



Faculty of Graduate Studies

M.Sc. Thesis in Environmental and Water Engineering

**Sustainability of Artificial Recharge Techniques In
Al-Qilt Catchment Area – Jericho District - Palestine**

Submitted By:

Ala' R. Masri

(Reg. # 1165397)

Supervisor:

Dr. Marwan Ghanem

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**Sustainability of Artificial Recharge Techniques In
Al-Qilt Catchment Area – Jericho District – Palestine**

الاستدامة المتكاملة لتقنيات الحقن الصناعي للحوض الجوفي في منطقة واد القلط

محافظة أريحا - فلسطين

Submitted by: Ala' R. Masri

(Reg. # 1165397)

This thesis was prepared under the main supervision of Dr. Marwan Ghanem and has been approved by all members of examination committee.

Examination committee:

Dr. Marwan Ghanem


Supervisor

Prof. Dr. Rashed Al-Sa'ed

Member

Dr. Ghassan Albarghouti

Member



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List of Abbreviations

ARIJ: Applied Research Institute / Jerusalem.

°C: degrees Centigrade.

CN: Curve Number.

DEM: Digital Elevation Model.

DWL: Dynamic Water Level.

GAR: Groundwater Artificial Recharge.

GIS: Geographic Information System.

HEC: Hydrological Engineering Centre.

HMS: Hydrological Modelling Software.

IWRM: Integrated Water Resources Management.

Km: Kilometre.

Masl: meters above sea level.

Mbsl: meters below sea level.

Mcm: Million Cubic Meter.

MEG: Millennium Engineering Group.

MoA: Ministry of Agriculture.

NRC: National Resources Conservations.

PCBS: Palestinian Central Bureau of Statistics

PMD: Palestinian Metrological Department.

PWA: Palestinian Water Authority.

SWL: Static Water Level.

TDS: Total Dissolved Solids.

WMS: Watershed Management System.

Dedication

To My Parents spirits,

To my beloved wife Shatha,

To my lovely kids: Sama, Abood, Maryam, and Ali

To My Brothers and Sisters,

To All My Friends,

For their Help, Support, and Encouragement

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Abstract

Surface and ground water in Palestine like many Middle East countries is very limited, so special interest should be given to develop the water resources and develop these resources in order to enhance the living of the Palestinians.

There is a huge amounts of water in Al-Qilt catchment (about 67000 m³/hr as a peak discharge according to our hydrological model) and this amount of water is discharged without any beneficial use except for the water that used for the water that used in Aqbat Jaber Refugee Camp after making some treatments using sand filtration.

Both Palestinian Water Authority and Ministry of Agriculture are concerned about Al-Qilt catchment and there are few studies conducted to construct large projects for artificial recharge in Al-Qilt catchment, including dam construction and also pools for collecting water. These projects are used either to collect water in the winter season or use it when needed and also to improve the quality of water and reduce the salinity.

In order to best use of integrated water resources management and to study the potentiality of artificial recharge in Al-Qilt catchment, a hydrological model was established, this HEC-HMS model is used for the best use of water resources in the catchment and it also study the metrological parameters especially the rainfall and evapotranspiration during the season.

It is highly recommended to install more divers and instruments to measure the flood of the tributaries in the catchment in order to enhance the model simulation, even though the model shows very good results but optimization will occur if we have more stations and instruments to measure the flood.

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الخلاصة

ان مصادر المياه في فلسطين السطحية منها والجوفية حالها حال العديد من دول الشرق الأوسط محدودة للغاية ، لذلك يجب إيلاء اهتمام خاص لتنمية هذه الموارد المائية وتطوير هذه الموارد من أجل تحسين وتطوير المعيشة للشعب الفلسطيني.

تحتوي منطقة مسقط المياه في القلط على كميات كبيرة من المياه ولديها عدد من الينابيع غير الموسمية والتي يحدث جريانها طوال العام ، لكن لسوء الحظ تتدفق كمية كبيرة من المياه عبر الوديان دون أي استخدام تقريبا باستثناء المياه التي يتم الاستفادة منها لمخيم عقبة جبر بعد عمل تنقية باستخدام الرمل.

يوجد هناك عمل مشترك بين سلطة المياه الفلسطينية ووزارة الزراعة لعمل مشاريع للحصاد المائي في منطقة واد القلط سواء كانت مشروع بناء سد تجميعي او انشاء برك مياه زراعية تستعمل لتخزين كميات المياه الجارية في فصل الشتاء واستعمالها لري المزروعات او لعمل حقن صناعي لتحسن جودة المياه وتخفيف الملوحة.

لتطبيق مبدء الادارة المتكاملة للمصادر المائية وكذلك لدراسة وضع الحقن الصناعي للحوض الجوفي في منطقة واد القلط تم في هذا البحث انشاء موديل محاكاة لدراسة المنطقة باستخدام برنامج HEC-HMS وهذا البرنامج قد اثبت فعاليته في العديد من المناطق لانه ايضا يأخذ العوامل المناخية من تبخر ونتح وهطول للأمطار بعين الاعتبار.

ولزيادة دقة النموذج الذي جرى عمله يجب القيام بتثبيت أجهزة قياس للاودية والأمطار والفيضانات بحيث تعطي قراءات دقيقة يمكن تدخيلها الى النموذج للحصول على أفضل محاكاة لدراسة مناطق التساقط – رغم جودة المعومات التي تم الحصول عليها من هذا النموذج – الا انه بحاجة الى تحسين اكثر وذلك للتخفيف من اثار الفيضانات والتحذير من الكوارث قبل وقوعها قدر الإمكان.

Chapter One

1. Introduction

1.1 Background

Since ancient times the water was considered to be the most basic elements to sustain the life on earth, Allah has made this blessing basis of creation of all living beings when he says Almighty (and 'We' made from the water every living thing) Al Anbyaa "The Prophets": 30.

In Palestine and through the ages the water –either surface or ground water- played an important role for establishing the life and building up the Palestinian community, this water is considered to be the vital resource that our fathers and grandfathers cover their basic needs for any use of water. The water played the historical rule in the development of social and industrial life for the whole community; this issue helped the Palestinians to stay in their lands like the old olive trees.

It is known that the Israeli was occupied the West Bank and Gaza Strip in 1967, where the main reason for the suffering of the Palestinian people is the significant shortfall in the amount of water that is needed for their necessary usage.

Also Israel controls over all the water resources, and digging deep wells inside the West Bank and Gaza Strip and along the Green Line from the western and northern sides of the West Bank, as well as on the eastern border of the Gaza Strip.

In order to pull out our resources of underground water and transfer it to the Israeli settlements and inside the Green Line, and preventing Palestinian farmers from reaching the Jordan River basin, closing the agricultural areas adjacent to the Jordan River, with a weak arguments and pretexts of security, all of these practices and procedures enabled the Israelis to control, plunder, and exploit most of our groundwater and surface water and deprive us of our rights of using the water.

Therefore, the water sector in Palestine is facing an acute and accumulated problem in the lack of water in order to meet the needs of domestic, industrial, agricultural, etc., and getting this problem greater, year after year, as a result of the increased population, and declining rates of rainfall, and the continuation of the Israelis in using and plundering our water.

1.2 Problem Statement

Palestine like many other areas of the Mediterranean Region is experiencing an increase in urban activities, and also Palestine is suffering from water deterioration in natural aquatic ecosystems and minimal development in water resources. This problem elevates when people discharging their septic tanks using trucks into Wadis at arbitrary places. Furthermore, this discharge mixes with urban runoff during the winter season. This makes it difficult to capture additional storm-water as runoff which is estimated to be 2.5 Mcm/y at Al-Qilt catchment (PWA, 2009).

Al-Qilt catchment area contains number of springs (Fara, Fawwar, and Ras Al-Qilt) and there is a significant quantity of water that is flowing, and these springs could be considered as the main source of water for the catchment, this make it difficult to have or guaranty potable water at downstream from the springs, also the wells are shallow with water table ranging from 20-188 m in depth, so most of the pumping wells are from the upper aquifer and fed from rainfall (PECDAR, 2001).

For integrated management of water resources (IWRM) and to benefit from the flowing water (including both rainfall and springs discharge) in the winter time and to increase the productivity of the downstream wells, the methodologies for artificial recharge could be developed.

This study will emphasize on the suitable methodology for choosing the best and appropriate places for artificial recharge.

Al-Qilt catchment is a big basin and rich of water; this basin is extended from the recharge area to the discharge area, and contains a complex cascade system of springs. There is a large amount of water that is flowing to the discharge area without any benefits.

There are many obstacles either from the Israeli side or other technical obstacles due to the lack of appropriate techniques, but recently the technical obstacles problems were minimized by using the modern methods for rain harvesting. These methods such as using the GIS make it feasible and easier for decision maker to decide and build their models to choose the best water harvesting method for artificial recharge.

1.3 Study Objectives

The current water supply in Jericho area described as inadequate and insufficient for future development mainly for the agricultural, municipal and industrial sectors. Thus, Palestinian Water Authority needs a lot of efforts from the researcher targeting Jericho and the eastern aquifer to increase the quantity of water and to decrease the salinity at downstream (Samhan, 2013).

The main objective of this research study is to determine the performance of artificial recharge methods in Wadi Al-Qilt depending on such criteria as slope, land use, geology, runoff, distribution of wells, water quality, rainfall, evapotranspiration, the water level in summer and geomorphology. This will be used for determining the best practical methodology for artificial recharge management, and their proposed appropriate site.

1.4 Research Methodology

The methodology for this research depends on some criteria using layers prepared through GIS, slope, land use, geology, and runoff, distribution of wells, water quality, and geomorphology. And the overall research methodology consists of many stages including:

- 1) Collection of data: Related data will be obtained from field visits, reports and from previous studies. The collected data including geological maps, topographical maps, geological cross-sections, climatic data (rainfall, temperature and evapotranspiration), the distribution of wells and springs and discharge amounts, water quality characteristics, as well as the infiltration capacity values.
- 2) Field work: Field visits will be conducted during the whole year of 2018 in order to study the geographical characteristics of the catchment.
- 3) Maps: Using GIS to determine the proper locations for artificial recharge based on the following criteria: slope, infiltration capacities of the sediments, runoff, land use, depth to groundwater, and distribution of wells in the study area.
- 4) Modeling: Using the Watershed Modeling System (WMS) and Hydrological Engineering System (HEC-HMS) to develop a surface hydrological model for Al-Qilt catchment area. WMS is a comprehensive graphical modeling environment for all phases of watershed hydrology and hydraulics. WMS includes powerful tools to automate modeling processes such as automated basin delineation, geometric parameter calculations; GIS overlay computations CN, rainfall depth, roughness coefficients, cross-section, and the amount of water extraction from terrain data etc., (Scientific Software Group, 2015).

1.5 Research Questions

The research questions are as the following:

- What are the best methodologies that will be used for artificial recharge in Al-Qilt catchment area?
- What is the amount of the discharged volume of the water runoff?
- What are the changes that may occur in the water balance components?

Chapter Two

2. Literature Review

2.1 General Background

Artificial recharge system design considerations involve hydrogeological, source of water, operation-maintenance, legal and regulatory issues. The factors that should be taken into account for locating, designing and operating artificial recharge projects are summarized by Banks et al., (1954).

Selecting a suitable location with respect to geology, specifying soil textures in recharge area, acquisition of sufficient lands, silt control, maintenance of percolation rates, quality of recharged water, degree of necessary prior treatment can be given as some examples. From hydrogeological point of view, type of the aquifer, permeability of geologic formations overlying the aquifer, characteristics of unsaturated zone and heterogeneity are the factors that affect recharge rate and design of artificial recharge system (Bouwer, 2002).

In Al-Qilt catchment, there were few studies dealing with artificial recharge (CH2MHill, 1999) conducted a survey and monitored the Eastern basin of the West Bank. The main objective for their survey was to understand the wastewater potential and expected pollution to local resources in the Eastern basin; they monitored and analysed the following parameters: Ammonia, Potassium, Nitrates, Chloride and TDS, Antimony, Lead, Selenium, Thallium, Iron, Beryllium, Mercury, Cadmium and Arsenic. Results revealed that there were incremental of pollutants levels in the springs downstream which are used for domestic purposes (CH2MHill, 1999)

The groundwater artificial recharge (GAR) is a process by which excess water is purposely directed into the ground to rebuild or augment groundwater supplies (Mahdavi, 2013). It is

accomplished by one of three methods: spreading on the surface, injecting water through recharge wells, and by altering natural conditions to increase infiltration (NRC, 1994).

Recharge Artificial groundwater recharge systems are engineered systems where surface water is put on or in the ground for infiltration and subsequent movement to aquifers to augment groundwater resources.

2.2 Reasons for using artificial recharge

The objectives of artificial recharge are to reduce land subsidence, to store water, to improve the quality of the water through soil-aquifer treatment or geo-purification, and to use the aquifer as water conveyance systems (Bouwer, 2002).

According to (Raju, et al., 1994) artificial recharge can be used for a reasons such as applying the integrated water resources management (IWRM), monitoring the short and long term and seasonal storage and recovery of water.

Also the emergency storage or strategic water reserve, and also in this study, the wells field production and restoration of groundwater levels leading to the reduction of pumping cost and stopping or reducing the rate of land surface subsidence. And finally it can also improve the groundwater quality to agricultural or municipal standards.

2.3 Methods for artificial recharge

In general there are three methods for artificial recharge; direct, indirect, and a combination of direct and indirect methods.

2.3.1 Direct Methods

Direct methods can be divided into surface recharge techniques and subsurface recharge techniques (ASCE, 2001).

In surface recharge, water moves from the land surface to the aquifer by means of infiltration through the soil. The surface is usually excavated and water is added to spreading basins, ditches,

pits, and shafts and thus is allowed to infiltrate. Surface infiltration consists of in-channel and off-channel facilities (Bouwer, 2002).

2.3.1.1 Surface techniques

In-channel systems consist of dams and weirs, canals, finger dikes, terrace or other structures in the stream bed or flood plain to impound and spread the water over as large a wetted area as possible, increasing the infiltration volume. Off-channel systems consist of recharge basins, pits, ponds and ditches specially constructed by excavation, construction of berms (or both) or by using of old gravel pits, borrow areas, or similar excavations. This method involves surface spreading of water in excavated basins. The amount of water entering the aquifer depends on three factors (Bouwer, 2002): the infiltration rate, the percolation rate, and the aquifer's capacity for horizontal water movement. These systems are depicted in Figure 2.1.

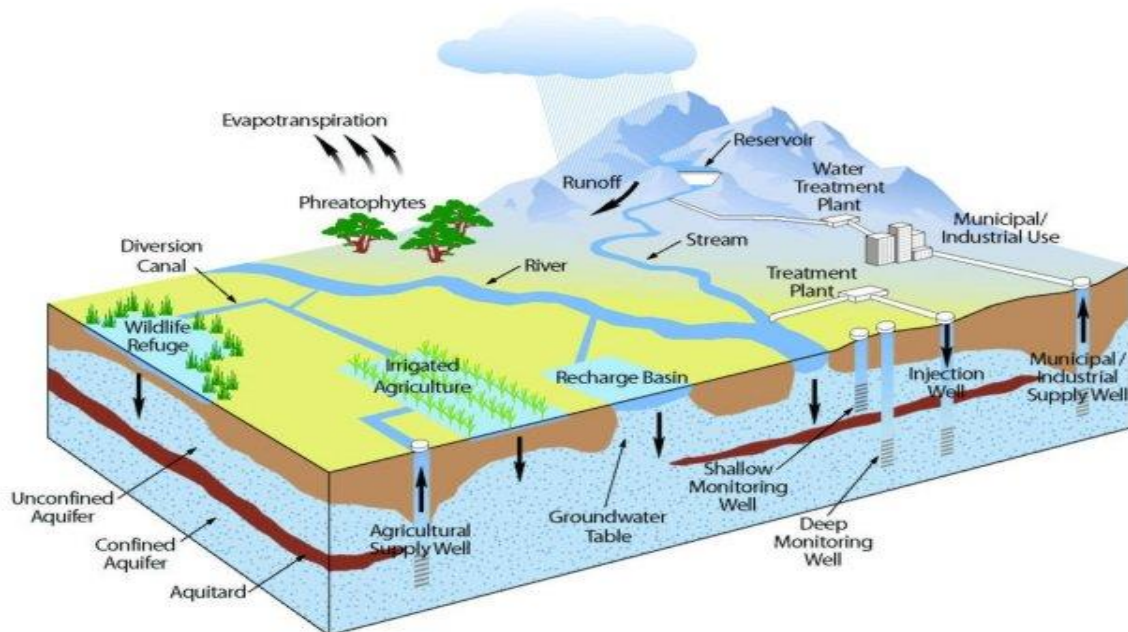


Figure 2.1: Hydrological Cycle (livpure.com)

2.3.1.2 Subsurface techniques (Injection wells)

Injection techniques are used as an alternative to surface spreading operations when a zone with low permeability, within the unsaturated zone, impedes the recharge of the water to a designed aquifer, Figure 2.2 clarifies the gravity injection wells or bores.

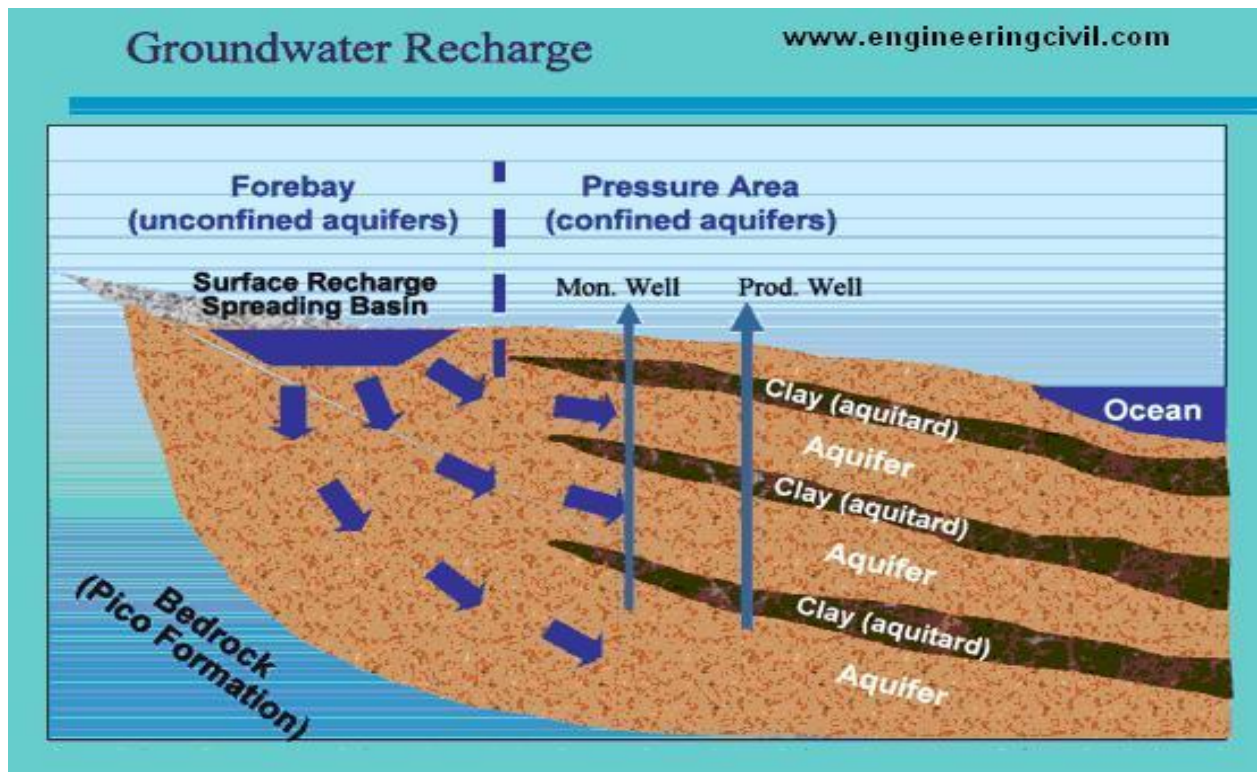


Figure 2.2: Infiltration basins (Jemal, 2006)

2.3.2 Indirect methods

Indirect methods include installing groundwater pumping facilities near connected surface water bodies to lower groundwater levels and induce infiltration elsewhere in the drainage basin. Indirect methods include modifying aquifers to enhance groundwater reserves.

2.3.3 Combination systems

This mixed recharge system is the combination of an infiltration basin and recharge wells. The advantage of this system is that the water has been pre-filtered through the soil and the perched

groundwater zone so that its clogging potential is significantly reduced. In this way the risk of aquifer obstruction is reduced (Raju, et al., 1994).

2.4 Factors determining the proper location of artificial recharge

Recharge Factors like topography, geology, geomorphology, pedology, surface and sub-surface hydrology, vegetation cover, social and economic conditions, and environmental impacts of the projects should be considered when selecting an area for flood spreading and artificial recharge (Jafar, et al., 2004).

2.5 Appropriate site for artificial recharge

(Hammouri, et al., 2013) used Slugger-Dol model to determine the appropriate sites for artificial recharge in the Jordan valley, eight parameters were used as thematic layers prepared by GIS, slope, land use, geology, runoff, distribution of wells, water quality, the water level in summer and geomorphology. All parameters are collected and integrated by GIS model builder.

The use of geology and type of rocks are important parameters that effect on the water movement, in addition, the presence of land uses (covers) have high influence on the behaviour of water flow on terrain surfaces and the recharge process to determine the appropriate location for artificial recharge.

2.6 Previous Studies in Al-Qilt catchment

There are few researches studies Wadi Al-Qilt such as (Thaher, 2015) master thesis's and she made 'The weighted overlay method' in order to determine the best locations for artificial recharge in Al-Qilt catchment using parameters of the slope, runoff, infiltration capacity, land use, density of wells and the depth of the ground water table. Results show that 91% of the total area is moderately suitable for artificial groundwater recharge by floodwater with a total area of 159 km². If treated wastewater is used as source for artificial recharge 66% of the total area is moderately suitable for artificial recharge with a total area of 115 km². The yearly average

recharge amounts are calculated to be 100 mm/year in the upper part of the catchment and drops to about 10 mm/year in its lower part. Based on recharge values and its good conditions indicated that most of the actual flood runoff which flows to the Jordan valley can be artificially recharged within Al-Qilt catchment.

(Ghanem, 2002) stated that the Lower Jordan River Valley is a place of extreme water scarcity and constitutes an overexploited closed river basin. No surface runoff currently leaves the area and the water level of the Dead Sea, as the final sink, has already dropped by more than 20 m over the past fifty years as a result. This demonstrates, that even apart from water quality considerations, total inflows into the system do not match outflows, resulting in a continuous depletion of the available storage, i.e. all available water is already utilised. The only means of providing additional volumes of water to the area are water imports or reduction of evaporation from open water bodies or reduction of evapotranspiration from irrigated agriculture. Wastewater reuse and desalinisation would increase the amount of water fit for human demand but not affect the water balance in total.

(Samhan, 2013) stated that there is growing concern over the accumulation of heavy and trace metals in sediments due to industrial and urban development; this will increase the dependence on anthropogenic pollutants due to discharge of raw wastewater. This study answered two questions at the same time: the first question, what anthropogenic pollutants are detected in Al-Qilt catchment? The second question: was the water used for domestic purposes at downstream safe for drinking? This study aimed to understand the occurrence, destiny, transport and mobility of these anthropogenic pollutants in order to identify the contaminated areas by using trace metals in sediment, wastewater and soil from Al-Qilt.

(Daghrah, 2009) took a number of twenty water samples from the five springs in Al Qilt drainage basin were analysed to determine their quality. Chemical, physical and biological

studies were conducted between November (2004) and March (2007) in Wadi Al Qilt drainage basin. Based on physical parameters, the water flowing from the springs is considered as good source of drinking water. According to the results of SAR and TH, the water is classified as suitable source for domestic, industrial and agricultural purposes. Results showed moderate levels of major ion and higher concentrations of lead and cadmium than allowable for drinking water in three spring samples, whereas, 47% of the samples were contaminated with fecal coliforms, which indicate the infiltration of pollutants in the recharge area of the springs.

2.7 Water quality effects on an artificial recharge system

Water used for in- and off-channel recharge systems should be of adequate quality to prevent under clogging of the infiltrating surface by deposition and accumulation of suspended solids (sediment, algae, and sludge).

The formation of bio-films and biomass on and in the soil, by precipitation of calcium carbonate or other salts on and in the soil, and by formation of gases that stays entrapped in the soil. All these processes block the pores and reduce the hydraulic conductivity. Gases sometimes also accumulate under the clogging layer, where they form a vapour barrier to downward flow. One source of these gases is dissolved air in the infiltrated water (Bouwer, 2002).

2.8 Pre-treatment of sewage effluent used in artificial recharge

If the recharge is via basins or other surface infiltration facilities, any sewage effluent is typically first given primary and secondary treatment and disinfection with chlorine (NRC, 1994). Some projects use tertiary effluent, where the sewage after secondary treatment is filtered through sand or another granular medium and then chlorinated or otherwise disinfected.

Tertiary treatment consists of sand filtration and disinfection; while the advanced treatment refers to all other treatment steps, such as lime precipitation; nitrification-de-nitrification; activated carbon filtration; and membrane filtration such as reverse osmosis. Often, water-quality

improvement is the main objective of recharge with sewage effluent. For this reason, systems are usually no longer called recharge systems but instead they are called soil-aquifer treatment systems or geo-purification systems (Bouwer, 2002).

2.9 The implementation of artificial groundwater recharge worldwide

A global overview of appropriate areas for groundwater recharge techniques has been developed. The idea of defining regions on a global scale has been developed from the realization that digital world maps with sufficient detail are now available.

The identification was executed for areas of South and Central America, Africa and Asia, using digital maps of geology, soils, climate, population and economic development, and by making overlays of the related spatial themes. The availability and quality of such digital maps has improved markedly in recent years. It should be realized that the areas identified only give a preliminary indication on a global scale of the suitability for artificial recharge. The analysis of local conditions remains necessary to determine actual suitable areas (Gale, I, et al., 2002).

2.10 Artificial recharge in the developing countries

Feasibility studies have been carried out around the year 1996 to find out whether conditions in Jordan are suitable to introduce artificial recharge schemes using surface runoff (rain) water. One of those studies was carried out by the Ministry of Water and Irrigation in cooperation with USAID (Chehata et al., 1997). The study focused on the Wadi Madoneh and the Wadi Butum areas, located northeast of Amman/ Jordan. Upon completion of the study, the conclusion was drawn that Wadi Madoneh offered the best scope for the implementation of artificial recharge. The artificial recharge scheme at that has been implemented. Studies were done to assess the available amounts of storm water for infiltration, to assess water balances and to determine locations for the artificial recharge infrastructure (Al-Qaisi, 2008).

In 2007, the actual infrastructure was built, consisting of four dams to infiltrate the Madoneh area. Another example of the application of synthetic recharge technology was in Saudi Arabia in the late 1950s and early 1960s, in the United Arab Emirates and Oman in the early 1980s. Dams were built in river valleys to retain water for the purpose of artificial recharge of groundwater reserves by facilitating water infiltration into the soil, rather than flowing into the sea or evaporating in desert areas. It is estimated, for example, that some 120 million cubic meters of water are lost or evaporated in Oman, a very large loss of water in the dry environmental conditions of the country. Large projects have been implemented in Qatar, including the injection of surface water stored for recharging aquifers. There are several experiments to test the efficiency and feasibility of groundwater recharge technology for the environmental conditions prevailing in Syria and Lebanon (UNESCO-IHE, 2007).

Chapter Three

3. Study Area

3.1 Location of the Study Area

AL-Qilt catchment is part of the West Bank which located in the eastern basin covering about 174 Km² (Daghrah, 2005).

The water drainage system in Al-Qilt catchment start from Ramallah and Jerusalem mountains (Central Mountains) moving toward the Jordan river - Dead Sea Sub-basin(Rofe and Raffety, 1963). Al-Qilt catchment is characterized as a steep area which varies in elevation from 900 m.a.s.l in the western part to - 400 m in the eastern part (Aed Rabo et al., 1999).

3.2 Tributaries of Al-Qilt

The total distance of Al-Qilt wadi with its tributaries is in the range of 45-50 km. Al-Qilt catchment is characterized by a steep relief and varies in elevation that range from 800 m.a.s.l. at the western part to -300 m.b.s.l. at the eastern part. Furthermore, Wadi Al-Qilt is characterized by relatively steep slopes at Ramallah (west) running downstream to Jericho (east) and it becomes flat when passing Jericho.

AL-Qilt catchment has a lot of tributaries such as Wadi Al-Ein (7.5 km), Wadi Mukhmas (9 km), Qalandiah (2 km) and Stone Cut (2 km), all of these Wadis were located on the left side of Al-Qilt catchment Figure 3.1.

Al-Qilt catchment has three major springs, these springs are:

- Fawwar: it is seasonal spring that emerges down of Sweanit wadi at an elevation of 75 masl.
- Al-Qilt: it is emerges 4.5 km downstream of Fawwar spring at an elevation of 10 m.a.s.l. Its flow has little variation from winter to summer.

- Fara spring which are used by the Israeli colonies for recreation (as swimming pools), thus there is no water available to the wadi.

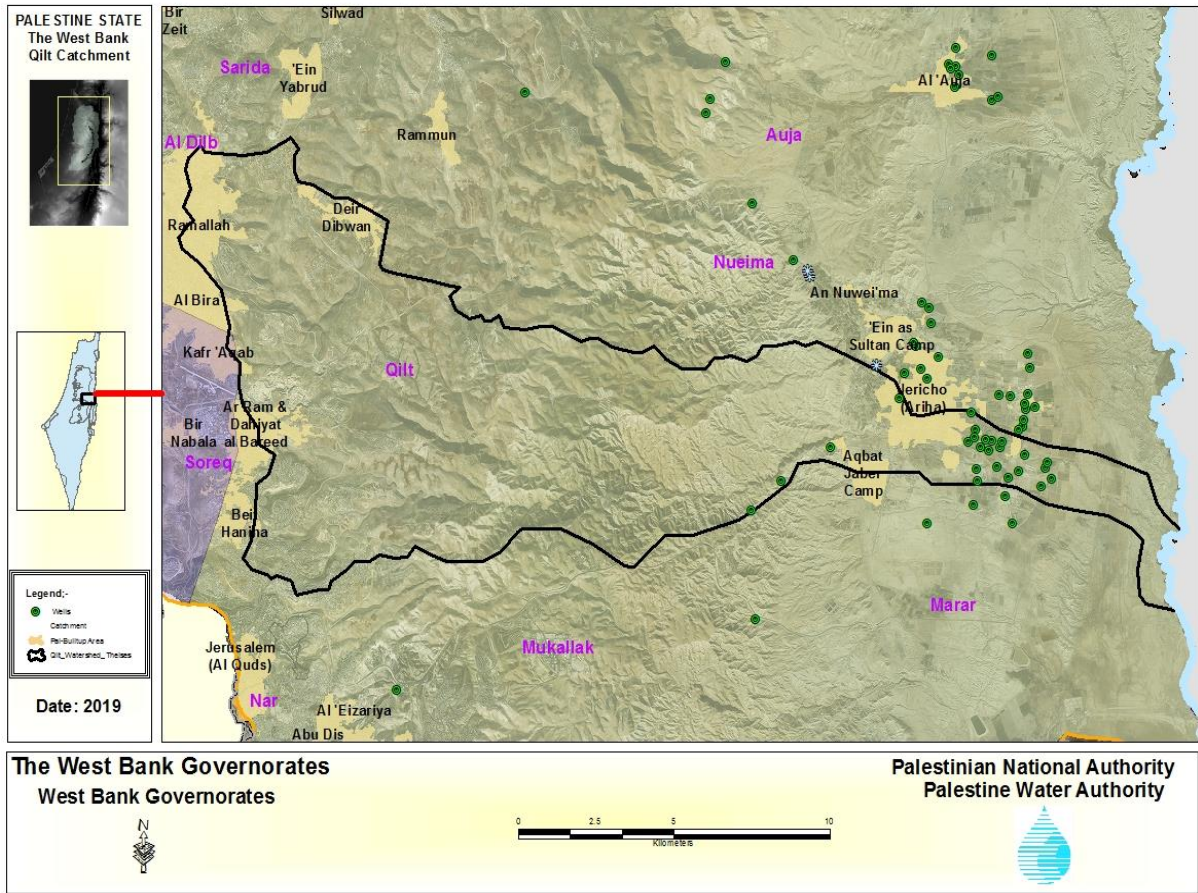


Figure 3.1: Location of the study area (PWA, 2019)

The major drainage system for Al-Qilt is from the Central Mountains between Jerusalem and Ramallah to the Jordan Valley with an average flow in the range of 3.0 Mm³/year depending on the annual rainfall, and the largest flood occurred in 1991/92 when water level record heights and adjacent land (Forward, 1998). The catchment includes five major springs, which are: (Ein Jumeiz, Ein Fara, Fawwar, Ras Al-Qilt, and Ru'yan). Al-Qilt catchment is bounded by Nueima drainage basin from north, Soreq and Al Dilb drainage basins from west, Mukallak and Marar drainage basins from south and Jordan River from the east (Daghray, 2009).

Al-Qilt catchment contains two main tributaries. The first tributary is called Wadi Sweanit which originates from the eastern part of Al-Bireh. contains two water springs, which are Fawwar and

Ras Al-Qilt. The second tributary named as Wadi Fara and contains three water springs, which are Ein Jumeiz, Ein Fara and Ru'yan (Samhan, 2013). This study focuses -for example- on Wadi Sweanit due to its continuous stream flow over the year, unlike Wadi Fara which is only seasonal.

3.3 Population

According to (PCBS, 2017) the Palestinian population in the catchment was estimated to be 168,795 inhabitants (Table 3.1). However, the number of Israeli settlers in six settlements was estimated to be 38,344 settlers (Table 3.2).

Table 3.1: Total inhabitants of Palestinian Communities in Al-Qilt Catchment (PCBS, 2017)

Number	Community	Population
1	Beitein	2,742
2	Al-Beireh	48,887
3	Deir Dibwan	6,721
4	Burqa	2,675
5	Kofr Aqab	12,220
6	Qalandia Camp	10,324
7	Mukhmas	1,692
8	Al-Ram	23,800
9	Jaba	3,721
10	Hizma	7,331
11	Beit Hanina	1,252
12	Anata	14,085
13	Ein Dyouk	1,039
14	Jericho	23,220
15	Aqbat Jaber	9,082
16	Deir Al-Qilt	4
Sum		168,795

Table 3.2: Total inhabitants of Israeli Settlements in Al-Qilt Catchment (PCBS, 2017)

Number	Settlement	Population
1	Psagot	1,902
2	Kokhav Yaqov	7,313
3	Malle Mukhmas	1,351
4	Almon	1,286
5	Adam	5,232
6	Neveh Yakov	21,260
Sum		38,344

3.4 Geology of the study area

Recent and Quaternary alluvial deposits are the youngest and shallowest materials, and consist of unconsolidated alluvial fan deposits developed along the sides of the major wadis. They overlie the Lisan Formation in the Jordan Valley and are composed of lenticular beds of gravel, sand, calcareous clays, and clays. The thickness of these deposits varies from few meters near the Jordan River to more than 100 meters near the foothills.

The Beida Formation represents remnants of older alluvial fans, valley fill or talus sediments. It consists of well-cemented conglomerate whose aggregates are derived from older formations exposed in the catchment areas. The exposures usually show deformation indicating that they have been subjected to tectonic activity prior to the deposition of the overlying Lisan Formation. This formation crops out near the escarpment of the Jordan Valley Rift Fault and near the apexes of alluvial fans. The thickness of the Beida is not documented.

The Pleistocene Lisan Formation covers a large part of the Jordan Valley, and underlies more recent alluvial deposits. The best exposures are found along the sides of the Jordan River flood plain where it has been exposed due to the rejuvenation and down cutting of the Jordan River. The maximum exposed thickness of the Lisan Formation is about 60 meters. The Cretaceous formations (Abu Deis, Bethlehem, Hebron, Yatta, and Beit Kahil) border the Jordan Valley on the western side and underlie the Lisan Formation at depth.

The geological map of Al-Qilt catchment, stratigraphic, structural resolution and prominent E-W striking indicates that more than 9 km long normal fault with throw of 80m down to the southeast has been identified. This fault causes structurally the spring outlets of Ras Al-Qilt. Moreover, within the Mountain Aquifer group there were three sub-aquifers: the Shallow Turonian Aquifer feeding the springs with flow velocities that are quite high rainfall peaks and with average annual discharge about 9 Mcm³/year from Fawwar, and Ras Al-Qilt. Then the Upper Cenomanian and a Lower Cenomanian-Albian Aquifer by more than 81 production wells used mainly for agriculture and these wells are pumping relatively low quantities of about 4 Mcm³/year (CH2MHill, 1999).

The quaternary deposits consist of different deposition formations according to (CH2MHill, 1999) as in which describes the following sub sections:

3.4.1 Alluvial deposits

Alluvial deposits are present along the western side of Al-Qilt consists of unconsolidated lenticular beds of gravels, sands, clay and laminated marls; these are not defined either vertically or horizontally. The thickness of these deposits is highly variable and become relatively great near the foothills in the west and small in the east. These deposits are inter-fingering with the lacustrine sediments of the lisan formation (CH2MHill, 1999).

3.4.2 Lisan formation

The Lisan formation covers a large part of the Jordan Valley, and consists mainly of laminated marl, gypsum and clay with some sand beds and pebbles. The best exposures are found along the sides of the Jordan River flood plain. The maximum thickness of this formation is not well known and according to many previous studies, this formation is acting as an aquiclude and underlying the alluvial deposits (CH2MHill, 1999).

3.4.3 Carbonate rocks

The carbonate rocks in the catchment are divided into two types:

3.4.3.1 Abu Dies formation

Abu Dies's formation crops out in the western part of the study area; this formation consists mainly of massive chalk with a distinctive twin band of cherty beds and little amounts of limestone. The total thickness of this formation is approximately range from 200 to 450 meters (CH2MHill, 1999).

3.4.3.2 Jerusalem formation

The Jerusalem formation covers a small area in Jericho; it is composed of limestone and dolomite limestone. In term of hydrogeology the groundwater in Jericho area is from the quaternary aquifer, which consist mainly gravels inter-fingering with impermeable layers of saline marl that deposited and transported from the western slopes of the Jordan Valley forming alluvial fans. Naturally, the infiltration of floodwater in Al-Qilt catchment is the main source of aquifer recharge during the winter season. Meanwhile, the water quality of this aquifer is varied with location and it is believed that this aquifer is overlaying the Lisan formation that acts as an impermeable or very low permeability layer (CH2MHill, 1999).

3.5 Aquifer Discharge System

Direct rainfall recharge to the aquifer is considered negligible because of low precipitation and high evapotranspiration. In addition to these components, the lateral flow from the Mountain Aquifer is believed to recharge both the alluvial deposit and Lisan Formation at certain locations. There is very little field data to indicate how much water flows from Mountain Aquifer to the east into the Quaternary Aquifer.

The groundwater flow direction in the alluvial deposit is toward the Jordan River and, ultimately, to the Dead Sea. The highest quality groundwater occurs near the recharge areas (or wadi mouths), while the water becomes more saline near the fringes of the fans, toward the Jordan River. Circulation of groundwater along the Jordan Valley brings it in contact with saline formations, which can contaminate previously fresh water. Figure 3.3 shows parts of the Israeli Hydrological sections in the catchment.

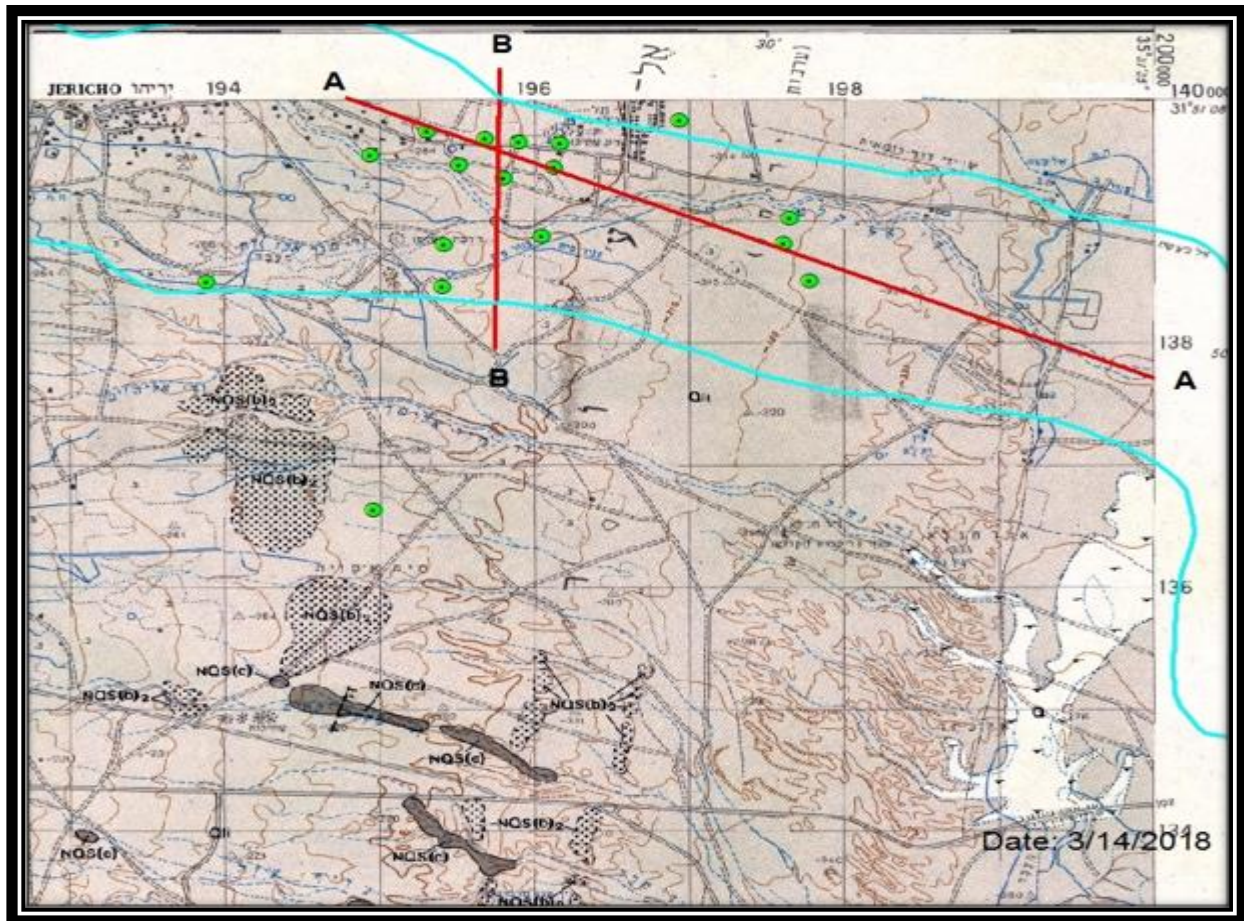


Figure 3.2: Al-Qilt Catchment Geological Plan (Israeli Hydrological Sections, 2018)

3.5.1 Flow Direction

Groundwater depth in Al-Qilt catchment area varies from 10 to 70 m meters below ground surface. Most of the wells in Al-Qilt area have records for water levels. Figure 3.4 shows the groundwater movement in Al-Qilt Catchment area Outflows (discharge). Using long term averages, recharge should equal discharge, unless a significant change storage occurs. The summary of the water balance is shown in Table 3.3

Table 3.3: Water balance summary (MEG, 2000)

	GW Recharge/ Discharge Sources	Mcm/y	Notes
Inflow	Recharge from Wadi Runoff	0.95	Average annual recharge according to PWA readings
	Return Flow	5.2	
	Lateral Flow	0.1	
	Total Inflow	6.25	
Outflow	Abstraction from wells	4.0 -	Approximate Figure since some wells does not have water meters
	Subsurface Lateral Flow and Deep discharge	5.0	
		2.05	
	Total Outflow	6.15	

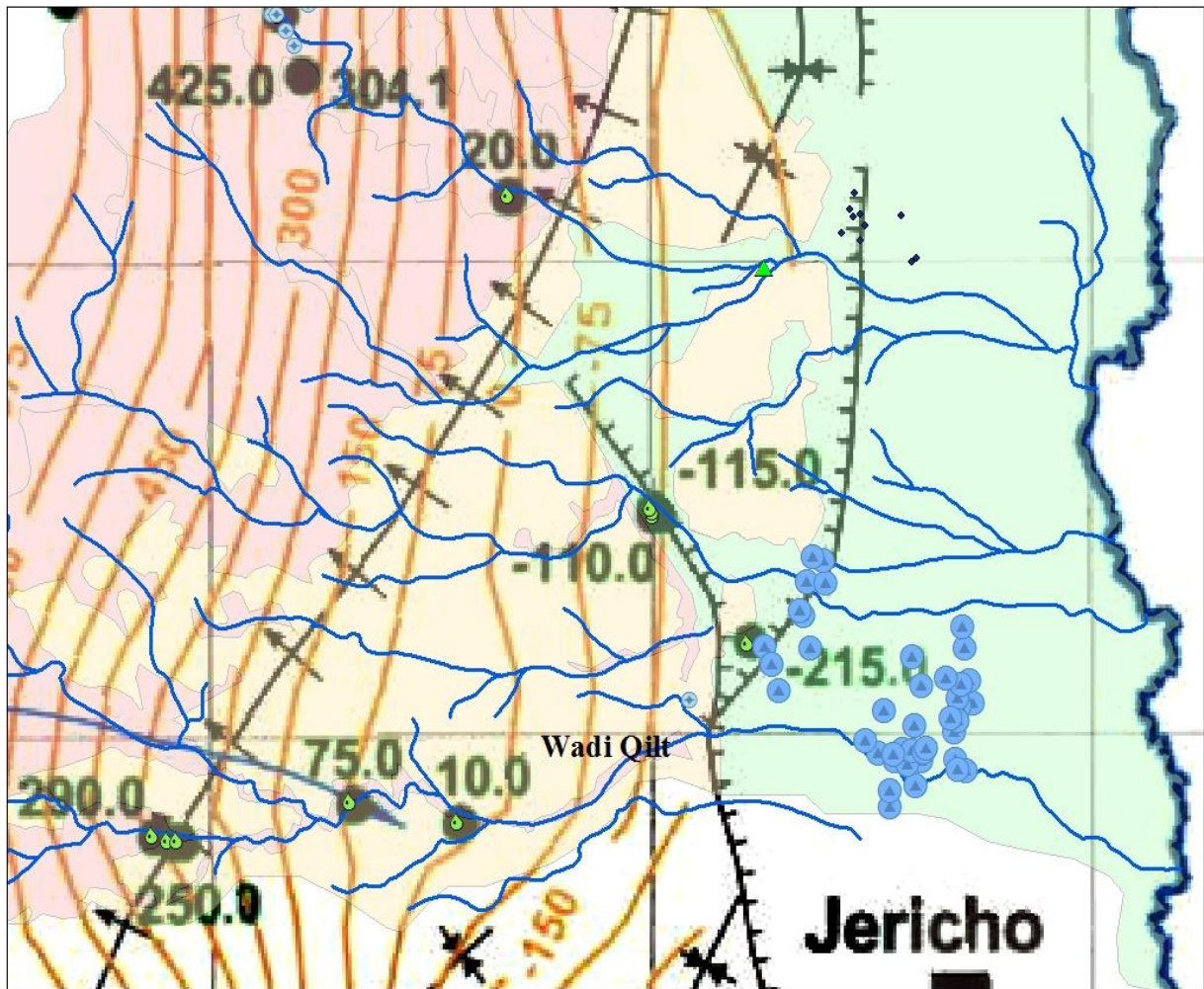


Figure 3.3: Groundwater movement in Al-Qilt Catchment (Israeli Hydrological Sections, 2018)

3.5.2 Groundwater Recharge

Because the average annual rainfall is less than 166 mm and annual potential evapotranspiration is more than 2200 mm, it is unlikely that a significant amount of recharge will reach the aquifer from direct rainfall to the Jordan Valley floor. Therefore, the three primary sources of groundwater recharge to Al-Qilt catchment area are: the recharge from the wadi's runoff, the return flow directed from the applied water, and the lateral flow from the Mountain Aquifer. Figure 3.5 and Figure 3.6 show the geological sections B-B, A-A.

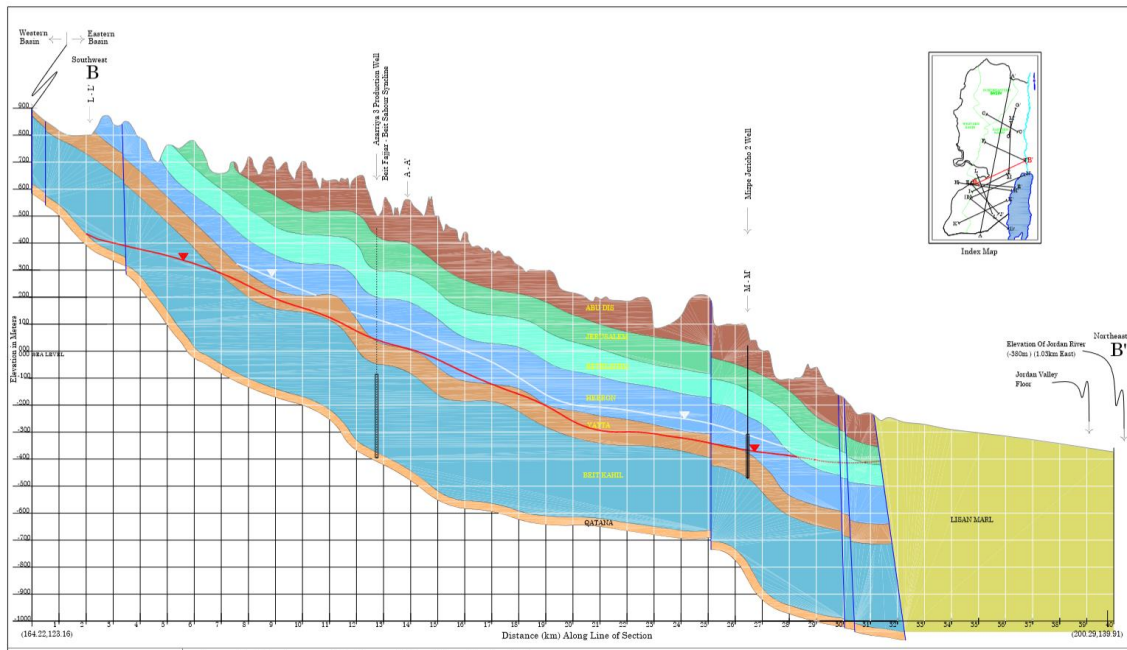


Figure 3.4: Al-Qilt catchment geological section B-B, (PWA, 2009)

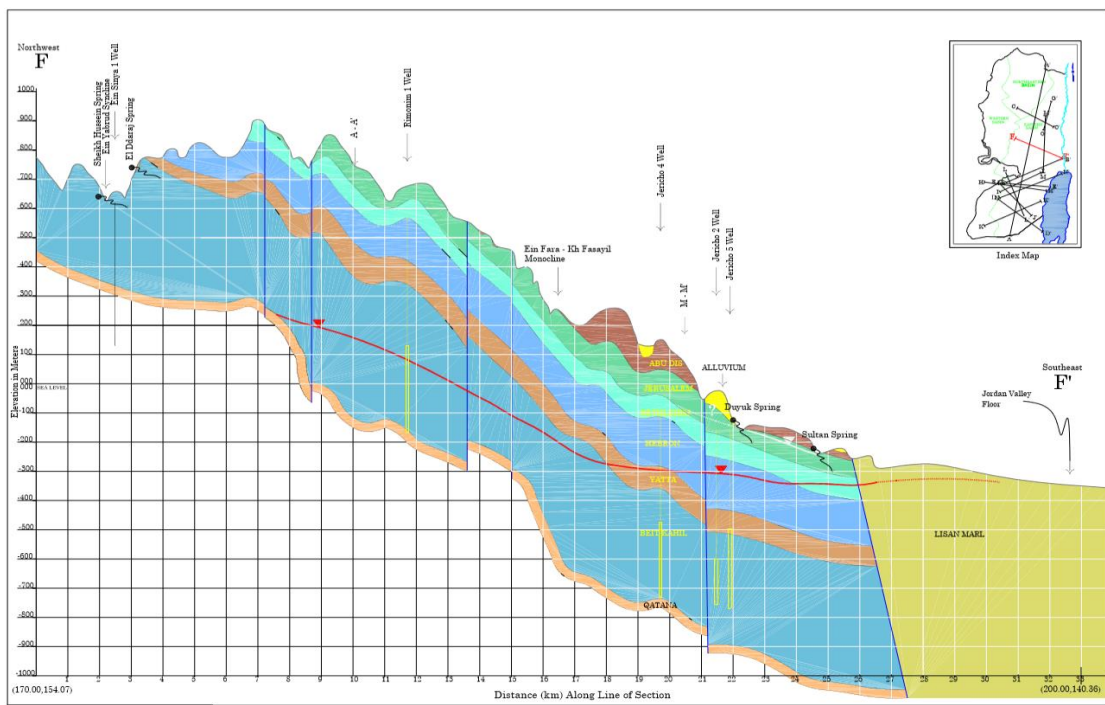


Figure 3.5: Al-Qilt catchment geological section A-A, (PWA, 2009)

3.5.2.1 Recharge from wadi runoff

Surface runoff occurs when the rainfall exceeds the infiltration capacity of the soil. Runoff depends on many factors, such as rainfall intensity, soil type, and slope of the catchment area. Al-Qilt surface catchment is extended to the mountainous area near Ramallah District on the west, the Jordan River to the east (Figure 3.1). Usually, the floods through these wadis are ‘flash’ events, which may not last for more than few days. Wadi flow typically occurs between December and March months. The runoff is generated from mountainous areas to the west and flow easterly to Jordan Valley then to Jordan River.

The main factors affecting the infiltration are rainfall intensity and duration. At any given time the infiltration rate will attain the maximum value only as long as rainfall exceeds the infiltration rate and soil moisture holding capacity.

3.5.2.2 Return Flow

The main source of return flow is infiltrated water from overland and irrigation leakage from irrigation activities in the area. However, this amount may be considered negligible since most of agricultural lands are irrigated by drip irrigation method and the shallowest depth to groundwater is 10 mbsl. The high evapotranspiration rates in the shallow root zone (where most of the infiltrated water is held) mean that most of this water is lost to evapotranspiration.

3.5.2.3 Lateral flow from the Mountain Aquifer

Previous modelling studies (Gutman, 1995, ANTEA, 1998, CDM, 1998, and MEG, 2000), stated that there is around 19 Mcm leaves the Mountain Aquifer along the Rift Fault (CH2MHill, 1999).

This water recharge alluvial lenses in areas with direct contact, and where fractured exist. Since Al-Qilt area is close to Turonian springs, it is believed that most of the southern part of the valley Rift Fault boundary between alluvial deposit and Mountain Aquifer acts as a barrier. Therefore, the recharge from lateral flow to the alluvial deposits occurs near the northern boundary (north Wadi Nuweimah and its out of our study area (CH2MHill, 1999).

3.5.3 Groundwater Discharge

Most of the groundwater from the alluvial aquifer is discharged through pumping wells. The remaining water is discharged through springs, seeps, and lateral flow to Jordan River. There are 18 working wells in Al-Qilt catchment area. These wells are shown in the Appendix 1. The location for each well is shown in Figure 3.7 and Figure 3.8.

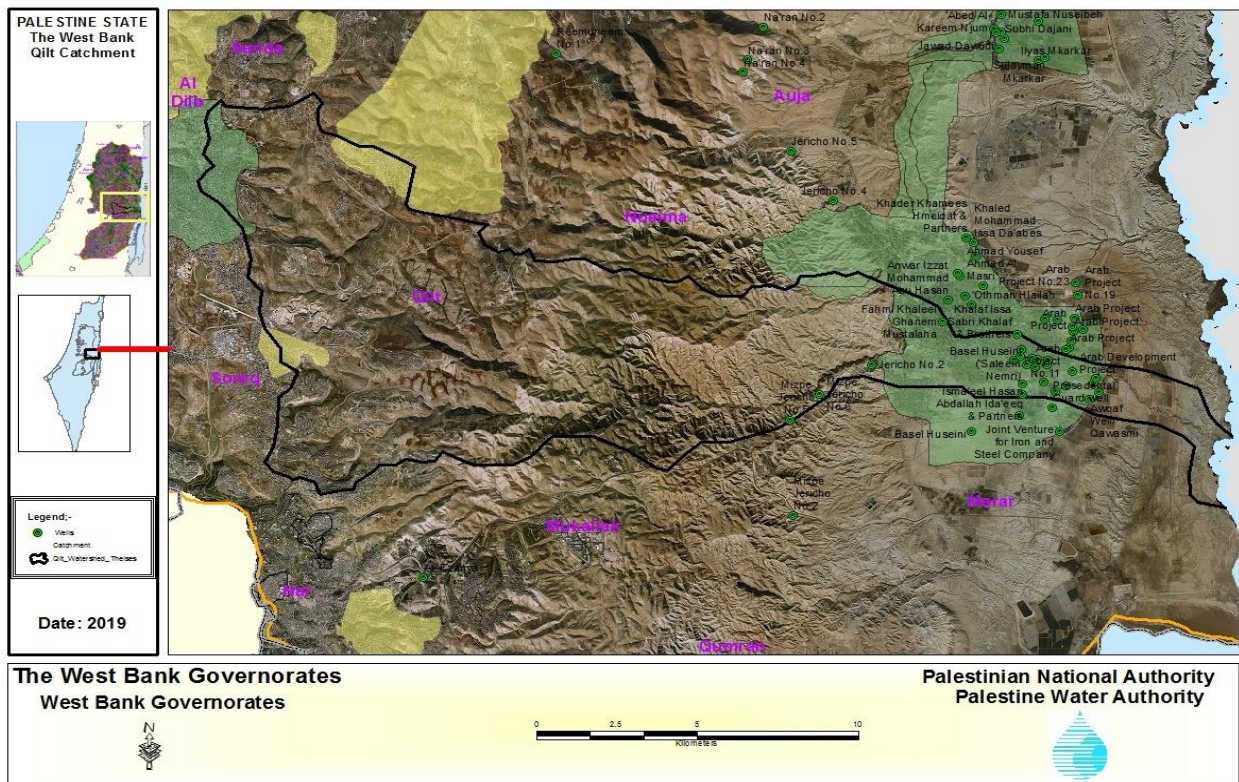


Figure 3.6: Al-Qilt Catchment ground wells names, (PWA, 2018).

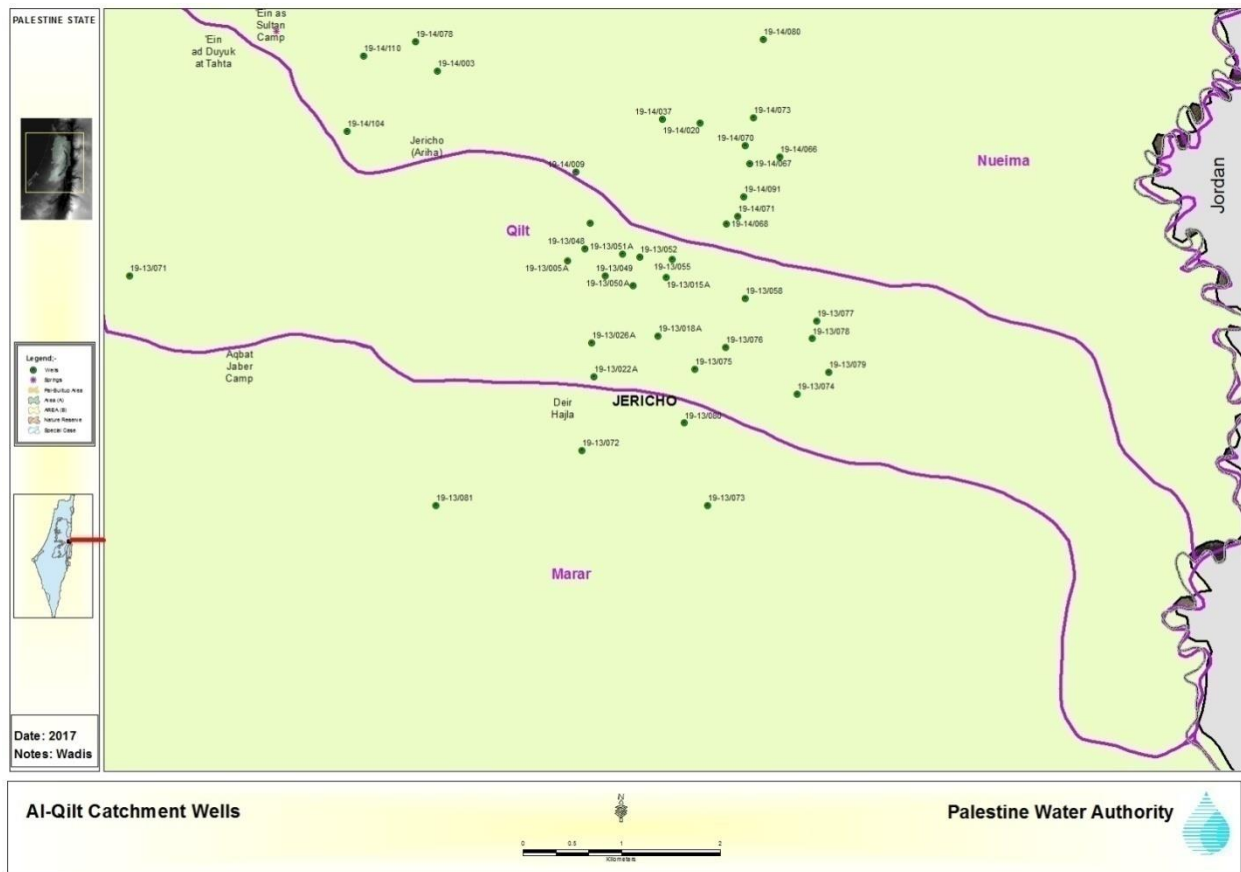


Figure 3.7: Al-Qilt Catchment working ground wells codes (PWA, 2018)

3.6 Climate

The West Bank has a typical Mediterranean climate with two distinct seasons: dry hot season from June to October and cold wet season from November to May.

In Al-Qilt there is variation in the climate according to the drainage basin such as: in the western part, the climate is influenced by the Mediterranean climate; a rainy winter and dry summer. The climate in the eastern part is classified as arid with hot summers and warm winters (ARIJ, 1996).

3.6.1 Rainfall

Along the West Bank there are considerable variations in the quantity of the annual rainfall from year to year or from upstream to downstream. Moist air masses from the Mediterranean bring

most of the rain that falls on the western part of Al-Qilt, since Ramallah and Jerusalem are on the upper mountains with annual rainfall of 500 to 700 mm/year (Aed Rabo et al., 1999). These rainfall values decrease down east to 150-200 mm/year (Ali, et al., 1999) Moreover, rainfall in Al-Qilt is estimated at the range of 500-700 mm/year in the west and 150 mm/year in the east with an average rainfall over the catchment being about 400 mm/year (PWA, 2009).

3.6.2 Temperature

The temperature increase from north to south and from west to east in the West Bank areas. January is the coldest month and August is the warmest month (Ghanem, 1999). The daily minimum temperature in the Jericho area ranges between 5.7-28 °C and the coldest month is January and it is in the range of 5.7-10.2°C (PMD, 2016), while the daily maximum temperature ranges between 15.2-41.2 °C and the hottest month is July with a range between 35.7-41 °C.

3.6.3 Relative humidity

In the West Bank, temperature increases from west to east and the main factors that control the atmospheric moisture content is expressed as Relative Humidity (RH %). The RH% varies from north to south and the mean annual relative humidity is between 29 % in the eastern part of Al-Qilt catchment to 85 % in the western part (PMD, 2016).

3.6.4 Evaporation

Due to high temperature and low relative humidity of the air during the summer time in the West Bank, the evaporation rate is high and reaches 11.1 mm/day. The evaporation rate decrease in winter due to the increase in humidity and decline to 9.6 mm/day (PMD, 2016).

Chapter Four

4. Watershed Modelling

4.1 Introduction to model

Watershed Modelling System (WMS) is a proprietary water modelling software application used to develop watershed computer simulations.

The software provides tools to automate various basic and advanced delineations, calculations, and modelling processes. It supports river hydraulic and storm drain models, lumped parameter, regression, 2D hydrologic modelling of watersheds, and can be used to model both water quantity and quality. Since January 2017, supported models include HEC-1, HEC-RAS, HEC-HMS, TR-20, TR-55, NFF, Rational, MODRAT, HSPF, CE-QUAL-W2, GSSHA, SMPDBK, and other models, these are "WMS Supported Models".

In addition to WMS, the HEC-HMS is designed to simulate the precipitation-runoff processes of dendritic drainage basins. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology and small urban or natural watershed runoff.

Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.

The program is a generalized modelling system capable of representing many different watersheds. A model of the watershed is constructed by separating the water cycle into manageable pieces and constructing boundaries around the watershed of interest. Any mass or

energy flux in the cycle can then be represented with a mathematical model. In most cases, several model choices are available for representing each flux. Each mathematical model included in the program is suitable in different environments and under different conditions. Making the correct choice requires knowledge of the watershed, the goals of the hydrologic study, and engineering judgement (Hydraulic Engineering Center website).

HEC-HMS is a product of the Hydrologic Engineering Centre within the U.S. Army Corps of Engineers. The program was developed in the beginning of 1992 as a replacement for HEC-1 which has long been considered a standard solution for hydrologic simulation. The new HEC-HMS provides almost all of the same simulation capabilities, but has modernized them with advances in numerical analysis that take advantage of the significantly faster desktop computers available today. It also includes a number of features that were not included in HEC-1, such as continuous simulation and grid cell surface hydrology. It also provides a graphical user interface to make it easier to use the software. The program is now widely used and accepted for many official purposes, such as floodway determinations for the Federal Emergency Management Agency in the United States.

4.1.1 HEC-HMS model and artificial recharge

The U.S. Army Corps of Engineers Hydrologic Modelling System (HEC-HMS) is a new-generation software for precipitation-runoff simulation that has superseded the HEC-1 Flood Hydrograph Package during the past decade. HEC-HMS is a significant advancement over HEC-1 in terms of both computer science and hydrologic engineering. It is a product of the Corps Civil Works Hydrologic Engineering R&D Program.

A lumped continuous model was built using the Hydrologic Engineering Center-Hydrologic Modelling System (HEC-HMS) in order to simulate surface flow and infiltration toward the

groundwater. The HEC-HMS is designed to model the precipitation-runoff processes of dendritic watershed systems. The program includes a variety of separate mathematical sub-models to represent each component of the runoff process, including models that compute rainfall losses, runoff generation, base flow, and channel routing. For the present investigation, we distinguished between diffuse groundwater recharge that occurs on the hill slopes over the majority of the study area and direct groundwater recharge which results from surface flow infiltration through highly developed karst conduits that are distributed along each of the distinct groundwater.

There are no records available in the stream-gauging stations nor measurements for basins with similar characteristics. The runoff modelling was done using the HEC-HMS code (USACE 2000). The option used in the present application to represent the rainfall runoff processes is the curve number method (Soil Conservation Service 1972). With this method the runoff can be related to soil cover complexes and rainfall through a parameter known as a curve number (CN). Rainfall excess, Q , in the SCS method is related to the precipitation P , in millimetres, and the retention capacity of the basin S , also in millimetres, as given calculated.

In this study, the available surface water was quantified using a proper surface water model. The storm-by-storm model and the HEC-HMS software were used, compared with a home-made spread sheet model. The generated flow hydrograph was managed through a small reservoir, where the inflow and outflow were developed. The infiltrated water through the reservoir bottom or through a recharge well was defined and quantified, where a groundwater recharge model was developed. Wadi Bayer data could be a calibration case study for the general surface-recharge groundwater model.

The direct runoff computation was done using the unit hydrograph triangular method and the flow routing with the Muskingum-Cunge method (Cunge 1969). The transmission losses along

the channels and the lamination effect of the dams were taken into consideration. For details of these methods see USACE (2000).

Among other capabilities, HEC-HMS is capable of simulating event-based and continuous modelling of variable hydrological processes. It offers the possibilities of evaluating three different layers in the hydrological system: atmosphere, vegetation and surface soil. The model allows the simulation of movement of water once

The CN is a function of the antecedent moisture condition (AMC), the lithology, and land use. The AMC is a function of the total rainfall in the 5-day period preceding a storm. It is considered an intermediate level

4.2 Watershed Modelling – HEC Interface (lumped parameter models)

The first step in building the model is to add the DEM for Al-Qilt area, editing the coordinate system to local and using metric units for both horizontal and vertical dimensions. Figure 4.1 shows Al-Qilt watershed as shown in the WMS.

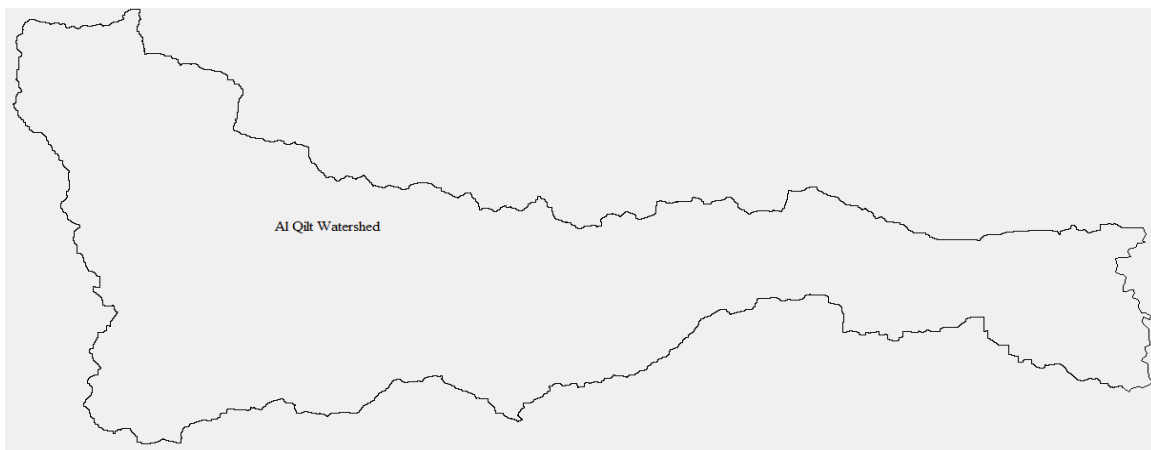


Figure 4.1: Al-Qilt watershed

4.2.1 Trimming DEMs

The digital elevation model can be trimmed by doing the following

- 1) Right-click on DEM in the Project Explorer and select Trim | Polygon
- 2) Choose the Enter a polygon interactively option then select OK
- 3) Click each of the vertices of the polygon around the boundary of Al-Qilt, double-clicking on the last to close the polygon

Figure 4.2 showing the trimming of the DEM for Al-Qilt Catchment

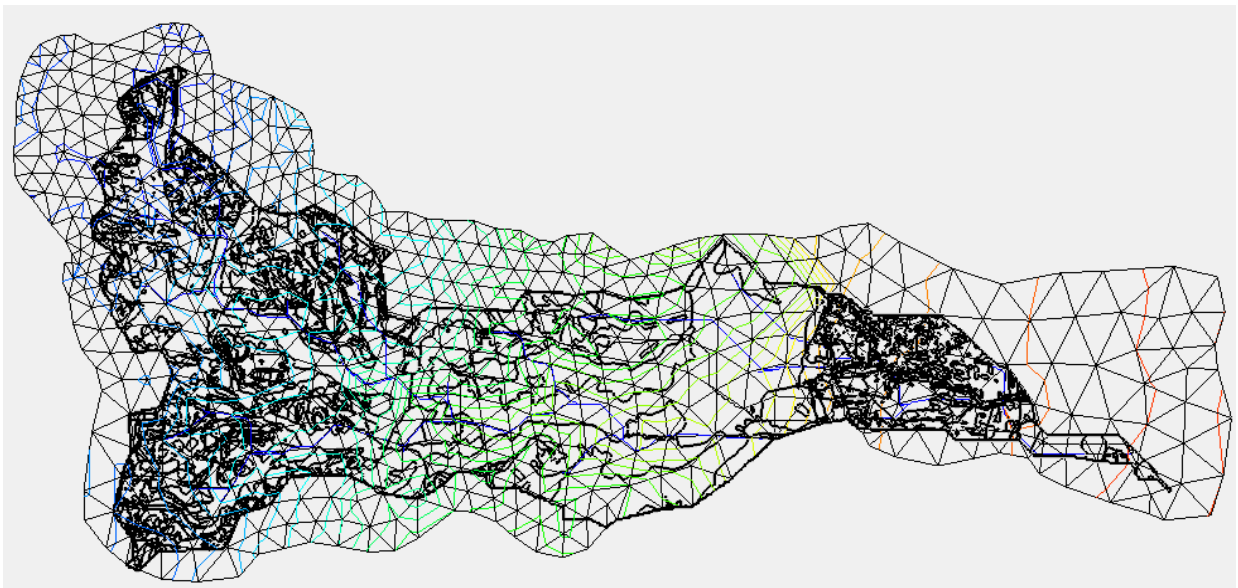


Figure 4.2: Trimming the DEM

4.2.2 Converting a TIN to a DEM

The triangular interpolated network (TIN) must be converted into DEM by doing the following

- 1) Open a new project and add TIN.
- 2) Right-click on the TIN in the Project Explorer and select Convert | TIN->DEM on the pop- up menu.
- 3) Enter a cell width and cell height of 25, then Select OK then select Yes.

- 4) Switch to the Drainage module then select DEM | Compute Flow. Direction/Accumulation then selects OK.
- 5) Select Close once TOPAZ finishes running.
- 6) Select Display | Display Options.
- 7) Select DEM Data and change the Minimum Accumulation for Display to 0.25 km² then.
- 8) Select the Create Outlet Point tool and create an outlet in the downstream.
- 9) Select DEM | Delineate Basins Wizard.
- 10) Select Delineate Watershed then select close.

4.2.3 Creating Land Use and Soil Coverage

The land use and soil coverage was previously estimated using the GIS for the catchment it is created by doing the following

- 1) Right-click on the Coverage folder in the Project Explorer and Select New Coverage
- 2) Change the coverage type to Land Use and select OK
- 3) Create a new coverage once again and set its coverage type to Soil Type

4.2.3.1 Open the Soils Data

In order to open the soil data we shall do the following

- 1) Make sure the Soil Type coverage is active in the Project Explorer
- 2) Right-click on GIS layers in the Project Explorer and select Add Shapefile Data
- 3) Open “Soil.shp” from “\\WMS-PWA\Shapes\”, open attribute table to check the soil type and its group. (Figure 4.3 shows the DEM for Al-Qilt watershed).



Figure 4.3: Al-Qilt Digital Elevation Model

4.2.3.2 Definition of Hydrologic Soil Groups

The soil characteristics used in this model are shown in the Table 4.1. The value for hydrologic soil group was derived from the (gSSURGO Map Unit Aggregate Attribute table field Hydrologic Group - Dominant Conditions hydrpdcd)

Table 4.1: Soil Group Hydraulic Definition

Hydrologic Soil Group	Soil Group Characteristics
A	Soils having high infiltration rates, even when thoroughly wetted and consisting chiefly of deep, well to excessively-drained sands or gravels. These soils have a high rate of water transmission.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
D	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

The Soil type and land use as shown in the WMS are shown in Figure 4.4 and 4.5.

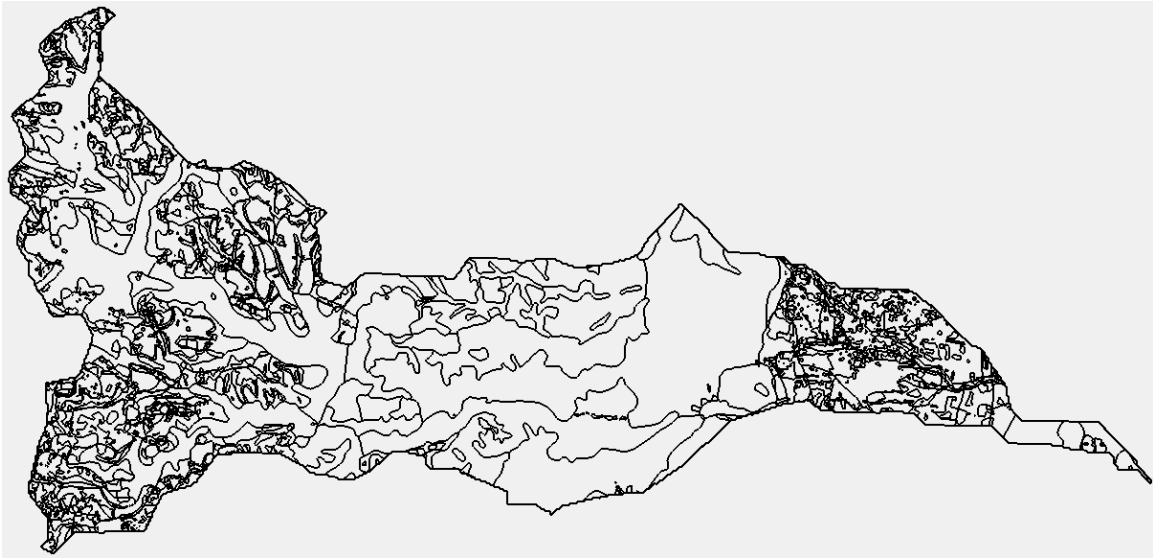


Figure 4.4: Land use for Al-Qilt catchment area

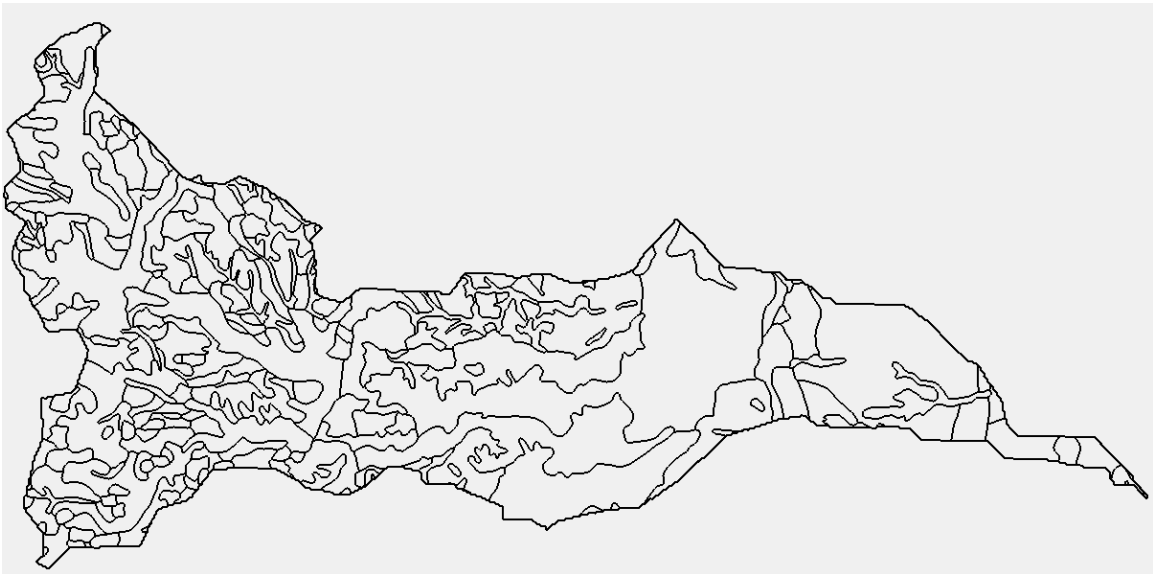


Figure 4.5: Soil types for Al-Qilt catchment area

4.3 Converting Soil Shapefile Data to Feature Objects

The shape file of the soil must be converted into feature object by:

- 1) Activate the GIS Module, Choose the Select Shapes tool and draw a selection box around the DEM extents.
- 2) Select Mapping | Shapes -> Feature Objects, then select Next, make sure the TYPE field. Is mapped to the SCS soil type attribute, select Next then select Finish.
- 3) Clear the selected polygons by single-clicking somewhere beyond the extents of the shapefile polygons.
- 4) Hide the Soil.shp file by toggling off its check box in the Project Explorer.

Repeat the steps listed in the above two section for land use. The name of land use shape file is "Al-Qilt.shp".

4.4 Delineate the Watershed

In order to delineate the watershed the following procedures should be taken:

- 1) Select the Drainage module.
- 2) Select DEM | Compute Flow Direction/Accumulation and select OK.
- 3) Select the Create Outlet Point tool.
- 4) Create a new outlet point close to Jericho city (downstream).
- 5) Select DEM | Delineate Basins Wizard.
- 6) Select Delineate Watershed and select Close.
- 7) Right-click on DEM in the Project Explorer and select Display Options.
- 8) On the DEM tab, toggle off the display for Watershed, Stream, Flow Accumulation, and DEM Contours.
- 9) On the Map tab, select Okay.

4.5 Setting up the Job Control

The Job Control for the model can be done by

- 1) Switch to the Hydrologic Modelling module
- 2) Select HEC-HMS it from the drop down list of models found in the Edit Window then select HEC-HMS | Job Control.
- 3) Enter “Al-Qilt Watershed” for the second ID line. Enter your name and current date in the third line.
- 4) Enter 5 (minutes) for the Computation time interval, and 300 for the Number of hydrograph ordinates. Leave the Beginning time at 0.
- 5) Set the computation units to Metric units then select OK.

4.6 Computing the CN Using Land Use and Soils Data

The Curve Number and the Land Use of the soil data can be computed in the following steps

- 1) Select the Hydrologic Modelling module
- 2) Select Calculators | Compute GIS Tributaries
- 3) Select the Import button to load the mapping table
- 4) Select OK to overwrite the current definition
- 5) Find and open the file named “scsland.tbl” stored in “\\WMS-HEC\”,
- 6) Select OK to compute the CN from the land use and soils layers
- 7) Close the Curve Number Report.

Figure 4.6A&B: shows the curve number (CN) and the area for each sub-catchment in both WMS and HEC-HMS models.

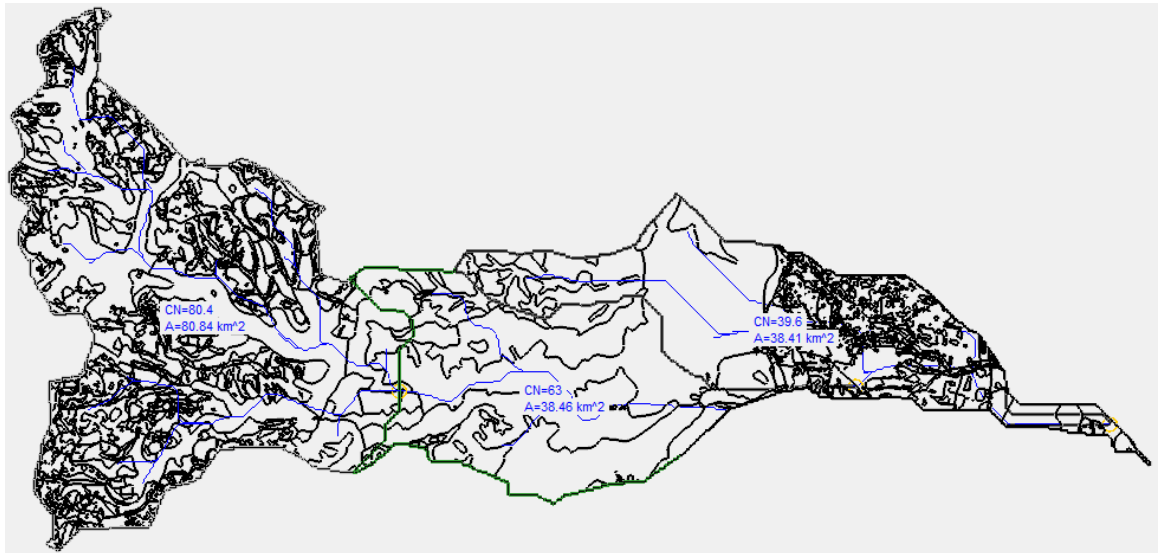


Figure 4.6A: curve number (CN) and the correspondence sub area as shown in WMS

4.7 Setting up the Basin Data Parameters

The basin data parameter shall be computed by doing the following steps

- 1) Select the Select Basin tool.
- 2) Double-click on the brown basin icon. (Jericho watershed) and change the name to "Jericho Catchment".
- 3) Check on "Loss Rate Method", "SCS Curve Number", "Transform" and "SCS".
- 4) On the properties box, click "Define" under the "Compute Basin Data" to calculate the lag time.
- 5) change the Time unit to "Hour".
- 6) Repeat all the steps from step 2 to step 6 for both Nabaa and Ramallah Catchments.

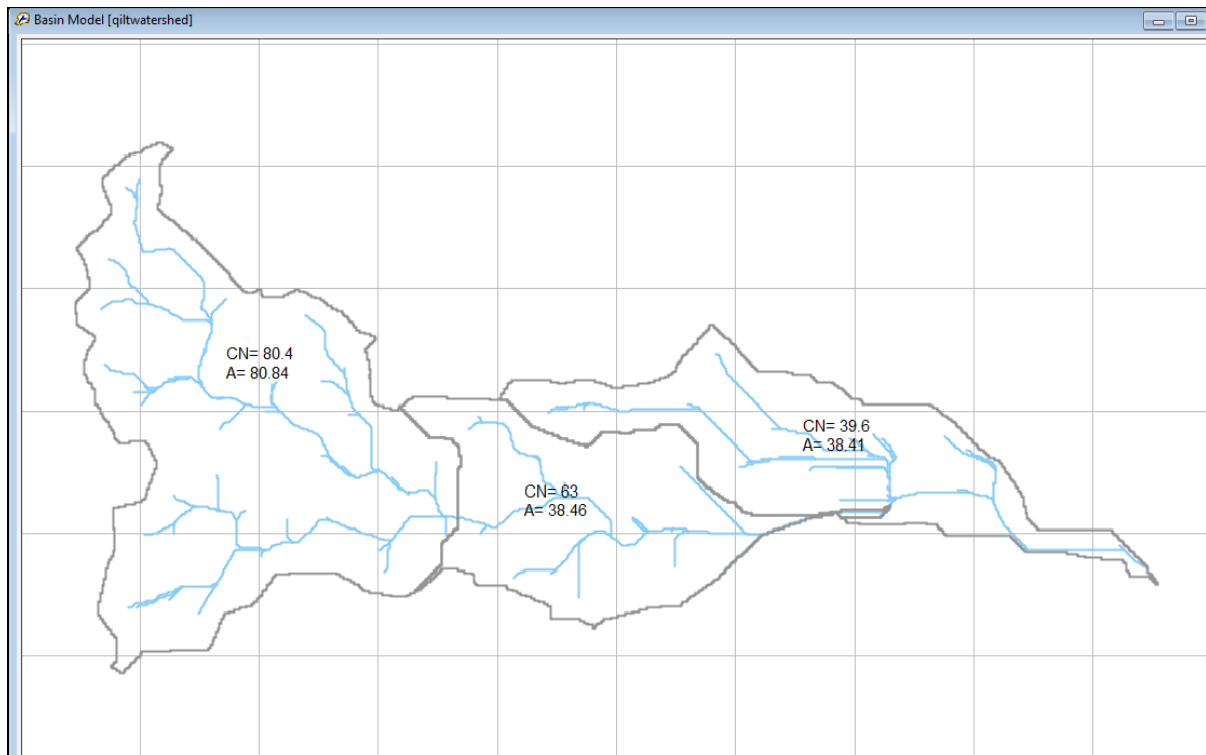


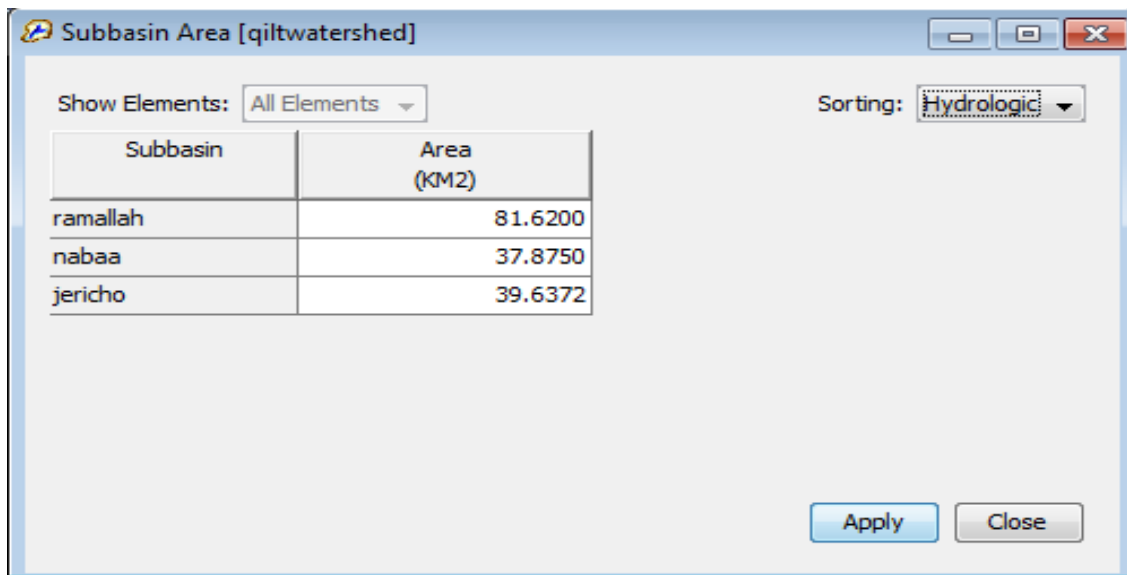
Figure 4.6B: curve number (CN) and the correspondence sub area as shown in HEC-HMS

4.8 Setting up the Routing Parameters

The routing parameter (including the river, the junctions, and the outlet) of the catchment can be calculated by

- 1) Select the Select Outlet tool.
- 2) Double-click on the outlet (the yellow circle icon) of the upper left basin (Jericho City).
- 3) Make sure the Type field at the top left of the dialog is set to Reaches
- 4) Toggle on the Display of Method and Show Muskingum Cunge Std.
- 5) Change the Routing Method to.
- 6) Set the bottom width field to be 10 (around three meters wide)
- 7) Set the side slope value to be 1 (1:1 side slope)
- 8) Set the Manning's roughness (N) to be 0.05 and select OK.

The catchment is divided into three catchment as shown in Figure 4.7



Subbasin	Area (KM2)
ramallah	81.6200
nabaa	37.8750
jericho	39.6372

Figure 4.7: Al-Qilt watershed sub-catchments

4.9 Setting up the Meteorological Data

The Metrological data parameters can be calculated by

- 1) Select HEC-HMS | Meteorological Parameters.
- 2) Set the Precipitation Method to SCS Hypothetical Storm.
- 3) Set the Storm Selection to Type II.
- 4) Set the Storm Depth to 1.8 (inches) then select OK.

4.10 Re-Setting up the Meteorological Data

The metrological data can be set by doing the following steps

- 1) From the WMS, export the boundary of the catchments to CAD using Map Module| CAD| Data > CAD.
- 2) Open ARCGIS, load the Cad drawings (from Step 1) and use the Rainfall_stations.shp 3. Use the ARCGIS tools to calculate the rain-gauge weights per catchments. (Feature to Polygon, Cut Features, Create Thiessen Polygon, Summarize, etc.).

- 3) In the HEC-HMS, Create the three gauges in the area; Components Time series Data Manager, select Precipitation Gages, then create the three Gauges.
- 4) Set the Time Series Gage to Manual Entry, Incremental Millimetres and 1 hr. time step.
- 5) Set the dates for each stations to 24 Oct. 2018 09:00AM to 03 Mar. 2019 09:00AM.
- 6) Open the Rain_Hr.xlsx files from "\\WMS\HEC-HMS\" and copy/paste the rainfall data for the three stations.
- 7) Select the Qilt_Meteorologic Data, then change the Precipitation method to Gage Weights and the Unit system to Metric.
- 8) For each Catchment, assign the related gauges and their weights. (Based on the results obtained from step 3).
- 9) From the Transformation Tab, Convert the Lag time to hr.
- 10) From the Loss tab, keep the value for "Initial Abstraction" empty.

Initial Abstraction: defines the amount of precipitation that must fall before surface excess results. It is not the same as initial interception or initial losses. User can define the value or the system can calculate it from the curve number.

- 1) Select the Compute Create Simulation run; rename the run "Run2". Then accept all default values.
- 2) Click the run Icon, then review the results obtained.

4.11 Introduction to HEC-HMS

HEC-HMS is designed to make the simulation for the rain-runoff process of the watershed system. It is designed to be applicable for a wide range of different situations and different areas including but not limited to large river basin water supply and flood hydrology to small urban or natural watershed runoff.

4.12 HMS Model Component

The model components are used to simulate the hydrologic response in watershed including basin models, metrological models controls specifications and input data. Data imputed such as gridded data, time series data, and paired data are essential in the basin and the metrological models.

4.13 Running HEC-HMS

The HEC-HMS model can be run by the following steps

- 1) Right click on Drainage Coverage Tree in the Project Explorer and select Save HMS File or select HEC-HMS |Save HMS File.
- 2) Change the HMS project file to Al-Qilt.
- 3) Start HEC-HMS on your computer.
- 4) Select File |Open.
- 5) Select the Browse button and browse to the location where you just saved your HMS Project from WMS.
- 6) Select the Al-Qilt.hms project file.

4.13.1 Basin Model Component

The basin model is representing the physics of the watershed and the user can develop a basin model and this can be done by adding the connecting hydrologic elements, this elements is using the mathematical models, providing the list and description of the available hydrologic elements. These components are including: sub basin, reach, junction, source, sink, reservoir, and diversion.

4.13.2 Metrologic Model Component

This component is calculating the precipitation input required by a sub basin element and can be utilized for both the gridded and point precipitation. The precipitation methods including frequency storm, gage weight, gridded precipitation, inverse distance, SCS storm, specified hyetograph, and standard project storm.

4.14 User Interface

This is consisting of a menu bar, tool bar, and four main panes, and these panes will be referred as the Watershed Explorer, the Component Editor, the Message Log, and the Desktop. Figure 4.8 show the user interface in HEC-HMS.

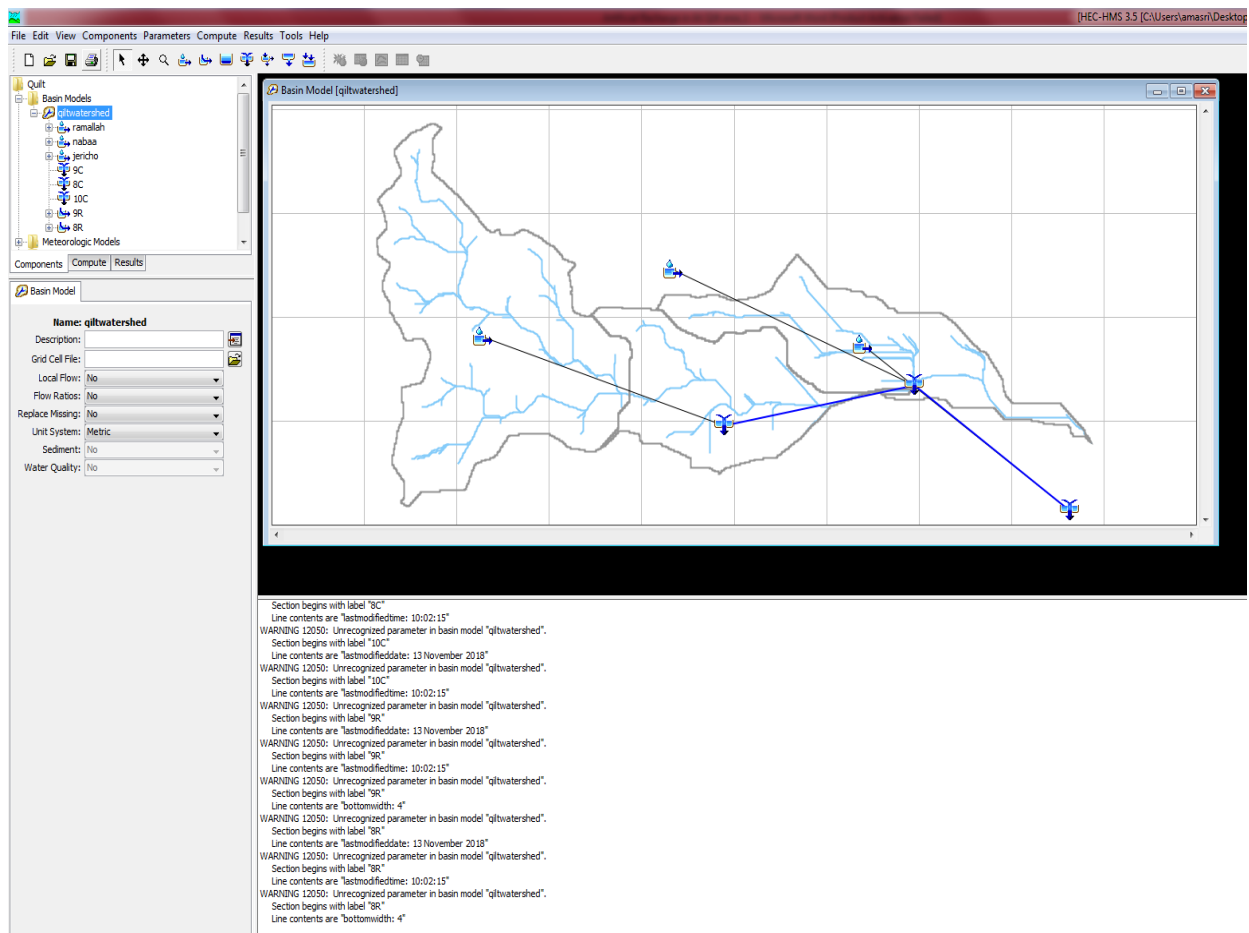


Figure 4.8: HEC-HMS user interface

4.14.1 Watershed Explorer

This was developed to provide a quick access to all of the components of the HEC-HMS project, and this explorer is divided into three parts: Components, Compute, and Results as shown in Figure 4.9.

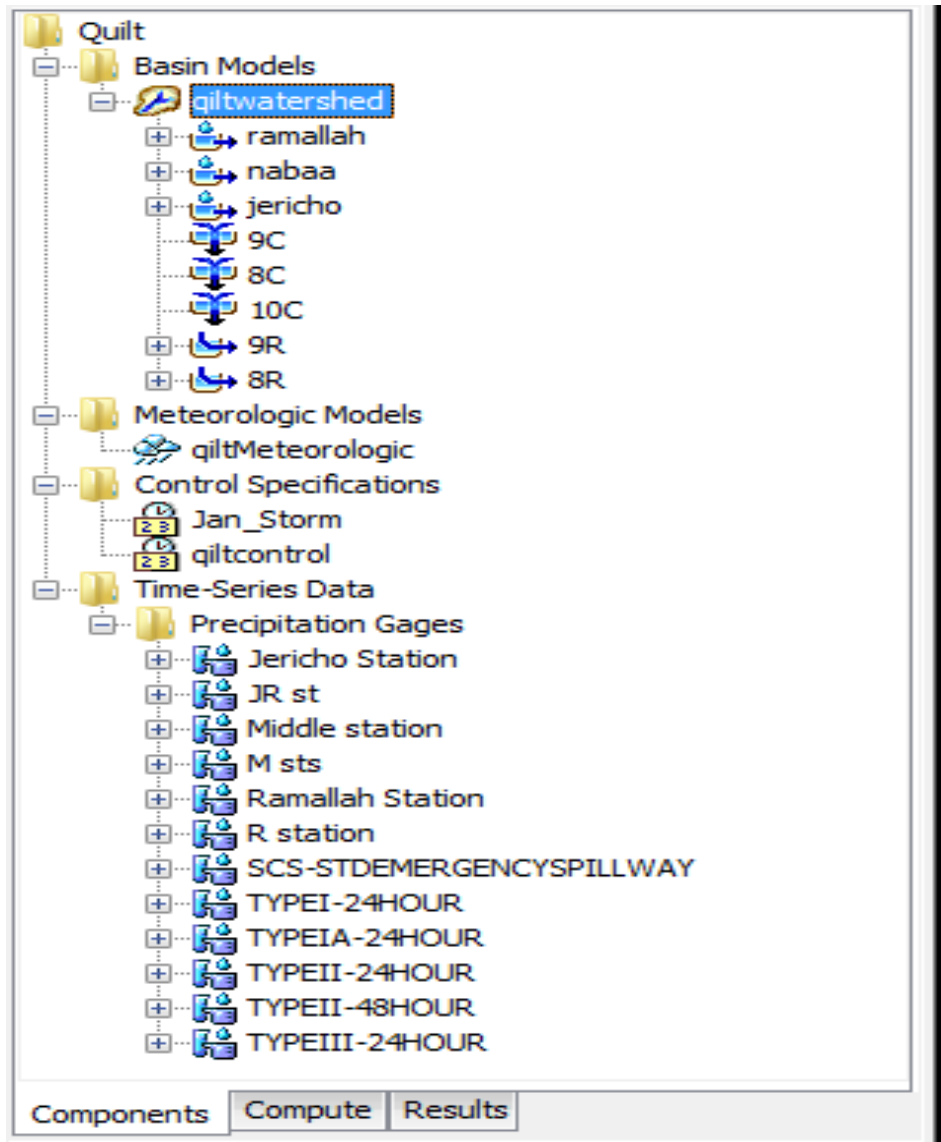


Figure 4.9: Watershed Explorer showing components in the project

4.14.2 Component Editor

All the data that can be specified in the components of the model is entered in the component editor, and any required data, the Component Editor for Al-Qilt catchment is shown in Figure 4.10.

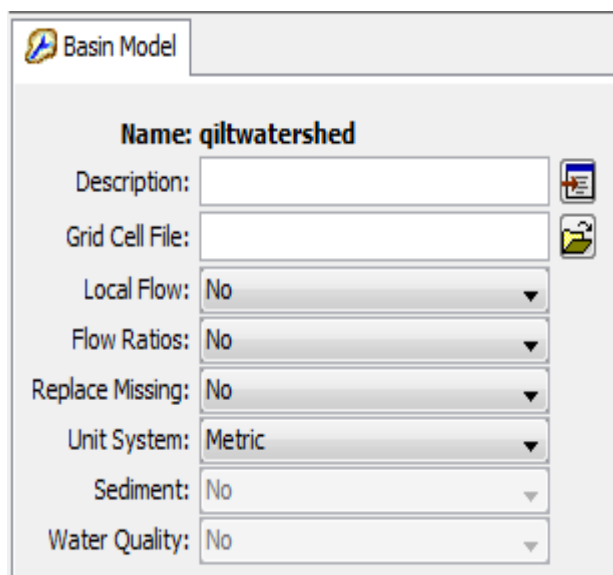


Figure 4.7: component editor for a basin model

4.14.3 Message Log

Notes, warnings and errors are shown in the Message Log (Figure 4.11). These messages are very useful for identifying the run of simulation or any required actions. This kind of message are very useful in identifying the reason for the failure of the simulation run or the reason for any requested action such as if the project opening was not completed correctly.

```

NOTE 10008: Finished opening project "Quit" in directory "C:\Users\amasri\Desktop\WMS-GIZ_MOA\Example\HMS\Quit" at time 27Feb2019, 12:34:17.
NOTE 10179: Opened basin model "qiltwatershed" at time 27Feb2019, 12:34:23.
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "ramallah"
Line contents are "lastmodifieddate: 13 November 2018"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "ramallah"
Line contents are "lastmodifiedtime: 10:02:15"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "ramallah"
Line contents are "plantuptakemethod: None"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "ramallah"
Line contents are "initialcanopystoragepercent: 0"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "ramallah"
Line contents are "canopystoragecapacity: 2"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "ramallah"
Line contents are "cropcoefficient: 1.0"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "ramallah"
Line contents are "endcanopy: "
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "ramallah"
Line contents are "initialsurfacestoragepercent: 0"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "ramallah"
Line contents are "surfacestoragecapacity: 3"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "ramallah"
Line contents are "surfacealbedo: 0.20"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "ramallah"
Line contents are "endsurface: "
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "nabaa"
Line contents are "lastmodifieddate: 13 November 2018"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "nabaa"
Line contents are "lastmodifiedtime: 10:02:15"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "nabaa"
Line contents are "plantuptakemethod: None"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "nabaa"
Line contents are "initialcanopystoragepercent: 0"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "nabaa"
Line contents are "canopystoragecapacity: 2"
WARNING 12050: Unrecognized parameter in basin model "qiltwatershed".
Section begins with label "nabaa"

```

Figure 4.8: Message Log

4.15 Developing HMS Model

In order to develop a hydrologic model the following steps should be completed:

- 1) Create a new project.
- 2) Input the time series, paired, and gridded data needed by the basin or metrological model.
- 3) Select a method for calculating sub basin precipitation and enter required information.
- 4) Define the control specifications.
- 5) Basin model, meteorological model, and control specifications results are viewed.

4.15.1 Create a New Model

The new project creation can be done by choosing File then New from the Menu bar and we have the options for the file menu such as open, save, save as, delete, and rename.

4.15.2 Input Data

Time series data, gridded data, and paired data, are created using component managers, this is opened from the components menu by selecting the Time-Series Data Manager, Grid Data Manager, or Paired Data Manager menu options.

4.16 Create Basin Model

The new model shall be added as in Figure 4.12 by selecting Components then Basin Model Manager.

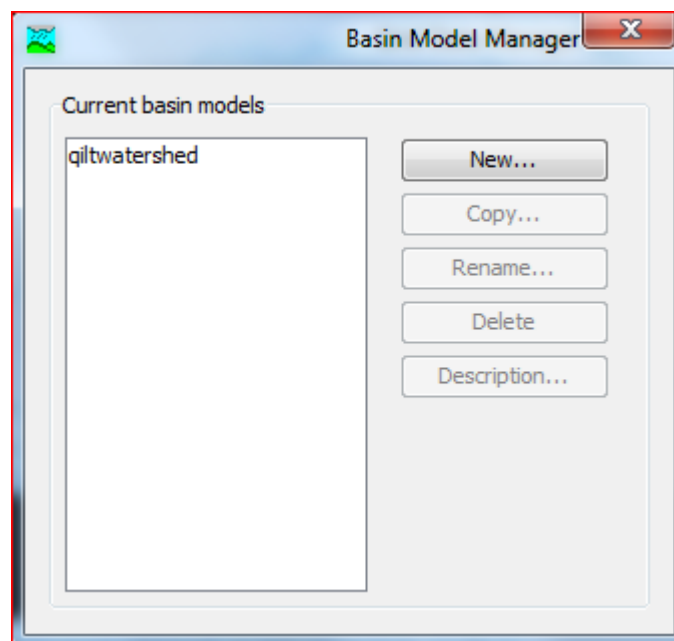


Figure 4. 9: Create a new Basin Model

When the basin model added the hydrologic elements shall be connected and added to give the reflection of the real world watershed. The hydrologic element and the Basin Model parameter

are entered in the Component Editor. Figure 4.13, 4.14, and 4.15 is showing the Component Editor for Ramallah, Nabaa, and Jericho subbasin, respectively.

Basin Name: qiltwatershed	
Element Name: ramallah	
*Initial Storage (%)	0
*Max Storage (MM)	2
Crop Coefficient:	1.0
Uptake Method:	Simple

Basin Name: qiltwatershed	
Element Name: ramallah	
*Initial Storage (%)	0
*Max Storage (MM)	15

Basin Name: qiltwatershed	
Element Name: ramallah	
Description:	<input type="text"/>
Downstream:	9C
*Area (KM2)	81.6200
Latitude Degrees:	<input type="text"/>
Latitude Minutes:	<input type="text"/>
Latitude Seconds:	<input type="text"/>
Longitude Degrees:	<input type="text"/>
Longitude Minutes:	<input type="text"/>
Longitude Seconds:	<input type="text"/>
Canopy Method:	Simple Canopy
Surface Method:	Simple Surface
Loss Method:	SCS Curve Number
Transform Method:	SCS Unit Hydrograph
Baseflow Method:	--None--

Basin Name: qiltwatershed	
Element Name: ramallah	
Graph Type:	Standard (PRF 484)
*Lag Time (MIN)	60

Basin Name: qiltwatershed	
Element Name: ramallah	
Initial Abstraction (MM)	<input type="text"/>
*Curve Number:	80.37
*Impervious (%)	5

Figure 4.10: Component Editor for Ramallah sub basin

Basin Name: qiltwatershed	
Element Name: nabaa	
Description:	<input type="text"/>
Downstream:	8C
*Area (KM2)	37.8750
Latitude Degrees:	<input type="text"/>
Latitude Minutes:	<input type="text"/>
Latitude Seconds:	<input type="text"/>
Longitude Degrees:	<input type="text"/>
Longitude Minutes:	<input type="text"/>
Longitude Seconds:	<input type="text"/>
Canopy Method:	Simple Canopy
Surface Method:	Simple Surface
Loss Method:	SCS Curve Number
Transform Method:	SCS Unit Hydrograph
Baseflow Method:	--None--

Basin Name: qiltwatershed	
Element Name: jericho	
Graph Type:	Standard (PRF 484)
*Lag Time (MIN)	364.0020

Basin Name: qiltwatershed	
Element Name: jericho	
Graph Type:	Standard (PRF 484)
*Lag Time (MIN)	364.0020


Basin Name: qiltwatershed	
Element Name: jericho	
Graph Type:	Standard (PRF 484)
*Lag Time (MIN)	364.0020

Basin Name: qiltwatershed	
Element Name: jericho	
Graph Type:	Standard (PRF 484)
*Lag Time (MIN)	364.0020

Figure 4.11: Component Editor for Nabaa sub basin

Basin Name: qiltwatershed
Element Name: jericho

Description:

Downstream: 10C 

*Area (KM2) 39.6372

Latitude Degrees:


Latitude Minutes:


Latitude Seconds:


Longitude Degrees:


Longitude Minutes:


Longitude Seconds:

Canopy Method: Simple Canopy 

Surface Method: Simple Surface 

Loss Method: SCS Curve Number 

Transform Method: SCS Unit Hydrograph 


Baseflow Method: --None-- 

Basin Name: qiltwatershed
Element Name: jericho

*Initial Storage (%) 0

*Max Storage (MM) 2

Crop Coefficient: 1.0

Uptake Method: Simple 

Basin Name: qiltwatershed
Element Name: jericho

*Initial Storage (%) 0

*Max Storage (MM) 3

Basin Name: qiltwatershed	
Element Name: jericho	
Initial Abstraction (MM)	<input type="text"/>
*Curve Number:	66.12
*Impervious (%)	2
Basin Name: qiltwatershed	
Element Name: jericho	
Graph Type:	Standard (PRF 484) ▼
*Lag Time (MIN)	364.0020

Figure 4.12: Component Editor for Jericho sub basin

4.17 Metrological Model Creation

The meteorological model can be added to the project in the same way as for the basin model as shown in Figure 4.16. The basin model is defined and requiring precipitation from the meteorological model.

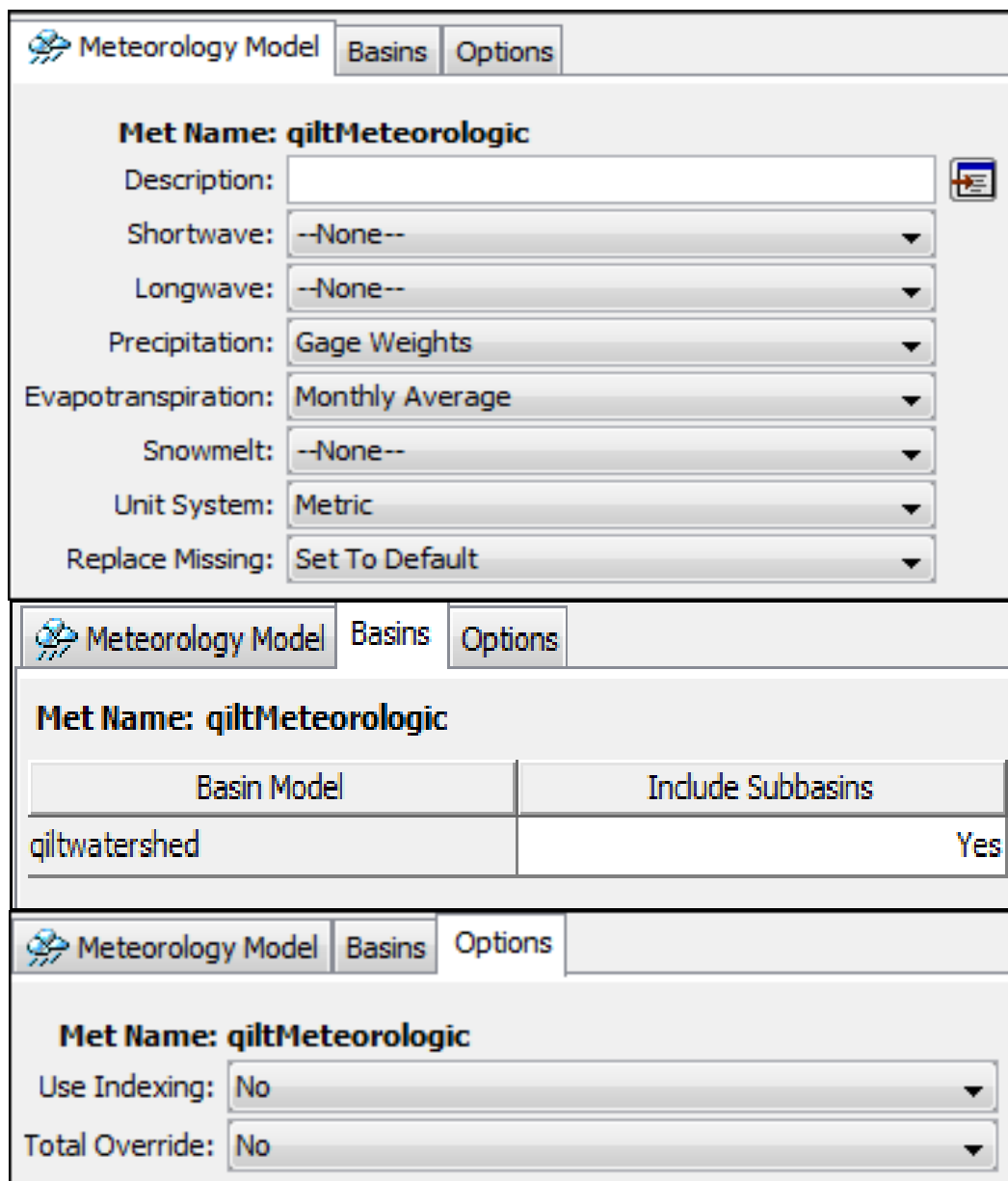


Figure 4.13: Component Editor for the meteorological model

For Jericho metrological station, noting that the values of evapotranspiration were taken from Remote Sensing tool. Figure 4.17 showing the evapotranspiration for Jericho sub-basin.

Element Name: jericho	
Gage Name	Use Gage
Jericho Station	Yes
Middle station	No
Ramallah Station	No

Components	Compute	Results
Monthly Average		
Met Name: qiltMeteorologic		
Month	Rate (MM/MONTH)	Coefficient
January	2.1	1
February	2.8	1
March	4.4	1
April	6.4	1
May	8.4	1
June	9.6	1
July	10	1
August	9.1	1
September	7.5	1
October	5.2	1
November	3.3	1
December	2.2	1

Figure 4.17: Component Editor for a meteorological model for Jericho sub-basin

Figure 4.18 is showing the evapotranspiration for the middle (Nabaa) metrological station

Selections		Weights	
Element Name: nabaa			
Gage Name	Depth Weight	Time Weight	
Middle station	1	1	

Components		Compute	Results
Monthly Average			
Met Name: qiltMeteorologic			
Month	Rate (MM/MONTH)	Coefficient	
January	1.5	1	
February	2.2	1	
March	2.6	1	
April	3.8	1	
May	4.8	1	
June	5.5	1	
July	5.7	1	
August	6.3	1	
September	4.7	1	
October	5.1	1	
November	4.2	1	
December	1.8	1	

Figure 4.14: Component Editor for a meteorological model for Nabaa (middle) sub-basin

For Ramallah metrological station the evapotranspiration values is in the Figure 4.19.

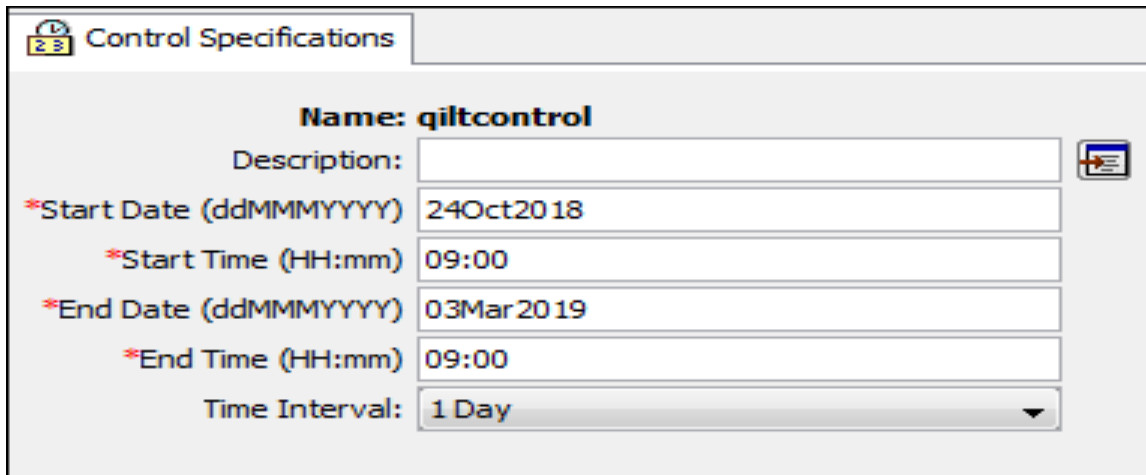
Selections		Weights	
Element Name: ramallah			
Gage Name	Depth Weight	Time Weight	
Ramallah Station	1	1	

Figure 4.15: Component Editor for a meteorological model for Ramallah sub-basin

Appendices 3 containing all the values of evapotranspiration for the three sub basin in al Qilt catchment area.

4.18 Defining Control Specifications

The control specification can be added to the project by selecting component icon then Control Specifications Manager menu options. Choose New and enter the description and the dates for the storm as shown in Figure 4.20.



Control Specifications	
Name:	qiltcontrol
Description:	
*Start Date (ddMMMYYYY)	24Oct2018
*Start Time (HH:mm)	09:00
*End Date (ddMMMYYYY)	03Mar2019
*End Time (HH:mm)	09:00
Time Interval:	1 Day

Figure 4.20: Control Specifications

4.19 Time series data

In this time series the rainfall data for each sub-catchment will be calculated, noting that these data for Ramallah and Jericho metrological data were taken from the Palestinian Metrological Department (PMD).

Two metrological stations were found in Al-Qilt catchment, one in the western side of the catchment called RAM00004 this station is at an elevation of 856 amsl, and the other metrological station is from the eastern side of the catchment and called JER00005 with an elevation of -260 bmsl, and in order to cover the whole catchment we create a hypothetical metrological station called Nabaa metrological station, the readings of this station were taken by adding 0.4 of RAM00004 and 0.4 of JER00005 plus 0.2 multiplied by the average readings of the two stations. Figure 4.21 showing the graph for Jericho, Ras Al-Al-Qilt spring which will be called after (Nabaa), and Ramallah sub-catchments.

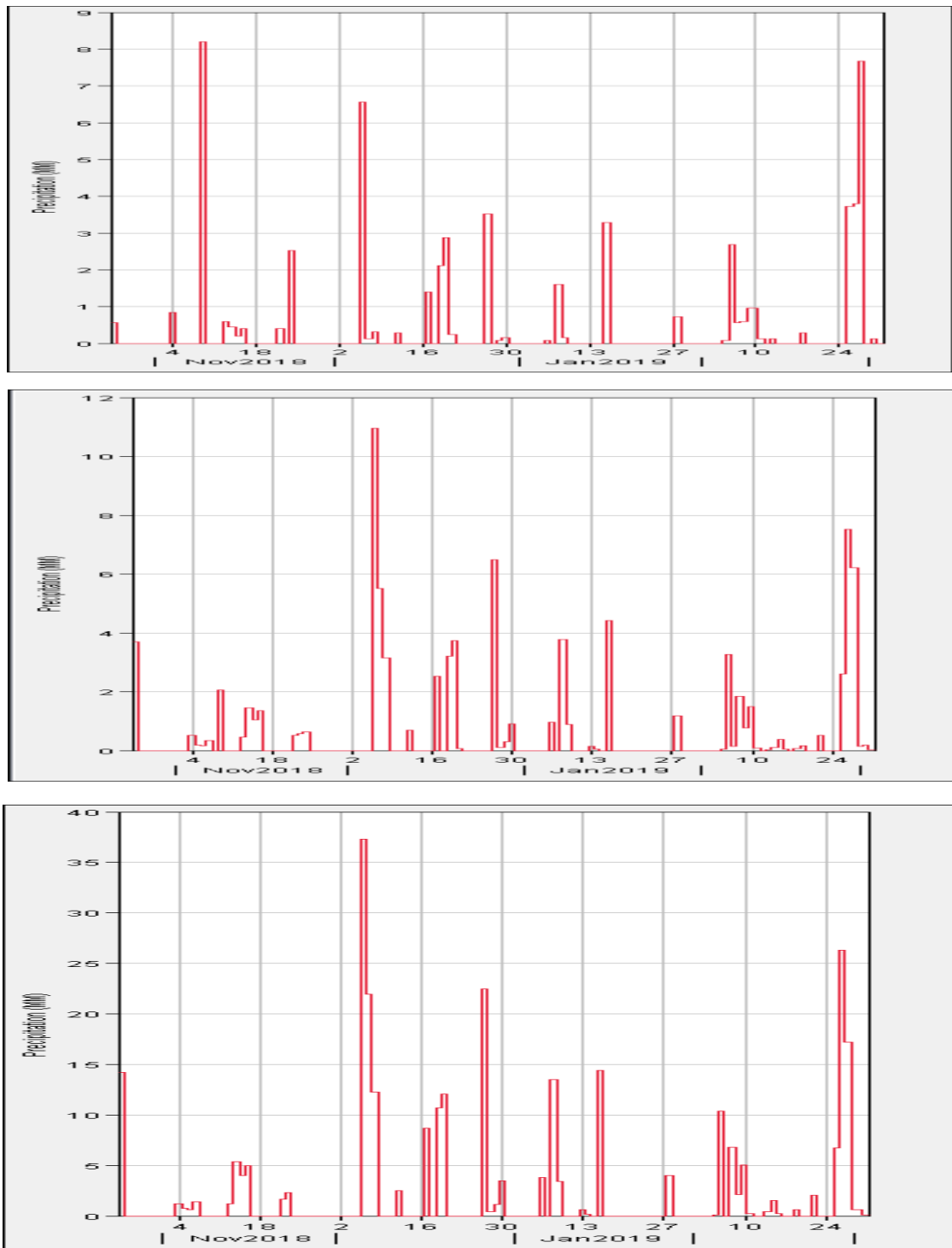


Figure 4.21: Hyetograph for the three sub-catchments

The hyetograph (Figure 4.21) is a graphical representation of the distribution of rainfall intensity over time. For instance, in the 24-hour rainfall distributions as developed by the Soil Conservation Service (now the NRCS or National Resources Conservation Service), rainfall intensity progressively increases until it reaches a maximum and then gradually decreases.

Where this maximum occurs and how fast the maximum is reached is what differentiates one distribution from another. One important aspect to understand is that the distributions are for design storms, not necessarily actual storms. In other words, a real storm may not behave in this same fashion. The maximum intensity may not be reached as uniformly as shown in the SCS hyetographs.

4.20 Create and Compute a Simulation Run

This run can be done by choosing Compute icon then Run Manager option. Then click New in the Simulation Run Manager window. The simulation run is calculated through choosing Compute then Select Run option and then choosing the simulation run.

4.20.1 Global Summary

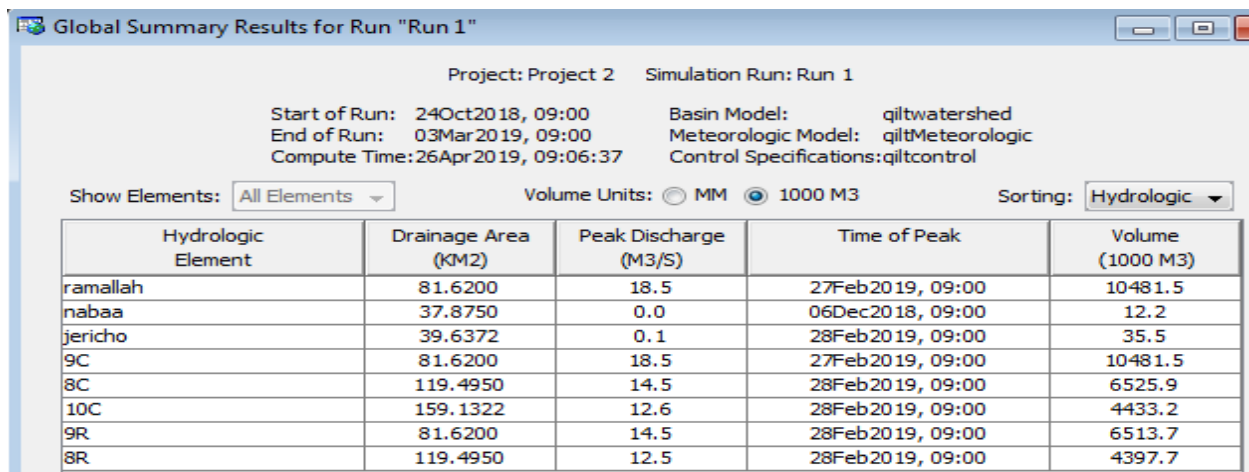


Figure 4.22: Global summary for the run (Run1)

4.20.2 Sub basin results for Jericho sub basin

Figure 4.23, Figure 4.24 is showing the graph and the summary results for Jericho sub basin after the run.

Each bar gives the volume of recharge with the corresponding day.

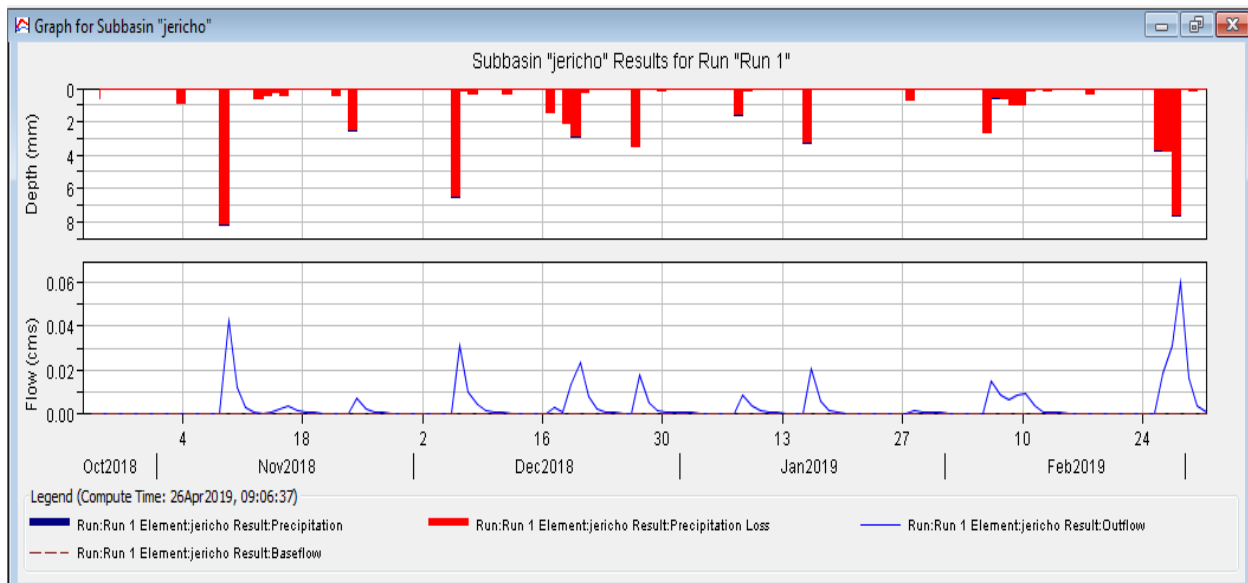


Figure 4.23: Summary results for Jericho sub basin

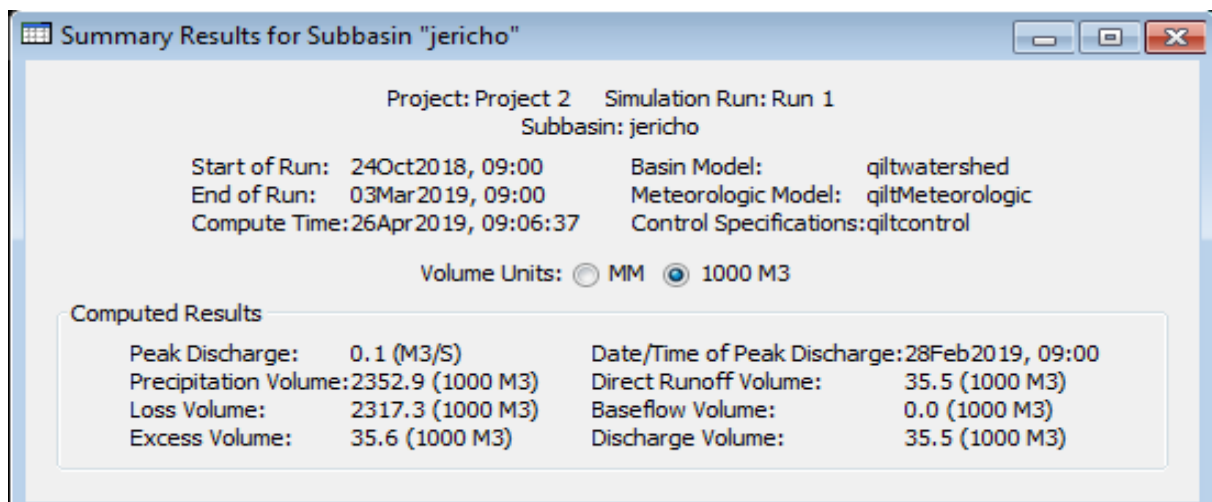


Figure 4.24: Summary results for Jericho sub basin

4.20.3 Sub basin results for Nabaa sub basin

Figure 4.25 and Figure 4.26, respectively is showing the graph and the summary results for Jericho sub basin after the run.

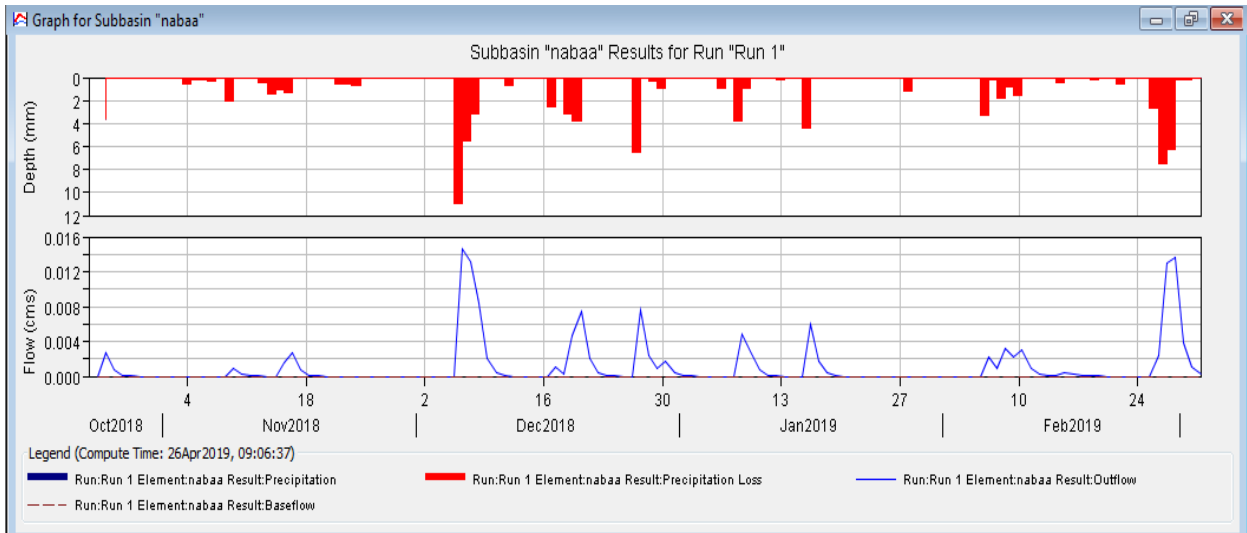


Figure 4.25: A Graph results for Nabaa sub basin

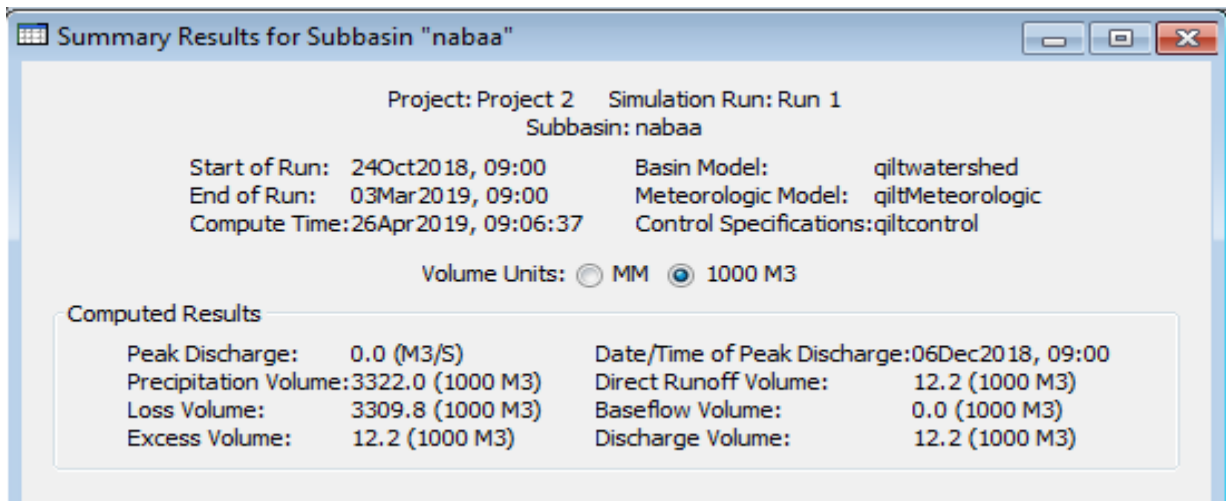


Figure 4.26: Summary results for Nabaa sub basin

4.20.4 Sub basin results for Ramallah sub basin

Figure 4.27 and Figure 4.28, respectively is showing the graph and the summary results for Ramallah sub basin after the run.

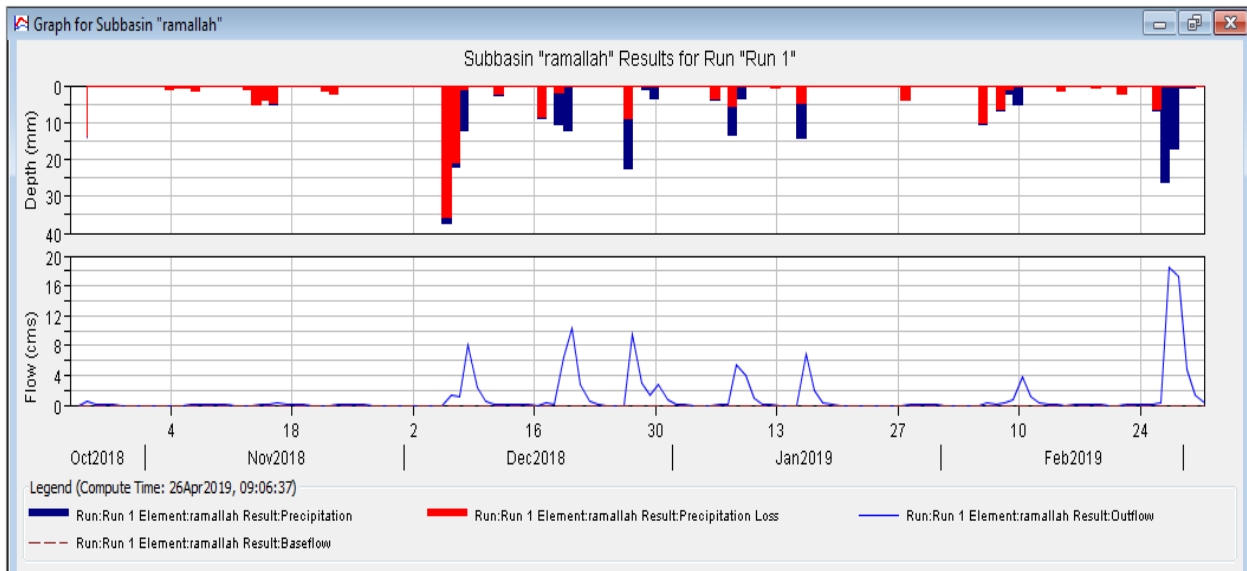


Figure 4.27: Graph for Ramallah sub basin

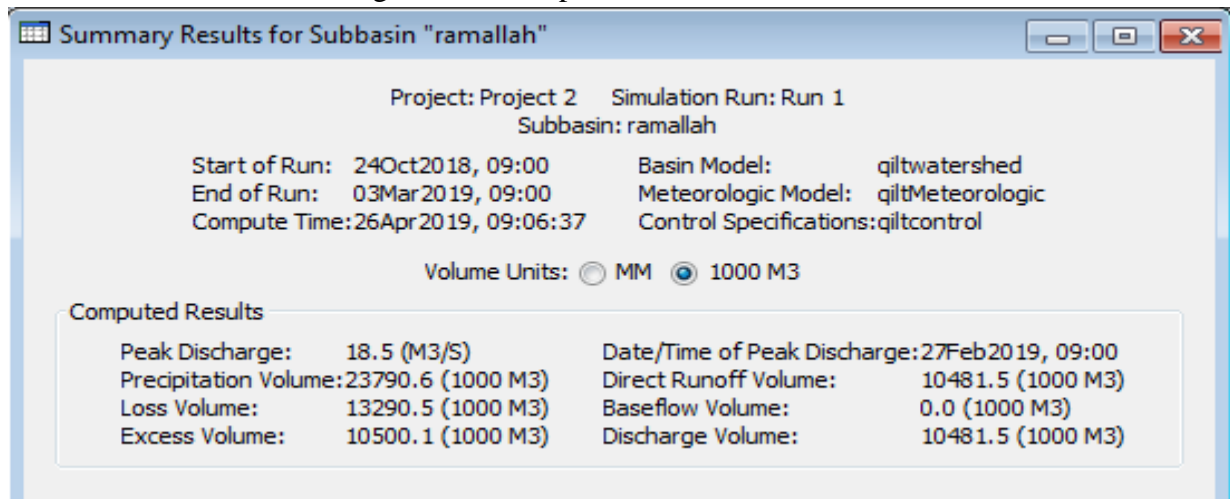


Figure 4.28: Summary Results for Ramallah sub basin

4.20.5 Sub basin results for Jericho sub basin

The results for the precipitation and outflow are shown in Figure 4.29.

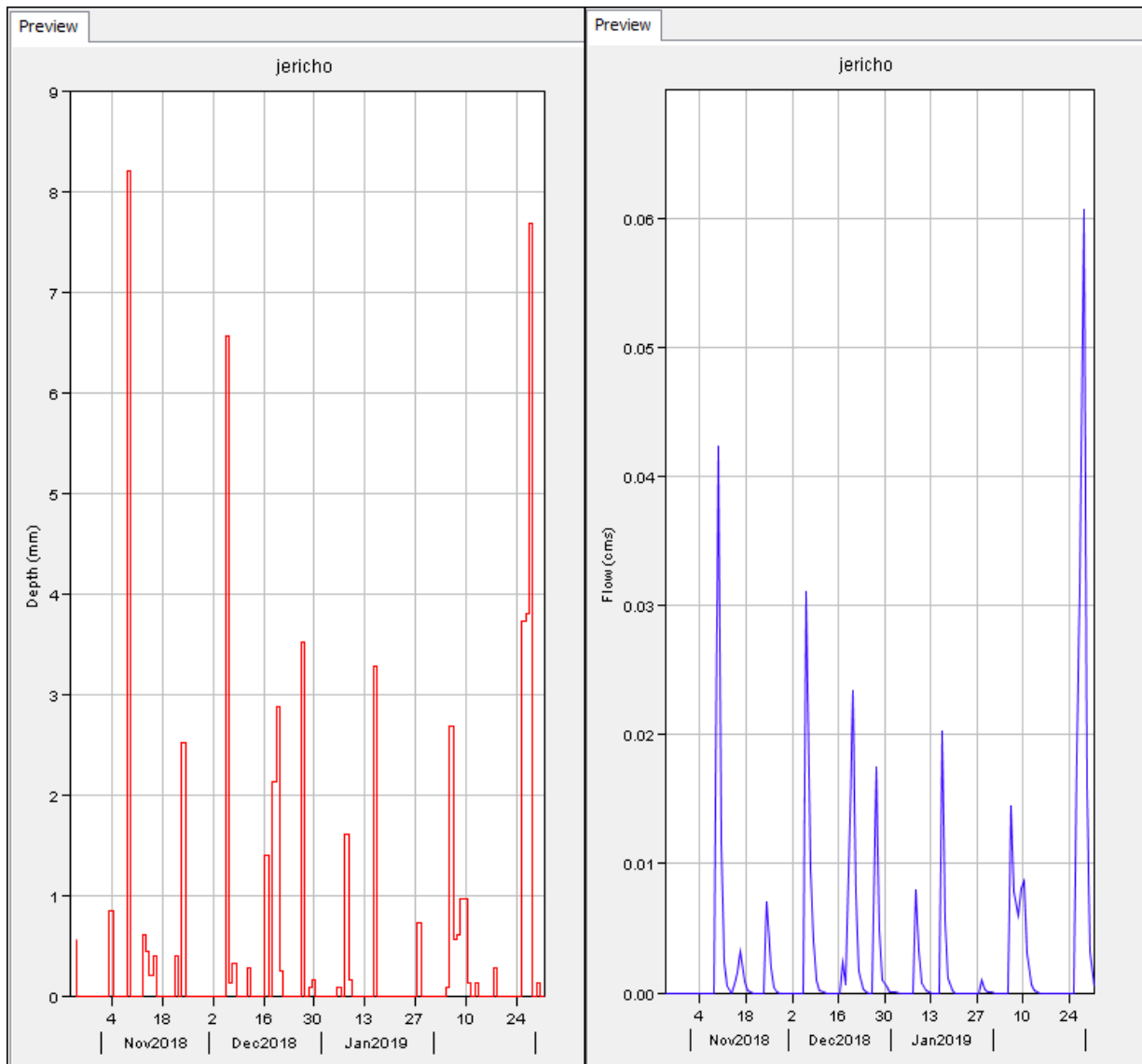


Figure 4.29: Outflow and Precipitation graph for Jericho

4.20.6 Sub basin results for Nabaa sub basin

The results for the precipitation and outflow are shown in Figure 4.30.

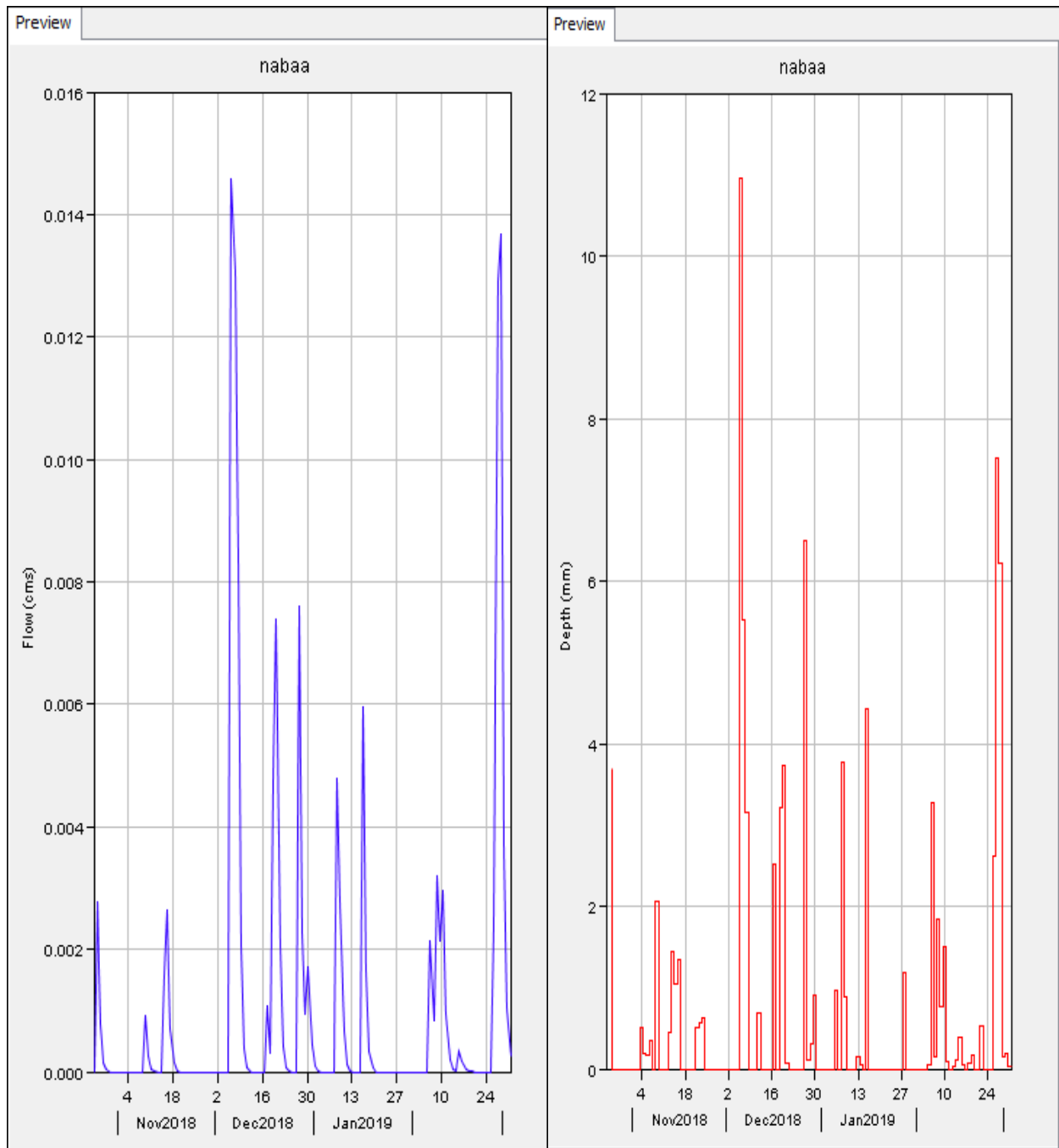


Figure 4.30: Outflow and Precipitation graph for Nabaa

4.20.7 Sub basin results for Ramallah sub basin

The results for the precipitation and outflow are shown in Figure 4.31.

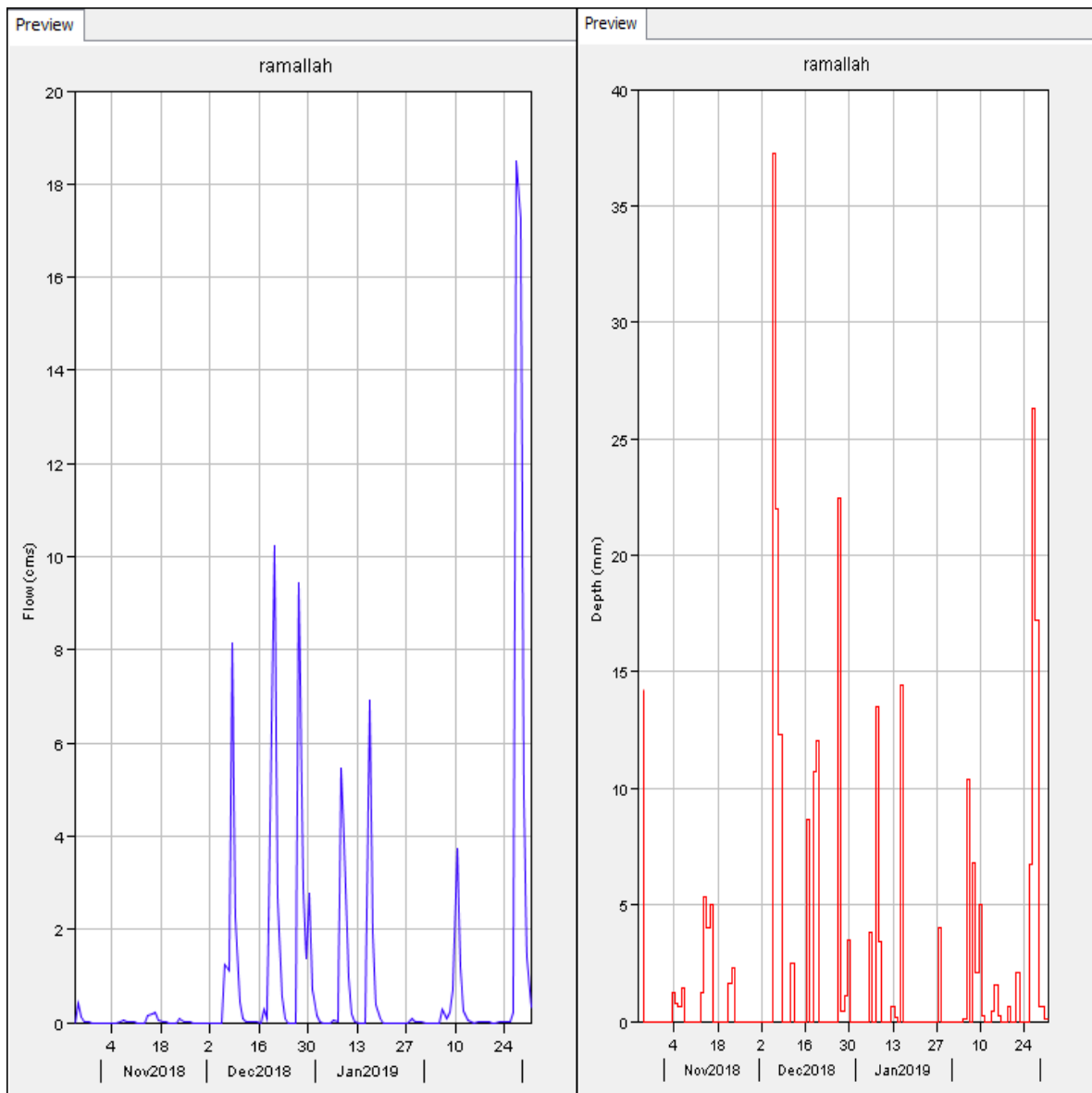


Figure 4.31: Outflow and Precipitation graph for Ramallah

4.21 HEC-HMS and choosing the appropriate method for artificial recharge

According to the results obtained from the model we can see that the basin is generating a huge amounts of water and by adding the voulumes of the three subcatchments we will have $35.5+12.2+10482= 10530 \text{ m}^3/\text{hr}$.

This enormous amount of water need to be considered and making use of this water in order to benifet the farmers downstream Al-Qilt catchment in the quantity and also in the quality of water, so that after studying the results obtained by the model it will help the hydrologists and the dissicion makers to choose the best method for artificial recharge.

HEC-HMS model have a lot of applications in the design of dam's spilway for example in a conjunction of other software, and a lot of studies can be carried out including the water quality studies and the treatment of water just before the process of artificial recharge.

Determining which of a wide variety of techniques is likely to provide reliable recharge estimates is often difficult. Various factors need to be considered when choosing a method of quantifying recharge.

The use of the HEC-HMS model is very essential to better understanding of the basin management since the results obtained from the model can be used in the aquifer management for determing the exact time of peak discharge, and also for determing the scale of artificaal recharge technique that will be used.

The space/time scales of recharge estimates are important because different study goals require recharge estimates over different space and/or time scales. Where as some studies focus on recharge estimates for water-resource assessment. Although spatial variability in recharge at local and intermediate scales may not be critical for water resource assessment, it is critical for contaminant transport, because focused recharge and preferential flow allow contaminants to migrate rapidly through the unsaturated zone to underlying aquifers.

Depending on the results obtained from the HEC-HMS model the hydrologists can estimate the volume of discharge and the basin behaviour depending on the hyetographs and the hydrographs, and also to decide the appropriate technique that will be used for artificial recharge.

Chapter Five

Conclusion and Recommendations

5.1 Conclusion

Al-Qilt Catchment have a big share of water flowing from the local streams and the mountains around and there is a need to benefit from the water that is flowing to the Jordan River without any significant use.

The created HEC-HMS model was well verified during a storm event by estimating the amount of discharged water from Al-Qilt catchment (Including the three subbasins) and comparing the results of the model with the results obtained by the Palestinian Water Authority team field's data, we can find:

- The results measured and estimated in the field on the 27th of February, 2019 was estimating that the surface speed of the water was 3.2 m/s, and the cross section was 9.2m wide with a height of water 0.75 m, and by taking 85% (as a protocol used in PWA since a long time) of the flow, the flow is 18.77 m³/s , and the total flow in the year is approximately 67565 m³/hr.
- The results of the model in the section were 18.5 m³/s, that's $18.5 * 60 * 60 = 66600$ m³/hr.

HEC_HMS can be used in building the early warning system in Palestine, this model can be used in predicting the possibility of flood by assuming a hypothetical storm and assuming the volume of discharge in the catchment. Also this software can be used in Dam's Spillway Design and flood forecasting.

5.2 Recommendations

- Al-Qilt catchment needs projects for artificial recharge such as dams, collecting pools, and injection wells. Unfortunately these projects need permission from the Israeli side since part of the catchment is fully controlled by the occupation.
- The HEC-HMS model is a very good simulation tools that PWA and General Administration of Local Resources will apply for many catchments in Palestine.
- In order to make the best benifets of this model divers and instrunents for flood measurements should be installed in the basin river in order to take periodic measurements of the water flood.

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Appendices

Appendix 1: Extraction Wells in Al-Qilt Catchment area

#	Well Code	Owner	X	Y	Z	Depth (m)	SWL (m)	DW L(m)	Pump sett.	Q (m/h)
1	19-13/005A(B)	Zuhair Manasrah	193533	143219	-284	104	70	104	103	25
2	19-13/015A	Jawad Masri	196142	139432	-293					40
3	19-13/018A	Naser Qtam	196065	138870	-291					
4	19-13/22A	Basil Hussaine	195418	138455	-280					
5	19-13/26A	Ismil D'eq	195428	138799	-273	90	59.9	81.5	85	35
6	19-13/048	Watheq Nahhas	195320	139727	-280	128	100	125	125	18
7	19-13/049	Saleem Nammari	195527	139446	-302	110	90		108	20
8	19-13/50A	Mahmud Ekremawi	195814	139347	-282	150			145	50
9	19-13/51A	Naeem E'sawi	195698	139668	-282	120			115	40
10	19-13/052	Zuhdi Hashwah	195916	139635		120				25
11	19-13/055	Abed Hameed Hashlamoon	196187	139625	-292	104		103	103	
12	19-13/071	Project Well (D'eq)	196953	139817	-308					
13	19-13/074	Jericho Gate	194981	136619						
14	19-13/075	Ismil D'eq	194955	139533						
15	19-13/076	Basel Hussaine	193900	138495						
16	19-13/077	Hosheyah /Awqaf	197670	139019	-322	70	21	69	69	10
17	19-13/078	Majed Tarifi/Awqaf	197628	138811	-324	75	17	34	63	50
18	19-13/079	Harb /Awqaf	197793	138500	-321	70	21	69	69	5

Appendices 2: Rainfall data in the study area for the three sub-catchments

Date	Ramallah	Jericho	Naba'a
25-Oct-18	14.24	0.56	3.7
26-Oct-18	0	0	0
27-Oct-18	0	0	0
28-Oct-18	0	0	0
29-Oct-18	0	0	0
30-Oct-18	0	0	0
31-Oct-18	0	0	0
1-Nov-18	0	0	0
2-Nov-18	0	0	0
3-Nov-18	0	0	0
4-Nov-18	1.2	0.84	0.51
5-Nov-18	0.76	0	0.19
6-Nov-18	0.64	0	0.16
7-Nov-18	1.4	0	0.35
8-Nov-18	0	0	0
9-Nov-18	0	8.2	2.05
10-Nov-18	0	0	0
11-Nov-18	0	0	0
12-Nov-18	0	0	0
13-Nov-18	1.2	0.6	0.45
14-Nov-18	5.36	0.44	1.45
15-Nov-18	4	0.2	1.05
16-Nov-18	5	0.4	1.35
17-Nov-18	0	0	0
18-Nov-18	0	0	0
19-Nov-18	0	0	0
20-Nov-18	0	0	0
21-Nov-18	0	0	0
22-Nov-18	1.64	0.4	0.51
23-Nov-18	2.28	0	0.57
24-Nov-18	0	2.52	0.63
25-Nov-18	0	0	0
26-Nov-18	0	0	0
27-Nov-18	0	0	0
28-Nov-18	0	0	0
29-Nov-18	0	0	0
30-Nov-18	0	0	0
1-Dec-18	0	0	0
2-Dec-18	0	0	0
3-Dec-18	0	0	0

4-Dec-18	0	0	0
5-Dec-18	0	0	0
6-Dec-18	37.28	6.56	10.96
7-Dec-18	21.96	0.12	5.52
8-Dec-18	12.28	0.32	3.15
9-Dec-18	0	0	0
10-Dec-18	0	0	0
11-Dec-18	0	0	0
12-Dec-18	2.48	0.28	0.69
13-Dec-18	0	0	0
14-Dec-18	0	0	0
15-Dec-18	0	0	0
16-Dec-18	0	0	0
17-Dec-18	8.68	1.4	2.52
18-Dec-18	0	0	0
19-Dec-18	10.72	2.12	3.21
20-Dec-18	12.04	2.88	3.73
21-Dec-18	0	0.24	0.06
22-Dec-18	0	0	0
23-Dec-18	0	0	0
24-Dec-18	0	0	0
25-Dec-18	0	0	0
26-Dec-18	0	0	0
27-Dec-18	22.44	3.52	6.49
28-Dec-18	0.4	0	0.1
29-Dec-18	1.12	0.08	0.3
30-Dec-18	3.48	0.16	0.91
31-Dec-18	0	0	0
1-Jan-19	0	0	0
2-Jan-19	0	0	0
3-Jan-19	0	0	0
4-Jan-19	0	0	0
5-Jan-19	0	0	0
6-Jan-19	3.8	0.08	0.97
7-Jan-19	0	0	0
8-Jan-19	13.48	1.6	3.77
9-Jan-19	3.4	0.16	0.89
10-Jan-19	0	0	0
11-Jan-19	0	0	0
12-Jan-19	0	0	0
13-Jan-19	0.6	0	0.15
14-Jan-19	0.16	0	0.04
15-Jan-19	0	0	0

16-Jan-19	14.4	3.28	4.42
17-Jan-19	0	0	0
18-Jan-19	0	0	0
19-Jan-19	0	0	0
20-Jan-19	0	0	0
21-Jan-19	0	0	0
22-Jan-19	0	0	0
23-Jan-19	0	0	0
24-Jan-19	0	0	0
25-Jan-19	0	0	0
26-Jan-19	0	0	0
27-Jan-19	0	0	0
28-Jan-19	4	0.72	1.18
29-Jan-19	0	0	0
30-Jan-19	0	0	0
31-Jan-19	0	0	0
1-Feb-19	0	0	0
2-Feb-19	0	0	0
3-Feb-19	0	0	0
4-Feb-19	0	0	0
5-Feb-19	0.08	0.08	0.04
6-Feb-19	10.4	2.68	3.27
7-Feb-19	0	0.56	0.14
8-Feb-19	6.8	0.6	1.85
9-Feb-19	2.12	0.96	0.77
10-Feb-19	5.04	0.96	1.5
11-Feb-19	0.24	0.12	0.09
12-Feb-19	0	0	0
13-Feb-19	0	0.12	0.03
14-Feb-19	0.4	0	0.1
15-Feb-19	1.56	0	0.39
16-Feb-19	0.2	0	0.05
17-Feb-19	0	0	0
18-Feb-19	0	0.28	0.07
19-Feb-19	0.64	0	0.16
20-Feb-19	0	0	0
21-Feb-19	0	0	0
22-Feb-19	2.08	0	0.52
23-Feb-19	0	0	0
24-Feb-19	0	0	0
25-Feb-19	0	0	0
26-Feb-19	6.72	3.72	2.61
27-Feb-19	26.28	3.8	7.52

28-Feb-19	17.2	7.68	6.22
1-Mar-19	0.6	0	0.15
2-Mar-19	0.6	0.12	0.18
3-Mar-19	0.08	0	0.02

Appendices 3: Evapotranspiration rates for the three subcatchments in the study area

- **For Jericho Subcatchment**

Month	Average
Jan	2.1
Feb	2.8
Mar	4.4
Apr	6.4
May	8.4
Jun	9.6
Jul	10
Aug	9.1
Sep	7.5
Oct	5.2
Nov	3.3
Dec	2.2

- **For Nabaa Subcatchment**

Month	Average
Jan	1.5
Feb	2.2
Mar	2.6
Apr	3.8
May	4.8
Jun	5.5
Jul	5.7
Aug	6.3
Sep	4.7
Oct	3
Nov	2.1
Dec	1.7

- **For Ramallah Subcatchment**

Month	Average
Jan	0.9
Feb	1.6
Mar	1.3
Apr	1.2
May	1.5
Jun	4
Jul	5.2
Aug	6.0
Sep	5.1
Oct	4.2
Nov	2.6
Dec	2.1