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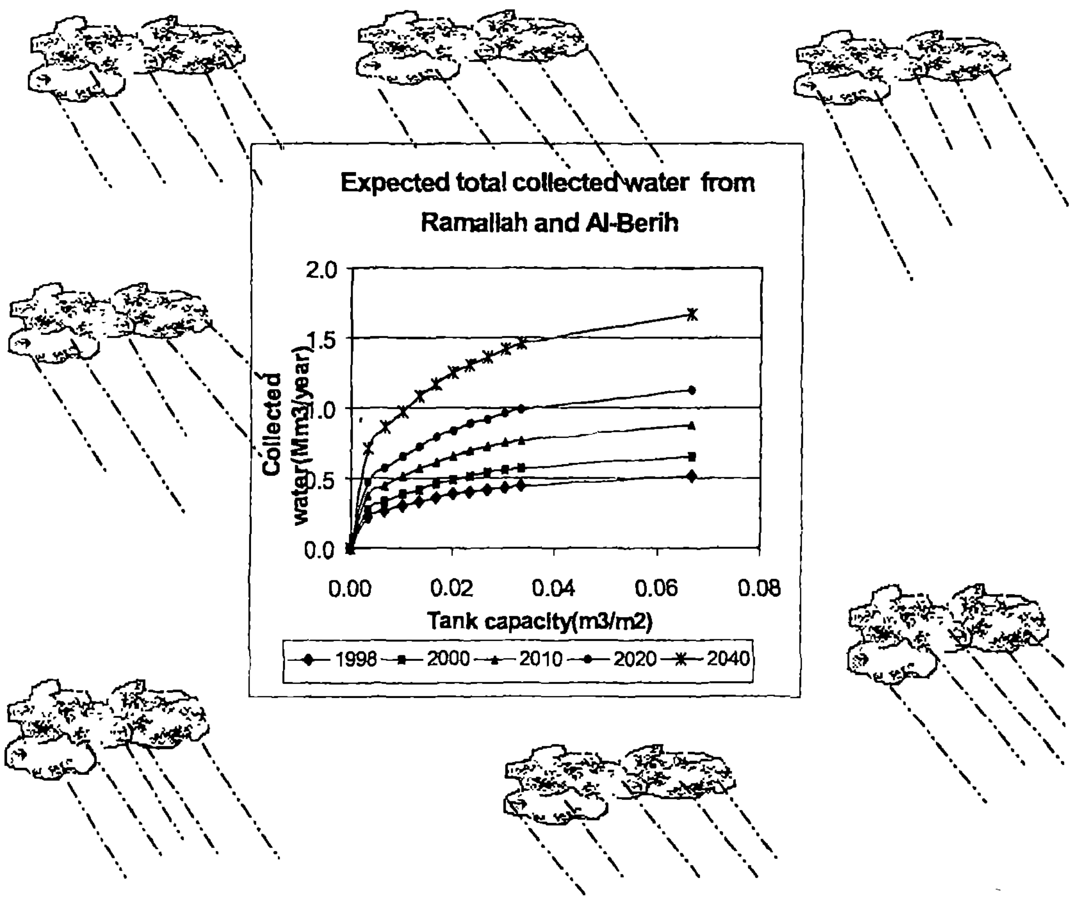

Integrated Approach to Assess the Feasibility of Rainwater Harvesting in Palestine

Case study: Ramallah and Al-Berih cities (Urban Areas)
Ain-Areek Village (Rural Areas)

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Integrated Approach to Assess the Feasibility of Rainwater Harvesting in Palestine

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Master of Science Thesis
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I dedicate my thesis to my parents,
my brothers Zoher and Ziad,
And to my sisters
with love.

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List of abbreviations

ARIJ: Applied Research Institute for Jerusalem
BZU: BirZeit University
EAC: Equivalent Annual Cost
GTZ: Deutsche Gesellschatt Fur Technische Zusammenarblet.(Technical cooperation-Federal Republic of Germany)
HIID: Harvard Institute for International Development
IRC: International Reference Center
JWU: Jerusalem Water Undertaking
MOPIC: Ministry Of Planning and International Cooperation
PCBS: Palestinian Central Bureau of Statistics
PHG: Palestinian Hydrological Group
PWA: Palestinian Water Authority
PWS: Public Water Supply
RWHS: Rainwater Harvesting System
UFW: Unaccounted For Water
WB: The West Bank
WHO: World Health Organization
WSDS: Water Supply Distribution System

Acknowledgements

Any words of thanks I say here cannot express fully my deep appreciation towards my father and my mother, who have throughout my life, and especially during my studies, given me unlimited care and support. I feel their "*Da'awat*", even as I am away from them. I love them very much and I wish I could do for them as much as they do for me. I am also deeply thankful for my brother Zoher, with whom, after so long, I shared a very special time that will be kept in a sweet place of my memory for the rest of my life. Together him, my bother Ziad, and my dear cousin Dawood Sa'eed gave me their help, encouragement, and financial support.

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Samhan Samhan

Abstract

Currently, groundwater is considered the only source of water for the Palestinians. The groundwater basin abstractions are to a large extent controlled by Mekorot (the Israelis water company). The Palestinians are prohibited to drill or to develop new wells and the aquifer cannot supply more sustainably. Consequently, the existing supply is not sufficient to overcome the water shortage. The Palestinians are considering different development options that seem feasible and acceptable to alleviate the water gap.

This study evaluates of the feasibility and acceptability of using a rainwater harvesting system to supplement and alleviate the water shortage in the Palestinian territories, taking as a case study Ramallah and Al-Berih cities (Urban areas) and Ain-Areek village (Rural areas).

Firstly, an estimation is made of the current and the future total demand for the years 2000, 2010, 2020 and 2040. Total demand includes domestic, industrial and commercial demand. It was estimated that the current total demand is 3.5 Mm^3 /a and it is expected to rise six times between 1998 and the year 2040.

Then, the financial and technical feasibility for rainwater harvesting system in urban and rural areas are studied. This includes an estimation of the financially optimal sizes of reservoir for the case that the full demand is satisfied by rainwater in times when water is available. Also, an estimation is made of the possible amount of rainwater that can be collected in an average and 75% dry year in a single household and on town scale and an inventory is made of disadvantages and advantages regarding water quality and structural components. Further more, the implementation possibilities and social, technical and financial constraints are discussed.

Rainwater harvesting can be considered as a viable resource that can supplement supply in urban and rural areas and can participate considerably in minimizing the water shortage if it is implemented at large scale. RWHS can supply about 28% of the current per capita domestic consumption in urban areas and about 55% in rural areas provided that financially optimal tank capacities are constructed. In addition to that, financial profits can be achieved especially in rural areas that don't have access to water supply distribution systems. Rainwater harvesting system can decrease the current gap for the whole of Ramallah and Al-Berih cities by about 40%. This value is expected to decrease to only 9% by the year 2040 because of the expected increase in total demand.

Rainwater harvesting participation cannot overcome the whole gap and rainwater-harvesting systems are unlikely to satisfy all the needs of the consumers. For this reason, other development options apart from rainwater harvesting are absolutely needed to overcome the available and future expected gap.

Chapter (1)
Introduction

Groundwater abstraction in West Bank cannot be increased any more. Further more, other alternatives are not available in the current situation. Therefore other possibilities to increase water supply have to be looked into. Rainwater harvesting is being regarded as a good option.

1.1 Description of the problem

Currently, groundwater is considered the only source of water for the Palestinians, except for small-scale rainwater harvesting in rural areas. There are three groundwater basins in the West Bank: The western, the northeastern, and the eastern basin. Their approximate yields are: 335-360, 120-140, 105-125 Mm^3/a respectively (ARIJ & HIID,1994). These basins are semi-completely controlled by Mekorot which is the Israeli water supply company. Mekorot controls the best wells that have the higher yields.

According to the law, that was enforced in 1967, all water resources are regarded public property (Mitwally,S. ,Samhan,S. and Musleh,M.,1996). This law allowed the transfer of water from the Palestinian basins (West Bank and Gaza) to Israel. Consequently 25% of the Israelis needs (which represents 90% of the Palestinian water production) are extracted from West Bank Aquifers (ARIJ, 1996). The remaining 10% are not sufficient to fulfill the increasing needs of the Palestinians. The Palestinians are prohibited to drill or develop new wells, and the aquifers cannot supply more sustainably, so the water extraction is restricted and the existing supply is not sufficient to overcome the water shortage, this is a problem in all the Palestinians territories.

Of the total population in the West Bank 12.3% has no access to piped water supply; while 87.7% are connected to piped system (PWA, 1997). The part that has no access to piped system depends mainly on rainwater harvesting from rooftops. Rainwater is collected by households in cisterns with an average volume of $70m^3$ each (ARIJ, 1996). Such a volume is roughly sufficient to catch the average annual precipitation of an average rooftop. Usually people construct cisterns of more or less $60m^3$,without reference to a special design for the tank capacity. Even the people who are connected to a water supply network are suffering continuously of shortage in quantity and pressure. Palestinian municipalities apply a scheduled supplying pattern for distributing water, in particular during summer. The distribution system is divided into several zones. Each zone receives water one or two days a week.(Saleibi, S. and Shaheen, H,1995). Ramallah and Al-Berih suffer from water shortage, which is expected to increase continuously in the dry season. The population is increasing, because of immigration. People from all-over Palestine would like to live in the cities of Ramallah and Al-Bireh as they are considered the commercial centers in the West Bank. Consequently, the demand increases, while the supply is restricted. Therefore the shortage increases and it becomes more problematic.

About 8.4 Mm^3/a are purchased from Mekorot and from the municipality of Jerusalem by JWU and the West Bank Water Department (WBWD). Of these 8.4Mm^3/a 6.2 Mm^3/a are distributed by JWU (1997). Including the villages and towns from east Jerusalem, while 2.2 Mm^3/a are distributed by WBWD for the district of Ramallah (ARIJ,1996, and JWU, 1998). In addition to the amount supplied by Mekorot, there is a supply from 5 wells owned by JWU which produce about 3.5 Mm^3/a (JWU,1998). There is an additional amount consumed by farmers and villagers that abstract from springs (There are 122 springs located in Ramallah district, the seven major springs together produce 3.8 Mm^3/a which constitute 90% of the total yield of all the springs).(ARIJ,1996)

A lot of money is paid yearly by JWU and WBWD and the other water establishments in the West Bank to the Israeli company Mekorot and Jerusalem Municipality. About Million US$7[1] was paid in the year 1997 to Mekorot for the purchased water to supply Ramallah district. This disturbs the national income, and negatively affects the Palestinian trade balance.

Overexploitation from Ramallah basins is another problem that affects the future allocation of water for the Palestinians. It also affects the groundwater level and causes further damage to it. About 9.8 Mm^3/a are pumped by the Israelis from 8 of their 9 wells that they own in the area, which equals the total Palestinian consumption in Ramallah district.(ARIJ,1996)

The Palestinian are looking for an option that seems feasible and acceptable to alleviate the gap between water demand and supply to decrease the dependence on Mekorot for water supply, and to improve our national trade balance. An option that could be promising and acceptable for minimizing the problem of shortage is rainwater harvesting. In the following subsections it will be explained why rainwater harvesting looks so promising and why this study chose Ramallah and Al-Berih for a case study.

1.2 Why rainwater harvesting?

The rainwater harvesting alternative was considered an option that needed further investigation because:

- Groundwater availability is very restricted and controlled by the Israelis.
- Applying other alternative options seems difficult:

➢ Waste water reuse:
  - Expensive, it cannot provide sufficient quantities at reasonable cost.
  - Not acceptable for the public.
  - Less water quality.
  - More needs for current maintenance and operation.

➢ Sea water desalination(For Dead sea(very high salinity) at Jericho and Mediterranean sea at Gaza):
  - Very expensive (In costs of operation and construction of the desalination stations and the conveyance system).
  - Restrictions by the Israelis.

[1] This value is estimated as follows [8 4*10^6 m3/y * 0.72US$/m^3+ 0 17*(8 4*10^6 m^3/y * 0.72US$/m3) = 7 Million US$]

- ➢ Water import (from Turkey):
  - Restrictions by the Israelis.

- ➢ Surface water(Jordan river):
  - We are not allowed to use our share (257 Mm^3/a) since 1967.
- Availability of relative impervious areas (roofs, streets,..) and the availability of natural slopes in the area.
- Rainwater harvesting is relatively cheap and an easy option to apply locally. Water can be used for domestic purposes after simple treatment.
- The availability of sufficient annual average rainfall in the area.
- The availability of nearby wadies and lands for construction of the storage facilities (Dams and tanks).
- The Palestinian authority has expressed its intention to implement rainwater-harvesting projects, when funds are available.

1.3 Why case study of Ramallah and Al-Bireh together?

To study the availability of rainwater harvesting in urban setting, the towns Ramallah an Al-Berih were together taken as the subject for a case study, for the following reasons:

- Ramallah and Al-Bireh borders are close to each other. Furthermore, they have a lot in common; they almost have the same weather; the same topography; the same type of buildings; and the same habits and traditions. Therefore to involve the two cities in the study is more efficient.
- They are two of the most developed cities in the West Bank (commercially, institutionally, touristically, and industrially). They are located in the middle of the West Bank and can be considered the commercial center of the West Bank. The area is an important industrial sub-region hosting leading branches of food production, chemicals, papers, printing and tourism products.(MOPIC,1996)
- Most of the establishments that are related to the Palestinian authority (Ministries and other institutions) are established in Ramallah and Al-bireh cities. In other words it is considered as: *Economic center,* because of the presence of head quarter of banks, insurance companies, accounting, legal services, and consultancies. Also they are *District shopping center and Regional cultural center*, because of the availability of suitable facilities like conferences halls, cinemas, theaters and parks. They are considered as *public service center* since of the high public service employment. The close location of Birziet university in the north, Qalandyah airport in the south (Formerly under Israel's authority)and the city of Jerusalem have made the two cities attractive for investment and have rise their importance. Consequently, people from all over Palestine like to live in them since they offer more opportunities for jobs. Also the others come for shopping or to practice their activities, even some of them come to enjoy the beautiful weather there (MOPIC,1996). This of course, increases the population in this area. As a result the water demand increases but the supply still is constant. Consequently the gap becomes wider.
- Ramallah has a good rainy season; it has an annual average rainfall of 686(mm/a).
- Data are available for Ramallah and Al -bireh more than for other parts of West Bank and it is easy to get access to data since national water establishments are located there, e.g. Palestinian water authority offices, Jerusalem Water Undertaking etc....

- They are located on a mountain and its natural slopes make it easy to collect the water by gravity flow.
- In side The two cities there is a high percentage of impervious surfaces , roofs and streets. So, infiltration rates are small.

1.4 Objectives of the study

The main objective of this study is to determine if, how and to what extent rain water harvesting can be a feasible option in urban areas to alleviate the water shortage (gap) in the municipalities of Ramallah and Al-Bireh, to decrease the public dependency on the municipal supplied water and to decrease the dependency of Jerusalem Water Undertaking (JWU) on Mekorot (the Israeli water company). Additionally, the objective is to study the feasibility of rainwater harvesting in rural areas.

1.5 Contents of the report

This study contains eight chapters that can be summarized briefly as follows:

Chapter Two gives a description of the study area including location, population, land use, topography and climate.

In chapter Three gives an overview of historical and current rainwater harvesting practices in the West Bank and the World . Definition, RWHS history and the conditions behind the feasibility are disputed. In details description for the roof catchment structural components are viewed. Finally, Technical, economical and social considerations and the advantages and disadvantages of the system are discussed.

Chapter Four demand projections for Ramallah and Al-Berih. Existing and future population, domestic demand, industrial and commercial demand and finally the total demand were estimated for the years 1998, 2000, 2010, 2020, 2040 in this chapter.

Chapter Five includes the hydrological analysis. It contains description of the available three stations in the area and an analysis to choose the most reliable station and finally a rainfall analysis for the chosen station.

Chapter Six a feasibility study for the roof catchment system in Ramallah and al-Berih.This chapter includes a description and evaluation of the existing situation, an estimation of the potential coverage by rainwater harvesting from actual consumption per roof annually for different tank capacities per year, estimation of the total expected collected water from the two cities, days of full demand supplied by rainwater and of spilling, design graphs for tank capacities for the case of Ramallah.A cost-benefit analysis for the system was done giving an estimate of the equivalent annual cost per cubic meter supplied and the expected profits on the long term, an estimate of the optimal tank capacity from the point of view of quantity and profits, and an evaluation of the year effects on investment and collected amount. Also issues for successful implementation were discussed and finally application of rainwater harvesting systems in rural areas is evaluated. To come up with the above results spreadsheet was created which is described in the appendixes.

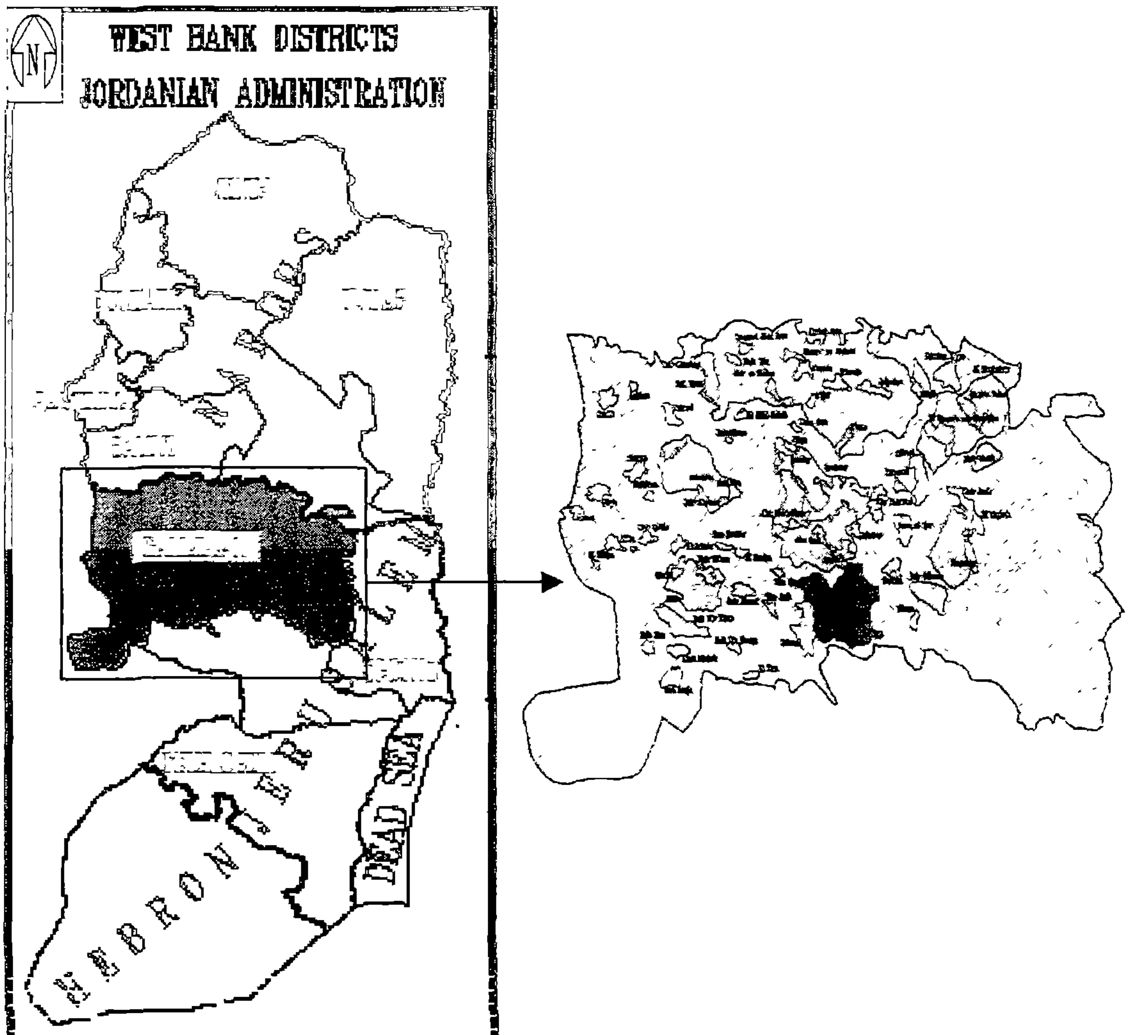
Chapter Seven discusses water resources available for the two cities now and in the future and the role of rainwater harvesting. Then finally, a brief description was given of other development options for full and continuous supply to overcome the expected gap.

Chapter Eight gives a list of conclusions and recommendations.

Chapter (2)
The study area

2.1 Location

Ramallah and Al-Bireh cities are located in the middle of the WB, enthroned upon mountain summits, 13Km to the north of Jerusalem. They are bounded from the north by Nablus, from the south by Jerusalem, from the east by Jericho, and from the west by Israel Figure (2.1) shows the location of Ramallah district and the two cities in the WB.



Figure(2.1): Ramallah district and location of Ramallah city (Dark color in the right map)
Scale: Left map (1:900,000), Right map (1cm≈4.3km)

2.2 Population and Land Use

The total number of people in Ramallah and Al-Bireh was estimated at approximately 48,000 inhabitants for the year 1998 based on a 3.0% growth rate in the medium scenario starting from the reference year 1997 (For more information about the population and their projections for the future, see chapter-4).

According to "Oslo II"- which is an interim agreement between the Israelis and the Palestinians –the Palestinian territories have been divided to three different zones: zone A, zone B, and zone C.Ramallah and Al-Bireh cities are included in zone A. This zone includes also Al-Ama'ri and Qaddura camps. Zone A covers about 23.5 $(Km)^2$, which is 2.8% of the district's total area of about 844 $(Km)^2$.Ramallah constitutes about 14.5 $(Km)^2$, while Al-Berih city constitutes about 9 $(Km)^2$.(ARIJ,1996 & Ramallah and Al-Berih Municipalities,1998).

Table(2.1): Built up areas in Ramallah and Al-Berih

Item/ City	Ramallah	Percentage (%)	Al-Berih	Percentage (%)	Total (dunum)
Residential area(A)	2700	18.62	4182	46.62	6882
Residential area(B)	4929	33.99	2727	30.40	7656
Residential area(C)	1169	8.06	79	0.88	1248
Villas areas	476	3.28	-	-	-
Hotels areas	25	0.17	-	-	-
Offices areas	-	-	266	2.97	-
Industrial areas	337	2.32	196	2.19	533
Commercial areas	319	2.20	39	0.43	358
Agricultural areas	814	5.61	8	0.09	822
Roads areas	847	5.84	1232	13.73	2079
Municipal properties	-	-	139	1.55	-
Religious properties	-	-	69	0.77	-
Other private properties	-	-	33	0.37	-
Public areas	210	1.45	-	-	-
Future planning areas	155	1.07	-	-	-
Side walks	43	0.30	-	-	-
Public buildings	409	2.82	-	-	-
Exhibitions areas	126	0.87	-	-	-
Activities areas	563	3.88	-	-	-
Suggested roads	1315	9.07	-	-	-
Cemeteries	31	0.21	-	-	-
Transportation center	32	0.22	-	-	-
Total	14500	100	8970	100	23470

From Ramallah and Al-Berih municipalities, 1998
All the areas in dunums (dunum=$1000m^2$)

About 60% of the area is inhabited by Palestinians. Table (2.1)shows built up areas in the two cities. They have an average population density of about 2000 capita/$(Km)^2$.

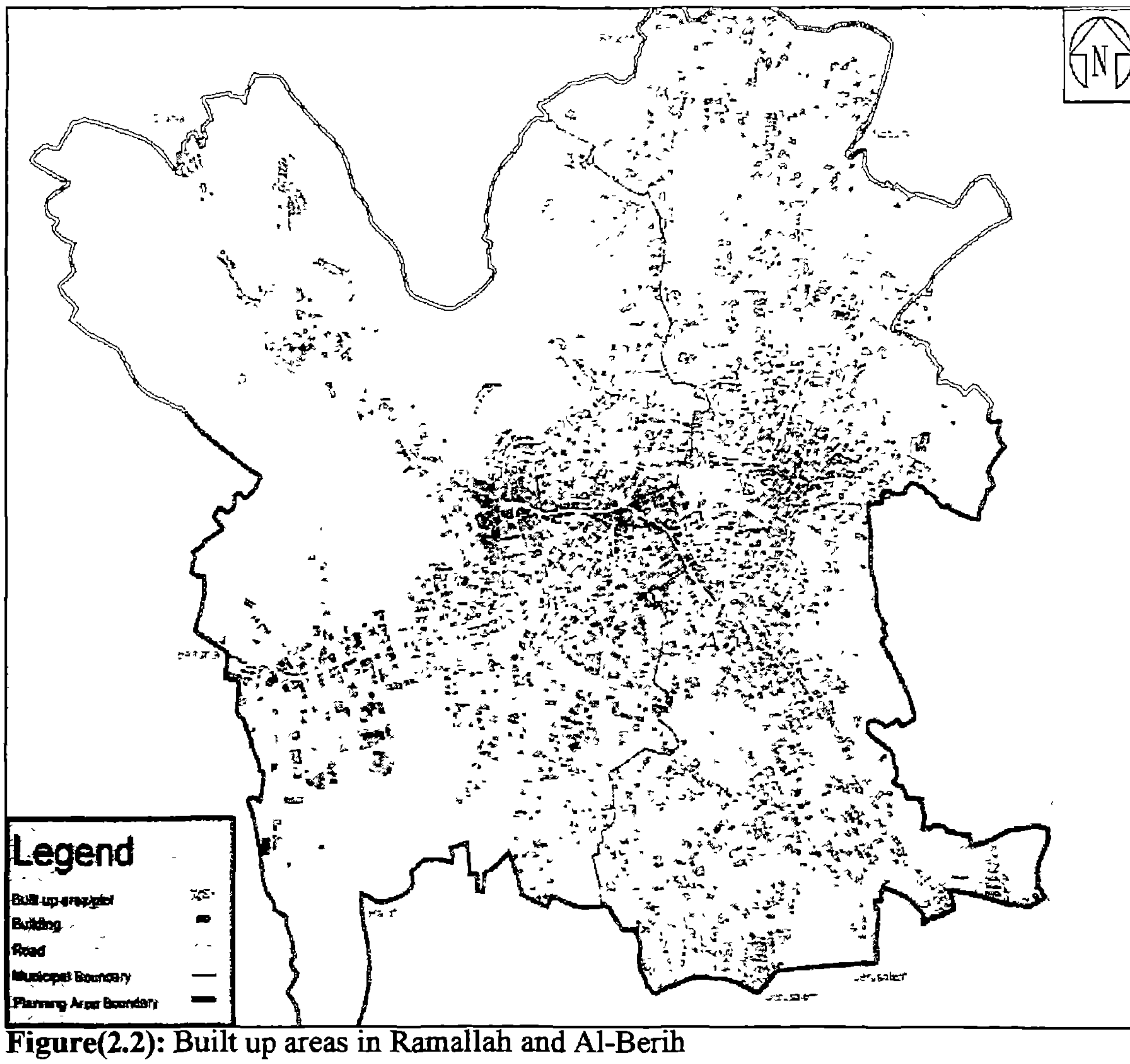
There are 27 Israelis settlements located in the district (ARIJ,1996), one of them is located within the boundaries of Ramallah and Al-Berih cities.

About 110 $(Km)^2$ which constitutes 12.7% of the total area of Ramallah district are occupied by the Israeli army and have been used as closed military basis and areas(ARIJ,1996). After liberation of the two cities no more basis are still located within Ramallah and Al-Bireh Municipalities.

Israel declared 15 natural reserves, which cover 5.6% of the district's area (ARIJ,1996). Non of these natural reserves are located in the boundaries of the two municipalities

Six Forests are located in the district; they have an area of 3 $(Km)^2$, which is about 0.36% of the total area (ARIJ,1996). Ramallah and Al-Bireh have no forests within their boundaries

Figure(2.2) shows Built-up areas, buildings, roads, municipal boundaries and the planning area boundaries for Ramallah and Al-Berih.



Figure(2.2): Built up areas in Ramallah and Al-Berih
From: MOPIC,1998
Scale: 1cm≈450m

Ramallah district has a cultivated area of 240 $(Km)^2$. Of this area only 0.4% is irrigated. Within Ramallah and Al-Bireh Municipalities boundaries there are no considerable agricultural areas.

About 0.5 $(Km)^2$ is covered by two industrial areas that are located in the south of Ramallah and on the east of Al-Bireh.(ARIJ,1996)

2.3 Topography

Ramallah district can be divided into three topographical parts: eastern slopes, mountain crests, and western slopes. Ramallah and Al-Bireh cities are located in the mountain crests, which form the watershed line and separate the eastern slopes from the western slopes. These two cities extend over several hills with an elevation between 600-900m above mean sea level (MOPIC,1996). They have two drainage systems consisting of several wadies, parts running towards the Mediterranean sea (Western slopes), while the other runs towards Jordan River (Eastern slopes).

2.4 Climate

Ramallah and Al-Bireh cities have a rainy winter and a dry summer. The annual average temperature is between 15-20 °C, while the annual average rainfall is 686mm/a. Most rainfall falls between November and March. On average, 51 days out of 365 days are rainy days. Ramallah and Al-bireh cities have an average humidity of about 70.2% which is registered in the year 94/95.(ARIJ,1996)

Chapter (3)
Experiences in rainwater harvesting in the Palestine and the World

3.1 Definition and historical review

Rainwater harvesting can be defined as inducing, collecting, storing and conserving rainfall from a surface (Catchment) to be used in various purposes (Agricultural, industrial and domestic purposes) (Borers, Th.M.,1994).Rainwater harvesting technique exists already for 4000 years in the Negev Desert(Geston, J.).These systems involved smoothing the soil by clearing the hill side to increase runoff then convey the water to lower lying fields by build contour ditches to irrigate crops.

By the time of the Roman Empire, in ancient Rome, individual cisterns were built with the houses, in which rainwater from the city aqueducts was collected.(Agriculture Research Service & U.S Department of Agriculture,1974 & Geston, J.).

Around 1930, in Australia catchments have been built in forms of roofs with out a house under them.(Agriculture Research Service & U.S Department of Agriculture,1974)

In 1959, in Australia, they constructed catchment system consists parallel series of roadway with graded soil drain into ditches which are used to convey the collected water a storage reservoir.

During the 1950s, a small number of catchments were built of sheet steel and concrete to provide water for livestock and wild life in the United States of America.(Agriculture Research Service & U.S Department of Agriculture,1974)

During the 1960s, a lot of studies have been done in the United States, to utilise the soil it self as a catchment structure, e.g. bonding of plastic and metal felms, soil compaction and dispersion which make soil as water repellents.(Agriculture Research Service & U.S Department of Agriculture,1974)

Currently, rainwater harvesting techniques are used all over the world for different purposes, since it is a very interesting option to solve water shortage problems. Particularly, it is used where there is no piped water supply system available, or when gray water is needed because potable water is too expensive. The majority of water harvesting techniques have been developed for agricultural use where the irrigation water is lacking.(United Nations, Water resources series No.63,?). Rainfall is collected from a catchment to maximise runoff for a specific site, e.g. cisterns, dams, cultivated area, soil or aquifer recharge.

Rainwater harvesting from roofs and green houses has been implemented in the West Bank as individual and independent systems on a household scale. The collected rainwater is used for domestic purposes in Urban areas, while it is used for domestic, irrigation and livestock purposes in rural areas.(Khouri,T, Abdulrazzak,M. and others,1995)

3.2 Advantages, disadvantages and conditions

Rainwater harvesting could be considered as a possibly feasible option if one or several of the following conditions is fulfilled.(United Nations, Water resources series No.63 & Helou A.H. and Shaheen H.Q., 1993):

- Lack of other options, or the inability to provide sufficient quantities of water at a reasonable cost. (Like the availability of a safe centralised water system).
- The consumers are located in isolated areas(scattered inhabitants)
- Poor water quality of other sources (e.g. Well water is contaminated) or expensive water treatment facilities are necessary to be constructed to obtain cleaner water suitable for domestic purposes, while rainwater can be used as domestic purposes after simple or no treatment.(See section3.5.2)
- The availability of large impervious areas which result in high surface runoff.
- The availability of acceptable and sufficient annual average rainfall to harvest adequate amounts of water.

Advantages and disadvantages of Rainwater Harvesting System for domestic supply are shown in the following table:

Table (3.1): Advantages and disadvantages for RWHS

Advantages:	***Disadvantages:***
1- RWHS-almost- meet considerable percentage of consumption point. *2- Easy maintenance and operation by users.* *3- The running cost is almost negligible.* *4- Relatively adequate water quality.* *5- Rainwater is renewable resource, with low environmental impact.* *6- Rainwater is ubiquitous source: Rainwater collection is always a water supply alternative wherever rainfalls and it is an essential backup water supply in times of emergency.* *7- The system is independent and suitable for scattered communities. In addition to that, household scale only requires simple construction with flexible technology.*	*1-Relativly the initial cost of each cubic meter is high.* *2-Limited supply by the amount of rainfall and the size of the cachment. It is not a dependable source during droughts.* *3- The ground catchment system is expensive in terms of construction of dams, conveyance, pumping and treatment, which make it unattractive for policy makers.* *4- The water is free from mineral; it may cause nutrition deficient diets. Further more, rainwater can easily be contaminated by animals and organic matter and standing water in the cistern may provide potential breeding sites for mosquitoes.*

After (Gould, J.E., 1991, IP International Environmental Technology Center & Helou A H and Shaheen H.Q., 1993)

3.3 Roof water harvesting in Palestine

Roof catchment system is considered as the most system in which rainwater can be used in domestic purposes with out a need to treatment. Roof catchment system depends on three components: The collection area which is the individual rooftop on the house, the conveyance system which is a series of gutters or pipes that convey the water to the storage facility (Cisterns) and the storage facility itself. The amount of the water that can be collected depends on the catchment area, the amount of rainfall and the storage volume.

Collecting of rainwater from roof catchments in cisterns is not new in Palestine. Palestinians built such systems already hundreds of years ago. They used cavities that were formed by geological formations as storage facility to collect rainwater in. They used the collected water for domestic and agricultural purposes in the dry season. Some of the ancient cisterns are excavated in rocks. They could be found in ancient places in cities and villages in Palestine. These cisterns took different shapes-they will be discussed in section 3.4. The Palestinian constructed them because of the urgent needs for water and because of the lack of water resources since of the unavailable technology to develop new resources. In Palestine people still construct new cisterns in particular in villages without water supply distribution systems (WSDS). Even in the villages that have access to WSDS they are using the collected rainwater for gardening and in some cases for domestic use.

The number of cisterns counted in the West Bank is 82656 cisterns. Of this number, 5574 cisterns are located in Ramallah district, 738 cisterns are located in localities without water supply distribution network, and 4836 cisterns are located in localities with a distribution net work (MOPIC, 1998).Currently, 200cisterns are available in Ramallah city, while 150 cisterns are located in Al-Berih city (MOPIC, 1998). In other words about 6.3% of the total number of cisterns in the district are located in the two cities.

The present total collected water from roofs in Ramallah and Al-Berih cities was estimated at 0.052 Mm^3/year assuming $80m^3$ tank capacity on average independent of the roof area (MOPIC, 1998), the maximum consumption per building is 1.2 m^3/day, the average yield of the tank per year and the present total number of cisterns was estimated 350 (MOPIC, 1998). About 8% percent of the houses in Ramallah and Al-Berih have cisterns. Most of these cisterns are not newly constructed. Actually, most of the new constructed houses do not contain an RWHS. Furthermore, the houses that have cisterns do not use the collected water for domestic purposes. Also often they do not collect rainwater at all and if they do they only use it for gardening.So the existing cisterns are not used so efficiently, and the people are not aware that building new ones may be useful.This behaviour could be related to different reasons:

- The availability of a water supply distribution network. About 60% of the people in Al-Berih and 50% in Ramallah have access to the water network (JWU, 1998). The people who are not connected can easily be connected to the system.
- The people prefer to consume water from the network, rather than rainwater, because firstly the taste of rainwater is not acceptable to them, and secondly they are afraid that rainwater is contaminated.

- The construction cost (capital cost) of the reservoir is relatively high, in particular for those who have a low income. So they prefer to pay a monthly amount of money for the consumed water from the net.
- There is lack of public awareness towards constructing an RWHS.

3.4 Structural components of roof water harvesting

Catchment systems consist of the following components. See figure (3.1).

1-Roof catchment: It consists of rooftop areas. There are different types of roofs: Ferrocement roofs, tiles or cement concrete roofs are easy to use and give clean water; galvanised iron sheets or aluminium sheets; thatched roofs covered with PVC or mud plaster which should be non erodable, and wooden roofs with PVC sheets. Roofs of asbestos are not recommended unless they covered by plastic sheets to prevent contamination by the fibres to water. Roofs should be in small slopes directed toward the outlet of the roof. The gutters should be in slope to enable the water to flow by gravity towards the cisterns that are under or above the ground near the house. The thatched roofs are not recommended to be used, since the debris that may enter the tanks causes contamination of the water. To prevent that, all the damaged thatched areas should be periodically repaired or they should be covered by plastic sheets[1].

Table (3.2): Runoff coefficients

Type of catchment	Runoff coefficient(f)
Roof catchment	
Flat(Concrete)	**0.8-0.9**
Corrugated metal sheet	**0.7-0.9**
Ground surface covering	
Concrete	**0.6-0.8**
Plastic sheeting	**0.7-0.8**
Butle rubber	**0.8-0.9**
Brick pavement	**0.5-0.6**
Treated ground catchment	
Compacted and smoothed soil	**0.3-0.5**
Clay/cow-dug threshing floors	**0.5-0.6**
Silicon-treated soil	**0.5-0.8**
Soil treated with sodium salts	**0.4-0.7**
Soil treated with paraffin wax	**0.6-0.6**
Untreated ground catchment	
Soil on slopes less than 10%	**0.0-0.3**
Rocky natural catchment	**0.2-0.5**

From Lee, M.D. and Visscher J.T., 1992 Technical paper series No. 30

In Ramallah and Al-Berih cities three types of roofs can be found: reinforced concrete, sheet metals, and red tiles. Reinforced concrete roofs are the dominant, they are usually

[1] National Drinking Water Mission Seminar on Water Harvesting System and their Management Vol.,1989

flat surfaces with a slope of 1-2%. This type of roofs is usually surrounded by concrete barrier of about 25-100cm height to prevent loss of rainwater to collect as much as possible. Steel metals and asbestos roofs are not common in the residential areas, but they can be noticed in the industrial areas. Red tile roofs are scattered in the residential areas. More water can be collected from this type because they have more surface area.

Maximum yield that can be obtained depends on three factors: Surface area, runoff coefficient, and the amount of average annual rainfall.30% of the total rainfall can be actually collected for pervious ground catchment, while this ratio is about 90% for covered and sloping catchments[2]. These percentages are estimated by taking into consideration different portions that can be considered as losses: portion that wet the catchment, evaporation portion and that are for foul flush. Table (3.2) show different runoff coefficients according to different types of catchments.
The Potential yield can be estimated from the following formula:

$$V=f*A*R/1000 \quad (1\text{-}2)$$ [2]

V *volume m3/month*
f *Runoff coefficient*
A *Area (m2)*
R *Rainfall mm/month. Reliable data are required for at least 10years. (Schiller&Lattam, 1982).*

2-Gutter and down pipe: This comprises the collecting and the conveying system. Gutter is fixed with gentle slope and connected to the down pipe that ends up with the inlet of the storage tank. This connection may for example be made of wood or bamboo [1&2]. In Ramallah and Al-Berih cities gutters and down pipes are made from steel, plastic, but metal is the most common type. (Costs and in details information are not available).These fittings are installed out side the building on the wall, or some times inside the wall itself.(Helou A.H. and Shaheen H.Q., 1993)

3-Foul flush system: The main aim of this arrangement is to prevent the contamination that results from the first flush that is mixed with leaves, birds dropping, and other dirts.It is an arrangement which is made by connecting two points by a movable pipe or by stopper to stop water entry in the filter and to convey water into a bypass pipe to carry water outside the tank [1&2].To improve the collected water quality it is advised to install such arrangement in the system. Currently, people whom have RWHS in Palestine foul flush only the first shower at the start of the rainy season. In spite of the fact that this step wash the roof which minimise the risk of contamination but periodical foul flushing certainly increase the collected rainwater quality level. This periodical foul flushing depends on the period after rain stops.

4- Filter. Its aim is to purify rainwater, it is connected between the down pipe and the storage tank [1&2]. Filters are not common in the Ramallah and Al-Berih cities. Surely, installation of filter in the system will improve the quality of supplied water from the

[1] National Drinking Water Mission Seminar on Water Harvesting System and their Management VoI ,1989
[2] National Drinking Water Mission Seminar on Water Harvesting System and their Management VoII ,1989

cisterns chemically and biologically. Although this installation increase the cost of the system, it is very important to be sure that the collected rainwater is safe for drinking. (Costs and in details information about filters in WB are not available).

5-Storage tank: It is considered the main component of the system. Storing the rainwater is the main objective. There are different types of tanks: Under ground tanks, ground tanks and elevated tanks. Out let pipe may be fitted at the bottom level of the tank for cleaning. The size of the tank depends on different factors: daily demand, duration of dry spell, catchment area and average annual rainfall. In Palestine (including Ramallah and Al-Berih), most of the storage tanks and divided for tow types:

-*Pear shape tank:* Most of the ancient cisterns are pear shape constructed more than 50 years ago (Abu-Sharkh,M.S,?) they were constructed under ground and excavated in rocks. This shape can be constructed manually by the family them selves(Helou A.H. and Shaheen H.Q., 1993).Pear shape has hole of(60*60*20cm) near the opening to treat water by sedimentation before flowing to the cistern.(Abu-Sharkh,M.S,?)

-*Square and rectangular shapes:* Square and rectangular shapes are the now days cisterns and some of them were constructed since about 20 years ago. They are constructed from reinforced concrete.(Helou A.H. and Shaheen H.Q., 1993).They are constructed near or under the house, underground or aboveground.

6-Withdrawal arrangement: For under ground tanks, the withdrawal can be done by installing a pump, while for ground and elevated by taps fitted at the bottom of the tank[1&2]. In Ramallah and Al-Berih small pumps are used (0.5in and 0.5HP) to withdraw water from the cistern to the balancing tank on the roof. The used pipes to convey water are from galvanised steel of 0.5in diameter. If the collected rainwater and municipal water have to be mixed in the same balancing tank -excluding filter installation- then the risk of drinking contaminated water is higher. For this reason installing a separate tap for drinking water from municipal water is important.

7-Overflow: Its purpose is to prevent flooding during high intensity rainstorms in the rainy season. Usually it is equipped at about 0.5m from the roof of the cistern taking into consideration safety to prevent entry of any pollutants to the cisterns.(Abu –Sharkh,?)

8-Disinfection: May water remain for long time, which is result in growth of pathogenic bacteria, for this reason a higher dosage of chlorine should be disinfected periodically to prevent contamination[1&2].This method is advised to be used in the WB. However, awareness is needed for the people of how much is the dosage size should be. In other words how much ml/m^3 should be disinfected?.

[1] National Drinking Water Mission Seminar on Water Harvesting System and their Management Vol ,1989
[2] National Drinking Water Mission Seminar on Water Harvesting System and their Management VolI ,1989

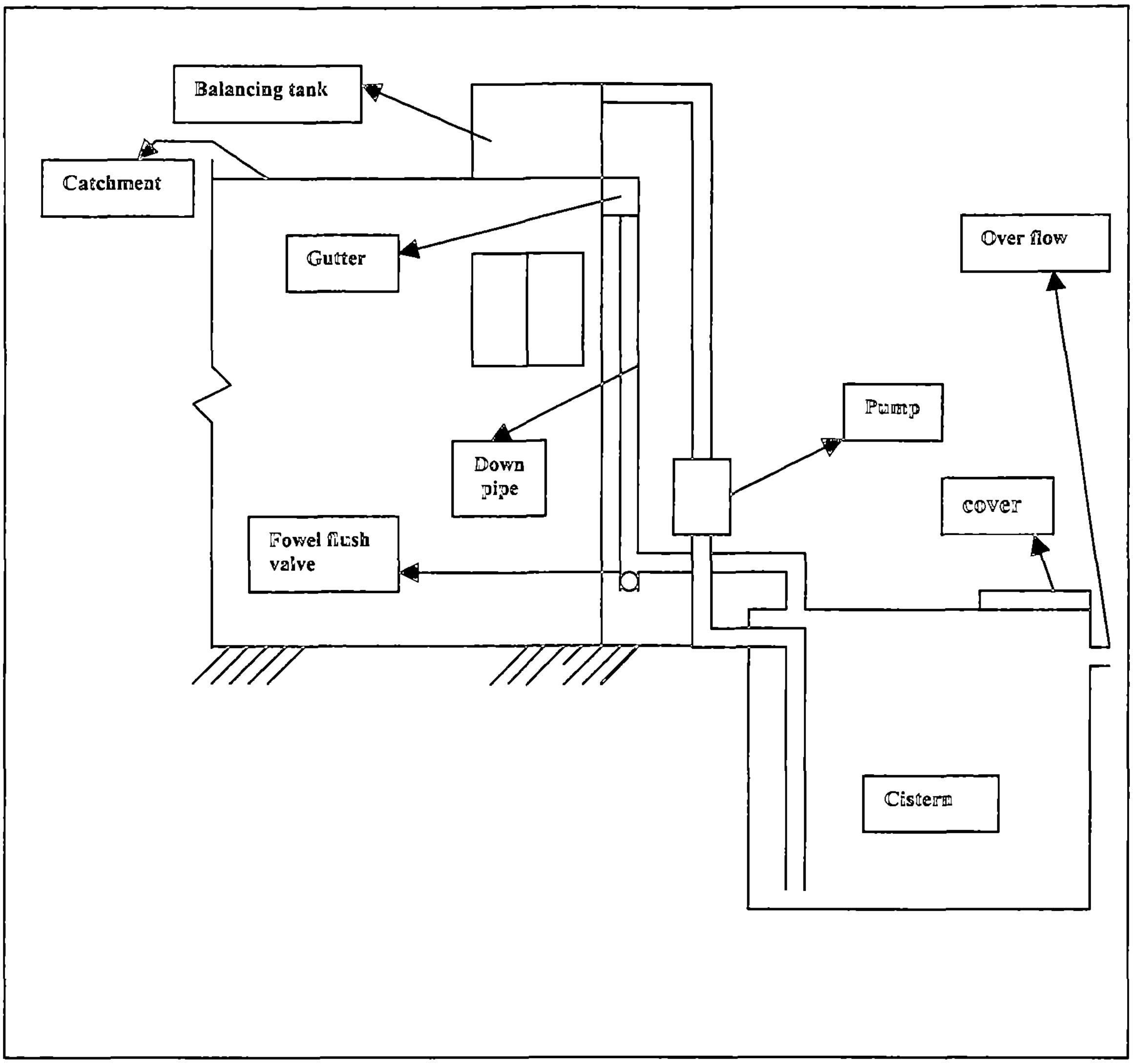


Figure (3.1): Sketch of Rainwater harvesting system components

3.5 Technical feasibility

Rainwater harvesting system is a source that supplement the other sources during times of droughts. Its technical feasibility depends on the estimation of the potential of collected rain to meet the demand, the storage capacity and quality.

3.5.1 Storage capacity

The minimum storage capacity for roof top rainwater harvesting can be estimated by the following formula:

*V=P*q*D/1000* .... *(3.2)* [2]

V   *Storage capacity volume (m3).*

[2] National Drinking Water Mission Seminar on Water Harvesting System and their Management VolI ,1989

P *Number of people to be served.*
Q *Per capita daily water consumption (l/c/d).*
D *Number of critical consecutive days without rainfall.*

The above factors affect the storage capacity. In addition to that, rainfall and its duration, size of the catchment and losses of water due to evaporation and leakage.
Usually models are used in the evaluation of maximum or optimal storage capacities. In this study a spreadsheet was created for this purpose.

3.5.2 Water quality

Supply safe water with good quality for drinking water is a target to be met. Rainwater can seriously be contaminated from atmosphere pollutants and bird droppings. Therefore, it deserves attention how to overcome the health consequences of microbiological, organic and mineral contamination.

Type of the catchment and the environment, are two factors that affect the rain water quality. The are a lack of tests for rainwater quality from the roof catchment or the ground catchment in the West Bank. However, some tests were done for specific parameter in different places but not for the city of Ramallah and Al-Berih.

One study has been done at BerZeit University, its result was: rainwater from the roofs is of high (good) quality, that can be used for domestic purposes. There is a need to mix the water with sodium hypochlorine(SH)(Liquid),which contains a percentage of 1-14% of chlorine. For large flows, calcium hypochlorine (CH)(powder), should be used, which contain 70% of chlorine. (Khatib & Alami, 1992)

Another study has been done for cisterns water quality in south of West Bank. A 200 cisterns scattered through the area (South of WB-Hebron) which were used to collect the required samples .The samples were tested, analysed for chemical and biological parameters (Abu-Sharekh M.S. and Subuh Y.M,1994). Many factors affect rainwater quality such as the atmospheric conditions, the materials found on the catchment, and the level of cleanliness of the catchment and the cistern. Also, air pollution could seriously affect rain quality. It results in formation of acid rain, which will affect the colour, odor, and taste of the harvested rainwater (Brand and Brand ford1991/Abu-Sharekh M.S. and Subuh Y.M,1994).

Table (3.3) shows results of the chemical analysis for rainwater from 200 different cisterns in south of West Bank compared with WHO standards.

Table (3.4) shows the total coliform counts in 200 samples from 200 cisterns, it could be noticed that 54 out of 200 cisterns contained coliforms, while 146 cisterns had zero coliform. WHO standards say that if coliform more than zero in 100ml-water sample, then it is contaminated. Which means that 27% of the tested samples were contaminated while the rest were not.

Table (3.3): Chemical analysis results of cisterns water supply in south of WB and tap water in Ramallah.

Constituents	WHO Stand. (mg/l)	Concentration observed(mg/l)			Tap water Avrerage (6 Sources)
		Minimum	Maximum	Aver. 200cistern	
pH	6.5-9.2	7.5	9	8.1	7.5
EC(μ mho/cm)	<250	0.17	1.2	0.45	-
TDS	200-500	80	560	237.5	322.5
TH	200-500	70	423	182.6	302.3
Calcium	75-200	18.1	94.6	45.1	65.9
Magnesium	50-150	1.0	92	20.8	28.0
Sodium	100-200	5	41	11	29.3
Potassium	0-10	1	12	3.3	2.6
Chloride	200-600	18	138	41.7	44.1
Carbonate	0-50	1.2	67.2	21.1	-
Bicarbonate	0-500	41.6	315.5	146.9	-

From Abu-Sharekh M.S. and Subuh Y.M,1994 & JWU,1995.

As a result of Abu-Sharkh study, it was concluded that cisterns in general can provide a good quality (chemically and microbiologically), that meets the WHO standards, with exceptions of some values that are more than maximum or less than the minimum of some chemical parameters such as total hardness. Further more, 27% of the samples were contaminated biologically. Accordingly, it can be concluded that the contamination was slight and the situation can be improved by taking care with the cleanliness of cisterns environment and improve the method of collecting water.(Abu-Sharekh M.S. and Subuh Y.M,1994).

Table (3.4): Total coliform counts in 100ml samples for stored rainwater in cisterns in south of WB.

Total coliform counts in 100ml samples	Total number of samples	% Total number of samples
0	146	73
1-10	10	5
11-20	15	7.5
21-30	12	6
31-40	7	3.5
41-50	4	2
>50	6	3
Total	200	100

From Abu-Sharekh M.S. and Subuh Y.M,1994

A main result of Abu-Sharkh study is that the water of high quality when the source of water is rain only, the roof is the only catchment, the cistern environment is very clean and the general cleanliness is very excellent.

The case of Ramallah and Al-Berih are almost similar to the south of WB case since the Palestinians almost have the same habits and traditions, the same environmental and social conditions, they almost build similar tanks and they have similar catchments. Consequently, it could be considered that the quality of rainwater cisterns in the two cities almost similar to the quality of the above described case in south of WB.

Some cases of other experience rather than the Palestinian's one in rainwater quality testing will be discussed in the following paragraphs:
Study have been done by Department of Environmental science in University of Pertanian in Malaysia about the quality of the rainwater from open surfaces that can be collected from two types of roofs: galvanised iron catchment and tile catchment. Approximately, they are located in the same environmental conditions. For the open surface results are with in the WHO standards except pH and lead, the measured pH is 5.9,which is lower than 6.5-8.5 that is quoted in the WHO for drinking water, while 200mg/l of lead which is four times more than WHO standard (50mg/l). General result for roof quality evaluation, that it is difficult to compare between roof types, but in this study samples analysis showed better quality of rainwater from galvanised iron catchment than from tile catchment (Yaziz,M. Y., Gutting, H. and others, 1989). Rainwater quality is affected by the dry periods between rainfall events (The larger the dry periods, the greater the amount of the pollutants deposited) and rainfall intensity (The higher intensity the faster the washout occurs). As a result, some form of treatment is needed before this water can be used as potable water. (Yaziz,M. Y., Gutting, H. and others, 1989)

Another study has been done in Thailand by Wirojanaghd et al. (1989). Different samples were collected from tanks, jars, roofs and gutters. They found that rainwater is the safest source for drinking water; non of the heavy metals exceed the WHO standards except Zinc and magnesium. Use of the disinfection with chlorine, exposure of water to UV radiation is recommended techniques to destroy the pathogenic bacteria.

Results of studies have been done in India is that roof water has a good quality. They suggest different measures to improve it: Construct roofs of non-toxic material (Avoid lead and asbestos roofs); try to make roofs free of over hanging trees (to prevent defecation on roofs); tap should be at 30 cm or more above the tank base (to allow the debris settles on the bottom); cleaning the tank periodically, and using of low cost filters which were developed in Kenya.(Gould, J.E., 1991)

3.6 Implementation

RWHS implementation programmes were focused on different strategies: Technical feasibility (physical design and construction technique which were discussed before); economical feasibility and social acceptability.

3.6.1 Economic considerations

RWHS costs depend on rainwater seasonality and how much large catchment surfaces are required. Economies of scale and affordability of the system should be taken into consideration where large tanks are used. (Gould, J.E., 1991)

Table (3.5): Different tanks types with different costs in different countries

System	Volume(m^3)	Cost($)	AEC($/$m^3$)	Country
Small jar standing	1	25	0.42	Africa/Tongo
Ferrocement standing	5.5	180	0.36	Kenya
Cement stave and rooftop	6	627	1.74	Togo
Ferrocement ball	7	168	0.27	Kenya
Polyethelene and rooftop	7	750	1.87	Botswana
Basket standing	8	250	0.35	Kenya
Ferrocement standing	9	221	0.27	Kenya
Granary standing	10	167	0.28	Togo
Round hut standing	10	222	0.37	Yogo
Ferrocement standing	10	250	0.28	Kenya
Brick standing	10	500	0.83	Botswana
Ferrocement standing	10	750	1.25	Botswana
Ferrocement standing	13.5	630	0.52	Kenya
Ferrocement standing	20	925	0.77	Tanzania
Ferrocement standing	21	534	0.28	Kenya
Ferrocement standing	25	1111	0.49	Kenya
Ferrocement standing	30	1073	0.39	Kenya
Masonary standing	50	3500	0.78	Kenya
Ferrocement groundtank	70	1750	0.28	Kenya
Ferrocement groundtank	75	1937	0.29	Kenya
Ferrocement groundtank	80	2000	0.27	Kenya
Reinforced cement jar	2	25	0.17	Asia/Thialand
Concrete ring	11.3	250	0.29	Thailand
Wired framed ferrocement	2	67	0.37	Philippines
Wired framed ferrocement	4	125	0.35	Philippines

From (Lee and Vissher,1990&.Gould, J.E., 1991)

Different factors affect the reliability, the applicability and the comparative value of the cost and these factors should be taken into the consideration in the cost estimation of tanks: Inflation since time of calculation; exchange rate conversions; if the project cost if it is research, demonstration, pilot or implementation in nature is included or excluded; exclusion or inclusion of commercial materials, skilled labour, local material, self help labour, transport, equipment, and technical costs; and finally different pricing in different countries (Lee, M.D. and Visscher J.T., 1992. Occasional paper 14). (Table (3.5)) shows costs of different types of tanks in Africa and Asia. To initiate any project of RWHS, it needs a cost that is far beyond the means of most households. As a result of that, developing mechanisms for financing RWHS such as subsidies, loans, etc. from funding agencies or government are needed to help them pay the cost of the systems.

Examples: Revolving funds in Kenya (Jevrees, 1987), grants/subsidies in Botswana (Ainley, 1984) and loans/income generating activities in Philippines (Appan, Villareal and Wings, 1989).

3.6.2 Social and cultural considerations

To implement RWHS successfully, high priority should be given for local customs, perceptions and preferences. The successfulness depends on social appropriation and acceptability. Taste is a factor that affects the acceptance of use rainwater for drinking It took long period before the consumers become familiarised with rainwater taste. (Paceg and Gullis, 1986).

Figure(3.2): Role of Palestinian woman in water supply.

Women as in other fields, should have a role in planning, design and construction of RWHS. In rural communities women do a lot of heavy labour In Palestine, especially in village with out WSDS woman and her children still have an important role in water supply, high scarcity is available and the only resources is rainwater and small spring
In Ain- Areek which is a Palestinian village located on the west of Ramallah city at about 7Km far, suffer very hard from water shortage. Women still use small buckets and pots to transfer water from springs to their houses for domestic purposes. Now days in the cities of Ramallah and Al-Berih there is no need for transfer water by buckets since of the availability of WSDS, and the two cities are some how civilised. The following photo (Figure (3.2)) shows role of women in water supply in the Palestinian villages.

Chapter(4)
Demand projection for Ramallah and Al-Berih

4.1 Population projections

In 1997 the total population of Ramallah and Al-Berih district was estimated at about 246,000(PCBS,1997 & 1998) which constitutes about (16%) of the total population of the West Bank (about 1,551,000)[1] and about (10%) of the total population in the Palestinian territories which was estimated approximately at 2,444,000[2]. About 46,600 people are living in Ramallah and Al-Berih cities(PCBS,1997).
To estimate the expected population for the next 42 years in different periods, the exponential growth method was used:

$$P_n=(1+r)^n * P_0 \quad \text{(4-1) (Hall,1995)}$$

P_n *The estimated population at a certain time in the future*
P_0 *The existing population (present)*
r *Population growth rate during the period of estimation*
n *Time duration*

In different studies the population was estimated on the basis of three different scenarios growth rate: low, medium and high scenario because the population growth depends on different factors that affect it, such as education level, standard of living, fertility rate, mortality rate, life expectancy and returnees. The low scenario represented the optimistic point of view while the high scenario represents the pessimistic impression. According to these scenarios, the population increases from the low to the high and as then years increases by a different values of percentages. The variations on percentages are shown in table (4.1). In table (4.1) four different studies suggest different values for each scenario and for each year. Palestinian Central Bureau of Statistics estimated values for the years 1992 to 2012 for each year, they don't mention the reasons behind these values, and it was taken from a published table related to a published report by PCBS,1994. For the years 1998-2000,and 2000-2010 the average values were taken. While for the remaining periods 2010-2020 and 2020-2040 the values were assumed based on the other values. Population average growth rate in a report done by ARIJ and HIID by the year 1994 are based on population projection document of Abdeen and Abu-libdeh(1993,fafo,1993). In their estimation they took into account different affecting factors: age, sex cohorts, fertility rates, life expectances and net migration rates. Their estimates were for the period 1990-2020.For the years 2020-2040 it was assumed that average annual population growth rate will still be the same for 2010 to2020 for the low scenario and it will drop by 0.5 for medium and high scenario. A study has been done by GTZ & Water and Environmental Studies Center, 1995 and a published report by PCBS, 1994 assumed different growth rates until the year 2040. Reason for these values are not mentioned. In this study logical values are chosen in the line of the four reports, assuming that all references are equally correct. The population growth rate by the year 1998-2000 is estimated here at 3.0 % for low scenario and 1.5% for the years 2020-2040. For the medium scenario it is estimated at 3.0% for the years 1998-2000 and 2.0% for the years

[1] An estimated value as follows 1505771*x (1+0 03)^1=1551000, * from PCBS 1996
[2] An estimated value as follows 2237000* x(1+0 03)^3= 2444000, * from PWA 1997

2020-2040.For the high scenario it is as high as 3.5% for the years 1998-2000 and 2.5% for the years 2020-2040.Within each scenario the population growth rate decreases, because the people will become more educated and the standard of living is expected to be higher.

Table(4.1): Population growth rates

Scenario	Year	1998-2000	2000-2010	2010-2020	2020-2040
	References	Rate(%)	Rate(%)	Rate(%)	Rate(%)
Low	Reference[3]	4.2	2.5	2	2
	Reference[4]	3	2	2	1.5
	Reference[5]	3.1	2.4	1.5	1.5
	Reference[6]	3	2	1.5	1.5
	Average	3.3	2.2	1.8	1.5
	This study	3	2	1.5	1.5
Medium	Reference[3]	4.5	3.3	2.8	2.3
	Reference[4]	3	2.5	2.5	2
	Reference[5]	3.6	3.2	2.5	2
	Reference[6]	3	3	2.5	2
	Average	3.5	3	2.6	2
	This study	3	3	2.5	2
High	Reference[3]	5	3.6	3.6	3.1
	Reference[4]	3	3	3	2
	Reference[5]	4.3	4.3	4	3.5
	Reference[6]	3	3	3	2.5
	Average	3.8	3.5	3.4	2.8
	This study	3.5	3	3	2.5

The following tables shows the existing and future population for Ramallah and Al-Berih cities based on different scenarios from the year 1997 to 2040.

Table(4.2): Population projections (Low scenario)

City/year	1997	1998	2000			2010	2020	2040
*1000	Exis.	Proj.	Proj.	Retur.	Total	Proj.	Proj.	Proj.
Ramallah	18.3	18.8	20.0	4.7	24.7	30.1	35.0	47.1
Al-Berih	28.4	29.2	31.0	7.3	38.3	46.7	54.2	73.0
Total	46.6	48.1	50.6	12.0	63.0	76.8	89.1	120.0

*All values *1000*

[3] PCBS, 1994. Demography of the Palestinian Population in the West Bank and Gaza Strip

[4] Water and Environmental Studies Center,1995 Middle East Regional Study on Water Supply and Demand

[5] ARIJ & HIID, 1994 Water Supply and Demand in Palestine 1990 Baseline estimates and projections for 2000,2010,2020.

[6] PCBS, 1994 Small Area Population in the West Bank and Gaza Strip

Table(4.3): Population projections (Medium scenario)

City/year	1997	1998	2000			2010	2020	2040
	Exis.	Proj.	Proj.	Retur.	Total	Proj.	Proj.	Proj.
Ramallah	18.3	18.8	20.0	4.7	24.7	33.2	42.5	63.2
Al-Berih	28.4	29.2	31.0	7.3	38.3	51.5	65.9	98.0
Total	46.6	48.1	50.6	12.0	63.0	84.7	108.4	161.1

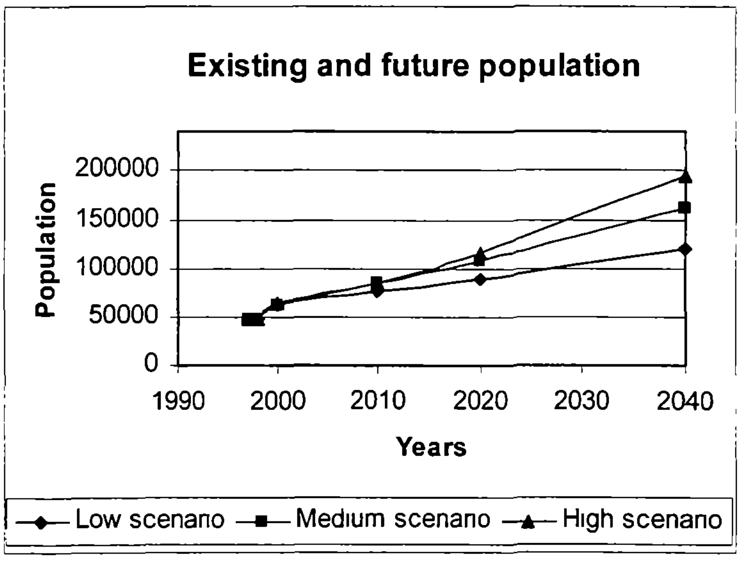
*All values *1000*

Table(4.4): projections (High scenario)

City/year	1997	1998	2000			2010	2020	2040
	Exis.	Proj.	Proj.	Retur.	Total	Proj.	Proj.	Proj.
Ramallah	18.3	18.9	20.3	4.7	25.0	33.6	45.1	74.0
Al-Berih	28.4	29.4	31.4	7.3	38.7	52.0	67.0	119.6
Total	46.6	48.3	51.7	12.0	63.7	85.6	115.0	193.5

*All values *1000*

In addition to the natural growth rate for estimation of future population to estimate the domestic demand, two groups should be taken into our accounts: The returning refugees and the visitors. By the year 2000 about 500,000 are assumed to return to the West Bank (WB) and Gaza (about 80% to the WB and 20% to Gaza strip) (ARIJ & HIID,1994).The total number of returnees that would go back to Ramallah and Al-Berih is a percentage proportional to the total population of the two cities in comparison to the total WB population.



Figure(4.1): Existing and future population projections

The number of returnees to Ramallah and Al-Berih was estimated for the three scenarios at about 12000 returnees by the year 2000 based on a percentage of 3%[7] from the total population of the WB.

[7]This value is estimated as follows: 50600*/1694800* = 0.03, * Based on 2000 projections

According to ARIJ & HIID, 1994, it was assumed that, 200,000, 250,000,and 300,000 visitors would visit Palestine in the years 2000,2010,2020, respectively, if the Palestinian territories were liberated. In this study it was assumed that for the year 2040, about 350,000(Depending on the above assumptions by ARIJ & HIID, 1994) visitors would visit the West Bank and Gaza. According to my overview, the visitors will stay for an average period of 2 months per year. Ramallah and Al-Berih share of the above numbers will be a proportion computed by dividing the total population of each city by the total population in the Palestine multiplied by the expected number of visitors for each year. These estimates will be used to assess the domestic demand estimation as will be shown later. The visitors only participate in increasing of the water demand for 2months a year and they are not a part of the resident population. See table (4.7).
Existing and a logical increase in future population for the years 1997-2040 based on the suggested three scenarios -as shown in tables (4.2,4.3,4.4)- could be seen clearly through the chart (4.1).

4.2 Present and future water demand:

4.2.1 Domestic demand

The 1997 total demand for the WB was estimated at 46.61 Mm^3/year (PWA, 1997) including east Jerusalem. Ramallah district share about 7.15 Mm^3/year (PWA, 1997) which is about 15% of the total demand. The above estimation of the total demand was based on a population estimation for the year 1996.The per capita water consumption was estimated at 29.5m^3/year including losses which were estimated at 41.1% as average for the whole of WB (PWA, 1998), that consumption is not what is needed but what is actually consumed. Prediction for future demand should not depend on that amount since it is not a representative value.
The per capita water consumption is 53, 100 m^3/year, for Jordan and Israel respectively.
For Ramallah and Al-Berih cities about 2,170,000 m^3/year were consumed by the year 1997 including industrial and commercial consumption and excluding unaccounted for water which is evaluated at 21.3%(JWU, 1998). So what actually is consumed is the above amount while what actually is supplied is 2,600,000 m^3/year. This value should be considered as the total consumption including industrial commercial and agricultural consumption, because the industrial and commercial areas consume water from the same water supply distribution network that is supplying water for domestic purposes.

There are no considerable irrigated areas available in the two cities. Irrigation is limited to small gardens located near the houses. As a result of that the gardening water is supplied from the drinking water and in addition from a limited amount of water supplied from cisterns, if cisterns are available.

The actual per capita consumption at the two cities was calculated at 46.5m^3/a (127l/c/d) for the year 1997 including equivalent industrial and commercial consumption per capita- not including losses- by dividing what actually consumed over the total population. However, the average daily per capita water consumption was estimated at 100 l/d by JWU for the year 1997.The following graph (Figure(4.2))shows the consumption patterns in Ramallah and Al-Berih for the year 1997/1998 which are estimated according to the given data of water supply from January1991 to September 1994.(See appendix-1 table (2)). It was assumed that the supply is the same for the years 1997 and 1998.The average per capita consumption for the wet season was estimated at about 100 l/c/d and 126 l/c/d for the dry season. Different studies assumed different values of average annual per capita water demand for different periods in future. For example ARIJ & HIID (1994) assumed 75 m^3/c/y (205 l/c/d), 100 m^3/c/y (274 l/c/d), 125 m^3/c/y (350 l/c/d), for the years 2000, 2010, 2020 respectively[8]. Optimistically, they assumed that the Israelis restrictions will be eliminated and they based on the studies that have been done by (Alkhatib et al, 1993). According to (WBWD, Ja'as, 1998),depending on CDM Morganti studies, PWA assumed that the average demand per capita for the years 2000,2010,2020 will be 170,230,270 l/c/d respectively[8].

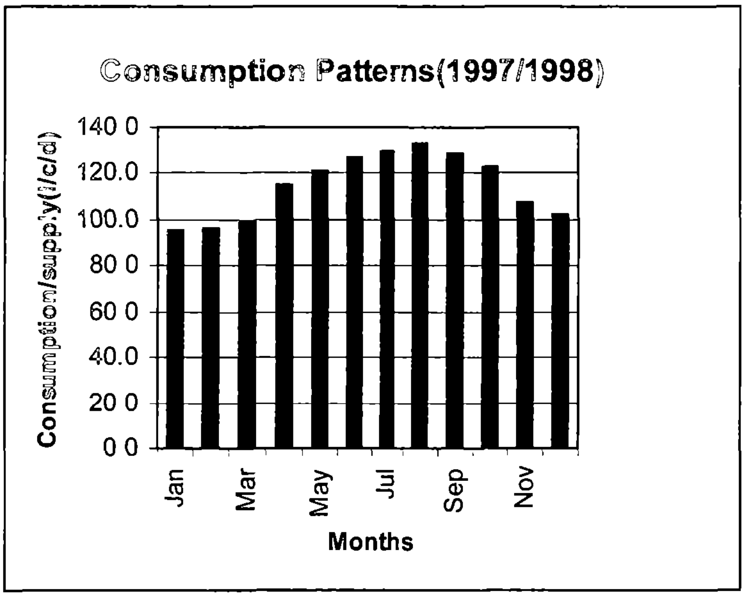


Figure (4.2): Consumption patterns for Ramallah and Al-Berih cities by 1997/1998.

In this study 120 l/c/d (not including losses) is used as a base line in the line of TU Delft and BirZeit University study, 1992 which proposes the following table.

Table(4.5): Domestic purposes consumption(l/c/d)

Purpose	**Quantity (l/c/d)**
Drinking +cooking	5
Washing	20
Dishes washing	15
Toilet	25
Bathing	40
Others	15
Total	120

From TU Delft & BZU,1992

The existing losses in the distribution system was estimated at 21.3%(JWU, 1997). This amount is expected to reach 15% by the year 2040 (Water and Environmental Studies Center, 1995). The increase efficiency of the performance by JWU and their management make this a realistic estimate. This agency actually reduced the losses from 33% in the 1974 to 21.3% in the year 1997.

The water needed for gardening is estimated at 30 l/c/d ($11m^3$/year). This estimation is based on assuming that about 0.7 m^3 per day per household are used daily for gardening on average on the dry season (See appendix-1). Consequently, the total actual amount of water demand per person is finally estimated at 180 l/c/d ($65m^3$/year) including the 21.3% of losses.

Future demand estimations (projections) were based on three scenarios: Low, medium and high. In the low scenario the conditions were assumed to stay as they are: no more economical development, and no more funds. Consequently, low level of standard of living. In this scenario the demand was assumed to stay constant until the year 2040.
For the medium scenario, it was assumed that the annual increase of demand was according to a growth rate, which was assumed to be 1.25% (Mitwally,S. ,Samhan,S. and Musleh,M.,1996). This percentage is an optimistic value in the sense that it expects improvement in the economy that increase the per capita income which lead to acceptable standards of living.

Better and more expected economical growth, more international funds, more improvement and development in the national and local income, and the expected stability in the political situation with more achievement of our rights in the next negotiations, will result in improvements in standard of living. Consequently, the annual growth rate of the per capita demand for the high scenario logically is assumed to reach double of that in the Medium scenario, in other words to be 2.5%.

Table(4.6): Per capita water demand projections(m^3/year)[8]

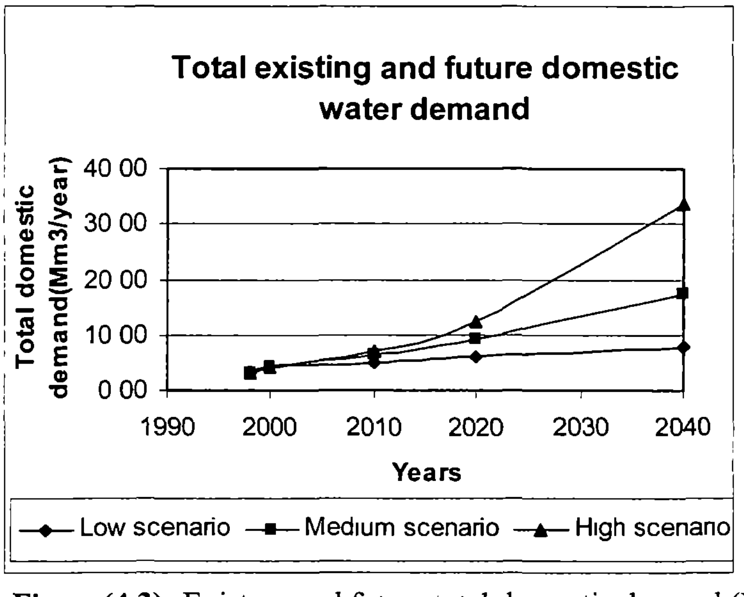
Scenario/year	**1998**	**2000**	**2010**	**2020**	**2040**
Low	65	65	65	65	65
Medium	65	65	74	83	106
High	65	65	83	106	173

In table(4.6) different values are estimated for the three different scenarios based on the above assumed growth rates by using formula(4-1).

8 The author releases that these per capita demand estimates don't consider any possible demand management measures, which could help considerably in decreasing the gap between demand and supply. The future per capita demands projected by the different sources referred to may have not considered such demand management measures for strategic reasons It was not in the scope of this research to comment on these projections

Table(4.7): Existing and future domestic water demand projections(Mm^3/y)

Scenario	Year	Popul.	Per capita domes. demand m^3/y	Tot. demand	Visitors	Equivel /capita domes. Demand m^3/y	Visitors demand Mm^3/y	Total demand Mm^3/y
		*1000			*1000			
Low	1998	48 1	65	3.13	3.8	11	0.04	3.17
	2000	63	65	4.10	4.7	11	0.05	4.15
	2010	76.8	65	4.99	5.9	11	0.06	5.06
	2020	89.1	65	5.79	7.1	11	0.08	5.87
	2040	120	65	7.80	8.3	11	0.09	7.89
Medium	1998	48.1	65	3 13	3.8	11	0.04	3.17
	2000	63	65	4.10	4.7	11	0.05	4.15
	2010	84.7	74	6.27	5.9	12	0.07	6.34
	2020	108.4	83	9.00	7.1	14	0.10	9.10
	2040	161.1	106	17.08	8.3	18	0.15	17.23
High	1998	48.3	65	3.14	3.8	11	0.04	3.17
	2000	63.7	65	4.14	4.6	11	0.05	4.15
	2010	85.6	83	7.10	5.8	14	0 08	7.19
	2020	115	106	12.19	6.9	18	0.12	12.31
	2040	193.5	173	33.48	8.1	29	0.23	33.71



Figure(4.3): Existing and future total domestic demand (Mm^3/year)

In table (4.7) estimation for the total domestic demand for the three scenarios are presented. It shows that in the low scenario the total domestic demand for the year 1998 is 3.17 Mm^3/year and this amount is expected to increase to 7.89Mm^3/year. While for medium and high scenarios the values are 3.17, 3.17 Mm^3/year for the year 1998 and are expected to be 17.23, 33.02 Mm^3/year in the high scenario by the year 2040 respectively. The values that are described above, and shown in the table include the water consumed by the visitors. Variation in domestic demand -according to the suggested different scenarios and different years- is shown in figure (4.3).

4.2.2 Industrial and commercial demand

As mentioned before Ramallah and Al-Berih cities are two of the most interesting cities in Palestine. They are very active commercially and they have only two industrial areas. Food, quarry and textile are the most water intensive industries at Palestine, and also in Ramallah and Al-Berih .

As a result of the Israelis restrictions against any extension of the industrial areas, and other difficulties against transporting and importing the raw materials that are needed for different industries, the industrial sector is still very limited. Furthermore, it is difficult to estimate accurately projections for industrial water demand in Ramallah and Al-Berih the absence of national plans for industrial development and the risk of investments because of the political situation. For this reason it was assumed that the industrial demand equals 7.7% of the total demand since we have similar conditions as Jordan. Industrial demand in Jordan is probably a bit more, and this value is the lowest of the Jordan estimations (9,11,10,7.7%)(GTZ & Water and Environmental Studies Center, 1995). In this study, the industrial demand was calculated at 7.6% of the total demand, depend on 1990 base line estimate in (ARIJ & HIID,1994). Further more, the trend of the given data for the years 1982 to 1994 shows an average increase by 0.46% yearly on average. As a result it was estimated that the rate for the year 1997 was 8.2% (See Appendix-1, table(1)). These three methods of estimation are very consistent. Consequently, the average of the three results was used for the year of 1998 which was estimated at 7.8%(7.5% was used).

For future industrial water demand, three scenarios were used: the low, medium and high scenario. The demand rate of growth are distributed as follows:

Table(4.8): Industrial demand growth rates(%)

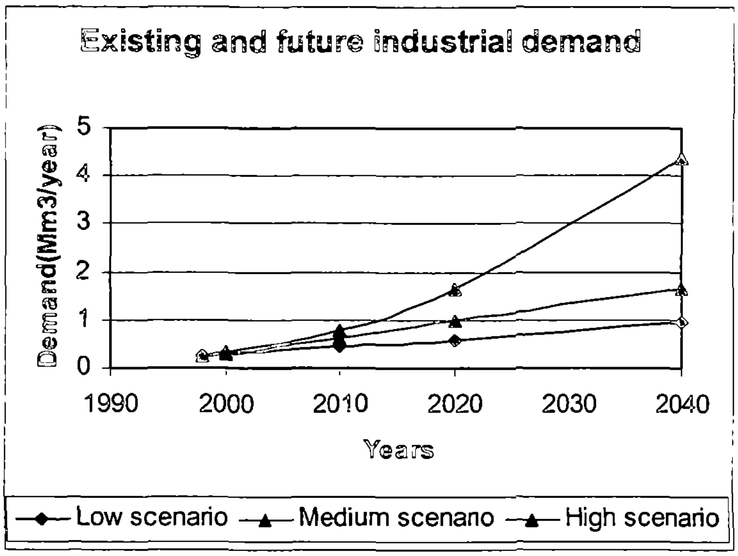
Scenario/year	2000	2010	2020	2040
Low	7.5	5	2.5	2.5
Medium	10	7.5	5	2.5
High	12.5	10	7.5	5

The above values are detected for the three scenarios from the year 1998-2020 from ARIJ & HIID,(1994) while for the year 2040 the rate was assumed still to be the same for the low scenario and to decrease by 2.5% for the medium and for the high scenario.
Although the rate decreases over time it increases as we move down from the low scenario to the high scenario.

Table(4.9): Existing and Projected industrial water demand(Mm^3/year)

Scenario/year	1998	2000	2010	2020	2040
Low	0.24	0.28	0.46	0.59	0.96
Medium	0.24	0.30	0.62	1.00	1.65
High	0.24	0.31	0.80	1.66	4.40

Table (4.9) shows the industrial demand for Ramallah and Al-Berih cities for different scenarios and for the years 1998 to 2040.See figure(4.4)



Figure(4.4): Existing and future industrial demand projections

Using JWU records for the years 1982 to 1994, it was estimated that the commercial demand equals approximately 2 % of the total demand on average (See appendix-1,table(1)).This percentage was assumed to increase by 0.1, 0.2, 0.4% for low, medium and high scenarios respectively.

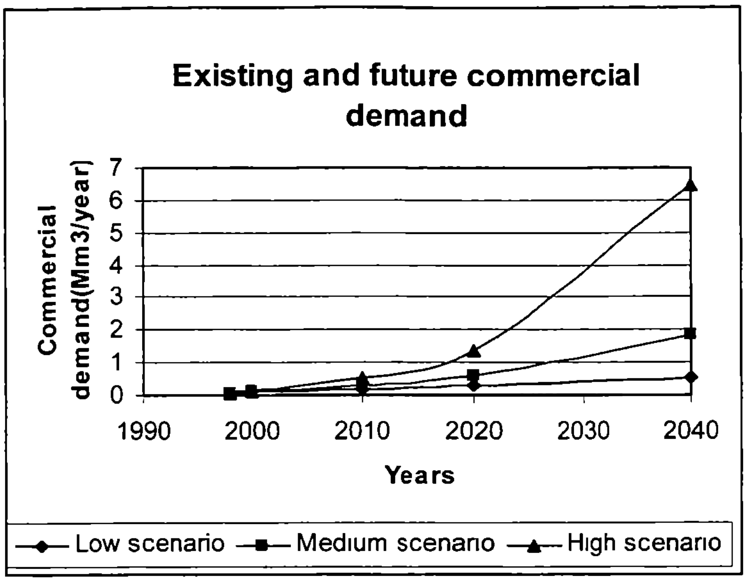
Table(4.10): Commercial demand percentages from total demand(%)

Scenario/year	1998	2000	2010	2020	2040
Low	2.4	2.6	3.6	4.6	6.6
Medium	2.4	2.8	4.8	6.8	10.8
High	2.4	3.2	7.2	11.2	19.2

The following table and graph show the existing and projected commercial demand

Table(4.11): Existing and projected commercial water demand(Mm^3/year)

Scenerio/year	1998	2000	2010	2020	2040
Low	0.08	0.11	0.18	0.27	0.52
Medium	0.08	0.12	0.30	0.62	1.86
High	0.08	0.13	0.52	1.38	6.47



Figure(4.5): Existing and future commercial demand(Mm^3/year)

4.2.3 Agricultural water demand

Currently about 90Mm^3/year is demanded by 89,000 dunums in the West Bank (GTZ and Water and Environmental Studies Center, 1995), of which 7900 dunums are located in Ramallah district. This amount constitutes about 8% of the total lands with a total demand of 5.5Mm^3/year. It was estimated that about 612000 dunums are the potential area that is suitable for cultivation (GTZ and Water and Environmental Studies Center, 1995). Of which Ramallah shares about 42,000 dunums. In spite of that fact, the irrigated area is so small because of the Israelis restrictions on land cultivation and because of a shortage for water for irrigation.

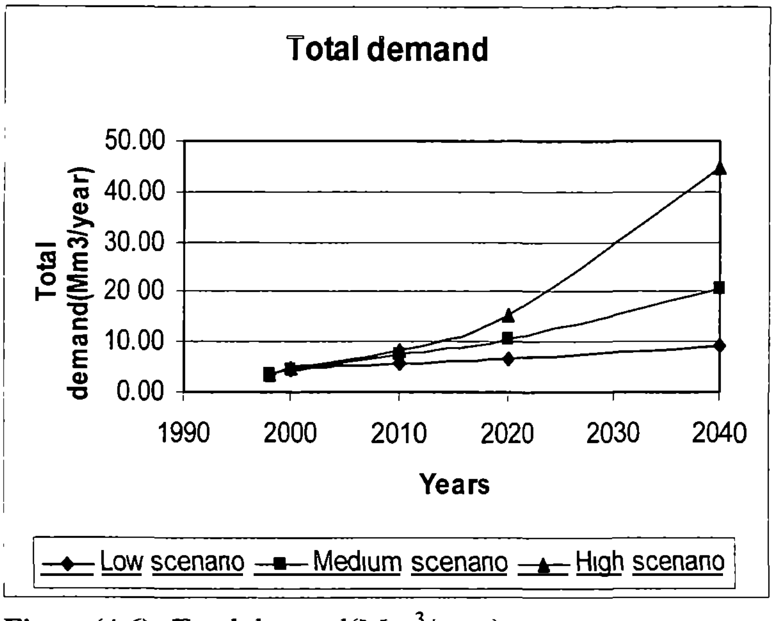
In Ramallah and Al-Berih cities no considerable agricultural lands are available, but there are small gardens beside the houses which are irrigated from the same connection to the houses in addition to a limited amount from the cisterns. That amount should be added to the domestic consumption. The water demand for agriculture in the two cities is assumed to be negligible.

4.2.4 Total demand

Total demand can be estimated by adding the estimated values of different demand types: domestic, industrial, commercial and agricultural demand. In our case the agricultural demand was assumed to be negligible. Consequently, the total demand for the two cities are consists of only the domestic demand, industrial demand and commercial demand. See table (4.12) and figure (4.6).

Table(4.12): Total demand(Mm^3/year)

Scenario	Year	Domestic demand (Mm^3/year)	Industrial demand (Mm^3/year)	Commercial Demand (Mm^3/year)	Total demand (Mm^3/year)
Low	1998	3.17	0.24	0.08	3.49
	2000	4.15	0.28	0.11	4.54
	2010	5.06	0.46	0.18	5.70
	2020	5.87	0.59	0.27	6.73
	2040	7.89	0.96	0.52	9.37
Medium	1998	3.17	0.24	0.08	3.49
	2000	4.15	0.30	0.12	4.57
	2010	6.34	0.62	0.3	7.26
	2020	9.10	1.00	0.62	10.72
	2040	17.23	1.65	1.86	20.74
High	1998	3.18	0.24	0.08	3.50
	2000	4.19	0.31	0.13	4.63
	2010	7.19	0.80	0.52	8.51
	2020	12.31	1.66	1.38	15.35
	2040	33.71	4.40	6.47	44.58



Figure(4.6): Total demand(Mm^3/year)

Chapter (5)
Analysis of rainfall data

5.1 Stations location

The three rainfall stations in and around the study area are Alhashimya, Betunia, and WBWD. Al-hashimya is located on the east at coordinates of (E171300, N146100) and WBWD on the north (E170850,N148000) and at elevation of about 880[1], 910[1]m above mean sea level respectively. Betunia is located on the West-south at coordinates of (E169000, N145500) and at elevation of about 740[1]m.

5.2 Time series

To identify possible errors, time series of daily data were plotted for the three stations for the 26 years of available data (Figure (1), Appendix 2), From this graph it was seen that there are errors in data measurement for the year 1988 to 1991 at Alhashimya and Betunia station. The reason is that both stations are schools and during a particular period they were only partially open during the study seasons because of the Intefada (Palestinian demonstration against occupation). As a result of that data were not measured regularly. For this reason these four years were deleted initially from the data for the three stations.

There are noticeable differences in daily records for the three station that can attributed to the difference in positions (X,Y,Z)(See 5.1), the observer's accuracy and different types of the rain gauges.

5.3 Double mass analysis and the correlation factor

To choose one of the three stations, double mass analysis (DMA) was done for the three stations versus each other by drawing cumulative yearly rainfall for each station versus others. Figures for the three station were shown in (Figures (2,3,4,5,6,7), Appendix-2). Also correlation factors for the three stations were estimated by using the following formula:

$$\rho(r) = \rho_0 e^{(-r/r_0)} \qquad \text{(5-1) (Delaat,1996)}$$

Where:

$\rho(r)$ *Correlation factor between two stations at distance r.*

ρ_0 *Correlation at distance zero.*

r_0 *Coefficient(Km).*

r *The distance between two stations (Km)*

The storm type in the WB was assumed mixed convective orographic (De Laat, 1998) and the period is used in days. From (table (1), Appendix-2), ρ_0=0.92, r_0=50Km.The estimated values of correlation factors for the three station are shown in (table(2), Appendix-2). The values are between 0.8 and 0.89, which considered good values. Consequently one station could be used for the analysis.

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[1] Approximate values were estimated from a topographical map for Ramallah and Al-Benh cities

WBWD, Alhashimya and Betunia stations almost fitted a line through double mass curve analysis, but WBWD station was chosen for analysis because :

- It has the largest number of measurements.
- It is most close to the study area.
- It has the more reliable data (Since it locates in a water agency, the reading can be assumed accurate and it was not affected by closure during the rainy season because of Intifada (the Palestinian uprising) (1988-1991) like the school stations.

5.4 WBWD rainfall analysis

The following figure shows the annual rainfall in WBWD station, the average, the maximum and the minimum annual rainfall:

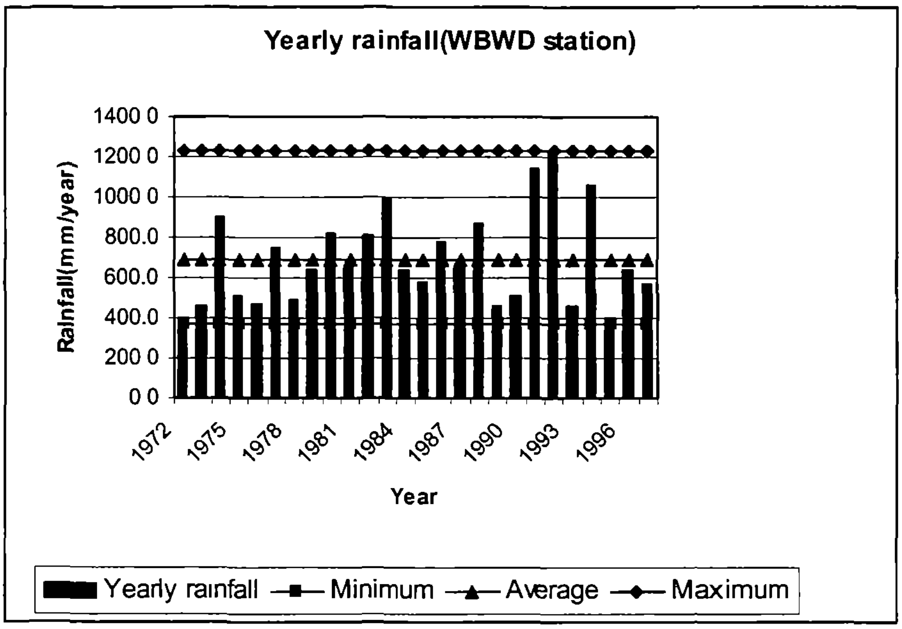
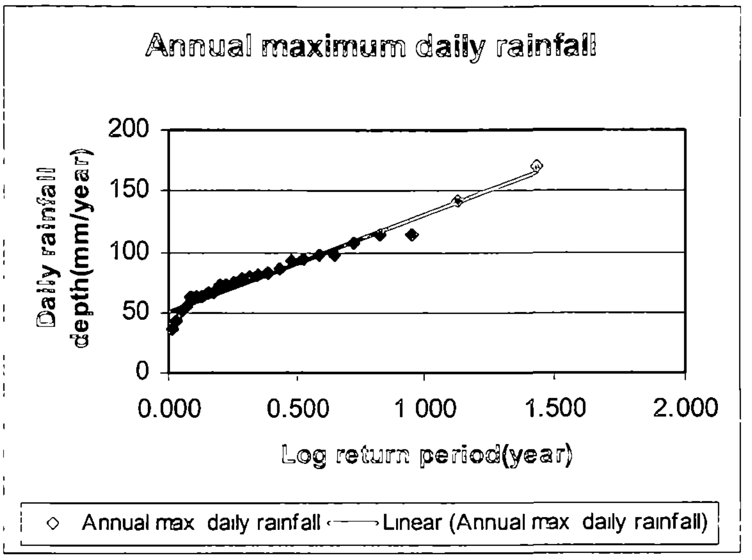


Figure (5.1): The annual rainfall in Ramallah (WBWD station)

The minimum annual rainfall was estimated at 371mm/year for the year 1995, while the maximum annual rainfall that was recorded during 26 year was 1228mm/year for the year 1992.The average rainfall for the 26 years is 686mm/year.

Figure (5.2) shows a linear relation between the logarithm of the return period and the extremes of daily rainfall for the 26 year (1972-1997) for the WBWD station. See (Table (3), appendix-2).The maximum daily rainfall reaches 171mm/day with probability of exceedence of 3.7%. In other words, it happened once during 26 year (return period=26 years).

On average, 5 months are rainy during the year: January, February, March, November and December and some times little amounts of rainfall in October.

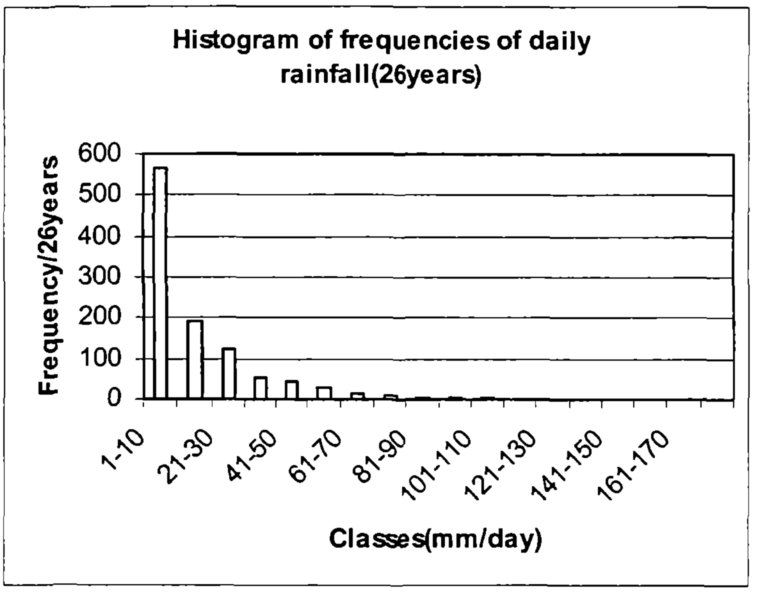


Figure(5.2): Annual maximum daily rainfall

Table(5.1): Distribution of the daily rainfall over class intervals(26 years)

Daily classes (mm/day)	Number of occasions (n)	Classes (mm/day)	Occurrence of class or more	Probability of occurrence (%)	Return period (years)
0-1	8429	0	9497	100	0.00
1-10	579	1	1068	11.2	0.02
11-20	193	11	489	5.15	0.05
21-30	125	21	296	3.12	0.09
31-40	55	31	171	1.80	0.15
41-50	44	41	116	1.22	0.22
51-60	29	51	72	0.76	0.36
61-70	16	61	43	0.45	0.61
71-80	10	71	27	0.28	0 96
81-90	4	81	17	0.18	1 53
91-100	6	91	13	0.14	2 00
101-110	3	101	7	0.07	3.72
111-120	2	111	4	0.04	6.50
121-130	0	121	2	0.02	13 00
131-140	0	131	2	0.02	13 00
141-150	1	141	2	0.02	13.00
151-160	0	151	1	0.01	26.00
161-170	0	161	1	0.01	26.00
171-180	1	171	1	0.01	26.00
Total	9497				

In table(5.1) and figure(5.3), frequency and probabilities of occurrences and their return periods of specific classes of daily rainfall during 26 years including dry and wet seasons are shown.

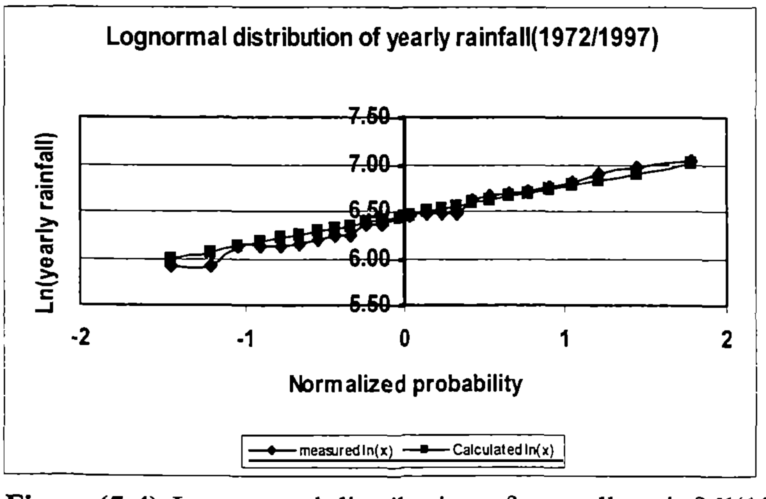


Figure(5.3): Histogram of frequencies of daily rainfall

The above table shows that days with outrain or very little rain occur most frequently and high rainfall amount are scarce. As it is seen in the graph (5.3), most of rainfall is more than 1 and less than or equal to10mm/day,which is a small amount. For the range of zero to less than 1mm/day are not shown here because this amount was assumed as losses that remain on roof and later on evaporate (See section 6.3).

5.5 Frequency distribution

To estimate a specific year that has 75% probability of exceedance log normal distribution graphs was created .See figure (5.4).



Figure(5.4): Log normal distribution of annually rainfall(1972/1997)

The available 26 years data were ranked in descending order. The normal logarithm and the probability of exceedence were calculated for each year.
The X-axis represents the normalized probability (t). Which is derived from a normal distribution that is related the probability of exceedance (or Non-exceedence).While the Y-axis represents the log normal values of annual rainfall.The straight line illustrates calculated values of annual rainfall for the 26 years. These values were calculated by using the following formula (See appendix- 3,table 4):

$Y_{cal}=Y_{aver}+t*\sigma y_{aver}$ .... *(5-2)(Delaat,1996)*

Where:
Y_{cal} *Calculated annual rainfall(mm/y).*
Y_{aver} *Average of measured Ln(x).*
t *Normalized probability.*
σy_{aver} *Standard deviation of measured Ln(x).*
X *Annual rainfall(mm/year)*

Chapter (6)
Feasibility study for roof catchment systems

6.1 Introduction

The main aim of this chapter is to determine to what extent rainwater harvesting is feasible, from a technical and an economical point of view, in urban and rural areas. Firstly the total annual amount that can be collected on micro and macro scales are to be estimated and to evaluate to what extent this amount participates in water supply. It was assumed that consumption was fully switched from Public Water Supply (PWS) to rainwater as soon as water was in the storage tank. Then to have a critical look on the financial feasibility of a certain capacity of storage tank depends on the yield depends on the rainy season, the size of the catcment and the consumption pattern. The financial benefits that can be achieved depend on the expected price development. What is the most feasible tank capacity from financial point of view is to be estimated. A spreadsheet was created to achieve this purpose. Description of this spreadsheet is shown in Appendix 3-b. The input and the output of this spreadsheet will be discussed in the following sections.

6.1.1 Catchment area

The computations analyze the case of flat blocks. The average area of the flat block's roofs was taken as a representative catchment area. The average was calculated by selecting different areas from different groups of houses from a map of the two cities. In addition to that, other areas of flat blocks are taken randomly from the study area through field survey. The average area that is used in the analysis is $300m^2$. Brief calculations for the average area are shown in (Table (1), Appendix 3-a). See section (6.4).

6.1.2 Per building water consumption

Since the cistern was assumed to be for the total flat block, the total consumption per building should be estimated. It was estimated at 1200 l/building/day by multiplying the per capita consumption by the average number of members per family by the average number of residential units per flat block. The present per capita water consumption is 100L/c/d which is the estimated number by JWU for the year 1997 for the two cities(See 4.2.1). The average number of members per residential unit is estimated at 4 members as the total number of population for the year 1997 was counted 46600 and the total number of the residential units 12432 units[1] (PCBS,1997). The average number of the residential units per building was estimated at 2 as the total number of the residential units and the total number of buildings (5885). However, not all the buildings are residential. Further more, the field survey of different random by picked buildings gave an average estimated number of residential units of 4. For this reason 3 residential units per flat block were used in this study. The number of the residential buildings is estimated at 4144 buildings[2] by the year 1997/1998. See (Table (2), Appendix 3-a). The analysis was taken a coverage of 100% of the demand in times when rainwater is available because the strategy is to utilize all the collected water (to consume the maximum amount from collected

[1] Was assumed the same for the year 1998.

[2] This value was estimated as follows [Al-Berih(7578**/3=2526)+Ramallah(4854**/3=1618)]=4144, for ** see table 2 appendix 3-a

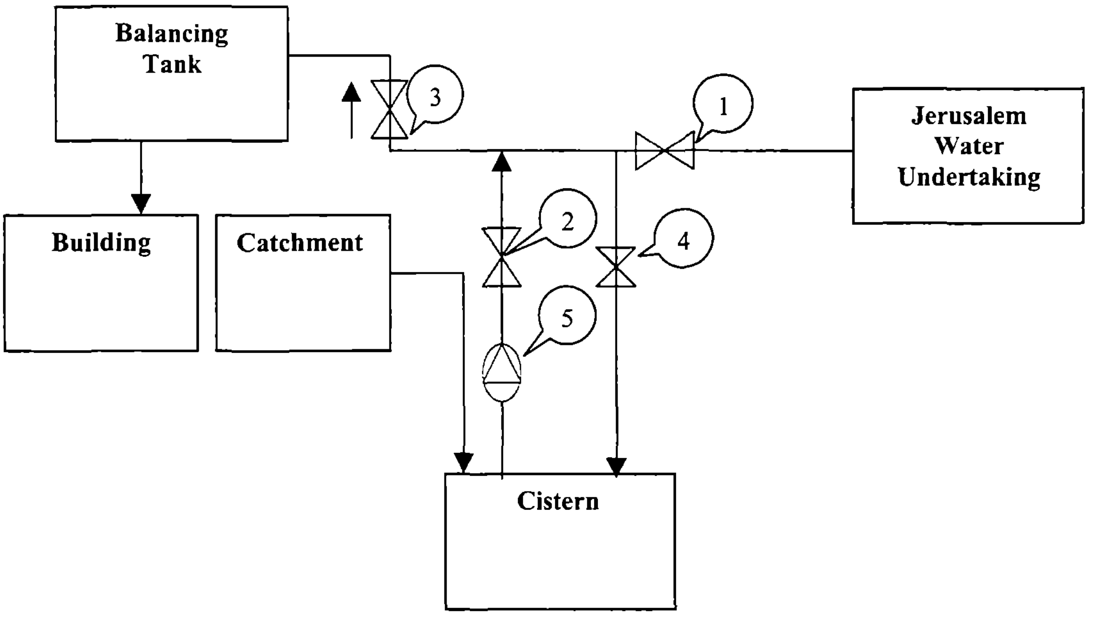
rainwater) which means to spill as little as possible and the maximum yield of tank can be achieved by applying this percentage. Further more, consume 100% of the demand from the available collected rainwater minimize residence time of water in the cistern. Long residence time provide potential breeding sites for mosquitoes that help in biological contamination and affect the health negatively. For the design graphs different values of consumption were used. See section (6.4).

6.1.3 Actual tank capacity

In the spreadsheet the tank capacity was considered as input. Two criteria would be taken into consideration: the present cost and the spilled water .The target is to consume as much as possible and to spill as little as possible. The tank capacity was varied between 1 and 200m^3 . A 200m^3 tank would have no spillage at all in any of the 26 rainfall years from which date were used. The performance was tested for the above criteria and for the creation of design graphs.

6.2 Recommended system:

Current systems are not suitable to make use rainwater in the rainy season in an efficient way. A Special system is advised to be applied. This simple system is described in the following sketch (figure (6.1).



Figure(6.1): Recommended system

Currently, all the houses are supplied by JWU from the available WSDS ,the supplying pipe is connected to the balancing tank or directly to the distribution system in the house. The suggested system can be operated manually, if there is any water in the cistern from rain which is collected by the down pipe in the cistern from the catchment then valve 1 should be closed, at the same time pump 5 and valve 2 should be opened. If the cistern becomes empty, valve 2 should be closed and valve 1 should be opened again. An additional advantage of this system apart from the use of rainwater is that if there any shortage during the dry season then people can fill the tank with JWU water by opening valve 4 in the supply period to use it in un-supplied days if a scheduled supplying pattern is applied in the two cities. A disadvantage of this system is that the rainwater could be mixed with the water from the WSDS which could lead to contamination of uncontaminated source in case the collected rainwater is contaminated. Further more, it may be unacceptable by users since the taste of drinking water will vary. To overcome this problem another system could be advised. Two balancing tanks instead of one could be used, one is for only drinking water from JWU supply and other for washing and other purposes for which rainwater use does not give a problem. This system should be connected in a way that in case of un- availability of rainwater, JWU water could fit the purpose. But this system would be difficult to implement, since it needs some how high level of controlling and install additional connections.

6.3 Harvested rainfall

The following equation was used to calculate the rainfall harvested in a rainfall day:

$$H = \eta * [(P-L)/1000] * A \quad \text{......(6-1)}$$

Where:

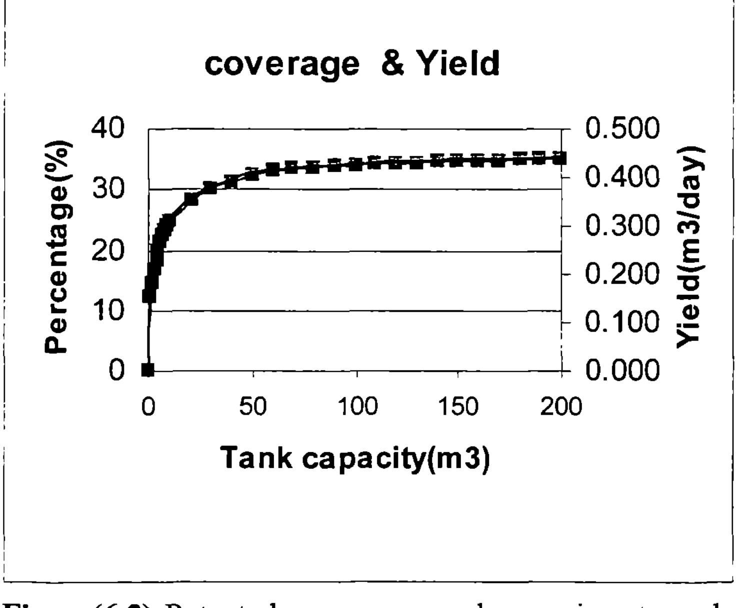
H Harvested rainfall (m^3/day)

η Runoff efficiency, 0 8 (Water harvesting, IRC, 1992).

P Precipitation (mm/day).

L The rainfall that remains on roof and later on evaporates is assumed 1 mm/rainfall day

A The cathment area (m^2).



Figure(6.2): Potential coverage by rainwater harvesting from the actual consumption/building/year and tanks yield.

Using this equation the average annual rainwater that can at maximum be harvested from a catchment area of $300m^2$ was estimated at ($154m^3$/year) which is 35% of the existing actual consumption. A 100% of coverage from total demand was used.

The total number of members per building is 12 persons on average. So, the average amount that can be harvested yearly per person 12.8 m^3/year. Consumption of the total amount depends on the tank capacity in the building.
The percentage of rainwater coverage from the total existing consumption per building and tanks yield based on different tank capacity are shown in graph (6.2). (See Table(1), appendix 3-b).In figure (6.2) the rainwater coverage increases as the tank capacity increases. With a tank of $10m^3$ 25% of the consumption can be harvested, increasing to 30% for $30m^3$ tank capacity and 34% for a $100m^3$ tank. The potential of 35% requires a tank of $200m^3$.The potential does not increase further with tanks larger than 200m3 because $200m^3$ can store the maximum amount of rainfall occurring in the 26 years over period in which it is consumed. Daily storage variation for different tank capacities can be seen in (figure (1) appendix 3-c). It shows that small tank capacities are full because the collected water most of the time has a potential more than or equal the tank sizes which means that there are spilling while it shows that for larger tank capacities, the tanks are full in less periods and those tanks can capture most of the potential.
If it was assumed that each residential building has a cistern, then the total expected amount of water that can be collected from the roofs in Ramallah and Al-Berih for different sizes of tanks, can be seen in the next graph. (For the calculations see table (1), appendix 3-d).

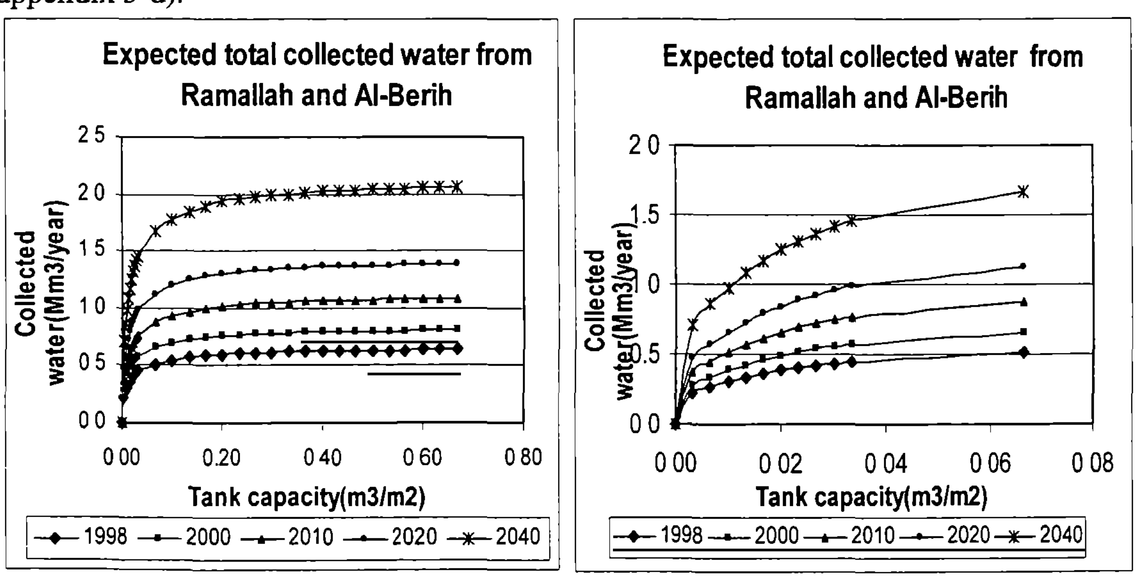


Figure (6.3): Current and future expected total collected water from Ramllah and Al-Berih roofs in case of each building has a cistern.

Provided each house has a cistern of $200m^3$capacity the maximum amount that possible can be collected from the two cities is $0.67Mm^3$ if there were cistern in each house and about 2.1Mm^3/a by the year 2040 after the expected urban development (See tables (1), appendix (3-c)). This means a capture of all the possible rainwater from a cachment of 300m^3. But such big cisterns mean high capital cost that reveals to high Equivalent Annual Cost (EAC).From the above chart, it can be seen how the amount of water collected increases with the tank capacity, it increases as the tank capacity increases.

6.4 Demand supplied by rainwater

In Ramallah and Al-Berih a Water Supply Distribution System is available. Therefore, the households do not depend on rainwater harvesting. No shortage will occur because of lack of rain. For this reason the probability of occurrence of a dry year once or more during the period are not taken into consideration in the calculations. The total 26 years were used to end up with a good average result. The total days of shortage and the average yearly days of shortage-related to rainwater supply were calculated. Chart (6.4) shows different tank capacities plotted versus average yearly days of full supply by rainwater. See table (1), appendix 3-b.

A graph was developed for preliminary assessment of feasibility and design for different tank capacities to assess of how many amounts does rainwater supplement PWS. Graphs creation was based on three different variables: Catchment area per capita, consumption per capita per day and tank capacity. Graphs for each consumption rate 50l/c/d and 200l/c/d were produced. In each graph a curve was drawn for different constant catchment altering tank capacities between 1-200m3.The graphs are per flat block of 12 persons. See figures (6.5,6,7,8)

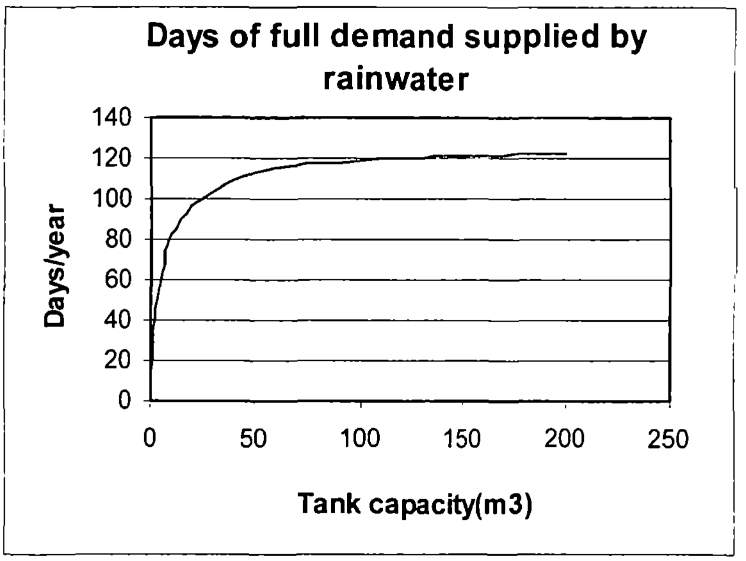
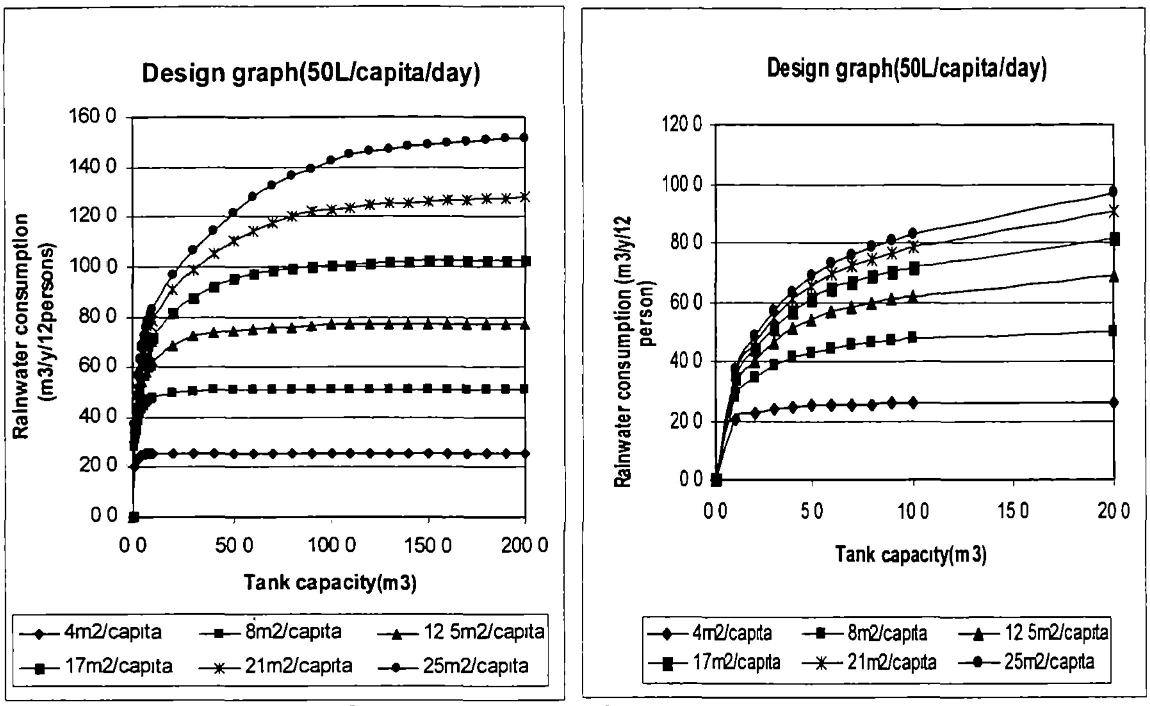


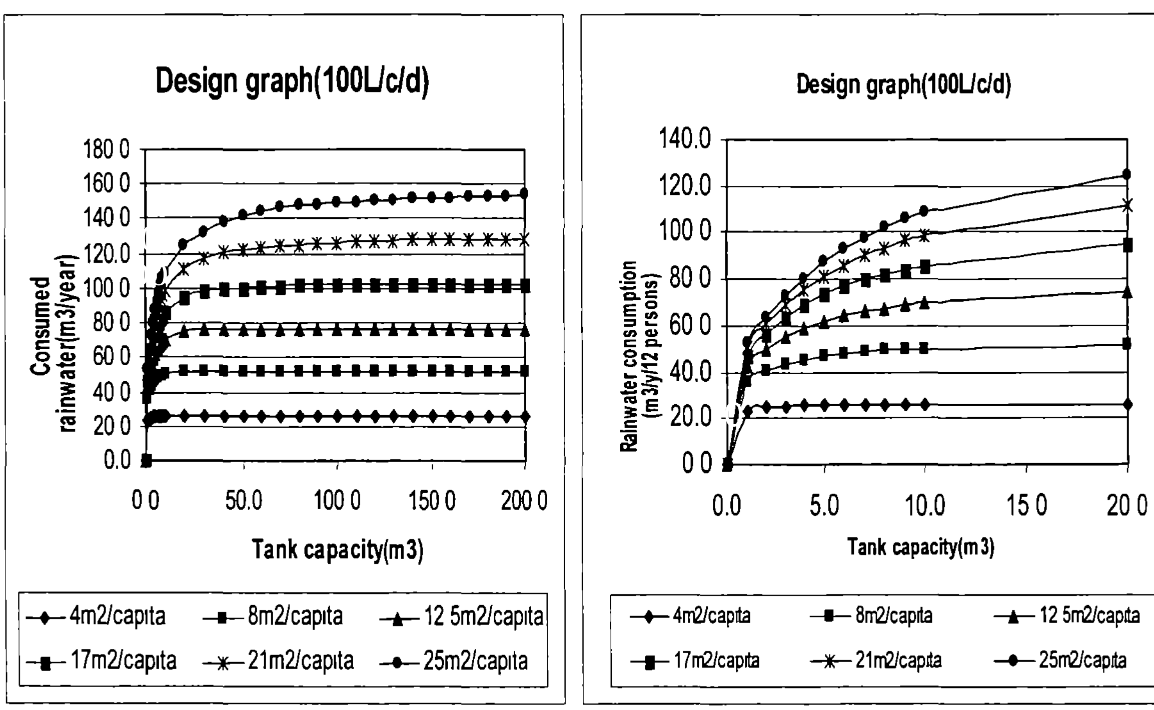
Figure (6.4): Average days of full demand supplied per year

As the area, the tank capacity and the per capita consumption increases, the tank yield increases. The maximum yield was restricted by the maximum amount of rainwater that can be collected, which was estimated at 154 m^3/year for 300m^2(=25m^2/capita for 12 persons). If the area increases the yield will be more.

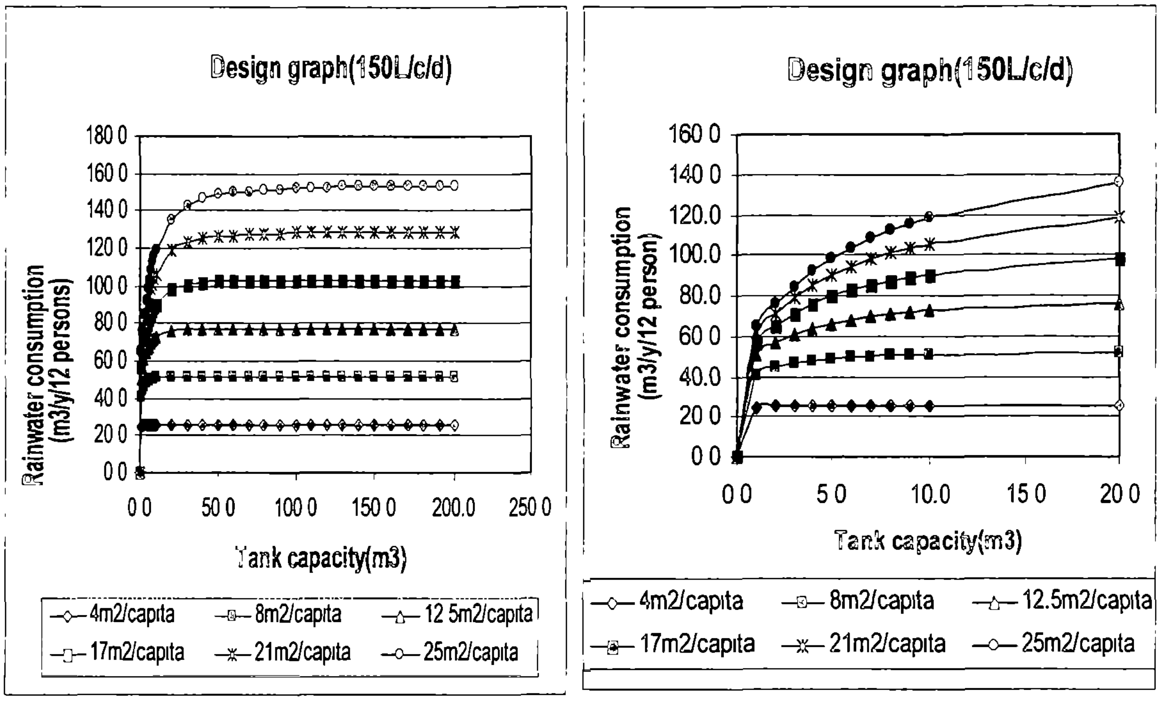
Graphs(6.5,6,7,8) show for a small catchment area, the yield is constant without restriction of the tank capacity and the consumption rate. The collected rainwater from $4m^2$ per capita is so small that it can be consumed by 12 persons within one day so you only need a storage for the day.



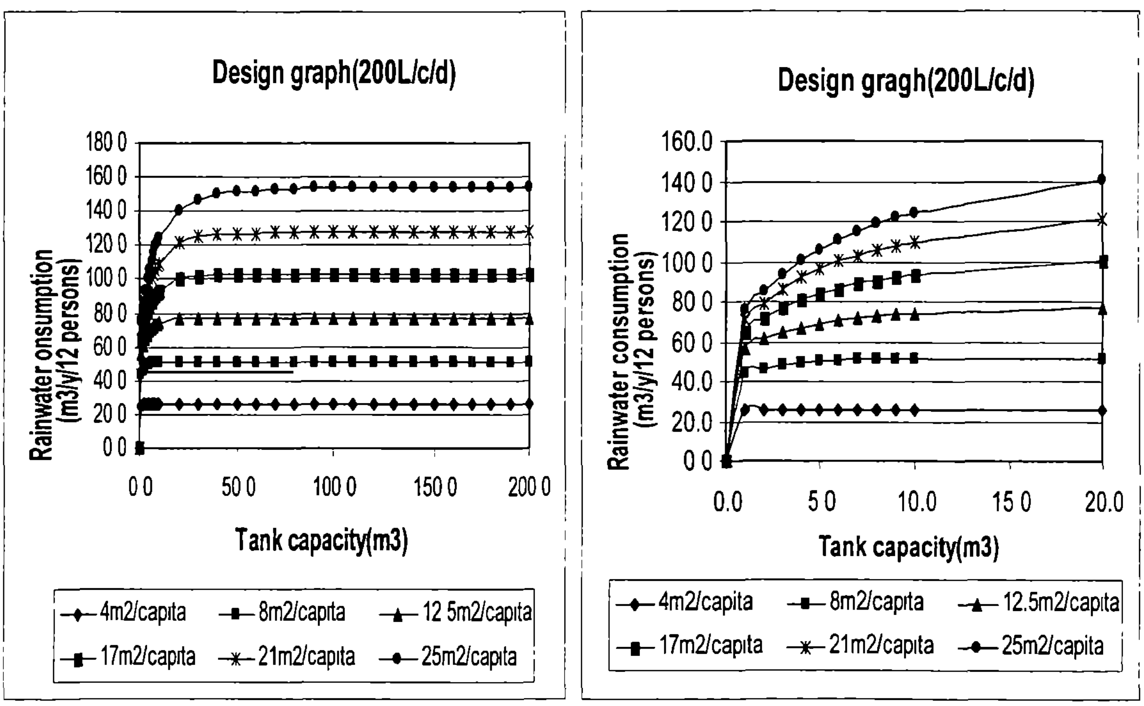
Figure(6.5): Design graph for a consumption of 50L/capita/day



Figure(6.6): Design graph for a consumption of 100L/capita/day



Figure(6.7):Design graph for a consumption of 150L/capita/day



Figure(6.8): Design graph for a consumption of 200L/capita/day

With larger areas per capita increases in yield per extra m^3 of tank capacity are still considered with larger amounts of tank capacity : i.e. the marginal benefits of an extra m3 are higher. The most curvature lines could be seen in 50L/c/d chart and they become less with high rate of consumption. Furthermore, each curve starts to be constant when the tank capacity can capture the whole amount harvested. As a result a larger tank capacity means no sense.

6.5 Spilling

Spilling is one of the two criteria that were taken into consideration, since the target is to use as much as possible of the rainwater.

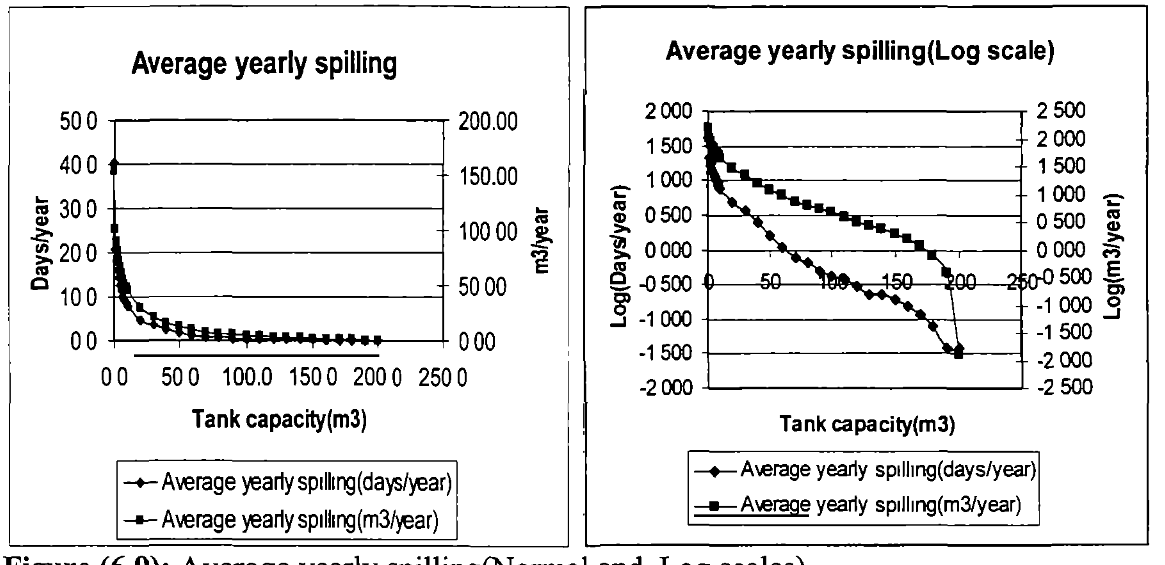


Figure (6.9): Average yearly spilling(Normal and Log scales)

The spilling differs with the tank capacity and the coverage of the total consumption. The variation in average per year spilling quantities and days for 100% coverage of the consumption were shown in the following charts. (See figure (6.9), and table(1), appendix 3-b).

6.6 Cost –benefit analysis

6.6.1 Capital cost

The capital costs for construction for different tank sizes were derived from capital cost estimation for common sizes of tanks that were constructed by the Palestinian Hydrological group(PHG) in different areas in the West Bank. The estimated cost for each component that participates in the construction of the reinforced concrete tanks were shown in (table (1), appendix 3-d). Table (6.1) shows different tank capacities with the estimated costs for each.

To estimate the construction capital cost of different reinforced concrete tanks, of which the costs are not shown in the above table, a formula was created with Excel based on the actual costs:

$$Y=0.0002X^3-0.1381X^2+61.225X-23.53 \quad \ldots\ldots (6\text{-}2)$$

Where:
Y *Cost (US$)*
X *Tank capacity (m^3)*
The relation between capacity and cost was drawn in the figure(6.10).

Table (6.1): Tank costs (US$)

Capacity(m3)	Cost($)
0	0
64	3250
80	4125
100	5000
144	6500
245	9500
320	11750

After PHG, 1998

Based on formula (6-2) the construction costs of 1 to 200m^3-tank capacities were estimated. Accessories cost were estimated approximately at US$750(See table(2), appendix 3-d). This value was assumed to be constant for any system. The per cubic meter pumping cost was estimated approximately at 0.038 US$/m^3. (For detailed calculations, see power, appendix 3-d).

The capital cost of tank construction per each cubic meter does not decrease much with higher capacities (See figure(6.10)). It almost fits a linear line through the origin until tank capacities of 100m^3.

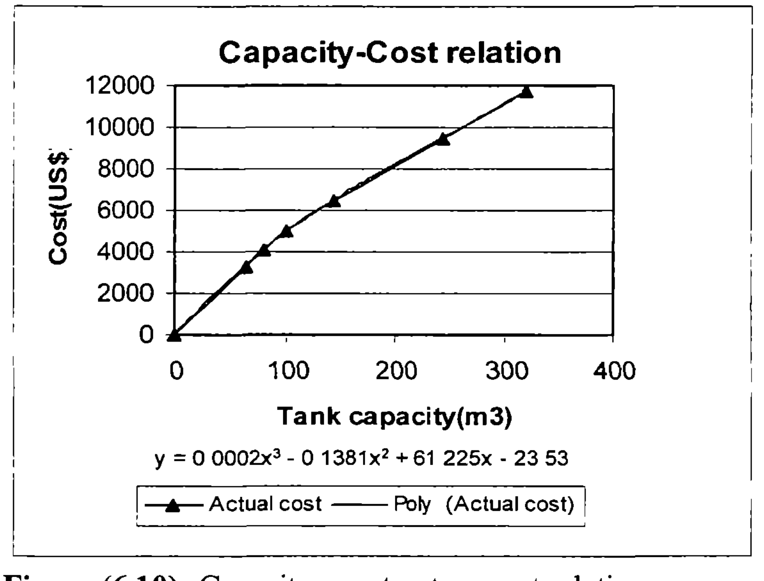


Figure (6.10): Capacity-construction cost relation

Only with capacities higher than 100m3 the costs per cubic meter are getting less. This would indicate that if several flat blocks would have a joint reservoir costs per cubic meter would be cheaper. However, if different flat blocks would need to be connected to the same reservoir extra pipes, pumps, and gutters should be necessary. These extra fittings will absolutely increase the equivalent annual cost and with the difficulties of sharing anyway, do not make it attractive to share a reservoir with different flat blocks.

6.6.2 Equivalent annual cost

EAC per each cubic meter supplied from RWHS were estimated for different tank capacities (See figure (6.11)). The following equation was used for the estimation:

EAC= $C*\{r(1+r)^n\}/\{(1+r)^n-1\}$*/Supplied rainwater…………………(6-3)(Lee, M.D. and Visscher J.T, 1992).*

Where:

EAC Equivalent annual cost ($/m3).
C Initial capital cost ($).
n Expected life time (years).
r Discount rate (%).

The expected life time (n) was assumed to be 50 years for the reinforced concrete tank while it was assumed 25years for the accessories standing life. The discount rate (r) was assumed 8% which is currently the minimum interest value for money that can be obtained from the bank (Al-Hudhud,A. and Najjar,T., 1993).(For more details see table(3) appendix 3-d). Total EAC per each cubic meter was estimated by adding the EAC for construction cost- and for accessories. The EAC for construction cost increases gradually as the tank capacity increases while EAC for accessories decreases as the tank capacity increases since the total cost for accessories was assumed constant for any system while the supplied water increases. Finally the power cost per each cubic meter was added (0.038US$/m^3).

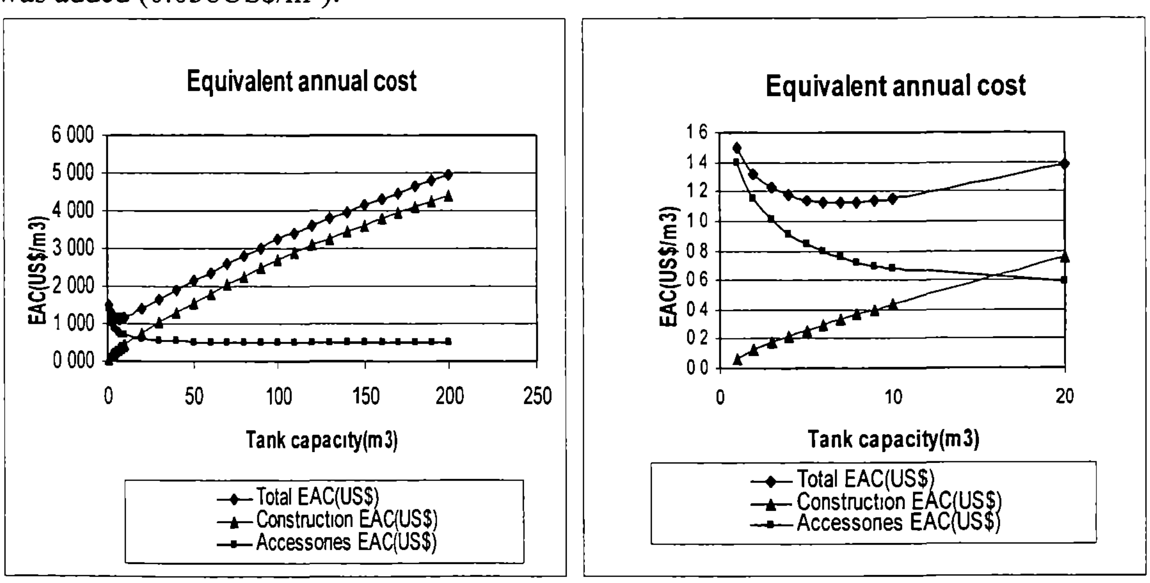


Figure (6.11): Equivalent annual cost (US$/m3)

The EAC started high at 1.5US$/m^3 then it started to decrease until it reaches 1.1US$/m^3 for 7m^3 tank capacity. Again an increase in the per cubic meter cost. It could be noticed from graph (6.11) that EAC per each cubic meter supplied increases as the tank capacity increases.

6.6.3 Optimal tank capacity

The optimal tank capacities per household depends on two criteria: the financial profits and the quantity that can be collected.

6.6.3.1 Financial Profits

Household profits

The chosen capacity should be based on the maximum benefit, assuming that water is available all times by tap and consequently the amount of water that can not be supplied by rainwater is not a problem. Based on the estimated EAC and the present costs per cubic meter for consumers as charged by JWU, a relation between benefit and tank capacities was drawn in figure (6.12).

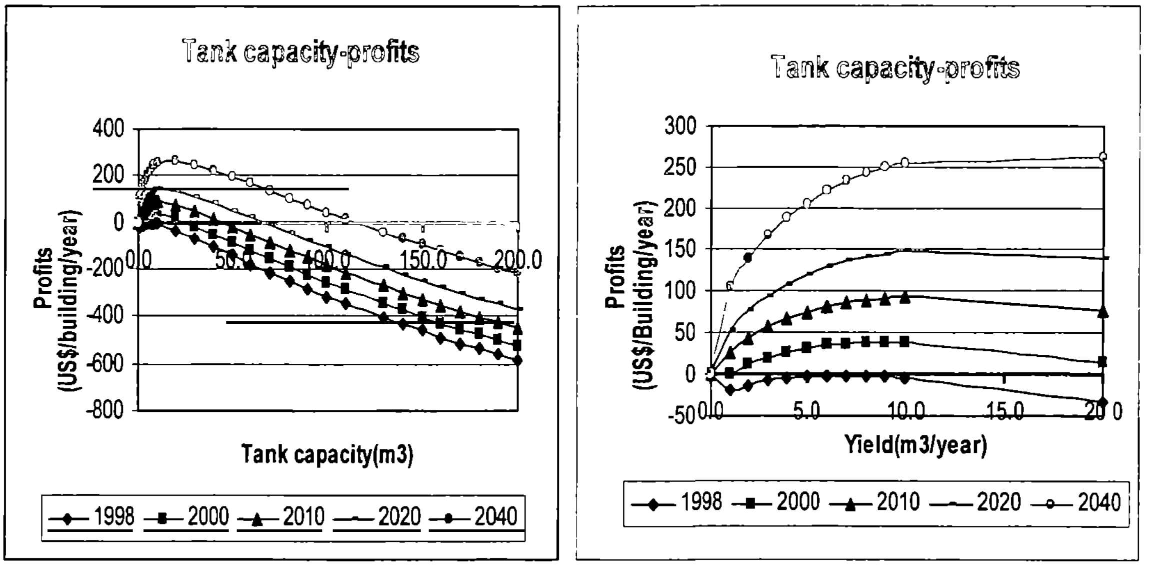


Figure (6.12): Tank capacity - Profit per year per building

It was recognized that under these prices no financial benefit could be achieved, since the costs for each cubic meter to be supplied to consumers from different tank capacities was always higher than the price of the sold water by JWU. For this reason one can notice the negative values in the chart 6.12. But JWU is expected to increase the price in the next few years. This increase in prices depends on different factors such as increase in Israeli price, increase in operation and maintenance costs, improvement in the economical situation, the differences in living index and there effects on the staff salary, water scarcity, data regards previous per cubic meter cost and future plans for cost increasing by JWU are not readily available and investigation of future costs is one of the most difficult issues that faces planners (Spaans, 1999), which is valid in particular in Palestine. All of the above reasons made an accurate estimation impossible. However, different scenarios with different growth rates can be suggested. These scenarios based on different variables that make prices increase such as the inflation rate, Israeli prices, etc...These factors are hardly controllable, and there are no good estimates available. For this reason it was assumed roughly that the price will increase to 1.5$/m^3 for the year 2000 and after that will increases by 0.5$/m^3 each 10 years. Accordingly, on long term the people can achieve benefits of rain water harvesting. See figure (6.12).

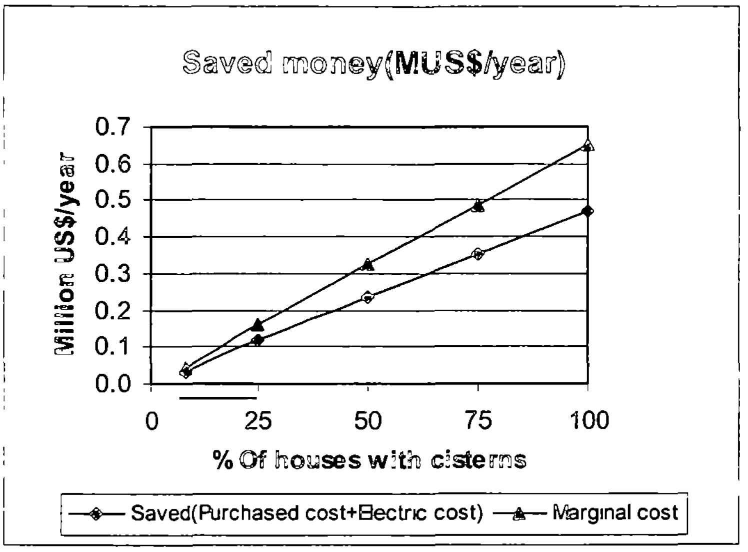
The optimum capacity is the capacity that gives the maximum profits. It could be recognized from the above graph that the optimum tank capacity is between tanks that have capacities 0 to 50 m^3. More exact optimal tank capacity for the year 1998 was estimated at 7m^3 and which would supply water at cost of 1.12US$/m^3. While the optimal tank capacities for the years 2000,2010,2020 and 2040 were estimated at 9,10,10,20m^3 with a supply cost of 1.14, 1.15, 1.15 and 1.39US$/m^3 respectively. Because tank will stand until 2040.Hence, it is advised to construct a tank of 20m^3 capacity. To use as much rainfall as possible, the consumption of the collected rain should be at maximum when there is water in the tank. People should be aware that rainwater has a good quality that competes water that is supplied from the net, also they should know how to use the collected rainfall in efficient way (See section 6.2).
Even there are benefits that can be achieved in the long term, these benefits are not considerable amounts if compared to the annual family income, and the expected increases in price are uncertain. Consequently, from the financial point of view constructing a rainwater collection system is not feasible. However, rainwater harvesting deserves to get attention, because it could be a solution for water shortage problem especially in villages without WSDS.

National profits
The total amount of money that was paid to JWU in the year 1997 by the consumers for use in the two cities –including the amount that is paid by industrial and commercial users- was estimated approximately at Million US$ 2.5/year. The amount that is paid to Mekorot was estimated at Million US$1.4 in 1997. Applied JWU tariffs and Israeli price are shown in (table (3), appendix 3-d). Future amounts of money that will be paid depend on the development of different parameters such as future per capita demand, future population, and future cost per m^3 sold.

The following graph (Figure (6.13)) shows the total expected amount of money that can be saved if the RWHS is implemented on large scale[3].The linear relations start from the existing situation, in which 8% of the houses have cisterns then an expected extent to 25%, 50%, 75%, 100% after the urban development. Water purchasing cost from Mekorot and pumping cost are the only two costs that can be saved if RWHS is implemented. These costs constitute 46% of the total cost per each cubic meter supplied by JWU on average. These average cubic meter costs are estimated at 0.72US$/m^3 according to JWU (See table (5), appendix 3-d). The graph shows that the maximum

[3] For the estimation it was assumed that
- JWU operations costs (including purchasing cost) are still the same in the short term
- The system will be implemented with in 2-3 years(2000 projections are used no of buildings = 5250(table 1, appendix 3-c)

amount of money that can be saved is about MUS$ 0.47/year provided that all the houses have a cistern of 20m^3 capacity.



Figure(6.13): Expected saved money Million US$/year if RWHS is implemented

Water production is at its maximum capacity from the wells that JWU owns and any increase in the supply has to be purchased from Mekorot (See figure (1) appendix 3-d).Also in the case that rainwater harvesting replaces existing supply, it will replace cubic meters bought from Mekorot, because the per cubic meter costs are higher for water purchased from Mekorot then for water produced in WB and because Palestine would like to decrease dependency from the Israelis. In case of replacing the existing supply, the amount of water that can be purchased from Mekorot could be minimized by about 30% if RWHS is implemented on large scale. Approximately 36% of the water supplied to the area by JWU was produced from their wells while the rest was purchased from Mekorot.

It can be concluded that any supply of one additional unit of water from Mekorot has a marginal cost. Marginal cost is about 1.3 times as much as the average PWS cost (average JWU tariff applied)(see table 4, appendix 3-d).The marginal cost includes all costs (power, purchasing and others). The saved costs are only the marginal costs of purchasing water from Mekorot and power which was estimated at 1US$/m^3 (See table 5, Appendix 3-d). The maximum amount of money that can be saved is estimated approximately at 0.65MUS$/a. See figure (6.13).

Influences on prices:

The average cost of a cubic meter from JWU is 1.31US$/m3 according to JWU report 1995(See table 5 appendix 3-d). To evaluate the effects of RWHS implementation on the cost per m^3 of the JWU operations, the following two scenarios could be discussed:

First scenario: scenario that rainwater harvesting decreases purchases from Mekorot. The cost of water from JWU is estimated at 1.44US$/m^3 -by using equation (6-4) and subtracting percentage of rainwater harvesting participation- which is more than the average cost per m^3 of JWU operations (See table (4) appendix 3-d). Because of the additional fixed costs now have to be divided over less cubic meters, the average costs per cubic meter has increased.

$$C_{fut} = \{[X \times (p_{pur} \pm r) + (V \times p_{pro})] / (p_{pur} \pm r + p_{pro})\} + C_{add} * (1 / (1 \pm r)) \qquad (6\text{-}4)$$

Where:

C_{fut}	*Future cost(US$/m³)*
X	*Marginal current costs of purchasing and power (1 US$/m3)*
p_{pur}	*% of current consumption covered by purchased water (64%)*
r	*% of current consumption that could be covered by rainwater(30%)*
V	*Marginal costs of production (0.67US$/m3)*
p_{pro}	*% of current consumption covered by produced water (36%)*
C_{add}	*additional cost (Administrative & distribution costs) (0.42US$/m3)*

Second scenario: scenario of rainwater harvesting instead of increasing of purchases from Mekorot. The average cost of a cubic meter of water supplied by JWU if RWHS wouldn't have been there but supply was increased by increasing purchases from Mekorot would have been 1.24US$/m^3 (by equation 6-4, but adding the percentage of rainwater harvesting participation) which is less than the existing cost per m^3 of JWU operations. Thus, the increase in average cubic meter cost by having larger percentage of the supply from purchases from Mekorot is more then compensated by the division of fixed operational costs by more cubic meter.

In the above two scenarios the additional cost (C_{add}) were considered a fixed amount for JWU as a whole (First case). If this cost is considered fixed per each cubic meter (C_{add}= constant) (Second case), the results of C_{fut} will be 1.26 and 1.33US$/m^3 for first and second scenarios respectively.

It can be concluded that by applying RWHS on large scales such that it decreases purchases from Mekorot, the operations cost per each cubic meter supplied by JWU increases to 1.44US$/m^3 in case Cadd is fixed as a whole while it decreases to 1.26US$/m^3 if Cadd is considered constant per each cubic meter supplied. But if RWHS used instead of increases of purchases from Mekorot, the future cost will decreases to 1.24US$/m^3 for the first case of Cadd and increases to 1.33US$/m^3 for the second case. This means that from the view point of JWU prices for the first case the second scenario is better than the first scenario since the per each cubic meter of JWU operations is reduced to 1.25US$/m^3 and vise versa for the second case.

Water value

Water in use has a value typically expected to be higher than the full cost. It depends upon the user and the use to which it is put. Value in use can be estimated by summing of the economic and intrinsic value. The intrinsic value is very difficult to define or estimate such as the pure existence value. The economic value has the following components:(Rogers,p. and others,1996)

Value to users of water. consists of the marginal value of product of water use of industry and agriculture.

Adjustment of societal objectives: such as poverty alleviation and employment.

Other components such as return flow value is not applicable in our case.

Water value in use is not estimated here. Because, estimation of such a value needs more data and information regarding water value components. A proper feasibility study should compare the full cost and the economic value of a resource.

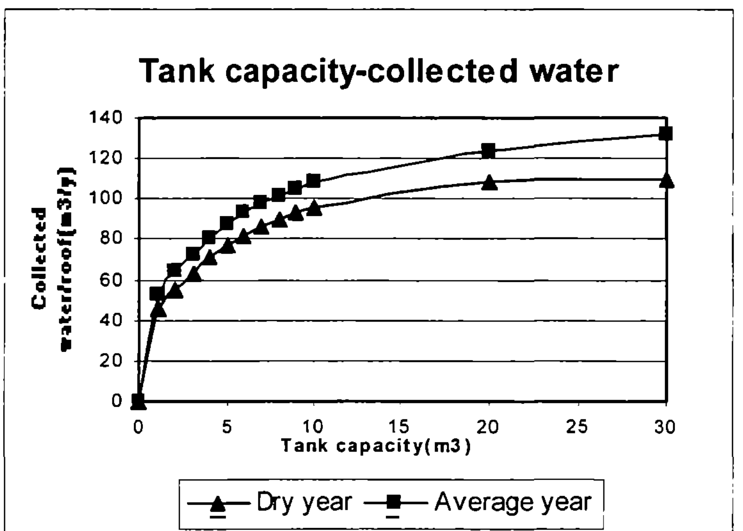
Rainwater harvesting option does not replace other resources but is considered as a supplementary resource that participates in alleviation of the water shortage. A proper comparison between other development options (See 7.4) and RWH option should include the value of the added new resource and compare it with the cost of development.

6.6.3.2 **Quantity**

The criterion is to consume as much as possible of rainwater and to spill as little as possible. The problem is shortage of water. The matter is to fulfil as much as possible of the expected gap. Only with a the tank capacity of 200m^3 the spilling is zero. In that case the yield is 154m^3/year which is the maximum average yield of the average roof per year. But the cost of this tank is high in comparison to the amount that it supplied. Extra yield per added cubic meter of tank capacity starts to decrease considerably for tanks larger than 10m^3(See figures 6.2 & 6.14). However, in case not always the system does not always withdraw the full average demand from the tank when there is water inside, for example because the demand is lower or because the value are not yet switched, increases in yield would still be considerable for tanks of about 20m3. A tank of 20 m^3 would be able to yield on average 124m3/year, which is about 81% of the 154m3/year and 28% of the existing per flat block consumption. The 20m^3 capacity can supply water with a cost of US$1.4 per each cubic meter.

6.7 Dry year situation

The feasibility of an investment in RWHS not only depends on the financial benefits that can be gained on average, but also on the risk that these benefits are less.



Figure(6.14): Tank capacity –collected water (Dry year).

As for the first years the price of the water could be estimated realistically, the risk that benefits are less depends on the occurrence of dry years. To evaluate the variability in annual yield from a quantitative and financial point of view, it was suggested that to study a year with rainfall with a probability of exceedence of 75%.

The year of 1978 had an annual rainfall of 491mm/a, which is close to the amount of a 75% dry year. Therefore the record of 1978 was used for a simulation of yields in comparatively dry years to 686mm/year in an average year. See section (5.4). It was found that the maximum amount of water can be collected and supplied in this year is $109m^3$/year by a $30m^3$ tank capacity. The $109m^3$/year covers about 25% of the current consumption. By constructing $1m^3$ tank already $49m^3$/year can be collected with 10% of coverage of the demand. See figure (6.14)

The following graph (figure (6.15)) shows the current and the expected future profits for a dry year with probability of exceedence of 75%.Less profit comparable with the revenues for the average year can be gained. The maximum profits that can be gained are -1.5, 39, 93, 147, 262US$/year for an average year, while they are -13, 21, 68, 116, 212US$/year for a dry year by the years 1998, 2000, 2010, 2020,and 2040 respectively. From the above results happening of dry year with 75% probability of exceedence does hardly affect the quantities that can be collected and the profits that can be gained. In other words people can invest in this system with expected low risk.

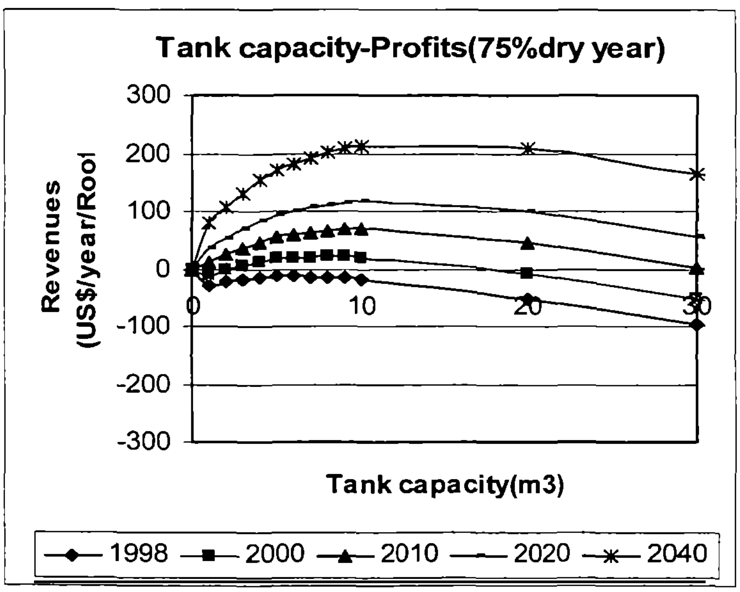


Figure (6.15): Tank capacity -Profits (Dry year)

6.8 Application in rural areas(Case study: Ain-Areek village)

6.8.1 Introduction

In most of the villages in the West Bank people have already implemented rainwater harvesting system, in particular in villages without WSDS.

In Ramallah district 67 communities have an access to WSDS, while 7 communities are without WSDN (PWA, 1998). Most of the villages suffered from water shortages in recent years. Rainwater harvesting system may be a solution for the problem. It was found that RWH deserves to have our attention to focus on the feasibility of the system in rural areas in particular the financial feasibility.

Ain-Areek village is a nice Palestinian village located in the west of Ramallah city at a distance of about 7Km from the city. Its houses are scattered on the two sides of two beautiful mountains, penetrated by Ain-Areek's wadi.

The total area of this village is about $6(km)^2$, about $0.15(km)^2$ of this area is built up areas (PCBS,1997). The Total number of population is estimated at 1400 distributed over 231 house units (PCBS,1997). In other words the average number of members per house is estimated at 6. The average roof area of the houses in the village is estimated at about $180m^2$ (See table(1),appendix 3-e).

6.8.2 Water resources

People in Ain-Areek don't have access to WSDS. This is considered as one of the most severe problems that face the people in this village. Always they suffer from water shortage during summer. They depend on three sources of water: Rainwater harvesting, springs, and tankers.

1-Rainwater harvesting: The total number of cisterns in Ain-Areek is 30 cisterns (MOPIC,1998).Which means 13% of the houses there have cisterns. The feasibility of this source will be estimated later.

2-Springs: Five springs are located in the village, two are used for domestic purposes, while the rest are used for agricultural purposes. The average yield of the two main springs (Areek Altehta and Areek Alfuqa) is estimated at about $0.38Mm^3$/year. People don't utilize this total yield. Of the total amount utilized, about 25% on average is used in domestic purposes while the rest is used in agriculture. The needed water is conveyed in pots by women, animals, cars, etc.. to the houses for the domestic use while it conveyed by open conduits to the agricultural fields. In the last period (1997) it was discovered that these springs are contaminated by wastewater.

3-Tankers. In dry seasons people buy their minimum needs of water from tankers, these tankers convey water from nearby springs that are located in nearby villages. These tankers have volumes of $3m^3$or $6m^3$ with a price of US$5/$m^3$. Most of people buy their needs as tankers in addition to that amount from springs.

6.8.3 Collected rainwater

Daily rainfall data from WBWD station are used for the estimation of the expected rainwater that can be collected from each flat block in the village. With the spreadsheet program, it was found that the average collected rainwater per year per building is 92 m^3/year while 56 m^3 can be collected in dry year that have a probability of exceedence of 75%. The total annual consumption per family is estimated at 110 m^3/year based on 50 l/c/d consumption (See table (1) appendix 3-e). It could be concluded that about 84% of the consumption could be covered by rainwater, if the full potential of water is harvested. On the other hand 51% could be covered for the dry year.

6.8.4 Optimal tank capacity

The Equivalent annual cost for each cubic meter that can be supplied from rainwater harvesting is varies as the tank capacity varies-as discussed before-. This cost is compared with the cost of each cubic meter that is supplied by tankers, which was estimated at US\$ 5/m^3.

To determine the optimum tank capacity that gives the maximum profits, a relation between tank capacity and expected profits is created. See figure (6.16). For 1m^3 tank capacity the total profits per year are estimated at about US\$ 50/year with a total yield of 25m^3/year. Then it increases to about 130 US\$/year for the 10m^3 tank capacity with annual yield of 50m^3/year (See figure 6.17). Which is equal to about 46% of the consumption.The optimal tank capacity is estimated at 20m^3 which gives profits of about 132 US\$/a/household and a coverage of about 55% of the current consumption. For larger tanks revenues started to decrease. Revenues reach zero for 88m^3 capacity. For higher values, profits start to be negative values, which mean no more profits can be obtained.

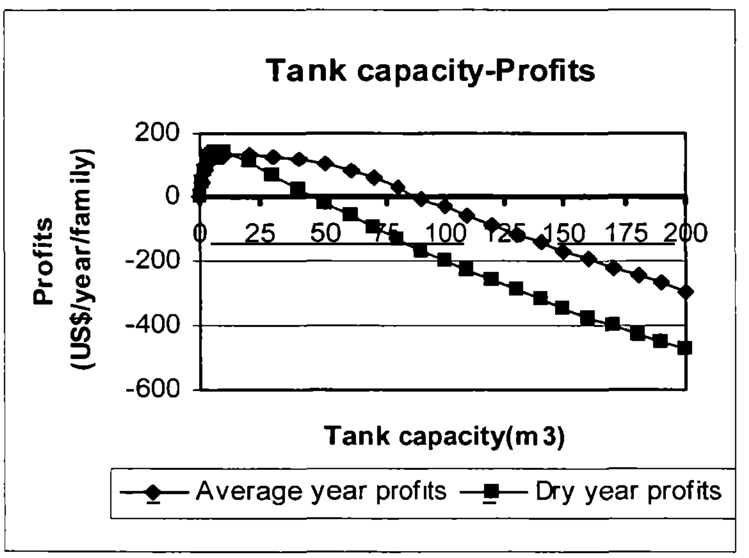
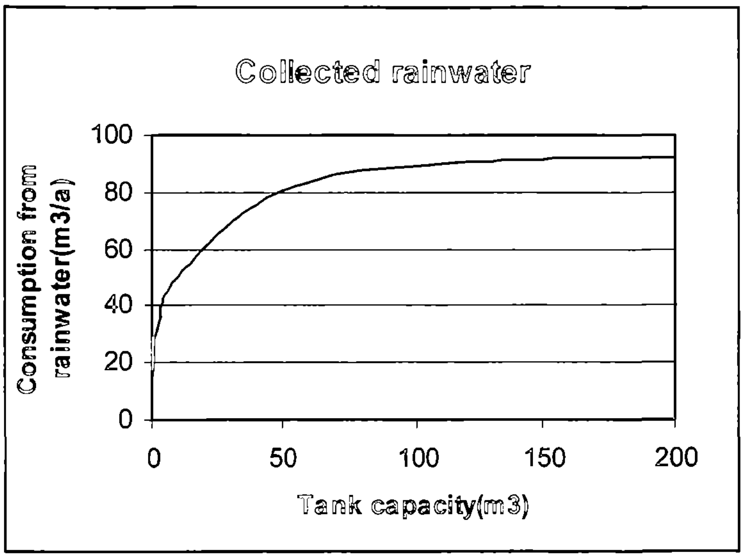


Figure (6.16): Tank capacity- profits relation for the village of Ain-Areek

For dry year less profits can be gained (See figure 6.16). The maximum profit that can be gained constitutes about 3.2 % of the average annual income per family.The average real monthly wage per seven persons in households in Palestine is estimated at 341US\$/month by the first quarter of the year 1997(United Nations, 1997).

This means that the average annual per capita income is about 585US\$/a. However, a difference between annual per capita income in rural areas and urban areas should be taken into consideration. It was estimated that the annual per capita in Ain-Areek areas constitutes about 67% of that in Ramallah city.



Figure(6.17):Annual consumption from collected rainwater in Ain-Areek in households(m^3/year)

For Ain-Areek case the following indicators should be taken into consideration for feasibility estimation:

- Spring water can not fulfill the people consumption, in particular for the houses with out cisterns.
- People in this village should buy their minimum needs from tankers, which has a high price in comparison to the family income.
- Tankers are not always available and it is difficult for people to contact them
- People suffer too much from springs water conveying by pots, because it consumes too much time especially women time. It was estimated roughly that about 3 hr/day/family can be saved if people utilize rainwater instead of conveying springs water from springs.(See Appendix 3-e)
- Each family has her own house with land around it.

6.8.5 Result

People in Ain-Areek village are advised to build storage tanks for rainwater collection, and for storage of water from tankers in dry years. If they want to get optimum profits, then they should build a tank with a capacity of 20m^3. In this case 55% of their consumption can come from rainwater. Furthermore they can save about 132US$ a year/family. But with constructing 30 or 40m^3 tanks, 130 or 121 US$/a can be gained, with about on average 9 or 16m^3/year yield more. In other words, the users will lose about 2 or 11 US$ but gain 9 or 16m^3/a respectively. The discriminate is depends on the users them selves. If they want to collect and consume as much as possible from rainwater then they should build a tank with more capacity, which enables them to consume more from their current consumption. In other words for the case of Ain-Areek RWHS is feasible financially and technically.

6.9 Implementation

To implement such system successfully in urban and rural areas the following issues should be discussed:

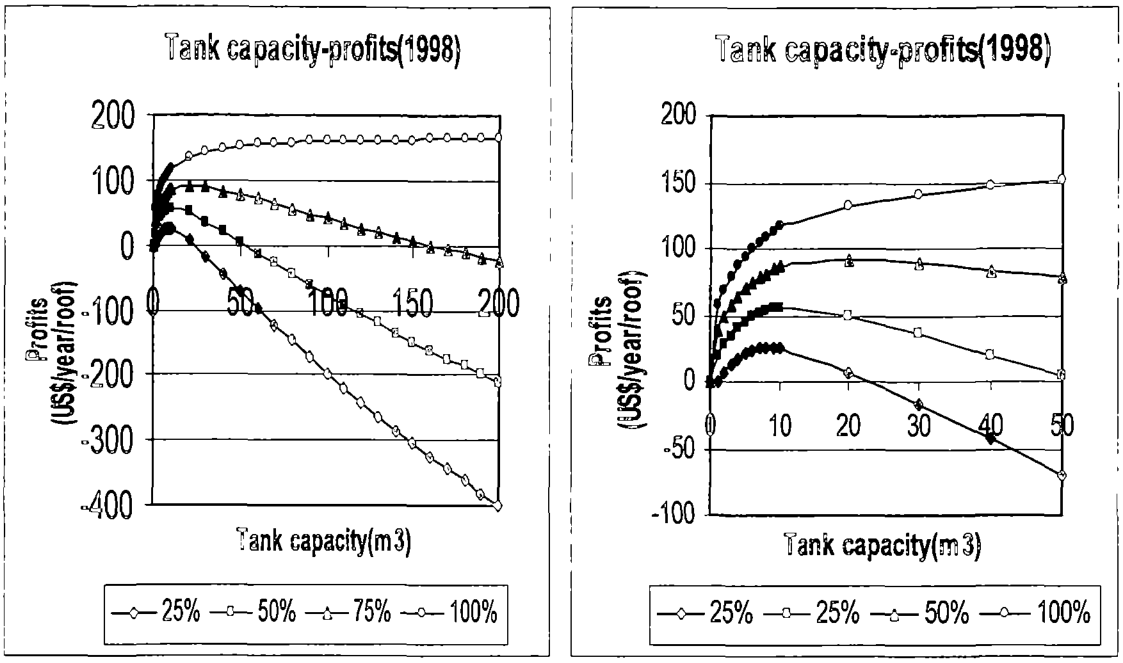
6.9.1 Subsidization

Financial problems are one of the most important problems that stand as obstacles in the way of adoption of RWHS in urban and rural areas in Palestine. Large storage facilities are necessary if rainwater is to have an impact on overall water supply of a household. The capital cost of constructing such a system is high. For example the cost of constructing a RWHS with a 10m3 tank capacity is about US$1400. This is far above the per capita income in particular in rural areas. Also, the financial profits to be expected are not very high. For this reason constructing RWHS has to be heavily subsidized. Subsidization has already been implemented by Palestinian NGO's in rural areas, especially in villages with out a WSDS.

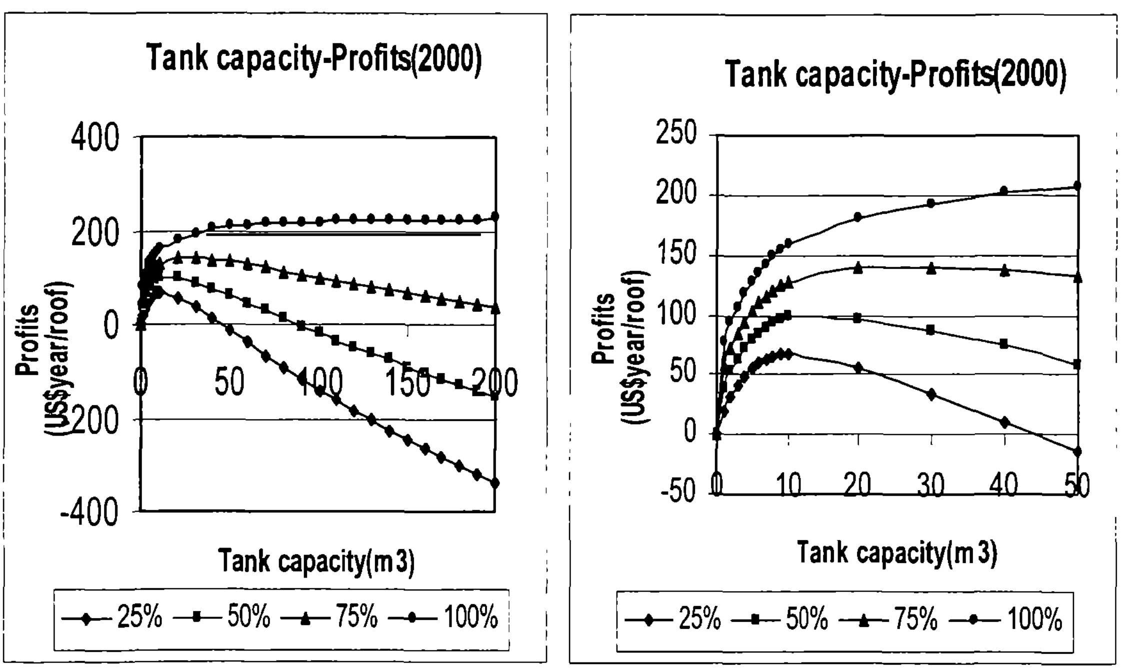
The Palestinian Hydrological Group(PHG) has encouraged people in villages to construct RWHS's . PHG has implemented partial subsidization programs funded by national and international development agencies as the World Bank, United Nation Development Programs(UNDP),Community Development Fund(CDF) and others. They buy the needed materials and supply this to the people. They encourage in this way public participation in constructing the system. Subsidization programs that have been implemented by NGO's should be extended to a larger scale and the Palestinian government must be willing to be involved in the system administratively and financially because the success of any project depends on the effective and good administration, sufficient financial supports and by the serious involvement of people. Two motivation measures could encourage people to construct RWHS. In particular in communities with out a WSDS.

- Loans with little or without interest. These loans should be repaid on the long term taking into account per family incomes.
- Subsidies as a percentage of capital cost. Most people like to be fully subsidized, but full subsidization on large scales needs sufficient funds for the concerned governmental and non-governmental organizations. Effects of different percentages of subsidization from the total cost of constructing such system on the expected gained revenues for each flat block are shown in (Figures 6.18,19,20,21,22).

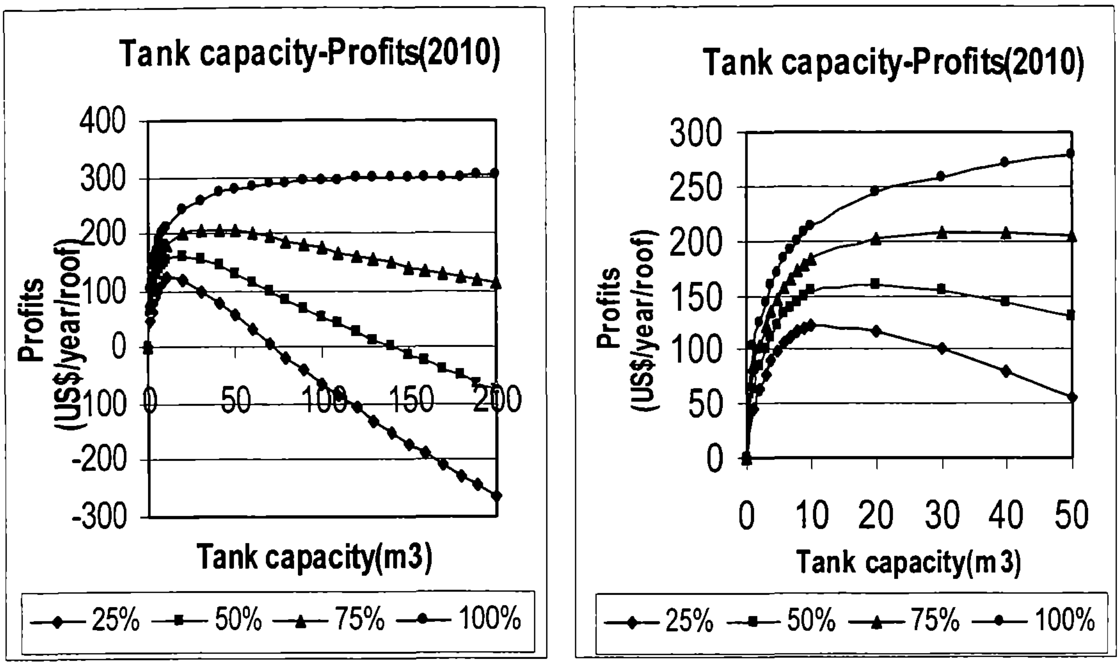
The subsidization program should be implemented by arrangement of the involved ministry or department in the Palestinian authority. Most people prefer to be intensively subsidized and unwilling to take loans especially if their income is low and they are not sure about the availability of cash money at the end of each month.



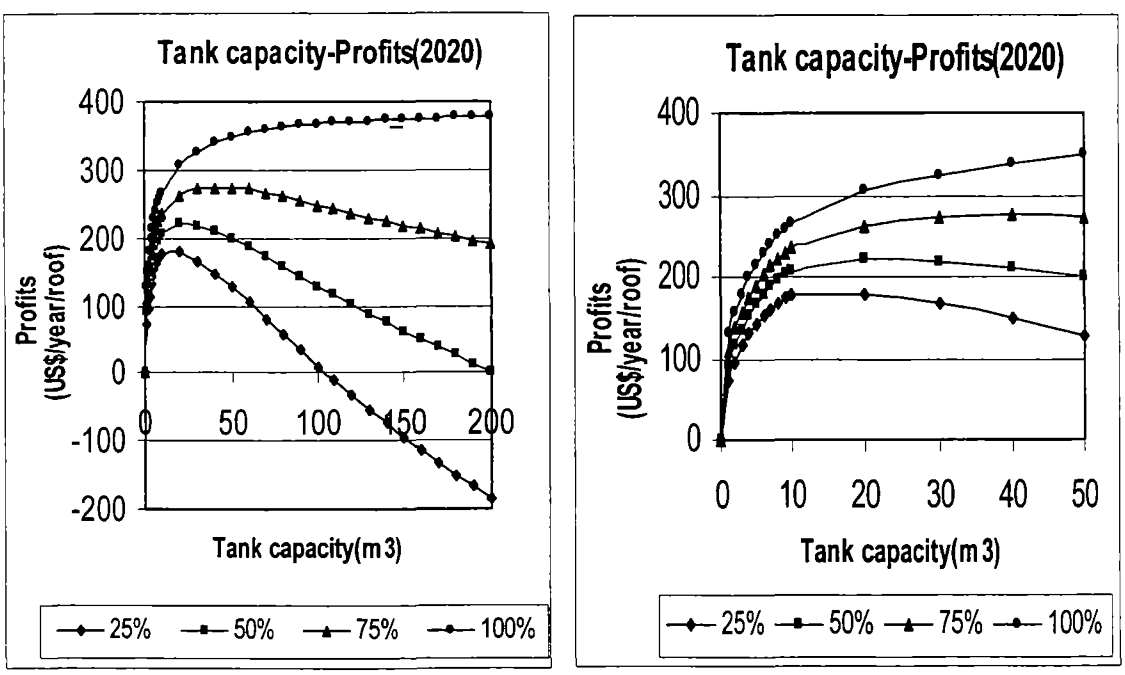
Figure(6.18):Expected profits by the year 1998/Subsidization program (% are the percentages of subsidization of the capital costs)



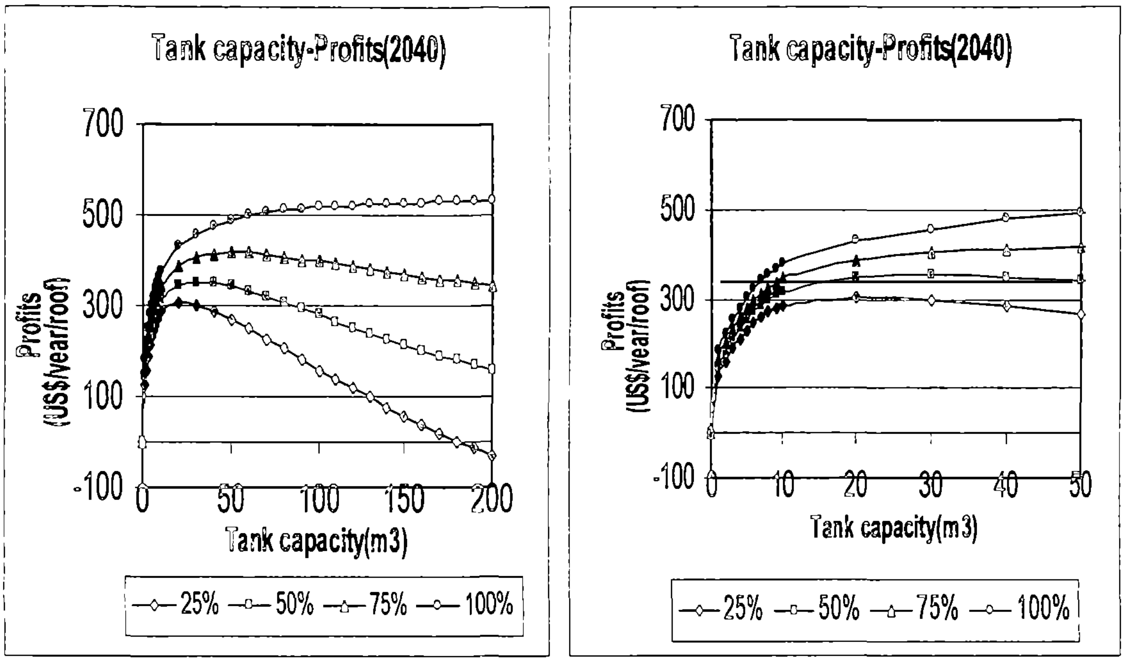
Figure(6.19): Expected profits by the year 2000/Subsidization program(% are the percentages of subsidization of the capital costs)



Figure(6.20): Expected profits by the year 2010/Subsidization program (% are the percentages of subsidization of the capital costs)



Figure(6.21): Expected profits by the year 2020/Subsidization program(% are the percentages of subsidization of the capital costs)



Figure(6.22): Expected profits by the year 2040/Subsidization program (% are the percentages of subsidization of the capital costs)

Different direct and indirect benefits could be achieved for the subsidizer (the government) and the user of the system:

- Resource conservation: Implementing rainwater-harvesting reveals to capture large quantities of rainwater, which constitutes an important and renewable source.
- Implementation of rainwater harvesting on large scales could increase the level of employment for skilled and unskilled workers.
- Increase public participation and self-reliance in water supply by the users.
- Time saving, in particular in rural areas. The time saved by women can be invested in other purposes such as food preparation and child care, etc...)
- Decrease pressure on WSDS's.

6.9.2 Public awareness

Public awareness is very important measure to over come two important constraints faced RWHS implementations:

6.9.2.1 Technical constraints:

Most of the cisterns are built without a proper design procedure. A design is needed to build the optimal tank capacity that fits the family needs of water taking into consideration the catchment area. Also it is not built in a financial way to give the maximum profits if it is compared with other options. Consequently, people who are going to build the system should order the help of a specialist engineer for the design of the system.

Sustainability of the system is also undermined by the lack of proper operation and maintenance. Most of the available systems are not regularly maintained, and the maintenance is not always as good as it should be. Some systems are not cleaned for two years or more, which gives high risk of contamination. People should be aware of the high importance of frequent cleaning of the RWHS to prevent the biological and chemical contamination. Maintenance and operation costs are negligible. Currently the operation and maintenance for the systems are done by the users them selves (The women and children participation) especially in rural areas.

6.9.2.2 Social constraints:

People have reservation or even a negative attitude about rainwater. They think that rainwater is impure. In other words they think that the harvested rainwater is contaminated. The taste is an indicator that affects rainwater utilization. Most of the people prefer to use water from the tap or springs water, they believe that these sources are safe for drinking than rainwater. Although rainwater could be contaminated, in most cases with regular and sufficient maintenance for the RWHS, rainwater can be used safely (See section 3.5.2).

Actually the beneficiaries rarely understand the importance and benefits of using rainwater for domestic use. The false opinion about rainwater should be changed, and people should be convinced about the benefits of rainwater harvesting. Gender is very important especially in rural areas. Women should be involved in planning, design, construction, as well as maintenance of RWHS.

For achievement of successful and sustainable RWHS, effective programs of public awareness should be created among the potential users. (Such as seminars, mass media, workshops, etc...).

Chapter (7)
Water Supply and Gap

7.1 Available water resources

Groundwater is the only and main source that is used currently to supply the cities of Ramallah and Al-Berih. Groundwater basins in Ramallah district are divided into two basins:

a- Western basin: It flows towards West and taps through shebtin wells. This basin underlies about 65% of the district area.

b- Eastern basin: It underlies of 35% of the district area. It flows towards east and eastwest. E'in samia wells tap this basin.

All wells are owned by JWU or by the Israeli Mekorot Company:

a- JWU Wells: JWU controls five wells (A'in-samia wells No.1, No.2, No.2a, No.3, No.4).These wells are located in the east of Ramallah city. Their total potential yield is estimated at 595m^3/hr.

The following table shows JWU wells in Ramalllah district and their potential yield:

Table (7.1): JWU wells and capacity:

Well	Potential Yield(m^3/hr)
Ein-samia well No.1	100
Ein-samia well No.2	35
Ein-samia well No.3	175
Ein-samia well No.4	60
Ein-samia well No.2a	225
Total yield	595

From Jerusalem Water Undertaking, 1995

b- Israelis Wells: They control 11 wells in the district, two of them are used to supply Palestinian villages and Israeli settlements in the district through WBWD. In addition to the amount that supplied to the JWU while the rest are connected with the Israeli national carrier to exclusively serve the Israelis. The following table shows well names with their capacity.

Table(7.2): Mekorot wells and their capacity

Well	Yield(m^3/hr)
Shebtin well No.4	90
Shebtin well No.5	85
Eshtaol No.6	10
Eshtaol No.3	300
Havi Yahuda	N/A
Modiin No.3	328
Modiin No.4	295
Modiin No.2	106
Modiin No.1	21
Shebtin Levona	38
Shebtin No.15	41

From ARIJ,1996

According to JWU, Ein-Samia wells are not used to supply the two cities but to supply other communities in the district. Most of Ramallah and Al-Berih needs are supplied by water that is purchased from Israeli Mekorote Company. About 2.2 Mm^3/a was supplied to the two cities by the year 1997.

7.2 Future resource

According to Oslo B, 0.5 Mm^3/a is assumed to be supplied to Ramallah district annually by the year 2000. Ramallah and Al-Berih together will use about 0.12Mm^3/a[1] See the following table.

Table (7.3): Available and future supply for low scenario

Scenario/years	1998-2000	2000-2010	2010-2020	2020-2040
Low	2.2	2.32	2.32	2.32

7.3 Gap and rain water-harvesting participation

It was considered that the demand medium scenario, which is described in chapter (3), will be the representative for our case since it describes the moderate situation. Taking firstly into account the pessimistic supply scenario that is described above. See table (7.4).

Table(7.4): Medium scenario demand. Current supply and gap

Year	Demand	Supply Mm^3/y			Gap	RWH	
	Mm^3/y	JWU	RWH*	Total	Mm^3/y	%of decreasing gap	%of partic. from total demand
1998	3.49	2.2	0.51	2.71	0.78	40	15
2000	4.57	2.32	0.65	2.97	1.60	29	14
2010	7 26	2.32	0.88	3.2	4.06	18	12
2020	10.72	2.32	1.12	3.44	7.28	13	10
2040	20.74	2.32	1.66	3.98	16.76	9	8

** Assuming each building has a 20 m^3 tank capacity (Optimal).*

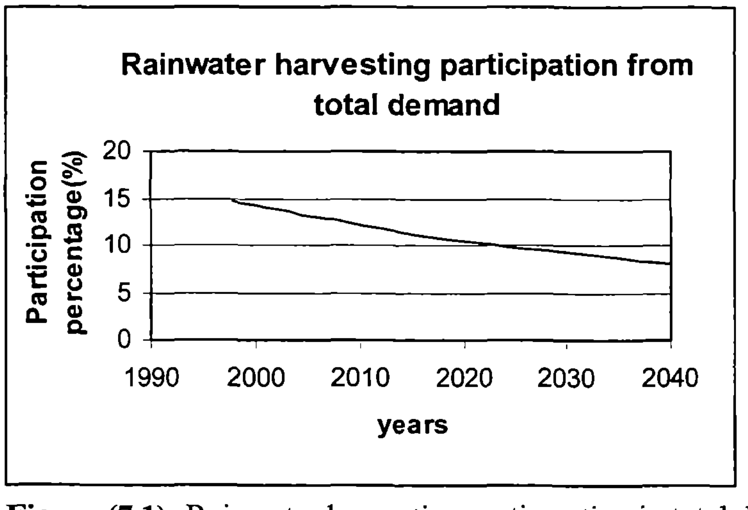


Figure (7.1): Rainwater harvesting participation in total demand

[1] Ratio of population =63000/269000=0 23 , 0 23*0 5=0 12Mm^3, (population projections based on a growth rate of3%)

It was seen from the above table that there is a remaining gap even if the RWHS is at large scale constructed. This gap is 0.78 Mm^3/a for the year 1998 while 16.8 Mm^3/a by the year 2040.To over come this gap other options should participate in the supply. Different options will be discussed briefly in the next section. However, rainwater-harvesting system shows a considerable participation percentage that should be taken into account. See figure (7.1)

7.4 Development options

As it was seen, the difference between supply and demand is increasing in the two cities and available resources of water are purchased from Mekorot or that amount that produced from own resources in addition to the rainwater collection option-if it is applied widely- cannot fulfill this increasing gap. Accordingly, other alternatives should participate in the supply.

7.4.1 Palestinian water resources liberation and development

The following table shows the Palestinian rights in water in the West Bank and Gaza.

Table(7.5): Palestinian rights of water Mm^3/a

Source/ District	West Bank	Gaza
Ground water	648	55
Surface water	257	-
Total	905	55
Overall total	960	

After Rofe & Raftey, 1965 and Johoson paln, 1953

Excluding the produced amounts by Palestinian from groundwater annually which was estimated at $182Mm^3$/year, most of the remaining potential of the $703Mm^3$/year are controlled and used by the Israelis. Furthermore, the Palestinians do not get their rights from the Jordan River, which was estimated at $257Mm^3$/year according to Johnson proposal since 1967 occupation for the West Bank and Gaza. From an optimistic point of view, if these resources are liberated and developed totally, then the problem of shortage in Ramallah and the other Palestinian districts can be tackled. The Ramallah and Al-Berih shares will be a portion according to their existing population percentage from the total population in Palestine (Estimated at 0.019%)[2]. It was estimated approximately at $18Mm^3$/year including the current produced amount. This option seems to be very difficult because it needs a base root solution for Palestinian people issue. But development of the resources owned by the Palestinians is possible. JWU are planning to dig a new well at E'in Samia area (Well No.6). The total yield of this well is expected to be 100-150m^3/hr (about $1(Mm)^3/a$ if it works 24hr a day). It was believed that any further drilling in this vicinity will not be productive (JWU, 1998).The total unit cost from groundwater from the western or eastern aquifers was estimated at 0.25-0.51US$/$m^3$, while from Jordan river was estimated at 0.83US$/$m^3$.(GTZ & Water and Environmental Studies Center, 1996.Report PhaseII)

[2] Since getting back or rights are uncertain , the ratio was estimated based on 1998 population ratio=48000/2500000=0 019

7.4.2 Surface runoff development

It was proposed that earth dams can be constructed on three different wadis in the WB :Wadi Quilt,Wadi Fara' and Wadi Anabta.

Wadi Quilt is located on the eastern slopes of the WB. The total potential that can be stored was estimated at 4 Mm^3/year. Since the soil in the wadi has a high permeability, the collected water is supposed to recharge the groundwater. The equivalent annual cost was estimated to range from 0.39 to 1.17 US$/m^3 based on the assumption that the yield of the dam will be 50% of the total storage capacity. (GTZ & Water and Environmental Studies Center, 1996.Report PhaseII)

Wadi fara': This wadi is located on the eastern slopes of the WB. Its yield was estimated at about 6 Mm^3/year. The collected water is assumed to be used in agriculture. The total unit water cost will be in the range of 0.33 to 1.12 US$/m^3. (GTZ & Water and Environmental Studies Center, 1996.Report PhaseII)

Wadi Anabta: This wadi is located west of Nablus. Its potential yield was estimated at about 3 Mm^3/year. The harvested water is assumed to be used in agricultural purposes. The cost of each cubic meter supplied from this reservoir was estimated to range between 0.25 to 0.84 US$/m^3.(GTZ & Water and Environmental Studies Center, 1996.Report PhaseII).

Utilization of urban runoff is one of the most important resources that PWA and Palestinian municipalities should pay attention into. It was estimated that the urban runoff in the WB is approximately 14.4 Mm^3/year. (GTZ & Water and Environmental Studies Center, 1996.Report PhaseII). Ramallah and Al-Berih have two main catchments: The western catchment and the eastern catchment. Current storm urban runoff that can be collected from these two catchments is about 0.54, 0.88 Mm^3/year respectively (Haddad M. and Mizyed, N., 1993). About 0.65 Mm^3/year is taken away from the total urban runoff in the two cities if RWHS is implemented on large scale. These amounts are assumed to increase in the near future because of the new political development increasing the area. Ramallah and Al-Berih cities don't have a separate storm water collection system but a combined sewer system is available their. A detailed technical and financial feasibility study for the urban runoff collection in reservoirs (Dams) is recommended to be done.

7.4.3 Water import

This option can be divided into two parts, Local import, and regional import:

7.4.3.1 Local water import

Currently about 2.2 Mm^3/year is purchased from Israeli Mekorot Company as mentioned before. To overcome the gap more quantities of water may be purchased, but this option is controlled by the Israelis and depends on the political situation. Currently the Palestinian National Authority is trying to regain control over the water resources and to eliminate the dependency on the purchased water from the Israelis.(JWU,1995).

7.5.3.2 Regional water import

Regional water import is to buy and transport water from water rich countries in the region to the demand centers. Turkey is the closest country to the region with availability of water resouces that could possibly be feasible for water import such as Manavagt River, which was subjected to many investigations to evaluate the feasibility. This project was designed to supply Turkey and other counties including Palestine with a capacity of 185 Mm^3/year. Ramallah and Al-Berih cities share of about 0.8Mm^3/year[3]. Conveying water from this river over sea by using large bags or/and tankers, either second hand old tankers or new tankers. The following table shows the total cost per imported cubic meter to West Bank demand center (Ramallah) by using different modes of transport.

Table(7.6): Imported per cubic meter water cost(US$/$m^3$)

Mode	Cost($/$m^3$)
Old tankers	0.87
New tankers	1.08
Bags	0.64

From GTZ & Water and Environmental Studies Center, 1996.Report PhaseII

This option is not feasible politically at least in the existing situation, because the implementation needs arrangements and permission from the Israelis.

7.4.4 Desalination of Brackish and sea water

The only source of brackish water in the West Bank is Al-fashkha (Next to the Dead sea) with a capacity of 50 Mm^3 /year. Ramallah and Al-Berih share by about 1.9 Mm^3/year[4].The cost of utilizing water treated from brackish water in Ramallah was estimated at 1.21US$/$m^3$.While the Red or the Mediterranean sea water desalination cost per cubic meter was estimated at 0.72-1.11 US$/$m^3$ (GTZ & Water and Environmental Studies Center, 1996.Report PhaseII).However, constructing desalination stations and conveyance systems requires permission from the Israelis, which is very difficult.

7.4.5 Waste water reuse

The Palestinian Authority has supported the municipalities to construct and rehabilitate wastewater collection systems and treatment plants since 1993. Currently, Al-Berih treatment plant is under construction and the treatment plant of Ramallah is to be rehabilitated since of its low efficiency (20%). The total amount of wastewater that can be utilized in short term in Ramallah and Al-Berih was estimated at about 0.92 Mm^3/year. This amount is assumed to be used for irrigation in agricultural areas outside the two cities. Then the water now used for irrigation can be reallocated to over come the shortage in the two cities. The per cubic meter cost of treated and reused water was estimated at 0.8US$/$m^3$.(GTZ & Water and Environmental Studies Center, 1996.Report PhaseII)

[3] Ramallah & Al-Berih share= [(185Mm3/y)- (4 countries)] × (59,000–3,300,000)* = 0 8 Mm^3/year , * is the ratio for the two cities based on population projections for the two cities and Palestine by the year 2005

[4] Ramallah & Al-Berih share= 50 Mm^3/year × (84700–2277000)* = 1 9 Mm^3/year , * is the ratio for the two cities based on population projections for the two cities and Palestine by the year 2010

7.4.6 Water Demand management

The available water resources for Ramallah and Al-Berih should be wisely dealt with. Water demand management should be taken into consideration especially that the resources are rare and scarce. The conservation could be achieved through three different measures of water demand management: Technical measures, financial and economic measures, and public awareness programs.

Technical measures include rehabilitation of wells with frequent and regular maintenance for the equipment, which increase the efficiency that reveals to higher production. In order to minimize the Unaccounted For Water (UFW) which is estimated at about 0.5 Mm^3/a by the year 1997, regular rehabilitation and replacement of the deteriorated parts of water mains and the network should be adopted. These measures enabled JWU to decrease the UFW from 33% by the year 1974 to 21% by the year 1997.An further increase in the UFW is possible if the black losses increase. It was estimated that 5.8% of the losses was because of black losses by the year 1994(JWU, 1995).

Water tariffs and water pricing strategy leads to control water demand. However, this policy is used in most of the Palestinian institutions as means for financing operation and maintenance cost rather than as a demand management tool. JWU had already implemented this policy. It enables them to achieve cost recovery and to transfer the financial burden of the different categories to the highest consuming category.(GTZ & Water and Environmental Studies Center, 1996.Report PhaseII)

To make the Palestinian people feel somehow responsible for their water use, and for conservation and protection of water resources, wide programs of public awareness should be implemented. These campaigns could be through seminars, lectures, mass media, related courses in schools, posters, and training.

7.4.7 Rainwater harvesting option evaluation

Table (1) in appendix 3-f shows a differentiation between rainwater harvesting from roof catchments and other possible development options. Selected criteria were chosen from the GTZ report on Middle East Regional Study on Water Supply and Demand development Phase II, 1996. In this report the options were not directly compared. Here the performances are judged by reading the evaluation of the individual options. The performances could not yet be quantified to the extent that a multi-criteria analysis can be done. But the table shows on what kind of criteria different development options should be compared and serves for discussion. The table shows that RWHS can supply the least amount of water estimated at 0.65 Mm^3/a provided that for each house an optimal tank capacity of $20m^3$ is constructed. This amount can be increased with urban development. Constructing RWHS is not a complicated process. It can be done by each household and in a short time. Further more, it needs small investments by households. Contrary, other options need a high technology in construction that need large investments on national scale. Time of implementation of such options is uncertain because the political constraints and risks are high. Implementation of such systems needs permission from the Israeli government, which needs in most cases hard negotiations with uncertain results. Constructing RWHS does not need such a complicated procedure, although, in some cases it is necessary to get a license for construction of RWHS from the Israelis, in particular in areas under the Israelis control. The unit cost of each cubic meter that can be

supplied by RWHS is 1.4 US$/m^3 which is more than any of the other options except the option of desalination for which costs are estimated at 1.7US$/m^3 as a maximum.
Overall, RWHS can be considered as a good option for water gap alleviation. It competes the other options in the short term.

Chapter (8)
Conclusions and recommendations

Conclusions:

1- The available water resources for Ramallah and Al-Berih cannot overcome the increasing demand. The present water supply to the two cities is purchased from Mekorot(The Israeli water company).It was estimated that about 2.2 Mm^3/a was purchased by the year 1997 for the two cities. This amount is expected to raise to 2.32 Mm^3/a by the year 2000 by adding the share of the two cities from the amount that will be supplied to the district by the year 2000 according to Oslo B.
2- The current per capita water consumption in Ramallah and Al-Berih is estimated at 100 l/c/d in the wet season and 127 l/c/d in the dry season not including losses. However, what is actually needed is estimated at approximately180 l/c/d including losses of about 21%. This demand is expected to reach 290 l/c/d by the year 2040.
3- The total demand in the two cities (Domestic, industrial and commercial demand) is estimated at 3.5 Mm^3/a by the year 1998 and is expected to become 21 Mm^3/a by the year 2040.
4- Rainwater harvesting can be considered as a viable resource that can supplement supply in urban and rural areas and that can participate considerably in minimizing water shortage if it is implemented at large scales.
5- Currently, people in Ramallah and Al-Berih hardly utilize rainwater. Only about 8%of the houses have RWCS and owners of these houses don't use the system in an efficient way.
6- For an average flat block that accommodate 12 persons under a roof of $300m^2$ in urban areas (Ramallah and Al-Berih) with a use of 100 l/c/d or a roof of $180m^2$ with 6 persons in rural areas (Ain-Areek village) with a use of 50 l/c/d. The financially optimal tank capacity is 20m3 provided the full demand is supplied by rainwater when water is in the tank.
7- The maximum number of days of full demand supplied by rainwater is assessed at 123 days out of 365 days if the tank capacity would not be restricting. But if the optimal tank capacity is constructed of 20 m^3, the average number of days of full supply is 97days/year.
8- With larger catchment areas per capita, increases in yield per extra m^3 tank capacity are still considerable with large amounts of tank capacity i.e. the marginal benefits of an extra m^3 are higher. As an example: For $4m^2$/capita the annual yield of $20m^3$ tank capacity is estimated at about $25m^3/a$ while for $25m^2$/capita the annual yield is estimated at about $98m^3/a$ if the per capita consumption as low as 50 l/c/d.
9- The capital cost of tank construction per each cubic meter does not decrease much with higher tank capacities. The relation almost fit a linear line especially for tank capacities less than $100m^3$. For capacities higher than $100m^3$, the costs per cubic meter constructed are getting less. But the extra costs for construction and fittings for joint system increase EAC. This implies that larger scale systems, like combining the reservoir of a few blocks of flats doesn't make much sense.
10- Potential coverage by rainwater harvesting increases with tank capacity. For the two cities the maximum coverage was estimated at 35% of the current consumption per

capita provided that a 200 m^3 is constructed. For optimal tank capacity (20 m^3) the percentage is estimated at 28%.The total amount of water that can be collected and utilized from the roofs of Ramallah and Al-Berih is estimated at about 0.65 Mm^3/a and 1.7 Mm^3/a by the years 2000, 2040 respectively if the optimal tank capacity will be constructed on large scale. In other words if each building has a cistern.

11- As Ramallah and Al-Berih have a PWS in place and rainwater harvesting will not be sufficient to cover the full demand, the rainwater reservoir can be emptied at the highest possible rate, which is the full demand, to maximize the yield of the reservoir.

12- Equivalent annual cost per each cubic meter supplied by rainwater harvesting is almost competitive with public water supply. It was estimated at 1.12US$/$m^3$ for 7m^3 tank capacity and it reaches 1.38 US$/$m^3$ if 20m^3 is constructed. The Public water supply price is currently estimated at 1.11US$/$m^3$ on average.

13- Profits that can be gained per roof in the long term if RWHS is implemented are not considerable compared to the annual family income. Further more, the expected increase in price of water from PWS is uncertain, making the threshold for implementation higher.

14- The total expected amount of money that can be saved by implementing the system on large scale is estimated at about 0.5 MUS$/a if the total yield is multiplied with the current average water costs. As the costs of a cubic meter purchased from mekorot is higher than the locally produced water and local production is reached its limits, a proper 'saving' should use the 'marginal costs' of a reduction (of the increase) of water supply. In this case, the saved amount is expected to increase to 0.65 MUS$/a. The saving costs that are included in the calculations consists of two costs: the purchasing cost from Mekorote and the power cost which are estimated currently at 0.72 US$/$m^3$ and 1 US$/$m^3$ as marginal cost.

15- Occurrence of a dry year with 75% probability of exceedence does hardly affect the quantities that can be collected or the profits that can be gained.

16- In rural areas, especially in areas without WSDS, rainwater harvesting is feasible technically and financially. It covers about 84% of the per capita water consumption if the full potential of water is harvested. But if the optimal tank capacity that give the maximum profits is constructed (20m^3), the system covers 55% of the current consumption with 132US$/y profits, if it is assumed that people use tankers as supplier.

17- Constructing the system is easy and the materials are available. Reinforced concrete flat roofs are the common type in Ramallah and Al-Berih; gutters and down pipes are mostly from Zinc and plastic; the conveying system consists of a pump of 0.5HP and a pipe from galvanized steel.

18- Rainwater quality is relatively good and can be used as drinking water. It almost meets with WHO standards. However, contamination of the water collected in the cisterns is possible. Different measures should be applied to minimize water contamination.

19- Financial issues are one of the most important problems that stand as obstacles in the way of RWHS adoption in urban and rural areas. Applying subsidization programs can encourage public participation and tackle the financial problem.

20- The gap between demand and supply is increasing. It reaches 16.8 Mm^3/a by the year 2040.Rainwater harvesting participation cannot overcome this gap and the system is unlikely to satisfy all the needs of the consumers. Rainwater can contribute to cover about 14% from the total demand by the year 1998 provided each house has a cistern with capacity of $20m^3$(Optimal) and it decreases to 8% by the year 2040.RWHS can decrease the gap by 40% and by 9% in the years 1998 and 2040 respectively. Although rainwater harvesting is some how unprofitable in the short term in urban areas, it absolutely alleviates the water shortage and supplements the PWS.

21- Other development options are absolutely needed to overcome the available and future expected gap apart from rainwater harvesting.

Recommendations:

1 -Rainwater harvesting systems should be implemented on large scale in urban and rural areas to alleviate the pressure on the water resources.

2- The standard tank capacity is recommended to be constructed at size of $20m^3$ for a roof of $300m^2$ with 12 persons in urban areas (Ramallah and Al-Berih) with a consumption of 100 l/c/d or for a roof of $180m^2$ with 6 persons in rural areas (Ain-Areek village) with a consumption of 50 l/c/d. For other conditions the design graphs by this report or the spreadsheet can be used to estimate a suitable tank capacities that are needed or to create a new graphs for other districts.

2-NGO's and PWA should take action by encouraging and participating in the process by applying sufficient subsidization and by awareness programs.

3-Municipalities and the engineers association should apply a law that enforces the people to construct rainwater collection system with the house and this RWHS should be designed in proper way.

4- To minimize the risk of contamination the following measures should be taken:

- Installation of filters.
- Sweeping the roof before the first shower and foul flush the roof periodically.
- Clean the cistern and scrubbing off the debris before the rainy season.

5- A Public awareness campaign should be held to make people aware of the importance of rainwater collection in water supply participation, to encourage people to build the system and to teach them the importance of the operation and maintenance and how to do it.

6-Technical and financial feasibility of urban runoff collection should be studied in detail.

7- Other development options apart from rainwater harvesting should participate in water supply to over come the increasing gap in the Palestinian territories.

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Appendix-1-

Appendix (1)

Calculation of gardening demand:

Average gardening demand = (0.7 m^3/day×185day/y÷365day)=0.35m3/day (30l/c/day)

Table(1):Net quantities of water distributed by the JWU by theyears1982,1987,1992,1993,1994.In cubic meter.

Year	Domestic m^3/y	Industrial m^3/y	Percentage from total consumption %	Commercial m^3/y	Percentage from total consumption %	Israeli army And settlement m^3/y	Total m^3/y
1982	1950902	58994	2 3	48000	1 9	476205	2534101
1987	3125555	159500	3 9	66000	1.6	707110	4058165
1992	3892509	261325	5 2	74220	1 5	819739	5047793
1993	4093969	378150	6 8	102220	1.8	952231	5526570
1994	4247268	385975	6 8	110220	1.9	924003	5667466

After Jerusalem Water Undertaking, 1995

Table(2):Water supply patterns1991-1994 and 1997 supply patterns estimation

Mon.	Days	1991 supply m^3	Per. (%) %	1992 Supply m^3	Per. %	1993 Supply m^3	Per. %	1994 Supply m^3	Per. %	Avr. Per. %	1997 Supply m^3	Cons./ m/c m^3/m/c	Cons. l/c/d	Cons. * l/c/d
Jan	31	487036	7 7	455544	6 6	503446	6 8	548787	7 3	7 1	153746	3.3	106	95 8
Feb	28	382325	6 0	481982	7 0	457856	6 2	495108	6 6	6 4	139700	3.0	107	96 4
Mar	31	452359	7.1	517924	7 5	527900	7 2	562979	7 5	7 3	158516	3.4	110	98 8
Apr	30	511856	8.1	541776	7 9	629814	8.5	651057	8 6	8.3	179274	3 8	128	115 4
May	31	608968	9.6	600336	8 7	663802	9.0	656265	8.7	9 0	195034	4.2	135	121.5
Jun	30	569596	9.0	621920	9 0	679585	9.2	704328	9.3	9 1	197984	4.2	142	127 5
Jul	31	632959	10 0	670495	9.7	712902	9.7	684622	9.1	9 6	208246	4.5	144	129.7
Aug	30	625863	9 8	687701	10.0	720463	9.8	643743	8 5	9.5	206619	4.4	148	133.0
Sep	30	582344	9 2	643891	9 4	675037	9.2	698286	9.2	9 2	200033	4.3	143	128 8
Oct	31	568603	8.9	631462	9.2	651284	8.8	706890	9 4	9 1	196754	4.2	136	122 6
Nov	30	475621	7.5	532079	7.7	569117	7.7	597629	7 9	7 7	167128	3.6	120	107 6
Dec	31	459361	7.2	498775	7.2	581216	7.9	606117	8.0	7.6	164618	3.5	114	102 6
Total		6356891	100	6883885	100	7372422	100	7555811	100	100	2167653	46.5		

** Consumption not including industrial and commercial consumption*

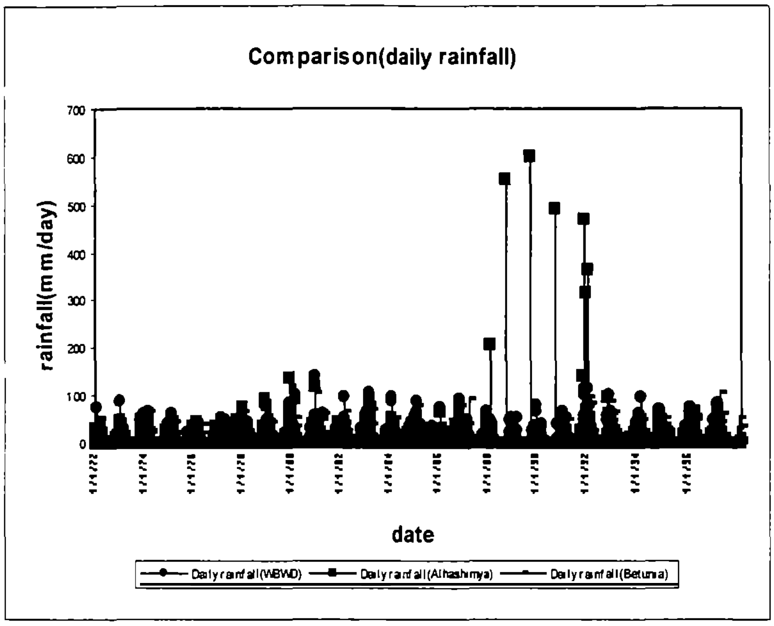
After Jerusalem Water Undertaking, 1995

Per.: Percentage, M: Month, Cons.. Consumption

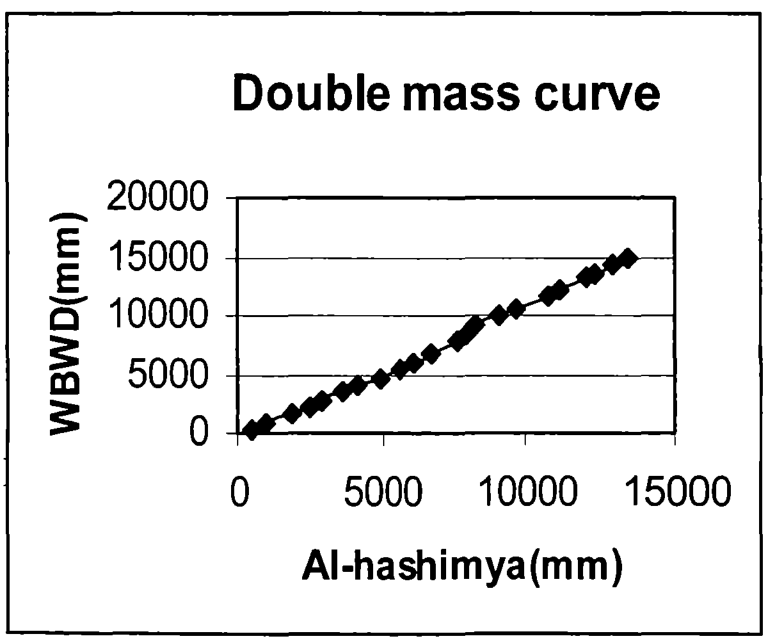
L/c/d· letter per capita per day

Appendix-2-

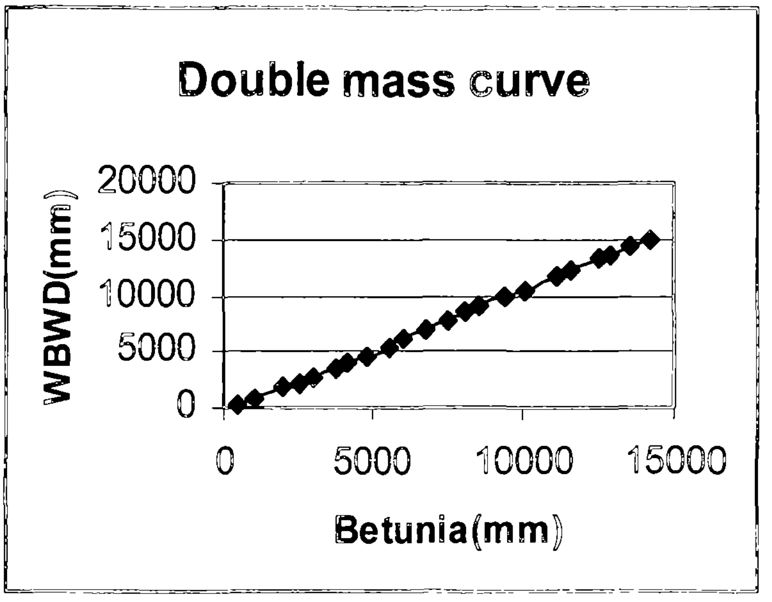
Appendix (2)



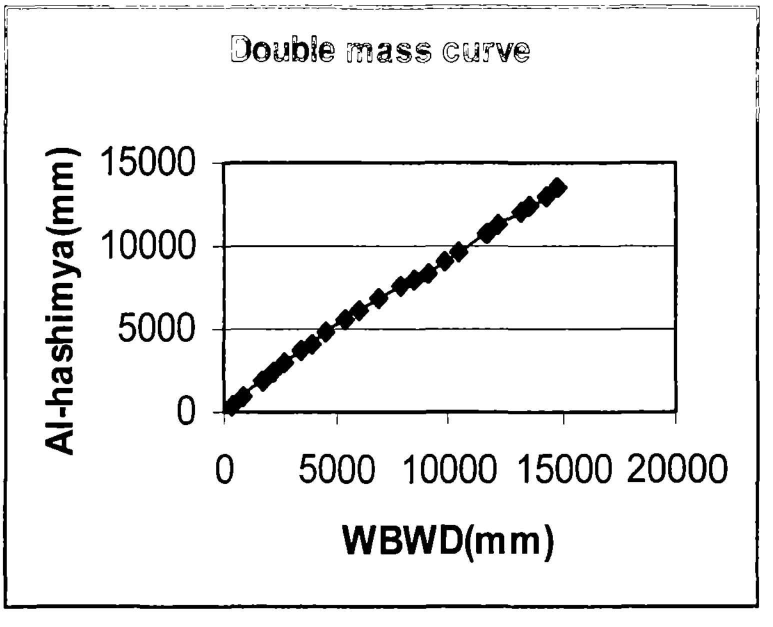
Figure(1): Daily rainfall for 26 years for the three stations



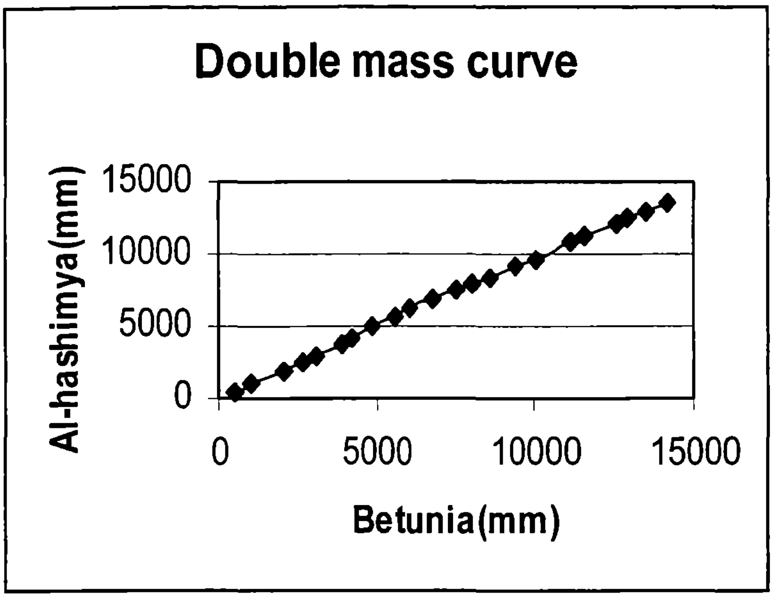
Figure(2): Double mass curve(Al-hashimya vr WBWD)



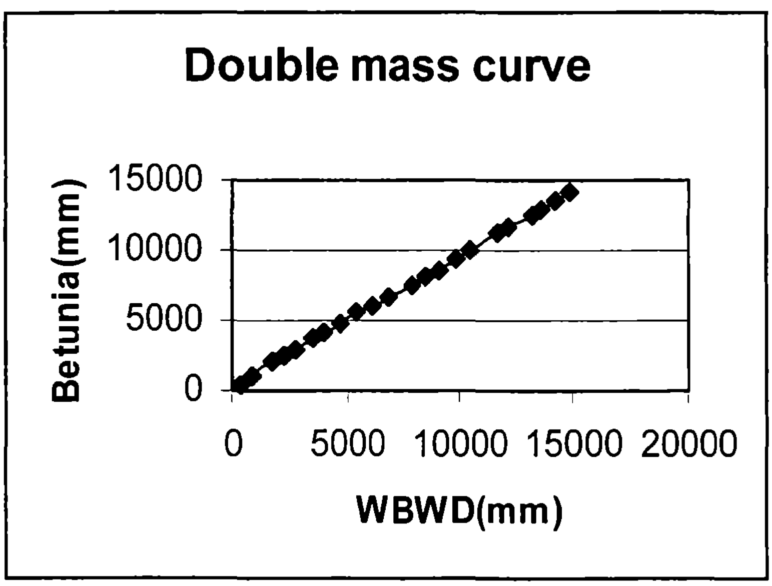
Figure(3):Double mass curve(Betunia vr WBWD)



Figure(4): Double mass curve(WBWD vr Al-hashimya)



Figure(5): Double mass curve(Betunia vr Al-hashimya)



Figure(6): Double mass curve(WBWD vr Betunia)

Table(4):Normal and log normal distribution of annually rainfall(1972-1997)

year	Rainfall (mm/y)	No.	year	x(mm/y)	ln(x)	n/(m+1)	T year	t		ycal mm/y	ln(y)
1972	375.1	1	1992	1228.2	7.11	0.037	27.0		1.78	1105.0	7.01
1973	462	2	1991	1140.2	7.04	0.074	13.5		1.45	1027.3	6.91
1974	902.6	3	1994	1057.3	6.96	0.111	9.0		1.22	973.2	6.83
1975	509.6	4	1983	992.2	6.90	0.148	6.8		1.05	933.2	6.78
1976	465.3	5	1974	902.6	6.81	0.185	5.4		0.9	897.9	6.73
1977	753.3	6	1988	868.4	6.77	0.222	4.5		0.77	867.3	6.69
1978	491.4	7	1980	819.2	6.71	0.259	3.9		0.65	839.1	6.66
1979	636.7	8	1982	807.2	6.69	0.296	3.4		0.54	813.2	6.62
1980	819.2	9	1986	780.1	6.66	0.333	3.0		0.43	787.3	6.59
1981	651.5	10	1977	753.3	6.62	0.370	2.7		0.33	763.8	6.55
1982	807.2	11	1987	652.3	6.48	0.407	2.5		0.24	742.6	6.53
1983	992.2	12	1981	651.5	6.48	0.444	2.3		0.14	719.1	6.50
1984	642.6	13	1984	642.6	6.47	0.481	2.1		0.04	695.5	6.46
1985	582	14	1996	640.8	6.46	0.519	1.9	0.481	-0.04	676.7	6.44
1986	780.1	15	1979	636.7	6.46	0.556	1.8	0.444	-0.14	653.2	6.41
1987	652.3	16	1985	582	6.37	0.593	1.7	0.407	-0.24	629.6	6.38
1988	868.4	17	1997	573.6	6.35	0.630	1.6	0.370	-0.33	608.5	6.35
1989	461.1	18	1990	514.6	6.24	0.667	1.5	0.333	-0.43	584.9	6.32
1990	514.6	19	1975	509.6	6.23	0.704	1.4	0.296	-0.54	559.0	6.28
1991	1140.2	20	1978	491.4	6.20	0.741	1.4	0.259	-0.65	533.2	6.25
1992	1228.2	21	1976	465.3	6.14	0.778	1.3	0.222	-0.77	504.9	6.21
1993	460.9	22	1973	462	6.14	0.815	1.2	0.185	-0.9	474.3	6.17
1994	1057.3	23	1989	461.1	6.13	0.852	1.2	0.148	-1.05	439.0	6.12
1995	371	24	1993	460.9	6.13	0.889	1.1	0.111	-1.22	399.0	6.07
1996	640.8	25	1972	375.1	5.93	0.926	1.1	0.074	-1.45	344.9	6.00
1997	573.6	26	1995	371	5.92	0.963	1.0	0.037	-1.78	267.2	5.89
Average(Yaver)				686.12	6.45						
stan.deviation(σyaver)				235.32	0.31						

X Yearly rainfall(measured)
T: Return period
t: Normalized probability
y cal: Yearly rainfall(calculated)

Appendix-3-

Appendix 3-a

Table(1): Roof area

Houses number	Houses Areas Area(m^2)
From the map	
1	225
2	300
3	1200
4	625
5	300
6	1200
7	300
8	400
9	150
10	400
11	100
12	200
13	200
14	470
15	300
16	100
17	225
18	300
19	600
20	200
21	600
22	500
23	370
24	370
25	270
26	100
27	330
28	600
29	150
30	500
31	100
32	150
33	150
34	150
35	200
36	400
37	225
38	100
39	200
40	150
41	120
42	120
43	150
44	360

45	80
46	400
47	250
48	150
49	650
50	250
51	100
52	300
53	100
54	750
55	200
56	300
57	250
58	150
59	300
60	180
from the survey	
61	250
62	110
63	205
64	320
65	360
66	160
67	290
68	280
69	320
70	270
71	200
72	150
73	280
74	380
75	320
Average	299 5

Table(2): Statistics for population, buildings and residential units,1997

City	Population	Buildings	Residential units
Ramallah	18297	2280	4854
Al-Berih	28351	3605	7578
Total	46648	5885	12432

From PCBS, 1998

Appendix 3-b

Description of the calculations

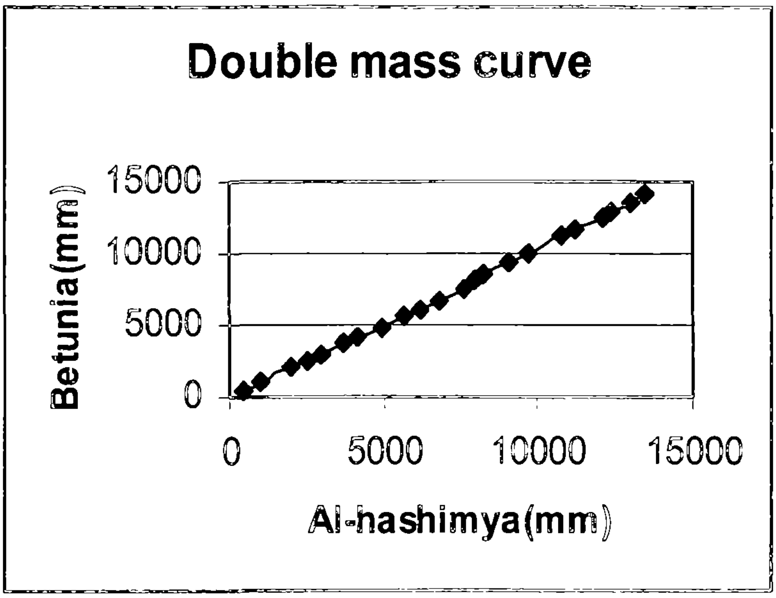
The table of calculations in the spreadsheet consists of the following columns:

-Date: The input date is from 1/1/1972 until 31/12/1997. This is not fixed and can be changed.

-Data: This column is to check if the rainfall equal to zero or more, if yes, the number one will be written in the cell, but if not the sign ("") will be written in the cell.

-Input: The daily rainfall in cubic meter was calculated in this column.

-Harvested rainfall: Formula(4-1) was used to calculate this column. If the harvested rainfall more than the losses then the harvested rain will be written in the cell, if not, the harvested rain will be zero.
-Maximum amount that can be harvested each day: If the collected rainfall is more than or equal to the tank capacity then the tank capacity will be written in the cell, if not, then the collected rainfall will be written.
-Consumption as a percentage of coverage: This column contains per building water consumption multiplied by the coverage percentage (See section (4.2.3)).
-Remaining: It is a supporter to calculate the next two columns. Each cell contains the storage minus the consumption plus the harvested rain, depends on daily bases.
-Storage: Here the hypothetical storage at the end of the day was calculated. If the 'remaining' more than the tank capacity, the tank capacity will be written, if not, if the 'remaining' less than zero, zero will be written, if more than zero, the 'remaining' will be written.
-The yield of the tank: If the 'remaining' more than zero, and if tank capacity equal zero, zero will be written, if not, 'consumption' will be written. If the 'remaining' is less than or equal zero, and/or if tank capacity equal zero, zero will be written, if not, the previous storage added to the next harvested rainwater will be written in the cell.
-Days of shortage: If the storage equals zero, 1 will be written in the cell, if not, zero will be written.
-Spilling: If the 'remaining' more than the tank capacity, the difference between the 'remaining' and the tank capacity will be written, if not, zero will be written.
-Days of spilling: if the spilling more than zero, one will be written, if not, zero will be written.
-Rainy days: This column is to calculate the total rainy days .
-Cumulated harvested rain: The harvested rainfall was cumulated here.
-Cumulated output: The input rainfall data was accumulated here.
-Cumulated consumption: The accumulation of the daily consumption was calculated in this column.
-Difference: It contains the difference between the accumulated harvested rain and the accumulated consumption, in order to calculate the maximum tank capacity needed.



Figure(7):Double mass curve(Al-hashimya vr Betunia)

Table(1):Typical spatial correlation structure from different storm types.

Rain type	Period 1hr		Period 1day		Period 1month	
	R_0 (Km)	ρ_0	r_0(Km)	ρ_0	r_0(Km)	ρ_0
Very local convective	5	0.8	10	0.88	50	0.95
Mixed convective orographic	20	0.85	50	0.92	1500	0.98
Frontal rainfrom depression	100	0.95	1000	0.98	5000	0.99

From De laat, lecture notes,1996

Table(2): Correlation factors

Station	Distance(Km)	r_0 (Km)	ρ_0	ρ
WBWD	6.5	50	0.92	0.81
Betunia				
Betunia	5.8	50	0 92	0.82
Alhashimya				
Alhashimya	1 9	50	0 92	0.89
WBWD				

$\rho(r)$ Correlation factor between two stations at distance r.
ρ_0 Correlation at distance zero.
r_0 Coefficient(Km).
R The distance between two stations (Km)

Table(3): Annual maximum daily rainfall

Year	Xext	Ranked years	Rank	Xext(ranked)	P(n/m+1)	T(1/p)	Log(T)
1972	72 8	1973	1	171	0.037	27.00	1 431
1973	171	1980	2	142	0.074	13.50	1.130
1974	66.3	1991	3	113.8	0.111	9.00	0 954
1975	62.4	1992	4	113.6	0 148	6 75	0 829
1976	43.1	1983	5	106.7	0 185	5 40	0.732
1977	74.9	1984	6	97.2	0.222	4 50	0 653
1978	79.1	1982	7	96.8	0.259	3.86	0.586
1979	81.5	1994	8	95	0.296	3.38	0.528
1980	142	1986	9	92	0.333	3.00	0.477
1981	62	1985	10	86.1	0.370	2.70	0 431
1982	96.8	1997	11	82	0.407	2.45	0.390
1983	106.7	1979	12	81 5	0.444	2 25	0.352
1984	97 2	1978	13	79 1	0 481	2 08	0.317
1985	86 1	1990	14	78.5	0 519	1.93	0.285
1986	92	1977	15	74.9	0 556	1.80	0.255
1987	66.2	1996	16	73.1	0.593	1.69	0.227
1988	51.6	1972	17	72 8	0.630	1.59	0 201
1989	54.6	1974	18	66.3	0.667	1 50	0.176
1990	78.5	1987	19	66.2	0.704	1.42	0 153
1991	113 8	1993	20	63.6	0.741	1.35	0.130
1992	113 6	1975	21	62.4	0.778	1 29	0 109
1993	63.6	1981	22	62	0.815	1 23	0 089
1994	95	1989	23	54.6	0.852	1.17	0.070
1995	36	1988	24	51 6	0.889	1.13	0.051
1996	73 1	1976	25	43.1	0.926	1.08	0 033
1997	82	1995	26	36	0.963	1.04	0 016

Xext: extremes daily rainfall(mm/day)
P: Probability of exceedence
T: Return period
n: Rank number
m: number of years

Table(1):Spread sheet output

Tank capacity m^3	Shortage days	Aver. Shortage days/y	Spilling days	Aver. spilling days/y	Tot. Spilling m^3	Aver. spilling m^3/y	Average yield m^3/day	Total cons. tot. period	Average cons. m^3/y
0.0	9497	365	652	25	3007.6	115.6	0.000	0.0	0.0
1.0	8063	310	540	21	2629.5	101.1	0.144	1369 5	52.6
2.0	7797	300	474	18	2342.6	90 0	0 174	1656 5	63 7
3.0	7593	292	421	16	2101.9	80 8	0 200	1897 1	72.9
4.0	7428	285	373	14	1902.6	73 1	0 221	2096.4	80 6
5.0	7279	280	329	13	1730.5	66 5	0.239	2268.5	87.2
6.0	7223	278	296	11	1580.9	60.8	0.255	2418.2	92.9
7.0	7110	273	264	10	1455.5	55 9	0.268	2543.5	97.8
8.0	7023	270	244	9	1348.8	51.8	0.279	2650.3	101.9
9.0	6944	267	219	8	1254.1	48 2	0 289	2744.9	105.5
10.0	6886	265	201	8	1175.4	45 2	0.297	2823.6	108 5
20.0	6604	254	125	5	774.2	29 8	0 340	3224.8	123 9
30.0	6447	248	95	4	567.4	21.8	0 361	3431.6	131 9
40.0	6333	243	64	2	419.0	16 1	0.377	3580 0	137 6
50.0	6252	240	42	2	317.7	12 2	0.388	3681.3	141 5
60.0	6188	238	29	1	243.5	9 4	0.395	3755 5	144 3
70.0	6147	236	20	1	193.4	7 4	0.401	3805 7	146 3
80.0	6122	235	17	1	161.9	6.2	0.404	3837 1	147.5
90.0	6105	235	13	0	141.9	5.5	0.406	3857 1	148.2
100.0	6089	234	11	0	121.9	4.7	0.408	3877.1	149.0
110.0	6072	233	10	0	101.9	3.9	0.410	3897.1	149 8
120.0	6055	233	8	0	81.9	3.1	0 412	3917.1	150 5
130.0	6046	232	6	0	70.3	2 7	0 414	3928.7	151 0
140.0	6037	232	6	0	60 3	2.3	0.415	3938.7	151.4
150.0	6029	232	5	0	50 3	1 9	0.416	3948 7	151 8
160.0	6021	231	4	0	40 3	1 5	0 417	3958.7	152.1
170.0	6012	231	3	0	30.3	1 2	0 418	3968.7	152 5
180.0	6004	231	2	0	20 3	0.8	0 419	3978.7	152 9
190.0	5996	230	1	0	10.3	0 4	0.420	3988 7	153 3
200.0	5987	230	1	0	0.3	0.0	0.421	3998 7	153 7

-Harvested rainwater: 75%

-Average harvested rainwater. 154m3/year/300m2

Appendix 3-c

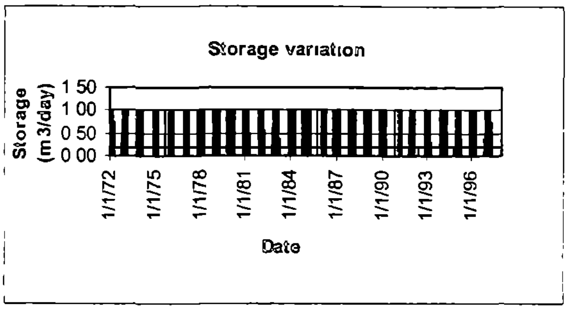
Table (1): Total expected collected rainwater(Current and future),in case each building has a cistern.

Year		1998	2000	2010	2020	2040
No of cisterns		4144*	5250**	7058**	9033**	13425**
Volume	Collected water	Total	Total	Total	Total	Total
0	0.0	0.00	0.00	0.00	0.00	0.00
1	52.6	0.22	0.28	0.37	0.48	0.71
2	63.7	0.26	0.33	0.45	0.58	0.85
3	72.9	0.30	0.38	0.51	0.66	0.98
4	80.6	0.33	0.42	0.57	0.73	1.08
5	87.2	0.36	0.46	0.62	0.79	1.17
6	92.9	0.39	0.49	0.66	0.84	1.25
7	97.8	0.41	0.51	0.69	0.88	1.31
8	101.9	0.42	0.53	0.72	0.92	1.37
9	105.5	0.44	0.55	0.74	0.95	1.42
10	108.5	0.45	0.57	0.77	0.98	1.46
20	123.9	0.51	0.65	0.87	1.12	1.66
30	131.9	0.55	0.69	0.93	1.19	1.77
40	137.6	0.57	0.72	0.97	1.24	1.85
50	141.5	0.59	0.74	1.00	1.28	1.90
60	144.3	0.60	0.76	1.02	1.30	1.94
70	146.3	0.61	0.77	1.03	1.32	1.96
80	147.5	0.61	0.77	1.04	1.33	1.98
90	148.2	0.61	0.78	1.05	1.34	1.99
100	149.0	0.62	0.78	1.05	1.35	2.00
110	149.8	0.62	0.79	1.06	1.35	2.01
120	150.5	0.62	0.79	1.06	1.36	2.02
130	151.0	0.63	0.79	1.07	1.36	2.03
140	151.4	0.63	0.79	1.07	1.37	2.03
150	151.8	0.63	0.80	1.07	1.37	2.04
160	152.1	0.63	0.80	1.07	1.37	2.04
170	152.5	0.63	0.80	1.08	1.38	2.05
180	152.9	0.63	0.80	1.08	1.38	2.05
190	153.3	0.64	0.80	1.08	1.38	2.06
200	153.7	0.64	0.81	1.08	1.39	2.06

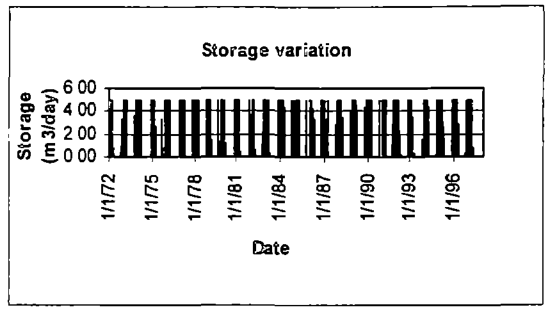
* *Existing number of residential building (1997/1998)*

***The number of buildings in Ramallah and Al-Berih after the expected urban development. Those values were estimated by dividing the population (Medium scenario, table(4.3)) over 12person per building.*

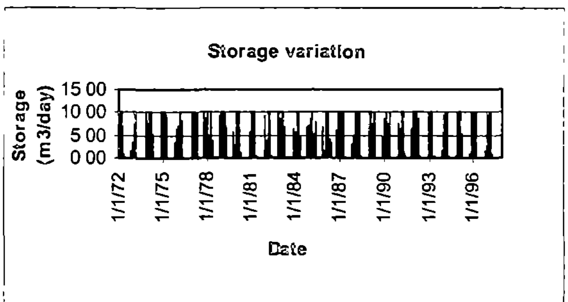
Existing no of cisterns in Ramallah and Al-Berih is 350 with a potential of 0.052Mm^3 /y based on a tank capacity of 80 m^3 each.



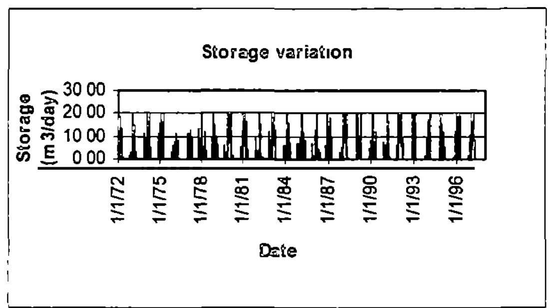
Tank capacity 1m3



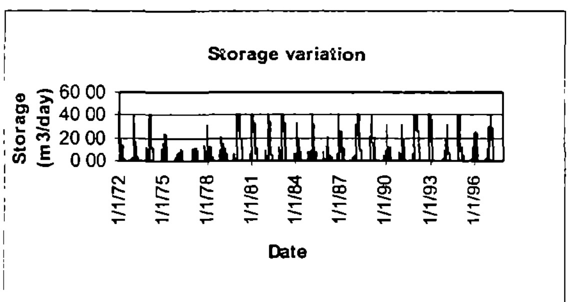
Tank capacity 5m3



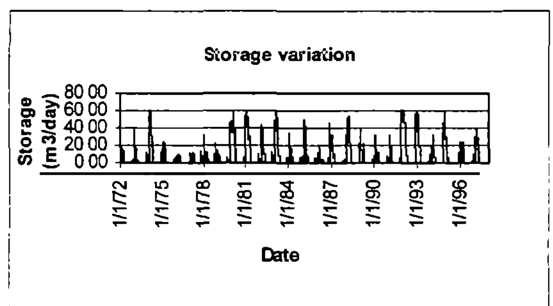
Tank capacity 10m3



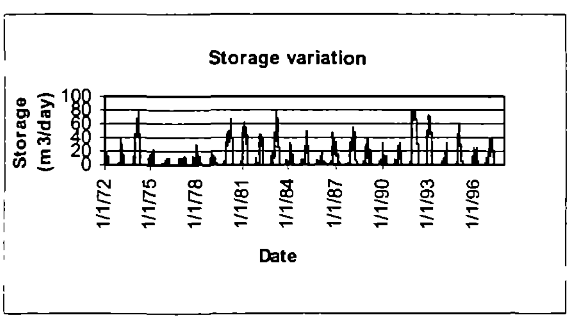
Tank capacity 20m3



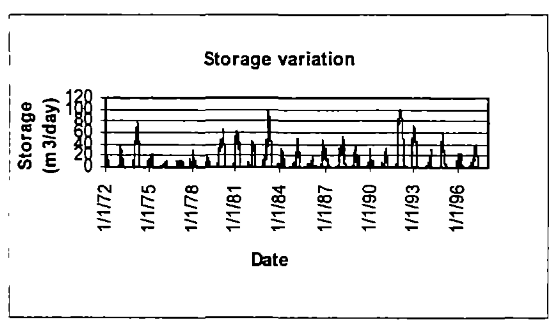
Tank capacity 40m3



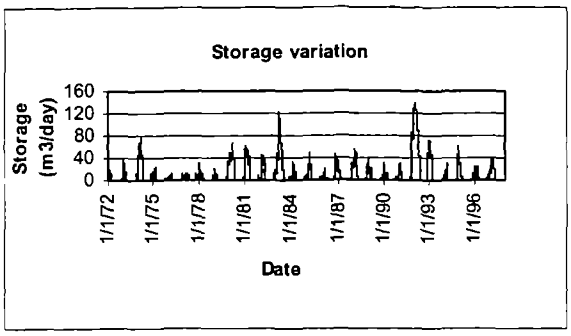
Tank capacity 60m3



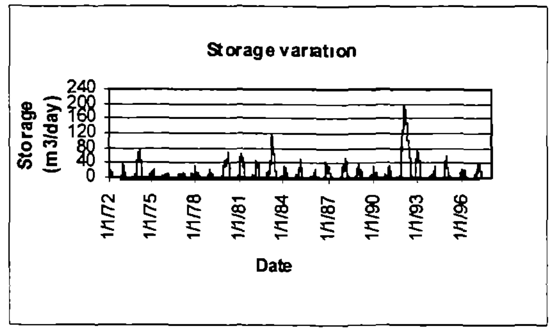
Tank capacity 80m3



Tank capacity 100m3



Tank capacity 140m3



Tank capacity 200m3

Appendix 3-d

Table(1): Capital cost of the tanks

Volume		Drilling cost	Material cost				Labor cost		Total *1000
Dimension	m^3		Steel	Concrete (B250)	Cement Texturing	Aggregates Texturing	Building	Texturing	
4*4*4	64	1920	1280	5280	875	200	1920	1500	13.0
4*4*5	80	2400	1600	6820	1050	250	2400	2000	16.5
5*5*4	100	3000	1920	8580	1225	250	3000	2000	20 0
6*6*4	144	4320	2400	11000	1400	300	4320	2500	26.2
7*7*5	245	7500	3200	15840	1575	300	6000	3500	37 9
8*8*5	320	9600	4000	18920	1575	400	7800	4500	46.8

The currency in NIS=New Israelian Shekel
From PHG,1998

Table(2): Additional costs for the system

Item	Unit	quantity	Total price	1998 value
Steel cover	Unit	1	100JD*	
Pump(1/2in,1/2 HP)	Unit	1	100JD*	
Pipes	m,(1.5JD/m)	30(4+12+10+3)	53JD*	
Fittings	Lump sum	15% of pipes price	8JD*	
Total			261JD	380(US$570)***
Balancing tank	Unit	1	US$70**	70
Gutter	Unit	1	US$10	10
Down pipe	m,(US$3/m)	12	US$35	35
Labor	Lump sum		US$100**	100
Total				$785

**From (Al-Hudhud,A. and Najjar,T., ,1993)*
*** Assumed.(1997),based on prices of construction material shopes.*
JD: Jordanian Dinar
**** Estimated by using PV=a/r[1-(1/(1+r)t)] and FV=a[(1+r)t-1]/r from(Opdam,1998)*
Where:
PV:present value
a: annuity
r: Interest rate

t: period
FV: future value

Power
Pump: 0.5HP
HP= Horse power =0.75KW(Kilo Watt)
0.5HP=0.75/2= 0.4KW
KW price = 0.45 NIS(WBWD,1998)
Assumed = 1hr pumping/day
Cost($)/pumbed m^3 =(Total pumping hours)×(Cost/kw)×(Consumed power/hr)÷(Total consumption ,regarding different tank capacities)

Table(3): Calculation of total EAC(US$/m3)

Tank capacity (m^3)	Capital Cost US$	Access. cost US$	Used RW m^3/a	EAC Tank US$/$m^3$	EAC Access. US$/$m^3$	Pump. days	Pump. Hours	Power cost US$/$m^3$	Total EAC US$/$m^3$	Resi. Time days
1	38	785	53	0.06	1 40	44	44	0 04	1.49	44
2	98	785	64	0 13	1 16	53	53	0 04	1.32	53
3	159	785	73	0 18	1 01	61	61	0 04	1.22	61
4	219	785	81	0 22	0 91	67	67	0 04	1.17	67
5	279	785	87	0 26	0.84	73	73	0 04	1.14	73
6	339	785	93	0 30	0 79	77	77	0.04	1.13	77
7	398	785	98	0 33	0.75	81	81	0 04	1.12	81
8	458	785	102	0.37	0.72	85	85	0 04	1.13	85
9	516	785	105	0 40	0.70	88	88	0.04	1.13	88
10	575	785	109	0.43	0 68	90	90	0.04	1.15	90
20	1147	785	124	0.76	0 59	103	103	0.04	1.39	103
30	1694	785	132	1.05	0 56	110	110	0.04	1.65	110
40	2217	785	138	1.32	0.53	115	115	0.04	1.89	115
50	2717	785	141	1.57	0 52	118	118	0.04	2 13	118
60	3196	785	144	1 81	0 51	120	120	0.04	2.36	120
70	3654	785	146	2 04	0.50	122	122	0.04	2 58	122
80	4093	785	147	2 27	0.50	123	123	0 04	2.80	123
90	4514	785	148	2 49	0.50	124	124	0 04	3.02	124
100	4918	785	149	2 70	0.49	124	124	0 04	3.23	124
110	5306	785	150	2 90	0.49	125	125	0 04	3.42	125
120	5680	785	151	3 08	0 49	125	125	0.04	3.61	125
130	6041	785	151	3.27	0 49	126	126	0.04	3.80	126
140	6390	785	151	3 45	0 49	126	126	0.04	3.97	126
150	6728	785	152	3.62	0 48	126	126	0.04	4 15	126
160	7056	785	152	3 79	0 48	127	127	0.04	4.31	127
170	7376	785	153	3 95	0 48	127	127	0.04	4.47	127
180	7689	785	153	4.11	0 48	127	127	0.04	4.63	127
190	7996	785	153	4 26	0 48	128	128	0.04	4.78	128
200	8297	785	154	4 41	0 48	128	128	0.04	4.93	128

Interest rate(%) 8
Expected lifetime(years),Tank 50

Expected life time(years),Accessories 25
Pumping hours(hr/d) 1
0.5HP 0.4 *kw/hr*
KW($) 0.113 *converted from NIS(0.45NIS/kw) to US$ (1US$ = 4NIS)*

RW: Rainwater
Access. : Accessories
EAC: Equivalent Annual Cost
HP: Horse power
KW: Kilo watt
NIS: New Israelian Shekel
Resi. time: Residence time

Table(4): Water tariff and consumption 1994 -Jerusalem Water Undertaking

Type of subscribe	Consumption(m^3/year)	Tarrif applied($/$m^3$)
Below 10m^3	309460	0.91
From 10-20m^3	1897822	0.91
From21-40m^3	923723	0.97
More 40m^3	1485410	1.32
Bulk customers	1243085	0.97
Average tariff		1.04
Meter rental/m^3		0.07
Total tarrif applied		1.11
Israeli price		0.5

From JWU,1995 & JWU,1998.

Marginal cost estimation:

Purchased water=64%
Produced water=36%
Marginal cost of pumping=0.05/0.64=0.08US$/$m^3$
Marginal cost of purchasing from Mekorot=0.59/.64=0.92US$/$m^3$
Marginal cost of production=0.25/0.36=0.69US$/$m^3$
Other costs=0.42/(0.36+.64)=0.42US$/$m^3$
Total Marginal cost of purchased water =0.42+0.92+0.08=1.42US$/$m^3$
Total Marginal cost of produced water =0.42+.67 =1.11US$/$m^3$

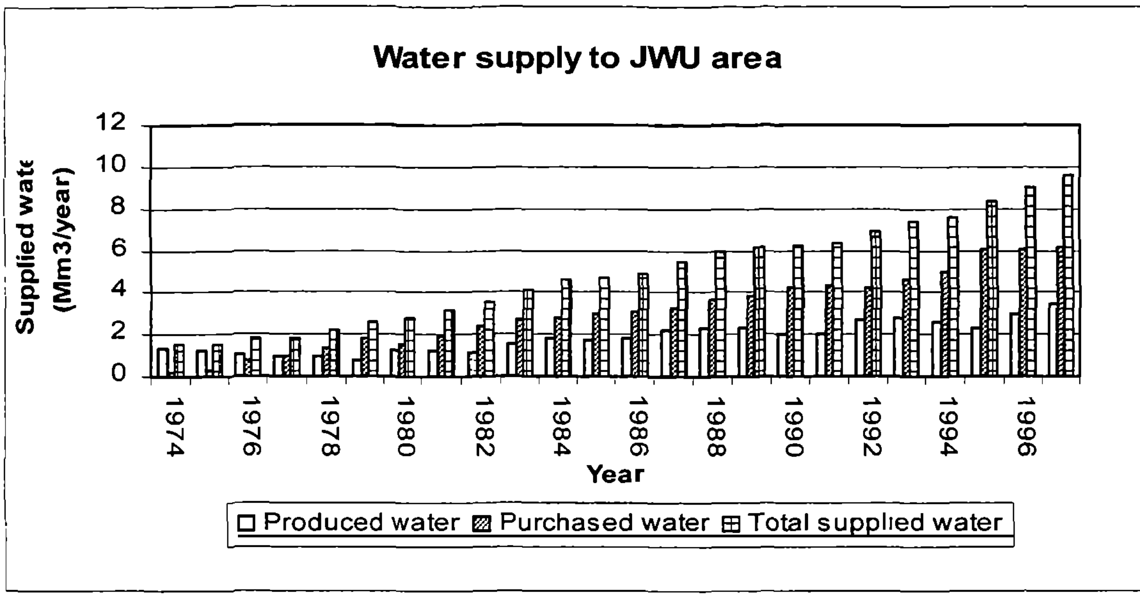
Table(5):Total cost per m^3 of JWU operations.

Items	Cost US$/m^3 Average*	Cost ratio including water purchasing (%)	Cost US$/m^3 Exact expenses **	Cost ratio including water purchasing (%)	Marginal cost In household Purchased from Mekorot US$/m^3 **		Cost ratio (%)	
					Owned GW	Mek.	Owned GW	Mek.
Production cost (Water produced in Ramallah)	0.25	19	0.29	19	0.69		62	
Pumping cost	0.05	4	0.05	3		0.08		5 6
Purchasing cost Water Purchased **from Mek.**	0.59	44	0.67	43		0.92		64 8
Distribution cost and meter **expenses**	0.31	25	0.38	24	0.31	0.31	28	21 8
Administration cost and financial expenses	0 11	8	0.17	11	0.11	0.11	10	7.8
Total	1 31	100	1.56	100	1.11	1.42	100	100

**From: JWU,1995*

*** Estimated from data on total expenses of JWU of water produced and water purchased and the amounts involved.*

Mek.: Mekorot



Figure(1): Water supply in JWU area

Appendix 3-e

Table(1): Field survey at Ain-Areek

House No.	Consumption m^3	Time Day	Members per family	Consumption l/c/d	Catchment m^2	Cistern
1	4	6	10	66 7	120	No
2	5	6	13	64 1	120	No
3	4.5	15	7	42 9	120	No
4	60	60	23	43 5	360	Yes
5	3	25	6	20 0	80	No
6	12	30	8	50.0	170	Yes
7	1.2	1	23	52.2	250	No
8	3 5	20	6	29.2	50	No
9	7	30	6	38 9	250	No
10	90	180	9	55.6	150	Yes
11	2	12	6	27.8	100	No
12	45	240	9	20.8	150	No
13	4	30	5	26 7	180	No
14	5	6	8	104.2	300	No
15	0.5	1	9	55 6	250	No
16	5	7	7	102.0	150	Yes
17	20	30	10	66 7	300	No
18	6	30	5	40.0	120	Yes
19	7	20	6	58.3	100	No
20	6	14	8	53 6	250	No
Average				50 9	178.5	

Time saving estimation:

- About 25% is used from springs on average
- Family needs: 300 l/family/d
- 0.25*300=75 l/family/day
- Bucket size = 20 l
- Average distance=500m (assumed)
- Average speed=1m/second (assumed)
- Nomber of bucket needed=75/20=~4
- Time=(500/1 *2)/60 + 20(waste time on the spring) =38minutes ~40min
- Total saved time=4*0.67=2.7hr/day/family~3hr

Appendix 4-e

Table(1): RWHS evaluation

Criteria		Option					
		TWW	B&SWD	WI	GW+JR	RWH	
						RC	UR
Technical aspects	Possible water quantity to be gained (Mm3/y)	0 92(ST), 4 9(2010)	1 9	0 8	18	0 65	1 42
	Use	Agri	Agr +Dom +Ind	Dom +Ind +Agr	Dom +Ind +Agr	Dom	Agr
	Technical deficiencies and need for further research	-	-	-	0	0	--
	Infrastructure requirement	- (LI)	-- (LI)	- (LI)	- (LI)	++ (HI)	- (LI)
	Time needed of implementation	2010?	2010?	2005?	?	2000	2010?
Economic /Financial Aspects	Unit cost(US$/$m^3$)	0 8	0 3-1(SW) 0 84-1 0(BW)	0 87(OT),1 08(NT), 0 64(by Bags)	0 25-0 51(GTZ) 0 76(JWU),0 83(JR)	1 4	0 25-1 17
Environmental Aspects	Short term and long term impact on GW and SW quantity	0	+	+	0	-	-
	Short term and long term impact on GW and SW quality	++	0	0	0	0	0
	Impact on climate and other environmental components	+	0	0	0	0	+
	Risk of pollution of the source	NA	-	-	-	-	-
Social Implications	Acceptance	--, 0*	++	++	++	+	++
Political implications	Constraints, risk	-	-	--	--	++	--

Most of the Information in this table is based on GTZ report on Middle east regional study on Water Supply and Demand Development, Phase II,1996

* *--: Domestic, 0: Irrigation*

Abbreviations: ***TWW***. *Treated waste water,* ***B&SWD****: Brackish and Sea Water Desalination,* ***WI****: Water Import,* ***GW& JR****: Ground water and Jordan River, RWH: Rainwater Harvesting,* ***RC:*** *Roof Catchment,* ***UR****: Urban Runoff ,* ***ST****: Short Term,* ***Agr.****: Agriculture,* ***Dom.****: Domestic ,* ***Ind.:*** *Industrial, ,* ***LI:*** *Large investment ,* ***HI:*** *Household Investment,* ***OT****: Old Tankers,* ***NT****: New Tankers,* ***B****: Bags,* ***GTZ****: Technical cooperation- Federal Republic of Germany,* ***JWU:*** *Jerusalem Water Under taking,* ***JR****: Jordan River,* ***NA****: Not Applicable,* ***SW****: Surface Water*

Distinguish keys:

++:	*Very positive*
+:	*Fairly positive*
0:	*Neutral*
- :	*Fairly negative*
- -:	*very negative*