAB is internationally known as the "Western Mountain Aquifer" since it emerges from the mountains of the West Bank (Blake and Goldschmidt, 1947). Since the WAB is composed of multi-aquifers, the Palestinians are sometimes naming it as the "Western Aquifer System". In this research, the Western Aquifer Basin (WAB) is used which is common for the Palestinian, the Israeli, and the international hydrologists and water experts.

The total estimated sustainable yield of the WAB aquifers is about 366 MCM/Yr based on the long term average recharge from natural rainfall as estimated by the author earlier in Chapter Three. Forty percent of its area is located within the West Bank boundary and the rest area is located within the Israeli boundary. As estimated earlier in Chapter Four, 92% of the groundwater recharge of the WAB comes from the mountains of the West Bank. Currently, Israel is using about 92% of the WAB's sustainable yield and the Palestinians of the West Bank are using the other 8%.

The WAB can be subdivided into three regions of hydrologic meaning which are: the West Bank mountainous region which represents its upstream phreatic portion, the foothill region which is overlain by impervious rocks confining the WAB, and the coastal plain region which confines the WAB except for certain foothill sections in which there is a direct connection between the coastal and the WAB aquifers.

The main aquifer system in the study area (WAB) is of the Albian-Turonian geologic time (Cretaceous Era). That aquifer is mainly composed of karstic permeable limestone and dolomite inter-bedded with argillaceous formations of lower permeability which separate the upper and lower parts of the Judea Group creating two sub-aquifers. Table 4-1, mentioned earlier in chapter four, provides all the terminologies, the schematic stratigraphic column, and the ideal thicknesses of the various rock formations in the study area. Given the comparison of the terminology provided by Table 4-1, any Palestinian, Israeli, Jordanian, and/or international Hydrologist or water expert can understand the formation naming.

5.2 Literature Review

Azmon and Gilad (1981) submitted the results of a hydro-ecological study on the percolation of Jerusalem sewage from the Soreq River into the karstic calcareous outcrops of the underlying mountainous aquifers of the WAB. The study was based on one to three months records of discharge losses between adjacent hydrometric stations during a five year period where the only explanation was percolation of sewage into the outcropped aquifer. The full text of this study is not available for the author due to political restrictions.

Fleischer, Gelberman and Wolff (1993) summarized the results of their geological-geophysical study of the Judea Group for the area extending from the northern Negev to Mt. Carmel. That study defined the structural configuration of the Judea Group, the main aquifer formation underlying Palestine and Israel, and provided the lithological information including facies changes. It also included the topographic and isopach maps of the main lithological units, lithostratigraphic cross sections, and ratio maps for the entire group and for each specific lithological unit. The full text of this study is not available for the author due to political restrictions.

Weinberger et al (1994), submitted a paper on the Yarkon-Taninim groundwater basin which included a rough review of the main accepted conventions regarding the conceptual model of the WAB which underlies the Palestine-Israel area. That review pointed out puzzling and contradictory phenomena and emphasized questionable issues that indicated the need for periodically revising concepts in view of accumulating knowledge on that basin.

Bachmat (1995) submitted a rough water supply steady state hydrologic model for the WAB where each administrative district was considered as one reporting cell. In his model he introduced a mathematical formulation of a multi-cell groundwater flow model. He calibrated his model based on the water level of 20 wells (one representative well for each administrative district). He actually created two models: a one-layer aquifer model as well as a two-layer aquifer model. In both models he got the same groundwater flow patterns except that the hydraulic barrier connecting the upper aquifer layer with the lower aquifer layer in the central part of the two-layer model had created a stagnant zone in the south-central part of the basin. The results of that model were questionable because he used a very coarse grid with 5 km x 5 km cell size and only 20 head observations were used to calibrate such large area model (about 5500 km^2).

Gutman and Zukerman (1995) did a groundwater modeling study on the Yarkon-Taninim-Beer-Sheva Basin to identify their sources of salinity. The results of that study are not available for the public because the report was written in Hebrew and can only be reviewed in the library of the Hydrological Services of Israel.

Rosenthal, E., B. Jones, & G. Weinberger (1995) submitted an internal report entitled: "Evolution of the hydro-geochemistry of groundwater in the Kurnub Group and its impact on groundwater quality in the southern part of the WAB". In that report geochemical models were used to identify possible relationships between the chemical composition of the water and the mineral composition of the aquiferous rocks. The chemical reactions between the two phases were found adequate to explain the lithological composition and the facial changes in the different parts of the Kurnub Group. The processes along the flow paths include dissolution, precipitation, degassing, ion exchange as well as mixing of waters. Salinization of the fresh groundwater in the southern flank of the WAB is explained by mixing with invading Kurnub Group waters.

Avisar, D. (1996) submitted a paper entitled: “The impact of pollutants from anthropogenic sources within a hydrologically sensitive area - Wadi Rabba Watershed - upon groundwater quality”. The catchment area of Wadi Rabba is situated on outcrops of the WAB. The study was carried out to investigate the influence of anthropogenic pollutants, mainly industrial effluents and urban sewage in the Wadi Rabba catchment area, upon the quality of the underlying groundwater. The study included chemical and bacteriological analyses of the effluents and of the water in surrounding wells. Isotopic analyses of uranium, tritium and radiocarbon content in some of the wells were also made to study the age of the groundwater. These analyses together with stratigraphic cross sections were used to identify the sources of the groundwater. The study revealed local effects of pollution sources on adjacent wells. However, no evidence was found for the effect of pollutant sources over aquiferous outcrops on wells lying downstream due to the differences between the stratigraphic unit and hydraulic characteristics of the outcrops.

Rothenthal, Weinberger and Kronfeld (1999) submitted a paper on the salinization of the lower layer of the southern part of the Judea Group Aquifer which constitutes the main aquifer of WAB. The study showed that salinization is related to Pliocene and Neogene erosion channels where the sea transgression at that time filled such channels with evaporates such as halite and gypsum which infiltrated into the Judea Group through the overlying rock formations.

The Palestine Consultancy Group and the Truman Institute of the Hebrew University (2000) submitted the final report of the six-year project (1994-1999) on the Environmental Protection of the Shared Israeli-Palestinian Mountain Aquifer. That report included a very course groundwater model simulating the transfer of pollutants from sewage water through the vadoze zone to the saturated zone of the WAB. The main result of that study indicates how easy the Palestinian groundwater can be affected by the human activities in the main urban communities of the West Bank and Israel.

All the previous studies didn't answer the question of the sources of the WAB's water and/or the sources of high water salinity in the Taninim Spring. It is estimated that the long term recharge of the WAB for the year 2000 was 366 MCM/Yr, whereas the 2000 water use from the WAB was 367 MCM/Yr plus the free outflow of about 55 MCM/Yr of spring water (from the Yarkon and Taninim). This means that the spring out flow comes from unknown source other than the natural recharge from rainfall. At the time when the quality water extracted from the WAB through wells is excellent, the water quality of the Taninim Spring is too saline and its flow is constant whatever the hydrologic year is wet or dry. The proposed model is trying to answer these queries.

5.3 Theoretical Groundwater Modeling Background

A groundwater flow model helps to understand the hydro-geologic flow system in terms of its past and present behavior and predict its future behavior under certain conditions. Generally, the model refers to a simplified representation of a real system to facilitate the understandings of the system. A groundwater flow model can be constructed to simulate either steady state or transient conditions.

The first step in building a groundwater flow model is to setup the conceptual model which is the approximation of the real field domain by a physical model to be solved mathematically.

The second step in building the groundwater flow model is to relate the conceptual model to a database of attributes and maps in order to convert it into a numerical flow model with coarse or fine grid cells based on the required accuracy.

The third step in building the model is to solve the mathematical partial differential equation representing the flow system based on certain boundary conditions to get the spatial distribution of head in different grid cells of the model domain. The general partial differential equation to be solved in the case is:

$$K_x \frac{\delta^2 h}{\delta x^2} + K_y \frac{\delta^2 h}{\delta y^2} + K_z \frac{\delta^2 h}{\delta z^2} = S_s \frac{\delta h}{\delta t} - R \qquad \textbf{(5-1)}$$

(Anderson and Woessner, 1992).

Where;

K_x, K_y, and K_z =	Hydraulic conductivities in x, y, and z directions, respectively.
h =	head
t =	time
S_s =	specific storage which represents the water volume stored in a unit volume of the aquifer per unit change in head
R =	source/sink term which could represent injection wells, extraction wells, rainfall/recharge, or evaporation

The term ($S_s \frac{\delta h}{\delta t} - R$) is equal to zero for steady state i.e. Equation 5-1 becomes:

$$K_x \frac{\delta^2 h}{\delta x^2} + K_y \frac{\delta^2 h}{\delta y^2} + K_z \frac{\delta^2 h}{\delta z^2} = 0 \qquad \textbf{(5-2)}$$

Equations 5-1 and 5-2 can only be applicable under the following assumptions:

1. The aquifer is saturated
2. Darcy's law is valid
3. Mass is conserved i.e. inflow-outflow = change in storage + sources and sinks

The fourth step is to calibrate the model based on observed data in order to get the best fit between measured and computed fields. The calibrated model can then be used to predict the future behavior of the aquifer system under certain conditions.

5.4 The Conceptual Model

The conceptual model deals mainly with the layers representing the aquifer geology, the lateral extent of the region to be modeled, the boundary conditions, the sources and sinks, the head and flow observations, etc.

In order to facilitate the development of a conceptual model of the study area, two west-east hydro-geological cross sections were prepared for the WAB. Figure 5-2 shows the hydro-geological cross section which represents the northern portion of the WAB. Figure 5-3 shows the hydro-geological cross section which represents the central portion of the WAB.

The hydro-stratigraphic classification indicates that the best representation of the aquifer system of the WAB is by a three-dimensional three layer models. The upper aquifer layer has a variable thickness ranging from zero meters in the outcrops over the mountains of the West Bank to 450 meters in some places downstream. The upper

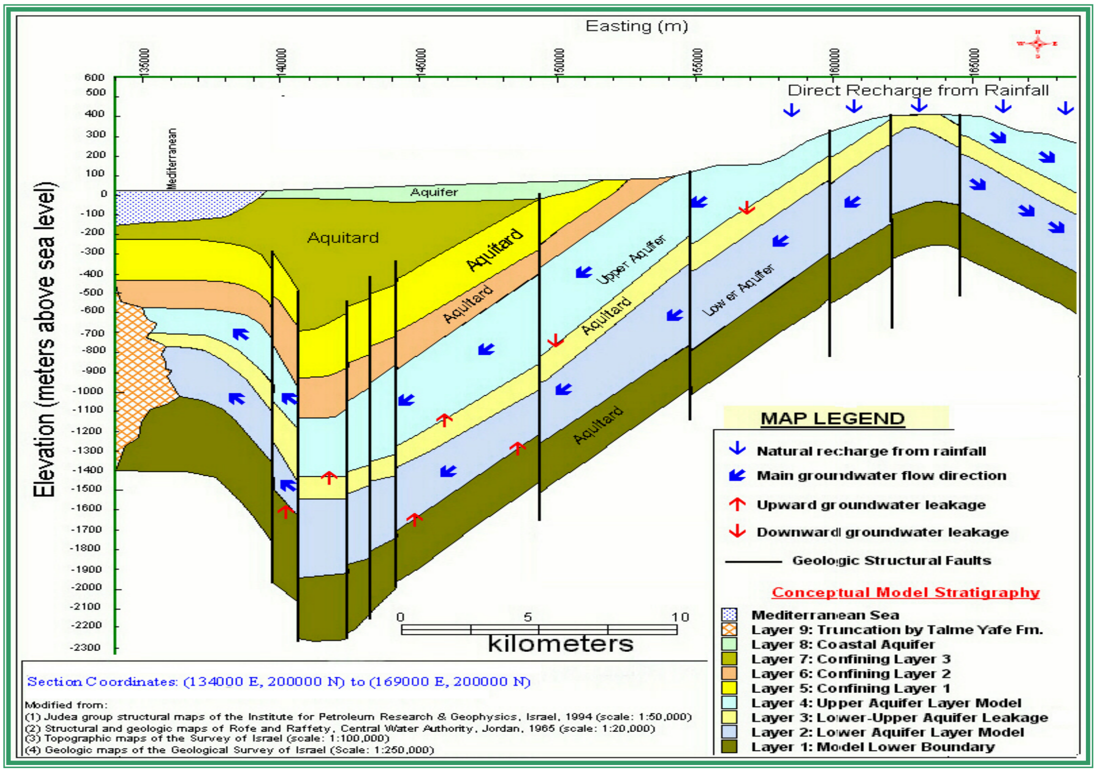


Figure 5-2: East-West Hydro-Geological Cross Section Of The WAB (Northern Area)

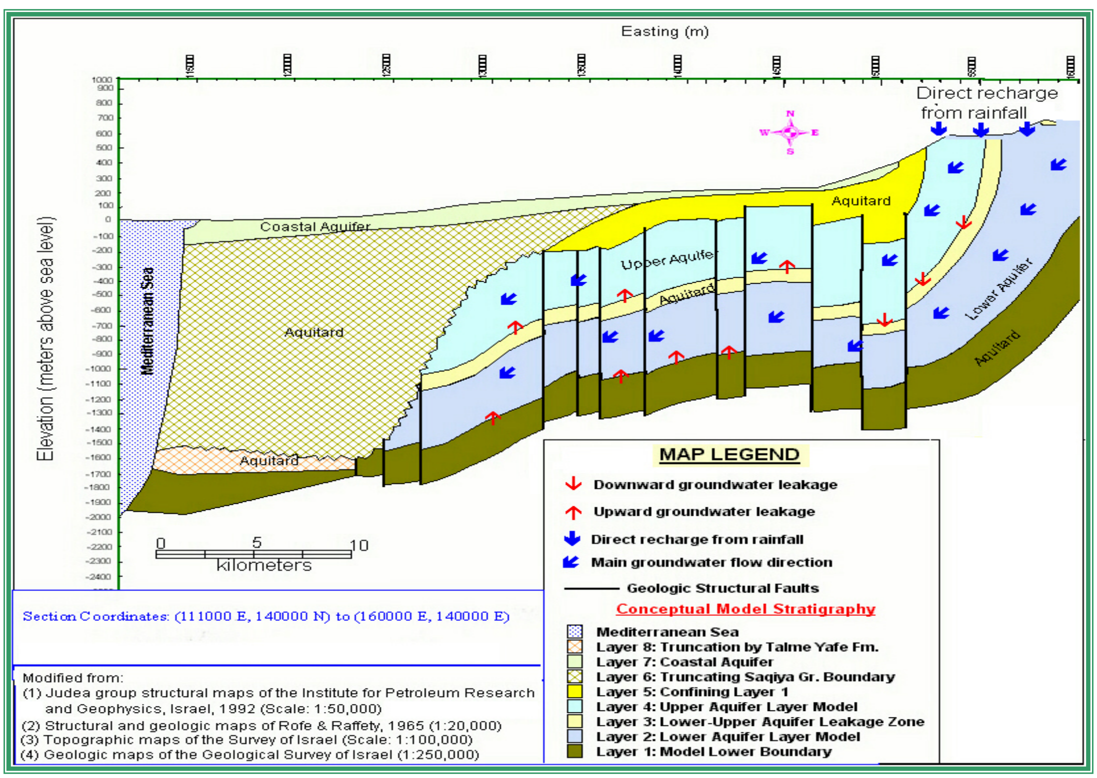


Figure 5-3: East-West Hydro-Geological Cross Section Of The WAB (Central Area)

aquifer is separated from the lower aquifer by another layer that acts as a confining layer (aquitard) most of the time while it behaves as an aquifer in some other places which merges the upper and lower aquifers into a single layer aquifer. As shown in the above figures, the aquifer system is highly affected by geological faults and folded structures which make the possibility of a hydraulic connection between the different aquifers very high.

5.4.1 Model Boundary Conditions

The horizontal boundaries of the WAB are shown in Figure 5-4. The horizontal boundaries (eastern, western, northern, and southern boundaries) of the study area are all of the no-flow boundary type. Based on Figure 5-4, the horizontal boundaries of the WAB are as follows:

1. The eastern boundary is a no-flow boundary corresponding to the highest crest of the fold structure in the Nablus-Jerusalem-Hebron mountain series. This boundary consists of four structural anticlines (polylines #1, 2, 4, and 5 shown in Figure 5-4) and one groundwater divide (polyline #3). The anticlinal structures are the Anabta, Ein Qinya-Ramallah, Surif-Hebron, and Kusseifa anticlines (Weinberger et al, 1994 and Rofe & Raffety, 1965).
2. The western boundary of the aquifer basin is defined by the gradual lateral transition from the permeable Judea Group formations into the impermeable Saqiya and Talme Yafe Groups.

The geological term for this lithological transition zone is "the hinge line" and is represented by poyline #11 in Figure 5-4. In the southern part, the western boundary extends beneath the coastal plain until it is truncated by the Saqiya Group along polyline #11. In the northern part of the western boundary (specifically in the area located between the north of Tel Aviv and Netanya cities), its boundary extends to the west of the Mediterranean as indicated by polyline #10 (Baida et al, 1987).

3. The northern boundary of the WAB consists of four no-flow boundaries as indicated by polylines #6, 7, 8, and 9). These boundaries are represented by the Binyamina structural fault (polyline #9) near Qesarya, the stratigraphic barrier created by the Daliya marl channel (polyline #8), the Menashe structural syncline (polyline #7), and the Har Yiron structural anticline (polyline #6).
4. The southern boundary of WAB extends further into the Negev desert, but for the sake of simplicity and availability of data that boundary (polyline #12) was truncated at the north coordinate of 68,000 which is located one kilometer south of Beer Shava city and one half kilometer north of Deir El Balah in the Gaza Strip. That boundary was assumed to be of no-flow because most of the flow goes parallel to that assumed boundary and then rotates northward to go parallel to the Saqiya group truncation boundary towards the Yarkon spring. A very limited amount of ground water crosses that assumed boundary to the south (less than 1% of its potential resources).

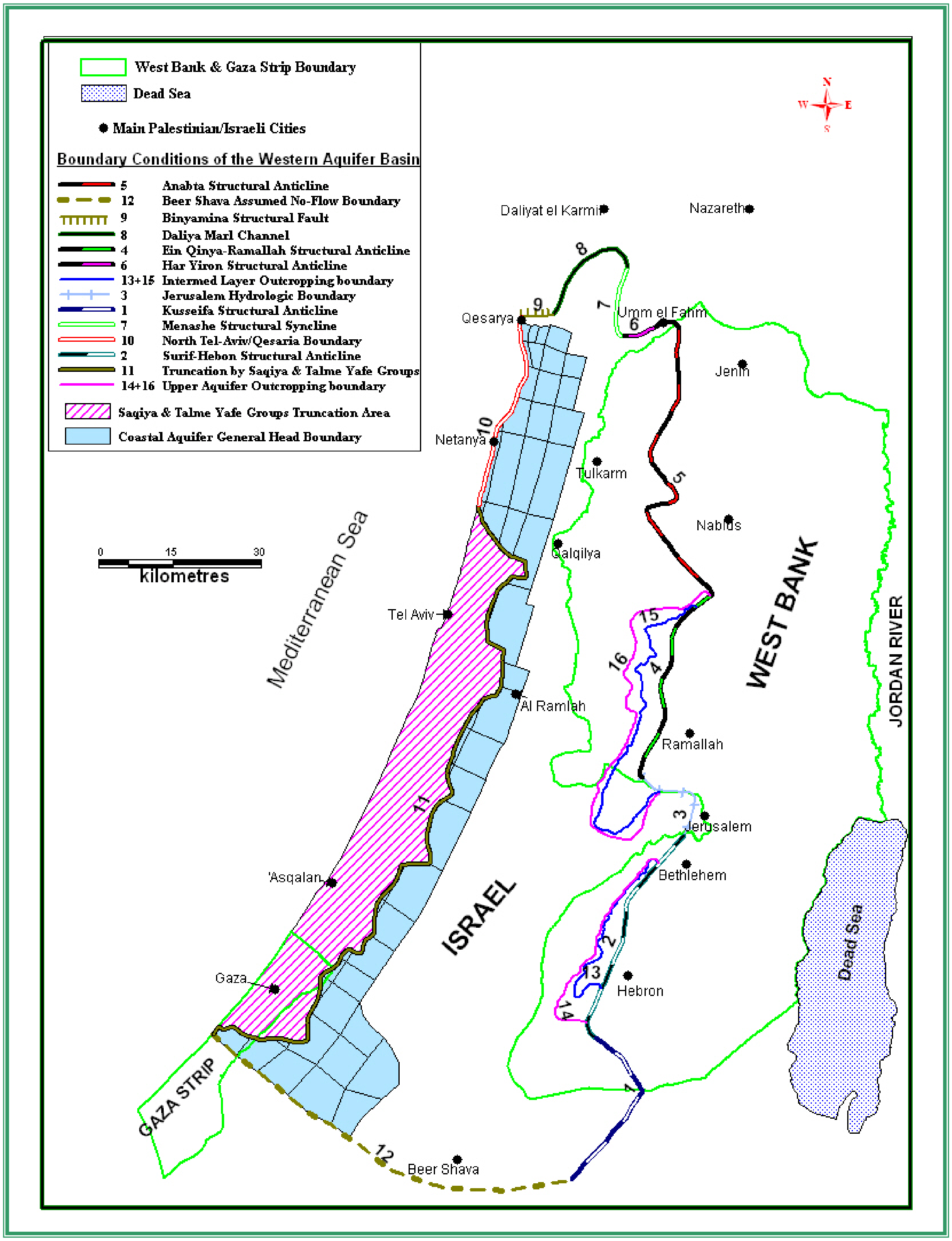


Figure 5-4: The Location Map Of The WAB And Its Main Boundary Conditions

The vertical boundary conditions of the WAB were identified based on the structural geology, the hydro-geology, and the hydro-stratigraphy of the WAB detailed in the previous sections (see Figures 5-2 and 5-3). The WAB consists of two main aquifers (the upper and the lower aquifers) separated by an aquitard. As shown in Figures 5-2 and 5-3, the coastal aquifer in the downstream potion of the WAB is located above the WAB's aquifers with one or more aquitards of various thicknesses separating the two aquifers. In building the conceptual model, the coastal aquifer was modeled as a general head boundary which permits the water to leak in between the two aquifers. The general head boundary regions and the water levels of the coastal aquifer were extracted from the 1998 water report submitted by the Israeli Hydrological Services.

In addition the indirect contact between different aquifers, there is a direct hydraulic connection between the upper and lower aquifers of the WAB and the coastal aquifer. The hydraulic connection between the WAB aquifers and the Coastal Aquifer could be responsible for high salinity of the Tamaseeh (Yarkon) spring near the Mediterranean coast.

5.4.2 Sources and Sinks

Historically (in the pre-1948 time), the aquifer basin water naturally discharged through two main springs (natural outlets) in the downstream area: the Auja spring (Yarkon in Hebrew) with a total average discharge of around 220 MCM/Yr and the Tamaseeh spring (Taninim in Hebrew) with an average of 130 MCM/Yr. In addition, there are around 100 low-scale springs and seeps in the upstream area with somewhat limited discharge. After the establishment of Israel in 1948, the natural groundwater flow system began to change due to the extensive drilling of wells by Israel to extract more groundwater. On the other hand, the Jordanian government, which was given the right to administer the West Bank, implemented a new well drilling policy to extract additional water. By the mid-1950s the extensive groundwater extraction policy by both sides caused the natural flow discharge of Auja spring to cease and the flow of the Tamaseeh spring was reduced to about 30 MCM/Yr (Weinburger et al, 1994). The natural flow of Auja spring came back after the wet hydrologic year of 1991/1992.

There are currently 507 production wells in the WAB; 469 wells are tapping the upper aquifer and 38 wells are tapping the lower aquifer. Of these wells, 140 are located in the West Bank and the other 367 wells are located inside Israel. Although there are 28 springs and seeps in the WAB area, the two major springs of Auja and Tamaseeh are still producing 97 percent of the total flow discharge of all springs and these are the only springs to consider in this modeling study. The two springs are draining from the upper aquifer. The intermediate layer separating the upper from the lower aquifer layers is mostly an aquitard and no wells or springs are draining from this layer. Figure 5-5 shows the sources and sinks of the WAB.

5.4.3 Recharge Coverage

The groundwater recharge coverage of the WAB was created based on the available water balance parameters for the hydrologic year 1999/00 including the rainfall, evapo-transpiration, and the runoff data using the general mass balance equation (Equation 3-1 in Chapter Three).

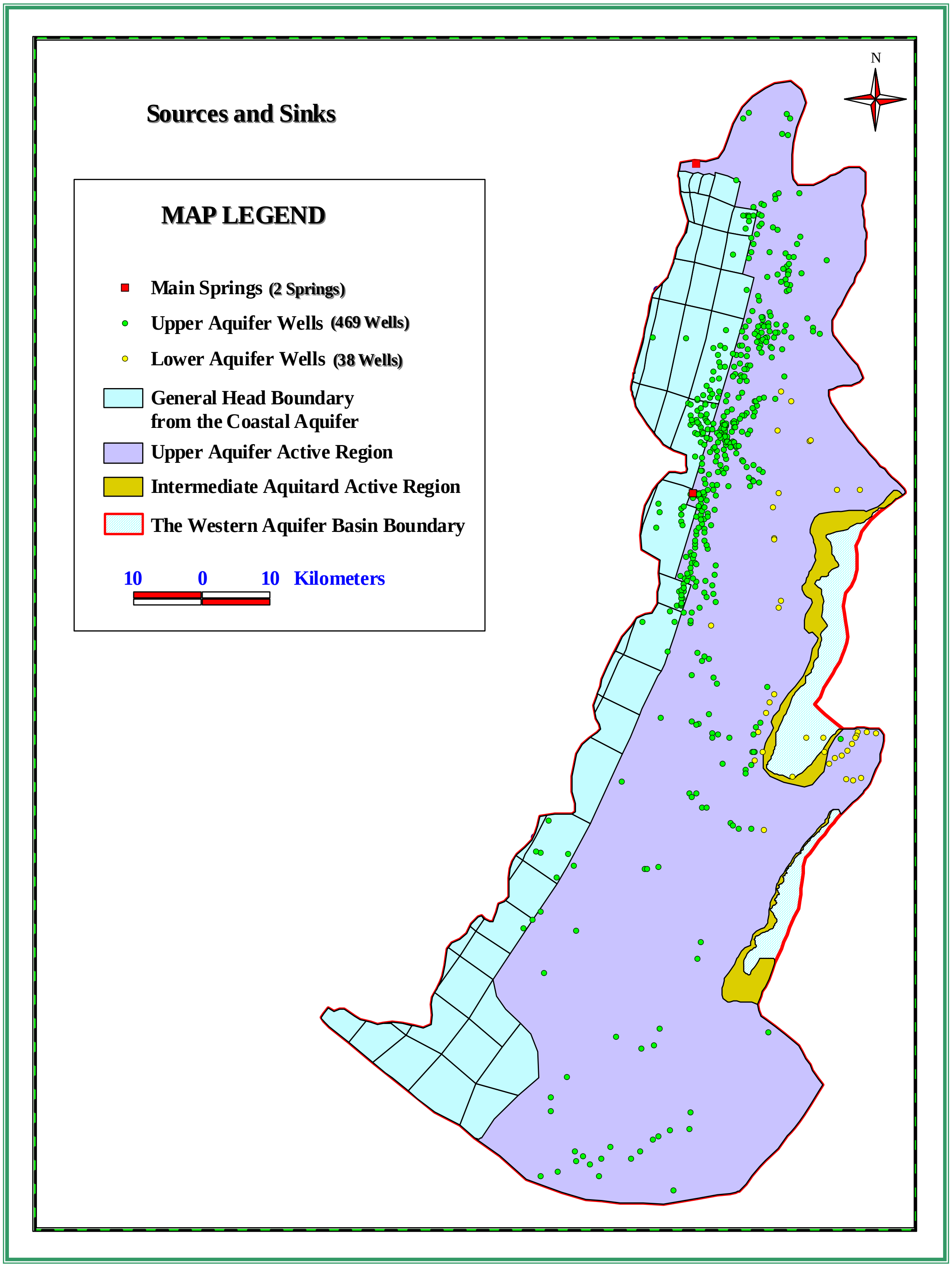


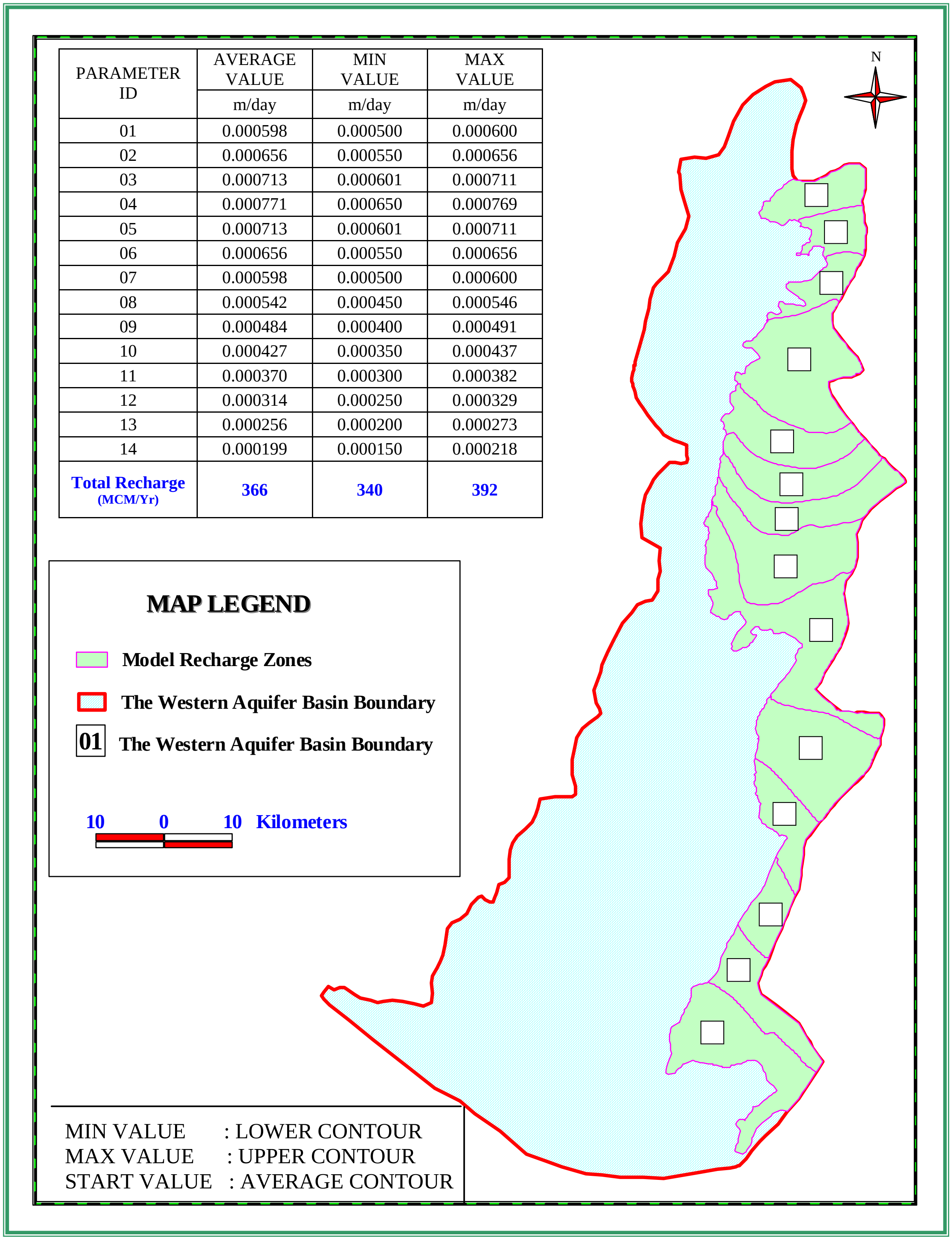
Figure 5-5: The Sources And Sinks Of The WAB

Figure 5-6 shows the recharge area coverage with the distribution of recharge zones that are used in this model and the corresponding recharge rates. These rates were optimized during the calibration process. This recharge coverage includes 14 zones with the average, minimum, and maximum recharge rates of the WAB area. Figure 5-6 shows that the minimum, average, and maximum long term volumes of recharge were 340 MCM/Yr, 366 MCM/Yr, and 392 MCM/Yr, respectively. The recharge area is a combination of outcroppings from the three layers constituting the WAB model.

5.4.4 Hydraulic Conductivity

There are no available hydraulic conductivity measurements for different aquifer layers of the WAB. Thus the average initial values of hydraulic conductivity were taken from the standard tables available in the hydrogeology text books. The hydraulic conductivity of the fractured limestone and dolomite, which is characterizing the WAB area, is ranging from 1E-07 meters per second (0.00864 meters per day) to 6E-04 meters per second (51.84 meters per day) (Bedient, Rifai, and Newell, 1999).

Doherty (2002) developed the pilot point method which can be used in conjunction with regularization to represent the hydraulic property of the aquifer matrix. In the WAB model, the pilot point method was used where seventeen hydraulic conductivity zones were defined based on the guidelines set by Doherty (2003). The geological heterogeneity for each model layer was identified in 17 zones which were then assumed to represent the hydraulic conductivity pilot points.



PARAMETER ID	AVERAGE VALUE	MIN VALUE	MAX VALUE
	m/day	m/day	m/day
01	0.000598	0.000500	0.000600
02	0.000656	0.000550	0.000656
03	0.000713	0.000601	0.000711
04	0.000771	0.000650	0.000769
05	0.000713	0.000601	0.000711
06	0.000656	0.000550	0.000656
07	0.000598	0.000500	0.000600
08	0.000542	0.000450	0.000546
09	0.000484	0.000400	0.000491
10	0.000427	0.000350	0.000437
11	0.000370	0.000300	0.000382
12	0.000314	0.000250	0.000329
13	0.000256	0.000200	0.000273
14	0.000199	0.000150	0.000218
Total Recharge (MCM/Yr)	**366**	**340**	**392**

Figure 5-6: The Recharge Rates Of Various Zones Of The WAB

The Upper Aquifer is mainly composed of fractured limestone and dolomite which gave it relatively higher hydraulic conductivity. The Lower Aquifer is composed of limestone and dolomite with some karsts, but the limestone of that layer is more crystalline which reduces its hydraulic conductivity. The intermediate layer is mainly composed of crystalline limestone and massive dolomite which gave it much lower hydraulic conductivity relative to the lower and upper layers. Since the hydraulic conductivity is not measured, it was assumed that the 17 zones of each layer have the same average value that will be adjusted during the model calibration using the Parameter Estimation (PEST). The average initial value of the hydraulic conductivity of the upper layer used in this model was 8 meters per day. The average initial value of the hydraulic conductivity of the lower upper layer used in this model was 5 meters per day. The average initial value of the hydraulic conductivity of the intermediate layer used in this model was 0.1 meters per day.

Figure 5-7 shows the location of the hydraulic conductivity pilot points for the three model layers and their initial values.

5.4.5 Head and Flow Observations

There are 165 head observations of wells and two flow observations at springs. There 142 wells located in the upper aquifer and 23 wells are located in the lower aquifer. The two springs are located in the upper aquifer in the downstream portion of the WAB. The main problem is the diversity of data sources. Since the WAB is shared between the West Bank and Israel, two main sources were used: the Palestinian Water Authority and the Israeli sources. The required head data from both sources had been

MAP LEGEND

Upper Aquifer Layer

Lower Aquifer Layer

Intermediate Aquitard Layer

Pilot Points by Layer

- Intermediate (17)
- Lower (17)
- Upper (17)

Upper Aquifer Layer		Intermediate Aquitard Layer		Lower Aquifer Layer	
Name	**K**	**Name**	**K**	**Name**	**K**
HK_100	8.00	HK_1800	0.10	HK_3500	5.00
HK_200	8.00	HK_1900	0.10	HK_3600	5.00
HK_300	8.00	HK_2000	0.10	HK_3700	5.00
HK_400	8.00	HK_2100	0.10	HK_3800	5.00
HK_500	8.00	HK_2200	0.10	HK_3900	5.00
HK_600	8.00	HK_2300	0.10	HK_4000	5.00
HK_700	8.00	HK_2400	0.10	HK_4100	5.00
HK_800	8.00	HK_2500	0.10	HK_4200	5.00
HK_900	8.00	HK_2600	0.10	HK_4300	5.00
HK_1000	8.00	HK_2700	0.10	HK_4400	5.00
HK_1100	8.00	HK_2800	0.10	HK_4500	5.00
HK_1200	8.00	HK_2900	0.10	HK_4600	5.00
HK_1300	8.00	HK_3000	0.10	HK_4700	5.00
HK_1400	8.00	HK_3100	0.10	HK_4800	5.00
HK_1500	8.00	HK_3200	0.10	HK_4900	5.00
HK_1600	8.00	HK_3300	0.10	HK_5000	5.00
HK_1700	8.00	HK_3400	0.10	HK_5100	5.00

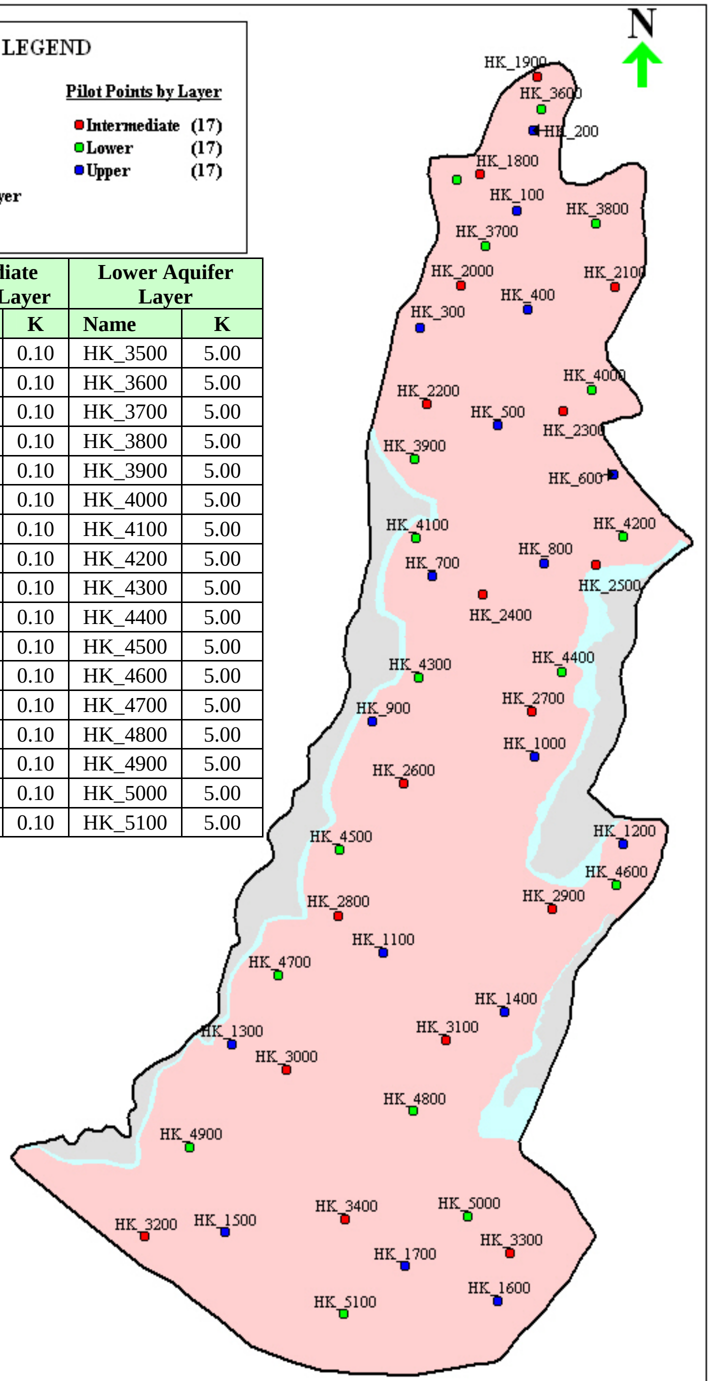


Figure 5-7: The Hydraulic Conductivity Pilot Points/Parameters Input Data Used In Various Layers On The WAB Model

integrated. One of the problems is that there are no observation wells in the study area and the heads in the production wells had to be used instead. The measurement of heads in the production wells are usually made at least 12 hours after rest in order to obtain the static water level. In MODFLOW, the model assumes that all wells are on and so the dynamic water level is needed rather than the static water levels on all observations.

In order to overcome this problem, MODFLOW was run twice for each well; once when the well is on and once when the well is off. The difference in the computed head ($Head_{on} – Head_{off}$) is the drawdown. This drawdown value is then subtracted from the static water level to get the dynamic water level (i.e. the head when the well is on). That runs were done for all the 165 wells used for the head observations.

The two major springs (Yarkon and Taninim) were used in this model as flux observations. Both the head and flow observations were used in the model calibration in order to match the computed and the observed heads and flows. These head and flow observations will be shown in the model calibration section.

5.4.6 Aquifer Geometry

Getting the accurate geometry of the aquifer system represented by the top and bottom of the model layers was the most difficult and challenging effort required to complete the model setup. There is no official place to get the borehole and well log data in the West Bank or Gaza Strip because the Palestinian Water Authority doesn't have such information.

The structural contour maps of the Institute for Petroleum Research and Geophysics prepared for the Judea Group Aquifer were used in this research to extract the aquifer geometry. One problem in the maps of that report was that the layers are geologically reconstructed, i.e. the researchers assumed that the three aquifer layers are not outcropped in the upstream recharge area. That assumption made the tops of the layers higher than the real ground surface and so geometry correction was required. The original structural maps of that report came in the form of three isopach maps (maps representing the thickness of geologic formations) for the Judea Group, Bina/Daliya Formation, and Negba Formation. A fourth map represented the geologically reconstructed elevation of the top of the Judea Group. These maps were geo-referenced, digitized, and then converted into xyz data points using the MapInfo Software. Due to the differences in the scales and resolutions of these maps, each xyz data file was interpolated into a grid with the same cell size to be able to use simple algebra to get the elevation of the top and bottom of the model layers.

After getting the elevations of the tops and bottoms of the lower aquifer, the intermediate layer, and the upper aquifer, correction were made for the geologically reconstructed elevations by replacing the values of those grid cells with ground surface elevation values which were taken from topographic maps with a scale of 1:100,000.

5.5 Numerical Groundwater Flow Model

The Department of Defense Groundwater Modeling System (GMS) was used for all model construction in this research. The map module and the conceptual model approach of GMS were used to create the conceptual model and to convert it into a numerical groundwater flow model. The GMS includes an interface to MODFLOW 2000 and PEST 2000.

All the model boundaries, sources/sinks, recharge rates, and the head and flow observations mentioned in the conceptual model section were integrated into ArcView shape files to facilitate importing them into the GMS conceptual model. The most recent available data required for this model was for the hydrologic year 1999/2000. Normally, the hydrologic year runs from October of a year to September of the next year.

GMS was used to create new coverages for a three-layer conceptual model including the sources/sinks, the hydraulic conductivity, the recharge, and the head and flow observations and then all the shape files of the conceptual model data were imported into their coverages in GMS. Because the study area is too large (5500 km^2), a three dimensional grid with 1000 meters X 1000 meters cell size was used. All the conceptual model coverages and their attributes were mapped onto a three-dimensional, three-layer steady state numerical flow model. The metric system of units was used in this model; meters per day for the hydraulic conductivity, meters for head, cubic meters (m^3) for volume, and days for time. In building the numerical groundwater flow model, the following MODFLOW packages were used:

1. MODFLOW Basic Package which is used to specify the grid dimensions, the computational time steps, and an array identifying which packages are to be used. The Basic packages include the Source/Sink Packages, the units, the starting head, the IBOUND (active/inactive cells), top and bottom elevations,

the run type (Forward Run, Parameter Estimation, or the Sensitivity Analysis). The Source/Sink Packages include the point sources/sinks (Well Package, Drain Package, General Head Package) and the Areal Sources/Sinks (the Recharge Package). The Drain Package was used for simulating the springs. The Parameter Estimation run option was used in this model.

2. The Flow Package used in this model is the Layer Property Flow (LPF) package of MODFLOW 2000 which performs the cell by cell flow calculations. The input to this package includes layer types and cell attributes. All layers of this model are convertible because they are all unconfined in some places and confined in others. The unconfined portion of the WAB is located upstream in the mountains of the West Bank and its confined portion is located downstream within Israel boundary. Within the LPF package, the horizontal hydraulic conductivity was assigned from 17 pilot points representing 17 different geologic formations exposed in the WAB. The vertical anisotropy used was 0.25 which represents the ratio between the vertical hydraulic conductivity and the horizontal hydraulic conductivity for each cell in the model domain.

3. The Solver Package used in this model was the Preconditioned Conjugate Gradient (PCG2) Package which is an iterative solver. The maximum outer iterations and the maximum inner iterations used in this Solver are 500 and 100, respectively. The relaxation parameter was reduced to 0.97 in order to reduce the number of iterations required for convergence.

All the above mentioned coverages and layer geometry were mapped into the MODFLOW grid and a steady state simulation was run using the initial values of hydraulic conductivity as shown in Figure 5-7 for the three layers composing the aquifer. The initial starting head was assumed to be ten meters below ground surface elevation. The recharge rates of various recharge zones are shown in Figure 5-6.

5.6 Model Calibration

The Model calibration consists of changing values of the model input parameters in an attempt to match the computed head with the field conditions within some acceptable criteria. This requires that the field conditions at the modeled site be properly characterized. Thus the main objective of model calibration is to make sure that the model accurately portrays the real situation in the field. That can be done by adding a set of observed heads and flux flow, running the MODFLOW model, and then comparing the computed head and flux with the observed head and flux.

Automatic calibration was used in this study which is based on the non-linear parameter estimation techniques which are currently very common in the field of groundwater modeling and other applied sciences. The newly developed ***Pilot Point Method*** for automated parameter estimation was used in conjunction with PEST which incorporates the advanced regularization functionality in conjunction with the pilot points as a spatial hydraulic property (Doherty, 2002). As mentioned earlier in section 5.4.4, a total number of 51 pilot points representing the hydraulic conductivity was used in this model. Thus the total number of parameters used in this model calibration was 51 (17 parameters of hydraulic conductivity for each model layer). The initial values of the hydraulic conductivity pilot points used in the model calibration are shown in Figure 5-7. After setting up the parameters and map them to the hydraulic conductivity pilot points, the MODFLOW was run with the Parameter Estimation (PEST) option on. The model took about 12 hours and 21 iterations to converge.

Figure 5-8 shows the variation of it the error with the iterations. That figure shows that the error was about 3.5 million the beginning of the simulation under the initial value of the hydraulic conductivity parameters derived from the pilot points. During the calibration process, PEST tends to modify the parameter values until it converged at iteration number 21 which gave the best fit between the computed and the observed head.

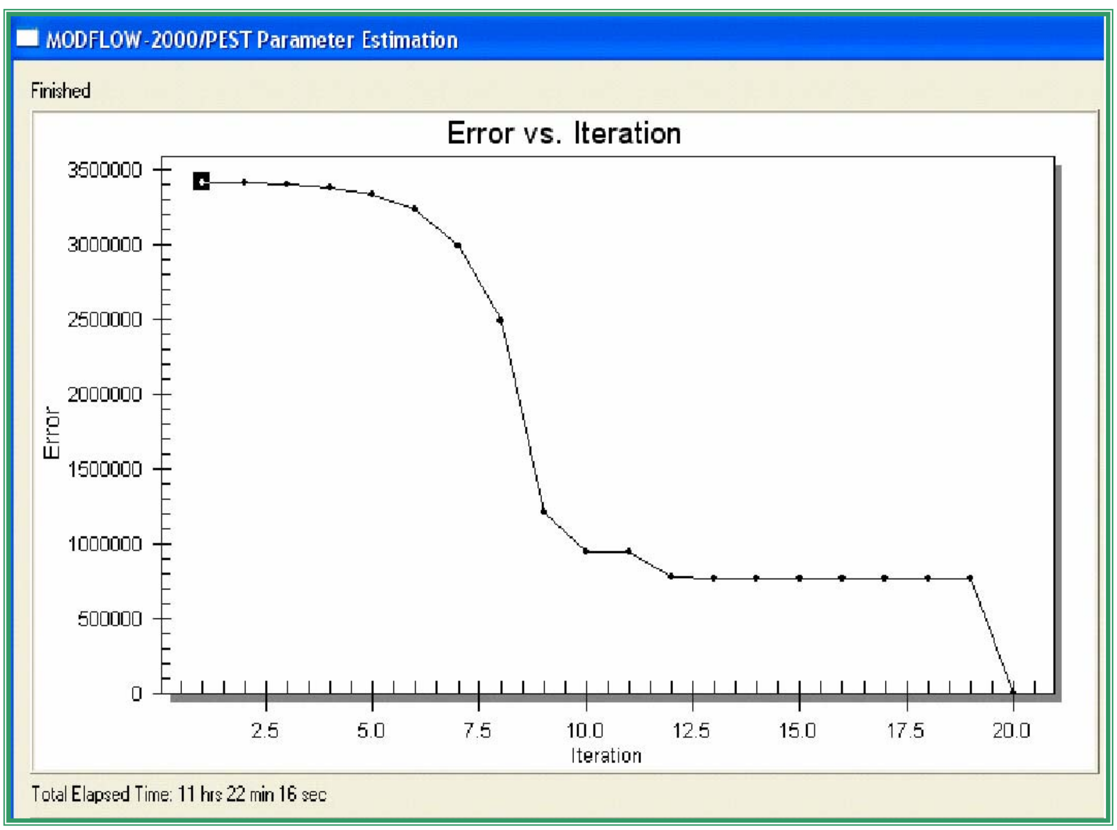


Figure 5-8: The Variation Of The Error Simulation Iterations

5.7 Presentation of the Model Calibration Results

The results of this calibrated groundwater flow model were presented using four types of comparisons. These are comparisons by maps, tables, graphs, and volumetric budget. The volumetric budget was used to check the degree of match between the computed and the observed flow of springs/drains.

5.7.1 Map Presentation of Calibration Results

This method of presentation is the best efficient one in terms of giving a more comprehensive description of the flow pattern, calibration targets, and problems in the geometry or the model parameters. The head observations are considered as the calibration targets. These targets are normally shown by maps and represent how good the model calibration is. Figure 5-9 shows the head distribution of the calibrated model and the head calibration targets.

As shown in the Figure 5-9, the calibration target was set to plus/minus 4 meters from the observed head. Under the calibration target criteria set in Figure 5-9, the number of observed heads which are located within the target range of acceptability was 125 out of 165 total observations (about 76% of the observations). Also 35 head observations were located with the error range of greater than 100% and less than 200%, i.e. the computed head is within plus or minus 8 meters from the observed head. The other 5 head observations were located with the error range of greater than 200%, i.e. the computed head is more than 8 meters greater or less than the observed head.

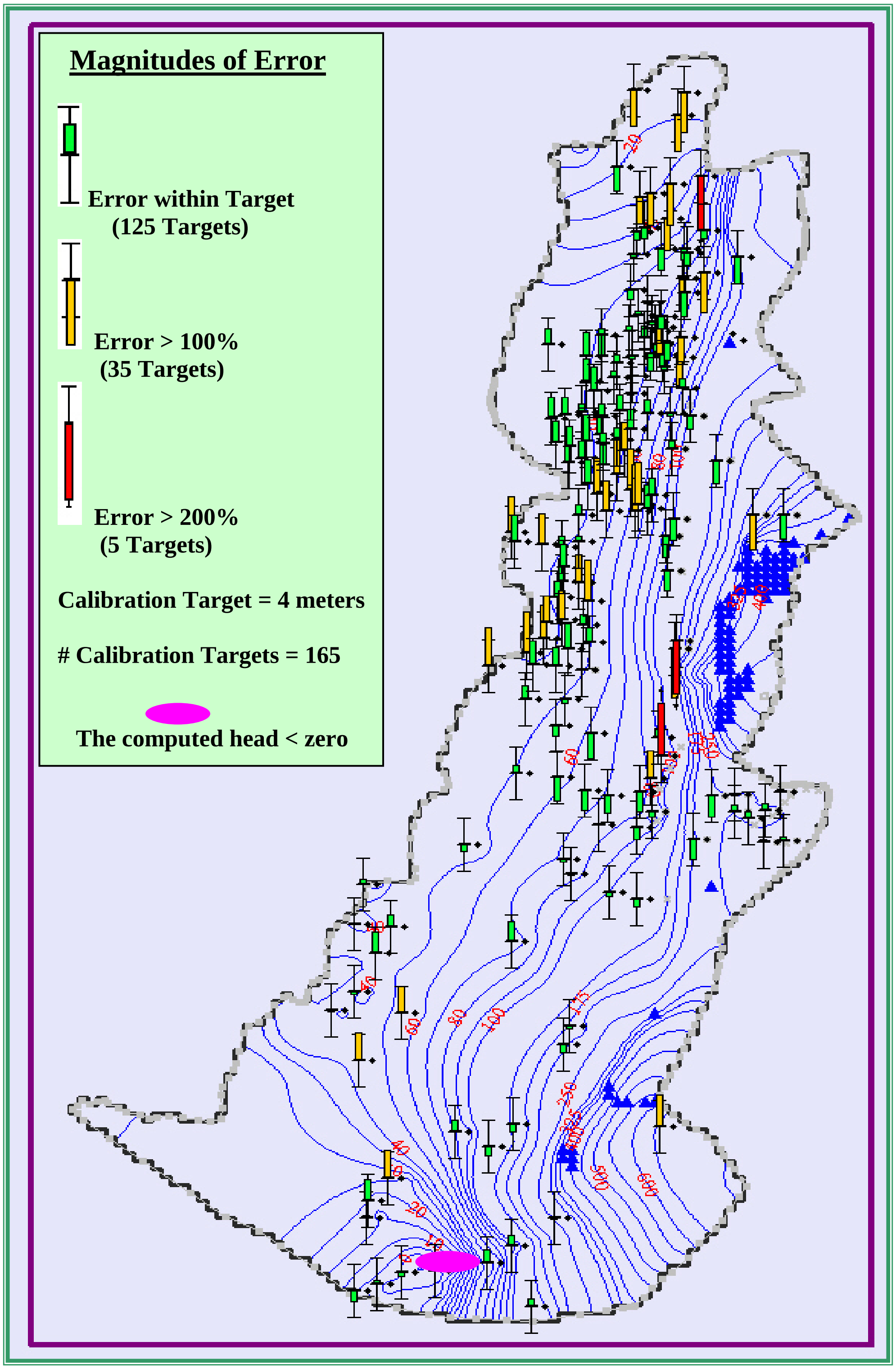


Figure 5-9: Head Distribution And Calibration Targets Of The Calibrated Groundwater Flow Model By Using The Parameter Estimation (PEST)

Although the model consists of three layers, the upper and the lower layers have observations whereas the intermediate layer is a confining bed separating the two aquifers which has no observations. Most of the observations are in the upper layer (143 head observations), whereas the lower layer has 22 head observations. Of the lower model layer, a number of 18 observations are within the target, two others are within the range of greater than 100% and less than 200% and the other two are within the error range of greater than 200%.

The groundwater flows from the West to the east and then it goes into the northwest in the major part of the area towards the two main spring outlets which are the Auja and Tamaseeh (Yarkon and Taninim) springs. In the southern most part of the WAB, the flow goes to southwest with a very steep hydraulic gradient of groundwater flowing from the east and northeast. The following notes can be seen from Figure 5-9:

- ❖ The groundwater head starts at an elevation of 650 meters above sea level and then it decreased very rapidly to a value of less than zero in the area located to the northeast of Beer Sheva City.
- ❖ The model cells in the east central part of the WAB area were dry which means that the computed head is lower than the bottom of the aquifer at these cells. That could be attributed to the fact that the model layers there are outcropped and to the absence of observation heads at that area. In order to better account for that area with dry cells, the WAB's model could be updated later on by looking for more observations and by installing more pilot points of hydraulic conductivity there.

5.7.2 Presentation of Calibration Results by Tables

This method of presenting the calibrated model was done by tabulating the results of the norms of error. The error norms used to present the model results are:

1. The Mean Residual (MR) which represents the sum of differences between the computed head and observed head divided by the number of observations. Equation 5-3 shows the mathematical formula of the Mean Residual.
2. Mean Absolute Residual (MAR) which represents the absolute value of the sum of differences between the computed and observed heads divided by the number of observations. Equation 5-4 shows the mathematical formula of the Mean Absolute Residual.
3. Root Mean Squared Residual (RMSR) which represents the square root of the sum of the squared differences between the computed and observed heads divided by the number of observations. Equation 5-5 shows the mathematical formula Root Mean Squared Residual.

$$MAR = \frac{1}{n}\sum_{i=1}^{n}(h_c - h_o)_i \qquad \textbf{(5-3)}$$

$$MAR = \frac{1}{n}\sum_{i=1}^{n}\left|(h_c - h_o)_i\right| \qquad \textbf{(5-4)}$$

$$\text{RMSR} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(h_c - h_o\right)_i^2} \qquad \textbf{(5-5)}$$

where n is the number of observations, h_c is the computed head, and h_o is the observed head. Table 5-1 shows the norms of error of the WAB's calibrated model.

Table 5-1: The Calibration Error Norms

ERROR TYPE	VALUE
Mean Residual (Head)	-0.41
Mean Absolute Residual (Head)	2.70
Root Mean Squared Residual (Head)	3.36
Mean Residual (Flow)	-7607.13
Absolute Residual (Flow)	10607.95
Root Mean Squared Residual (Flow)	13053.62
Mean Weighted Residual (Head+Flow)	-0.94
Mean Absolute Weighted Residual (Head+Flow)	5.51
Root Mean Squared Weighted Residual (Head+Flow)	7.17
Sum of Squared Weighted Residual (Head+Flow)	8493.17

Table 5-1 shows that the mean residual between the computed head and the observed head was -0.41 meters, and its mean absolute residual was 2.7 meters, and the root mean squared residual of head was 3.36 meters. It also shows that the Mean Residual of Flow was -7607 cubic meters, and the Mean Absolute Residual of the Flow was 10608 cubic meters, and the Root Mean Squared Residual of Flow was 13053 cubic meters.

The Mean Residual of (Head + Flow) was -0.94, and the Mean Absolute Residual of the (Head + Flow) was 5.51, and the Root Mean Squared Residual of (Head + Flow) was 7.17. The Sum of Squared Weighted Residual (Head + Flow) was 8493.

The overall results of the error norms show that the computed head matches the observed head to an acceptable degree. But the match is not that good for the flow observations represented by the springs/drains. This is related to the fact that the two main springs are taking major parts of their water from the coastal aquifer overlying the WAB through the general head boundary as shown in this model.

5.7.3 Graphical Presentation of Calibration Results

The model results were presented on simple graphs to identify the model error. Figure 5-10 compares the observed and the computed heads. The closer the value to the line, the smaller the error and the so model is calibrated.

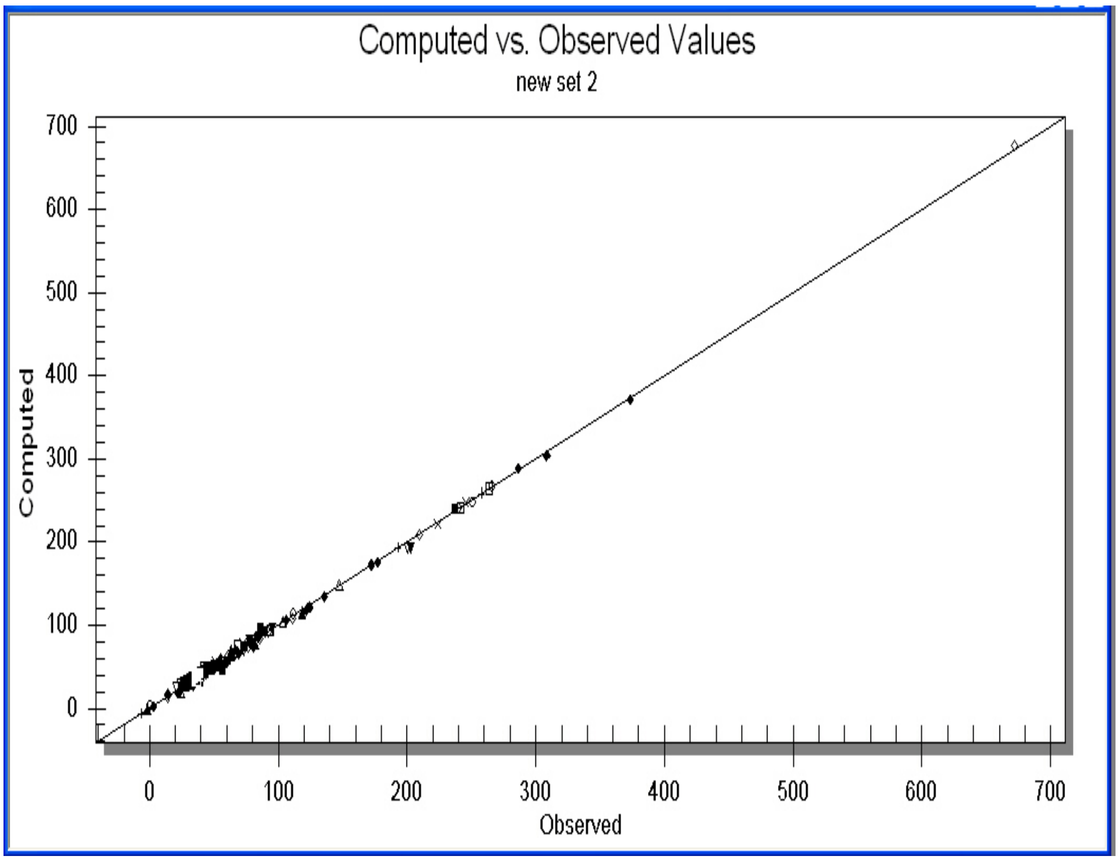


Figure 5-10: The Comparison Of The Computed With The Observed Head

As shown in Figure 5-10, the computed head matches the observed head. This means that the model is well calibrated.

5.7.4 Presentation of Calibration Results by the Volumetric Flow Budget

The volumetric flow budget was used in this study to compare the computed flow through springs/drains with their real-world observed flow volumes. Table 5-2 shows the summary of the volumetric budget of the WAB calibrated model.

Table 5-2: The Summary of the Volumetric Budget of the WAB Calibrated Model

The 3D Three-Layer Model Calibrated by PEST			
CATEGORY	**M/DAY**	**MCM/Yr**	**MCM/Yr**
GHB-IN	176965.9688	64.61	**430.61**
RECHARGE	1002771.0000	366.00	
CATEGORY	**m/day**	**MCM/Yr**	**MCM/Yr**
GHB-OUT	52067.3750	19.01	**430.61**
DRAINS/SPRINGS	135470.7188	49.454	
WELLS	992198.8125	362.15	
***GHB (IN-OUT)**	124898.5938	45.60	

* General Head Boundary

As shown in Table 5-2, the model and output are the same with a volume of 430.61 MCM/Yr which is normal since the model was converged. The real world extraction from all wells was already known to be 362 MCM/Yr which is reproduced in this model since it was already given by the user. The flow from the two main drains/springs which was already known and used in this model as flow observations to be 55 MCM/Yr. Table 5-2 also shows that the computed flow of springs by the model was about 49.45 MCM/Yr, while the real-world observed flow volume was about 55 MCM/Yr. Thus the absolute relative error between the measured and observed flow was 5.3%. This could be an acceptable error but it higher than the error resulted from the mismatch between the computed and observed heads. It was noted from Table 5-2 that the 45.6 MCM/Yr (92% of the total spring flow) of the computed spring flow comes from the general head boundary. A total of 8% comes from the natural recharge.

5.7.5 Calibration Results by the Optimal Hydraulic Conductivity

Table 5-3 shows the initial and the optimal values of hydraulic conductivity resulted from the calibrated model. Appendix C shows the detailed change of the 51 parameters of hydraulic conductivity by iteration during the model calibration.

Table 5-3: Initial And Optimized Hydraulic Conductivity Values Of The Calibrated Model By Using The Parameter Estimation (PEST)

Upper Aquifer Layer			Intermediate Aquitard Layer			Lower Aquifer Layer		
Parameter	**Initial**	**Final**	**Parameter**	**Initial**	**Final**	**Parameter**	**Initial**	**Final**
sc1v1	8.00	35.7060	sc2v1	0.10	0.1833	sc3v1	5.00	1.3998
sc1v2	8.00	2.5474	sc2v2	0.10	0.0736	sc3v2	5.00	0.7656
sc1v3	8.00	1.3855	sc2v3	0.10	0.0317	sc3v3	5.00	3.6963
sc1v4	8.00	0.0438	sc2v4	0.10	0.0335	sc3v4	5.00	0.0182
sc1v5	8.00	10.5950	sc2v5	0.10	0.0052	sc3v5	5.00	7.7721
sc1v6	8.00	0.2841	sc2v6	0.10	0.0070	sc3v6	5.00	0.6721
sc1v7	8.00	4.5032	sc2v7	0.10	0.0009	sc3v7	5.00	3.1703
sc1v8	8.00	0.1021	sc2v8	0.10	0.0007	sc3v8	5.00	0.0051
sc1v9	8.00	5.5396	sc2v9	0.10	0.0035	sc3v9	5.00	0.0720
sc1v10	8.00	5.2152	sc2v10	0.10	0.0001	sc3v10	5.00	0.0035
sc1v11	8.00	0.1804	sc2v11	0.10	0.0051	sc3v11	5.00	0.0924
sc1v12	8.00	3.4968	sc2v12	0.10	0.0045	sc3v12	5.00	0.4633
sc1v13	8.00	0.0754	sc2v13	0.10	0.0034	sc3v13	5.00	0.0719
sc1v14	8.00	0.0188	sc2v14	0.10	0.0180	sc3v14	5.00	0.0083
sc1v15	8.00	3.0345	sc2v15	0.10	0.0578	sc3v15	5.00	0.2619
sc1v16	8.00	0.0820	sc2v16	0.10	0.0752	sc3v16	5.00	0.0444
sc1v17	8.00	0.0159	sc2v17	0.10	0.0250	sc3v17	5.00	0.0072

In any future model for the WAB area, the optimal values of the resulted hydraulic conductivity shown in Table 5-3 should be used in order to save time and effort. For example, the use of this calibrated model as initial conditions for the transient and pollution transport models will save too much time till they converge. In order for the model to give better results, more parameters should be used by increasing the number of hydraulic conductivity pilot points especially in those areas which are affected by faulting geological structures.

5.8 Model Conclusions and Contribution

Although this is a steady state groundwater flow model, it gave very good information for those who are interested in conducting a modeling research for the WAB any other similar Palestinian aquifer basin. The model is informative in terms of the conceptual model and the overall setup of the numerical model. The main contribution of this model could be summarized by a list of conclusions which were not known before. These conclusions can be listed as follows:

- This model concluded that the major part of spring flow comes from the Coastal Aquifer which overlies the WAB with thick geologic formations separating them. That relationship was simulated by using the general head boundary.
- The model showed that in addition to the already known northwest flow pattern of the WAB, there another flow pattern which goes from Hebron mountains to the southwest towards Beer Sheva with a very steep hydraulic gradient which changed the head from 650 meters above sea level into 10 meters below sea level with few kilometers of horizontal distance. That zone could be over-pumping zone which

need very good care. Also it is urgent to get more observations about that area, check the stratigraphy, or take more hydraulic conductivity pilot points.

- The number of calibrated targets which match the specified range of acceptability are pretty good compared to such complicated area in terms of structural geology and the high contrast between one well and the other.
- Both the conceptual and the steady state model of this study could be adopted for any future transient or pollution transport model which can save time and effort.

CHAPTER SIX

SUSTAINABLE WATER SUPPLY AND DEMAND

The goal of this chapter is to study and analyze the current water supply management (as of the year 2002) for various sectors in the West Bank and to propose several scenarios for water demand projections for the time period 2005-2025 (See objective #5, Chapter One). Water sustainability will be evaluated against the future water needs of the Palestinians, i.e. the projected water needs should not exceed the sustainable limits of the various aquifers underlying the West Bank.

The area under study is the West Bank including East Jerusalem. This study was done on governorate by governorate basis to ensure an equal share of water for all people in all locations of the West Bank.

The water policy in Palestine in general and in the West Bank in particular changed much during the past 40 years due to political reasons. Until the 1967 War, the Jordanian role was used and the West Bank water management and distribution was the responsibility of the Natural Resources Authority of Jordan (NRAJ). After 1967, the Israeli role was imposed on all the Palestinian water resources including the management, distribution, and the well licensing and drilling. In 1978, Israel issued the licensing policy for the Palestinian groundwater wells by giving a constant annual pumping quota for each Palestinian well and that license should be renewed every year.

According to that policy, if the pumping from a Palestinian well exceeded its specified quota in one year, that extra quantity of water above the licensed pumping quota was deducted from the new annual pumping quota for the next year upon its renewal. Such Israeli water policy continued in practice until the establishment of the Palestinian National Authority (PNA) and the Palestinian Water Authority (PWA) in 1994 and 1995, respectively (OSLO I & II Agreements). By 1995, the responsibility for water distribution management including the licensing of the existing wells was transferred to the PWA, but the licensing for drilling new wells continued as a joint responsibility of the PWA and Israel through the Joint Water Committee (JWC) which was established within the context of the OSLO II Agreement signed in 1995.

With the help of the United States Agency for International Development (USAID), which financed a Water Resources Program in Palestine during the past nine years (1995-2003), the JWC had granted 12 drilling licenses for groundwater wells in the Eastern Aquifer Basin (EAB) to serve the Palestinians of the West Bank who had shortages with their water needs. Eight of these wells are currently producing a combined water quantity of about 6.3 MCM/Yr (PWA, 2004) and work is being conducted on the other four wells. These new wells are known as the PWA Phase I Wells (4 wells) and PWA Phase II Wells (8 wells).

6.1 Literature Review

The signature of the Interim Peace Agreements between the Palestinian Liberation Organization (P.L.O) and Israel from 1993 to 1995 opened the hope for the Palestinians to establish their own state and started their thinking of the future Palestinian State and its requirements. The land and water were among the first issues to think of in terms of the capability of land to absorb the Palestinian returnees and to develop the water resources required to meet the future demands on water.

Several water supply and demand studies were conducted in Palestine which estimated the current supply and the future demand of water. Most of those studies were conducted by joint Palestinian-Israeli-Jordanian institutions which mainly aimed at launching regional cooperation in the water field in order to foster the peace process. That kind of research didn't really address the real water needs because the Palestinian and Israeli partners were trying to avoid discussing the political sovereignty over water resources. That research was looking to investigate additional water sources to bridge the gap between the future water demands and the available water sources.

The Israeli point of view in all joint Palestinian-Israeli water research projects was that all the natural water resources in the Palestine-Israel area are completely utilized and so there is an urgent need for regional cooperation to develop the non-conventional sources such as wastewater reuse and desalination to meet the future demands on water. On the other side, the Palestinians have the dilemma that Israel should stop the unilateral over-pumping of the Palestinian water resources and there is an urgent need to reach a just and fair agreement between both sides concerning the Palestinian allocation and the rights to use their national water resources. Once the Palestinians get their just water share then they will decide if they need additional water, especially since Israel is using 80% of the West Bank water resources.

A three-year (1993-1995) water supply and demand study was conducted in Palestine within the context of the Harvard Middle East Water Project which was funded by the

Harvard University Institute for Social and Economic Policy in the Middle East. That study provided the 1990 baseline data of water supply and projections of water demand for 2000, 2010, and 2020 for household, industrial, and agricultural sectors in Palestine (West Bank and Gaza Strip). Isaac et al (1995) of the Palestinian Consultancy Group have reported the updated results of that water research project for the West Bank and Gaza Strip. The report included low, middle, and high scenarios for various water sectors where the medium scenario is the most reasonable one in terms of water sustainability. The reported results of the middle scenario for the West Bank for various water sectors were as follows:

1. The household water demand was projected to be 125.86 MCM/Yr, 231.4 MCM/Yr, and 313.75 MCM/Yr for the years 2000, 2010, and 2020, respectively.
2. The agricultural water demand was projected to be 146.3 MCM/Yr, 234.3 MCM/Yr, and 345 MCM/Yr for the years 2000, 2010, and 2020, respectively.
3. The industrial water demand was projected to be 5 MCM/Yr, 13 MCM/Yr, and 26.7 MCM/Yr for the years 2000, 2010, and 2020, respectively.

The problem in the above mentioned and the other similar studies was that the baseline data were not accurate enough due to the lack of data sources at that time. The PWA, the Palestinian Central Bureau of Statistics (PCBS), and the Palestinian Ministry of Agriculture (MOA) established in 1994/1995 have good databases on the current water supply, population, agricultural and irrigated areas, and the industrial and commercial establishments. Given the fact that these new databases are currently available encouraged the author to do this sustainable water supply and demand study.

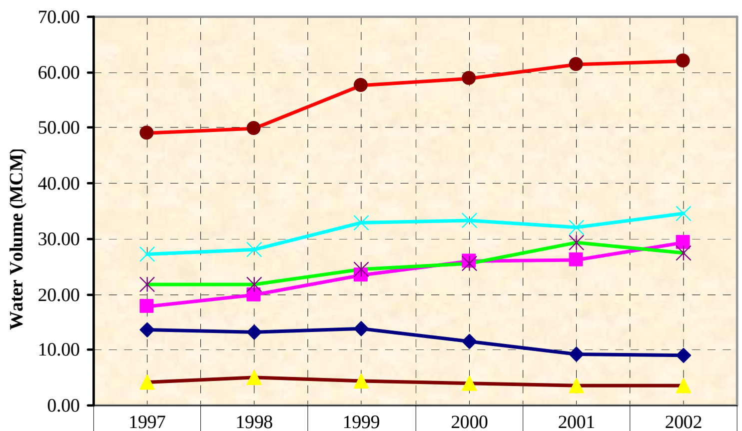
6.2 The Current Water Use

The current water supply for household purposes is managed and distributed by eight institutions which serve about 75% of the West Bank population. These management institutions and the water quantities they distributed will be discussed in more detail in the next chapter (Chapter Seven). Figure 6-1 shows the sources and the variation of the used water for household purposes during the period (1997-2002).

As shown in Figure 6-1, about 62.1 MCM/Yr of piped water were supplied to the Palestinian population of the West Bank in 2002 excluding East Jerusalem. About 29.4 MCM/Yr (47% of the total water supply) of that supplied water was purchased from the Israeli Water Company known as Mekorot. That piped water is being supplied mainly for household use, but the Palestinians are using an undeclared quantity of that water for light industries and commercial purposes due to common connections. For the purpose of this study, the author was able to estimate that undeclared water quantity based on the number of such establishments surveyed by the PCBS for the year 2002. The estimated water quantity used for industrial and commercial purposes in all governorates of the West Bank was about 10 MCM/Yr.

That water supply shown in Figure 6-1 does not include the water quantities used by about 25% of the West Bank population who are living in those communities which have no access to the piped water.

At the end of the year 2002, approximately 466,000 Palestinians have no access to piped water, but they meet their water needs by purchasing water tanks from the nearby irrigation and domestic wells, local springs, and from water cisterns. The water cisterns are very common in the West Bank. They collect the water from the rooftops of houses



	1997	1998	1999	2000	2001	2002
Produced by WBWD Wells	13.61	13.28	13.81	11.47	9.22	8.96
Purchased by WBWD from Mekorot	17.72	19.83	23.51	25.92	26.28	29.39
Israeli Settlements Supply by WBWD	4.10	4.93	4.40	3.97	3.48	3.66
Total WBWD Water Supply	27.23	28.18	32.92	33.42	32.02	34.69
Produced by Palestinian Wells	21.86	21.81	24.61	25.49	29.33	27.45
Total Domestic Water Supply	49.09	49.98	57.53	58.91	61.35	62.13

Figure 6-1: The Variation And Classification Of Piped Water Quantities Used For Domestic Purposes In The West Bank During (Adapted From PWA Database, 2003)

and other places during the rainy winter season and store it for the dry season. The average capacity of each water collection cistern ranges from 50–70 cubic meters.

In order to account for the water used by these non-included and non-served population communities, estimates were conducted by tabulating the served population by their governorates and the water quantities they used and then using the same per capita water consumption as of those who have piped water for each governorate.

Table 6-1 shows the overall estimated household water use, after separating the estimated 10 MCM/Yr which are used for industrial and commercial purposes, for all governorates of the West Bank. Table 6-1 includes the non-served Palestinian population by governorates and the derivation of the water volumes used by the communities who have no access to piped water as well as the water used by those Palestinians who are living within the Israeli municipal boundary of Jerusalem and are being served by the Israeli Municipality of Jerusalem (IMJ).

To account for the household water use by the Palestinians of Jerusalem governorate, the J1 and J2 areas of Jerusalem population subdivided by the PCBS were used. The J1 area represents the Palestinian population who live out of the Israeli municipal boundary of Jerusalem, while J2 area represents the Palestinian population who live within the Israeli municipal boundary of Jerusalem. The West Bank Water Department (WBWD) and the Jerusalem Water Undertaking (JWU) are responsible for providing 37 percent (11% by WBWD and 26% by JWU) of the Palestinian population in Jerusalem governorate (141,549 Palestinians who live in the J1 area) with their water needs for household purposes. On the other hand, the Israeli Municipality of Jerusalem (IMJ) is responsible for providing the other 63 percent of the Palestinian population (246,752 Palestinians who live in the J2 area) with their water needs for household purposes. For the purposes of this research, the average per capita water consumption was adapted from an internal statistical report published by the Israeli municipality of Jerusalem in 1997 (Jerusalem Municipality, 1997). According to that report, the total 1996 water supply for the 213,000 Palestinians who were living within the Israeli municipal boundary of Jerusalem (J1 Area) was about 10.1 MCM with an average per capita water use of 129.5 liter per capita per day. The average per capita water use in 2002 was assumed to be the same as for the year 1996 (129.5 liter per capita per day) which is then used to estimate the water use by the Palestinians of J2 area of Jerusalem in 2002.

Table 6-1: The Overall Estimated Household Water Use in the West Bank (as of 2002)

Governorate	Total Population	Piped Water Supply	Served Population	Per Capita Water Use	Non-Served Population	Un-piped Water Supply	Overall Water Supply
	(Capita)	(MCM/Yr)	(Capita)	(l/c/d)	(Capita)	(MCM/Yr)	
Jenin	**242,603**	3.68	172,732	58.4	69,871	1.49	5.17
Tubas	**44,283**	0.27	24,946	29.2	19,337	0.21	0.47
Tulkarm	**160,306**	4.19	120,858	95.0	39,448	1.37	5.56
Nablus	**312,242**	7.82	212,315	100.9	99,926	3.68	11.50
Qalqiliya	**88,780**	2.75	64,738	116.5	24,041	1.02	3.77
Salfit	**58,914**	1.19	41,858	77.8	17,056	0.48	1.67
Ramallah	**263,957**	12.27	220,368	152.6	43,589	2.43	14.70
Jerusalem J1*	**246,852**	**11.66**	**246,852**	**129.5**	**0.0**	**0.00**	**11.66**
Jerusalem J2**	**141,589**	2.63	120,139	60.0	21,450	0.47	3.10
Jericho	**40,053**	3.09	34,321	246.9	5,732	0.52	3.61
Bethlehem	**165,952**	3.97	139,769	77.8	26,183	0.74	4.71
Hebron	**495,068**	10.27	394,992	71.2	100,076	2.60	12.87
Total	**2,260,596**	**63.79**	**1,793,887**	**101.3**	**466,708**	**15.01**	**78.80**

Source: Palestinian Central Bureau of Statistics (PCBS, 2004) which classified East Jerusalem for two groups; J1 and J2. **J1*** is defined by the as the entire part of East Jerusalem which is included within the Israeli municipal boundary of Jerusalem.
J2** is defined by the Palestinian Central Bureau of Statistics as the entire part of the pre-1967 Palestinian district of Jerusalem which is located out of the Israeli municipal boundary of Jerusalem.
***** The average per capita water consumption was weighted based on the number of population

The following three notes can be observed from Table 6-1:

1. The un-piped water supply for the non-served Palestinian population (466,000 capita) was estimated to be about 15 MCM/Yr using the same average per capita water consumption of the governorates they are living in.
2. All the population data in Table 6-1 were taken from the PCBS (PCBS, 2004), while the data on the water use were taken from the PWA hydrological database (PWA, 2003) after deducting the water used for industrial and commercial purposes mentioned earlier.
3. The 2002 estimated water use was about 3.69 MCM/Yr in the J1 area of Jerusalem and 11.66 MCM/Yr in the J2 area of Jerusalem. Therefore, the total 2002 estimated water use by the population of the Palestinian Governorate of Jerusalem was 15.35 MCM/Yr.

Table 6-2 shows the estimated water use for various purposes in the West Bank (as of the year 2002). According to Table 6-2, the total water use as of the year 2002 was estimated to be about 78.8 MCM/Yr, 75 MCM/Yr, and 10 MCM/Yr for the household, irrigation, and industrial purposes, respectively. Therefore, the overall estimated water use for various purposes in the West Bank was 163.8 MCM/Yr.

The results shown in Table 6-2 will be used later as a baseline for projecting the future water demand in the various governorates of the West Bank for the years 2005, 2010, 2015, 2020, and 2025.

Table 6-2: The Estimated Water Supply For Various Purposes In The West Bank (As Of 2002)

Governorate	Household			Irrigation			Industrial			Grand Total
	Wells*	Springs	Total	Wells	Springs	Total	Wells	Springs	Total	
Jenin	5.07	0.10	5.17	5.48	0.00	5.48	0.55	0.00	0.55	**11.21**
Tubas	0.31	0.16	0.47	6.21	3.50	9.71	0.10	0.00	0.10	**10.29**
Tulkarm	5.56	0.00	5.56	9.76	0.00	9.76	1.00	0.00	1.00	**16.32**
Nablus	9.18	2.33	11.50	1.83	1.50	3.33	1.60	0.00	1.60	**16.43**
Qalqiliya	3.77	0.00	3.77	6.63	0.00	6.63	0.45	0.00	0.45	**10.86**
Salfit	1.59	0.09	1.67	0.00	0.13	0.13	0.10	0.00	0.10	**1.90**
Ramallah	14.70	0.00	14.70	0.56	0.15	0.71	1.40	0.00	1.40	**16.81**
Jerusalem	14.76	0.00	14.76	0.00	0.15	0.15	0.50	0.00	0.50	**15.41**
Jericho	1.30	2.31	3.61	9.32	28.50	37.82	0.20	0.00	0.20	**41.63**
Bethlehem	4.71	0.00	4.71	0.00	0.56	0.56	1.60	0.00	1.60	**6.87**
Hebron	12.87	0.00	12.87	0.00	0.71	0.71	2.50	0.00	2.50	**16.08**
Total	**73.83**	**4.98**	**78.80**	**39.80**	**35.20**	**75.00**	**10.00**	**0.00**	**10.00**	**163.80**

Source: Integrated from PWA Hydrological Database (2003) & the Palestinian Central Bureau of Statistics (PCBS, 2004).
* Note that about one third of this quantity (29.4 MCM/Yr) is purchased annually from Mekorot Israeli Water Company i.e. it is hard to tell if the water comes from wells or from the Tiberias Lake which flows in the Israeli Water Carrier.
** It is assumed that the springs used for irrigation were completely utilized, but in reality a high percentage of spring water is lost by evaporation because they are mostly flowing in open flow canals.

In addition to the water use by the Palestinian population of the West Bank, the Israeli Settlers (about 405,000 in 2002), who are living in 154 Israeli Settlements in the West Bank including East Jerusalem, are extracting large quantities of water to be used for various purposes. The Israeli Government drilled 42 groundwater wells in the West

Bank after 1967 to provide the Israeli colonies with their water needs for various purposes. Six of these wells are monitoring wells, while the other 36 wells are production wells. The Israeli Settlers could be subdivided into two groups based on the place where they live and the source of water they are served. These groups are:

1. The Israeli Settlers who live in the West Bank excluding East Jerusalem. The population of this group is 176,000 (PCBS, 2004) and they are being served by about 49.5 MCM/Yr of water extracted from the 36 settlement wells mentioned earlier (PWA, 2003).
2. The Israeli Settlers who live in East Jerusalem whose total 2002 number is 229,000 (PCBS, 2004). There are no official figures about the water used by this Settlers group. For the purpose of this research, the total water use was roughly estimated based on the reported average per capita water consumption of 250 l/c/d which is currently used in Israel (Jewish Virtual Library, 1997). The 2002 estimated total water use for all purposes by the Israeli settlers living in East Jerusalem was about 20.9 MCM/Yr.

Table 6-3 shows the Palestinian population, the number of the Israeli Settlers, and their overall estimated water use by the various governorates of the West Bank (as of the year 2002).

As shown in Table 6-3, the overall estimated water use by the Israeli Settlers in the West Bank including East Jerusalem was 69.7 MCM/Yr, while the overall estimated water use by the Palestinian population of the West Bank is about 163.8 MCM/Yr.

Table 6-3: The Population Of The Palestinian Communities And The Israeli Colonies In The West Bank And Their Water Use By Governorate (As Of 2002)

Governorate	Palestinians		Israeli Settlers		Total West Bank	
	Population (Capita)	Water Use (MCM/Yr)	Population (Capita)	Water Use (MCM/Yr)	Population (Capita)	Water Use (MCM/Yr)
Jenin	242,603	11.21	2,237	0.00*	244,840	11.21
Tubas	44,283	10.29	1,305	10.68	45,588	20.97
Tulkarm	160,306	16.32	1,829	0.29	162,135	16.61
Nablus	312,242	16.43	7,614	5.47	319,856	21.90
Qalqiliya	88,780	10.86	24,403	1.52	113,183	12.38
Salfit	58,914	1.90	27,575	0.00*	86,489	1.90
Ramallah	263,957	16.81	58,381	6.05	322,338	22.86
Jerusalem (J1+J2)	388,441	15.41	229,256	20.92	617,697	36.33
Jericho	40,053	41.63	4,802	23.22	44,855	64.85
Bethlehem	165,952	6.87	34,929	1.61	200,881	8.48
Hebron	495,068	16.08	13,154	0.00*	508,222	16.08
Total	**2,260,596**	**163.80**	**405,485**	**69.76**	**2,666,081**	**233.56**

Source: Integrated from the PWA Hydrological Database (PWA, 2003), the Palestinian Central Bureau of Statistics (PCBS,2003) and the Israeli Central Bureau of Statistics (PCBS, 2003).
* The zero value of water use by the Israeli settlers for Jenin, Salfit, and Hebron means that there are no wells serving the Israeli settlers within these West Bank governorates to provide water, but they may get their water needs either from the Israeli wells in other governorates of the West Bank or from Mekorot Israeli Water Company.

Based on Table 6-3, it is noticed that although the total Palestinian population constitutes about 85% of all the total West Bank population (including Palestinians and Israeli Settlers), they are only using 70% of the overall water used in the West Bank.

Table 6-1 and Table 6-3 show that 466,000 Palestinians have no access to piped water, but all the Israeli Settlers (405,000 capita) who live in the West Bank including East Jerusalem have a continuous access to piped water.

6.3 Requirements of Sustainable Water Demand

Studying the sustainable management of the water supply and demand is the main goal of this study. In order to achieve the water sustainability, four requirements were taken into consideration; these are the water resources availability, the economic feasibility, the social equity, and the current and future land use.

6.3.1 Water Resources Availability

The water resources availability is the key factor in studying the water supply and demand in any region. It includes both natural and artificial conditions. The natural conditions include the natural existence of water resources in terms of the groundwater sustainability and the surface water potentials. The artificial conditions include the availability of groundwater wells, reservoirs, water networks, etc.

In this study, the Water Sustainability Map (WSM) was created. Since the groundwater is the only accessible source of water for the Palestinian population of the West Bank, the WSM was assumed to be equal to the Aquifer Sustainable Yield (ASY). The ASY can be defined as the average annual renewable natural recharge of all outcropped aquifers underlying the West Bank. The 10-Year average recharge (and so the ASY) was estimated for the West Bank area in Chapter Three. Figure 6-2 shows the estimated ASY for the various governorates of the West Bank. The ASY was derived by intersecting the governorates coverage and the recharge coverage created earlier in Chapter Three by using the GIS geo-processing tools. Figure 6-2 also compares the ASY with the 2002 Palestinian total water use from all aquifers in the various governorates of the West Bank. The 10-Year estimated average ASY was about 679.7 MCM/Yr. In terms of water sustainability, the groundwater extraction was should not exceed the ASY limit.

In addition to the ASY, Chapter Three shows that the aquitard outcropped formations of the West Bank are being annually recharged by about 142 MCM/Yr of natural rainfall. A possible fraction of the aquitard recharge water may end up flowing into surface water streams, emerge in the form of springs, or leak to the underlying aquifers which could increase the ASY.

Comparison of the 2002 water supply with the aquifers' natural recharge

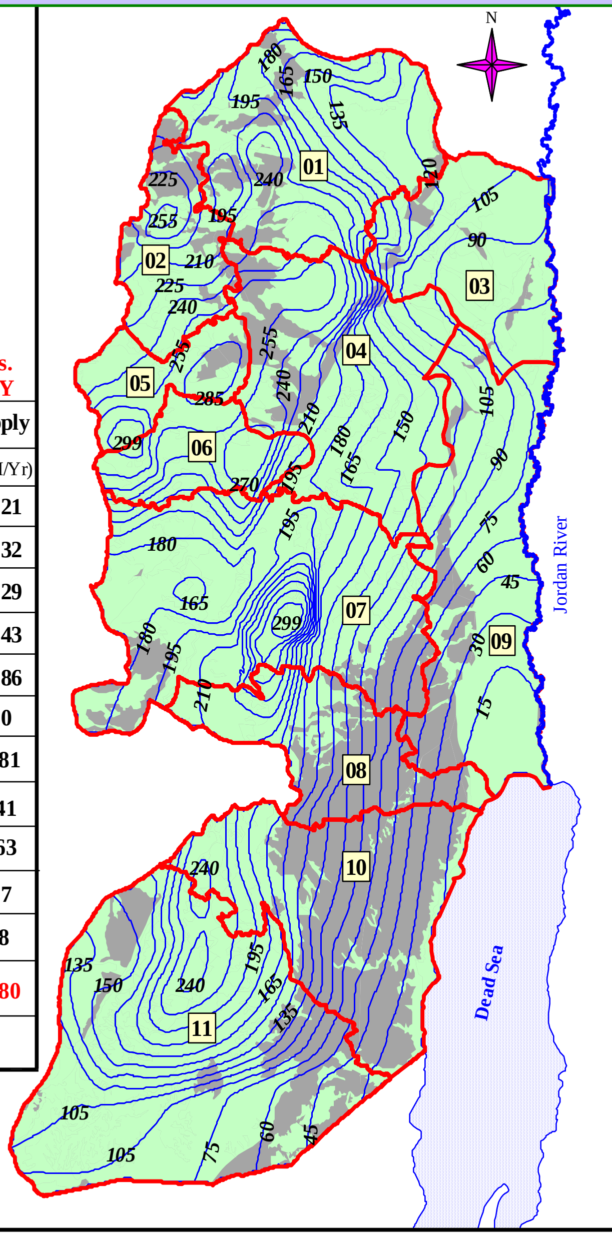
MAP LEGEND

- 155 Contour Value (mm/yr)
- Dead Sea
- Governorate Boundary
- Non-Recharge Area
- Recharge Area
- Jordan River

ESTIMATED AQUIFER YIELD Vs. 2002 WEST BANK WATER SUPPLY

ID	GOVERNORATE	Recharge (MCM/Yr)	Supply (MCM/Yr)
01	JENIN	76.87	11.21
02	TULKARM	80.32	16.32
03	TUBAS	44.31	10.29
04	NABLUS	92.71	16.43
05	QALQILIYA	47.07	10.86
06	SALFIT	50.51	1.90
07	RAMALLAH	94.08	16.81
08	JERUSALEM	31.88	15.41
09	JERECHO	27.92	41.63
10	BETHLEHEM	29.56	6.87
11	HEBRON	104.49	16.08
	WEST BANK TOTAL	679.71	163.80

9 0 9 Kilometers



The aquifers' sustainable yield was esimated for the West Bank governorates based on the recharge map created in chapter three by using the GIS Geo-Processing Tools

Figure 6-2 [1]: The Estimated Aquifer Sustainable Yield (ASY) And The Total Palestinian Water Use For Various Purposes In The West Bank (As Of 2002)

[1] This recharge looks higher than the actual value because it is estimated based on the assumption that no minor losses will occur during the percolation of rainfall into the groundwater aquifers

Other than the groundwater resources, limited surface water quantities including seasonal flood runoff in winter streams were considered in this water sustainability study. The long term average annual flood runoff was estimated earlier in Chapter Three to be about 78 MCM/Yr.

These surface water resources are not currently sustainable, but could be sustainable by the year 2020 if the PWA constructed dams to capture the flood runoff water from the major streams of the West Bank to be used for various purposes. That could increase the upper limit of the water sustainability beyond the ASY in the West Bank. As shown in Figure 6-2 and the accompanied table of attributes, the total estimated ASY of the West Bank aquifers was about 679.7 MCM/Yr and the total water use by the Palestinians is about 163.8 MCM/Yr, i.e. the Palestinians are only using 25% of the annual ASY. Whereas, the combined water use by the Palestinians and the Israeli Settlers of the West Bank is currently about 233.6 MCM/Yr (Table 6-3) which constitutes about 34% of the annual ASY in the West Bank.

Since the boundaries of the West Bank governorates are not natural hydrological boundaries, the groundwater tends to flow across these boundaries following the hydraulic gradient, the recharge areas, and the storage reservoirs of the West Bank aquifers. The numbers shown in the table of attributes of Figure 6-2 don't mean that the water extraction from various governorates cannot exceed the recharge numbers because, in addition to its vertical flow, the groundwater flows horizontally from one governorate to another. For example, the current water use from Jericho governorate (Figure 6-2) is greater than the annual recharge, but in reality there is horizontal groundwater flow from the upstream areas of Ramallah, Jerusalem, and Nablus governorates into Jericho's underground aquifers which could increase the availability of groundwater there. Also since the West Bank is one geographic unit, the transfer of water from one governorate to another is possible all the time if the aquifers underlying any governorate are not able to provide enough water for its population.

6.3.2 Economic Feasibility

The economic and technical feasibility to rehabilitate and maintain the existing water networks, reservoirs, groundwater wells, springs, and to install extra wells and develop the related infrastructure to meet the future demand on water is an important component of this water sustainability research. The water use should be economically sustainable by gradual increase of the per capita water use until it reaches the sustainable limit of about 250 l/c/d by the year 2025.

6.3.3 Demography, Population, and Social Equity

The demographic status is an important issue in determining the shape of the current and future water supply and demand in the West Bank. According to the 1997 population census of Palestine, the population of the West Bank was 1.78 million. The PCBS updated the current population of the West Bank (by the end of the year 2002) based on the 1997 census to be approximately 2.26 million (PCBS, 2004). These 2.26 million Palestinians are living in 642 communities (cities, towns, villages, and camps) distributed in 11 governorates. Out of these 642 communities, 257 communities with an approximate population of 466,000 capita (about 25% of West Bank population) still have no access to piped water (PWA, 2003).

The social equity deals with providing all people with sufficient water wherever and whenever they need the water for various purposes with an acceptable quality and affordable price. The World Health Organization (WHO) requires that the minimum standard for the per capita water consumption is about 150 l/c/d. As shown in Table 6-1, only two Palestinian governorates are exceeding the WHO standard limit while the other governorates are currently using less water. The two governorates are Ramallah and Jericho with a combined total population of about 304,000 which constitutes about 13% of the total Palestinian population in the West Bank.

In this study, the social equity to access water was maintained through increasing the water supply in order to achieve the 150 l/c/d limit by the year 2010. In addition, the water use should increase gradually until it equalizes the current Israeli per capita water use of about 250 l/c/d (Jewish Virtual Library, 2003) by the year 2025.

6.3.4 The Current and Future Land Use Patterns

The land use sustainability is required to know the capability of land to absorb the natural increase of the Palestinian population, the return of an assumed number of Palestinians, the Palestinians living out of Palestine who usually visit their families and stay the summer months of the year, and the proposed increase in the irrigated areas in order to provide enough water and food to its population within a specified period of time.

Table 6-4 shows the current (as of 2002) and the projected (as of 2025) areas of various land use patterns in the West Bank. Figure 6-3 shows the created land use map of the West Bank before and immediately after the release of the Israeli occupation.

Table 6-4: The Current Areas Of Land Use Patterns As Derived From The Land Use Map (As Of 2002) And The Projected Areas Of The Land Patterns (As Of The Year 2025)

The Current Areas of Land Use Patterns by the Year 2002

Land Use Pattern	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah
	Area (hectare)						
BUILT-UP AREAS	2,326	487	2,110	2,747	699	688	3,843
PALESTINIAN IRRIGATED AREAS	1,196	1,100	1,921	433	1,068	17	91
ISRAELI IRRIGATED AREAS	0	738	0	117	0	0	0
RAINFED AGRICULTURE	42,647	3,047	11,123	24,223	9,261	11,203	25,791
NATURE RESERVES & FORESTS	3,353	5,057	228	4,864	817	2,300	5,323
ISRAELI COLONIES	192	222	109	482	772	636	1,355
CLOSED MILITARY AREAS	1,175	19,963	0	8,165	107	1,751	12,662
MILITARY BASES	120	184	0	184	16	0	235
STATE LAND AND OTHERS	7,117	6,680	8,803	19,356	4,516	3,579	33,577
DEAD SEA							
TOTAL	58,126	37,478	24,294	60,571	17,257	20,173	82,878

Land Use Pattern	Jerusalem	Jericho	Bethlehem	Hebron	WEST BANK TOTAL	
	Area (hectare)				Area (ha)	%
BUILT-UP AREAS	3,361	1,029	2,955	7,763	28,010	4.8%
PALESTINIAN IRRIGATED AREAS	19	4,466	86	103	10,500	1.8%
ISRAELI IRRIGATED AREAS	0	1,782	93	0	2,730	0.5%
RAINFED AGRICULTURE	2,370	0	4,491	38,995	173,151	29.7%
NATURE RESERVES & FORESTS	1,919	3,706	5,042	1,606	34,214	5.9%
ISRAELI COLONIES	1,966	1,018	740	477	7,969	1.4%
CLOSED MILITARY AREAS	9,270	18,538	34,382	17,519	123,532	21.2%
MILITARY BASES	307	265	20	137	1,469	0.3%
STATE LAND AND OTHERS	14,314	32,484	13,703	37,524	181,654	31.2%
DEAD SEA					18,971	3.30%
TOTAL	33,526	63,288	61,513	104,125	582,200	100.0%

The Overall Projected Areas of Land Use Patterns by the Year 2025

Land Use Pattern	WEST BANK TOTAL	
	Area (ha)	**%**
AREAS BUILT-UP	87,330	15.0%
PALESTINIAN IRRIGATED AGRICULTURE	30,000	5.2%
RAINFED AGRICULTURE	105,212	18.1%
FORESTS & NATURE RESERVES	34,214	5.9%
STATE LAND AND OTHERS *	306,473	52.6%
DEAD SEA	18,971	3.3%
TOTAL	582,200	100.0%

* The state land and others in the projected land use is the outcome of merging all the Israeli controlled areas with the current state land based on the assumption that the occupation will be released.

The 2002 land use map was integrated into ArcView GIS coverage based on the various Palestinian and Israeli websites sources including the Applied Research Institute of Jerusalem (ARIJ, 2004), the Palestinian Central Bureau of Statistics (PCBS, 2004), the Palestinian Academic Studies Society for International Affairs (PASSIA, 2004), the

Palestinian Hydrology Group (PHG, 2004) and the Central Bureau of Statistics – Israel (CBS, 2004). The land use coverage was then used to calculate the areas of various land use patterns for each West Bank governorate and a table of attributes was created which tabulates the results using the GIS geo-processing tools.

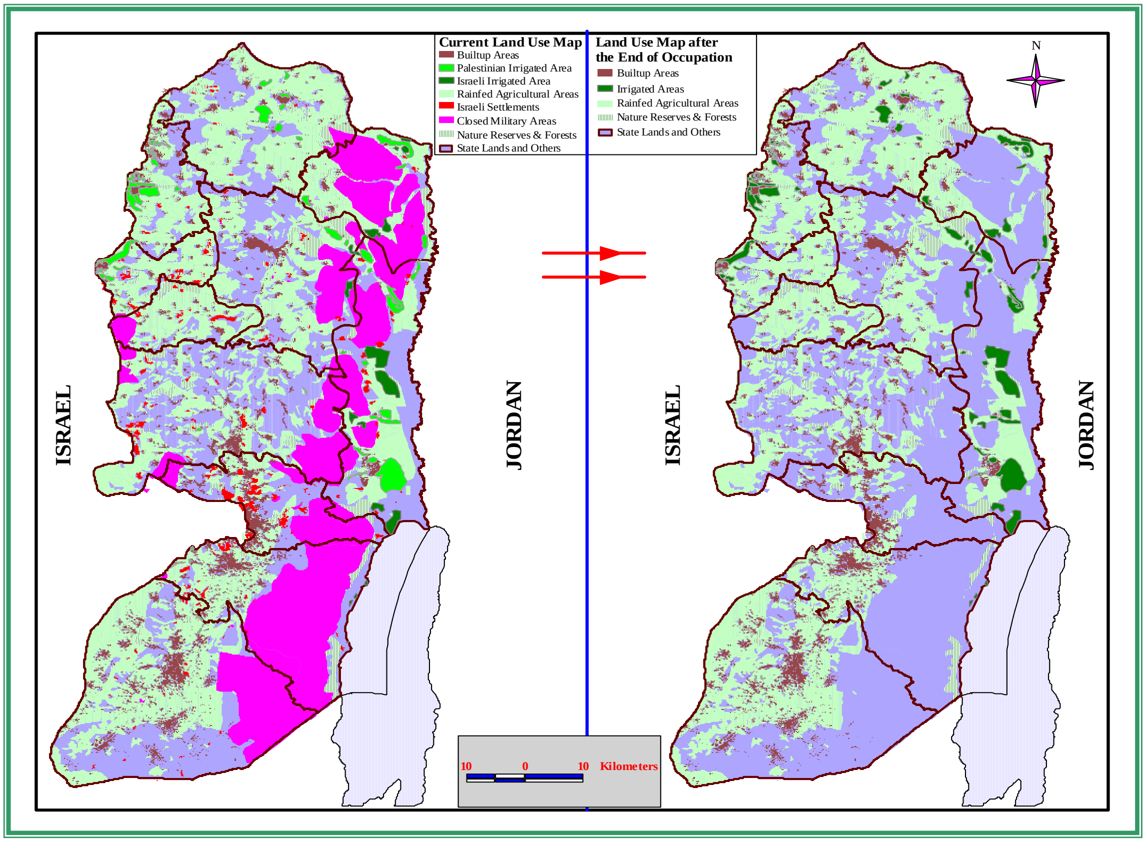


Figure 6-3: The Current Land Use Map Of The West Bank (As Of The Year 2002)

As shown in Table 6-4, the current Palestinian built-up area constitutes about 4.8% and the irrigated agricultural area constitutes about 1.8% of the total West Bank area. Table 6-4 also shows that more than 60% of the West Bank area will be available for the Palestinians to use upon the release of the Israeli occupation. Figure 6-4 shows the pie graph of the current percentage areas and Figure 6-5 shows the pie graph of the projected percentage areas of various land use patterns in the West Bank.

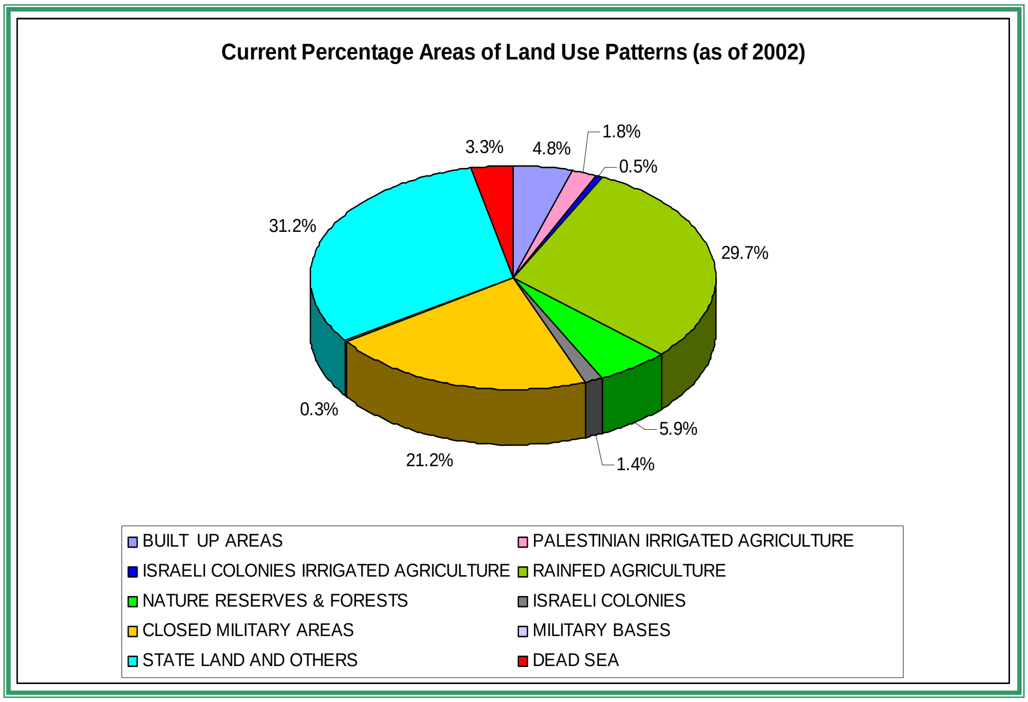


Figure 6-4: The Current Percentage Areas Of Various Land Use Patterns (As Of 2002)

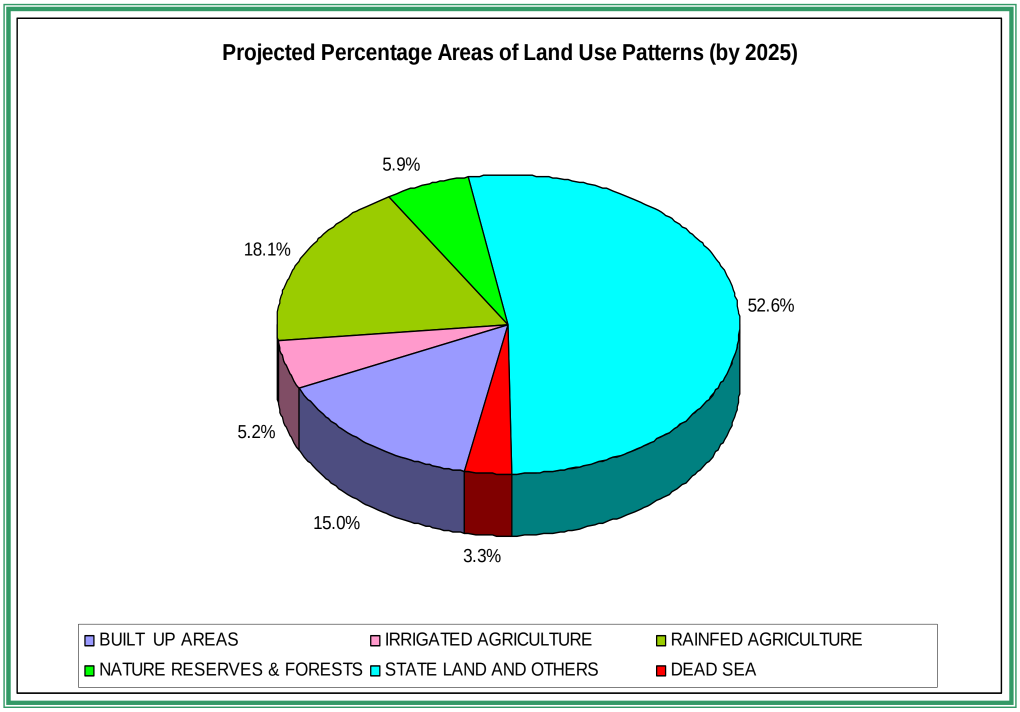


Figure 6-5: The Projected Percentage Areas Of Various Land Use Patterns (As Of 2002)

Figure 6-3 shows that the current Palestinian land use in the West Bank is about 36% which includes the built-up/urban areas (4.8%), the irrigated agricultural areas (1.8%), and the rain-fed agricultural areas (29.7%). The other 64% includes the closed military areas, Israeli settlements, state lands, nature reserves, and others which are all still being controlled by Israel (Figure 6-3).

Figure 6-4 shows that although Israel is controlling more than 60% of the West Bank area, the Palestinians still have potential areas represented by the rain-fed agricultural sector which constitutes about 30% of the West Bank. This could help the Palestinians to expand their urban built-up areas and the irrigated agricultural area. According to Figure 6-5, it was assumed that the current land use will change gradually based on the proposed release of the Israeli occupation and the establishment of the Palestinian State by the end of the year 2005 according to the American proposed Road Map for peace in the Middle East. By the year 2025 (see Figure 6-3, Figure 6-4, and Table 6-4), this study assumed the following land use modifications:

- ❖ The projection period will be from the year 2005 to the year 2025. Since the Palestinian built-up areas are very close to the rain-fed agricultural areas, a part of the rain-fed areas will be converted into the built up areas and/or into the irrigated areas. For example, 8.8% of the West Bank area will be converted into built-up areas and 2.9% will convert into irrigated agriculture area by the year 2025.
- ❖ The Israeli Settlements which constitute about 1.4% of the total area of the West Bank will be converted into Palestinian built-up areas.

- The Israeli irrigated agriculture area which constitute about 0.5% of the total area of the West Bank will be converted into Palestinian irrigated areas.
- The other closed military areas, military bases, state lands and others will be all merged into state lands which will be available for the Palestinian State to be used for various purposes. The Palestinians could use the state land for building the road networks, water infrastructure, new urban centers, economic institutions, industries and the other basic needs and requirements of a newly established Palestinian State.

As shown in Figure 6-5, the proposed state land area is about 52% of the West Bank area which will be open for future development to build a stable Palestinian State. That area can absorb most of the Palestinian refugees and/or absentees who are currently living out of Palestine due to political complexities.

6.4 Water Demand Scenario Projections

The household water sector is currently consuming about 48% (78.8 MCM/Yr) of the total water used for all purposes in the West Bank. The irrigated agricultural sector is consuming about 46% (75 MCM/Yr) and the industrial and commercial sector is only consuming about 6% (10 MCM/Yr) of the total water used for all purposes. The first priority was given in this water demand study to the household water needs by the increased population of West Bank. In this study, the future water demands for various purposes were projected for the period (2005-2025) based on the 2002 baseline data.

Appendix D shows the detailed results of the various projection scenarios and sub-scenarios for different water demand purposes. Although there are many sectors that consume water in the West Bank, this water supply and demand study dealt with the these three main sectors. These are the household, the agricultural, and the industrial and commercial water sectors.

6.4.1 Household Water Demand

The West Bank household water supply usually consists of a combination of other minor components of water supply which are not possible to be separated from the household water use due to the common water connections. These minor water use components include, but not limited to, the commercial and industrial uses, tourism, livestock, plant and flower nurseries, house yards watering, etc. For the sake of this research, the water used in the water-intensive industries which primarily include textile, food processing, and quarrying was estimated based on the average number of such establishments surveyed by the PCBS (PCBS, 2004) and the average water use by each establishment.

The 2002 baseline data used in this research is shown in Table 6-2 which was used to project the future household water demand in the West Bank for the years 2005, 2010, 2015, 2020, and 2025.

The household water demand was conducted on governorate by governorate basis for the Palestinian population of the West Bank.

Figures 6-6 through 6-8 show the population, the household water use, and the average per capita water use by governorates of the West Bank, respectively. As shown in Figures 6-6 through 6-8, the allocation of household water is not consistent between different governorates. The per capita water use is not proportional to the population

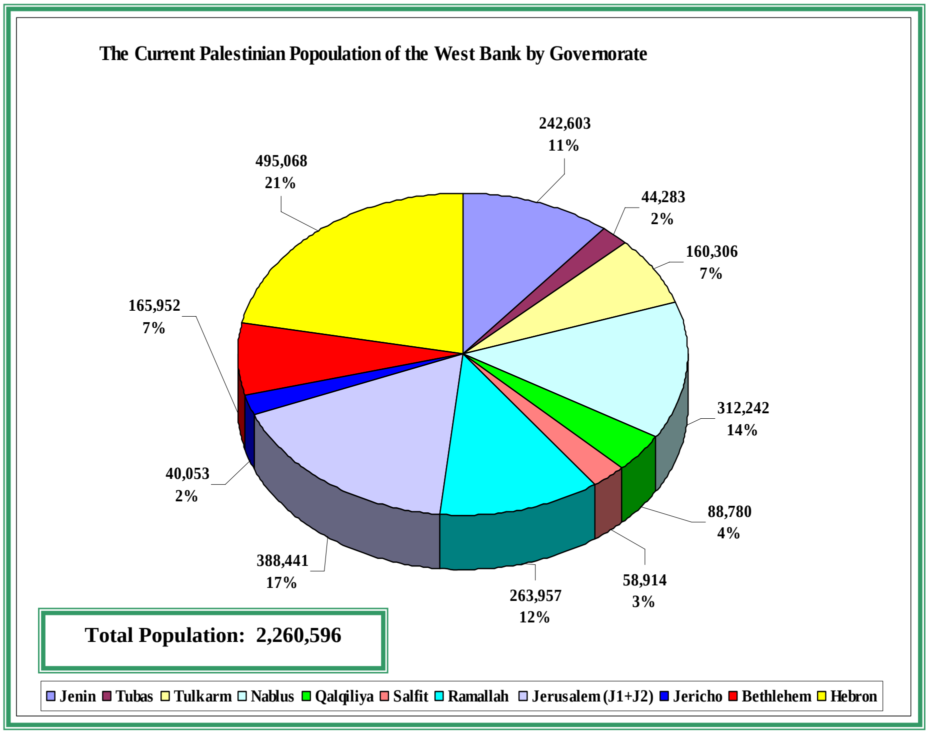


Figure 6-6: The 2002 West Bank Population By Governorates

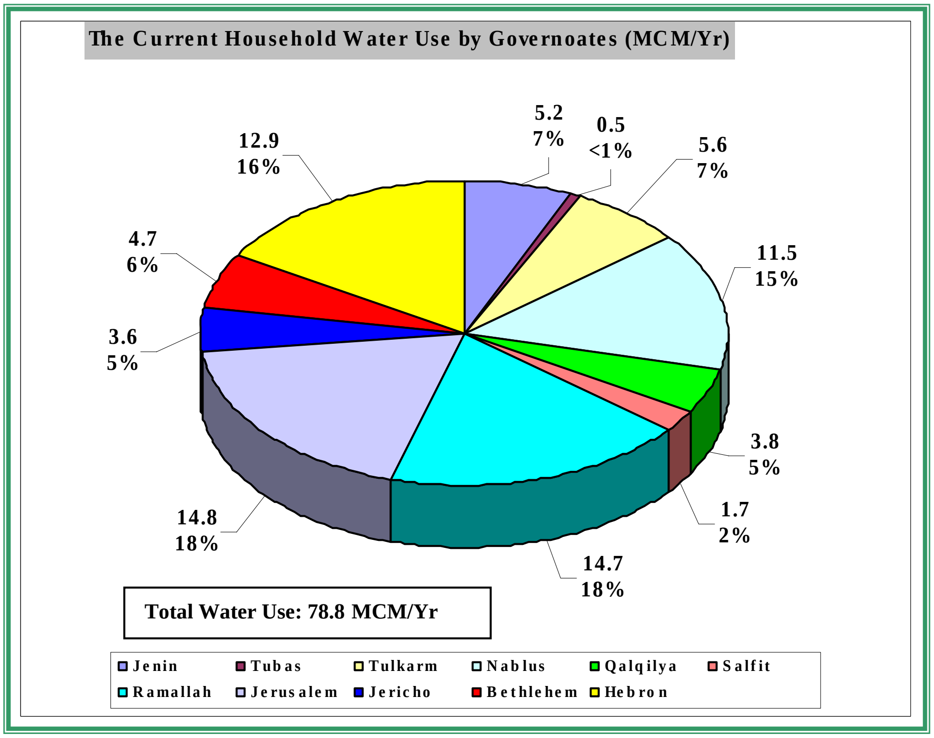


Figure 6-7: The 2002 West Bank Household Water Use By Governorates

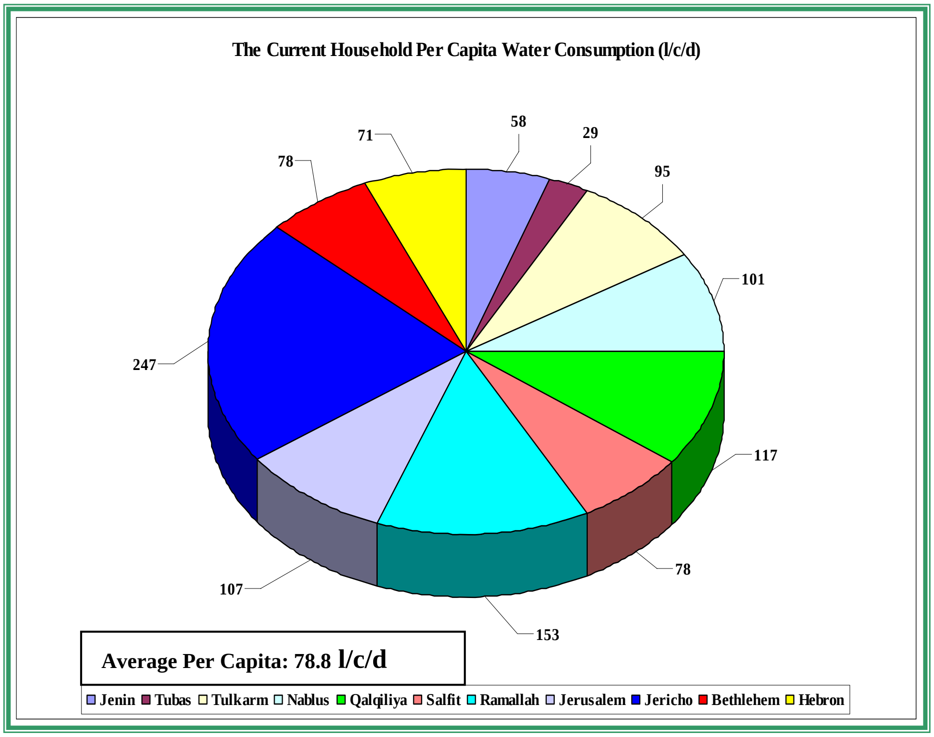


Figure 6-8: The 2002 Household Per Capita Water Use By Governorates

living in each governorate. For example, the percentage of population is the least in Jericho (2%) and its per capita water use was the highest (263 l/c/d). On the other hand, the percentage of population is the highest in Hebron (21%) while its per capita water use was 71 l/c/d. That was much below the 150 l/c/d of the WHO standards for the household water needs.

The study of the household water supply and demand in the West Bank is a little challenging due to the complicated demographic situation. The research difficulty comes from the scattering of the Palestinians in many several countries due to political complexities. It is hard to account for all the Palestinians in any water supply and demand study because about 60% of Palestinians are currently living out of Palestine. Although, the population of the West Bank was about 2.26 millions in the year 2002, there is about one million non-refugee Palestinians living abroad in the Arab Gulf States and other Arab countries, Europe, and the Americas. Most of these people lost the right of return either permanently or to visit their relatives in Palestine (PCBS, 2004). In addition, there are about 2.5 million Palestinian refugees who were forced to leave Palestine and live mainly in Jordan, Syria, and Lebanon.

According to the United Nations Resolution # 194, all the Palestinian refugees have the right to return to their land which they left (UNRWA, 2004). There are too many complicated issues when dealing with the right of return of the Palestinian refugees stated by the United Nations Resolution #194 in 1949. That resolution gave the right for the Palestinian refugees and their descents to return to their original lands which are currently located within the State of Israel.

In order to overcome the political sensitivity of the return of the Palestinian refugees, the term "returnees" was used instead of the term "refugees" in the various scenarios of the water demand projections proposed in this study.

Three household water demand scenarios were proposed based on three factors; the natural population growth of the current West Bank population (the basic sub-scenario), an assumed number of visitors, and an assumed number of returnees. The current Population Growth Rate (PGR) in the West Bank is about 3.25% (PCBS, 2004) which was assumed to be the same in 2005. According to the PCBS, it is expected that the PGR of the Palestinians will decrease to about 2% within 30 years. That proposed decrease can be attributed to the fact of increasingly higher costs of living, higher education levels and general welfare.

In this study, it was assumed that the PGR will decrease by 0.05% per year to reach about 3%, 2.75%, 2.5%, and 2.25% by the years 2010, 2015, 2020, and 2025, respectively. The proposed visitors were assumed to stay three months a year and so the equivalent population for visitors was estimated by dividing the proposed number of visitors by four in order to account for their annual water use. For example, the equivalent number of population for the 250,000 visitors of the low household scenario is 62,500 capita per year. The number of visitors and returnees per year per governorate were determined based on the current population percentage and the population density in the various governorates, respectively.

The current population percentage (Figure 6-6) was used to determine the number of visitors per each governorate. The population density for each governorate was determined by dividing the population by the total area of the governorate. Then the Population Absorption Percentage Rate (PAPR) for returnees was derived by giving the highest percentage to the governorate with the lowest population density and so on. Table 6-5 shows the derived PAPR from the population density for the various governorates of the West Bank.

In projecting the household water demand, the 2002 baseline per capita water use for each governorate was assumed to be constant until the year 2005 and then it started to increase annually until it reached the 150 l/c/d by the year 2010 which is the minimum requirement of the WHO standards for household. For the case of Ramallah and Jericho governorates, whose current per capita water use is greater than 150 l/c/d, the per capita water use will be 175 l/c/d, and 250 l/c/d, respectively. After the year 2010, the proposed per capita water use will be 200 l/c/d, 225 l/c/d, and 250 l/c/d by the years 2015, 2020, and 2025, respectively. In all proposed scenarios, the final per capita water use should reach 250 l/c/d by the year 2025 which is equivalent to the current Israeli per capita water use.

Based on the social water equity introduced earlier in this study, all population of the various Palestinian governorates should be getting the same household water quota which is about 250 l/c/d by the year 2025. The social water equity should also mean that all population who are sharing the same water resource, as in the case of Palestine/Israel countries, should have the right to get the same household water quota.

As shown in Table 6-5, Tubas Governorate has the lowest population density and the highest PAPR. Also Tulkarm Governorate has the highest population density and the lowest PAPR for returnees.

Table 6-5: The Population Density and the PAPR

Governorate	Population Density	PAPR
Tubas	2.7%	15.3%
Jericho	2.8%	14.2%
Bethlehem	6.3%	11.9%
Salfit	6.8%	11.9%
Ramallah	7.4%	11.0%
Jenin	9.7%	9.7%
Hebron	11.0%	7.4%
Qalqilya	11.9%	6.8%
Nablus	11.9%	6.3%
Jerusalem	14.2%	2.8%
Tulkarm	15.3%	2.7%

In this study, three household water demand projection scenarios were proposed. These scenarios are:

- The Low Scenario which accounts for the water demand of the basic West Bank population and their future natural growth, the 250,000 Palestinian returnees from the Diaspora, and the 250,000 visitors who will visit their relatives in the West Bank. The number of returnees and visitors gradually increases year by year until they reach the limiting number of 250,000 in the year 2025. The account for returnees and visitors started by the year 2005 with 10,000 capita and 50,000 capita, respectively. The annual rate of increase was 12,000 returnees per year during the period from 2006 to 2025. The annual rate of increase was 10,000 visitors per year during the period from 2006 to 2025. The overall projected household water demand was 88 MCM/Yr, 169.7 MCM/Yr, 258.7 MCM/Yr, 335.7 MCM/Yr, and 424.1 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively (Appendix D).

- Medium Scenario which accounts for the water demand of the basic West Bank population and their future natural growth, the 500,000 Palestinian returnees from the Diaspora, and the 500,000 visitors who will visit their relatives in the West Bank. The number of returnees and visitors gradually increases year by year until they reach the limiting number of 500,000 in the year 2025. The account for returnees and visitors started by the year 2005 with 20,000 capita and 100,000 capita, respectively. The annual rate of increase was 20,000 returnees per year during the period from 2006 to 2025. The annual rate of increase was 24,000 visitors per year during the period from 2006 to 2025. The overall projected household water demand was 88.8 MCM/Yr, 175.7 MCM/Yr, 272.8 MCM/Yr, 379.4 MCM/Yr, and 459.5 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively (Appendix D).

- ❖ High Scenario which accounts for the water demand of the basic West Bank population and their future natural growth, the 750,000 Palestinian returnees from the Diaspora, and the 750,000 visitors who will visit their relatives in the West Bank. The number of returnees and visitors gradually increases year by year until they reach the limiting number of 750,000 in the year 2025. The account for returnees and visitors started by the year 2005 with 30,000 capita and 150,000 capita, respectively. The annual rate of increase was 36,000 returnees per year during the period from 2006 to 2025. The annual rate of increase was 10,000 visitors per year during the period from 2006 to 2015 and it increased by a rate of 50,000 visitors per year from 2016 to 2025. The overall projected household water demand was 89.6 MCM/Yr, 180.2 MCM/Yr, 283.2 MCM/Yr, 380.9 MCM/Yr, and 494.9 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively (Appendix D).

6.4.2 Agricultural Water Demand

In this study, the agricultural water demand is the water which is required for irrigation purposes and didn't include any other agricultural water use purposes. As of the year 2002, the irrigated agricultural areas in the West Bank were about 10,500 hectares which constitutes only 1.8% of the total West Bank area. That irrigated area didn't change much during the past 20 years due to restrictions on water use imposed by Israel. Figure 6-9 shows pie graph for the 2002 irrigated areas distributed by governorates of the West Bank.

The cultivated lands in the West Bank have an area of about 173,150 hectares which constitutes about 31% of the total area of the West Bank (see Table 6-4). Of that cultivated land, only 6% is currently under irrigation and the other 94% is rain-fed area.

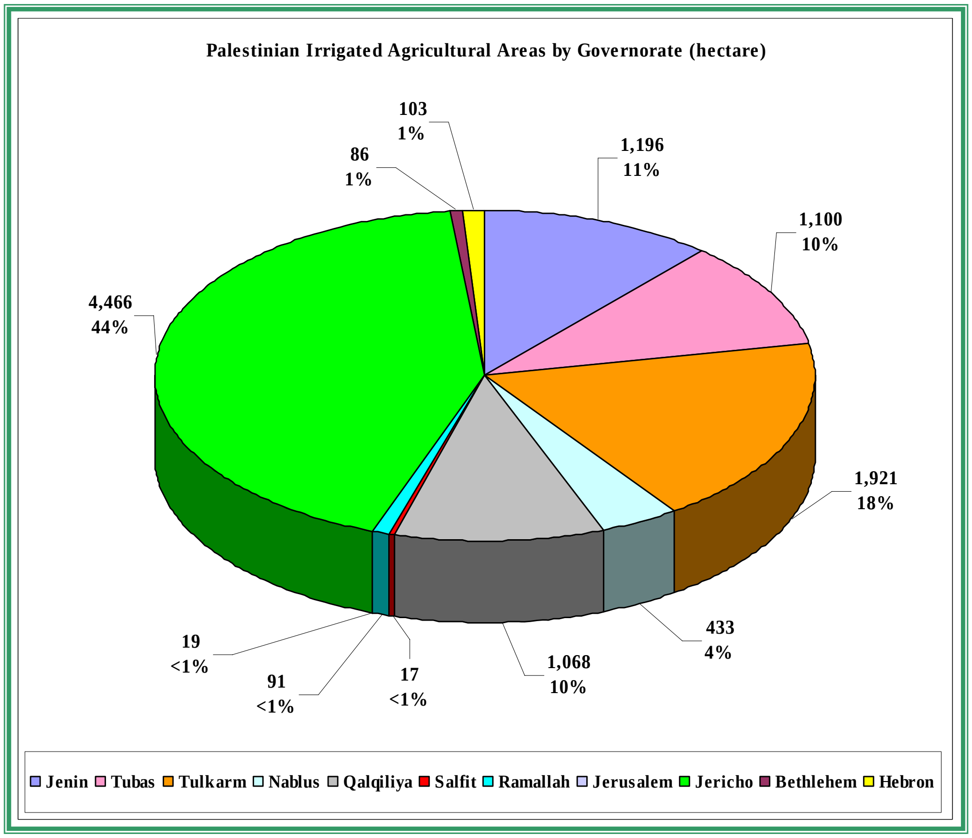


Figure 6-9: The Irrigated Agricultural Areas (Hectare) By Governorate (As Of 2002)

The agriculture in the West Bank is very important for the Palestinian economy since it contributes between 25-30 percent to the Gross National Product (GNP) and employs about 17 percent of the Palestinian work force. Although the irrigated areas constitute about 6% of the cultivated areas, the1995 total production from irrigated agriculture was about 53% of the total agricultural production of all the cultivated lands (Isaac and Sabbah, 1998).

The 2002 agricultural water use was about 75 MCM/Yr, of which 40 MCM/Yr is being extracted from groundwater wells and the other 35 MCM/Yr is being taken from the freely flowing springs.

About one half of the current cultivated land in the West Bank could be converted into irrigated lands which can strongly support the Palestinian economy. Due to water sustainability reasons, this water demand study gives priority for the household water supply rather than for irrigation.

By the year 2025, the projected rain-fed and irrigated agricultural areas will constitute 18.1% and 5.2% of the total West Bank area, respectively (Table 6-4 and Figure 6-5). The 2002 baseline for irrigated areas was assumed the same until the year 2005 which means that the baseline moved into the year 2005. In this study, it was assumed that the irrigated areas will expand gradually from the year 2006 through the year 2025. It was also assumed that the expansion of the irrigated areas was the result of converting some rain-fed areas into irrigated areas. In Jericho Governorate, the only area expansion was due to the proposed transfer of the Israeli agricultural areas in the Jordan Valley Settlements by the release of the Israeli occupation.

The average per hectare water use in Israel was 6500 m^3/hectare (Jewish Virtual Library, 1997). This average per hectare water use was then used for projecting the future irrigation water demand in this research. Based on the average per hectare water use and the proposed increase of the irrigated agricultural areas, three water demand scenarios were considered in this research. These scenarios are:

- The Low Scenario which assumed that the irrigated agricultural areas of the West Bank will expand gradually until they reach 25,000 hectares (4.3% of the total

West Bank area) by the year 2025. The projected irrigation water demand was estimated to be 75 MCM/Yr, 113.8 MCM/Yr, 130 MCM/Yr, 146.2 MCM/Yr, and 162.5 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively (Appendix D).

- The Medium Scenario which assumed that the irrigated agricultural areas of the West Bank will expand gradually until they reach 27,500 hectares (4.7% of the total West Bank area) by the year 2025. The projected irrigation water demand was estimated to be 75 MCM/Yr, 120.2 MCM/Yr, 139.8 MCM/Yr, 159.2 MCM/Yr, and 178.8 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively (Appendix D).
- The High Scenario which assumed that the irrigated agricultural areas of the West Bank will expand gradually until they reach 30,000 hectares (5.2% of the total West Bank area) by the year 2025. The projected irrigation water demand was estimated to be 75 MCM/Yr, 123.5 MCM/Yr, 146.2 MCM/Yr, 170.6 MCM/Yr, and 195 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively. (Appendix D).

6.4.3 Industrial Water Demand

There are no heavy industries which consume much water in the West Bank. There are mainly two categories of industries in the West Bank. These are:

Light industries with minor water use that cannot be separated from the domestic water use due to the existence of common connections (Isaac et al, 1995).

Water-intensive industries which mainly include the textiles, the food processing, and the quarrying which includes stone cutting and washing (Isaac et al, 1995).

As mentioned earlier in the household section, the 2002 water use for industrial purposes was separated from the household water based on the existing number of Palestinian establishments surveyed by the PCBS. The estimated water use for industry was about 10 MCM/Yr which constitutes about 6% of the total water use for all purposes in the West Bank. Figure 6-10 shows the 2002 baseline industrial water use by the various governorates of the West Bank.

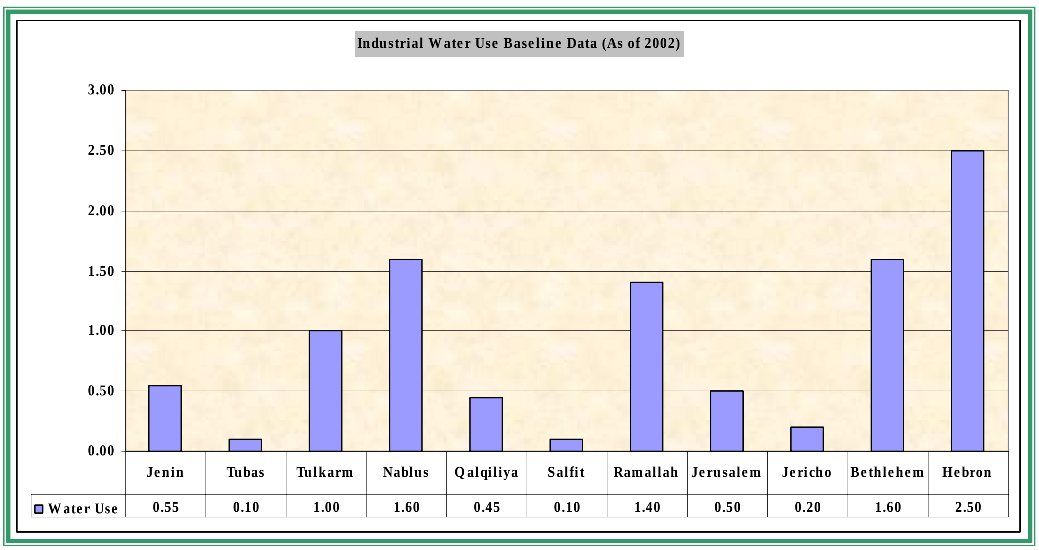


Figure 6-10: The 2002 Baseline Industrial Water Use (MCM/Yr)

During the past 10 years, the annual growth rate of the number of industrial establishments in the West Bank was about 1.5% (PCBS, 2004). In this research, the annual growth on water demand for industry was assumed to stay the same from the year 2002 to the year 2005. Three scenarios were set for projecting the industrial water demand in the West Bank during the period (2005-2025).

These scenarios can be listed as follows:

- ❖ The Low Scenario in which the projected annual growth on water demand for industry is assumed to be 3%. The projected industrial water demand was estimated to be 10.46 MCM/Yr, 12.12 MCM/Yr, 14.05 MCM/Yr, 16.29 MCM/Yr, and 18.89 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively (Appendix D).
- ❖ The Medium Scenario in which the projected annual growth on water demand for industry is assumed to be 4%. The projected industrial water demand was estimated to be 10.46 MCM/Yr, 12.72 MCM/Yr, 15.48 MCM/Yr, 18.83 MCM/Yr, and 22.91 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively (Appendix D).
- ❖ The High Scenario in which the projected annual growth on water demand for industry is assumed to be 5%. The projected industrial water demand was estimated to be 10.46 MCM/Yr, 13.35 MCM/Yr, 17.03 MCM/Yr, 21.74 MCM/Yr, and 27.74 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively (Appendix D).

6.5 Overall Water Demand Integration and Water Sustainability

In order to check the water demand sustainability in the West Bank, the overall projected water demand for various purposes was compared to the ASY for each governorate. Table 6-6 shows the total water demand results of the West Bank governorates for the low, medium, and high scenario projections.

Table 6-6 [1]: The Total Water Demand Projections (MCM/Yr) In The West Bank (2005-2025)

LOW SCENARIO TOTAL WATER DEMAND										
Year	**2002**	**2005**	**2010**	**2015**	**2020**	**2023**	**2024**	**2025**	**ASY**	***Difference**
Jenin	11.21	11.80	28.32	39.96	49.95	56.55	58.85	61.20	**76.87**	**15.67**
Tubas	10.29	10.36	17.46	21.84	26.11	28.92	29.90	30.91	**44.31**	**13.40**
Tulkarm	16.32	16.96	27.30	35.41	42.40	46.97	48.55	50.16	**80.32**	**30.16**
Nablus	16.43	17.75	30.63	44.90	56.98	64.96	67.73	70.57	**92.71**	**22.14**
Qalqiliya	10.86	11.31	15.89	21.45	26.46	29.72	30.86	32.01	**47.07**	**15.06**
Salfit	1.90	2.12	6.52	11.22	15.66	18.57	19.58	20.61	**50.51**	**29.90**
Ramallah	16.81	18.50	26.44	35.96	46.90	54.15	56.67	59.25	**94.08**	**34.83**
Jerusalem	15.41	17.42	29.97	46.70	60.58	69.73	72.92	76.17	**31.88**	**-44.29**
Jericho	41.63	42.15	55.42	57.16	59.05	60.24	60.65	61.06	**27.92**	**-33.14**
Bethlehem	6.87	7.48	16.59	25.66	33.71	39.04	40.90	42.79	**29.56**	**-13.23**
Hebron	16.08	17.58	40.99	62.48	80.46	92.37	96.53	100.77	**104.49**	**3.72**
Total	**163.80**	**173.42**	**295.54**	**402.75**	**498.26**	**561.23**	**583.14**	**605.50**	**679.71**	**74.22**
MEDIUM SCENARIO TOTAL WATER DEMAND										
Year	**2002**	**2005**	**2010**	**2015**	**2020**	**2023**	**2024**	**2025**	**ASY**	**Difference**
Jenin	11.21	11.85	29.55	42.38	53.70	61.22	63.85	66.54	**76.87**	**10.33**
Tubas	10.29	10.38	18.78	24.56	30.45	34.41	35.80	37.23	**44.31**	**7.08**
Tulkarm	16.32	17.00	28.22	37.02	44.77	49.84	51.60	53.39	**80.32**	**26.93**
Nablus	16.43	17.83	31.83	47.17	60.46	69.28	72.35	75.50	**92.71**	**17.21**
Qalqiliya	10.86	11.36	16.90	23.34	29.34	33.29	34.66	36.06	**47.07**	**11.01**
Salfit	1.90	2.16	7.70	13.59	19.38	23.23	24.58	25.96	**50.51**	**24.55**
Ramallah	16.81	18.64	27.89	38.66	51.15	59.48	62.39	65.37	**94.08**	**28.71**
Jerusalem	15.41	17.51	31.01	48.52	63.25	72.97	76.35	79.81	**31.88**	**-47.93**
Jericho	41.63	42.30	56.45	59.20	62.21	64.14	64.80	65.46	**27.92**	**-37.54**
Bethlehem	6.87	7.54	17.92	28.37	38.01	44.45	46.70	49.01	**29.56**	**-19.45**
Hebron	16.08	17.67	42.40	65.22	84.71	97.68	102.21	106.85	**104.49**	**-2.36**
Total	**163.80**	**174.24**	**308.65**	**428.03**	**537.43**	**609.99**	**635.31**	**661.19**	**679.71**	**18.54**
HIGH SCENARIO TOTAL WATER DEMAND										
Year	**2002**	**2005**	**2010**	**2015**	**2020**	**2023**	**2024**	**2025**	**ASY**	**Difference**
Jenin	11.21	11.90	30.31	44.08	57.08	65.76	68.81	71.92	**76.87**	**4.94**
Tubas	10.29	10.40	19.74	26.89	34.60	39.82	41.67	43.56	**44.31**	**0.75**
Tulkarm	16.32	17.04	28.72	38.06	46.86	52.64	54.65	56.71	**80.32**	**23.61**
Nablus	16.43	17.92	32.51	48.64	63.56	73.51	76.99	80.56	**92.71**	**12.15**
Qalqiliya	10.86	11.41	17.53	24.77	32.00	36.77	38.44	40.15	**47.07**	**6.93**
Salfit	1.90	2.21	8.53	15.54	22.88	27.81	29.55	31.32	**50.51**	**19.19**
Ramallah	16.81	18.78	28.84	40.62	55.05	64.73	68.13	71.61	**94.08**	**22.47**
Jerusalem	15.41	17.61	31.48	49.40	65.42	76.02	79.71	83.49	**31.88**	**-51.61**
Jericho	41.63	42.45	57.44	61.15	65.34	68.03	68.95	69.88	**27.92**	**-41.96**
Bethlehem	6.87	7.60	18.84	30.51	42.05	49.82	52.56	55.37	**29.56**	**-25.81**
Hebron	16.08	17.76	43.18	66.87	88.45	102.89	107.95	113.13	**104.49**	**-8.64**
Total	**163.80**	**175.07**	**317.12**	**446.53**	**573.29**	**657.82**	**687.40**	**717.69**	**679.71**	**-37.98**

* Difference between ASY and the 2025 water demand.

[1] This ASY looks higher than the actual value of recharge because it is estimated based on the assumption that no minor losses will occur during the percolation of rainfall into the groundwater aquifers

The last two columns of Table 6-6 show the ASY for all governorates and the difference evaluated for the year 2025. The difference or deficit was calculated by subtracting the water demand of the year 2025 from the ASY. If the result in the difference column is negative (deficit), it means that the water is not sustainable, and if the result in the difference column is positive (surplus), then the water is sustainable.

The following points could be made from Table 6-6:

- The overall water demand is sustainable for the low scenario, but three out of eleven governorates have non-sustainable water situations. These are Jerusalem, Jericho, and Bethlehem governorates.
- The overall water demand is sustainable for the medium scenario, but four out of eleven governorates have non-sustainable water situations. These are Jerusalem, Jericho, Bethlehem, and Hebron governorates.
- The overall water demand for the high scenario is sustainable until the year 2023, but the years 2024 and 2025 have non-sustainable water situations. Also four out of eleven governorates have non-sustainable water situations. These are Jerusalem, Jericho, Bethlehem, and Hebron governorates. In this high scenario, the overall deficit was 7.7 MCM/Yr and 38 MCM/Yr for the years 2024 and 2025, respectively.

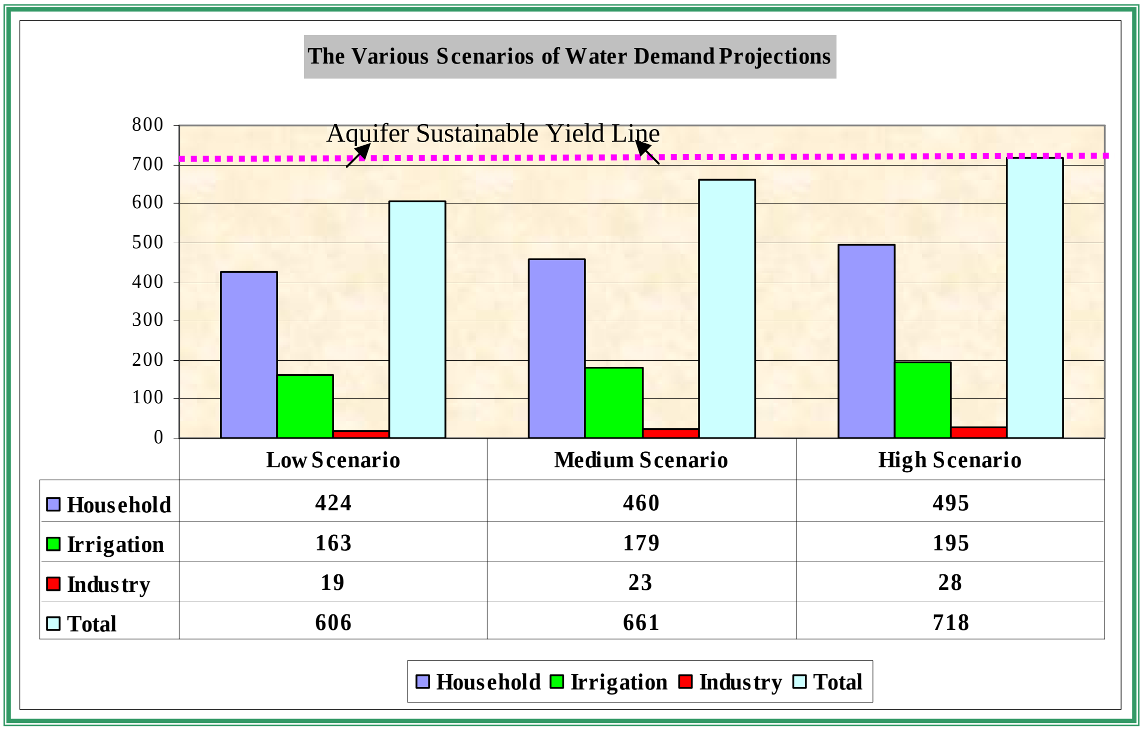
Table 6-7 shows the overall summary for all scenarios of water demand projections for all purposes for the years 2005, 2010, 2015, 2020, and 2025.

Table 6-7 shows that all water demand scenarios are sustainable for the time period 2005-2025 except for the years 2024 and 2025 of the high scenario as mentioned earlier. In order to overcome the water deficit and to achieve the water sustainability, it was proposed that by the year 2020, the PWA will have the technical capacity and the financial resources to get use of the surface water runoff through water harvesting tools.

Table 6-7: The Overall Summary Of Water Demand Projections (MCM/Yr) (2005-2025)

LOW SCENARIO WATER DEMAND PROJECTION							
Year	**Household**				**Irrigation**	**Industry**	**Total**
	Basic	**Returnees**	**Visitors**	**Total Household**			
2005	87.14	0.39	0.44	87.96	75.00	10.46	**173.42**
2010	163.66	4.60	1.41	169.67	113.75	12.12	**295.54**
2015	244.59	11.36	2.75	258.70	130.00	14.05	**402.75**
2020	312.08	19.52	4.11	335.72	146.25	16.29	**498.26**
2025	388.70	29.71	5.70	424.11	162.50	18.89	**605.50**
MEDIUM SCENARIO WATER DEMAND PROJECTION							
Year	**Household**				**Irrigation**	**Industry**	**Total**
	Basic	**Returnees**	**Visitors**	**Total Household**			
2005	87.14	0.77	0.88	88.79	75.00	10.46	**174.24**
2010	163.66	9.19	2.82	175.68	120.25	12.72	**308.65**
2015	244.59	22.72	5.50	272.80	139.75	15.48	**428.03**
2020	312.08	39.04	8.23	359.35	159.25	18.83	**537.43**
2025	388.70	59.42	11.41	459.53	178.75	22.91	**661.19**
HIGH SCENARIO WATER DEMAND PROJECTION							
Year	**Household**				**Irrigation**	**Industry**	**Total**
	Basic	**Returnees**	**Visitors**	**Total Household**			
2005	87.14	1.16	1.31	89.61	75.00	10.46	**175.07**
2010	163.66	13.79	2.82	180.27	123.50	13.35	**317.12**
2015	244.59	34.07	4.58	283.24	146.25	17.03	**446.53**
2020	312.08	58.55	10.29	380.93	170.63	21.74	**573.29**
2025	388.70	89.14	17.11	494.95	195.00	27.74	**717.69**

The long term average estimated value of surface water runoff is about 78 MCM/Yr. Since the maximum projected deficit for the year 2025 will be about 38 MCM/Yr, only one half of the long term runoff will balance that water situation to be sustainable. Figure 6-11 shows the final summary of scenarios of water demand projections in the West Bank. Figure 6-11 also shows the Aquifer Sustainable Yield (ASY) line.



	Low Scenario	Medium Scenario	High Scenario
Household	424	460	495
Irrigation	163	179	195
Industry	19	23	28
Total	606	661	718

Figure 6-11 : The Summary Of The Water Demand (MCM/Yr) Scenarios In The West Bank.
(This ASY looks higher than the actual value of recharge because it is estimated based on the assumption that no minor losses will occur during the percolation of rainfall into the groundwater aquifers)

As shown in the Figure 6-11, the total projected water demand should not exceed the ASY line for any scenario to be sustainable. The figure also shows that the household, the irrigation, the industrial water demand sectors are consuming about 69%, 27%, and 4% of the total annual water use, respectively for the three scenarios.

CHAPTER SEVEN

INSTITUTIONAL WATER MANAGEMENT AND OPTIMIZATION OF WATER USE

Institutional water management is the key issue for an efficient water use management which includes the legal, the structural, and the administrative aspects of the institutions dealing with water distribution and all related issues.

7.1 Institutional Background

The Palestinian Water Authority (PWA) was established by the Palestinian National Authority (PNA) in 1995 to be the official body responsible for all water resources management including the regulation of laws for monitoring, controlling, planning, licensing policy, water distribution and billing , and all water related issues in Palestine.

Soon after the establishment of the PWA and the signature of OSLO II Agreement in 1995, the United States Agency for International Development (USAID) funded a three-year project (1996-1998) aimed at helping the PWA for institutional building, technical assistance, water supply, and water master planning.

At the same time, the Norwegian Government (NG) signed an agreement with the PNA in which they took responsibility for building a sustainable PWA. Within that agreement, the NG funded a three-year project (1996-1998) to deal mainly with building the institutional framework and the infrastructure of the PWA. In 1996, the PWA and

An-Najah National University, a Palestinian University based in Nablus City, organized an "International Seminar on Water Management in Palestine". As a PWA representative for the NG conducted project, Daibes (1996) introduced a presentation to that seminar in which she gave a background about the NG project methodology. According to that presentation, three main tools were used in that project. These tools were:

- The infrastructure and administrative tools which included the organizational structure, the regulations, and the budgeting and accounting for the PWA.
- The PWA water management tools which included the water rules and legislation, the water licensing system and procedures, the water tariff study, the data bank unit, and the laboratories.
- Evaluating and restructuring of the West Bank Water Department (WBWD). The tools used for that included assessing the WBWD strength and weakness, assessing its finance and accounting tools, proposing a plan to develop it, and setup its internal regulations.

Figure 7-1 shows the organizational structure of the PWA as implemented by the Norwegian project during the period (1996-1998). In Figure 7-1, the national Water Council (WC) and the Advisory Group (AG) are not a part of the PWA structure. Their responsibility is to advise the PWA and to follow up the implementation of the National Water Policies in Palestine.

The institutional management of water in the West Bank is currently scattered between several water bodies in coordination of the PWA (see the Section 7.2).

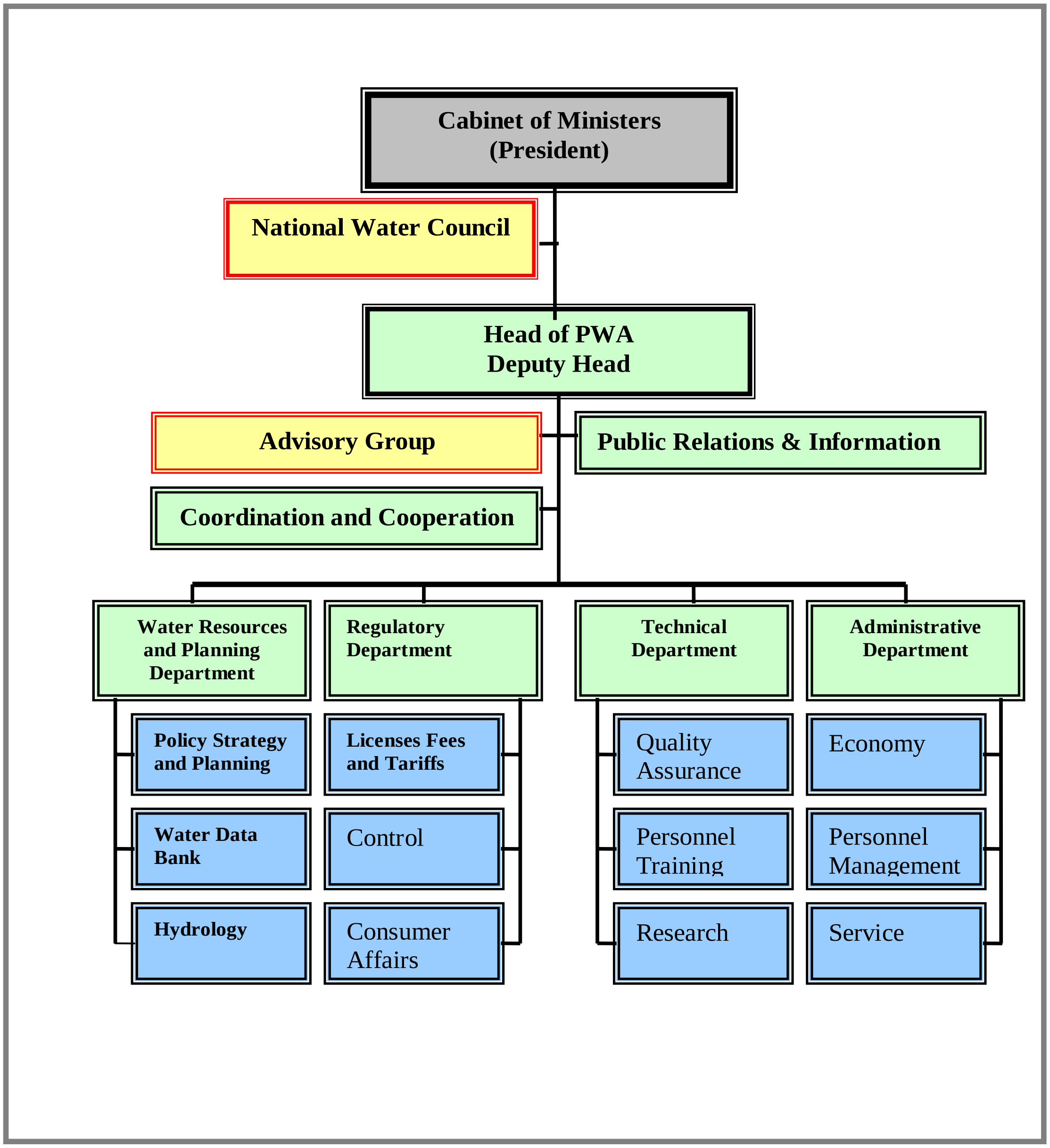


Figure 7-1: The Organizational Framework Of The PWA

By the end of 1999, the Palestinian Legislative Council (PLC) declared the Palestinian Water Law (PWL) of which Article 7 defined the PWA as an artificial body which is financially and administratively independent institution.

Based on that declared PWL:

1. The PWA works under the jurisdiction of the President of the PNA who appoints its president and deputy president.
2. The PWA can own and rent movable and immovable property necessary for its functions.
3. The PWA can conclude contracts and transactions and can be entitled to take legal action, itself or through one of its agent, or via an agent from outside the PWA.

Article 20 of that declared PWL defined the Water Council (WC) as a national body which was established for the purpose of outlining the Palestinian water policies. The WC consists of eleven members appointed by a decree issued by the President of the PNA. Such appointment is based on nominations made by the following bodies: the Ministry of Agriculture, the Ministry of Finance, the Ministry of Environment, the Ministry of Industry, the Ministry of Local Government, the Ministry of Health, the Ministry of Planning and International Cooperation, the Ministry of Justice, the various authorities and companies that assume the responsibility for the supply and distribution of water and the disposal of waste water, the water cooperatives and associations, and the Palestinian Universities. The President of the PWA acts as the Secretary General of the WC (PWA, 2003).

7.2 Water Distribution Management

There are several water supply management institutions in the West Bank. These institutions are responsible for network installation, reservoirs construction, maintenance and rehabilitation of water facilities as well as the water distribution and billing under the supervision of the PWA. These Palestinian water management institutions include the governmental, the semi-governmental, and the non-governmental institutions.

7.2.1 Palestinian Governmental Institutions

There are three governmental groups responsible for the distribution of water for the public. These are the West Bank Water Department (WBWD), the Palestinian Water Authority (PWA), and the Municipal and Local Councils (MLC).

7.2.1.1 The West Bank Water Department

The West Bank Water Department is administered by the Palestinian Water Authority. It owns 13 groundwater wells used for domestic purposes which were basically drilled during the Jordanian Administration period before 1967 under the direct supervision of the Natural Resources Authority of Jordan. After the 1967 War, these wells were controlled by Mekorot Israeli Water Company. Within the context of OSLO II agreement signed in 1995, these wells which are currently known as the "Thirteen Wells Group" were transferred from Mekorot into the PWA.

The WBWD is responsible for operation and maintenance of the pumping stations, supplying the water and collect their bills and fees from the public. The WBWD is also responsible for purchasing extra water quantities from Mekorot in order to provide the other water distribution services with water. The WBWD coordinates with the Mekorot on managing and distributing the water supplied to some Israeli settlements which are linked to the WBWD networks.

The WBWD is currently the biggest water distributor and water network supervisor in the West Bank. In addition to the production of 8.96 MCM/Yr from its owned "Thirteen Wells Group", the WBWD purchased 33.88 MCM from Mekorot in 2002. The WBWD distributed about 42.84 MCM/Yr of water in 2002 either directly to its target users or indirectly through selling the water to some other water distribution services. Of the total water it managed, the WBWD provided 3.66 MCM/Yr for the Israeli settlements which are linked to its networks with their household water needs. The water distributed by the WBWD is being used for domestic purposes except for about 4.5 MCM/Yr which is being supplied to the farmers of Bardala area for irrigation purposes (PWA, 2003).

7.2.1.2 The Palestinian Water Authority

The PWA had constructed 12 new groundwater wells during the period (1997 to present) to provide the areas which have water shortage with their water needs for domestic use. Four of these wells are known as the "PWA Phase I Wells" and the other 8 wells are known as the "PWA Phase II Wells". By the year 2002, the four wells of the "PWA Phase I Wells" were only working which produced about 4.2 MCM (PWA, 2003).

7.2.1.3 The Municipal and Local Councils

The MLC are non-profit governmental institutions which own 28 wells and serve 54 Palestinian communities in the West Bank. The 2002 total production of the MLC wells was about 21 MCM/Yr. In addition to wells, some MLC are using about 4.98 MCM/Yr from 16 main springs for household purposes.

7.2.2 Palestinian Semi-Governmental Institutions

These are non-profit institutions which are administratively and financially independent institutions owned by some municipalities of the West Bank and distribute water for domestic purposes. These water institutions are the Jerusalem Water

Undertaking (JWU), the Water and Sanitation Authority (WSA), and the Joint Services Water Council (JSWC).

7.2.2.1 The Jerusalem Water Undertaking

The JWU is owned by Ramallah and Al-Bireh municipalities. The JWU is responsible for supplying 50 communities whose approximate population is about 240,000 capita in Ramallah and Jerusalem governorates. In 2002, the JWU produced about 2 MCM/Yr from its five owned wells (from Ein Samia Well Field) and purchased about 6 MCM/Yr of additional water quantities. Of that purchased water, about 0.75 MCM/Yr was purchased from the Municipality of Jerusalem and the other 5.25 MCM/Yr from the WBWD (PWA, 2003 and JWU, 2004).

7.2.2.2 The Water and Sanitation Authority

The WSA owned by the municipalities of Bethlehem, Beit Jala, and Beit Sahur. The WSA owns one well which produce about 1.7 MCM/Yr while the other water needs are being purchased from the WBWD and the newly constructed PWA wells (PWA, 2003).

7.2.2.3 The Joint Services Water Council

The JSWC is owned by the municipality of Jenin and 12 other villages in the governorate of Jenin. It owns one well that produces about 0.65 MCM/Yr while the other water needs are being purchased from the nearby private irrigation wells (PWA, 2003).

7.2.3 Palestinian Non-Governmental Institutions

There are two non-governmental institutions dealing with the water distribution and management in the West Bank. These are the Arab Development Society Project (ADSP) and the Private Water Sector (PWS).

7.2.3.1 The Arab Development Society Project

The ADSP is a co-operative association. The ADSP owns 8 groundwater wells used for irrigation purposes which produced about 4.3 MCM/Yr in 2002 (PWA, 2003).

7.2.3.2 The Private Water Sector

The PWS owns 307 wells which are mainly used for irrigation purposes. Some Palestinian municipalities and local councils are purchasing water from some of these private irrigation wells to overcome their water deficit. In 2002, the total production from these private irrigation wells was about 31 MCM/Yr (PWA, 2003).

In addition to the above mentioned Palestinian water institutions, the Israeli Municipality of Jerusalem (IMJ) is responsible for providing the Palestinians of East Jerusalem (about 246,000 capita) with their water needs. There are no official figures on the total water quantities supplied by the IMJ to the Palestinians. The total water supplied to the Palestinians by the IMJ was estimated for the year 2002 to be about 11.66 MCM/Yr (see Chapter Six).

Table 7-1 summarizes the various water management institutions and their water distribution shares for different water use purposes.

Table 7-1: Classification Of The Various Water Institutions By Their Responsibility Of Water Distribution For Different Purposes

Institution	Household	Industry	Irrigation	Total
	(MCM/Yr)	(MCM/Yr)	(MCM/Yr)	(MCM/Yr)
WBWD	18.68	5.50	4.50	**28.68**
PWA	4.20			**4.20**
MLC	19.41	4.00		**23.41**
JWU	8.00			**8.00**
WSA	1.70			**1.70**
JSWC	0.65			**0.65**
ADSP			4.30	**4.30**
PWS			31.00	**31.00**
IMJ	11.16	0.50		**11.66**
Public Springs			35.20	**35.20**
Un-piped Water	15.00			**15.00**
Total	**78.80**	**10.00**	**75.00**	**163.80**

Although the WBWD is the largest water distribution institution in the West Bank, Table 7-1 shows different values. That was attributed to the fact that some of the other water institutions are purchasing additional water quantities from the WBWD and or from other institutions to overcome their water deficits. The figures shown in Table 7-1 are the final numbers for the year 2002 after certain water quantities have been transferred between the various water institutions. The following points clarify the transferred water quantities between the institutions listed in Table 7-1:

- ❖ The WBWD is the only body responsible for purchasing water from Mekorot, whereas the other institutions can purchase their additional water needs from the WBWD. In addition to producing 8.96 MCM/Yr from its owned wells, the WBWD purchased 33.88 MCM/Yr from Mekorot.
- ❖ The MLC usually purchase additional water quantity based on the need from the irrigation wells owned by the PWS. In addition to their own wells, the MLC owned 16 springs and they use them to get about 4.98 MCM/Yr.

- The JWU purchased about 6 MCM/Yr, of which about 0.75 MCM/Yr was purchased from the IMJ and about 5.25 MCM/Yr was purchased from the WBWD.
- The WSA usually purchase undeclared water quantities from the WBWD
- The WBWD is also responsible for providing a number of Israeli Settlements which are linked to its network with about 3.66 MCM in 2002.
- All the water quantities distributed by or sold from the WBWD are used for household purposes except for about 4.5 MCM/Yr which are provided to the Palestinian farmers in the Bardalah area for irrigation purposes.

Figure 7-2 shows the various water management institutions by the percentage of responsibility for water distribution in the West Bank, as derived from Table 7-1. Figure 7-2 shows that the PWS is the largest water distributor whose percentage responsibility was about 27%. The WBWD was the second water distributor whose percentage responsibility was about 25%. The MLC was third whose percentage responsibility was about 21%. The IMJ was fourth whose percentage responsibility was about 10%. The other institutions were minor water distributors.

7.3 Water Distribution Efficiency

The water losses from the water distribution networks represent the main problem of the household water supply in the West Bank. Table 7-2 shows the percentages and volumes of the water losses from the household water distribution networks in the various governorates of the West Bank (PWA, 2003). There is no information about the

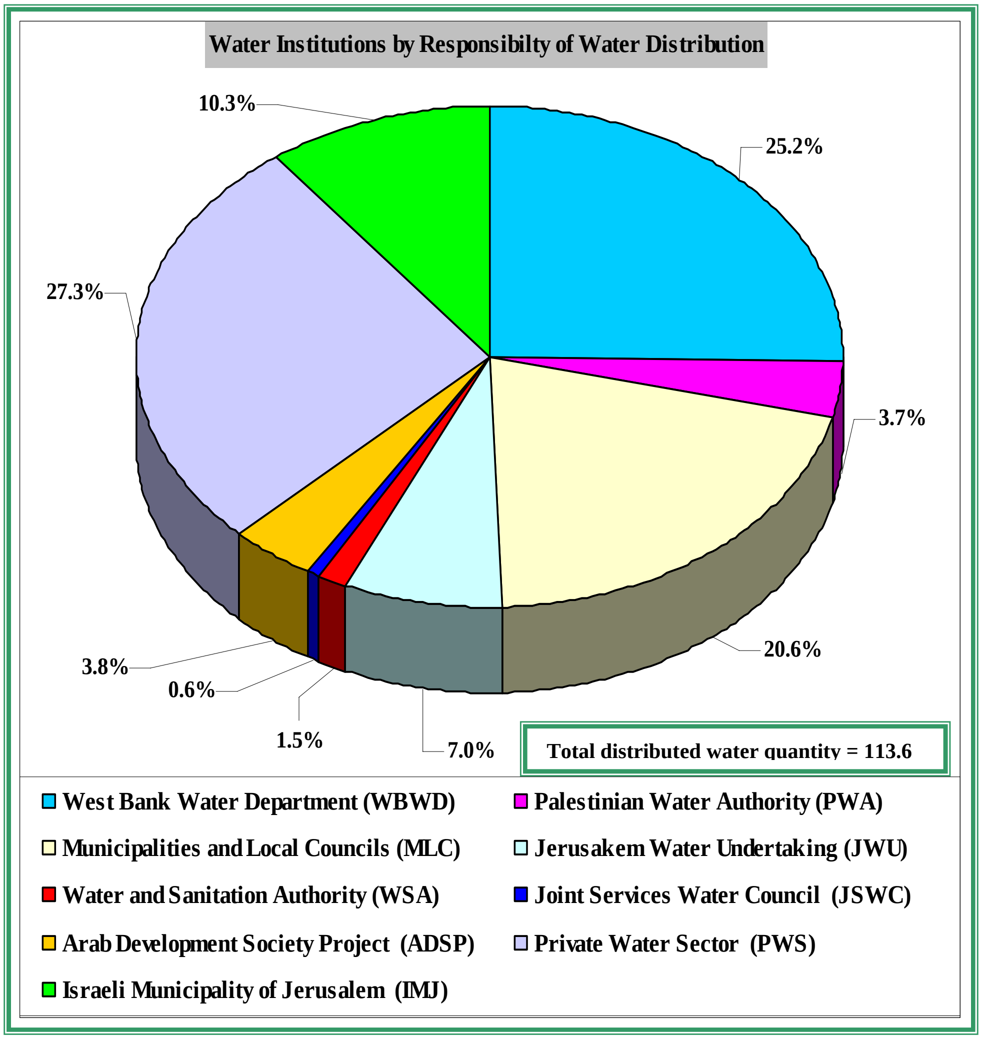


Figure 7-2: Water Management Institutions By Responsibility Of Water Distribution In The West Bank

water networks used in irrigation, but from the author's field work experience in the West Bank study area, the most serious problems of water losses occur in the open flow canals which constitute the main distribution systems used to convey the irrigation water from the springs into the irrigated farms. Other than the high amounts of evaporation in summer months, most of these canals are damaged in many places which increase the amounts of water losses there. Such high possibilities of water losses emphasize the urgent need for a good water plan to maintain and replace these open canals with pressure pipes, if possible, to achieve more efficient water use management.

Table 7-2: The Percentages And Volumes Of Water Losses From The Household Water Distribution Networks In Various Governorates Of The West Bank (The Combined Household And Industrial)

Governorate	Network Losses	Water Supply	Losses Volume
	%	(MCM/Yr)	(MCM/Yr)
Jenin	45%	4.23	1.90
Tubas	40%	0.37	0.15
Tulkarm	66%	5.19	3.42
Nablus	38%	9.42	3.58
Qalqiliya	62%	3.20	1.99
Salfit	36%	1.29	0.46
Ramallah	26%	13.67	3.56
Jerusalem (J1 Area)	28%	11.66	3.27
Jerusalem (J2 Area)*	25%	3.13	0.78
Jericho	41%	3.29	1.35
Bethlehem	38%	5.57	2.12
Hebron	42%	12.77	5.36
Total	**38%**	**73.80**	**27.94**

Source: PWA Hydrological Database (2003). ***Adapted from the statistical report of the Municipality of Jerusalem (1997)

As shown in Table 7-2, the percentage losses in the networks vary from 25% in Jerusalem governorate into 66% in Tulkarm governorate with the weighted average loss percentage of about 38%. The average percentage was weighted based on the water use quantities. The table also shows that out of 73.8 MCM/Yr of piped water distributed by different Palestinian water management institutions in the West Bank, about 27.9 MCM/Yr was lost in the networks.

Due to the high leakage percentage in the water distribution networks in the study area, the real water consumption is much less than the water supply. Therefore, there is an urgent need to maintain, rehabilitate, and/or install new water networks to reduce the water losses and use the water more efficiently.

7.4 Proposed Water Management Structure

The main problem in the current water management can be attributed to the multiple institutions responsible for water distribution in the West Bank. Table 7-2 showed that the minimum leakage and water losses from the water distribution networks occur in Ramallah region. Ramallah is being served by the Jerusalem Water Undertaking (JWU) with a percentage average water loss of about 26%. The JWU is very successful in managing the water distribution not only from the technical point of view, but also from the legal and administrative points of view. In order to manage the water more efficiently, this study suggested that the JWU experience could be generalized as a model for the other water institutions serving other governorates in the West Bank. Thus, this study introduced an alternative structure for the PWA in an attempt to achieve a more sustainable PWA and water resources management. The alternative PWA structure includes four regional water bodies as follows:

- Nablus Water Undertaking (NWU) for the northern districts of the West Bank.
- Jerusalem Water Undertaking (JWU) for the central districts of the West Bank.
- Hebron Water Undertaking (HWU) for the southern districts of the West Bank.
- The Jordan Valley Water Undertaking (JVWU).

Figure 7-3 shows the proposed alternative structure for the PWA. As shown in Figure 7-3, each water undertaking is in turn subdivided into three district water utilities. Then district water utility is in turn subdivided into the household water utility and irrigation and drainage water utility.

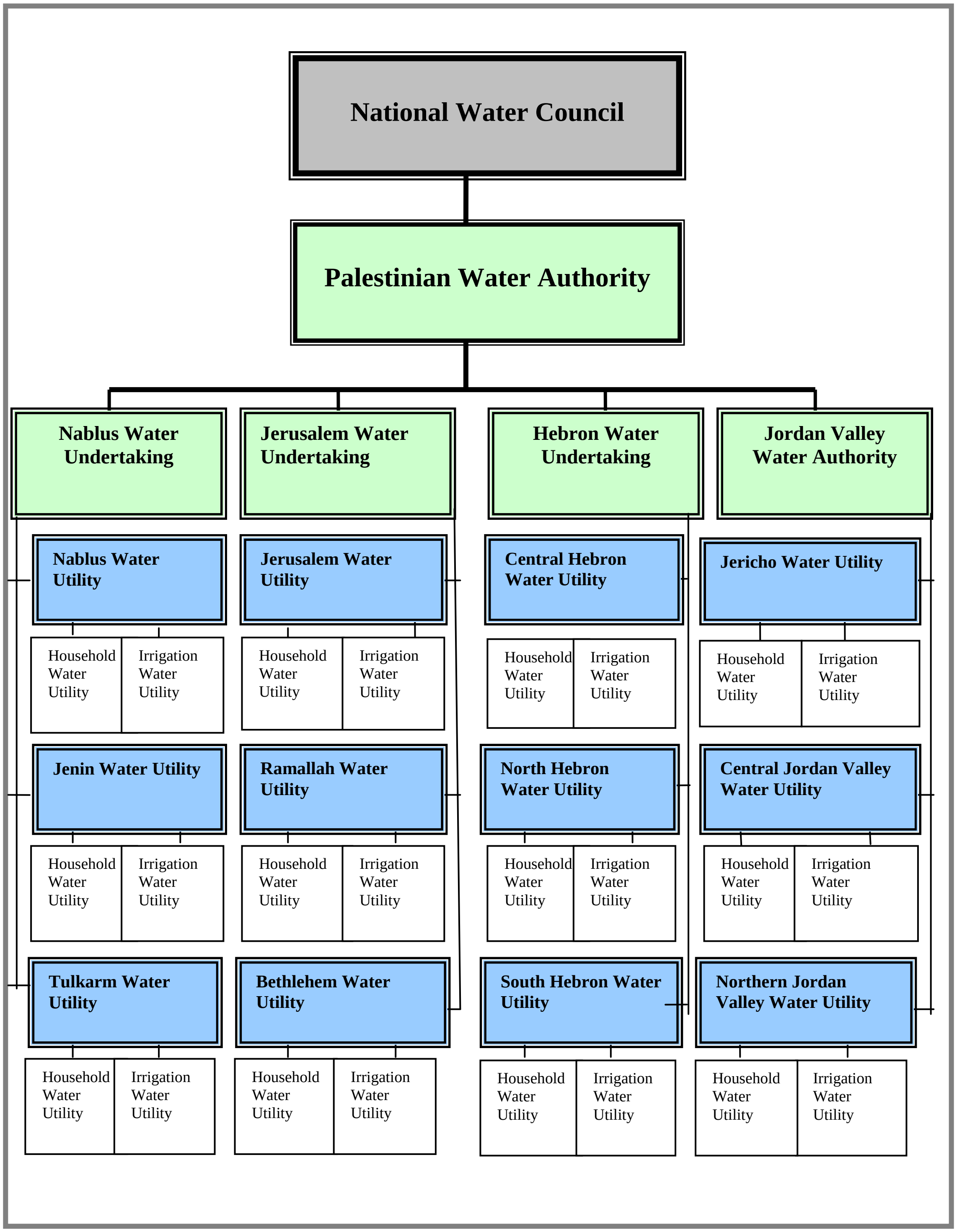


Figure 7-3: The Proposed Alternative Structure For The PWA And The Water Management Utilities.

7.5 Options for Optimization of Water Use

In order to maintain the water sustainability and to use the available water resources more efficiently, the following tools could be used during the future time domain of this research (2005-2025):

1. Rehabilitation and maintenance of water networks, wells, reservoirs, and other water facilities. This could include replacing the old pipe lines which have high leakage. As can be seen from Table 7-2, the 2002 total water losses from the water distribution networks in the various governorates of the West Bank was about 38%. For example, if all water networks in all governorates of the West Bank used for the household purposes are renewed and losses are reduced to reach the same percentage loss of 26% as of Ramallah governorate, there would be 8.5 MCM/Yr of saved water.

2. Rehabilitation of springs and their open flow water canals that could save large water quantities. For example, the long term flow discharge volume of the West Bank springs is about 55 MCM/Yr, but the current used water quantity of that springs is about 40 MCM/Yr for different purposes. This means that major portion of the rest of the spring flow water (15 MCM/Yr) could be used.

3. Using more efficient water Irrigation systems, modifying the cropping patterns, and follow irrigation scheduling in order to know when to irrigate and how much water quantity should be applied to get the optimal production per each cubic meter of water used.

4. Optimization of water use for irrigation based on the optimal water demand. The optimal irrigation water demand was estimated in this study based on the crop water requirements estimated earlier in Chapter Three. The irrigation

requirements are the product of the estimated crop water requirement minus the effective rain which falls in the area under study. Table 7-3 shows the average optimal irrigation water demand per hectare and the overall optimal water use which was estimated for each governorate of the West Bank. Table 7-3 shows that the overall 2002 estimated volume of water demand for irrigation was about 78.7 MCM/Yr, while the actual water use was about 75 MCM/Yr. It is shown that there is a deficit of 3.7 MCM/Yr which means that the production of crops is not optimal because more water was needed. That was attributed to the fact that the water available for irrigation was restricted.

Table 7-3: The Overall Estimated Optimal Irrigation Water Demand For The Various Governorates Of The West Bank.

District	Irrigation requirements	Current Irrigated Area	Water Use Per Unit Area	Actual Water Use	Optimal Water Use	Surplus or Deficit
	ETc-EffRain	(hectate)	(m3/ha)	(MCM/Yr)	(MCM/Yr)	(MCM/Yr)
Jenin	573.0	1,196	5730	5.48	6.85	-1.37
Tubas	707.9	1,100	7079	9.71	7.79	1.93
Tulkarm	636.0	1,921	6360	9.76	12.22	-2.46
Nablus	594.8	433	5948	3.33	2.58	0.75
Qalqiliya	617.6	1,068	6176	6.63	6.60	0.04
Salfit	610.3	17	6103	0.13	0.10	0.03
Ramallah	498.3	91	4983	0.71	0.45	0.25
Jerusalem	676.3	19	6763	0.15	0.13	0.02
Jericho	911.9	4,466	9119	37.82	40.73	-2.90
Bethlehem	735.7	86	7357	0.56	0.63	-0.07
Hebron	588.3	103	5883	0.71	0.61	0.10
Total		**10,500**	**6500**	**75.00**	**78.68**	**-3.68**

5. Surface water harvesting tools are required to capture the surface water runoff and get use of it. As estimated earlier in Chapter Three, the total long term flood was about 78.6 MCM/Yr. Constructing water dams could be an efficient tool.

6. Launching awareness programs on the best efficient way to use water for farmers and householders.
7. Long Term Development of Non-Conventional Water Sources which may include the waste water reuse and desalination. These water projects need regional co-operation between Palestine and Israel which is out of the scope of this research study.

CHAPTER EIGHT

CONCLUSIONS AND CONTRIBUTIONS

This research has developed an approach based on GIS and hydrological modeling to integrate the main components of sustainable water resources management in such a way that could help setup the Comprehensive Water Master Plan (CWMP) for the West Bank of Palestine.

In addition to the evaluation of the water balance component which is the most important component of water sustainability, this approach took several other components into consideration in order to get an applicable water resources planning and management program for a growing country both in the short and long terms. These components include the socio-economic, the demographic and population, the land use, the environmental, as well as the institutional components.

8.1 Major Research Assumptions

For evaluating the water balance component, the introduced approach was used to create the Water Sustainability Map (WSM) represented by the Aquifer Sustainable Yield (ASY). For estimating the ASY, it was assumed that the ASY is equivalent to the annual renewable recharge from the natural rain which falls on the aquifer outcrops of the West Bank area.

The recharge coverage was determined by integrating the watershed boundaries derived from the Digital Elevation Model (DEM) and the available hydrological and meteorological data by using GIS and watershed modeling. The developed GIS based approach was used to derive the recharge coverage from the general mass balance equation (Equation 3-1). The rainfall coverage was created by direct interpolation from the measured rainfall at 61 stations in the study area using the MapInfo GIS Software. The runoff coverage was created by direct interpolation runoff values measured at 26 hydrometric stations, of which 18 stations are located out of the West Bank and within the Israeli boundary. The evapo-transpiration was estimated based on the best available meteorological and crop data at 15 weather stations using the FAO CROPWAT Software. The estimated values of crop evapo-transpiration (ET_c) for the 15 weather stations were interpolated to create the ET_c Coverage. Thus the only unknown in the general mass balance equation (Equation 3-1) is the recharge coverage which was simply estimated by substituting the other grids of rainfall, ET_c and runoff into Equation 3-1 using the simple grid algebra. The only requirement for the simple grid algebra to work is that the cell size and grid dimensions for all water balance parameters should be similar.

The total estimated recharge volume which is equivalent to the ASY determined by this approach was 679.7 MCM/Yr. This volume constituted the upper limit for any assumed future water use scenario.

Although other studies have reported higher values of groundwater recharge represented by the ASY, this estimated ASY seems high in terms of the geologic characteristics of the study area. The apparent overestimate of ASY could be attributed to the ignorance of other minor losses in the water balance equation such as the initial abstraction, subsurface flow, and depression storage which were not measured in the study area.

That overestimate of ASY could also be attributed to the underestimate of ET_c. Since this study dealt with evaluating the ET_c that comes from the natural rainfall, the following two assumptions were made in estimating the monthly and annual ET_c values:

1. The ET_c was assumed to equal zero for the months with zero rainfall.
2. When the estimated monthly ET_c is greater than the monthly rainfall, the ET_c value is assumed to be equal to the rainfall of that month which means that 100% of the rainfall is evaporated.

Other assumptions were made to fulfill the demographic, social, and economic water sustainability components by proposing several future water use scenarios based on the gradual increase of population and their per capita water use, the available water infrastructure, and the economic value of water.

For fulfilling the environmental dimension of water sustainability, the developed approach took the water quality into consideration by interpolating the Nitrate and Chloride concentrations which are pollution and salinity indicators, respectively. The zones with high pollution and salinity indicators were identified to check the water suitability for various water use purposes and to recommend ways to prevent the environmental degradation and to protect the groundwater from pollution.

Based on the developed approach, the institutional component of water sustainability was fulfilled by reviewing the current institutions responsible for water management and distribution, recommending options to enhance their efficiency, and proposing some options to save additional water for various purposes in the West Bank.

For studying the sustainability of water supply and demand, it was assumed that the Israeli occupation of the West Bank will be released by the end of 2005 and the Palestinian State will be established by that date based on the US sponsored Road Map Initiative for Peace between the Palestinian Authority and Israel.

The study also assumed that once the Israeli occupation is released, the Palestinian State will restore their full ownership of the Palestinian land and water in the West Bank, i.e. the natural replenishment of all aquifers underlying the West Bank area will be completely managed and used by the Palestinian population.

The above developed approach is a new, workable, and applicable technique for water balance derivation and sustainable water resources management in Palestine. The method is flexible since it consists of input and output components (pre-processor and post-processor), i.e. any update in the input data will in turn update the outcome. Thus once more accurate data on the aquifer recharge and/or the minor losses of the water mass balance equation become available, a more accurate Water Sustainability Map (WSM) will be introduced for water sustainability applications.

Politically, if any water agreement is signed between the Palestinian Authority and Israel in the future, the developed approach in this research could be used to update the future Water Sustainability Map for Palestine.

Due to the high possibility of inaccurate input data and estimated output, the ASY numbers should be verified before using them in water resources planning, even though this modeling approach is still valid and applicable for water sustainability studies. Footnotes with assumptions and disclaimers were added to the tables and figures of the estimated groundwater recharge in Chapter Three. These footnotes should be copied along with their tables and figures in order to avoid misinterpretations regarding the accuracy with these numbers.

Thus it is important to note that the main contribution of this research is the development of a GIS and hydrological modeling based approach for sustainable water resources management.

Four sub-scenarios were assumed for household water demand; these are:

1. The Basic household scenario which only accounts for the water demand required by the natural growth of the West Bank population without any returnees or visitors.
2. The Returnees household water demand sub-scenario which accounts for the return of 250,000, 500,000, and 750,000 returnees by the year 2025 for the low, medium, and high scenarios, respectively.
3. The Visitors household water demand sub-scenario which accounts for the return of 250,000, 500,000, and 750,000 visitors by the year 2025 for the low, medium, and high scenarios, respectively.
4. The Overall household water demand scenario which consists of the Basic, the Returnees, and the Visitors for the low, medium, and high scenarios.

The current per capita water use for household purposes in nine out of eleven governorates of the West Bank is less than 150 l/c/d which is the water poverty limit as declared by the World Health Organization (WHO). In projecting the household water demand, the per capita water use was assumed to be 150 l/c/d, 200 l/c/d, 225 l/c/d, and 250 l/c/d for all governorates for the years 2010, 2015, 2020, and 2025, respectively.

The current natural population growth in the West Bank is about 3.25%, while the future natural population growth was assumed to be 3%, 2.75%, 2.5%, and 2.25% for the years 2010, 2015, 2020, and 2025, respectively. These values were used for projecting the future population in the area.

The current irrigated area in the West Bank is 10,500 hectares with a total water use of about 75 MCM/Yr. The irrigated agricultural water demand was assumed to increase into 25,000 hectares, 27500 hectares, and 30,000 hectares for the low, medium, and high scenarios, respectively. The future water demand for irrigation was estimated based on an assumed per hectare water use of 6500 m^3/hectare/Yr.

The current water use for industrial purposes is 10 MCM/Yr with an average annual growth rate of about 1.5% (PCBS, 2004). Three industrial water demand scenarios were assumed with 3%, 4%, and 5% of an average annual growth rate of the industrial water use for the low, medium, and high scenarios, respectively.

8.2 Conclusions

As derived from the created DEM, there are 14 main watersheds; of which 8 watersheds are draining their surface water to the west towards the Mediterranean and the other 6 watersheds are draining their surface water to the east towards the Jordan River and the Dead Sea. Using the DEM, these main watersheds were in turn subdivided into 72 sub-watersheds of which 58 sub-watersheds are draining their surface water within the boundaries of the West Bank. The other fourteen sub-watersheds which occupy about 17% of the total area of the West Bank are draining their surface water out of the West Bank.

In order to get use of the surface water drained by these watersheds, there is a need for installing 58 entire hydrometric stations to gauge the stream outlets and measure the event by event floods of the entire sub-watersheds to get better evaluation of sustainable runoff water. This could help locating the best sites to place dam structures to capture such water and use it for various purposes.

The total long term estimated rainfall volume over the West Bank area is about 2508 MCM/Yr with a weighted average of 445 mm/Yr of which, the total estimated rainfall volume over the aquifer outcropped formations of the West Bank is about 2040 MCM/Yr with a weighted average of 468 mm/Yr.

The total long term estimated evapo-transpiration volume over the West Bank is about 1607 MCM/Yr with a weighted average of 285 mm/Yr of which, the total estimated evapo-transpiration volume over the aquifer outcropped formations of the West Bank is about 1395 MCM/Yr with a weighted average of 297 mm/Yr.

The total long term estimated runoff volume over the West Bank is about 78 MCM/Yr with a weighted average of 14 mm/Yr. Of which, the total estimated runoff volume over the aquifer outcropped formations of the West Bank is about 65 MCM/Yr with a weighted average of 15 mm/Yr.

The total long term estimated recharge volume over the West Bank is about 823 MCM/Yr with a weighted average of 146 mm/Yr. Of which, the total estimated recharge volume over the aquifer outcropped formations of the West Bank is about 680 MCM/Yr with a weighted average of 156 mm/Yr (see Table 3-3).

Although the eastern and western watersheds are approximately occupying an equal area (49.4%, and 50.6% of the total West Bank area, respectively), their total estimated flood runoff volumes are about 21 MCM/Yr, and 57 MCM/Yr, respectively. Also the western watersheds are responsible for two thirds of the total recharge of the West Bank aquifers (see Table 3-4). The total estimated recharge volumes are about 274 MCM/Yr, and 549 MCM/Yr for the eastern and western watersheds, respectively.

In terms of water sustainability, the groundwater recharge for the aquifer outcropped formations from natural rainfall was only included. Thus the total estimated long term sustainable groundwater recharge is about 680 MCM/Yr. Another part of natural rainfall is recharging the aquitard outcropped formations of the West Bank with about 142 MCM/Yr. Although there is a possibility to get benefit of this water, the fate of this water is questionable in terms of water sustainability.

In addition to the topography and soil types, the structural geology is the main factor which determines the groundwater flow patterns and the boundary conditions of the various groundwater basins in the West Bank. Figure 4-11 shows a very steep hydraulic gradient at the zone of transfer between the eastern slopes of the West Bank mountains and the Jordan River Valley in the eastern portions of Nablus, Ramallah, and Jerusalem Governorates. That forms an indication of an expected high production flow rate of the wells there. For the time being, the Palestinians have no wells there but the Israeli settlements have 22 wells used for irrigating their settlements in the Jordan Valley.

This study classified the West Bank aquifers into three systems whose recharge were also estimated. These are:

- ❖ First the Shallow Aquifer System (SAS) which consists of the Eocene and the Pleistocene aquifers with a total estimated long term groundwater recharge of about 163 MCM/Yr.
- ❖ Second the Upper Aquifer System (UAS) which consists of the Upper Cenomanian and the Turonian aquifers in terms of geologic age. This system is composed of limestone and dolomite carbonate rock formations and it is mainly subdivided between the eastern and the western groundwater basins. The total estimated long term groundwater recharge of this aquifer was about 364 MCM/Yr.
- ❖ Third the Lower Aquifer System (LAS) which consists of two aquifers; the Albian and the Lower Cenomanian aquifers. The total estimated long term groundwater recharge of this system was about 153 MCM/Yr.

The long term estimated recharge for the main West Bank aquifer basins was about 202.1 MCM/Yr, 336.6 MCM/Yr, and 141 MCM/Yr, for the Eastern Aquifer Basin (EAB), the Western Aquifer Basin (WAB), and the North-Eastern Aquifer Basin (NEAB), respectively.

Although the estimated direct recharge of the Dead Sea groundwater basin which is a part of the Eastern Aquifer Basin (EAB) was about 10 MCM/Yr, it is currently discharging about 45-80 MCM/Yr. This huge water quantity may be attributed to the groundwater flow from recharge areas in Jerusalem and Hebron Governorates which flows downstream towards the Dead Sea. The problem of that water is very saline. For example the Total Dissolved Solids (TDS) of the Fashkha springs on the western shore of the Dead Sea was about 5200 ppm in 1995 (Isaac and Sabbah, 1998). Groundwater inflow from the deeper Kurnub Sandstone Aquifer underlying the main West Bank aquifers could be responsible for such high salinity.

The total volume of groundwater extracted from wells or from the freely flowing springs of all aquifers of the West Bank was about 671 MCM/Yr in the year 2000. Of which 129 MCM/Yr (19% of the ASY) were used by the Palestinians and the rest is being used by Israel. Compared to the ASY which was estimated to be about 680 MCM/Yr, the 2000 water use was about equivalent.

The Electric Conductivity, the Chloride, and the Sodium are very high for the Jordan Valley representative well samples which restricts the water use even for irrigation. The Sodium could destroy the soil structure due to its high cation exchange capacity. Based on the results of chemical analysis of the selected water samples, three hydro-chemical water types were identified. These are:

1. Ca^{++}/HCO_3^- water type where Calcium (Ca^{++}) is the predominant cation and the Bicarbonate (HCO_3^-) is the predominant anion in nine of the tested water samples. This water type is attributed to the Calcite which is one of the main constituents of the West Bank carbonate aquifers.
2. Mg^{++}/HCO_3^- water type where Magnesium (Mg^{++}) is the predominant cation and the Bicarbonate (HCO_3^-) is the predominant anion in five of the tested water samples. This water type is attributed to dolomite which is one of the main constituents of the West Bank carbonate aquifers.
3. Na^+/Cl^- water type where Sodium (Na^+) is the predominant cation and the Chloride (Cl^-) is the predominant anion in one of the tested water samples for a well located in Jericho. This water type indicates that the wells of Jericho are

tapping the shallow Pleistocene aquifer which is composed of sand stone and marl with intercalations of Gypsum, Halite, and Anhydrite. The Gypsum, Halite, and Anhydrite were deposited during the formation of the Lisan Lake which was extending from north of the Tiberias Lake into south of the Dead Sea.

As a salinity indicator, the map of Chloride distribution in the West Bank's groundwater which was interpolated from 296 water samples in 2000 showed two zones of high salinity which makes the water unsuitable for drinking and caution should taken when used for irrigation. These two zones are located in the southern and northern Jordan Valley which constitutes about 10% of the West Bank area (see Figure 4-15).

As a pollution indicator, the map of Nitrate distribution in the West Bank's groundwater which was interpolated from 296 water samples in 2000 showed six zones of high Nitrates which make the water unsuitable for drinking and good for irrigation. These six zones are underlying six Palestinian urban centers which indicate that the Nitrates were derived from human activities through leakage from sewage because these centers have inefficient sewage networks. The six zones are occupying an area which constitutes about 10% of the West Bank area (see Figure 4-16). The six urban centers are Jenin, Tulkarm, Tubas, Qalqiliya, Jerusalem, and Bethlehem cities.

The minimum, average, and maximum long term volumes of recharge for the WAB were estimated to be 340 MCM/Yr, 366 MCM/Yr, and 392 MCM/Yr, respectively. The recharge area is a combination of outcroppings from the three layers constituting the WAB model.

The calibrated model of the WAB gave an acceptable model results. The total number of the head observations was 165 of which 143 observations were representing the upper aquifer layer and the other 22 head observations were representing the lower aquifer layer. Of the upper model layer, a number of 107 observations were within the target, another 33 observations were within the range of greater than 100% and less than 200%, and the other three observations were within the error range of greater than 200%. Of the lower model layer, a number of 18 observations were within the target, two others were within the range of greater than 100% and less than 200% and the other two are within the error range of greater than 200%.

The overall results of the error norms indicated that the computed head matches the observed head to an acceptable degree. But the match is not that good for the flow observations represented by the springs/drains. That could be related to the fact that the two main springs are taking major parts of their water from the coastal aquifer overlying the WAB through the general head boundary.

This model concluded that the major part of spring flow comes from the Coastal Aquifer which overlies the WAB through the general head boundary. The model concluded that the groundwater flow from Hebron mountains to the southwest towards Beer Sheva has a very steep hydraulic gradient which changed the head from 650 meters above sea level into 10 meters below sea level within few kilometers of horizontal distance. High care should be taken in that zone which could be resulted from over-pumping.

The non-served Palestinian population was 466,000 capita in the year 2002. The un-piped water supply for that population was estimated to be about 15 MCM/Yr using the same average per capita water consumption of the governorates they are living in.

The J1 and J2 areas of Jerusalem have a Palestinian population of 142000 and 246000 in the year 2002, respectively. The total water use was estimated to be about 3.69 MCM/Yr and 11.66 MCM/Yr in J1 and J2 areas, respectively. Thus the combined water use by the population of the Palestinian Governorate of Jerusalem was 15.35 MCM/Yr. The population of J1 area is served by the PWA and JWU while J2 population is being served by the Israeli municipality of Jerusalem.

The overall estimated water use for various purposes in the West Bank including East Jerusalem was about 163.8 MCM/Yr in the year 2002. Of which about 78.8 MCM/Yr, 75 MCM/Yr, and 10 MCM/Yr were used for the household, irrigation, and industrial purposes, respectively.

It was estimated the Israeli Settlers are currently using 69.7 MCM/Yr from the West Bank groundwater. Of which 49.5 MCM/Yr are supplied from 36 wells drilled in the West Bank after 1967. The other 20 MCM/Yr were provided from the East Jerusalem wells which are controlled by the Israeli Municipality of Jerusalem. The total number of Israeli Settlers in 2002 was approximately 405000 of which 229000 are living in the settlements located in East Jerusalem and 176000 are living in the other areas of the West Bank.

The Aquifer Sustainable Yield (ASY) which was assumed to be equal to the estimated recharge was about 680 MCM/Yr. All scenarios of the overall water demand for various purposes were compared to the ASY in order to ensure the water sustainability.

The Palestinians are currently utilizing 25% of the annual ASY. Whereas, the combined water used by the Palestinians and the Israeli Settlers living in the West Bank including East Jerusalem is currently about 233.6 MCM/Yr which constitutes about 34% of the annual ASY in the West Bank aquifers.

The current Palestinian water use for the household, the irrigated agriculture, and the industrial sectors are currently about 48%, 46%, and 6%, respectively. The social equity to access water was maintained in this study through the gradual increase of the per capita water use in order to achieve the 150 l/c/d limit by the year 2010 and the 250 l/c/d by the year 2025. All governorates achieved the 250 l/c/d water limit by the year 2025.

The overall projected household water demand for the low scenario was 88 MCM/Yr, 169.7 MCM/Yr, 258.7 MCM/Yr, 335.7 MCM/Yr, and 424.1 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively. The overall projected household water demand for the medium scenario was 88.8 MCM/Yr, 175.7 MCM/Yr, 272.8 MCM/Yr, 379.4 MCM/Yr, and 459.5 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively. The overall projected household water demand for the high scenario was 89.6 MCM/Yr, 180.2 MCM/Yr, 283.2 MCM/Yr, 380.9 MCM/Yr, and 494.9 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively.

The overall projected irrigation water demand for the low scenario was 75 MCM/Yr, 113.8 MCM/Yr, 130 MCM/Yr, 146.2 MCM/Yr, and 162.5 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively. The overall projected irrigation water demand for the medium scenario was 75 MCM/Yr, 120.2 MCM/Yr, 139.8 MCM/Yr, 159.2 MCM/Yr, and 178.8 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively. The overall projected irrigation water demand for the high scenario was 75 MCM/Yr, 123.5 MCM/Yr, 146.2 MCM/Yr, 170.6 MCM/Yr, and 195 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively.

The overall projected industrial water demand for the low scenario was 10.46 MCM/Yr, 12.12 MCM/Yr, 14.05 MCM/Yr, 16.29 MCM/Yr, and 18.89 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively. The overall projected industrial water demand for the medium scenario was 10.46 MCM/Yr, 12.72 MCM/Yr, 15.48 MCM/Yr, 18.83 MCM/Yr, and 22.91 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively. The overall projected industrial water demand for the high scenario was 10.46 MCM/Yr, 13.35 MCM/Yr, 17.03 MCM/Yr, 21.74 MCM/Yr, and 27.74 MCM/Yr for the years 2005, 2010, 2015, 2020, and 2025, respectively.

The overall projected water demand for all purposes in the year 2025 was about 606 MCM/Yr, 661 MCM/Yr, and 717 MCM/Yr for the low, medium, and high scenarios, respectively.

In terms of water sustainability, the total projected water demand for the low and medium scenarios are less than the ASY during the entire time domain of this research study (2005-2025). Whereas, the high scenario will be sustainable during the time domain of this research except for the years 2024 and 2025. By the year 2025, the deficit between the overall water demand and the ASY will be about 38 MCM/Yr which could be overcome easily by getting benefit from the surface water runoff which was estimated to be 78 MCM/Yr.

The overall projected water demand for the household, the irrigation, and the industrial water use sectors in the year 2025 will be consuming about 69%, 27%, and 4% of the total annual water use, respectively.

The current household water sector in the West Bank is being served by eight different Palestinian institutions whereas the irrigation sector was controlled by the private sector. The industrial water use is included within the household water sector. The multi-institutional water distribution and management is currently creating lots of difficulties in terms of efficient water management.

Restructuring of the Palestinian Water Authority was proposed in order to better manage the Palestinian water resources. Unifying all the current water institutions and integrate them into one body such as the PWA is much more efficient.

8.3 Recommendations

The main recommendations of this research could be summarized as follows:

- ❖ More potential hydrological research study should be conducted to determine the fate of the water that recharges the aquitards formations of the West Bank which constitute 23% of the West Bank area. The current research estimated questionable water quantity to be about 142 MCM/Yr (20% of the ASY mentioned earlier).
- ❖ In addition to updating the comprehensive WAB groundwater flow model, more groundwater modeling studies should be conducted on smaller sub-basins of the

WAB and other basins. That could include transient and pollution transport models. The goal of such studies could be investigating the potential aquifers which are not utilized, identifying the zones and sources of pollution, and identifying the potential sources of recharge. The final goal is to provide the tools for fulfilling a sustainable water management.

- ❖ Conduct a separate study about the Dead Sea groundwater basin to identify the sources of high salinity there. A sea water intrusion groundwater model could be used to locate the zones of mixing between the salt water and the fresh water. The huge water quantity which is currently unused could be a good potential if such modeling study locates the places to abstract the water upstream before the mixing occurs.
- ❖ For the groundwater quality to be sustainable in the West Bank urban centers' underground area, high care should be taken by maintaining, rehabilitating, and installing new sewage networks in order to minimize the leakage and to protect the groundwater from Nitrates and other pollutants resulted from human activities.
- ❖ Both the conceptual and the steady state models of this study should be adopted for any future transient or pollution transport model which can save too much time and effort.
- ❖ There is an urgent need to maintain, rehabilitate, and/or install new water networks to reduce the water losses and use the water more efficiently. The current average leakage in the water distribution networks of the West Bank is

about 38%. Reducing that loss rate is important for a more efficient water management.

- ❖ Rehabilitation of springs and their open flow water canals that could save large water quantities since the current use of the total spring flow discharge is about 73%. The spring water use could add 15 MCM/Yr of more water to be used for different purposes.
- ❖ Using more efficient water Irrigation systems, modifying the cropping patterns, and follow irrigation scheduling in order to optimize the water use for irrigation.
- ❖ Conducting surface water harvesting tools to capture the surface water runoff and get use of it.
- ❖ Launching awareness programs on the best efficient way to use water both for the farmers and householders.

8.4 Contributions

The main contribution of this research could be summarized as follows:

- ❖ The DEM was created and used to delineate the watershed boundaries as well the drainage system for the various watersheds. Before this study the known watersheds were only 14. This study integrated another 72 sub-watersheds which facilitated the estimation of water balance on watershed by watershed basis.
- ❖ The GIS and hydrological modeling based approach used in this research introduced an excellent tool for estimating the surface water balance for the

various groundwater basins and their aquifers and can relate that water balance to the various components of water sustainability.

- The Groundwater model of the WAB is the first Palestinian research on this important basin which gave very good information that could open the door for a number of detailed studies that could help manage the WAB more efficiently.
- The water supply and demand of this study is the first to take the water sustainability which took the land use and the Aquifer Sustainable Yield (ASY) into consideration
- Different sustainability factors were considered in performing the water supply and demand. These factors included the ASY, the social equity, demography, the land use, and the institutional structure of water management.
- This study could help very much in setting up a Comprehensive Water Mater Plan for Palestine.
- The outcome of this study will be used by researchers, planners and decision makers to understand the current water situation and to pursue future research on main issues of water.

8.5 Future Research and Publication

This study could be published in the form of technical articles in international refereed journals. The main potential topics for that proposed articles could include, but not limited to, the following:

- Evaluation of surface water balance and its interaction with groundwater in the West Bank.
- The groundwater flow model of the WAB could be updated when more data become available to be a good applicable forecasting model.
- Options for sustainable water supply and demand in the West Bank.
- Optimization of water use and water sustainability in the West Bank.
- Sustainable institutional development and water master planning in Palestine.

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APPENDIX A

The 10-Year Average Monthly Meteorological Data And The Estimation Of Evapo-Transpiration For Various Stations In The Study Area (1990/91—1999/00)

TABLE KEY

Measured Parameters

1: Maximum Temperature (^{0}C) **2**: Minimum Temperature (^{0}C) **3**: Humidity (%)
4: Wind Speed (km/day) **5**: Sunshine (Hours) **6**: Solar Radiation (MJ/m2/d)
7: Rainfall (mm/month)

Calculated Parameters

8: Daily Reference Evapo-Transpiration (mm) **9**: Monthly Reference Evapo-Transpiration (mm)
10: Crop Coefficient (K_c) **11**: Monthly Crop Evapo-Transpiration (mm)

JENIN	1	2	3	4	5	6	7	8	9	10	11
JANUARY	17.60	6.90	80.80	182.80	5.40	10.20	105.72	1.67	51.77	0.719	37.24
FEBRUARY	18.40	7.20	84.80	191.90	5.70	12.50	70.85	2.00	56.00	0.739	41.40
MARCH	21.80	8.70	76.80	191.90	6.90	16.60	72.85	3.10	96.10	0.749	72.00
APRIL	28.60	11.30	67.70	191.90	7.90	20.30	28.23	4.79	143.70	0.702	100.85
MAY	31.30	14.10	39.40	218.20	9.80	24.40	7.33	6.78	210.18	0.711	149.44
JUNE	33.20	17.50	63.60	227.30	11.40	27.10	0.00	6.80	204.00	0.757	154.47
JULY	33.90	19.80	63.60	235.30	11.20	26.50	0.00	6.86	212.66	0.766	162.99
AUGUST	34.50	21.30	65.70	209.10	10.10	23.80	0.00	6.20	192.20	0.776	149.08
SEPTEMBER	33.50	20.00	64.60	174.70	9.20	20.40	0.00	5.15	154.50	0.739	114.13
OCTOBER	30.90	16.30	65.70	131.30	8.20	16.20	20.30	3.65	113.15	0.711	80.45
NOVEMBER	25.30	11.90	66.70	148.50	6.90	12.10	53.58	2.56	76.80	0.823	63.19
DECEMBER	19.00	8.80	74.70	182.80	5.40	9.50	97.17	1.79	55.49	0.719	39.91
MINIMUM	**17.60**	**6.90**	**39.40**	**131.30**	**5.40**	**9.50**	**0.00**	**1.67**	**51.77**	**0.702**	**37.24**
MAXIMUM	**34.50**	**21.30**	**84.80**	**235.30**	**11.40**	**27.10**	**105.72**	**6.86**	**212.66**	**0.823**	**162.99**
TOTAL/AVERAGE	**27.33**	**13.65**	**67.84**	**190.48**	**8.18**	**18.30**	**456.02**	**4.28**	**1566.55**	**0.745**	**1165.16**
TIRAT ZVI	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
JANUARY	20.60	10.30	72.70	53.90	4.90	9.70	84.74	1.39	43.09	0.844	36.36
FEBRUARY	20.40	8.20	67.70	76.30	6.70	13.60	48.23	2.06	57.68	0.860	49.58
MARCH	23.20	10.20	67.70	71.80	7.80	17.70	30.37	2.90	89.90	0.748	67.26
APRIL	32.30	14.80	42.40	94.30	9.40	22.50	5.24	4.94	148.20	0.758	112.36
MAY	35.30	17.50	41.40	125.70	11.50	26.90	0.00	6.49	201.19	0.768	154.54
JUNE	36.20	20.20	45.50	116.70	12.30	28.40	0.00	6.76	202.80	0.818	165.89
JULY	37.70	22.50	46.50	175.10	12.30	28.10	0.00	7.68	238.08	0.828	197.12
AUGUST	38.90	23.20	50.50	121.20	11.80	26.30	0.00	6.65	206.15	0.838	172.74
SEPTEMBER	37.80	23.60	48.50	170.60	9.90	21.40	0.00	6.24	187.20	0.798	149.39
OCTOBER	35.30	21.60	52.50	80.80	7.70	15.70	15.72	3.62	112.22	0.768	86.20
NOVEMBER	24.10	14.10	70.70	148.10	5.20	10.40	119.51	2.27	68.10	0.879	59.86
DECEMBER	20.40	7.70	72.70	121.20	6.00	10.10	49.97	1.69	52.39	0.844	44.21
MINIMUM	**20.40**	**7.70**	**41.40**	**53.90**	**4.90**	**9.70**	**0.00**	**1.39**	**43.09**	**0.748**	**36.36**
MAXIMUM	**38.90**	**23.60**	**72.70**	**175.10**	**12.30**	**28.40**	**119.51**	**7.68**	**238.08**	**0.879**	**197.12**
TOTAL/AVERAGE	**30.18**	**16.16**	**56.57**	**112.98**	**8.79**	**19.23**	**353.77**	**4.39**	**1607.00**	**0.813**	**1295.50**
TULKARM	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
JANUARY	13.53	8.69	72.72	104.03	5.25	10.14	137.84	1.34	41.54	1.275	52.98
FEBRUARY	13.94	8.79	76.76	96.96	5.56	12.43	98.77	1.64	45.92	1.311	60.19
MARCH	16.87	10.91	75.75	90.90	6.57	16.23	77.72	2.38	73.78	1.188	87.65
APRIL	21.72	13.94	66.66	81.81	7.78	20.26	24.67	3.48	104.40	1.204	125.69
MAY	24.85	16.06	62.62	80.80	9.09	23.45	4.32	4.35	134.85	1.220	164.48
JUNE	27.47	19.59	69.69	70.70	10.40	25.72	0.22	4.93	147.90	1.299	192.11
JULY	29.29	22.32	69.69	70.70	9.80	24.59	0.00	4.98	154.38	1.315	202.98
AUGUST	29.90	22.93	74.74	64.64	8.99	22.37	0.00	4.53	140.43	1.331	186.86
SEPTEMBER	28.48	21.41	70.70	63.63	8.38	19.47	1.01	3.75	112.50	1.267	142.57
OCTOBER	27.07	19.39	67.67	70.70	7.68	15.73	26.98	2.87	88.97	1.220	108.52
NOVEMBER	21.01	14.44	65.65	92.92	6.77	12.09	87.15	1.94	58.20	1.329	77.32
DECEMBER	16.06	10.71	71.71	96.96	5.35	9.57	153.14	1.33	41.23	1.275	52.58
MINIMUM	**13.53**	**8.69**	**62.62**	**63.63**	**5.25**	**9.57**	**0.00**	**1.33**	**41.23**	**1.188**	**52.58**
MAXIMUM	**29.90**	**22.93**	**76.76**	**104.03**	**10.40**	**25.72**	**153.14**	**4.98**	**154.38**	**1.331**	**202.98**
TOTAL/AVERAGE	**22.51**	**15.76**	**70.36**	**82.06**	**7.63**	**17.67**	**611.82**	**3.13**	**1144.10**	**1.268**	**1453.93**

(Continue)

NABLUS	1	2	3	4	5	6	7	8	9	10	11
JANUARY	13.23	6.26	67.67	211.09	4.75	9.67	143.53	1.75	54.25	0.737	40.00
FEBRUARY	14.54	6.77	67.67	229.27	4.85	11.65	134.00	2.18	61.04	0.727	44.38
MARCH	17.37	8.89	62.62	242.40	6.46	16.12	97.52	3.16	97.96	0.768	75.24
APRIL	22.42	12.12	53.53	246.44	8.28	20.99	33.33	4.71	141.30	0.728	102.91
MAY	25.96	15.05	51.51	259.57	8.99	23.31	7.00	5.76	178.56	0.887	158.41
JUNE	28.18	17.57	55.55	290.88	8.48	22.90	0.21	6.14	184.20	0.921	169.62
JULY	29.39	19.49	61.61	301.99	9.70	24.45	0.00	6.27	194.37	0.932	181.16
AUGUST	29.69	19.70	65.65	283.81	11.01	25.28	0.11	6.02	186.62	0.943	176.04
SEPTEMBER	28.68	18.69	64.64	249.47	10.30	22.06	1.65	5.14	154.20	0.898	138.53
OCTOBER	26.06	16.36	57.57	185.84	9.90	18.38	19.03	3.92	121.52	0.738	89.66
NOVEMBER	20.40	12.22	57.57	187.86	7.07	12.43	72.10	2.62	78.60	0.768	60.37
DECEMBER	14.75	7.88	67.67	185.84	4.85	9.13	137.95	1.67	51.77	0.748	38.70
MINIMUM	**13.23**	**6.26**	**51.51**	**185.84**	**4.75**	**9.13**	**0.00**	**1.67**	**51.77**	**0.727**	**38.70**
MAXIMUM	**29.69**	**19.70**	**67.67**	**301.99**	**11.01**	**25.28**	**143.53**	**6.27**	**194.37**	**0.943**	**181.16**
TOTAL/AVERAGE	**22.56**	**13.42**	**61.11**	**239.54**	**7.89**	**18.03**	**646.44**	**4.11**	**1504.39**	**0.819**	**1275.01**
FAR'AH	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
JANUARY	19.70	9.39	73.73	113.12	5.76	10.70	54.12	1.84	56.90	0.524	29.84
FEBRUARY	20.40	9.29	73.73	157.56	6.06	13.05	34.07	2.34	65.40	0.556	36.33
MARCH	24.54	12.22	63.63	148.47	7.58	17.59	58.20	3.44	106.54	0.558	59.43
APRIL	29.39	14.54	63.63	86.86	8.79	21.73	17.84	4.24	127.12	0.508	64.60
MAY	34.95	19.19	52.52	78.78	10.40	25.39	0.00	5.34	165.50	0.515	85.20
JUNE	37.47	21.31	51.51	86.86	11.72	27.65	0.00	6.24	187.18	0.548	102.62
JULY	39.79	22.93	51.51	165.64	11.82	27.55	0.00	7.54	233.77	0.555	129.73
AUGUST	38.89	24.44	52.52	157.56	11.11	25.44	0.00	6.94	215.10	0.562	120.81
SEPTEMBER	36.97	23.13	43.43	122.21	10.00	21.68	0.47	5.64	169.06	0.535	90.43
OCTOBER	33.84	20.40	54.54	60.60	8.59	16.87	7.16	3.43	106.32	0.515	54.74
NOVEMBER	28.18	16.97	55.55	60.60	7.37	12.78	26.17	2.33	69.80	0.501	35.00
DECEMBER	21.72	12.02	67.67	52.52	6.26	10.49	44.22	1.62	50.35	0.524	26.40
MINIMUM	**19.70**	**9.29**	**43.43**	**52.52**	**5.76**	**10.49**	**0.00**	**1.62**	**50.35**	**0.501**	**26.40**
MAXIMUM	**39.79**	**24.44**	**73.73**	**165.64**	**11.82**	**27.65**	**58.20**	**7.54**	**233.77**	**0.562**	**129.73**
TOTAL/AVERAGE	**30.49**	**17.15**	**58.66**	**107.57**	**8.79**	**19.24**	**242.25**	**4.24**	**1553.04**	**0.533**	**835.12**
TEL-AVIV	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
JANUARY	20.20	11.92	65.65	435.42	5.35	10.41	135.22	3.22	99.82	0.651	65.03
FEBRUARY	19.49	10.91	61.61	457.87	7.58	14.42	105.01	3.82	106.96	0.660	70.63
MARCH	19.29	11.82	68.68	426.44	8.08	17.93	78.72	3.74	115.94	0.678	78.63
APRIL	25.45	15.96	60.60	363.60	8.99	23.18	10.05	5.52	165.60	0.670	111.01
MAY	25.76	17.68	66.66	363.60	11.51	27.51	1.52	5.85	181.35	0.688	124.69
JUNE	28.28	20.50	66.66	386.04	12.22	29.36	0.51	6.59	197.70	0.705	139.33
JULY	30.50	22.73	68.68	404.00	12.22	28.64	0.10	6.91	214.21	0.722	154.64
AUGUST	31.11	23.03	68.68	354.62	11.41	27.09	0.00	6.47	200.57	0.722	144.80
SEPTEMBER	31.21	23.43	68.68	354.62	9.90	22.25	0.10	5.78	173.40	0.705	122.20
OCTOBER	31.21	21.51	63.63	323.20	8.28	15.56	19.70	5.11	158.41	0.688	108.92
NOVEMBER	23.23	14.44	65.65	430.93	5.45	10.51	99.63	3.67	110.10	0.696	76.64
DECEMBER	17.88	8.69	66.66	421.96	6.46	10.30	118.40	2.81	87.11	0.678	59.08
MINIMUM	**17.88**	**8.69**	**60.60**	**323.20**	**5.35**	**10.30**	**0.00**	**2.81**	**87.11**	**0.651**	**59.08**
MAXIMUM	**31.21**	**23.43**	**68.68**	**457.87**	**12.22**	**29.36**	**135.22**	**6.91**	**214.21**	**0.722**	**154.64**
TOTAL/AVERAGE	**25.30**	**16.88**	**65.99**	**393.53**	**8.96**	**19.76**	**568.95**	**4.96**	**1811.17**	**0.688**	**1255.60**
BEIT DAJAN	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
JANUARY	19.80	10.20	70.70	296.27	5.25	9.50	137.31	2.51	77.81	0.696	54.15
FEBRUARY	18.89	8.79	65.65	345.64	7.47	11.40	99.86	3.22	90.16	0.706	63.63
MARCH	19.80	9.80	69.69	269.33	7.98	16.10	74.05	3.41	105.71	0.735	77.71
APRIL	26.87	13.53	58.58	255.87	8.89	20.80	22.84	5.33	159.90	0.715	114.40
MAY	27.57	15.66	58.58	273.82	11.41	23.10	3.05	6.20	192.20	0.734	141.03
JUNE	28.89	18.99	61.61	255.87	12.12	22.60	0.00	6.45	193.50	0.752	145.53
JULY	30.70	21.31	65.65	291.78	12.12	24.20	0.00	6.69	207.39	0.770	159.79
AUGUST	31.01	21.61	67.67	228.93	11.31	25.00	0.00	5.97	185.07	0.770	142.59
SEPTEMBER	31.51	21.82	66.66	237.91	9.80	21.80	0.79	5.36	160.80	0.743	119.47
OCTOBER	31.31	19.80	63.63	228.93	8.18	18.20	23.18	4.52	140.12	0.715	100.25
NOVEMBER	22.52	13.53	68.68	309.73	5.35	12.30	75.43	2.97	89.10	0.735	65.50
DECEMBER	17.98	7.88	68.68	242.40	6.36	9.00	137.21	2.17	67.27	0.725	48.80
MINIMUM	**17.98**	**7.88**	**58.58**	**228.93**	**5.25**	**9.00**	**0.00**	**2.17**	**67.27**	**0.696**	**48.80**
MAXIMUM	**31.51**	**21.82**	**70.70**	**345.64**	**12.12**	**25.00**	**137.31**	**6.69**	**207.39**	**0.770**	**159.79**
TOTAL/AVERAGE	**25.57**	**15.24**	**65.48**	**269.71**	**8.85**	**17.83**	**573.73**	**4.57**	**1669.03**	**0.733**	**1232.84**

(Continue)

RAMALLAH	1	2	3	4	5	6	7	8	9	10	11
JANUARY	17.57	3.64	77.77	227.25	5.45	10.43	160.18	2.01	62.31	0.792	49.38
FEBRUARY	17.98	1.21	76.76	244.42	7.17	14.34	147.29	2.64	73.92	0.804	59.40
MARCH	21.51	3.74	71.71	218.16	7.47	17.48	113.74	3.52	109.12	0.826	90.12
APRIL	30.00	3.94	64.64	244.42	9.49	22.75	22.96	5.96	178.80	0.832	148.81
MAY	37.88	8.89	57.57	200.99	11.51	27.03	5.10	7.55	234.05	0.805	188.45
JUNE	35.55	13.64	61.61	200.99	12.52	28.84	0.00	7.28	218.40	0.826	180.35
JULY	35.45	16.46	72.72	218.16	12.22	28.15	0.00	6.98	216.38	0.846	183.15
AUGUST	34.64	17.68	75.75	227.25	11.92	26.61	0.00	6.41	198.71	0.867	172.30
SEPTEMBER	33.84	16.26	70.70	200.99	10.20	21.98	0.00	5.42	162.60	0.815	132.60
OCTOBER	26.77	13.23	71.71	244.42	7.37	15.46	23.65	3.70	114.70	0.843	96.73
NOVEMBER	24.54	11.31	73.73	261.59	5.05	10.45	84.61	2.83	84.90	0.826	70.12
DECEMBER	20.40	1.41	77.77	296.94	5.96	10.24	142.76	2.66	82.46	0.804	66.26
MINIMUM	**17.57**	**1.21**	**57.57**	**200.99**	**5.05**	**10.24**	**0.00**	**2.01**	**62.31**	**0.792**	**49.38**
MAXIMUM	**37.88**	**17.68**	**77.77**	**296.94**	**12.52**	**28.84**	**160.18**	**7.55**	**234.05**	**0.867**	**188.45**
TOTAL/AVERAGE	**28.01**	**9.28**	**71.04**	**232.13**	**8.86**	**19.48**	**700.29**	**4.75**	**1736.35**	**0.825**	**1437.66**
JERUSALEM	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
JANUARY	11.51	6.16	67.67	395.92	5.45	10.48	135.60	2.07	64.17	0.790	50.67
FEBRUARY	13.03	6.97	66.66	437.33	7.17	14.39	111.53	2.64	73.92	0.801	59.20
MARCH	16.16	8.79	59.59	445.41	7.47	17.52	99.06	3.76	116.56	0.845	98.53
APRIL	21.11	10.40	50.50	449.45	9.49	22.78	27.79	5.59	167.70	0.786	131.75
MAY	25.05	15.45	45.45	436.32	11.51	27.05	3.34	7.15	221.65	0.816	180.92
JUNE	27.57	17.88	48.48	470.66	12.52	28.85	0.28	7.94	238.20	0.837	199.29
JULY	28.68	19.09	53.53	493.89	12.22	28.16	0.00	7.87	243.97	0.857	209.10
AUGUST	28.89	19.19	57.57	451.47	11.92	26.64	0.00	7.17	222.27	0.847	188.23
SEPTEMBER	27.78	18.28	58.58	414.10	10.20	22.02	0.28	6.06	181.80	0.816	148.40
OCTOBER	24.75	16.56	56.56	314.11	7.37	15.51	18.90	4.37	135.47	0.796	107.81
NOVEMBER	18.89	12.42	59.59	343.40	5.05	10.49	65.90	3.08	92.40	0.765	70.71
DECEMBER	13.43	8.08	67.67	386.83	5.96	10.29	109.26	2.15	66.65	0.812	54.12
MINIMUM	**11.51**	**6.16**	**45.45**	**314.11**	**5.05**	**10.29**	**0.00**	**2.07**	**64.17**	**0.765**	**50.67**
MAXIMUM	**28.89**	**19.19**	**67.67**	**493.89**	**12.52**	**28.85**	**135.60**	**7.94**	**243.97**	**0.857**	**209.10**
TOTAL/AVERAGE	**21.40**	**13.27**	**57.65**	**419.91**	**8.86**	**19.52**	**571.94**	**4.99**	**1824.76**	**0.814**	**1498.74**
JERICHO	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
JANUARY	17.39	6.47	75.50	206.14	4.45	9.46	40.65	1.90	58.90	0.409	24.10
FEBRUARY	19.11	7.38	70.05	241.49	5.05	11.92	29.07	2.60	72.80	0.443	32.27
MARCH	22.54	9.61	67.77	307.14	7.48	17.17	24.05	4.00	124.00	0.449	55.71
APRIL	27.59	12.34	55.05	382.89	8.29	20.76	9.28	6.30	189.00	0.455	86.05
MAY	32.04	15.78	48.48	373.80	9.60	23.97	1.89	8.00	248.00	0.461	114.39
JUNE	35.07	18.60	48.58	361.68	11.12	26.51	0.28	8.90	267.00	0.491	131.15
JULY	36.18	20.32	50.91	377.84	11.42	26.71	0.00	9.10	282.10	0.497	140.26
AUGUST	35.98	20.62	54.44	346.53	11.12	25.19	0.00	8.30	257.30	0.503	129.47
SEPTEMBER	34.46	19.31	57.67	294.01	9.70	21.00	0.38	6.70	201.00	0.479	96.33
OCTOBER	30.62	16.08	61.71	217.25	8.49	16.41	6.82	4.50	139.50	0.461	64.35
NOVEMBER	24.66	11.03	68.10	178.87	6.67	11.64	20.64	2.70	81.00	0.449	36.39
DECEMBER	18.71	7.09	70.90	167.76	4.65	8.51	32.94	1.90	58.90	0.409	24.10
MINIMUM	**17.39**	**6.47**	**48.48**	**167.76**	**4.45**	**8.51**	**0.00**	**1.90**	**58.90**	**0.409**	**24.10**
MAXIMUM	**36.18**	**20.62**	**75.50**	**382.89**	**11.42**	**26.71**	**40.65**	**9.10**	**282.10**	**0.503**	**140.26**
TOTAL/AVERAGE	**27.86**	**13.72**	**60.76**	**287.95**	**8.17**	**18.27**	**166.00**	**5.41**	**1979.50**	**0.459**	**934.57**
BETHLEHEM	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
JANUARY	14.44	7.88	57.57	224.22	5.45	10.50	116.09	2.20	68.20	0.848	57.83
FEBRUARY	13.03	6.16	60.60	262.60	7.17	14.41	129.71	2.50	70.00	0.836	58.54
MARCH	15.96	7.78	89.89	224.22	7.47	17.54	90.81	2.28	70.68	0.871	61.57
APRIL	26.26	15.05	69.69	228.26	9.49	22.79	20.15	4.80	144.00	0.826	118.97
MAY	26.66	14.85	59.59	297.95	11.51	27.05	0.00	6.13	190.03	0.975	185.25
JUNE	29.80	17.98	45.45	305.02	12.52	28.85	0.00	7.60	228.00	1.012	230.70
JULY	29.80	20.50	31.31	362.59	12.22	28.17	0.00	8.72	270.32	1.024	276.86
AUGUST	33.13	21.61	22.22	235.33	11.92	26.65	0.00	7.87	243.97	1.037	252.88
SEPTEMBER	31.61	20.20	54.54	182.81	10.20	22.03	0.00	5.42	162.60	0.987	160.51
OCTOBER	28.68	18.18	66.66	181.80	7.37	15.52	12.83	3.69	114.39	0.826	94.51
NOVEMBER	19.39	11.82	75.75	176.75	5.05	10.51	53.59	1.94	58.20	0.871	50.70
DECEMBER	17.78	10.81	81.81	142.41	5.96	10.31	87.19	1.44	44.64	0.860	38.37
MINIMUM	**13.03**	**6.16**	**22.22**	**142.41**	**5.05**	**10.31**	**0.00**	**1.44**	**44.64**	**0.826**	**38.37**
MAXIMUM	**33.13**	**21.61**	**89.89**	**362.59**	**12.52**	**28.85**	**129.71**	**8.72**	**270.32**	**1.037**	**276.86**
TOTAL/AVERAGE	**23.88**	**14.40**	**59.59**	**235.33**	**8.86**	**19.53**	**510.37**	**4.55**	**1665.03**	**0.917**	**1586.69**

(Continue)

AL-ARROUB	1	2	3	4	5	6	7	8	9	10	11
JANUARY	12.40	4.40	77.80	209.10	6.30	11.30	156.20	1.52	47.12	0.993	46.79
FEBRUARY	13.10	4.80	78.80	244.40	6.30	13.40	129.62	1.91	53.48	0.993	53.10
MARCH	16.70	6.40	71.70	261.60	7.60	17.60	97.59	2.98	92.38	1.020	94.24
APRIL	21.10	8.20	65.70	235.30	8.60	21.40	37.49	4.16	124.80	0.831	103.76
MAY	26.00	12.40	57.60	157.60	10.20	25.00	5.67	5.15	159.65	0.842	134.48
JUNE	28.80	14.90	54.50	122.20	11.90	27.80	0.00	5.72	171.60	0.897	153.94
JULY	29.90	16.10	59.60	122.20	11.70	27.30	0.00	5.71	177.01	0.908	160.73
AUGUST	30.30	16.40	64.60	131.30	11.10	25.40	0.00	5.34	165.54	0.919	152.12
SEPTEMBER	28.70	14.50	70.70	122.20	10.00	21.70	0.12	4.28	128.40	0.908	116.59
OCTOBER	26.00	12.20	64.60	139.40	8.70	17.10	17.02	3.35	103.85	0.831	86.34
NOVEMBER	20.60	9.70	72.70	139.40	7.70	13.20	72.30	2.11	63.30	1.020	64.58
DECEMBER	14.90	6.50	75.80	191.90	6.40	10.70	122.88	1.57	48.67	1.007	48.99
MINIMUM	**12.40**	**4.40**	**54.50**	**122.20**	**6.30**	**10.70**	**0.00**	**1.52**	**47.12**	**0.831**	**46.79**
MAXIMUM	**30.30**	**16.40**	**78.80**	**261.60**	**11.90**	**27.80**	**156.20**	**5.72**	**177.01**	**1.020**	**160.73**
TOTAL/AVERAGE	**22.38**	**10.54**	**67.84**	**173.05**	**8.88**	**19.33**	**638.89**	**3.65**	**1335.80**	**0.930**	**1215.66**
HEBRON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
JANUARY	10.40	4.04	74.94	300.98	4.75	9.84	146.89	1.57	48.67	0.772	37.57
FEBRUARY	11.62	4.75	72.92	310.07	4.85	11.81	132.83	1.97	55.16	0.783	43.17
MARCH	14.75	6.57	66.66	307.04	6.46	16.25	90.64	2.93	90.83	0.815	74.01
APRIL	19.80	10.00	55.15	278.76	8.18	20.94	38.51	4.43	132.90	0.780	103.65
MAY	23.84	13.33	48.78	226.24	9.09	23.50	4.45	5.34	165.54	0.955	158.04
JUNE	26.16	15.96	51.51	224.22	8.38	22.77	0.43	5.58	167.40	0.979	163.81
JULY	27.47	17.17	57.37	222.20	9.70	24.47	0.00	5.73	177.63	0.991	175.94
AUGUST	27.47	17.17	60.50	211.09	11.01	25.36	0.00	5.54	171.74	1.002	172.16
SEPTEMBER	26.26	16.06	62.32	195.94	10.30	22.21	2.06	4.65	139.50	0.955	133.18
OCTOBER	23.43	14.14	59.49	195.94	9.90	18.59	14.75	3.67	113.77	0.780	88.73
NOVEMBER	17.68	10.00	64.74	212.10	7.07	12.63	63.73	2.35	70.50	0.815	57.44
DECEMBER	12.22	5.66	73.43	244.42	4.75	9.22	117.45	1.55	48.05	0.783	37.61
MINIMUM	**10.40**	**4.04**	**48.78**	**195.94**	**4.75**	**9.22**	**0.00**	**1.55**	**48.05**	**0.772**	**37.57**
MAXIMUM	**27.47**	**17.17**	**74.94**	**310.07**	**11.01**	**25.36**	**146.89**	**5.73**	**177.63**	**1.002**	**175.94**
TOTAL/AVERAGE	**20.09**	**11.24**	**62.32**	**244.08**	**7.87**	**18.13**	**611.74**	**3.78**	**1381.69**	**0.870**	**1245.32**
GAZA SHORE	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
JANUARY	19.19	12.02	69.69	390.53	4.75	9.99	108.90	2.74	84.94	0.491	41.69
FEBRUARY	18.69	10.91	64.64	395.02	5.76	12.07	81.04	3.29	92.12	0.497	45.82
MARCH	18.48	12.32	74.74	363.60	6.97	16.85	64.78	3.13	97.03	0.511	49.55
APRIL	24.14	16.06	68.68	314.22	7.78	21.53	9.99	4.54	136.20	0.504	68.69
MAY	25.25	18.18	72.72	260.36	6.77	24.13	2.99	4.44	137.64	0.517	71.17
JUNE	27.27	21.11	73.73	269.33	9.60	23.41	0.00	5.29	158.70	0.523	83.07
JULY	29.19	22.93	75.75	300.76	10.30	25.18	0.00	5.63	174.53	0.530	92.47
AUGUST	29.90	23.23	80.80	237.91	10.20	26.11	0.00	5.11	158.41	0.536	84.94
SEPTEMBER	30.20	23.63	76.76	269.33	9.39	22.78	0.23	4.81	144.30	0.530	76.46
OCTOBER	29.80	22.52	69.69	287.29	7.27	19.04	11.60	4.28	132.68	0.511	67.76
NOVEMBER	22.52	15.15	68.68	444.40	5.15	12.90	63.57	3.42	102.60	0.517	53.08
DECEMBER	17.57	9.90	68.68	404.00	6.06	9.36	102.48	2.62	81.22	0.504	40.94
MINIMUM	**17.57**	**9.90**	**64.64**	**237.91**	**4.75**	**9.36**	**0.00**	**2.62**	**81.22**	**0.491**	**40.94**
MAXIMUM	**30.20**	**23.63**	**80.80**	**444.40**	**10.30**	**26.11**	**108.90**	**5.63**	**174.53**	**0.536**	**92.47**
TOTAL/AVERAGE	**24.35**	**17.33**	**72.05**	**328.06**	**7.50**	**18.61**	**445.58**	**4.11**	**1500.37**	**0.514**	**775.64**
BEER SHEVA	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
JANUARY	17.88	8.89	71.71	318.71	4.65	9.89	66.61	2.35	72.85	0.627	45.69
FEBRUARY	18.08	7.68	63.63	327.69	6.36	11.95	33.11	3.12	87.36	0.854	74.57
MARCH	20.00	9.29	70.70	282.80	6.67	16.69	30.27	3.35	103.85	0.899	93.38
APRIL	29.19	13.64	47.47	323.20	9.19	21.33	4.79	6.67	200.10	0.911	182.20
MAY	31.11	15.55	47.47	318.71	10.00	23.90	1.54	7.39	229.09	0.933	213.81
JUNE	32.42	18.38	54.54	359.11	9.09	23.18	0.00	7.50	225.00	0.945	212.55
JULY	33.63	20.10	52.52	354.62	9.49	24.93	0.00	7.84	243.04	0.956	232.36
AUGUST	34.14	20.50	57.57	291.78	11.21	25.86	0.00	7.26	225.06	0.979	220.29
SEPTEMBER	33.53	20.20	61.61	291.78	10.10	22.56	0.00	6.29	188.70	0.933	176.11
OCTOBER	32.02	19.49	55.55	269.33	8.08	18.85	4.46	5.25	162.75	0.899	146.34
NOVEMBER	21.01	12.42	69.69	359.11	4.75	12.77	16.47	2.92	87.60	0.876	76.77
DECEMBER	15.66	6.46	73.73	354.62	4.65	9.27	31.57	2.09	64.79	0.854	55.31
MINIMUM	**15.66**	**6.46**	**47.47**	**269.33**	**4.65**	**9.27**	**0.00**	**2.09**	**64.79**	**0.627**	**45.69**
MAXIMUM	**34.14**	**20.50**	**73.73**	**359.11**	**11.21**	**25.86**	**66.61**	**7.84**	**243.04**	**0.979**	**232.36**
TOTAL/AVERAGE	**26.55**	**14.38**	**60.52**	**320.96**	**7.85**	**18.43**	**188.82**	**5.17**	**1890.19**	**0.877**	**1729.37**

10-Year Average Monthly Measured Rainfall and the Estimated ET_C Summary

STATION INFO		OCTOBER		NOVEMBER		DECEMBER		JANUARY	
ID	STATION NAME	Rainfall	ET_c	Rainfall	ET_c	Rainfall	ET_c	Rainfall	ET_c
		(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
1	**JENIN**	20.30	80.45	53.58	63.19	97.17	39.91	105.72	37.24
2	**TIRAT ZVI**	15.72	86.20	119.51	59.86	49.97	44.21	84.74	36.36
3	**TULKARM**	26.98	108.52	87.15	77.32	153.14	52.58	137.84	52.98
4	**NABLUS**	19.03	89.66	72.10	60.37	137.95	38.70	143.53	40.00
5	**FAR'AH**	7.16	54.74	26.17	35.00	44.22	26.40	54.12	29.84
6	**TEL AVIV**	19.70	108.92	99.63	76.64	118.40	59.08	135.22	65.03
7	**BEIT DAJAN**	23.18	100.25	75.43	65.50	137.21	48.80	137.31	54.15
8	**RAMALLAH**	23.65	96.73	84.61	70.12	142.76	66.26	160.18	49.38
9	**JERUSALEM**	18.90	107.81	65.90	70.71	109.26	54.12	135.60	50.67
10	**JERICHO**	6.82	64.35	20.64	36.39	32.94	24.10	40.65	24.10
11	**BETHLEHEM**	12.83	94.51	53.59	50.70	87.19	38.37	116.09	57.83
12	**AL ARROUB**	17.02	86.34	72.30	64.58	122.88	48.99	156.20	46.79
13	**HEBRON**	14.75	88.73	63.73	57.44	117.45	37.61	146.89	37.57
14	**GAZA SHORE**	11.60	67.76	63.57	53.08	102.48	40.94	108.90	41.69
15	**BEER SHEVA**	4.46	146.34	16.47	76.77	31.57	55.31	66.61	45.69

STATION INFO		FEBRUARY		MARCH		APRIL		MAY	
ID	STATION NAME	Rainfall	ET_c	Rainfall	ET_c	Rainfall	ET_c	Rainfall	ET_c
		(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
1	**JENIN**	70.85	41.40	72.85	72.00	28.23	100.85	7.33	149.44
2	**TIRAT ZVI**	48.23	49.58	30.37	67.26	5.24	112.36	0.00	154.54
3	**TULKARM**	98.77	60.19	77.72	87.65	24.67	125.69	4.32	164.48
4	**NABLUS**	134.00	44.38	97.52	75.24	33.33	102.91	7.00	158.41
5	**FAR'AH***	34.07	36.33	58.20	59.43	17.84	64.60	0.00	85.20
6	**TEL AVIV**	105.01	70.63	78.72	78.63	10.05	111.01	1.52	124.69
7	**BEIT DAJAN**	99.86	63.63	74.05	77.71	22.84	114.40	3.05	141.03
8	**RAMALLAH**	147.29	59.40	113.74	90.12	22.96	148.81	5.10	188.45
9	**JERUSALEM**	111.53	59.20	99.06	98.53	27.79	131.75	3.34	180.92
10	**JERICHO***	29.07	32.27	24.05	55.71	9.28	86.05	1.89	114.39
11	**BETHLEHEM**	129.71	58.54	90.81	61.57	20.15	118.97	0.00	185.25
12	**AL ARROUB**	129.62	53.10	97.59	94.24	37.49	103.76	5.67	134.48
13	**HEBRON**	132.83	43.17	90.64	74.01	38.51	103.65	4.45	158.04
14	**GAZA SHORE**	81.04	45.82	64.78	49.55	9.99	68.69	2.99	71.17
15	**BEER SHEVA***	33.11	74.57	30.27	93.38	4.79	182.20	1.54	213.81

STATION INFO		JUNE		JULY		AUGUST		SEPTEMBER	
ID	STATION NAME	Rainfall	ET_c	Rainfall	ET_c	Rainfall	ET_c	Rainfall	ET_c
		(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
1	**JENIN**	0.00	154.47	0.00	162.99	0.00	149.08	0.00	114.13
2	**TIRAT ZVI**	0.00	165.89	0.00	197.12	0.00	172.74	0.00	149.39
3	**TULKARM**	0.22	192.11	0.00	202.98	0.00	186.86	1.01	142.57
4	**NABLUS**	0.21	169.62	0.00	181.16	0.11	176.04	1.65	138.53
5	**FAR'AH***	0.00	102.62	0.00	129.73	0.00	120.81	0.47	90.43
6	**TEL AVIV**	0.51	139.33	0.10	154.64	0.00	144.80	0.10	122.20
7	**BEIT DAJAN**	0.00	145.53	0.00	159.79	0.00	142.59	0.79	119.47
8	**RAMALLAH**	0.00	180.35	0.00	183.15	0.00	172.30	0.00	132.60
9	**JERUSALEM**	0.28	199.29	0.00	209.10	0.00	188.23	0.28	148.40
10	**JERICHO***	0.28	131.15	0.00	140.26	0.00	129.47	0.38	96.33
11	**BETHLEHEM**	0.00	230.70	0.00	276.86	0.00	252.88	0.00	160.51
12	**AL ARROUB**	0.00	153.94	0.00	160.73	0.00	152.12	0.12	116.59
13	**HEBRON**	0.43	163.81	0.00	175.94	0.00	172.16	2.06	133.18
14	**GAZA SHORE**	0.00	83.07	0.00	92.47	0.00	84.94	0.23	76.46
15	**BEER SHEVA***	0.00	212.55	0.00	232.36	0.00	220.29	0.00	176.11

ET_c Summary

ID	STATION	X	Y	Rainfall	ET_c	ET_c/Rain	ET_0	ET_c/ET_0
		(m)	(m)	(mm/yr)	(mm/yr)	(%)	(mm/yr)	(%)
1	**JENIN**	183217.62	208305.28	456.02	1165.16	255.5%	1566.55	74.4%
2	**TIRAT ZVI**	199215.67	202805.94	353.77	1295.50	366.2%	1607.00	80.6%
3	**TULKARM**	153103.61	190606.93	611.82	1453.93	237.6%	1144.10	127.1%
4	**NABLUS**	173826.25	180634.26	646.44	1275.01	197.2%	1504.39	84.8%
5	**FAR'AH**	196627.43	172125.51	242.25	835.12	344.7%	1553.04	53.8%
6	**TEL AVIV**	129465.44	167437.10	568.95	1255.60	220.7%	1811.17	69.3%
7	**BEIT DAJAN**	132260.13	157467.40	573.73	1232.84	214.9%	1669.03	73.9%
8	**RAMALLAH**	169260.10	145225.18	700.29	1437.66	205.3%	1736.35	82.8%
9	**JERUSALEM**	170054.65	140799.11	571.94	1498.74	262.0%	1824.76	82.1%
10	**JERICHO**	192770.78	139717.27	166.00	934.57	563.0%	1979.50	47.2%
11	**BETHLEHEM**	169800.00	123700.00	510.37	1586.69	310.9%	1665.03	95.3%
12	**AL ARROUB**	164361.69	115351.30	638.89	1215.66	190.3%	1335.80	91.0%
13	**HEBRON**	159606.61	104290.16	611.74	1245.32	203.6%	1381.69	90.1%
14	**GAZA SHORE**	94997.92	101237.06	445.58	775.64	174.1%	1500.37	51.7%
15	**BEER SHEVA**	129126.97	82235.69	188.82	1729.37	915.9%	1890.19	91.5%

The Adjusted ET_C based on the assumption that monthly ET_c <= monthly rainfall

STATION INFO		OCTOBER		NOVEMBER		DECEMBER		JANUARY	
ID	STN_NAME	Rainfall (mm)	ET_c (mm)	Rainfall (mm)	ET_c (mm)	Rainfall (mm)	ET_c (mm)	Rainfall (mm)	ET_c (mm)
1	**JENIN**	20.30	20.30	53.58	53.58	97.17	39.91	105.72	37.24
2	**TIRAT ZVI**	15.72	15.72	119.51	59.86	49.97	44.21	84.74	36.36
3	**TULKARM**	26.98	26.98	87.15	77.32	153.14	52.58	137.84	52.98
4	**NABLUS**	19.03	19.03	72.10	60.37	137.95	38.70	143.53	40.00
5	**FAR'AH**	7.16	7.16	26.17	26.17	44.22	26.40	54.12	29.84
6	**TEL AVIV**	19.70	19.70	99.63	76.64	118.40	59.08	135.22	65.03
7	**BEIT DAJAN**	23.18	23.18	75.43	65.50	137.21	48.80	137.31	54.15
8	**RAMALLAH**	23.65	23.65	84.61	70.12	142.76	66.26	160.18	49.38
9	**JERUSALEM**	18.90	18.90	65.90	65.90	109.26	54.12	135.60	50.67
10	**JERICHO**	6.82	6.82	20.64	20.64	32.94	24.10	40.65	24.10
11	**BETHLEHEM**	12.83	12.83	53.59	50.70	87.19	38.37	116.09	57.83
12	**AL ARROUB**	17.02	17.02	72.30	64.58	122.88	48.99	156.20	46.79
13	**HEBRON**	14.75	14.75	63.73	57.44	117.45	37.61	146.89	37.57
14	**GAZA SHORE**	11.60	11.60	63.57	53.08	102.48	40.94	108.90	41.69
15	**BEER SHEVA**	4.46	4.46	16.47	16.47	31.57	31.57	66.61	45.69

STATION INFO		FEBRUARY		MARCH		APRIL		MAY	
ID	STN_NAME	Rainfall (mm)	ET_c (mm)	Rainfall (mm)	ET_c (mm)	Rainfall (mm)	ET_c (mm)	Rainfall (mm)	ET_c (mm)
1	**JENIN**	70.85	41.40	72.85	72.00	28.23	28.23	7.33	7.33
2	**TIRAT ZVI**	48.23	48.23	30.37	30.37	5.24	5.24	0.00	0.00
3	**TULKARM**	98.77	60.19	77.72	77.72	24.67	24.67	4.32	4.32
4	**NABLUS**	134.00	44.38	97.52	75.24	33.33	33.33	7.00	7.00
5	**FAR'AH***	34.07	34.07	58.20	58.20	17.84	17.84	0.00	0.00
6	**TEL AVIV**	105.01	70.63	78.72	78.63	10.05	10.05	1.52	1.52
7	**BEIT DAJAN**	99.86	63.63	74.05	74.05	22.84	22.84	3.05	3.05
8	**RAMALLAH**	147.29	59.40	113.74	90.12	22.96	22.96	5.10	5.10
9	**JERUSALEM**	111.53	59.20	99.06	98.53	27.79	27.79	3.34	3.34
10	**JERICHO***	29.07	29.07	24.05	24.05	9.28	9.28	1.89	1.89
11	**BETHLEHEM**	129.71	58.54	90.81	61.57	20.15	20.15	0.00	0.00
12	**AL ARROUB**	129.62	53.10	97.59	94.24	37.49	37.49	5.67	5.67
13	**HEBRON**	132.83	43.17	90.64	74.01	38.51	38.51	4.45	4.45
14	**GAZA SHORE**	81.04	45.82	64.78	49.55	9.99	9.99	2.99	2.99
15	**BEER SHEVA***	33.11	33.11	30.27	30.27	4.79	4.79	1.54	1.54

STATION INFO		JUNE		JULY		AUGUST		SEPTEMBER	
ID	STN_NAME	Rainfall (mm)	ET_c (mm)	Rainfall (mm)	ET_c (mm)	Rainfall (mm)	ET_c (mm)	Rainfall (mm)	ET_c (mm)
1	**JENIN**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	**TIRAT ZVI**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	**TULKARM**	0.22	0.22	0.00	0.00	0.00	0.00	1.01	1.01
4	**NABLUS**	0.21	0.21	0.00	0.00	0.11	0.11	1.65	1.65
5	**FAR'AH***	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.47
6	**TEL AVIV**	0.51	0.51	0.10	0.10	0.00	0.00	0.10	0.10
7	**BEIT DAJAN**	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.79
8	**RAMALLAH**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	**JERUSALEM**	0.28	0.28	0.00	0.00	0.00	0.00	0.28	0.28
10	**JERICHO***	0.28	0.28	0.00	0.00	0.00	0.00	0.38	0.38
11	**BETHLEHEM**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	**AL ARROUB**	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.12
13	**HEBRON**	0.43	0.43	0.00	0.00	0.00	0.00	2.06	2.06
14	**GAZA SHORE**	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.23
15	**BEER SHEVA***	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Adjusted Annual ET_c Summary based on monthly ET_C <=rainfall

ID	STATION NAME	X	Y	Rainfall	ETc	ET_c/Rain
1	**JENIN**	183217.62	208305.28	**456.02**	**300.00**	65.8%
2	**TIRAT ZVI**	199215.67	202805.94	**353.77**	**240.00**	67.8%
3	**TULKARM**	153103.61	190606.93	**611.82**	**378.00**	61.8%
4	**NABLUS**	173826.25	180634.26	**646.44**	**320.00**	49.5%
5	**FAR'AH**	196627.43	172125.51	**242.25**	**200.13**	82.6%
6	**TEL AVIV**	129465.44	167437.10	**568.95**	**382.00**	67.1%
7	**BEIT DAJAN**	132260.13	157467.40	**573.73**	**356.00**	62.1%
8	**RAMALLAH**	169260.10	145225.18	**700.29**	**387.00**	55.3%
9	**JERUSALEM**	170054.65	140799.11	**571.94**	**379.00**	66.3%
10	**JERICHO**	192770.78	139717.27	**166.00**	**140.62**	84.7%
11	**BETHLEHEM**	169800.00	123700.00	**510.37**	**300.00**	58.8%
12	**AL ARROUB**	164361.69	115351.30	**638.89**	**368.00**	57.6%
13	**HEBRON**	159606.61	104290.16	**611.74**	**310.00**	50.7%
14	**GAZA SHORE**	94997.92	101237.06	**445.58**	**255.90**	57.4%
15	**BEER SHEVA**	129126.97	82235.69	**188.82**	**167.91**	88.9%

APPENDIX B

Nitrate Concentration (mg/l) in Groundwater for 296 Sampled Wells and Springs in the West Bank in 1998 (PWA, 2003)

Well ID	X	Y	NO_3^-	Well ID	X	Y	NO_3^-	Well ID	X	Y	NO_3^-	Well ID	X	Y	NO_3^-	Well ID	X	Y	NO_3^-
19-14/062	193380	142630	5	18-18/036	187600	182550	19	17-20/015Q	174600	203850	30	14-17/002	148700	174780	46	14-17/034	146900	177300	74
19-14/081	197060	142310	6	19-17/007	196640	172290	19	18-18/023	187210	183070	30	15-17/011	151300	179100	46	15-09/010	156280	98110	74
17-11/003	171850	117220	7	19-17/010	197060	170150	19	17-21/010	174480	210200	31	15-19/043	154540	192040	46	14-17/013	147350	175070	75
17-20/007Q	174860	205550	7	19-17/031	197680	171060	19	19-13/015	196100	139510	31	15-19/044	153500	192210	46	14-17/022A	146580	177400	75
19-15/012	194590	150940	7	19-17/044	192000	179030	19	19-14/058	194880	141170	31	15-20/001	156400	201500	46	17-20/009J	178760	207940	75
16-11/006	169460	114080	8	19-17/047	192410	178970	19	15-18/024	155500	188500	32	19-13/020	194320	139480	46	15-09/012	156320	98110	76
17-20/035A	174370	205320	8	20-17/018	200240	175710	19	15-19/033	151720	191000	32	19-14/070	196890	140670	46	18-18/017	182300	189650	76
17-20/037J	175260	205790	8	15-17/005	150850	177060	20	15-20/004	157500	201030	32	14-17/048	146500	176200	47	14-17/052	147920	174640	78
15-09/013	157000	96200	9	15-18/023	152800	181600	20	19-16/010	196850	169730	32	17-21/012	174600	210400	47	18-18/016	182370	188890	78
17-11/002	170150	119330	9	15-19/028	156800	190100	20	19-17/008	196250	170250	32	19-14/009	195230	140530	47	18-18/025A	181650	189540	78
17-19/002	175000	198320	9	17-20/041Q	174800	203200	20	19-17/021	196520	170560	32	20-17/011	201160	176870	47	15-19/018	152480	191900	82
17-20/035Q	176100	204950	9	18-18/019	188730	181150	20	19-17/023	194200	175230	33	15-17/009	150200	179540	48	15-19/032	156650	197580	82
17-20/036A	174960	206140	9	19-17/009	197470	170230	20	14-17/027	148600	177460	34	15-18/019	153950	188650	48	14-17/010	147400	175640	84
18-18/037	180150	185400	9	19-19/010	194480	199190	20	14-17/037	149650	176900	34	17-20/033J	178500	207400	48	14-17/023A	146700	178100	84
19-15/011	194750	151000	9	15-18/007	152350	189000	21	15-09/001	153460	92260	34	17-20/042Q	177300	201500	48	14-17/045	148400	178100	85
17-20/014A	172100	202060	10	15-19/011	155530	199800	21	15-20/006	156100	200200	34	17-20/044Q	177410	202470	48	14-17/015	146950	177800	89
17-20/023Q	175310	204800	10	17-20/029Q	175230	203560	21	17-20/036Q	177700	202200	34	17-21/032	178550	212260	48	14-17/028	147140	177860	90
17-20/024A	173350	201700	11	17-20/050Q	178800	201500	21	19-14/052	195680	140980	34	19-14/023	195040	140240	49	16-19/011	160020	190980	91
18-18/038	182750	185750	11	17-20/051A	171250	200900	21	15-18/009	152380	189720	35	14-17/038	147520	176120	49	18-18/032	182120	188950	92
15-15/004	155200	153000	12	18-15/003A	182100	154000	21	15-19/047	157500	195450	35	15-19/006	155920	191840	50	14-17/008	148440	175340	94
16-19/012	169460	193410	12	19-17/011	198810	174870	21	15-20/003	156000	202080	35	18-18/033	182140	189770	50	15-19/021	156100	197640	95
17-20/020Q	175110	204750	12	19-17/034	192740	178370	21	15-19/002	153660	190960	36	14-17/025	147200	177900	51	14-17/009	147500	175500	97
18-15/006	182200	155800	12	20-17/010	200940	176820	21	15-19/030	154770	190910	36	15-20/008	158140	204280	51	17-20/046Q	177100	201900	102
19-16/009	196970	169220	12	20-17/019	200020	175150	21	19-14/015	195670	140530	36	15-19/003	152580	192970	52	14-17/023	146850	178200	113
16-18/003A	166750	184750	13	17-20/028Q	175280	203360	22	19-16/001	196770	169900	36	17-20/012J	176800	208500	52	16-19/001	161100	190400	125
17-20/008Q	174640	205210	13	18-15/001	181550	155250	22	19-17/006	196780	170000	36	14-17/003	148500	175400	53	17-20/021J	178950	207920	138
18-15/005	181550	155250	13	15-17/008	151160	170100	23	14-17/029	146280	176280	37	19-14/019	196460	140500	53	BA/165	164370	147800	4.0
19-17/054	197600	169150	13	15-19/038	154440	190880	23	14-17/051	148400	177450	37	14-17/018	148850	178250	54	BA/170	163630	145880	5.0
15-19/048	159050	192800	15	15-19/042	158280	199100	23	15-18/005	151620	181150	37	14-17/035	147200	177940	54	BA/110	166800	161300	6.0
16-11/001A	169600	115100	15	19-14/001	195910	149990	23	15-19/036	155320	198000	37	14-17/047	149260	178660	54	BA/121	156880	160080	6.0
16-18/005	168900	183000	15	19-16/003	198460	169650	23	17-20/024J	178000	205750	37	15-18/001	151420	181120	54	BA/172	163300	145100	6.0
17-20/005Q	174400	202750	15	19-17/020	199980	175060	23	17-21/013	174850	210500	37	16-20/003	167000	205380	54	BA/153	164700	149900	7.0
17-20/009Q	174450	203300	15	15-18/020	153870	187320	24	19-14/066	197310	140660	37	18-20/005	180920	209580	54	BA/167	164400	147800	7.0
17-20/018Q	172620	204990	15	19-13/069	196950	139250	24	15-17/017	150400	176600	38	15-17/010	150000	179140	55	BA/112	157300	152400	8.0
19-13/029	197150	139080	15	19-15/023	196020	150090	24	15-19/010	154800	198960	38	14-17/005	148800	173900	56	BA/164	165370	148700	8.0
19-15/005	194750	150440	15	19-17/055	196150	173400	24	17-20/013Q	174480	204060	38	15-19/041	155960	198340	56	BA/122	156960	158960	9.0
19-19/011	194400	199150	15	19-17/027	196250	171470	25	19-14/054	195500	141630	38	17-21/015	178500	211080	56	BA/120	156950	159180	11.0
17-19/001	174830	198600	16	19-17/033	196510	172910	26	15-17/004	154700	177000	39	17-21/022	178860	211370	56	BA/163	164380	147920	11.0
17-20/006Q	174800	205020	16	15-17/018	150540	170380	27	15-18/017	153150	189550	39	18-20/003	181000	200000	56	BB/083	154700	100250	11.0
17-20/030Q	175280	203140	16	15-19/012	155730	191000	27	16-19/002	160970	190650	39	14-17/024	147100	176420	57	BA/108	169100	160300	12.0
17-20/051Q	175180	205000	16	15-20/007	157550	203310	27	18-18/004	181910	188710	39	17-21/024	178620	211350	58	BB/029	159500	122050	13.0
18-18/013	187290	182440	16	17-20/003Q	173970	204160	27	19-13/049	195530	139480	39	19-13/021	194960	138560	58	BA/117	161350	157250	15.0
19-14/002	192620	142510	16	17-20/016Q	174400	203550	27	19-14/067	197010	140560	39	15-19/029	156040	196640	59	BB/083A	154650	100350	18.0
19-17/001	196900	170740	16	19-14/073	197030	141050	27	14-17/040	149630	179200	40	15-18/022	151760	189500	61	BA/109	169050	160270	19.0
19-17/002	196520	171240	16	15-16/003	152070	169610	28	15-19/005	152600	192750	40	15-19/013	153470	191600	61	BA/066	159880	209350	20.0
16-11/007	169460	114130	18	15-18/006	152500	187950	28	15-19/014	152970	190020	40	15-18/003	152070	181520	64	BB/027	162200	124350	24.0
17-11/001A	170900	118300	18	15-19/031	156330	199040	28	15-19/035	156430	196820	40	15-19/017	152400	190920	65	BA/171	163330	146120	29.0
17-20/040A	173310	201810	18	17-20/006J	179060	207750	28	18-18/019A	188570	181320	41	15-19/020	152700	191650	65	BB/086	154860	99140	29.0
17-20/048Q	175360	204180	18	20-17/016	200290	175850	28	19-14/037	196120	141060	41	17-21/014	175500	210140	66	BB/034	159800	123750	30.0
17-20/049Q	175080	204100	18	20-18/012A	202000	182600	28	19-17/056	194600	174100	41	14-17/012	147080	176260	67	BA/085A	166860	165920	31.0
18-18/011B	187040	183140	18	14-17/044	149600	172920	29	14-17/017	148220	178240	42	14-17/036	147360	177680	67	BB/077	154900	101500	33.0
18-18/014	186610	182950	18	17-21/034	174250	209850	29	14-17/043	149780	172760	42	15-18/008	153750	188800	67	BB/030	159890	123770	36.0
19-14/064	197230	141140	18	18-18/001	181050	188620	29	17-20/020J	178250	206100	42	19-13/006	195500	139580	67	BB/028	161150	121800	43.0
20-17/022	201300	178400	18	15-17/012	151500	179660	30	19-14/010	195220	140610	42	17-21/009	176000	210800	68	BB/032	159900	123800	44.0
15-18/015	156800	181200	19	15-17/013	151300	172200	30	15-17/015	150280	171840	43	17-21/028	171080	214600	69	BA/111	166900	158900	58.0
15-19/019	151970	191750	19	15-18/002	151170	180160	30	19-13/048	195310	139660	43	15-19/046	152920	191840	70	BB/031	159940	123760	62.0
17-20/031Q	175210	204340	19	15-19/016	151900	190300	30	19-13/050A	195810	139380	43	19-17/046	192560	176230	70	BA/152	166800	152600	67.0
18-18/002	182200	188350	19	15-20/002A	156450	200470	30	19-14/012	195380	140010	45	14-17/014	147300	175400	72	BA/137	161680	157420	103.0
18-18/030	186240	183350	19	15-20/005	157100	201560	30	19-17/028	198150	170500	45	17-20/046	174730	209800	73	BB/022	162200	124400	183.0
																BB/023	162300	124350	198.0

Chloride Concentration (mg/l) in Groundwater for 296 Sampled Wells and Springs in the West Bank in 1998 (PWA, 2003)

Well ID	X	Y	Cl^-	Well ID	X	Y	Cl^-	Well ID	X	Y	Cl^-	Well ID	X	Y	Cl^-	Well ID	X	Y	Cl^-
14-17/002	148700	174780	40	15-18/017	153150	189550	80	17-19/002	175000	198320	36	18-18/004	181910	188710	45	19-17/010	197060	170150	780
14-17/003	148500	175400	43	15-18/019	153950	188650	33	17-20/003Q	173970	204160	93	18-18/011B	187040	183140	48	19-17/011	198810	174870	553
14-17/005	148800	173900	53	15-18/020	153870	187320	18	17-20/005Q	174400	202750	63	18-18/013	187290	182440	53	19-17/020	199980	175060	1020
14-17/008	148440	175340	88	15-18/022	151760	189500	60	17-20/006J	179060	207750	120	18-18/014	186610	182950	40	19-17/021	196520	170560	795
14-17/009	147500	175500	180	15-18/023	152800	181600	33	17-20/006Q	174800	205020	155	18-18/016	182370	188890	68	19-17/023	194200	175230	80
14-17/010	147400	175640	138	15-18/024	155500	188500	25	17-20/007Q	174860	205550	120	18-18/017	182300	189650	98	19-17/027	196250	171470	492
14-17/012	147080	176260	133	15-19/002	153660	190960	35	17-20/008Q	174640	205210	138	18-18/019	188730	181150	68	19-17/028	198150	170500	1250
14-17/013	147350	175070	95	15-19/003	152580	192970	173	17-20/009J	178760	207940	250	18-18/019A	188570	181320	115	19-17/031	197680	171060	1170
14-17/014	147300	175400	290	15-19/005	152600	192750	55	17-20/009Q	174450	203300	59	18-18/023	187210	183070	100	19-17/033	196510	172910	355
14-17/015	146950	177800	158	15-19/006	155920	191840	113	17-20/012J	176800	208500	95	18-18/025A	181650	189540	68	19-17/034	192740	178370	69
14-17/017	148220	178240	38	15-19/010	154800	198960	58	17-20/013Q	174480	204060	90	18-18/030	186240	183350	45	19-17/044	192000	179030	80
14-17/018	148850	178250	50	15-19/011	155530	199800	60	17-20/014A	172100	202060	58	18-18/032	182120	188950	58	19-17/046	192560	176230	475
14-17/022A	146580	177400	175	15-19/012	155730	191000	35	17-20/015Q	174600	203850	88	18-18/033	182140	189770	58	19-17/047	192410	178970	69
14-17/023	146850	178200	145	15-19/013	153470	191600	73	17-20/016Q	174400	203550	75	18-18/036	187600	182550	48	19-17/054	197600	169150	865
14-17/023A	146700	178100	163	15-19/014	152970	190020	50	17-20/018Q	172620	204990	170	18-18/037	180150	185400	43	19-17/055	196150	173400	462
14-17/024	147100	176420	68	15-19/016	151900	190300	85	17-20/020J	178250	206100	150	18-18/038	182750	185750	55	19-17/056	194600	174100	272
14-17/025	147200	177900	73	15-19/017	152400	190920	73	17-20/020Q	175110	204750	110	18-21/003	182100	210400	200	19-19/010	194480	199190	58
14-17/027	148600	177460	55	15-19/018	152480	191900	93	17-20/021J	178950	207920	145	19-13/005	195170	139650	423	19-19/011	194400	199150	48
14-17/028	147140	177860	83	15-19/019	151970	191750	358	17-20/023Q	175310	204800	145	19-13/006	195500	139580	720	20-17/010	200940	176820	560
14-17/029	146280	176280	165	15-19/020	152700	191650	78	17-20/024A	173350	201700	43	19-13/015	196100	139510	335	20-17/011	201160	176870	1100
14-17/034	146900	177300	83	15-19/021	156100	197640	58	17-20/024J	178000	205750	128	19-13/020	194320	139480	243	20-17/016	200290	175850	795
14-17/035	147200	177940	95	15-19/028	156800	190100	25	17-20/028Q	175280	203360	90	19-13/021	194960	138560	510	20-17/018	200240	175710	665
14-17/036	147360	177680	63	15-19/029	156040	196640	90	17-20/029Q	175230	203560	78	19-13/029	197150	139080	1310	20-17/019	200020	175150	770
14-17/037	149650	176900	65	15-19/030	154770	190910	35	17-20/030Q	175280	203140	85	19-13/048	195310	139660	240	20-17/022	201300	178400	373
14-17/038	147520	176120	43	15-19/031	156330	199040	63	17-20/031Q	175210	204340	110	19-13/049	195530	139480	370	20-18/012A	202000	182600	865
14-17/040	149630	179200	45	15-19/032	156650	197580	75	17-20/033J	178500	207400	153	19-13/050A	195810	139380	403	BA/066	159880	209350	65.0
14-17/043	149780	172760	45	15-19/033	151720	191000	130	17-20/035A	174370	205320	185	19-13/069	196950	139250	705	BA/085	162400	165500	15.0
14-17/044	149600	172920	43	15-19/035	156430	196820	43	17-20/035Q	176100	204950	105	19-14/001	195910	149990	310	BA/085A	166860	165920	38.0
14-17/045	148400	178100	55	15-19/036	155320	198000	48	17-20/036A	174960	206140	160	19-14/002	192620	142510	368	BA/108	169100	160300	23.0
14-17/047	149260	178660	53	15-19/038	154440	190880	35	17-20/036Q	177700	202200	165	19-14/009	195230	140530	512	BA/109	169050	160270	28.0
14-17/048	146500	176200	128	15-19/041	155960	198340	55	17-20/037J	175260	205790	95	19-14/010	195220	140610	435	BA/110	166800	161300	28.0
14-17/051	148400	177450	55	15-19/042	158280	199100	48	17-20/040A	173310	201810	54	19-14/012	195380	140010	238	BA/111	166900	158900	38.0
14-17/052	147920	174640	68	15-19/043	154540	192040	48	17-20/041Q	174800	203200	108	19-14/015	195670	140530	235	BA/112	157300	152400	18.0
15-09/001	153460	92260	65	15-19/044	153500	192210	53	17-20/042Q	177300	201500	133	19-14/019	196460	140500	744	BA/117	161350	157250	28.0
15-09/010	156280	98110	63	15-19/046	152920	191840	75	17-20/044Q	177410	202470	158	19-14/023	195040	140240	114	BA/120	156950	159180	135.0
15-09/012	156320	98110	68	15-19/047	157500	195450	38	17-20/046	174730	209800	115	19-14/037	196120	141060	860	BA/121	156880	160080	150.0
15-09/013	157000	96200	40	15-19/048	159050	192800	28	17-20/046Q	177100	201900	190	19-14/052	195680	140980	490	BA/122	156960	158960	80.0
15-15/004	155200	153000	38	15-20/001	156400	201500	83	17-20/048Q	175360	204180	115	19-14/054	195500	141630	477	BA/137	161680	157420	73.0
15-16/003	152070	169610	30	15-20/002A	156450	200470	63	17-20/049Q	175080	204100	168	19-14/058	194880	141170	950	BA/152	166800	152600	50.0
15-17/004	154700	177000	45	15-20/003	156000	202080	65	17-20/050Q	178800	201500	120	19-14/062	193380	142630	550	BA/153	164700	149900	18.0
15-17/005	150850	177060	40	15-20/004	157500	201030	56	17-20/051A	171250	200900	52	19-14/064	197230	141140	1960	BA/163	164380	147920	20.0
15-17/008	151160	170100	33	15-20/005	157100	201560	70	17-20/051Q	175180	205000	145	19-14/066	197310	140660	1360	BA/164	165370	148700	18.0
15-17/009	150200	179540	35	15-20/006	156100	200200	71	17-21/009	176000	210800	145	19-14/067	197010	140560	1070	BA/165	164370	147800	18.0
15-17/010	150000	179140	55	15-20/007	157550	203310	73	17-21/010	174480	210200	90	19-14/070	196890	140670	1200	BA/167	164400	147800	15.0
15-17/011	151300	179100	48	15-20/008	158140	204280	108	17-21/012	174600	210400	148	19-14/073	197030	141050	835	BA/170	163630	145880	20.0
15-17/012	151500	179660	48	16-11/001A	169600	115100	30	17-21/013	174850	210500	145	19-14/081	197060	142310	1270	BA/171	163330	146120	33.0
15-17/013	151300	172200	45	16-11/006	169460	114080	23	17-21/014	175500	210140	155	19-15/005	194750	150440	138	BA/172	163300	145100	20.0
15-17/015	150280	171840	40	16-11/007	169460	114130	33	17-21/015	178500	211080	207	19-15/011	194750	151000	83	BB/022	162200	124400	70.0
15-17/017	150400	176600	50	16-18/003A	166750	184750	25	17-21/022	178860	211370	218	19-15/012	194590	150940	93	BB/023	162300	124350	75.0
15-17/018	150540	170380	40	16-18/005	168900	183000	25	17-21/024	178620	211350	465	19-15/023	196020	150090	230	BB/027	162200	124350	33.0
15-18/001	151420	181120	43	16-19/001	161100	190400	100	17-21/028	171080	214600	128	19-16/001	196770	169900	1080	BB/028	161150	121800	33.0
15-18/002	151170	180160	40	16-19/002	160970	190650	43	17-21/032	178550	212260	193	19-16/003	198460	169650	609	BB/029	159500	122050	18.0
15-18/003	152070	181520	45	16-19/011	160020	190980	100	17-21/034	174250	209850	88	19-16/009	196970	169220	1220	BB/030	159890	123770	33.0
15-18/005	151620	181150	35	16-19/012	169460	193410	33	18-15/001	181550	155250	28	19-16/010	196850	169730	1140	BB/031	159940	123760	33.0
15-18/006	152500	187950	33	16-20/003	167000	205380	65	18-15/003A	182100	154000	35	19-17/001	196900	170740	810	BB/032	159900	123800	25.0
15-18/007	152350	189000	25	17-11/001A	170900	118300	23	18-15/005	181550	155250	28	19-17/002	196520	171240	570	BB/034	159800	123750	25.0
15-18/008	153750	188800	30	17-11/002	170150	119330	25	18-15/006	182200	155800	30	19-17/007	196640	172290	500	BB/077	154900	101500	35.0
15-18/009	152380	189720	38	17-11/003	171850	117220	23	18-18/001	181050	188620	45	19-17/008	196250	170250	1262	BB/083	154700	100250	30.0
15-18/015	156800	181200	33	17-19/001	174830	198600	43	18-18/002	182200	188350	40	19-17/009	197470	170230	680	BB/083A	154650	100350	33.0
																BB/086	154860	99140	38.0

APPENDIX C

The Change of the Values of Hydraulic Conductivity Paramters During the Model Calibration

Upper Aquifer Layer

Iteration No	Error	sc1v1	sc1v2	sc1v3	sc1v4	sc1v5	sc1v6	sc1v7	sc1v8	sc1v9	sc1v10	sc1v11	sc1v12	sc1v13	sc1v14	sc1v15	sc1v16	sc1v17
1	**3418290**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**
2	3418290	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000	8.0000
3	3418500	7.5377	8.6659	6.0511	8.1458	7.9681	7.3575	7.7456	8.3874	8.2956	9.4718	8.1442	8.2609	5.1989	2.5411	13.7100	8.4954	10.6480
4	3406180	7.2638	9.3283	4.3728	8.1970	7.7751	6.7852	7.6008	8.2503	8.5108	10.5260	6.5363	8.1874	2.2256	1.5040	10.3670	11.5380	11.0070
5	3378250	6.5995	10.8330	1.4614	8.0662	7.3631	5.3838	7.4852	7.0900	6.4265	12.6320	4.2282	9.1388	0.4810	2.3998	2.4146	16.5700	8.6991
6	3338670	6.3369	11.0810	1.1758	7.3704	6.5093	4.4134	7.5338	6.2622	5.4402	14.0550	2.9464	9.7506	0.3422	3.0554	0.4829	15.5150	5.7563
7	3241010	6.3703	11.1950	1.0669	5.8949	5.4338	2.9214	8.2385	5.3868	3.9482	18.2630	1.3854	8.9314	0.2427	0.6528	0.2650	7.7321	3.7208
8	2996330	6.7222	11.1790	1.0381	3.6139	5.1621	1.8251	9.7587	3.8482	2.7329	26.3690	0.6171	4.3052	0.1790	0.3652	0.2270	1.5464	2.2193
9	2492010	8.2078	11.0590	1.0388	1.9900	5.2454	1.6661	9.1987	3.3623	2.5711	22.4090	0.4076	3.0760	0.1397	0.2381	0.2297	1.1202	1.0534
10	1217120	12.6850	11.1010	1.0407	1.6701	5.5304	1.6605	7.6271	3.1930	2.1874	7.0210	0.3573	1.8305	0.1305	0.1684	0.2266	0.7716	0.2107
11	946470	24.0920	8.8911	1.0246	0.7922	7.9051	1.6986	4.9634	2.4190	3.2657	4.3757	0.2965	1.3991	0.1109	0.0531	0.4775	0.1718	0.1477
12	945719	30.7600	6.0090	1.0106	0.3817	10.7130	1.4243	3.9839	1.2297	11.8520	2.0183	0.2972	2.9085	0.0979	0.0347	2.3877	0.1453	0.0912
13	777702	33.5230	4.0238	1.0556	0.1910	12.1010	0.9229	3.1709	0.6225	9.5954	1.2468	0.2042	3.0304	0.0837	0.0277	2.3954	0.1223	0.0381
14	773918	34.9920	3.1601	1.1106	0.1216	13.5150	0.6513	3.3674	0.2592	9.9710	4.6204	0.1645	2.9305	0.0724	0.0248	2.4823	0.0990	0.0305
15	774335	34.6570	3.0276	1.1394	0.1087	12.1040	0.5659	3.3803	0.2424	6.4816	8.6181	0.1595	2.7473	0.0736	0.0265	2.8206	0.0960	0.0210
16	773265	34.7060	2.9987	1.1475	0.1059	11.8300	0.5593	3.5931	0.2407	6.2289	6.4998	0.1616	3.0574	0.0737	0.0267	2.7919	0.0947	0.0211
17	772524	35.0060	3.0164	1.2154	0.0968	15.5760	0.6323	3.9129	0.2307	7.9352	3.4310	0.1619	3.4673	0.0718	0.0254	2.8014	0.0920	0.0199
18	768223	34.4460	2.8070	1.3019	0.0766	13.8700	0.4349	3.9515	0.1896	7.6422	3.4976	0.1603	3.3826	0.0687	0.0225	2.8000	0.0841	0.0179
19	767029	34.7160	2.5529	1.3658	0.0477	10.6030	0.3133	4.4801	0.1168	7.0154	3.8912	0.1791	3.4459	0.0785	0.0201	3.0502	0.0836	0.0170
20	766226	35.8340	2.5449	1.3658	0.0447	10.7530	0.2922	4.8159	0.1060	6.4620	4.9308	0.1773	3.4205	0.0756	0.0190	3.0304	0.0814	0.0160
21	**8490**	**35.7060**	**2.5474**	**1.3855**	**0.0438**	**10.5950**	**0.2841**	**4.5032**	**0.1021**	**5.5396**	**5.2152**	**0.1804**	**3.4968**	**0.0754**	**0.0188**	**3.0345**	**0.0820**	**0.0159**

Intermediate Layer

Iteration No	Error	sc2v1	sc2v2	sc2v3	sc2v4	sc2v5	sc2v6	sc2v7	sc2v8	sc2v9	sc2v10	sc2v11	sc2v12	sc2v13	sc2v14	sc2v15	sc2v16	sc2v17
1	**3418290**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
2	3418290	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
3	3418500	0.1233	0.0898	0.1748	0.1429	0.0672	0.0789	0.1085	0.0652	0.0789	0.1373	0.0450	0.0432	0.0590	0.5000	0.1412	0.1041	0.1157
4	3406180	0.1376	0.0863	0.2539	0.1680	0.0498	0.0597	0.1128	0.0390	0.0365	0.1991	0.0249	0.0086	0.0519	0.5175	0.1492	0.1032	0.1574
5	3378250	0.1993	0.0774	0.3584	0.1958	0.0209	0.0376	0.1128	0.0260	0.0138	0.1991	0.0123	0.0038	0.0230	0.1035	0.1225	0.1227	0.3716
6	3338670	0.2379	0.0771	0.3154	0.2009	0.0160	0.0381	0.1069	0.0238	0.0121	0.1249	0.0108	0.0026	0.0163	0.0659	0.0967	0.1098	0.2699
7	3241010	0.2737	0.0768	0.2639	0.2069	0.0136	0.0383	0.0765	0.0224	0.0107	0.0628	0.0091	0.0020	0.0112	0.0370	0.0770	0.0973	0.2239
8	2996330	0.2943	0.0770	0.2188	0.2025	0.0128	0.0359	0.0318	0.0211	0.0096	0.0322	0.0060	0.0016	0.0061	0.0207	0.0641	0.0810	0.1293
9	2492010	0.3176	0.0774	0.1971	0.1941	0.0124	0.0344	0.0215	0.0203	0.0091	0.0252	0.0046	0.0014	0.0040	0.0148	0.0577	0.0721	0.0925
10	1217120	0.3585	0.0777	0.1962	0.1915	0.0124	0.0343	0.0204	0.0200	0.0090	0.0226	0.0045	0.0014	0.0039	0.0148	0.0571	0.0711	0.0830
11	946470	0.4309	0.0780	0.1892	0.1788	0.0123	0.0335	0.0152	0.0183	0.0089	0.0158	0.0044	0.0014	0.0037	0.0133	0.0611	0.0740	0.0604
12	945719	0.4651	0.0778	0.1763	0.1545	0.0121	0.0322	0.0103	0.0152	0.0088	0.0083	0.0043	0.0014	0.0036	0.0120	0.0660	0.0858	0.0428
13	777702	0.4609	0.0774	0.1566	0.1211	0.0116	0.0298	0.0063	0.0120	0.0084	0.0042	0.0043	0.0014	0.0035	0.0117	0.0647	0.0846	0.0313
14	773918	0.4395	0.0770	0.1386	0.0957	0.0110	0.0276	0.0043	0.0097	0.0077	0.0032	0.0042	0.0015	0.0035	0.0115	0.0632	0.0845	0.0293
15	774335	0.4291	0.0769	0.1318	0.0891	0.0107	0.0267	0.0038	0.0093	0.0074	0.0030	0.0042	0.0015	0.0035	0.0117	0.0635	0.0714	0.0302
16	773265	0.4243	0.0768	0.1289	0.0872	0.0106	0.0263	0.0037	0.0089	0.0073	0.0026	0.0042	0.0015	0.0035	0.0117	0.0635	0.0738	0.0303
17	772524	0.3956	0.0765	0.1156	0.0801	0.0102	0.0239	0.0031	0.0069	0.0069	0.0015	0.0042	0.0015	0.0035	0.0117	0.0631	0.0669	0.0288
18	768223	0.3370	0.0757	0.0864	0.0637	0.0091	0.0179	0.0022	0.0031	0.0058	0.0003	0.0043	0.0017	0.0034	0.0124	0.0624	0.0708	0.0260
19	767029	0.2088	0.0738	0.0386	0.0372	0.0062	0.0083	0.0010	0.0008	0.0045	0.0001	0.0050	0.0035	0.0034	0.0170	0.0584	0.0719	0.0258
20	766226	0.1815	0.0732	0.0319	0.0334	0.0053	0.0068	0.0009	0.0007	0.0034	0.0001	0.0050	0.0040	0.0034	0.0172	0.0579	0.0729	0.0252
21	**8490**	**0.1833**	**0.0736**	**0.0317**	**0.0335**	**0.0052**	**0.0070**	**0.0009**	**0.0007**	**0.0035**	**0.0001**	**0.0051**	**0.0045**	**0.0034**	**0.0180**	**0.0578**	**0.0752**	**0.0250**

Lower Aquifer Layer

Iteration No	Error	sc3v1	sc3v2	sc3v3	sc3v4	sc3v5	sc3v6	sc3v7	sc3v8	sc3v9	sc3v10	sc3v11	sc3v12	sc3v13	sc3v14	sc3v15	sc3v16	sc3v17
1	3418290	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**
2	3418290	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000	5.0000
3	3418500	5.2657	4.6606	7.3207	4.5666	5.2008	4.9875	5.1041	4.6938	4.5856	4.6051	4.3765	4.7572	10.2930	11.0550	2.0092	5.9524	2.6535
4	3406180	5.3975	4.2870	9.2576	4.2404	5.4800	4.9702	5.1826	4.4443	4.3382	4.2778	6.7181	4.6752	15.7900	9.7327	1.0930	5.5778	1.4284
5	3378250	5.6660	3.5388	14.8470	3.4934	6.2733	4.9164	5.3325	3.7677	5.5116	3.4722	12.9330	4.5175	25.7240	4.8171	0.7399	3.9951	0.2989
6	3338670	5.8014	3.4649	15.8800	3.1386	7.2981	4.8660	5.3952	3.2647	5.6458	2.9511	17.2280	4.3707	27.2630	1.5752	0.3077	3.2927	0.2533
7	3241010	5.8586	3.5156	17.3580	2.5936	8.7825	4.7394	5.3421	2.4590	5.4157	2.0744	20.9470	3.9264	17.5490	0.3150	0.1575	3.6585	0.2170
8	2996330	6.2295	3.6187	19.0330	1.7430	9.3479	4.2977	5.3367	1.4058	6.0604	1.0039	8.6528	3.3985	6.6882	0.1124	0.1313	3.0196	0.1024
9	2492010	6.9083	3.4800	17.4670	0.8463	9.2353	3.1262	5.1973	0.5371	5.8619	0.3797	1.7306	2.2211	2.0476	0.0816	0.1311	1.0253	0.0757
10	1217120	8.6275	3.2275	9.7626	0.6695	5.9840	1.0259	2.0342	0.1610	1.8732	0.1910	0.7157	0.4880	0.6477	0.0639	0.1282	0.4624	0.0556
11	946470	7.6628	2.3962	4.0749	0.3111	6.7855	0.7971	1.4221	0.0421	1.3334	0.0382	0.2249	0.4710	0.1525	0.0193	0.2296	0.3185	0.0222
12	945719	4.0527	1.6054	2.9154	0.1455	7.6782	0.7480	1.9124	0.0233	0.9995	0.0208	0.1674	0.4395	0.1012	0.0114	0.6211	0.1286	0.0125
13	777702	2.5164	1.1143	2.8866	0.0742	7.5171	0.7354	2.8686	0.0162	0.3332	0.0138	0.1002	0.4739	0.0740	0.0093	0.3646	0.0489	0.0087
14	773918	1.8408	0.9025	2.7982	0.0481	7.5841	0.8854	2.1188	0.0108	0.1558	0.0110	0.0846	0.4648	0.0751	0.0085	0.4074	0.0373	0.0085
15	774335	1.7669	0.8752	2.9315	0.0433	7.6937	0.7676	2.5032	0.0106	0.1463	0.0113	0.0852	0.4929	0.0800	0.0091	0.3336	0.0383	0.0088
16	773265	1.7524	0.8691	3.0063	0.0422	7.9214	0.7976	2.2642	0.0105	0.1440	0.0105	0.0880	0.4828	0.0824	0.0094	0.3488	0.0425	0.0089
17	772524	1.6827	0.8355	3.0724	0.0387	6.7587	0.8078	2.1311	0.0093	0.1343	0.0084	0.0873	0.4909	0.0791	0.0090	0.3337	0.0401	0.0085
18	768223	1.5784	0.7867	3.8241	0.0310	6.8743	0.8190	2.1910	0.0069	0.1159	0.0057	0.0910	0.4921	0.0788	0.0088	0.3492	0.0464	0.0079
19	767029	1.4796	0.7481	4.2151	0.0198	7.8787	0.7917	2.5839	0.0055	0.0772	0.0037	0.0916	0.4821	0.0736	0.0085	0.2558	0.0427	0.0074
20	766226	1.4121	0.7565	3.6176	0.0186	8.3948	0.7672	2.1693	0.0052	0.0727	0.0035	0.0902	0.4840	0.0710	0.0083	0.2564	0.0420	0.0072
21	**8490**	**1.3998**	**0.7656**	**3.6963**	**0.0182**	**7.7721**	**0.6721**	**3.1703**	**0.0051**	**0.0720**	**0.0035**	**0.0924**	**0.4633**	**0.0719**	**0.0083**	**0.2619**	**0.0444**	**0.0072**

APPENDIX D

Low Scenario Detailed Water Demand Projections for All Purposes By Governorates of the West Bank (2005-2025)

Low Scenario Household Water Demand Projection By Governorates of the West Bank

Year	Jenin (MCM/Yr)	Tubas (MCM/Yr)	Tulkarm (MCM/Yr)	Nablus (MCM/Yr)	Qalqiliya (MCM/Yr)	Salfit (MCM/Yr)	Ramallah (MCM/Yr)	Jerusalem (MCM/Yr)	Jericho (MCM/Yr)	Bethlehem (MCM/Yr)	Hebron (MCM/Yr)	Total (MCM/Yr)
2002	5.17	0.47	5.56	11.50	3.77	1.67	14.70	14.76	3.61	4.71	12.87	78.80
2003	5.34	0.49	5.74	11.87	3.90	1.73	15.18	15.62	3.73	4.87	13.28	81.74
2004	5.51	0.50	5.93	12.26	4.02	1.78	15.67	16.13	3.85	5.02	13.72	84.40
2005	5.74	0.54	6.16	12.74	4.21	1.88	16.33	16.75	4.12	5.25	14.25	87.96
2006	7.83	1.05	7.11	14.47	4.63	2.36	17.20	18.71	4.46	6.47	18.01	102.31
2007	10.05	1.63	8.11	16.30	5.08	2.87	18.41	20.78	4.76	7.78	21.99	117.77
2008	12.42	2.28	9.17	18.22	5.55	3.42	19.66	22.96	5.07	9.18	26.21	134.14
2009	14.93	2.99	10.29	20.25	6.05	4.02	20.97	25.23	5.38	10.67	30.66	151.44
2010	17.58	3.77	11.46	22.37	6.57	4.66	22.33	27.62	5.70	12.24	35.36	169.67
2011	19.38	4.25	12.61	24.62	7.26	5.21	23.75	30.37	6.03	13.53	38.90	185.92
2012	21.27	4.76	13.82	26.98	8.00	5.78	25.22	33.24	6.36	14.89	42.61	202.94
2013	23.26	5.30	15.08	29.45	8.77	6.40	26.75	36.24	6.70	16.32	46.49	220.74
2014	25.33	5.89	16.39	32.02	9.57	7.04	28.33	39.37	7.05	17.82	50.53	239.33
2015	27.49	6.50	17.76	34.70	10.42	7.72	29.95	42.62	7.40	19.38	54.74	258.70
2016	29.04	6.98	18.73	36.60	11.03	8.24	31.65	44.91	7.76	20.52	57.72	273.18
2017	30.64	7.49	19.72	38.56	11.67	8.78	33.40	47.27	8.12	21.69	60.78	288.12
2018	32.28	8.01	20.75	40.58	12.32	9.33	35.20	49.70	8.49	22.91	63.94	303.52
2019	33.98	8.56	21.81	42.66	13.00	9.91	37.05	52.20	8.86	24.16	67.19	319.39
2020	35.73	9.12	22.90	44.80	13.70	10.51	38.96	54.76	9.24	25.45	70.53	335.72
2021	37.53	9.71	24.01	47.00	14.42	11.13	40.93	57.40	9.63	26.78	73.96	352.50
2022	39.38	10.32	25.16	49.25	15.16	11.77	42.95	60.10	10.02	28.15	77.49	369.74
2023	41.27	10.95	26.34	51.56	15.92	12.43	45.02	62.87	10.41	29.56	81.10	387.43
2024	43.22	11.60	27.54	53.93	16.71	13.11	47.14	65.70	10.81	31.01	84.79	405.55
2025	45.21	12.27	28.77	56.35	17.51	13.81	49.32	68.60	11.21	32.49	88.57	424.11

Low Scenario Irrigation Water Demand Projection By Governorates of the West Bank

Year	Jenin (MCM/Yr)	Tubas (MCM/Yr)	Tulkarm (MCM/Yr)	Nablus (MCM/Yr)	Qalqiliya (MCM/Yr)	Salfit (MCM/Yr)	Ramallah (MCM/Yr)	Jerusalem (MCM/Yr)	Jericho (MCM/Yr)	Bethlehem (MCM/Yr)	Hebron (MCM/Yr)	Total (MCM/Yr)
2002	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	75.00
2003	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	75.00
2004	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	75.00
2005	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	75.00
2006	8.45	11.95	13.00	4.70	7.15	0.11	0.79	0.12	49.48	0.78	0.98	97.50
2007	9.10	12.60	13.65	5.35	7.80	0.76	1.44	0.77	49.48	1.43	1.63	104.00
2008	9.43	12.92	13.98	5.67	8.13	1.09	1.76	1.10	49.48	1.76	1.95	107.25
2009	9.75	13.25	14.30	6.00	8.45	1.41	2.09	1.42	49.48	2.08	2.28	110.50
2010	10.08	13.57	14.63	6.32	8.78	1.74	2.41	1.75	49.48	2.41	2.60	113.75
2011	10.40	13.90	14.95	6.65	9.10	2.06	2.74	2.07	49.48	2.73	2.93	117.00
2012	10.73	14.22	15.28	6.97	9.43	2.39	3.06	2.40	49.48	3.06	3.25	120.25
2013	11.05	14.55	15.60	7.30	9.75	2.71	3.39	2.72	49.48	3.38	3.58	123.50
2014	11.38	14.87	15.93	7.62	10.08	3.04	3.71	3.05	49.48	3.71	3.90	126.75
2015	11.70	15.20	16.25	7.95	10.40	3.36	4.04	3.37	49.48	4.03	4.23	130.00
2016	12.03	15.52	16.58	8.27	10.73	3.69	4.36	3.70	49.48	4.36	4.55	133.25
2017	12.35	15.85	16.90	8.60	11.05	4.01	4.69	4.02	49.48	4.68	4.88	136.50
2018	12.68	16.17	17.23	8.92	11.38	4.34	5.01	4.35	49.48	5.01	5.20	139.75
2019	13.00	16.50	17.55	9.25	11.70	4.66	5.34	4.67	49.48	5.33	5.53	143.00
2020	13.33	16.82	17.88	9.57	12.03	4.99	5.66	5.00	49.48	5.66	5.85	146.25
2021	13.65	17.15	18.20	9.90	12.35	5.31	5.99	5.32	49.48	5.98	6.18	149.50
2022	13.98	17.47	18.53	10.22	12.68	5.64	6.31	5.65	49.48	6.31	6.50	152.75
2023	14.30	17.80	18.85	10.55	13.00	5.96	6.64	5.97	49.48	6.63	6.83	156.00
2024	14.63	18.12	19.18	10.87	13.33	6.29	6.96	6.30	49.48	6.96	7.15	159.25
2025	14.95	18.45	19.50	11.20	13.65	6.61	7.29	6.62	49.48	7.28	7.48	162.50

Low Scenario Industrial Water Demand Projection By Governorates of the West Bank

Year	Jenin (MCM/Yr)	Tubas (MCM/Yr)	Tulkarm (MCM/Yr)	Nablus (MCM/Yr)	Qalqiliya (MCM/Yr)	Salfit (MCM/Yr)	Ramallah (MCM/Yr)	Jerusalem (MCM/Yr)	Jericho (MCM/Yr)	Bethlehem (MCM/Yr)	Hebron (MCM/Yr)	Total (MCM/Yr)
2002	0.55	0.10	1.00	1.60	0.45	0.10	1.40	0.50	0.20	1.60	2.50	10.00
2003	0.56	0.10	1.02	1.62	0.46	0.10	1.42	0.51	0.20	1.62	2.54	10.15
2004	0.57	0.10	1.03	1.65	0.46	0.10	1.44	0.52	0.21	1.65	2.58	10.30
2005	0.58	0.10	1.05	1.67	0.47	0.10	1.46	0.52	0.21	1.67	2.61	10.46
2006	0.59	0.11	1.08	1.72	0.48	0.11	1.51	0.54	0.22	1.72	2.69	10.77
2007	0.61	0.11	1.11	1.77	0.50	0.11	1.55	0.55	0.22	1.77	2.77	11.09
2008	0.63	0.11	1.14	1.83	0.51	0.11	1.60	0.57	0.23	1.83	2.86	11.43
2009	0.65	0.12	1.18	1.88	0.53	0.12	1.65	0.59	0.24	1.88	2.94	11.77
2010	0.67	0.12	1.21	1.94	0.55	0.12	1.70	0.61	0.24	1.94	3.03	12.12
2011	0.69	0.12	1.25	2.00	0.56	0.12	1.75	0.62	0.25	2.00	3.12	12.49
2012	0.71	0.13	1.29	2.06	0.58	0.13	1.80	0.64	0.26	2.06	3.22	12.86
2013	0.73	0.13	1.32	2.12	0.60	0.13	1.85	0.66	0.26	2.12	3.31	13.25
2014	0.75	0.14	1.36	2.18	0.61	0.14	1.91	0.68	0.27	2.18	3.41	13.64
2015	0.77	0.14	1.41	2.25	0.63	0.14	1.97	0.70	0.28	2.25	3.51	14.05
2016	0.80	0.14	1.45	2.32	0.65	0.14	2.03	0.72	0.29	2.32	3.62	14.47
2017	0.82	0.15	1.49	2.39	0.67	0.15	2.09	0.75	0.30	2.39	3.73	14.91
2018	0.84	0.15	1.54	2.46	0.69	0.15	2.15	0.77	0.31	2.46	3.84	15.36
2019	0.87	0.16	1.58	2.53	0.71	0.16	2.21	0.79	0.32	2.53	3.95	15.82
2020	0.90	0.16	1.63	2.61	0.73	0.16	2.28	0.81	0.33	2.61	4.07	16.29
2021	0.92	0.17	1.68	2.68	0.76	0.17	2.35	0.84	0.34	2.68	4.20	16.78
2022	0.95	0.17	1.73	2.77	0.78	0.17	2.42	0.86	0.35	2.77	4.32	17.28
2023	0.98	0.18	1.78	2.85	0.80	0.18	2.49	0.89	0.36	2.85	4.45	17.80
2024	1.01	0.18	1.83	2.93	0.83	0.18	2.57	0.92	0.37	2.93	4.58	18.34
2025	1.04	0.19	1.89	3.02	0.85	0.19	2.64	0.94	0.38	3.02	4.72	18.89

Low Scenario Total Water Demand Projection for all purposes By Governorates of the West Bank

Year	Jenin (MCM/Yr)	Tubas (MCM/Yr)	Tulkarm (MCM/Yr)	Nablus (MCM/Yr)	Qalqiliya (MCM/Yr)	Salfit (MCM/Yr)	Ramallah (MCM/Yr)	Jerusalem (MCM/Yr)	Jericho (MCM/Yr)	Bethlehem (MCM/Yr)	Hebron (MCM/Yr)	Total (MCM/Yr)
2002	11.21	10.29	16.32	16.43	10.86	1.90	16.81	15.41	41.63	6.87	16.08	163.80
2003	11.38	10.30	16.51	16.82	10.99	1.96	17.31	16.28	41.75	7.05	16.53	166.89
2004	11.56	10.32	16.72	17.24	11.12	2.02	17.82	16.79	41.88	7.23	17.00	169.70
2005	11.80	10.36	16.96	17.75	11.31	2.12	18.50	17.42	42.15	7.48	17.58	173.42
2006	16.87	13.11	21.19	20.90	12.26	2.57	19.50	19.38	54.16	8.98	21.67	210.58
2007	19.76	14.34	22.87	23.42	13.38	3.74	21.40	22.11	54.46	10.99	26.39	232.86
2008	22.47	15.31	24.29	25.73	14.19	4.62	23.02	24.63	54.78	12.76	31.01	252.82
2009	25.33	16.35	25.77	28.13	15.03	5.55	24.71	27.25	55.10	14.63	35.88	273.71
2010	28.32	17.46	27.30	30.63	15.89	6.52	26.44	29.97	55.42	16.59	40.99	295.54
2011	30.47	18.27	28.81	33.27	16.93	7.39	28.24	33.07	55.76	18.26	44.95	315.41
2012	32.71	19.11	30.38	36.01	18.00	8.30	30.08	36.28	56.10	20.01	49.08	336.05
2013	35.03	19.98	32.00	38.87	19.11	9.24	31.99	39.63	56.45	21.82	53.37	357.49
2014	37.45	20.89	33.68	41.83	20.26	10.21	33.95	43.10	56.80	23.70	57.84	379.72
2015	39.96	21.84	35.41	44.90	21.45	11.22	35.96	46.70	57.16	25.66	62.48	402.75
2016	41.86	22.65	36.75	47.20	22.41	12.07	38.04	49.33	57.53	27.19	65.88	420.90
2017	43.81	23.48	38.12	49.55	23.39	12.94	40.17	52.04	57.90	28.76	69.38	439.53
2018	45.80	24.34	39.51	51.96	24.39	13.82	42.36	54.82	58.28	30.37	72.98	458.63
2019	47.85	25.21	40.94	54.44	25.41	14.73	44.60	57.66	58.66	32.02	76.67	478.21
2020	49.95	26.11	42.40	56.98	26.46	15.66	46.90	60.58	59.05	33.71	80.46	498.26
2021	52.10	27.02	43.89	59.58	27.53	16.61	49.26	63.56	59.44	35.45	84.33	518.78
2022	54.30	27.96	45.41	62.24	28.61	17.58	51.68	66.61	59.84	37.22	88.31	539.77
2023	56.55	28.92	46.97	64.96	29.72	18.57	54.15	69.73	60.24	39.04	92.37	561.23
2024	58.85	29.90	48.55	67.73	30.86	19.58	56.67	72.92	60.65	40.90	96.53	583.14
2025	61.20	30.91	50.16	70.57	32.01	20.61	59.25	76.17	61.06	42.79	100.77	605.50
ASY	**76.87**	**44.31**	**80.32**	**92.71**	**47.07**	**50.51**	**94.08**	**31.88**	**27.92**	**29.56**	**104.49**	**679.71**

Medium Scenario Detailed Water Demand Projections for All Purposes By Governorates of the West Bank (2005-2025)

Medium Scenario Household Water Demand Projection By Governorates of the West Bank

Year	Jenin (MCM/Yr)	Tubas (MCM/Yr)	Tulkarm (MCM/Yr)	Nablus (MCM/Yr)	Qalqiliya (MCM/Yr)	Salfit (MCM/Yr)	Ramallah (MCM/Yr)	Jerusalem (MCM/Yr)	Jericho (MCM/Yr)	Bethlehem (MCM/Yr)	Hebron (MCM/Yr)	Total (MCM/Yr)
2002	5.17	0.47	5.56	11.50	3.77	1.67	14.70	14.76	3.61	4.71	12.87	78.80
2003	5.34	0.49	5.74	11.87	3.90	1.73	15.18	15.62	3.73	4.87	13.28	81.74
2004	5.51	0.50	5.93	12.26	4.02	1.78	15.67	16.13	3.85	5.02	13.72	84.40
2005	5.79	0.56	6.20	12.83	4.25	1.93	16.47	16.84	4.27	5.31	14.34	88.79
2006	7.93	1.13	7.17	14.61	4.72	2.46	17.44	18.85	4.78	6.60	18.16	103.86
2007	10.23	1.79	8.21	16.50	5.22	3.05	18.75	20.96	5.25	8.00	22.23	120.20
2008	12.70	2.56	9.30	18.50	5.75	3.70	20.12	23.19	5.73	9.50	26.55	137.60
2009	15.33	3.44	10.46	20.60	6.31	4.41	21.56	25.52	6.22	11.11	31.13	156.09
2010	18.13	4.43	11.67	22.82	6.90	5.19	23.05	27.97	6.72	12.83	35.97	175.68
2011	20.06	5.08	12.87	25.17	7.68	5.87	24.61	30.79	7.24	14.28	39.64	193.29
2012	22.10	5.78	14.12	27.65	8.51	6.60	26.23	33.74	7.76	15.80	43.50	211.80
2013	24.25	6.55	15.44	30.24	9.38	7.38	27.92	36.83	8.30	17.41	47.53	231.22
2014	26.49	7.36	16.81	32.94	10.30	8.22	29.67	40.04	8.85	19.11	51.75	251.55
2015	28.85	8.23	18.25	35.77	11.27	9.10	31.48	43.40	9.41	20.89	56.15	272.80
2016	30.57	8.95	19.27	37.80	11.99	9.80	33.37	45.77	9.98	22.22	59.29	289.02
2017	32.34	9.69	20.33	39.90	12.75	10.53	35.32	48.22	10.56	23.60	62.53	305.77
2018	34.18	10.47	21.43	42.06	13.53	11.29	37.33	50.74	11.15	25.03	65.87	323.08
2019	36.08	11.29	22.55	44.28	14.33	12.08	39.41	53.34	11.75	26.51	69.31	340.94
2020	38.04	12.14	23.71	46.58	15.17	12.90	41.55	56.01	12.36	28.04	72.85	359.35
2021	40.05	13.03	24.90	48.94	16.03	13.76	43.77	58.75	12.97	29.62	76.49	378.31
2022	42.13	13.95	26.12	51.36	16.92	14.65	46.04	61.56	13.60	31.25	80.23	397.81
2023	44.26	14.91	27.37	53.84	17.84	15.57	48.38	64.44	14.24	32.93	84.07	417.85
2024	46.45	15.90	28.66	56.40	18.78	16.52	50.79	67.39	14.88	34.66	88.00	438.43
2025	48.70	16.93	29.98	59.01	19.75	17.50	53.25	70.41	15.53	36.44	92.02	459.53

Medium Scenario Irrigation Water Demand Projection By Governorates of the West Bank

Year	Jenin (MCM/Yr)	Tubas (MCM/Yr)	Tulkarm (MCM/Yr)	Nablus (MCM/Yr)	Qalqiliya (MCM/Yr)	Salfit (MCM/Yr)	Ramallah (MCM/Yr)	Jerusalem (MCM/Yr)	Jericho (MCM/Yr)	Bethlehem (MCM/Yr)	Hebron (MCM/Yr)	Total (MCM/Yr)
2002	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	75.00
2003	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	75.00
204	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	75.00
2005	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	75.00
2006	8.45	11.95	13.00	4.70	7.15	0.11	0.79	0.12	49.48	0.78	0.98	97.50
2007	9.10	12.60	13.65	5.35	7.80	0.76	1.44	0.77	49.48	1.43	1.63	104.00
2008	9.59	13.08	14.14	5.84	8.29	1.25	1.92	1.26	49.48	1.92	2.11	108.88
2009	10.08	13.57	14.63	6.32	8.78	1.74	2.41	1.75	49.48	2.41	2.60	113.75
2010	10.73	14.22	15.28	6.97	9.43	2.39	3.06	2.40	49.48	3.06	3.25	120.25
2011	11.12	14.61	15.67	7.36	9.82	2.78	3.45	2.79	49.48	3.45	3.64	124.15
2012	11.51	15.00	16.06	7.75	10.21	3.17	3.84	3.18	49.48	3.84	4.03	128.05
2013	11.90	15.39	16.45	8.14	10.60	3.56	4.23	3.57	49.48	4.23	4.42	131.95
2014	12.29	15.78	16.84	8.53	10.99	3.95	4.62	3.96	49.48	4.62	4.81	135.85
2015	12.68	16.17	17.23	8.92	11.38	4.34	5.01	4.35	49.48	5.01	5.20	139.75
2016	13.07	16.56	17.62	9.31	11.77	4.73	5.40	4.74	49.48	5.40	5.59	143.65
2017	13.46	16.95	18.01	9.70	12.16	5.12	5.79	5.13	49.48	5.79	5.98	147.55
2018	13.85	17.34	18.40	10.09	12.55	5.51	6.18	5.52	49.48	6.18	6.37	151.45
2019	14.24	17.73	18.79	10.48	12.94	5.90	6.57	5.91	49.48	6.57	6.76	155.35
2020	14.63	18.12	19.18	10.87	13.33	6.29	6.96	6.30	49.48	6.96	7.15	159.25
2021	15.02	18.51	19.57	11.26	13.72	6.68	7.35	6.69	49.48	7.35	7.54	163.15
2022	15.41	18.90	19.96	11.65	14.11	7.07	7.74	7.08	49.48	7.74	7.93	167.05
2023	15.80	19.29	20.35	12.04	14.50	7.46	8.13	7.47	49.48	8.13	8.32	170.95
2024	16.19	19.68	20.74	12.43	14.89	7.85	8.52	7.86	49.48	8.52	8.71	174.85
2025	16.58	20.07	21.13	12.82	15.28	8.24	8.91	8.25	49.48	8.91	9.10	178.75

Medium Scenario Industrial Water Demand Projection By Governorates of the West Bank

Year	Jenin (MCM/Yr)	Tubas (MCM/Yr)	Tulkarm (MCM/Yr)	Nablus (MCM/Yr)	Qalqiliya (MCM/Yr)	Salfit (MCM/Yr)	Ramallah (MCM/Yr)	Jerusalem (MCM/Yr)	Jericho (MCM/Yr)	Bethlehem (MCM/Yr)	Hebron (MCM/Yr)	Total (MCM/Yr)
2002	0.55	0.10	1.00	1.60	0.45	0.10	1.40	0.50	0.20	1.60	2.50	10.00
2003	0.56	0.10	1.02	1.62	0.46	0.10	1.42	0.51	0.20	1.62	2.54	10.15
2004	0.57	0.10	1.03	1.65	0.46	0.10	1.44	0.52	0.21	1.65	2.58	10.30
2005	0.58	0.10	1.05	1.67	0.47	0.10	1.46	0.52	0.21	1.67	2.61	10.46
2006	0.60	0.11	1.09	1.74	0.49	0.11	1.52	0.54	0.22	1.74	2.72	10.88
2007	0.62	0.11	1.13	1.81	0.51	0.11	1.58	0.57	0.23	1.81	2.83	11.31
2008	0.65	0.12	1.18	1.88	0.53	0.12	1.65	0.59	0.24	1.88	2.94	11.76
2009	0.67	0.12	1.22	1.96	0.55	0.12	1.71	0.61	0.24	1.96	3.06	12.23
2010	0.70	0.13	1.27	2.04	0.57	0.13	1.78	0.64	0.25	2.04	3.18	12.72
2011	0.73	0.13	1.32	2.12	0.60	0.13	1.85	0.66	0.26	2.12	3.31	13.23
2012	0.76	0.14	1.38	2.20	0.62	0.14	1.93	0.69	0.28	2.20	3.44	13.76
2013	0.79	0.14	1.43	2.29	0.64	0.14	2.00	0.72	0.29	2.29	3.58	14.31
2014	0.82	0.15	1.49	2.38	0.67	0.15	2.08	0.74	0.30	2.38	3.72	14.88
2015	0.85	0.15	1.55	2.48	0.70	0.15	2.17	0.77	0.31	2.48	3.87	15.48
2016	0.89	0.16	1.61	2.58	0.72	0.16	2.25	0.80	0.32	2.58	4.02	16.10
2017	0.92	0.17	1.67	2.68	0.75	0.17	2.34	0.84	0.33	2.68	4.19	16.74
2018	0.96	0.17	1.74	2.79	0.78	0.17	2.44	0.87	0.35	2.79	4.35	17.41
2019	1.00	0.18	1.81	2.90	0.81	0.18	2.54	0.91	0.36	2.90	4.53	18.11
2020	1.04	0.19	1.88	3.01	0.85	0.19	2.64	0.94	0.38	3.01	4.71	18.83
2021	1.08	0.20	1.96	3.13	0.88	0.20	2.74	0.98	0.39	3.13	4.90	19.59
2022	1.12	0.20	2.04	3.26	0.92	0.20	2.85	1.02	0.41	3.26	5.09	20.37
2023	1.17	0.21	2.12	3.39	0.95	0.21	2.97	1.06	0.42	3.39	5.30	21.18
2024	1.21	0.22	2.20	3.52	0.99	0.22	3.08	1.10	0.44	3.52	5.51	22.03
2025	1.26	0.23	2.29	3.67	1.03	0.23	3.21	1.15	0.46	3.67	5.73	22.91

Medium Scenario Total Water Demand Projection for all purposes By Governorates of the West Bank

Year	Jenin (MCM/Yr)	Tubas (MCM/Yr)	Tulkarm (MCM/Yr)	Nablus (MCM/Yr)	Qalqiliya (MCM/Yr)	Salfit (MCM/Yr)	Ramallah (MCM/Yr)	Jerusalem (MCM/Yr)	Jericho (MCM/Yr)	Bethlehem (MCM/Yr)	Hebron (MCM/Yr)	Total (MCM/Yr)
2002	11.21	10.29	16.32	16.43	10.86	1.90	16.81	15.41	41.63	6.87	16.08	163.80
2003	11.38	10.30	16.51	16.82	10.99	1.96	17.31	16.28	41.75	7.05	16.53	166.89
2004	11.56	10.32	16.72	17.24	11.12	2.02	17.82	16.79	41.88	7.23	17.00	169.70
2005	11.85	10.38	17.00	17.83	11.36	2.16	18.64	17.51	42.30	7.54	17.67	174.24
2006	16.98	13.18	21.26	21.05	12.36	2.68	19.75	19.52	54.47	9.12	21.86	212.23
2007	19.95	14.50	22.99	23.66	13.53	3.92	21.77	22.30	54.95	11.24	26.68	235.51
2008	22.93	15.77	24.62	26.22	14.57	5.06	23.69	25.04	55.44	13.30	31.60	258.24
2009	26.08	17.14	26.30	28.88	15.64	6.27	25.68	27.88	55.94	15.47	36.78	282.08
2010	29.55	18.78	28.22	31.83	16.90	7.70	27.89	31.01	56.45	17.92	42.40	308.65
2011	31.91	19.82	29.86	34.66	18.09	8.78	29.91	34.24	56.98	19.84	46.59	330.67
2012	34.36	20.92	31.56	37.60	19.33	9.91	32.00	37.61	57.52	21.84	50.97	353.61
2013	36.93	22.08	33.32	40.67	20.62	11.08	34.15	41.11	58.06	23.92	55.53	377.48
2014	39.60	23.29	35.14	43.86	21.96	12.31	36.38	44.75	58.62	26.10	60.28	402.29
2015	42.38	24.56	37.02	47.17	23.34	13.59	38.66	48.52	59.20	28.37	65.22	428.03
2016	44.52	25.67	38.50	49.69	24.48	14.68	41.02	51.32	59.78	30.19	68.91	448.76
2017	46.72	26.81	40.01	52.28	25.66	15.81	43.45	54.19	60.37	32.06	72.70	470.06
2018	48.98	27.99	41.56	54.94	26.85	16.97	45.95	57.13	60.97	33.99	76.60	491.94
2019	51.31	29.20	43.15	57.67	28.08	18.16	48.52	60.15	61.59	35.97	80.60	514.40
2020	53.70	30.45	44.77	60.46	29.34	19.38	51.15	63.25	62.21	38.01	84.71	537.43
2021	56.14	31.74	46.42	63.33	30.63	20.63	53.86	66.42	62.84	40.10	88.93	561.04
2022	58.65	33.06	48.11	66.27	31.94	21.92	56.63	69.66	63.49	42.25	93.25	585.23
2023	61.22	34.41	49.84	69.28	33.29	23.23	59.48	72.97	64.14	44.45	97.68	609.99
2024	63.85	35.80	51.60	72.35	34.66	24.58	62.39	76.35	64.80	46.70	102.21	635.31
2025	66.54	37.23	53.39	75.50	36.06	25.96	65.37	79.81	65.46	49.01	106.85	661.19
ASY	**76.87**	**44.31**	**80.32**	**92.71**	**47.07**	**50.51**	**94.08**	**31.88**	**27.92**	**29.56**	**104.49**	**679.71**

High Scenario Detailed Water Demand Projections for All Purposes By Governorates of the West Bank (2005-2025)

High Scenario Household Water Demand Projection By Governorates of the West Bank

Year	Jenin (MCM/Yr)	Tubas (MCM/Yr)	Tulkarm (MCM/Yr)	Nablus (MCM/Yr)	Qalqiliya (MCM/Yr)	Salfit (MCM/Yr)	Ramallah (MCM/Yr)	Jerusalem (MCM/Yr)	Jericho (MCM/Yr)	Bethlehem (MCM/Yr)	Hebron (MCM/Yr)	Total (MCM/Yr)
2002	5.17	0.47	5.56	11.50	3.77	1.67	14.70	14.76	3.61	4.71	12.87	78.80
2003	5.34	0.49	5.74	11.87	3.90	1.73	15.18	15.62	3.73	4.87	13.28	81.74
2004	5.51	0.50	5.93	12.26	4.02	1.78	15.67	16.13	3.85	5.02	13.72	84.40
2005	5.84	0.58	6.24	12.92	4.30	1.97	16.61	16.94	4.42	5.37	14.43	89.61
2006	8.02	1.20	7.22	14.73	4.81	2.56	17.64	18.95	5.08	6.71	18.28	105.21
2007	10.38	1.95	8.27	16.65	5.35	3.22	19.03	21.07	5.71	8.18	22.39	122.19
2008	12.91	2.84	9.38	18.68	5.92	3.96	20.48	23.30	6.36	9.77	26.75	140.34
2009	15.63	3.88	10.55	20.82	6.54	4.78	21.99	25.63	7.02	11.48	31.38	159.70
2010	18.53	5.06	11.78	23.08	7.18	5.68	23.58	28.09	7.70	13.33	36.27	180.27
2011	20.56	5.88	13.00	25.48	8.03	6.49	25.24	30.91	8.39	14.89	40.00	198.87
2012	22.70	6.77	14.28	28.01	8.94	7.36	26.97	33.87	9.11	16.55	43.91	218.45
2013	24.95	7.73	15.62	30.66	9.89	8.30	28.77	36.96	9.83	18.31	48.01	239.03
2014	27.32	8.78	17.02	33.44	10.91	9.31	30.64	40.19	10.58	20.17	52.29	260.63
2015	29.82	9.89	18.48	36.34	11.98	10.38	32.58	43.55	11.34	22.13	56.76	283.24
2016	31.73	10.84	19.58	38.53	12.83	11.27	34.69	46.06	12.13	23.67	60.13	301.47
2017	33.72	11.84	20.73	40.81	13.71	12.20	36.88	48.65	12.93	25.28	63.61	320.35
2018	35.78	12.89	21.90	43.15	14.62	13.17	39.14	51.32	13.75	26.95	67.20	339.88
2019	37.92	13.98	23.12	45.57	15.57	14.19	41.49	54.07	14.58	28.68	70.91	360.07
2020	40.12	15.12	24.37	48.07	16.56	15.24	43.91	56.90	15.43	30.48	74.73	380.93
2021	42.39	16.31	25.66	50.64	17.57	16.35	46.41	59.81	16.29	32.34	78.65	402.43
2022	44.74	17.56	26.99	53.29	18.63	17.49	48.99	62.80	17.16	34.26	82.69	424.59
2023	47.16	18.85	28.35	56.01	19.72	18.68	51.64	65.86	18.05	36.24	86.84	447.40
2024	49.64	20.19	29.75	58.80	20.84	19.91	54.38	69.01	18.94	38.29	91.10	470.86
2025	52.20	21.59	31.18	61.67	22.00	21.18	57.19	72.23	19.85	40.40	95.47	494.95

High Scenario Irrigation Water Demand Projection By Governorates of the West Bank

Year	Jenin (MCM/Yr)	Tubas (MCM/Yr)	Tulkarm (MCM/Yr)	Nablus (MCM/Yr)	Qalqiliya (MCM/Yr)	Salfit (MCM/Yr)	Ramallah (MCM/Yr)	Jerusalem (MCM/Yr)	Jericho (MCM/Yr)	Bethlehem (MCM/Yr)	Hebron (MCM/Yr)	Total (MCM/Yr)
2002	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	75.00
2003	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	75.00
2004	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	75.00
2005	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	75.00
2006	8.45	11.95	13.00	4.70	7.15	0.11	0.79	0.12	49.48	0.78	0.98	97.50
2007	9.10	12.60	13.65	5.35	7.80	0.76	1.44	0.77	49.48	1.43	1.63	104.00
2008	9.75	13.25	14.30	6.00	8.45	1.41	2.09	1.42	49.48	2.08	2.28	110.50
2009	10.40	13.90	14.95	6.65	9.10	2.06	2.74	2.07	49.48	2.73	2.93	117.00
2010	11.05	14.55	15.60	7.30	9.75	2.71	3.39	2.72	49.48	3.38	3.58	123.50
2011	11.38	14.87	15.93	7.62	10.08	3.04	3.71	3.05	49.48	3.71	3.90	126.75
2012	11.86	15.36	16.41	8.11	10.56	3.52	4.20	3.54	49.48	4.19	4.39	131.63
2013	12.35	15.85	16.90	8.60	11.05	4.01	4.69	4.02	49.48	4.68	4.88	136.50
2014	12.84	16.33	17.39	9.09	11.54	4.50	5.17	4.51	49.48	5.17	5.36	141.38
2015	13.33	16.82	17.88	9.57	12.03	4.99	5.66	5.00	49.48	5.66	5.85	146.25
2016	13.81	17.31	18.36	10.06	12.51	5.47	6.15	5.49	49.48	6.14	6.34	151.13
2017	14.30	17.80	18.85	10.55	13.00	5.96	6.64	5.97	49.48	6.63	6.83	156.00
2018	14.79	18.28	19.34	11.04	13.49	6.45	7.12	6.46	49.48	7.12	7.31	160.88
2019	15.28	18.77	19.83	11.52	13.98	6.94	7.61	6.95	49.48	7.61	7.80	165.75
2020	15.76	19.26	20.31	12.01	14.46	7.42	8.10	7.44	49.48	8.09	8.29	170.63
2021	16.25	19.75	20.80	12.50	14.95	7.91	8.59	7.92	49.48	8.58	8.78	175.50
2022	16.74	20.23	21.29	12.99	15.44	8.40	9.07	8.41	49.48	9.07	9.26	180.38
2023	17.23	20.72	21.78	13.47	15.93	8.89	9.56	8.90	49.48	9.56	9.75	185.25
2024	17.71	21.21	22.26	13.96	16.41	9.37	10.05	9.39	49.48	10.04	10.24	190.13
2025	18.20	21.70	22.75	14.45	16.90	9.86	10.54	9.87	49.48	10.53	10.73	195.00

High Scenario Industrial Water Demand Projection By Governorates of the West Bank

Year	Jenin (MCM/Yr)	Tubas (MCM/Yr)	Tulkarm (MCM/Yr)	Nablus (MCM/Yr)	Qalqiliya (MCM/Yr)	Salfit (MCM/Yr)	Ramallah (MCM/Yr)	Jerusalem (MCM/Yr)	Jericho (MCM/Yr)	Bethlehem (MCM/Yr)	Hebron (MCM/Yr)	Total (MCM/Yr)
2002	0.55	0.10	1.00	1.60	0.45	0.10	1.40	0.50	0.20	1.60	2.50	10.00
2003	0.56	0.10	1.02	1.62	0.46	0.10	1.42	0.51	0.20	1.62	2.54	10.15
2004	0.57	0.10	1.03	1.65	0.46	0.10	1.44	0.52	0.21	1.65	2.58	10.30
2005	0.58	0.10	1.05	1.67	0.47	0.10	1.46	0.52	0.21	1.67	2.61	10.46
2006	0.60	0.11	1.10	1.76	0.49	0.11	1.54	0.55	0.22	1.76	2.74	10.98
2007	0.63	0.12	1.15	1.84	0.52	0.12	1.61	0.58	0.23	1.84	2.88	11.53
2008	0.67	0.12	1.21	1.94	0.54	0.12	1.69	0.61	0.24	1.94	3.03	12.11
2009	0.70	0.13	1.27	2.03	0.57	0.13	1.78	0.64	0.25	2.03	3.18	12.71
2010	0.73	0.13	1.33	2.14	0.60	0.13	1.87	0.67	0.27	2.14	3.34	13.35
2011	0.77	0.14	1.40	2.24	0.63	0.14	1.96	0.70	0.28	2.24	3.50	14.01
2012	0.81	0.15	1.47	2.35	0.66	0.15	2.06	0.74	0.29	2.35	3.68	14.71
2013	0.85	0.15	1.54	2.47	0.70	0.15	2.16	0.77	0.31	2.47	3.86	15.45
2014	0.89	0.16	1.62	2.60	0.73	0.16	2.27	0.81	0.32	2.60	4.06	16.22
2015	0.94	0.17	1.70	2.73	0.77	0.17	2.38	0.85	0.34	2.73	4.26	17.03
2016	0.98	0.18	1.79	2.86	0.80	0.18	2.50	0.89	0.36	2.86	4.47	17.88
2017	1.03	0.19	1.88	3.00	0.85	0.19	2.63	0.94	0.38	3.00	4.69	18.78
2018	1.08	0.20	1.97	3.15	0.89	0.20	2.76	0.99	0.39	3.15	4.93	19.72
2019	1.14	0.21	2.07	3.31	0.93	0.21	2.90	1.04	0.41	3.31	5.18	20.70
2020	1.20	0.22	2.17	3.48	0.98	0.22	3.04	1.09	0.43	3.48	5.43	21.74
2021	1.26	0.23	2.28	3.65	1.03	0.23	3.20	1.14	0.46	3.65	5.71	22.83
2022	1.32	0.24	2.40	3.83	1.08	0.24	3.36	1.20	0.48	3.83	5.99	23.97
2023	1.38	0.25	2.52	4.03	1.13	0.25	3.52	1.26	0.50	4.03	6.29	25.17
2024	1.45	0.26	2.64	4.23	1.19	0.26	3.70	1.32	0.53	4.23	6.61	26.42
2025	1.53	0.28	2.77	4.44	1.25	0.28	3.88	1.39	0.55	4.44	6.94	27.74

High Scenario Total Water Demand Projection for all purposes By Governorates of the West Bank

Year	Jenin (MCM/Yr)	Tubas (MCM/Yr)	Tulkarm (MCM/Yr)	Nablus (MCM/Yr)	Qalqiliya (MCM/Yr)	Salfit (MCM/Yr)	Ramallah (MCM/Yr)	Jerusalem (MCM/Yr)	Jericho (MCM/Yr)	Bethlehem (MCM/Yr)	Hebron (MCM/Yr)	Total (MCM/Yr)
2002	11.21	10.29	16.32	16.43	10.86	1.90	16.81	15.41	41.63	6.87	16.08	163.80
2003	11.38	10.30	16.51	16.82	10.99	1.96	17.31	16.28	41.75	7.05	16.53	166.89
2004	11.56	10.32	16.72	17.24	11.12	2.02	17.82	16.79	41.88	7.23	17.00	169.70
2005	11.90	10.40	17.04	17.92	11.41	2.21	18.78	17.61	42.45	7.60	17.76	175.07
2006	17.08	13.25	21.32	21.18	12.45	2.78	19.97	19.62	54.78	9.25	22.00	213.69
2007	20.11	14.66	23.07	23.84	13.67	4.09	22.08	22.42	55.42	11.45	26.90	237.72
2008	23.33	16.21	24.89	26.61	14.92	5.49	24.26	25.32	56.08	13.78	32.05	262.95
2009	26.73	17.90	26.77	29.50	16.21	6.97	26.51	28.34	56.75	16.25	37.48	289.41
2010	30.31	19.74	28.72	32.51	17.53	8.53	28.84	31.48	57.44	18.84	43.18	317.12
2011	32.70	20.89	30.33	35.35	18.74	9.67	30.91	34.66	58.15	20.83	47.40	339.63
2012	35.37	22.27	32.16	38.48	20.16	11.03	33.23	38.14	58.88	23.09	51.98	364.79
2013	38.15	23.74	34.06	41.73	21.64	12.47	35.62	41.76	59.62	25.46	56.74	390.98
2014	41.05	25.27	36.03	45.12	23.18	13.97	38.09	45.51	60.38	27.93	61.71	418.23
2015	44.08	26.89	38.06	48.64	24.77	15.54	40.62	49.40	61.15	30.51	66.87	446.53
2016	46.53	28.33	39.74	51.46	26.14	16.92	43.35	52.44	61.96	32.68	70.94	470.48
2017	49.06	29.83	41.45	54.36	27.55	18.35	46.14	55.56	62.78	34.92	75.13	495.13
2018	51.66	31.37	43.21	57.34	29.00	19.82	49.03	58.76	63.62	37.22	79.44	520.48
2019	54.33	32.96	45.01	60.41	30.48	21.33	52.00	62.05	64.47	39.60	83.88	546.53
2020	57.08	34.60	46.86	63.56	32.00	22.88	55.05	65.42	65.34	42.05	88.45	573.29
2021	59.90	36.29	48.74	66.79	33.55	24.48	58.19	68.87	66.22	44.57	93.14	600.76
2022	62.80	38.03	50.67	70.11	35.14	26.13	61.42	72.41	67.12	47.16	97.95	628.93
2023	65.76	39.82	52.64	73.51	36.77	27.81	64.73	76.02	68.03	49.82	102.89	657.82
2024	68.81	41.67	54.65	76.99	38.44	29.55	68.13	79.71	68.95	52.56	107.95	687.40
2025	71.92	43.56	56.71	80.56	40.15	31.32	71.61	83.49	69.88	55.37	113.13	717.69
ASY	**76.87**	**44.31**	**80.32**	**92.71**	**47.07**	**50.51**	**94.08**	**31.88**	**27.92**	**29.56**	**104.49**	**679.71**

The Baseline Per Capita Water Consumption, the Projected Population, and the Projected Basic Household

BASIC HOUSEHOLD SCENARIO

PER CAPITA BASELINE (L/C/D)

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Average**
2005	58.4	29.2	95.0	100.9	116.5	77.8	152.6	106.7	246.9	77.8	71.2	**103.0**
2010	150	150	150	150	150	150	175	150	250	150	150	**161.4**
2015	200	200	200	200	200	200	200	200	250	200	200	**204.5**
2020	225	225	225	225	225	225	225	225	250	225	225	**227.3**
2025	250	250	250	250	250	250	250	250	250	250	250	**250.0**

BASIC POPULATION

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**
2005	267,034	48,742	176,449	343,685	97,720	64,846	290,538	427,558	44,086	182,663	544,922	**2,488,244**
2010	311,071	56,781	205,548	400,363	113,835	75,540	338,451	498,067	51,356	212,787	634,786	**2,898,584**
2015	357,998	65,346	236,556	460,760	131,008	86,936	389,508	573,204	59,104	244,887	730,547	**3,335,852**
2020	407,021	74,295	268,949	523,855	148,947	98,841	442,846	651,696	67,197	278,421	830,586	**3,792,653**
2025	457,146	83,444	302,071	588,369	167,291	111,013	497,383	731,954	75,472	312,709	932,875	**4,259,728**

BASIC WATER DEMAND

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**
2005	5.69	0.52	6.12	12.66	4.16	1.84	16.18	16.65	3.97	5.19	14.16	**87.14**
2010	17.03	3.11	11.25	21.92	6.23	4.14	21.62	27.27	4.69	11.65	34.75	**163.66**
2015	26.13	4.77	17.27	33.64	9.56	6.35	28.43	41.84	5.39	17.88	53.33	**244.59**
2020	33.43	6.10	22.09	43.02	12.23	8.12	36.37	53.52	6.13	22.87	68.21	**312.08**
2025	41.71	7.61	27.56	53.69	15.27	10.13	45.39	66.79	6.89	28.53	85.12	**388.70**

The Projected Returnees and their Projected Household Water Demand by Governorates of the West Bank (2005-2025)

LOW SCENARIO

POPULATION (capita)

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**
2005	970	1,530	270	630	680	1,190	1,100	280	1,420	1,190	740	**10,000**
2010	7,316	11,539	2,036	4,751	5,128	8,975	8,296	2,112	10,709	8,975	5,581	**75,418**
2015	14,574	22,988	4,057	9,466	10,217	17,880	16,528	4,207	21,336	17,880	11,119	**150,251**
2020	22,695	35,797	6,317	14,740	15,910	27,842	25,736	6,551	33,223	27,842	17,313	**233,966**
2025	31,584	49,817	8,791	20,513	22,141	38,747	35,816	9,117	46,236	38,747	24,095	**325,604**

WATER DEMAND (MCM/Yr)

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**
2005	0.02	0.02	0.01	0.02	0.03	0.03	0.06	0.01	0.13	0.03	0.02	**0.39**
2010	0.40	0.63	0.11	0.26	0.28	0.49	0.53	0.12	0.98	0.49	0.31	**4.60**
2015	1.06	1.68	0.30	0.69	0.75	1.31	1.21	0.31	1.95	1.31	0.81	**11.36**
2020	1.86	2.94	0.52	1.21	1.31	2.29	2.11	0.54	3.03	2.29	1.42	**19.52**
2025	2.88	4.55	0.80	1.87	2.02	3.54	3.27	0.83	4.22	3.54	2.20	**29.71**

MEDIUM SCENARIO

POPULATION (capita)

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**
2005	1,940	3,060	540	1,260	1,360	2,380	2,200	560	2,840	2,380	1,480	**20,000**
2010	14,632	23,080	4,073	9,503	10,258	17,951	16,593	4,224	21,420	17,951	11,163	**150,847**
2015	29,150	45,979	8,114	18,932	20,435	35,761	33,057	8,414	42,673	35,761	22,238	**300,515**
2020	45,391	71,596	12,635	29,481	31,820	55,686	51,474	13,103	66,448	55,686	34,628	**467,947**
2025	63,169	99,637	17,583	41,027	44,283	77,496	71,635	18,234	92,474	77,496	48,191	**651,225**

WATER DEMAND (MCM/Yr)

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**
2002	0.04	0.03	0.02	0.05	0.06	0.07	0.12	0.02	0.26	0.07	0.04	**0.77**
2005	0.80	1.26	0.22	0.52	0.56	0.98	1.06	0.23	1.95	0.98	0.61	**9.19**
2010	2.13	3.36	0.59	1.38	1.49	2.61	2.41	0.61	3.89	2.61	1.62	**22.72**
2015	3.73	5.88	1.04	2.42	2.61	4.57	4.23	1.08	6.06	4.57	2.84	**39.04**
2020	5.76	9.09	1.60	3.74	4.04	7.07	6.54	1.66	8.44	7.07	4.40	**59.42**

HIGH SCENARIO

POPULATION (capita)

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**
2005	2,910	4,590	810	1,890	2,040	3,570	3,300	840	4,260	3,570	2,220	**30,000**
2010	21,948	34,619	6,109	14,255	15,386	26,926	24,890	6,336	32,130	26,926	16,744	**226,270**
2015	43,725	68,968	12,171	28,399	30,653	53,642	49,585	12,622	64,010	53,642	33,357	**450,773**
2020	68,086	107,394	18,952	44,221	47,731	83,528	77,211	19,654	99,673	83,528	51,942	**701,920**
2025	94,753	149,456	26,375	61,541	66,425	116,244	107,452	27,351	138,711	116,244	72,286	**976,838**

WATER DEMAND (MCM/Yr)

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**
2005	0.06	0.05	0.03	0.07	0.09	0.10	0.18	0.03	0.38	0.10	0.06	**1.16**
2010	1.20	1.90	0.33	0.78	0.84	1.47	1.59	0.35	2.93	1.47	0.92	**13.79**
2015	3.19	5.03	0.89	2.07	2.24	3.92	3.62	0.92	5.84	3.92	2.44	**34.07**
2020	5.59	8.82	1.56	3.63	3.92	6.86	6.34	1.61	9.10	6.86	4.27	**58.55**
2025	8.65	13.64	2.41	5.62	6.06	10.61	9.81	2.50	12.66	10.61	6.60	**89.14**

The Projected Visitors and their Projected Household Water Demand by Governorates of the West Bank (2005-2025)

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	Total		
2005	5,366	979	3,546	6,906	1,964	1,303	5,838	8,592	886	3,671	10,950	**50,000**	**POPULATION (capita)**	**LOW SCENARIO**
2010	10,732	1,959	7,091	13,812	3,927	2,606	11,676	17,183	1,772	7,341	21,900	**100,000**		
2015	16,098	2,938	10,637	20,719	5,891	3,909	17,515	25,775	2,658	11,012	32,850	**150,000**		
2020	21,464	3,918	14,183	27,625	7,855	5,212	23,353	34,366	3,544	14,682	43,800	**200,000**		
2025	26,830	4,897	17,728	34,531	9,818	6,515	29,191	42,958	4,429	18,353	54,750	**250,000**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	0.03	0.00	0.03	0.06	0.02	0.01	0.08	0.08	0.02	0.03	0.07	**0.44**	**WATER DEMAND (MCM/Yr)**	
2010	0.15	0.03	0.10	0.19	0.05	0.04	0.19	0.24	0.04	0.10	0.30	**1.41**		
2015	0.29	0.05	0.19	0.38	0.11	0.07	0.32	0.47	0.06	0.20	0.60	**2.75**		
2020	0.44	0.08	0.29	0.57	0.16	0.11	0.48	0.71	0.08	0.30	0.90	**4.11**		
2025	0.61	0.11	0.40	0.79	0.22	0.15	0.67	0.98	0.10	0.42	1.25	**5.70**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	10,732	1,959	7,091	13,812	3,927	2,606	11,676	17,183	1,772	7,341	21,900	**100,000**	**POPULATION (capita)**	**MEDIUM SCENARIO**
2010	21,464	3,918	14,183	27,625	7,855	5,212	23,353	34,366	3,544	14,682	43,800	**200,000**		
2015	32,195	5,877	21,274	41,437	11,782	7,818	35,029	51,549	5,315	22,023	65,700	**300,000**		
2020	42,927	7,836	28,365	55,249	15,709	10,424	46,706	68,733	7,087	29,364	87,599	**400,000**		
2025	53,659	9,795	35,457	69,062	19,636	13,031	58,382	85,916	8,859	36,705	109,499	**500,000**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	0.06	0.01	0.06	0.13	0.04	0.02	0.16	0.17	0.04	0.05	0.14	**0.88**	**WATER DEMAND (MCM/Yr)**	
2010	0.29	0.05	0.19	0.38	0.11	0.07	0.37	0.47	0.08	0.20	0.60	**2.82**		
2015	0.59	0.11	0.39	0.76	0.22	0.14	0.64	0.94	0.12	0.40	1.20	**5.50**		
2020	0.88	0.16	0.58	1.13	0.32	0.21	0.96	1.41	0.16	0.60	1.80	**8.23**		
2025	1.22	0.22	0.81	1.58	0.45	0.30	1.33	1.96	0.20	0.84	2.50	**11.41**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	16,098	2,938	10,637	20,719	5,891	3,909	17,515	25,775	2,658	11,012	32,850	**150,000**	**POPULATION (capita)**	**HIGH SCENARIO**
2010	21,464	3,918	14,183	27,625	7,855	5,212	23,353	34,366	3,544	14,682	43,800	**200,000**		
2015	26,830	4,897	17,728	34,531	9,818	6,515	29,191	42,958	4,429	18,353	54,750	**250,000**		
2020	53,659	9,795	35,457	69,062	19,636	13,031	58,382	85,916	8,859	36,705	109,499	**500,000**		
2025	80,489	14,692	53,185	103,593	29,454	19,546	87,573	128,873	13,288	55,058	164,249	**750,000**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	0.09	0.01	0.09	0.19	0.06	0.03	0.24	0.25	0.06	0.08	0.21	**1.31**	**WATER DEMAND (MCM/Yr)**	
2010	0.29	0.05	0.19	0.38	0.11	0.07	0.37	0.47	0.08	0.20	0.60	**2.82**		
2015	0.49	0.09	0.32	0.63	0.18	0.12	0.53	0.78	0.10	0.33	1.00	**4.58**		
2020	1.10	0.20	0.73	1.42	0.40	0.27	1.20	1.76	0.20	0.75	2.25	**10.29**		
2025	1.84	0.34	1.21	2.36	0.67	0.45	2.00	2.94	0.30	1.26	3.75	**17.11**		

The Overall Projected Household Water Demand by Governorates of the West Bank (2005-2025)

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	Total		
2005	5.74	0.54	6.16	12.74	4.21	1.88	16.33	16.75	4.12	5.25	14.25	**87.96**	**WATER DEMAND (MCM/Yr)**	**LOW SCENARIO**
2010	17.58	3.77	11.46	22.37	6.57	4.66	22.33	27.62	5.70	12.24	35.36	**169.67**		
2015	27.49	6.50	17.76	34.70	10.42	7.72	29.95	42.62	7.40	19.38	54.74	**258.70**		
2020	35.73	9.12	22.90	44.80	13.70	10.51	38.96	54.76	9.24	25.45	70.53	**335.72**		
2025	45.21	12.27	28.77	56.35	17.51	13.81	49.32	68.60	11.21	32.49	88.57	**424.11**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	5.79	0.56	6.20	12.83	4.25	1.93	16.47	16.84	4.27	5.31	14.34	**88.79**	**WATER DEMAND (MCM/Yr)**	**MEDIUM SCENARIO**
2010	18.13	4.43	11.67	22.82	6.90	5.19	23.05	27.97	6.72	12.83	35.97	**175.68**		
2015	28.85	8.23	18.25	35.77	11.27	9.10	31.48	43.40	9.41	20.89	56.15	**272.80**		
2020	38.04	12.14	23.71	46.58	15.17	12.90	41.55	56.01	12.36	28.04	72.85	**359.35**		
2025	48.70	16.93	29.98	59.01	19.75	17.50	53.25	70.41	15.53	36.44	92.02	**459.53**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	5.84	0.58	6.24	12.92	4.30	1.97	16.61	16.94	4.42	5.37	14.43	**89.61**	**WATER DEMAND (MCM/Yr)**	**HIGH SCENARIO**
2010	18.53	5.06	11.78	23.08	7.18	5.68	23.58	28.09	7.70	13.33	36.27	**180.27**		
2015	29.82	9.89	18.48	36.34	11.98	10.38	32.58	43.55	11.34	22.13	56.76	**283.24**		
2020	40.12	15.12	24.37	48.07	16.56	15.24	43.91	56.90	15.43	30.48	74.73	**380.93**		
2025	52.20	21.59	31.18	61.67	22.00	21.18	57.19	72.23	19.85	40.40	95.47	**494.95**		

The Projected Irrigated Areas and their Projected Irrigation Water Demand by Governorates of the West Bank (2005-2025)

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	Total		
2005	1,196	1,100	1,921	433	1,068	17	91	19	4,466	86	103	**10,500**	AREA (hectare)	LOW SCENARIO
2010	1,550	2,088	2,250	973	1,350	267	371	269	7,612	370	400	**17,500**		
2015	1,800	2,338	2,500	1,223	1,600	517	621	519	7,612	620	650	**20,000**		
2020	2,050	2,588	2,750	1,473	1,850	767	871	769	7,612	870	900	**22,500**		
2025	2,300	2,838	3,000	1,723	2,100	1,017	1,121	1,019	7,612	1,120	1,150	**25,000**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	1,196	1,100	1,921	433	1,068	17	91	19	4,466	86	103	**10,500**	AREA (hectare)	MEDIUM SCENARIO
2010	1,650	2,188	2,350	1,073	1,450	367	471	369	7,612	470	500	**18,500**		
2015	1,950	2,488	2,650	1,373	1,750	667	771	669	7,612	770	800	**21,500**		
2020	2,250	2,788	2,950	1,673	2,050	967	1,071	969	7,612	1,070	1,100	**24,500**		
2025	2,550	3,088	3,250	1,973	2,350	1,267	1,371	1,269	7,612	1,370	1,400	**27,500**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	1,196	1,100	1,921	433	1,068	17	91	19	4,466	86	103	**10,500**	AREA (hectare)	HIGH SCENARIO
2010	1,700	2,238	2,400	1,123	1,500	417	521	419	7,612	520	550	**19,000**		
2015	2,050	2,588	2,750	1,473	1,850	767	871	769	7,612	870	900	**22,500**		
2020	2,425	2,963	3,125	1,848	2,225	1,142	1,246	1,144	7,612	1,245	1,275	**26,250**		
2025	2,800	3,338	3,500	2,223	2,600	1,517	1,621	1,519	7,612	1,620	1,650	**30,000**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	**75.00**	WATER DEMAND (MCM/Yr)	LOW SCENARIO
2010	10.08	13.57	14.63	6.32	8.78	1.74	2.41	1.75	49.48	2.41	2.60	**113.75**		
2015	11.70	15.20	16.25	7.95	10.40	3.36	4.04	3.37	49.48	4.03	4.23	**130.00**		
2020	13.33	16.82	17.88	9.57	12.03	4.99	5.66	5.00	49.48	5.66	5.85	**146.25**		
2025	14.95	18.45	19.50	11.20	13.65	6.61	7.29	6.62	49.48	7.28	7.48	**162.50**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	**75.00**	WATER DEMAND (MCM/Yr)	MEDIUM SCENARIO
2010	10.73	14.22	15.28	6.97	9.43	2.39	3.06	2.40	49.48	3.06	3.25	**120.25**		
2015	12.68	16.17	17.23	8.92	11.38	4.34	5.01	4.35	49.48	5.01	5.20	**139.75**		
2020	14.63	18.12	19.18	10.87	13.33	6.29	6.96	6.30	49.48	6.96	7.15	**159.25**		
2025	16.58	20.07	21.13	12.82	15.28	8.24	8.91	8.25	49.48	8.91	9.10	**178.75**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	5.48	9.71	9.76	3.33	6.63	0.13	0.71	0.15	37.82	0.56	0.71	**75.00**	WATER DEMAND (MCM/Yr)	HIGH SCENARIO
2010	11.05	14.55	15.60	7.30	9.75	2.71	3.39	2.72	49.48	3.38	3.58	**123.50**		
2015	13.33	16.82	17.88	9.57	12.03	4.99	5.66	5.00	49.48	5.66	5.85	**146.25**		
2020	15.76	19.26	20.31	12.01	14.46	7.42	8.10	7.44	49.48	8.09	8.29	**170.63**		
2025	18.20	21.70	22.75	14.45	16.90	9.86	10.54	9.87	49.48	10.53	10.73	**195.00**		

The Projected Industrial Water Demand by Governorates of the West Bank (2005-2025)

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	Total		
2005	0.58	0.10	1.05	1.67	0.47	0.10	1.46	0.52	0.21	1.67	2.61	**10.46**	WATER DEMAND (MCM/Yr)	LOW SCENARIO
2010	0.67	0.12	1.21	1.94	0.55	0.12	1.70	0.61	0.24	1.94	3.03	**12.12**		
2015	0.77	0.14	1.41	2.25	0.63	0.14	1.97	0.70	0.28	2.25	3.51	**14.05**		
2020	0.90	0.16	1.63	2.61	0.73	0.16	2.28	0.81	0.33	2.61	4.07	**16.29**		
2025	1.04	0.19	1.89	3.02	0.85	0.19	2.64	0.94	0.38	3.02	4.72	**18.89**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	0.58	0.10	1.05	1.67	0.47	0.10	1.46	0.52	0.21	1.67	2.61	**10.46**	WATER DEMAND (MCM/Yr)	MEDIUM SCENARIO
2010	0.70	0.13	1.27	2.04	0.57	0.13	1.78	0.64	0.25	2.04	3.18	**12.72**		
2015	0.85	0.15	1.55	2.48	0.70	0.15	2.17	0.77	0.31	2.48	3.87	**15.48**		
2020	1.04	0.19	1.88	3.01	0.85	0.19	2.64	0.94	0.38	3.01	4.71	**18.83**		
2025	1.26	0.23	2.29	3.67	1.03	0.23	3.21	1.15	0.46	3.67	5.73	**22.91**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	0.58	0.10	1.05	1.67	0.47	0.10	1.46	0.52	0.21	1.67	2.61	**10.46**	WATER DEMAND (MCM/Yr)	HIGH SCENARIO
2010	0.73	0.13	1.33	2.14	0.60	0.13	1.87	0.67	0.27	2.14	3.34	**13.35**		
2015	0.94	0.17	1.70	2.73	0.77	0.17	2.38	0.85	0.34	2.73	4.26	**17.03**		
2020	1.20	0.22	2.17	3.48	0.98	0.22	3.04	1.09	0.43	3.48	5.43	**21.74**		
2025	1.53	0.28	2.77	4.44	1.25	0.28	3.88	1.39	0.55	4.44	6.94	**27.74**		

The Overall Projected Water Demand for all Purposes by Governorates of the West Bank (2005-2025)

Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	11.80	10.36	16.96	17.75	11.31	2.12	18.50	17.42	42.15	7.48	17.58	**173.42**	**WATER DEMAND (MCM/Yr)**	**LOW SCENARIO**
2010	28.32	17.46	27.30	30.63	15.89	6.52	26.44	29.97	55.42	16.59	40.99	**295.54**		
2015	39.96	21.84	35.41	44.90	21.45	11.22	35.96	46.70	57.16	25.66	62.48	**402.75**		
2020	49.95	26.11	42.40	56.98	26.46	15.66	46.90	60.58	59.05	33.71	80.46	**498.26**		
2025	61.20	30.91	50.16	70.57	32.01	20.61	59.25	76.17	61.06	42.79	100.77	**605.50**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	11.85	10.38	17.00	17.83	11.36	2.16	18.64	17.51	42.30	7.54	17.67	**174.24**	**WATER DEMAND (MCM/Yr)**	**MEDIUM SCENARIO**
2010	29.55	18.78	28.22	31.83	16.90	7.70	27.89	31.01	56.45	17.92	42.40	**308.65**		
2015	42.38	24.56	37.02	47.17	23.34	13.59	38.66	48.52	59.20	28.37	65.22	**428.03**		
2020	53.70	30.45	44.77	60.46	29.34	19.38	51.15	63.25	62.21	38.01	84.71	**537.43**		
2025	66.54	37.23	53.39	75.50	36.06	25.96	65.37	79.81	65.46	49.01	106.85	**661.19**		
Year	Jenin	Tubas	Tulkarm	Nablus	Qalqiliya	Salfit	Ramallah	Jerusalem	Jericho	Bethlehem	Hebron	**Total**		
2005	11.90	10.40	17.04	17.92	11.41	2.21	18.78	17.61	42.45	7.60	17.76	**175.07**	**WATER DEMAND (MCM/Yr)**	**HIGH SCENARIO**
2010	30.31	19.74	28.72	32.51	17.53	8.53	28.84	31.48	57.44	18.84	43.18	**317.12**		
2015	44.08	26.89	38.06	48.64	24.77	15.54	40.62	49.40	61.15	30.51	66.87	**446.53**		
2020	57.08	34.60	46.86	63.56	32.00	22.88	55.05	65.42	65.34	42.05	88.45	**573.29**		
2025	71.92	43.56	56.71	80.56	40.15	31.32	71.61	83.49	69.88	55.37	113.13	**717.69**		