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ENGINEERING MANAGEMENT AND FINANCIAL ANALYSIS OF AL FASHKHA SPRINGS DESALINATION PROJECT

Final Report

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ABSTRACT

Desalination is a fast growing technology that is spreading throughout the world especially in countries with scarce water resources. Desalination technology offers the potential to convert the almost infinite supply of seawater and large quantities of brackish groundwater into a new source of freshwater. Technological advances over the last decades have reduced its cost dramatically and made it to be a realistic option for increasing water supplies in many areas around the world having a role in the water management portfolio.

The main objective of this research is to assess the financial feasibility and proposes management model of the utilization options of the PWA proposed reverse osmosis desalination project for Al Fashkha Springs which has an overall capacity of desalinating 22 MCM/year. In this research, and after discussion and agreement with PWA, two options of utilizing the desalinated water have been analyzed including the "Al Fashkha - Jericho" in Jericho Governorate and "Al Fashkha – Al Ubedeyya" in Bethlehem Governorate.

Al Fashkha springs are located at the north western side of the Dead Sea within a nature reserve that is under control of the Israeli occupation. Al Fashkha springs have an estimated volume of water discharged to be around 80 MCM per year which runs eastwards towards the Dead Sea. During the course of this research work, three water samples were taken from Al Fashkha springs and were tested at PWA laboratory and gave the following average results: TDS (2087 mg/l), Salinity (1700 mg/l) and EC (3810 µS/cm). These results show that the water of Ein Al Fashkha is considered as brackish water.

The overall calculated cost (desalination and conveyance) per cubic meter for the Al Fashkha – Jericho option is 0.85 $\$/m^3$. While for the Al Fashkha – Al Ubedeyya option is 1.06 $\$/m^3$. The BOT agreement is suggested to be adopted for running this project. It is suggested to be signed between potential consortium of international companies and a government agency. The agreement is proposed to have a period of 25 years. Construction of the desalination plant is suggested to go through two phases over 18 months; 11 MCM/year facility for each. This research has shown that the proposed Al Fashkha Springs Desalination Project could be a realistic option for PWA to consider in the future as it will create a new vital water resource that will alleviate the local water supply/demand gap particularly in the southern West Bank.

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I would like to extend my gratitude to everyone who supported me throughout the course of this thesis research. I am thankful for their aspiring guidance, invaluably constructive criticism and friendly advice during this research work. I am sincerely grateful to them for sharing their truthful and enlightening views on a number of issues related to this research.

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Special thanks to my family. Words cannot express how grateful I am to my parents for all of the sacrifices that you have made on my behalf, and brothers and sisters for being always around. Your prayer for me was what sustained me thus far. I would also like to thank all of my friends who supported me in writing, and incented me to strive towards my goal.

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Executive Summary

Desalination is a fast growing technology that is spreading throughout the world especially in countries with scarce water resources. Desalination technology offers the potential to convert the almost infinite supply of seawater and large quantities of brackish groundwater into a new source of freshwater. Technological advances over the last decades have reduced its cost dramatically and made it to be a realistic option for increasing water supplies in many areas around the world having a role in the water management portfolio.

Palestine as the other countries in the Middle East is suffering from limited and strained natural water resources, increasing water demand due to increasing rapid population, limited access to water resources due to the Israeli occupation and its unlimited constraints on the development of the water sector. Results of previous studies show that the total water needs in Palestine (municipal, industrial and agricultural) will be around 860 MCM by the year 2020. Current water supply is merely about one-third of that figure and Palestinians should develop some 550 MCM/Yr additional conventional/non-conventional water resources need to be developed. This includes groundwater resources, the Jordan River basin, reuse of treated wastewater, developing desalination plants for brackish and seawater, and considering water transfer options

The main objective of this research is to assess the financial feasibility and proposes management model of the utilization options of the PWA proposed reverse osmosis desalination project for Al Fashkha Springs which has an overall capacity of desalinating 22 MCM/year. In this research, and after discussion and agreement with PWA, two options of utilizing the desalinated water have been analyzed including the “Al Fashkha - Jericho” in Jericho Governorate and “Al Fashkha – Al Ubedeyya” in Bethlehem Governorate.

The methodology of the research is divided into three main phases. The first phase of initiating this research was the Concept and Data Collection Phase; mainly consisted of data collection from relevant authorities, basically from the Palestinian Water Authority (PWA), including available reports, maps, studies, and the submitted PWA proposal to donor agencies for establishing the proposed Al Fashkha springs desalination project. Moreover, literature review work was carried out to develop an understanding of the desalination technologies, their costs and adopted management models in running such large scheme

projects. All available data, reports and literature documents were thoroughly reviewed and linked together to enable the establishment of a preliminary (inception) report that was discussed with relevant stakeholders and used as a key document to further proceed in conducting this research.

The second phase of developing this research was the Data Analysis Phase. In this phase the description of the existing baseline environmental conditions of the Al Fashkha springs was developed in support of creation of visual GIS maps representing the different environmental aspects of the area using ArcGIS 10.1 program. Then the process of proposing and laying out conceptual design for the conveyance systems of the desalinated water from Al Fashkha springs that was done in constant stakeholder consultation mainly with PWA and the Ministry of Agriculture (MoA) to identify the direct beneficiary communities from this proposed project. After setting out the conceptual designs, detailed hydraulic designs were developed with more than once option using the Water CAD V8i software program that was companied with conducting costing analysis for the proposed options to account for the capital and operational costs of each option.

On the other hand, along with the technical work done to establish the engineering designs and their costs, another analysis was done to establish management framework for establishing and running such a non-conventional large scheme project that was done in direct consultation with relevant authorities and stakeholders. This work investigated available scenarios to run such a project and the development of the possible management models was done.

The third and last phase of finalizing this research was the Decision Analysis phase. In this phase the selection of the desalination technology and the conveyance system for the desalinated water associated with its capital and running costs was done after evaluating the developed options. Moreover, the management framework for the project was set out and finalized.

Al Fashkha springs are located at the north western side of the Dead Sea within a nature reserve that is under control of the Israeli occupation. Al Fashkha springs have an estimated volume of water discharged to be around 80 MCM per year which runs eastwards towards the Dead Sea. During the course of this research work, three water samples were taken from Al Fashkha springs and were tested at PWA laboratory and gave the following average results: TDS (2087 mg/l), Salinity (1700 mg/l) and EC (3810 µS/cm). These results show that the water of Ein Al Fashkha is considered as brackish water.

The overall calculated cost (desalination and conveyance) per cubic meter for the Al Fashkha – Jericho option is 0.85 $/m3. While for the Al Fashkha – Al Ubedeyya option is 1.06 $/m3. The BOT agreement is suggested to be adopted for running this project. It is suggested to be signed between potential consortium of international companies and a government agency. The agreement is proposed to have a period of 25 years. Construction of the desalination plant is suggested to go through two phases over 18 months; 11 MCM/year facility for each. This research has shown that the proposed Al Fashkha Springs Desalination Project could be a realistic option for PWA to consider in the future as it will create a new vital water resource that will alleviate the local water supply/demand gap particularly in the southern West Bank.

List of Abbreviations

km^2	Square kilometer
km	Kilometer
m	Meter
mm	Millimeter
mm/yr	Millimeter per year
mbsl	Meter below sea level
masl	Meter above sea level
L	L iters
l/c/d	Liters per capita per day
MCM	Million cubic meters
MCM/yr	Million cubic meters per year
m^3/d	Cubic meter per day
$\$/m^3$	US dollar per cubic meter
mg/l	Milligram per liter
^oC	Celsius degrees
NIS	New Israeli Shekel
PSI	Palestine Standards Institute
PWA	Palestinian Water Authority
JWU	Jerusalem Water Undertaking
WBWD	West Bank Water Department
MoA	Ministry of Agriculture
MoLG	Ministry of Local Government
MoH	Ministry of Health
EQA	Environment Quality Authority
NWC	National Water Company
WUA	Water Users Association
GIS	Geographic Information System
TDS	Total Dissolved Solids
EC	Electrical Conductivity
RO	Reverse Osmosis
BOT	Build Operate Transfer
PPP	Public Private Partnership
EPC	Engineering and Procurement Contract
O&M	Operation and Maintenance

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Chapter One: Introduction

1.1 Introduction

Availability of fresh water given the increased demand for water driven by the global demographic growth, the advancement in the industrial sector, and improvement in the standards of living is considered a global concern. In many parts of the world the local demand for water is exceeding the available conventional water resources. The application of water saving practices and best water management concepts may help in alleviating this problem but if there is still a shortfall then considering non-conventional water resources such as desalination of seawater or brackish water may be an option.

Palestine as the other countries in the Middle East is suffering from limited and strained natural water resources, increasing water demand due to increasing rapid population, limited access to water resources due to the Israeli occupation and its unlimited constraints on the development of the water sector. Results of previous studies show that the total water needs in Palestine (municipal, industrial and agricultural) will be around 860 MCM by the year 2020. Current water supply is merely about one-third of that figure and Palestinians should develop some 550 MCM/Yr additional conventional/non-conventional water resources need to be developed. This includes groundwater resources, the Jordan River basin, reuse of treated wastewater, developing desalination plants for brackish and seawater, and considering water transfer options **(Jayyousi and Srouji, 2009).**

Desalination technology offers the potential to convert the almost inexhaustible supply of seawater and apparently vast quantities of brackish groundwater into a new source of freshwater. Technological advances over the past 40 years have reduced its cost and have led to dramatic increases in its use worldwide **(The National Academy of Sciences, 2008)**.

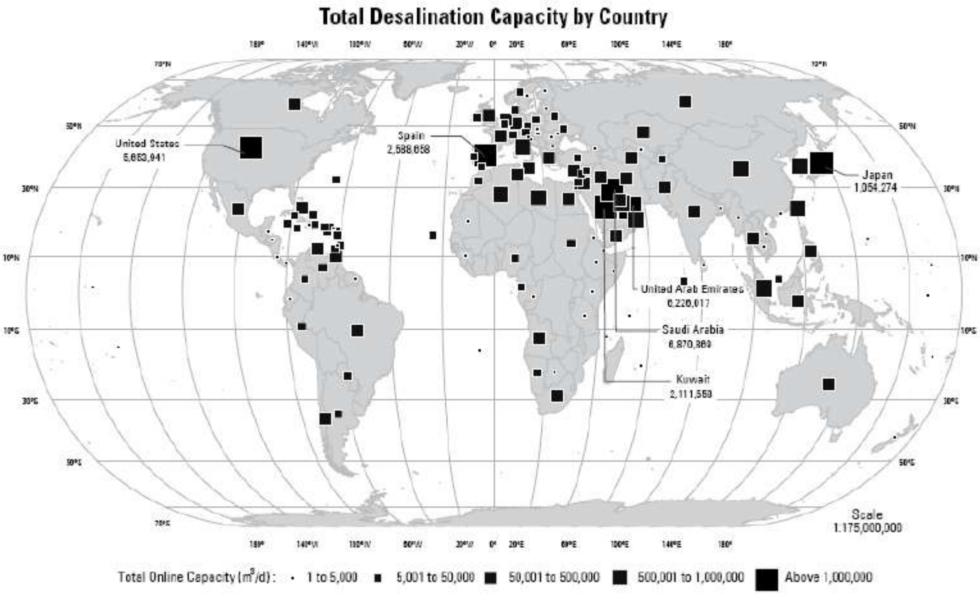

Figure (1-1): Worldwide Desalination Capacity in 2006 (The National Academy of Sciences, 2008)

Desalination is a fast growing technology that is spreading throughout the world especially in countries with scarce water resources. Desalination is the process of removing salts from brackish/seawater to provide purified water for industry, irrigation and drinking **(HWE, 2009)**. Today, desalination is becoming a serious option for the production of drinking and industrial water as an alternative to traditional surface water treatment and long distance conveyance **(Martin and Rabi, 2009)**.

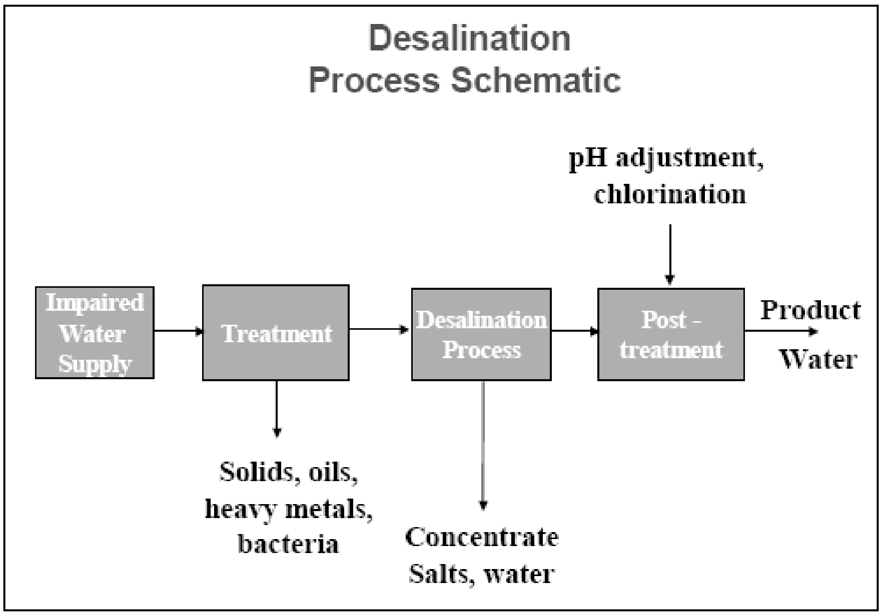

Figure (1-2): Desalination Process Schematic (Cooly et al., 2006)

Economics is one of the most important factors determining the ultimate success and extent of desalination. Desalination's financial costs, energy demands, environmental implications, reliability, and social consequences are intertwined with economic issues **(Cooly et al., 2006).** The cost of the desalinated water varies according to the desalination technology, the size of the plant, the salinity of water, and the cost of the energy input to the plant **(ACE, 2008).**
The capital and operating costs of desalination plants have decreased significantly in real terms, over the last decades. This is due to several factors, such as process design and manufacturing improvements, increased competition and privatization **(DHV Water et al., 2004).** Such previously mentioned factors made desalination to be a realistic option for increasing water supplies in many areas around the world, and desalination is gradually having a role in the water management portfolio. However, the potential of desalination is constrained by financial, social, and environmental factors **(The National Academy of Sciences, 2008).**

Turning towards desalination as a new source of water will play a role in the future planning and execution of all governments' tasks in the water sector, including resource assessment and monitoring, planning and allocation, development and distribution of water and the mobilization of sector investments. Once a government has determined that it is necessary to develop a desalination project, the main issue is how this can be realized. High capital investment and specific high-tech knowledge requirement both of which are scarce in Palestine could be real challenges. Therefore a realistic option might be to turn towards the private sector as a provider of both capital and knowledge **(DHV Water BV et al., 2004)**.

1.2 Statement of the Problem

The Palestinian Water Authority (PWA) is developing plans to utilize Al Fashkha springs (brackish water) for domestic and agricultural uses. This proposal supports the PWA plans and will further extend the idea to develop a plan to drill wells in the Pleistocene aquifer to extract brackish water for agricultural use **(Aliewi, 2010)**. Much of the water in the Dead Sea springs is discharged haphazardly without any real benefit derived to the surrounding environment. Aimed at utilizing this discharge, this research investigates the utilization of construction of a desalination plant capable of desalinating the brackish water discharged from Al Fashkha springs**.**

The PWA still has not formalized clear options of utilizing the desalinated water from the proposed project of Al Fashkha springs which entails the establishment of water conveyance systems for the benefited communities. Moreover, the costs associated with the construction and operation of this project are considered as main constraint but yet have not been investigated by PWA. Managing the establishment and operation of such a large scale non-conventional project would also impose another challenge to PWA to consider.

1.3 Research Questions

This research tries to answer the following questions:

1. What is the available water resource for desalination in Al Fashka springs?
2. What are the proposed utilization options of the desalinated water and their associated costs?
3. What is the proposed management model for the establishment and running of Al Fashkha springs desalination project?

1.4 Research Objectives

The aim of this research is to assess the financial feasibility and propose management model of the utilization options of the proposed PWA desalination project for Al Fashkha Springs. The specific objectives are:

- To describe the study area of Al Fashkha Springs.
- To conduct financial feasibility for the utilization options of the PWA proposed desalination project of brackish water at Al Fashkha springs.
- To propose management model for the establishment and operation of future desalination project of Al Fashkha springs.

1.5 Significance of the Research

This research will be a significant attempt in assessing the financial feasibility and management model for the proposed Al Fashkha springs desalination project. This study will contribute to enhancing the knowledge of possible utilizing options of the desalinated water from Al Fashkha springs and the proposed management model to run this non-conventional project. The results of this study will provide some insight and information for further research for Palestinian decision makers and water economists. The study provides a scientific discussion of concerning costs of utilizing the desalinated water from the future Al Fashkha springs desalination project and intends to provide useful information on the proposed management model of this project.

1.6 Research Approach and Methodology

The methodology of the research is divided into three main phases. The first phase of initiating this research was the Concept and Data Collection Phase; mainly consisted of data collection from relevant authorities, basically from the Palestinian Water Authority (PWA), including available reports, maps, studies, and the submitted PWA proposal to donor agencies for establishing the proposed Al Fashkha springs desalination project. Moreover, literature review work was carried out to develop an understanding of the desalination technologies, their costs and adopted management models in running such large scheme projects. All available data, reports and literature documents were thoroughly reviewed and linked together to enable the establishment of a preliminary (inception) report that was discussed with relevant stakeholders and used as a key document to further proceed in conducting this research.

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The research approach and methodology are fully discussed in chapter four of this research thesis.

1.7 Research Outline

This thesis research is comprised of six chapters. Chapter one offers an introduction to the content and structure of the research, including the statement of the problem, research questions and objectives. Chapter two describes the different characteristics of the study area of Al Fashkha springs, providing a briefing of the general environmental characteristics and water resources of the area. Chapter three, the literature review, discusses the desalination technologies, their associated costs and available management options in running such large scheme projects. Chapter four explains the approach and methodology adopted in this research from purpose of the study to the data collection and analysis phase. Chapter five provides the results and offers a discussion of the research results. Lastly, chapter six demonstrates the main conclusions and recommendations formulated as an outcome of this research.

Chapter Two: Study Area of Al Fashkha Springs

2.1. Geography and Topography

The study area is considered as a part of Jordan Rift Valley. It is the lowest point on the surface of the earth about 418 m below mean sea level. The valley slopes gently upward to the north along the Jordan River and to the south along WadiAraba. It extends from the Red Sea to Lake Tiberias and beyond with a major 107 km sinistral strike-slip fault between the Arabian plate to the east and the northeastern part of the African plate to the west. Due to extensional forces a topographic depression was formed. As a result of an arid environment it is filled with evaporites, lacustrine sediments, and clastic fluvial components (see Figure 2-1) **(Toll et. al., 2008).**

Figure (2-1): Location Map of the Study Area (source: researcher)

The Jordan valley contains one of the richest water resources in the West Bank which is Fashkha springs. They are located in a nature reserve and archeological site located in the north-west shore of the Dead Sea(400 m below mean sea level) and about 3 km south of Qumran wadi.

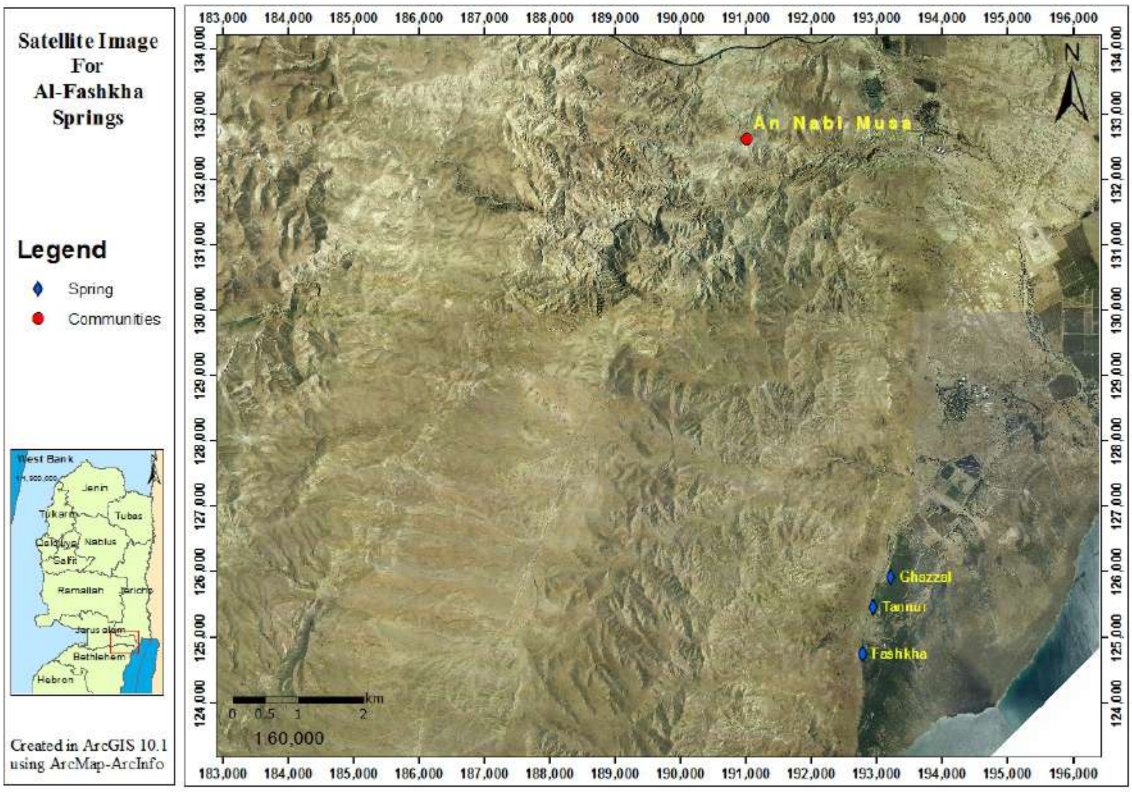


Figure (2-2): Satellite Image of the Study Area (source: researcher)

Topography is a unique feature of the area; as it changes significantly throughout the area. It descends gently from attitude of -100 in the west to less than -300 m in the eastwards to Sea level in the vicinity of Dead Sea (see Figure 2-3).

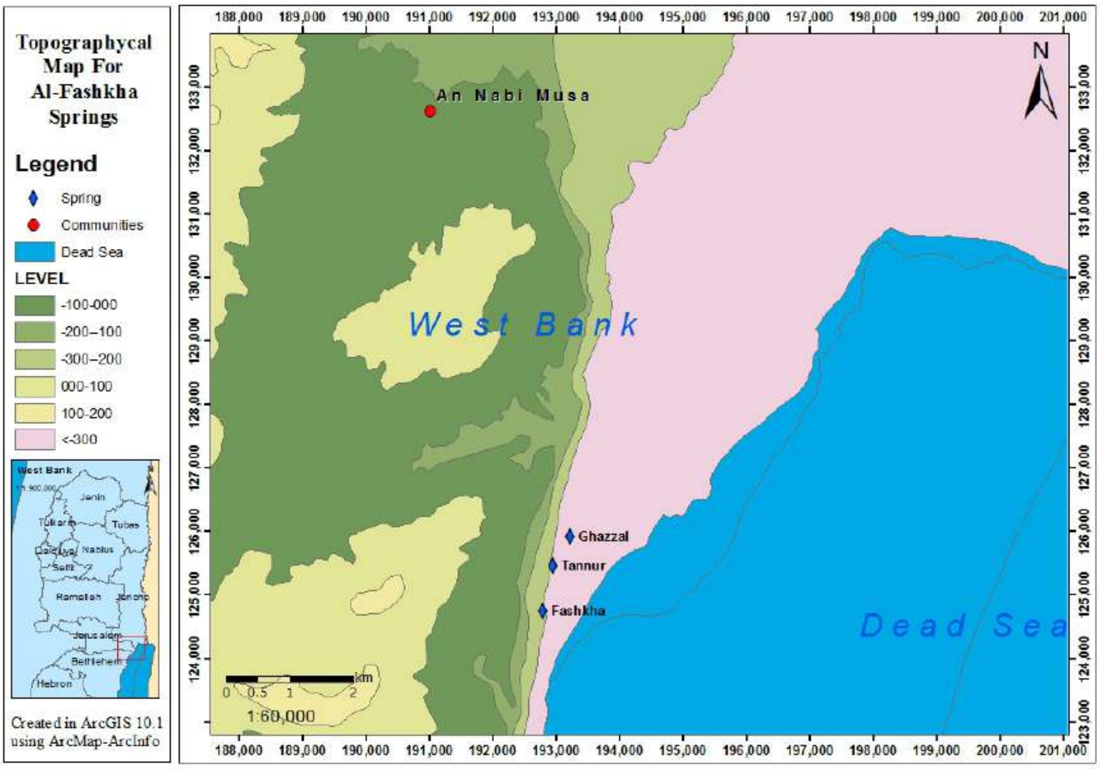


Figure (2-3): Topographic Map of the Study Area (source: researcher)

2.2. Water Resources

The Jordan Valley contains one of the richest water resources in the West Bank. It grounds approximately one third of the water reserve in the West Bank and it contains water from the Jordan River Basin, underground water from the Eastern Aquifer and water flowing into the Jordan River from the West Bank **(PLO, 2011).**

2.2.1 Surface Water

Surface water depends mainly on the quantity and duration of rainfall during the wet season. It mainly includes the Jordan River along with its tributaries and wadis flow from the central mountains towards the Jordan valley. Table (1) shows wadis that contribute to the Dead Sea Basin from the West Bank. These wadis are of importance for surface water streams, where floods from them coincide together to form major streams which rush unchecked fresh rainwater down to the Dead Sea **(Lahlabat, 2013).** This source of water is limited Since Israel diverted all of the flow of the Upper Jordan River at Lake Tiberias, the Jordan River has been reduced to a foul trickle (15%) causing a serious decline of 1m/year in the Dead Sea level **(EWASH, 2011).**

Table (2-1): Flow Contribution to the Dead Sea Basin (Al Yacoubi, 2007)

Surface Catchment Name	Flow (MCM/Year)
Mukallak (Og)	2
Qurman	3.9
Al-Nar	2
Daraja	5.3
Al-Gar	3.4
Abu El Hayyat	0.8
TOTAL	**17.4**

There are four surface catchments situated in the study area: Marar, Mukallak (Og), Nar, and Qurman. Fashkha springs are located in Nar Catchments which has a length of 25.78 km and drains towards the Dead Sea.

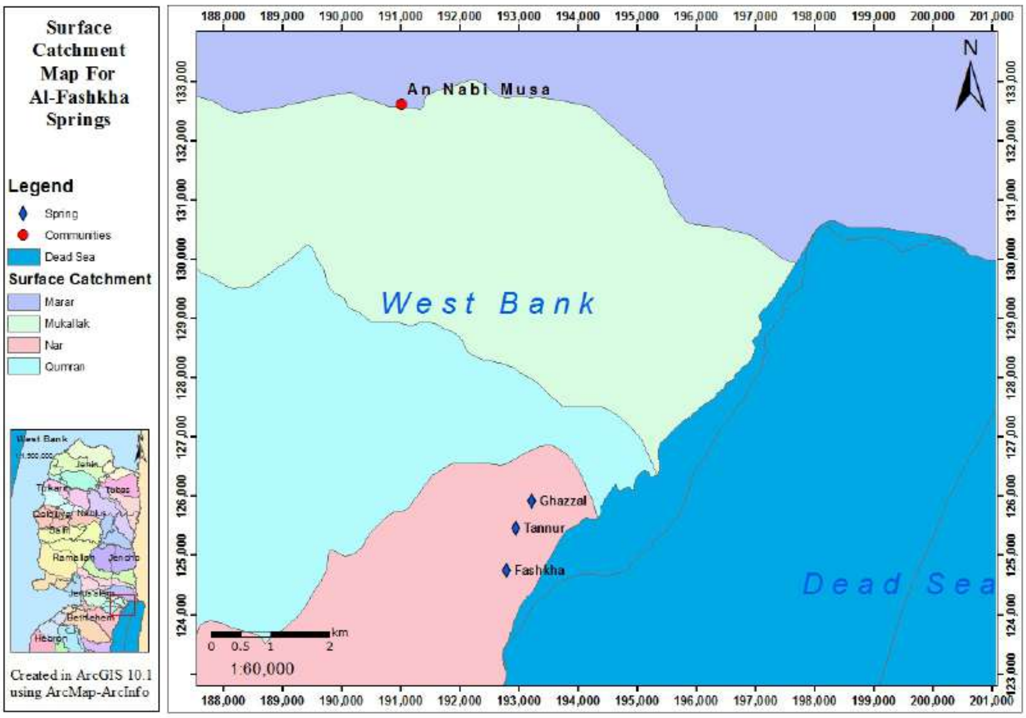


Figure (2-4): Surface Catchments Situated in the Study Area (source: researcher)

2.2.2 Groundwater

The Mountain Aquifer is the main groundwater source in the West Bank. This aquifer is divided into three sub-basins (The Western Aquifer, the Eastern Aquifer, and the Northeastern Aquifer). The study area is located in the eastern aquifer (see Figure 2-5) which has an area of 3,079.5 km^2 and mainly consists of carbonate sedimentary rocks with deeply incised wadis draining to the east **(Aliewi, 2007).**

In the West Bank, ground water (wells and springs) is considered the main sources of potable water. The following sections detail the current condition for springs and wells in the study area.

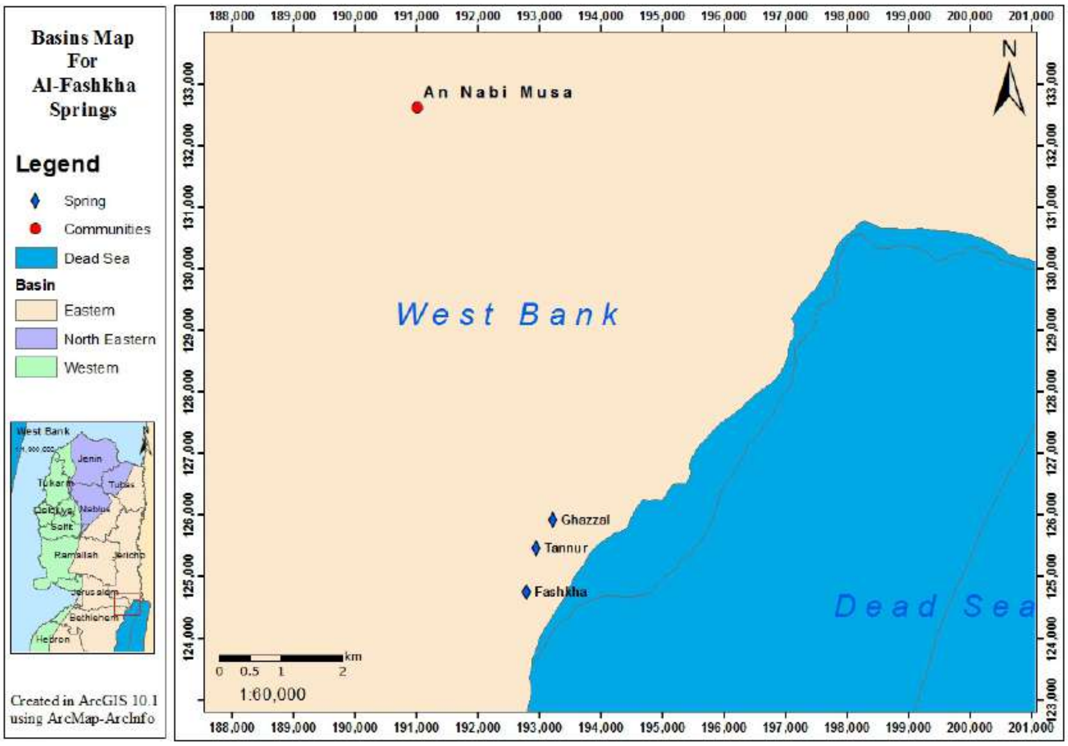


Figure (2-5): Basin Map for the study Area (source: researcher)

According to available data, there are more than 500 springs located across the West Bank. The most important of these are located in the Jordan Valley, including the group of springs located along the western shoreline of the Dead Sea. These springs are considered among the most important in the West Bank including **(PWA, 2002)**:

- Fashkha Group Springs
- Turaba spring group
- Ghweir Spring
- Ghazal group springs
- Tanur Spring

Located within the West Bank (see Figure 2-4), the Dead Sea Springs serve as a final southeastern outlet for the Eastern Basin, and have an estimated annual flow of 100-110 million cubic meters of brackish water, which runs eastwards towards the Dead Sea **(PWA, 2002).**

In the West Bank the renewable water can be estimated to be 760 MCM where 10% of this quantity can be considered brackish water **(HWE, 2009).** Brackish water is basically concentrated in the Jordan Valley. According to Palestinian Water Authority (PWA) records and studies, brackish water in Jordan valley could reach up to 80 million cubic meters. This quantity is basically used for agriculture and drinking. Those 80 MCM could be considered in planning a new desalination plant **(HWE, 2009).**

The main amount of brackish water located in the Jordan valley can be found in Al Fashkha springs group; which is composed of ten springs within close proximity to each other, the volume of water discharged by these springs could be around 70 to 100 MCM per year **(HWE, 2009).**

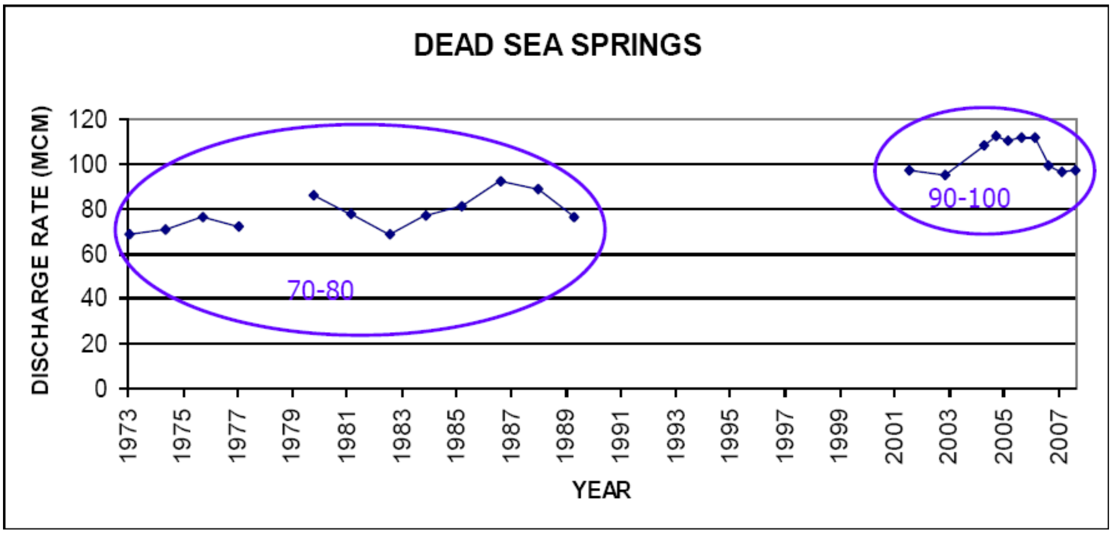


Figure (2-6): Discharge of Dead Sea Springs (Abdelghafour, 2009)

Historical Records show that the Dead Sea springs flow ranges from 70-80 MCM/y, while recent records show that the flow ranges from 90-117 MCM/y **(Abdelghafour, 2009).**

Available records show that some of the Dead Sea springs, such as Fashkha and Tannur Springs, have relatively high values of Total Dissolved Solids (TDS) ranging from 1,500 to 5,000 mg/l and making them brackish, as well as a high content of chloride and other constituents **(PWA, 2002).**

The water quality of these springs largely depends on the surrounding geological regime. In particular, the main source of salinity affecting the springs are the saline layers deposited along the shoreline of the Dead Sea, through which fresh groundwater passes as it emerges to the surface. As such, salinity levels vary according to the degree of solubility, though more data is needed on the water quality of the Dead Sea Springs, after which further studies into salinity levels can be carried out **(PWA, 2002).**

Water samples were taken from the Ein Al Fashkha springs during a site visit done by the researcher and were measured for salinity, TDS and electric conductivity (EC) at the PWA labs using Jenway digital meter. The results obtained are shown in table (2-2) and all are within the ranges of the brackish water.

Table (2-2): Results of Ein Al Fashkha Water Samples

	TDS (mg/l)	Salinity (mg/l)	EC (µS/cm)
Sample # 1	2010	1700	3700
Sample # 2	2120	1700	3860
Sample # 3	2130	1700	3870
Average	**2087**	**1700**	**3810**
Standard Ranges For Brackish Water	**1000-10,000***	**1000-3000***	**TDS = 0.6 EC** (conversion factor)**

*(McKinney, D.C., 2014)

** (Al-Motaz, I. S., 2014)

2.3 Climate

In general, the climate of the Jordan Valley is Mediterranean in its basic pattern, it is characterized by arid to semi-arid climate which are dominated by low annual rainfall, low soil moisture conditions and very high potential evapotranspiration levels. The study area has hot dry summer and warm low rain winter. The temperature varies from high temperature in the south that slightly decreases further to the north. The average temperature is about 40 °C in summer and about 15 °C in winter. The winds are generally from the west and southwest, coming from the Mediterranean Sea, and have a moderating influence in the summer weather. Occasional winds coming from the south and east over the desert are cold and dry in the winter, and dusty and scorching in the spring. The study area is characterized by low amount in rainfall. The amount of rainfall decreases eastwards with rainfall gradient changes from more than 150 to less than 100 mm/year in the vicinity of the Dead Sea. The mean annual rainfall is approximately 100 mm/year (see Figure 2-7), of which approximately 60% falls in the three months of December, January and February.

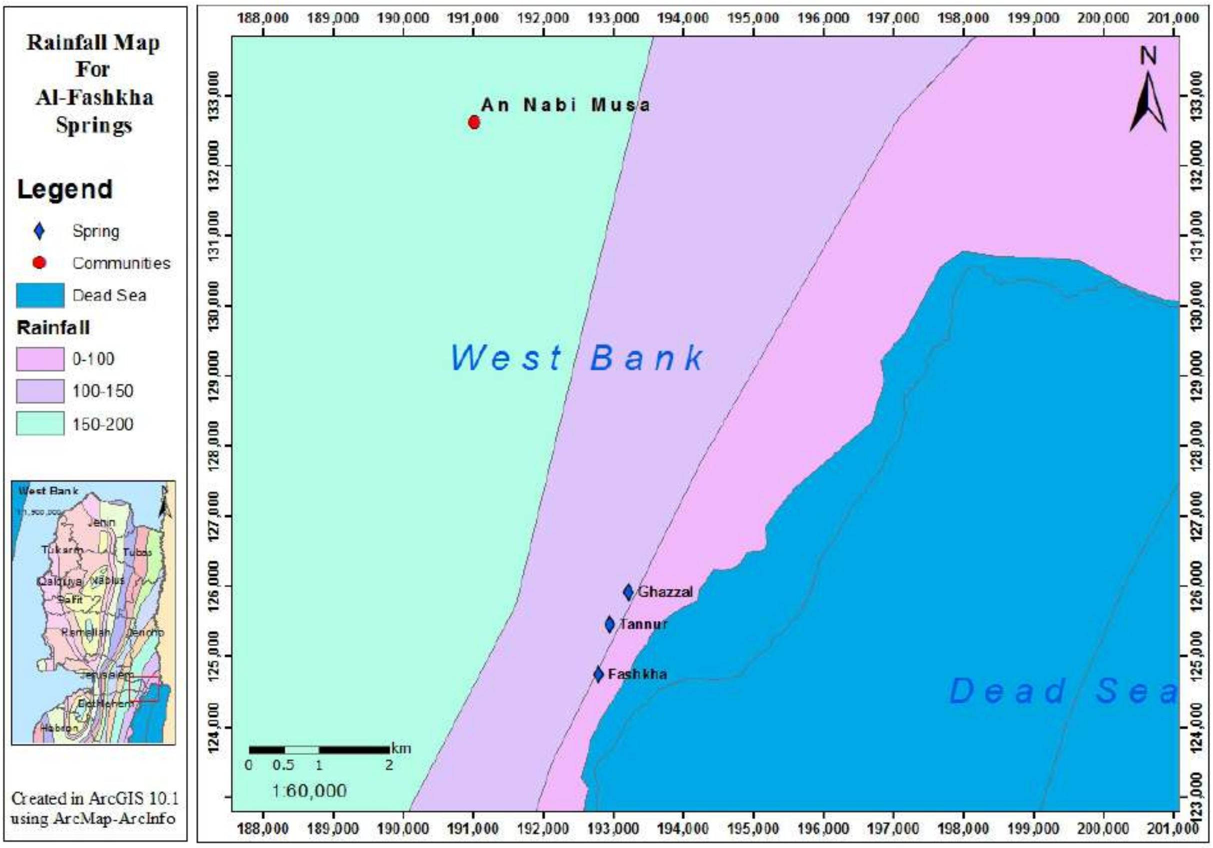


Figure (2-7): Rainfall Contour of the Study Area (source: researcher)

2.4 Geology and Soil

In the Jordan Valley, approximately, 28% of it is composed of Coniacian-Camparian and Camparian Chalk and Chert formations, 27% is composed of Turonian and Cenomanian limestone, marl and dolostone formations while 16% is composed of Sandstone, siltstone, dolostone and limestone formations. Dolostone, clay, sand loess and gravel make up the remaining 29%.

Fashkha springs group area is mainly composed of continental sediments of quarternary age (see figure 8). These constitute clastic (clay, sand and gravel) deposited in fan deltas with some intercalations of lacustrine sediments (clay, gypsum and aragonite) of the lisan formation and younger holocenic sediments **(Hasan, 2009).**

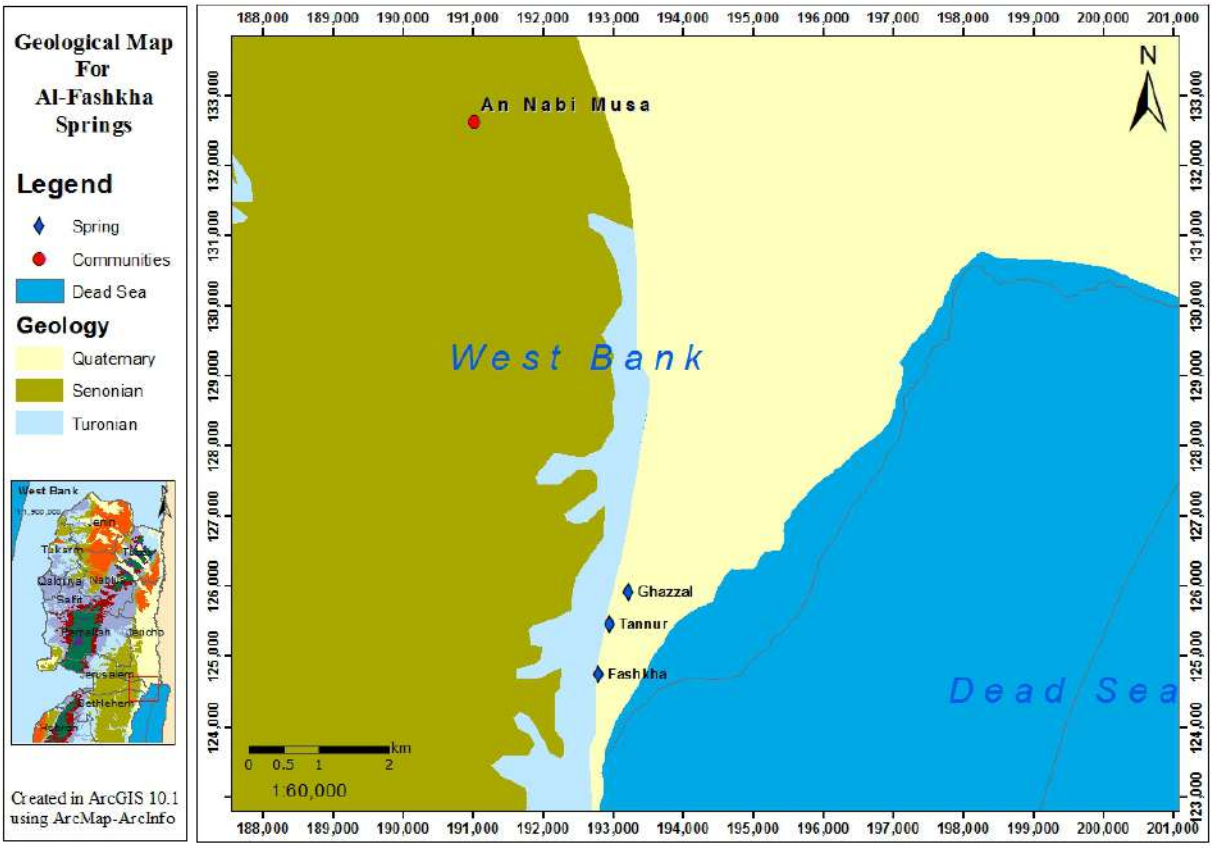


Figure (2-8): Geological Map for the study Area (source: researcher)

The soil depth varies widely along depending on surface geology and vegetation density. In the Jordan Valley; the main rock type are Lisan marls. They are deposits of a former inland lake and consist of loose diluvial marls. The Lisan marl soils are generally of a rather light nature, their clay content varies from approximately 10 to 20%. High concentration of lime content is present, which varies between 25 and 50%. Where there is no possibility for irrigation, the Lisan marls are covered with a very sparse growth of halophytic plants. In the Eastern Slopes region, the main soil types are the semi-desert soils, the secondary soil types are the mountain marls. For the semi-desert soils, the formation of sand and gravel is characteristic of desert weathering **(Hasan, 2009).**

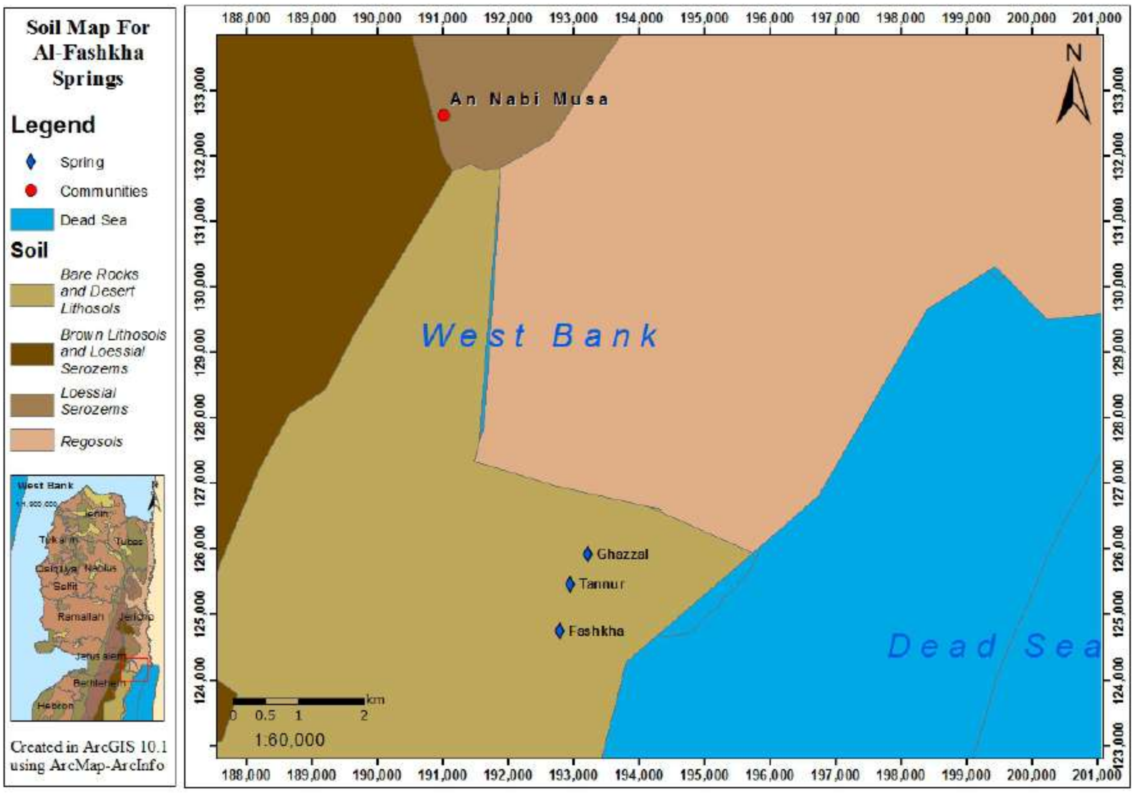


Figure (2-9): Soil Map for the study Area (source: researcher)

2.5 Land use

Al Fashkha springs are located in an area under the Israeli control which is considered as natural reserve area surrounded by closed rang Israeli military areas that is not utilized for any purposes. The lands surrounding the springs area are mainly covered by shrub plants.

The natural reserve of Ein Al Fashkha is considered as the lowest natural reserve in the world and is managed by the Israeli Nature and Parks Authority **(Wikipedia, 2015)**. The reserve is divided into three sections; the northern section which is called the “closed reserve” and has an area of 2,700 donums. This section is closed to the public and used by scientists and researchers. The central section, which is called the “visitors reserve”, is open to the public and features a series of pools for swimming filled with natural spring water and has an overall area of 500 donums. The southern section, which is called the “hidden reserve”, has an area of 1,500 donums and open to the public only when visiting on an organized group tour or a specially licensed private tour guide **(INPA, 2015)**. Photos taken by the researcher of the Ein Fashkha springs reserve are provided in Annex (A).

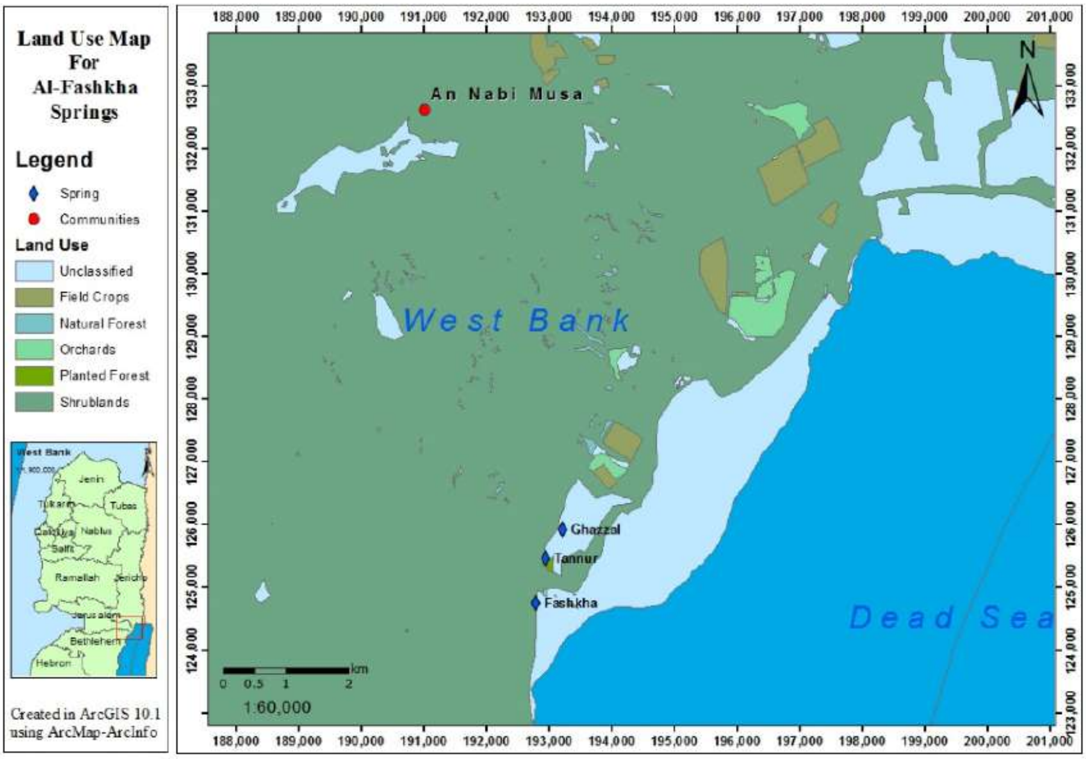


Figure (2-10): Land use of the Study Area (source: researcher)

Chapter Three: Literature Review

3.1 Desalination Technologies

3.1.1 Preface

Amongst all of our planet's water, 97.5% is salt water from the oceans and about 2.5% is fresh. More than two thirds of the fresh water is underground and the rest exist in glaciers (**The National Academy of Sciences, 2008)**. Given that sea water has commercial importance in supporting the mankind's life such as; sea trade, transport and fishing, but it has limited use in the domestic and agricultural sectors which are vital sectors to support the human life. Fresh water scarcity has led in different parts of the world to develop options and technologies to utilize the non-fresh water resources (brackish and saline) particularly by removing the dissolved salts from them through the process of desalination to allow for developing and utilizing new non-conventional water resources that can be added to the available conventional water resources.

Ongoing increased demand for fresh water is considered a global concern. Across the world, the water demand is higher than the available conventional water resources. Applying water saving practices, improving the water supply systems and increasing the use of recycled water may have a role in relieving this challenge but when the supply/demand gap keeps prevailing, then investment in the desalination technologies could be a strategic option.

Today, desalination is becoming a serious option for the production of drinking, agricultural and industrial water as an alternative to traditional surface water treatment and long distance conveyance. In some countries, desalination has long been confined to situations where no other alternatives were available to produce drinking water (some coastal towns, islands, remote industrial sites, etc.), or where energy is abundantly available (power stations, gas and oil production fields) **(Martin and Rabi, 2009).**

Recent technological advances have made removing salt from seawater and ground (brackish) water a realistic option for increasing water supplies in many areas around the world, and desalination is gradually having a role in the water management portfolio. However, the potential of desalination is constrained by financial, social, and environmental factors. Substantial uncertainties remain about its environmental impacts and financial viability, which have led to delays in its application. A coordinated, strategic research effort with steady funding is needed to better understand and minimize desalination's environmental impacts—and to find ways to further lower its costs and energy consumption **(The National Academy of Sciences, 2008**).

This section discusses the various seawater/brackish water desalination technologies. These technologies are constantly being improved and enhanced in terms of economical, technological and sustainable perspectives.

3.1.2 Historical Overview

The late decades of the nineteenth century had a dramatic evolution in the application of desalination technologies in different parts of the world particularly; in the regions that suffer from shortfall of precipitation and availability of fresh water resources such as: the Pacific and Caribbean islands, north Africa and the middle east **(AFFA, 2002**).

The application of the desalination technologies was intensively developed after the end of the World War II. Commercial application of thermal/distillation desalination technologies were predominant in the 1960’s – 1970’s. While through the period of 1980’s and 1990’s the development of the membrane desalination technologies was dramatically experienced and introduced to the global market on a commercial scale which were noticeable cheaper and easier in application **(AFFA, 2002**).

This growth of the investment in the desalination technologies is shown in figure (3-1).

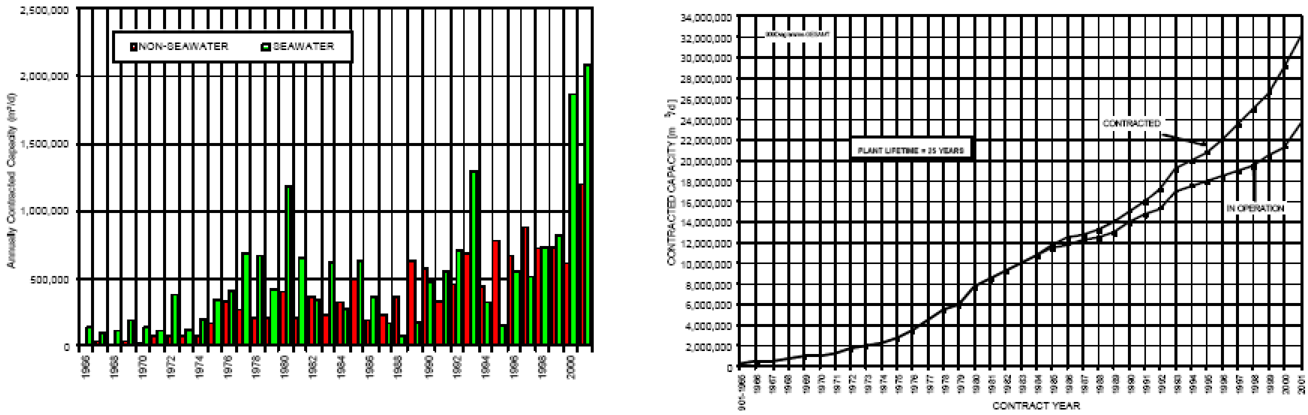


Figure (3-1): Annually contracted desalination capacity (on the left). **Cumulative contracted and operated desalination capacity** (on the right) (DHV Water BV et al., 2004)

As can be seen from the above figure dated in 2004, 20% of the total global desalination capacity is produced using membrane processes and currently this proportion is steadily increasing particularly in the Mediterranean region. Thermal processes dominate the oil-rich gulf countries in the Middle East **(DHV Water BV et al., 2004)**.

Figure (1-1) in chapter one, shows the worldwide desalination capacity by country which shows a substantial increment in the desalinated water quantities over time due to the technological advancement and reduced costs **(The National Academy of Sciences, 2008).**

3.1.3 Types of Desalination Technologies

There are a wide range of technologies that have been developed to effectively desalinate salty water producing water with low concentration of salt (fresh water) and another product with high concentration of remaining salts (the brine or concentrate). Mainly, these technologies depend on two major processes to separate salt from the product water; distillation and filtration via membranes. Ultimately, the selection of a desalination process depends on site-specific conditions, including the salt content of the feed water, economics, the quality of water needed by the end user, and local engineering experience and skills **(Cooly et al., 2006).**

Desalination is the process of removing salts from brackish/seawater to provide purified water for industry, irrigation and drinking **(HWE, 2009)**. According to the principles of the processes used in the desalination technique, the desalination technologies can be classified into three main categories: **(AFFA, 2002**):

- Thermal/distillation processes
- Membrane processes
- Chemical processes

Desalination technologies that are based on thermal and membrane processes are the dominating technologies used for desalinating brackish and seawater on the commercial scale. Chemical based desalination technologies are used on the smaller scale to end up producing very high quality water primarily for industrial purposes. **(AFFA, 2002**).

The following sections investigate the desalination processes that are based on the two main processes; membrane and thermal processes.

3.1.3.1 Membrane and Filtration Processes

The main desalination technologies fall under this category are: Reverse Osmosis (RO) which is a pressure driven technique and Electrodialysis (ED) which is a voltage driven technique. The ability of the membranes and filters to permit or prohibit the movement of certain ions is the basic concept behind designing these technologies. These membrane technologies are considerably efficient in desalinating brackish water. But they have been constantly utilized for desalinating seawater due to the ongoing enhancement and improvement of the technology's reliability and economics. **(Cooly et al., 2006)**

Figure (3-2) shows the two main membrane and filtration processes used in desalination **(AFFA, 2002**).

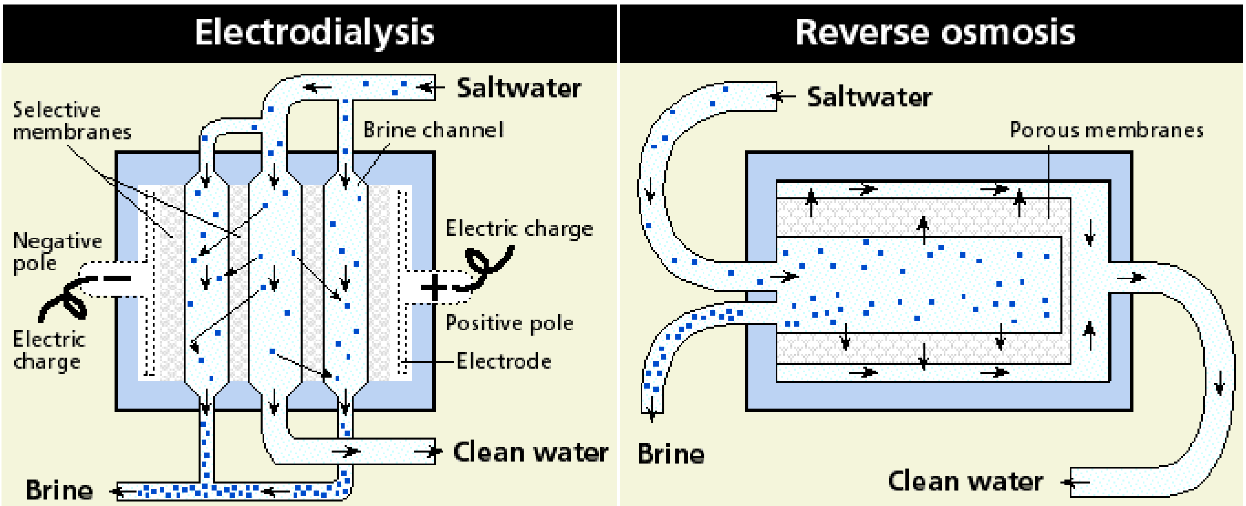


Figure (3-2): Basic illustration of membrane processes (AFFA, 2002)

Electrodialysis (ED)

"Electrodialysis is an electrochemical separation process that uses electrical currents to move salt ions selectively through a membrane, leaving fresh water behind" **(AFFA, 2002**). Electrodialysis involves the removal of salts by separating and collecting their chemical components through electrolysis and is more suited to salty groundwater than seawater **(Gold Coast Water, 2006).** ED has relatively high recovery ratios and they are primarily used on smaller scale capacity in desalinating water for industrial purposes. **(Cooly et al., 2006).**

“ED works on the principle that salts dissolved in water are naturally ionized and membranes can be constructed to selectively permit the passage of ions as they move toward electrodes with an opposite electric charge. Brackish water is pumped at low pressure between stacks of flat, parallel, ion-permeable membranes that form channels. These channels are arranged with anion selective membranes alternating with cation-selective membranes such that each channel has as an anion-selective membrane on one side and a cation-selective membrane on the other (Figure 3-3). Water flows along the face of these alternating pairs of membranes in separate channels and an electric current flows across these channels, charging the electrodes. The anions in the feed water are attracted and diverted towards the positive electrode. These anions pass through the anion-selective membrane, but cannot pass through the cation-selective membrane and are trapped in the concentrate channel. Cations move in the opposite direction through the cation selective membrane to the concentrate channel on the other side where they are trapped. This process creates alternating channels, a concentrated channel for the brine and a diluted channel for the product water” **(Cooly et al., 2006).**

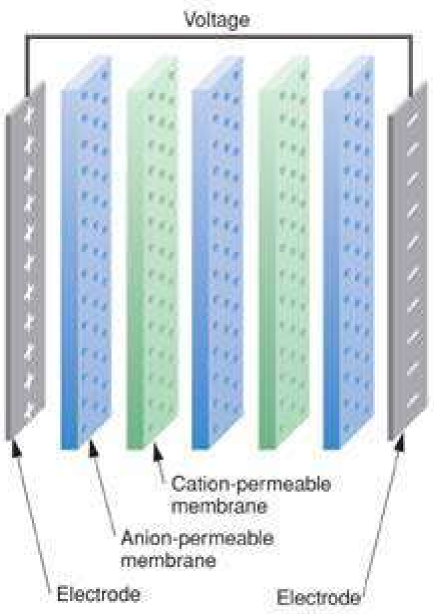


Figure (3-3): Schematic of an Electrodialysis Stack (Cooly et al., 2006)

“ED membranes are arranged in a series of cell-pairs, which consist of a cell containing brine and a cell containing product water. A basic ED unit or “membrane stack” consists of several hundred cell-pairs bound together with electrodes on the outside. Feed water passes simultaneously in parallel paths through all of the cells to produce continuous flows of fresh water and brine” **(AFFA, 2002**).

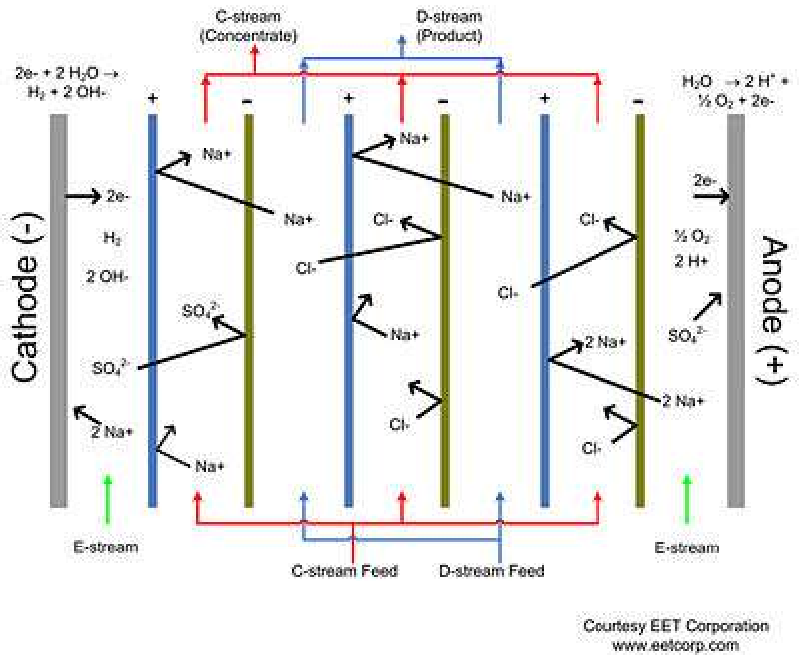


Figure (3-4): Stack of Electrodyalisis Cells (AFFA, 2002)

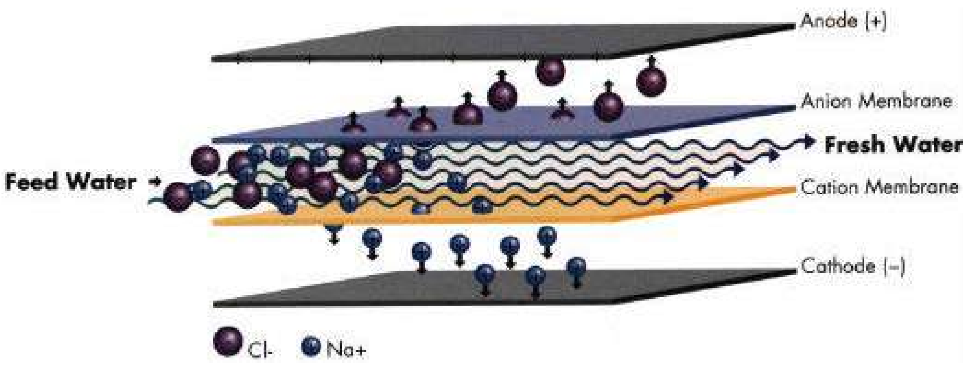


Figure (3-5): Electrodialysis Cell (DHV Water BV et al., 2004)

Table (3-1): Advantages and disadvantages of Electrodialysis technology (AFFA, 2002)

Advantages	Disadvantages
• High recovery ratio (85-94% for one stage) • Can treat feedwater with a higher level of suspended solids • Pre-treatment has a low chemical usage • Relatively high membrane life expectancy (7-10) years • Non-susceptible bacterial attack or silica scaling. • Manual cleaning of membranes • Low to moderate operating pressure and energy is proportional to salts removal	• Periodic cleaning of the membranes with chemicals • Leaks sometimes occur in the membrane stacks. • Bacteria, non-ionic substances and residual turbidity can remain in product water • Post treatment may be needed • Primarily used for small scale applications

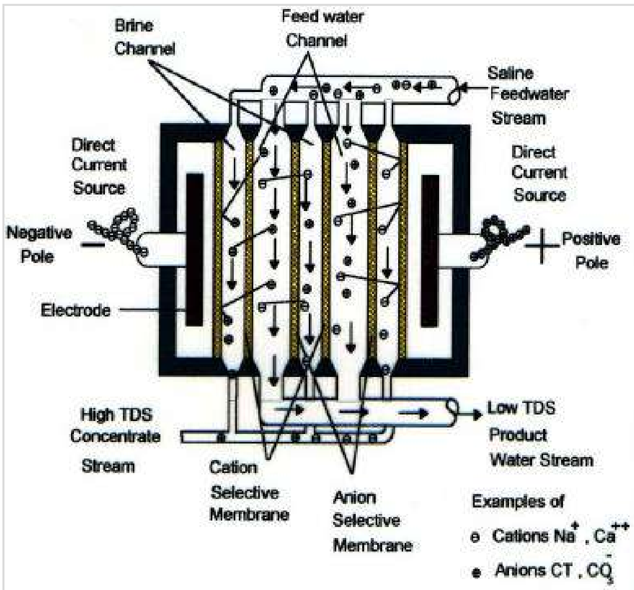


Figure (3-6): Electrodialysis Membrane (DHV Water BV et al., 2004)

Reverse Osmosis

Reverse osmosis uses pressure on solutions with concentrations of salt to force fresh water to move through a semi-permeable membrane (microscopic strainer), leaving the salts behind. The amount of desalinated water that can be obtained ranges between 30% and 85% of the volume of the input water, depending on the initial water quality, the quality of the product, and the technology and membranes involved. **(Cooly et al., 2006)** This filtering process removes 95% to 99% of dissolved salts and inorganic material. Reverse osmosis is the finest level of filtration available and supplies water that is clean, safe, healthy and pleasant to drink **(Gold Coast Water, 2006).**

An RO system is made up of the following basic components: pretreatment, high-pressure pump, membrane assembly, and post-treatment. Pretreatment of feed water is often necessary to remove contaminants and prevent fouling or microbial growth on the membranes, which reduces passage of feed water. Pretreatment typically consists of filtration and either the addition of chemicals to inhibit precipitation or efficient filtering to remove solids. A high-pressure pump generates the pressure needed to enable the water to pass through the membrane **(Cooly et al., 2006).**

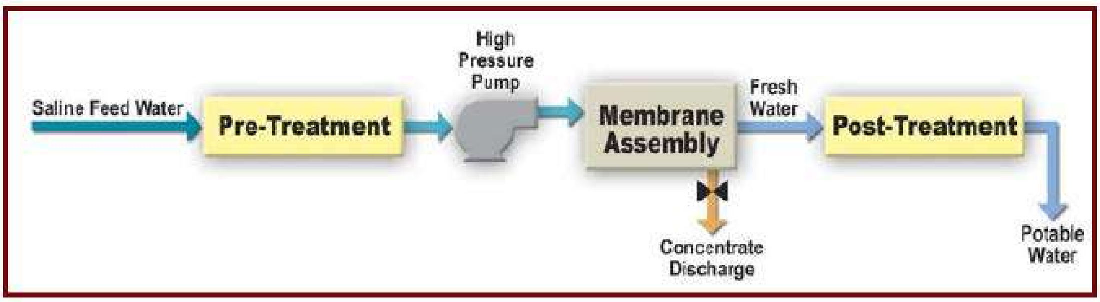


Figure (3-7): RO Desalination Plant flow chart (Banat, 2007)

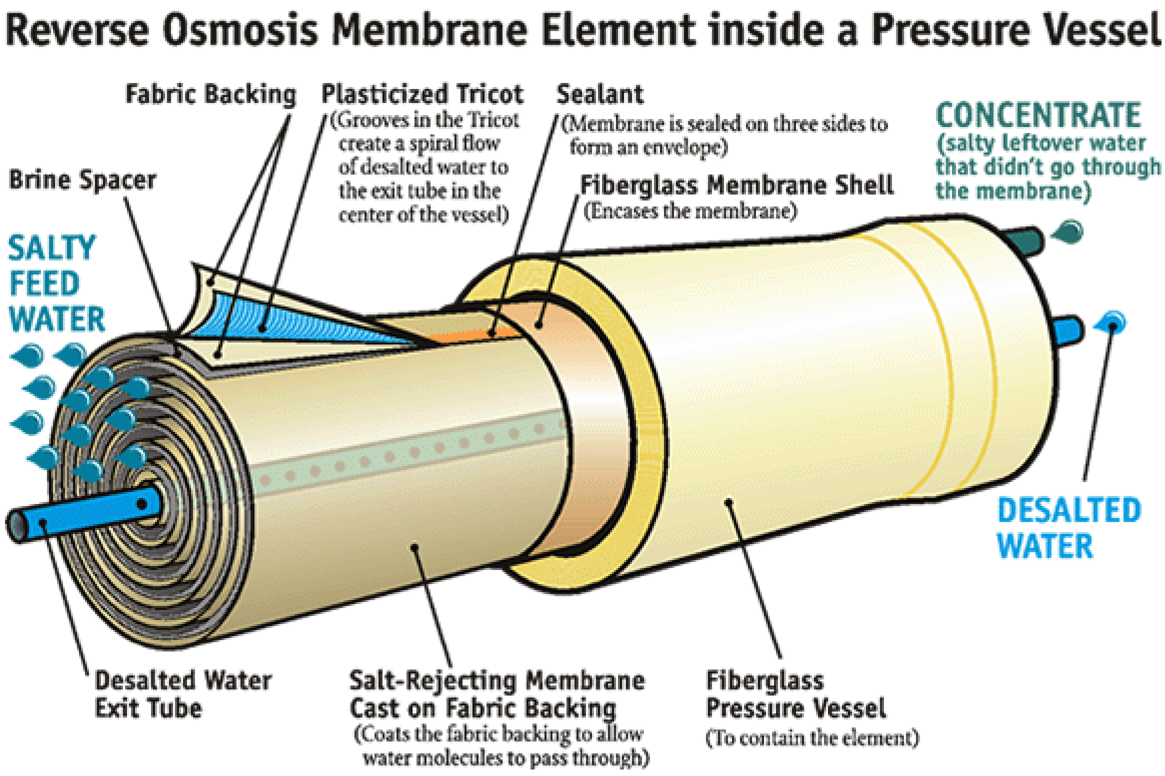


Figure (3-8): Schematic of a Reverse-Osmosis Desalination Membrane (Cooly et al., 2006)

Membranes may differ in their filtration capacity and they are mainly manufactured in two configurations; the spiral wound and hollow-fine fiber. The membrane assembly consists of a pressure vessel and a membrane that permits the feed water to be pressurized against the semi-permeable membranes. Post-treatment adjusts the pH, removes gases and makes the product water ready for distribution **(Cooly et al., 2006).**

The concentration of salts in the feed water is the main determining factor of the required energy for RO Consequently; *RO technology is economically most efficient when desalinating brackish water***(Cooly et al., 2006).**

Investment in RO technology has been growing and advances in technology have seen reverse osmosis become the most popular desalination process used in most parts of the world. Improvements in efficiency have led to reduced energy consumption, cheaper processing costs and a superior product being produced **(Gold Coast Water, 2006).** Some of the largest new desalination plants under construction and in operation use RO membranes, including Ashkelon in Israel and the new plant at Tuas in Singapore **(Cooly et al., 2006).**

Improvements in the RO technologies are continuously investigated and can be mainly: better pretreatment of feedwater, enhanced membranes recovery ratios and biofouling resistance, energy efficiency; cost of membranes materials **(Cooly et al., 2006).**

Increases in the reliability of reverse osmosis also come from the increased life span of the membrane. Research indicates that the cost of producing water from a reverse osmosis plant is often less than half that produced by the distillation method of processing water. Key parameters for selecting reverse osmosis over other processing methods include **(Gold Coast Water, 2006):**

- Quality and salinity of the water intake
- Temperature of water intake
- Efficiency of membranes has improved significantly
- Energy consumption has reduced and is less than other processing methods
- Lower capital and operating costs
- Most major desalination plants now use reverse osmosis

Table (3-2): Advantages and Disadvantages of Reverse Osmosis technology (AFFA, 2002)

Advantages	Disadvantages
• Quick and cheap to build • Simplicity in operation • It can handle a large range of flow rates • Easy expandability and increasing the system capacity • High space/production capacity ratio, ranging from 25,000 to 60,000 L/day/m^2. • Energy consumption is low. • Contaminants removal • Low usage of cleaning chemicals • Simplicity in maintenance	• RO membranes are relatively expensive and have a life expectancy of 2-5 years. • It is necessary to maintain an extensive spare parts inventory. • There is a possibility of bacterial contamination. • Pre-treatment of the feedwater is required. • The plant operates at high pressures

3.1.3.2 Thermal Processes

Thermal desalination processes approximately contributes in total of 40% of the global desalination capacity. The distillation process mimics the natural water cycle by producing water vapor that is then condensed into fresh water. In the simplest approach, water is heated to the boiling point to produce the maximum amount of water vapor **(Cooly et al., 2006).** Briefly, Thermal technologies involve boiling saline water and collecting the purified vapor to produce freshwater after condensation **(Gold Coast Water, 2006).**

The water boiling degree is directly related to the prevailing pressure, to benefit from this principle, “multiple boiling” systems have been developed to save energy **(Cooly et al., 2006).**

Distillation systems are often affected by scaling, which occurs when substances like carbonates and sulfates1 found in seawater and brackish water precipitate out of solution and cause thermal and mechanical problems. Scale is difficult to remove and reduces the effectiveness of desalination operations by restricting flows, reducing heat transfer, and coating membrane surfaces. Ultimately scaling increases costs. Keeping the temperature and boiling point low slows the formation of scale **(Cooly et al., 2006).**

Multi-Stage Flash Distillation

Multi-stage flash distillation (MSF) is the technology used for the largest installed thermal distillation capacity. MSF can produce high-quality product water from high salty feedwater. MSF used to be the primary technology used for desalinating seawater particularly in countries where the energy cost is not a constraint **(Cooly et al., 2006).**

"In MSF distillation, water is heated in a series of stages. Typical MSF systems consist of many evaporation chambers, each with successively lower pressures and temperatures that cause flash evaporation of hot brine, followed by condensation on cooling tubes. The steam generated by flashing is condensed in heat exchangers that are cooled by the incoming feed water. This warms up the feed water, reducing the total amount of thermal energy needed" **(Cooly et al., 2006).**

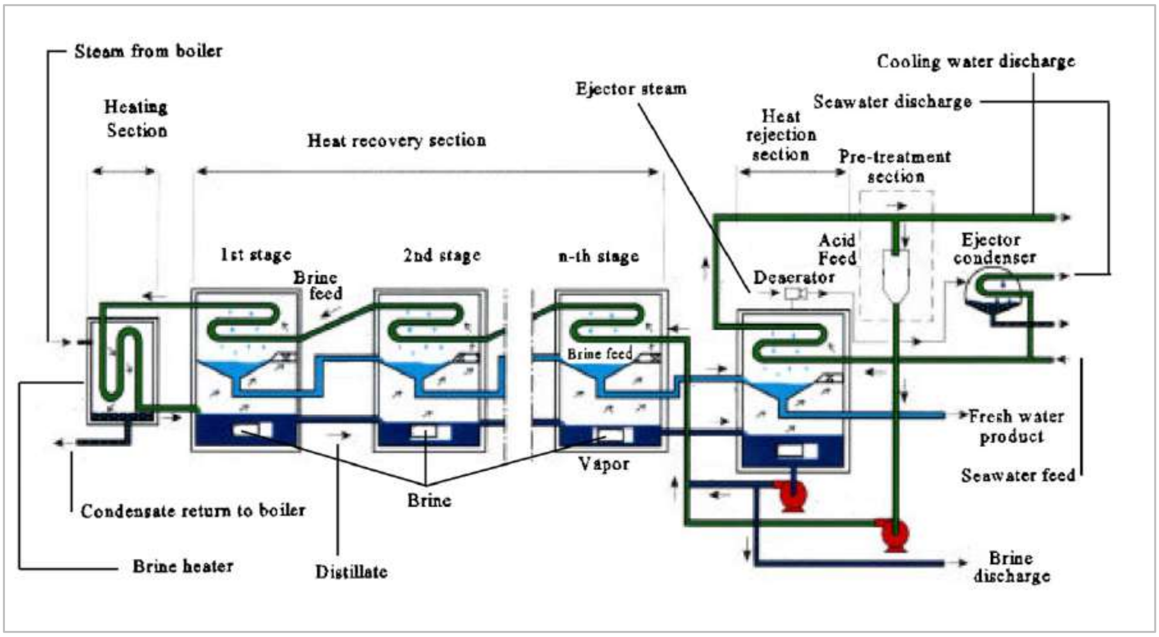


Figure (3-9): Multi-Stage Flash Process (DHV Water BV et al., 2004)

"Generally, only a small percentage of feed water is converted to water vapor, depending on the pressure maintained in each stage. MSF plants may contain between 4 and 40 stages, but most typically are in the range of 18 to 25. Multi-stage flash plants are typically built in sizes from (10,000 m^3/d) to over (35,000 m^3/d), with several units grouped together. As of early 2005, the largest MSF plant in operation was in Shuweihat in the United Arab Emirates. This plant desalinates seawater for municipal purposes with a total capacity of 120 MGD (455,000 m^3/d)" **(Cooly et al., 2006).**

Table (3-3): Advantages and disadvantages of Multi-Stage Flash desalination technology

(AFFA, 2002)

Advantages	Disadvantages
• Large handling capacities • The salinity of the feedwater is not a cost concern • Very high quality product water (less than 10 mg/L TDS) • Minimal pre-treatment requirement • Long history of commercial use and reliability • It can be combined with other processes	• Expensive to build and operate • High level of technical knowledge is required • Highly energy intensive • The recovery ratio is low • The plant cannot be operated below 70-80% of the design capacity • Blending is often required when there is less than 50mg/l TDS in the product water

Multiple-Effect Distillation

Over the past century, Multiple-Effect Distillation (MED) which is a thermal desalination technology has been used successfully. "MED takes place in a series of vessels or "effects" and reduces the ambient pressure in subsequent effects. There are 8 to 16 effects in a typical large plant. This approach reuses the heat of vaporization by placing evaporators and condensers in series. Vapor produced by evaporation can be condensed in a way that uses the heat of vaporization to heat salt water at a lower temperature and pressure in each succeeding chamber, permitting water to undergo multiple boiling without supplying additional heat after the first effect. In MED plants, the salt water enters the first effect and is heated to the boiling point. Salt water may be sprayed onto heated evaporator tubes or may flow over vertical surfaces in a thin film to promote rapid boiling and evaporation" **(Cooly et al., 2006).**

"Only a portion of the salt water applied to the tubes in the first effect evaporates. The rest moves to the second effect, where it is applied to another tube bundle heated by the steam created in the first effect. This steam condenses to fresh water, while giving up heat to evaporate a portion of the remaining salt water in the next effect. The condensate from the tubes is recycled" **(Cooly et al., 2006).**

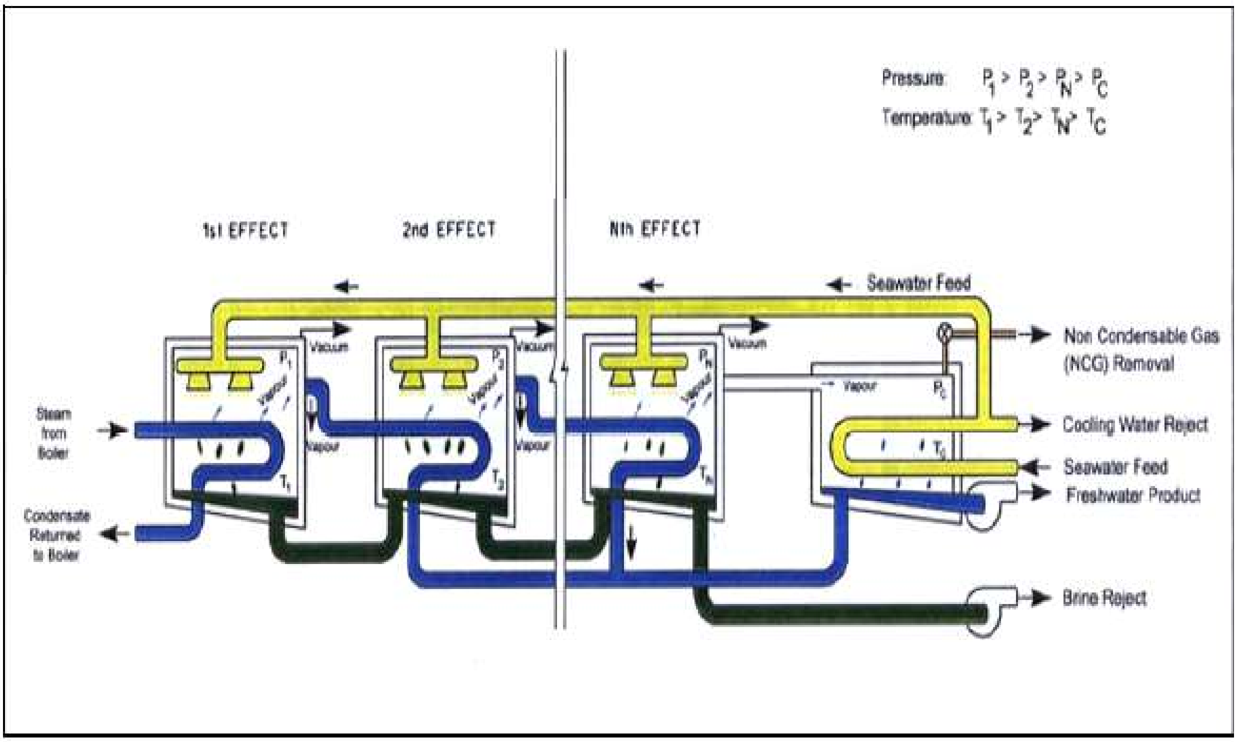


Figure (3-10): Basic illustration of the MED process (AFFA, 2002)

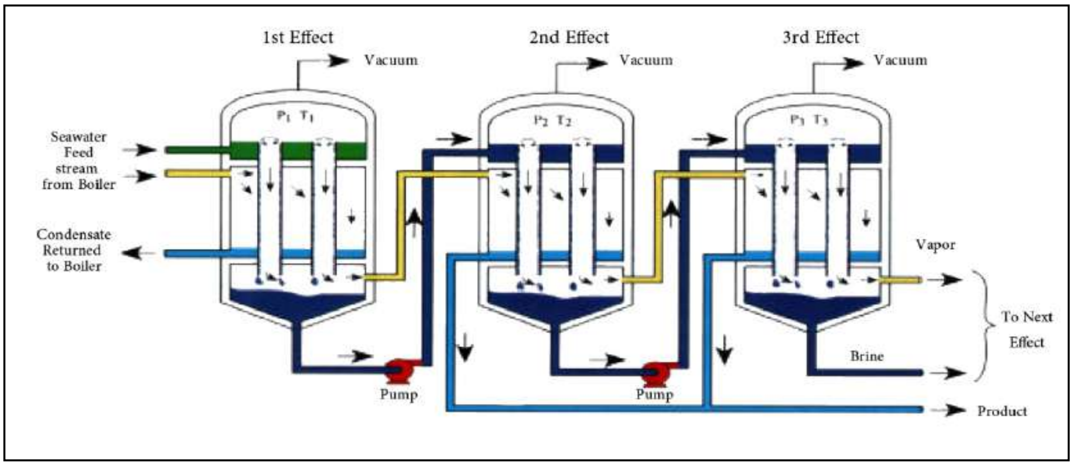


Figure (3-11): MED Evaporator Three Effects (DHV Water BV et al., 2004)

Table (3-4): Advantages and disadvantages of Multi-Effect Distillation desalination technology (AFFA, 2002)

Advantages	Disadvantages
• Minimal feedwater pre-treatment requirements • Product water is of a high quality. • Very reliable plants • The plant can be combined with other processes • The plant can handle normal levels of biological or suspended matter. • Minimal operating staff requirements	• Expensive to build and operate • Energy consumption is particularly high. • The plant can be susceptible to corrosion • Cooling of product water is required • Low recovery ratio

Vapor Compression Distillation

"Vapor compression (VC) distillation has typically been used for small and medium-scale desalting units. These units also take advantage of the principle of reducing the boiling point temperature by reducing ambient pressure, but the heat for evaporating the water comes from the compression of vapor rather than the direct exchange of heat from steam produced in a boiler. The two primary methods used to condense vapor to produce enough heat to evaporate incoming seawater are mechanical compression or a steam jet. The mechanical compressor can be electrically driven, making this process the only one to produce water by distillation solely with electricity". VC plants are constructed for small scale capacity such as: small industries, resorts, remote sites and built in the range of (250 to 2,000 m^3/d) **(Cooly et al., 2006).**

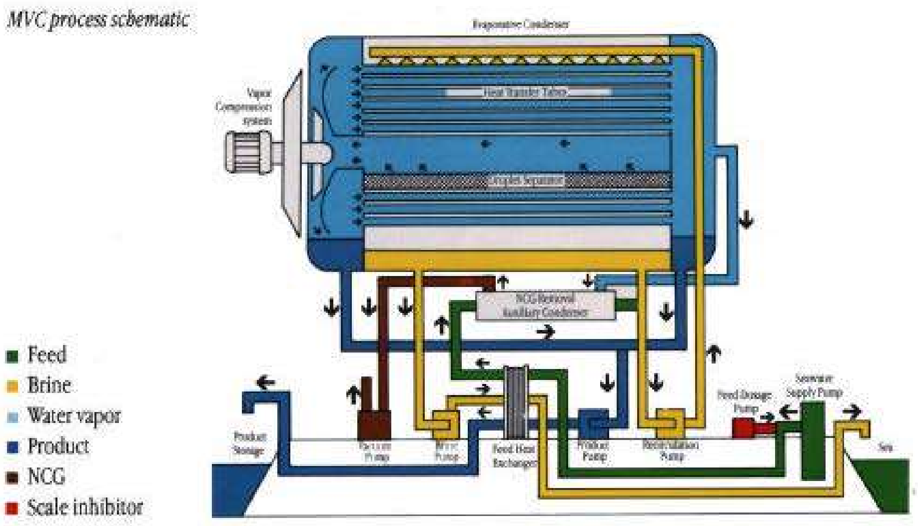


Figure (3-12): Mechanical Vapor Compression schematic (DHV Water BV et al., 2004)

Table (3-5): Advantages and disadvantages of Vapor Compression desalination technology

(AFFA, 2002)

Advantages	Disadvantages
• Very compact and portable plants • Minimal pre-treatment requirements • Reasonable plant capital cost • Simple and reliable operation • The recovery ratio is good. • High quality product water • Relatively low energy requirements	• Starting up the plant is difficult. • Smaller scale capacity • It requires large, expensive steam compressors • Not readily available spares

“VC units use a compressor to create a vacuum, compress the vapor taken from the vessel, and condense it inside a tube bundle that is also in the same vessel, producing a stream of fresh water. As the vapor condenses, it produces fresh water and releases heat to warm the tube bundle. Salt water is then sprayed on the outside of the heated tube bundle where it boils and partially evaporates, producing more fresh water. Steam jet-type VC units, also called thermo-compressors, create lower ambient pressure in the main vessel. This mixture is condensed on the tube walls to provide the thermal energy (through the heat of condensation) to evaporate salt water on the other side of the tube walls” **(Cooly et al., 2006).**

3.1.3.3 Other Desalination Processes

There are a number of other technologies used on the smaller scale to desalinate the brackish and saline water including but not limited to: ion-exchange resins, freezing, and membrane distillation. These processes may be more feasible than the other commercial processes under special site and utilization circumstances **(Cooly et al., 2006).**

3.2 Cost of Desalination

3.2.1 Background

Over the history of application of desalination technologies, the perception of the high costs associated with the establishment and operating desalination schemes limited and even prevented the utilization of desalination technologies as an alternative in providing new water resource in different areas around the world. Nowadays, the perception towards the desalination technologies as a costly alternative has been changed due to the improvement and enhanced energy-efficient processes. This has led more and more governments to invest in desalination technologies as an attractive option to alleviate the water supply/demand gap amongst their communities. **(The National Academy of Sciences, 2008)**.

However, the costs of desalination, like the costs of water supply alternatives, are locally variable and are influenced by several factors **(The National Academy of Sciences, 2008)**. These costs vary according to the desalination technology, the size of the plant and the cost of the energy input to the plant **(ACE, 2008)**. Moreover, the salinity of the feed water might be an influencing factor of the costs of desalination **(Craig, 2010).** So far, the present trends have shown that the oil-rich states particularly in the Gulf region kept in investing in thermal/distillation technologies like MED and MSF technologies. **(DHV Water BV et al., 2004)**. This continued trend in investment in thermal processes is due to high salinity and organic constitutes of seawater in the Arabian Gulf and the large plant capacities needed to be met in such poor availability of fresh water resources in these countries. Moreover, and above all, the low costs associated with energy input due to being one of the oil richest areas around the world **(Craig, 2010).** Reverse osmosis (RO) technologies prevail where higher energy costs are present due to the lack of the available local energy sources **(DHV Water BV et al., 2004)**.

3.2.2 Cost of Desalination

The capital and operating costs of desalination plants have decreased significantly in real terms, over the last decades. This is due to several factors, such as process design and manufacturing improvements, increased competition and privatization **(DHV Water BV et al., 2004)**. Historical data show that production cost of desalinated water using thermal processes has dropped from US$9.0/m^3 to US$0.7/m^3. While the costs associated with reverse osmosis processes has dropped from US$1.55/m^3 to US$0.53/m^3 **(Craig, 2010).**

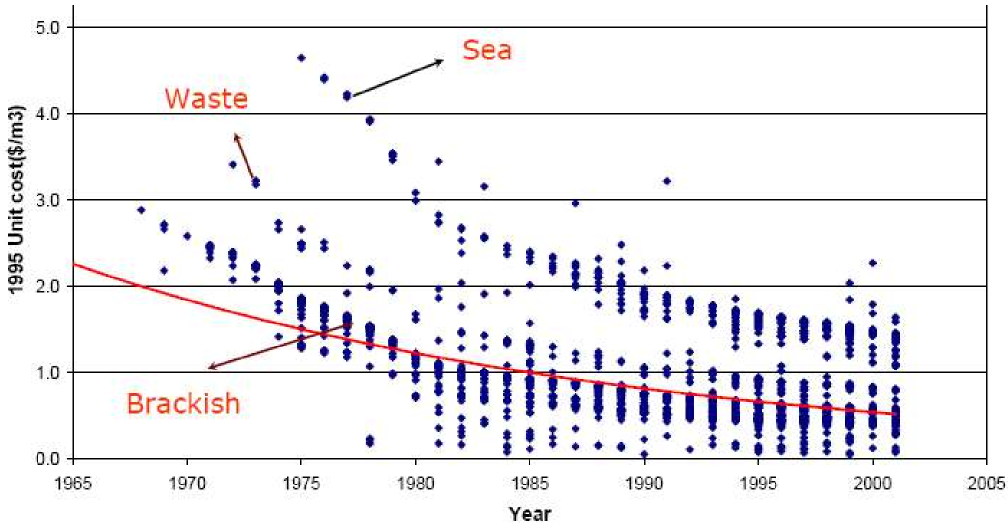


Figure (3-13): Cost Analysis of RO Desalination Plants over Years (Banat, 2007)

3.2.2.1 Capital and Operating Costs

The cost of a desalination plant comprises of both capital and operational costs. The capital costs of a desalination plant include direct and indirect costs that fall into the following categories **(Banat, 2007)**:

- Direct costs that include but not limited to: land costs, construction costs, equipment purchase and installation and the pre-treatment costs of feedwater.

- Indirect costs that include but not limited to: project management and overhead costs, interest rates, insurances and contingency costs.

After the establishment of the desalination project and the plant is set into operation, the project is still subjected to post-construction costs that comprise primarily of annual operational and maintenance costs include **(Banat, 2007)**:

- Labor
- Energy
- Chemicals
- Consumables
- Spares

Significant drop in the costs associated with the development of desalination schemes has been experienced in the past decades. Several factors have led to this global achievement which decreased both the capital and running costs of desalination projects. Advances in the processes design efficiency, enhancement in the membranes production and reliability, in addition to the involvement of the private sector and increased market competition have all played a significant role in lowering the capital and operating costs of desalination schemes **(DHV Water BV et al., 2004)**.

Table (3-6): **Summary of estimation of product water cost components for a large capacity (200,000 m^3/d) RO seawater RO plant** (Wilf, 2004)

Product water cost component	$/m^3
Capital cost, including land fee(25years@6.0%interest)	0.203–0.338
Electric power($0.060/kWhr)	0.180–0.240
RO membrane replacement (5yearsmembranelife)	0.025–0.035
MF membrane replacement (7yearsmembranelife)	0.000–0.030
Chemicals	0.020–0.025
Maintenance and spare parts	0.023–0.038
Labor	0.030
Total cost	0.481–0.706

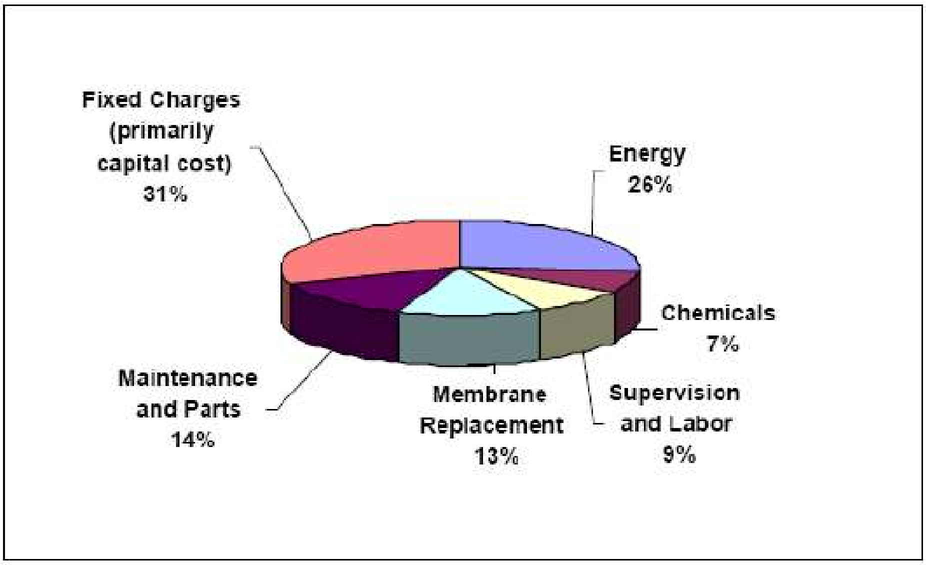


Figure (3-14): Cost composition for a typical RO Desalination plant (Banat, 2007)

Reverse Osmosis (RO) desalination technology became more popular during the last decades as operating costs has been reduced significantly due to having lower membrane cost, higher flux capacity, higher salt-rejecting membranes, lower operational pressures and the installation of pressure recovery devices. Costs of desalinating by RO vary with: raw water quality, location and capacity. To date the average cost of desalted water using MSF has been reduced to about 0.9 $\$/m^3$ for seawater and RO to 0.5 $\$/m^3$ for brackish water. This became to be competitive for traditional water resources **(Banat, 2007)**.

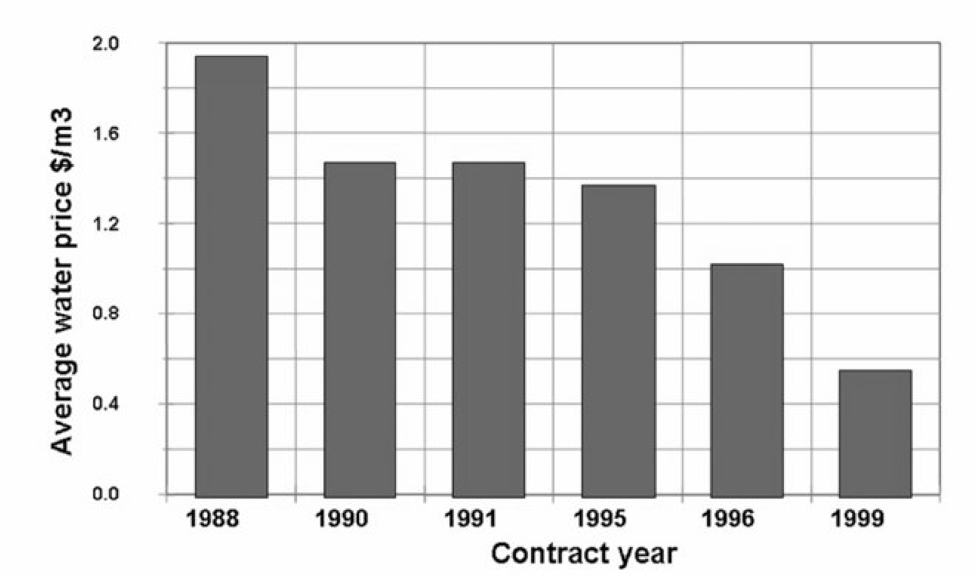


Figure (3-15): Sea water RO systems-water sell prices, Capacity10,000-100,000 m^3/day (Wilf, 2004)

Table (3-7): Desalination Economics (Banat, 2007)

	MSF	MED	VC	RO
Specific Investment Cost [$/m³/day]	1,200 – 1,500	900 – 1,000	950 – 1,000	700 - 900
Total Cost Product [$/m³]	1.10 – 1.25	0.75 – 0.85	0.87 – 0.95	0.68 – 0.82

Hypothesis:	Plant Capacity	30,000 m³/day
	Interest Rate	7 %
	Project Life	20 years
	Price Electricity	0.065 $/kWh

Table (3-8): Water Cost in Recently Built RO Seawater Plants (Wilf, 2004)

Location	Permeate capacity,	Status	Water price,
Eilat Israel	20,000	10,000m^3/day commenced Operation in June1997	0.72
Larnaca, Cyprus	56,000	Commenced operation in	0.83
Tampa, Fl	106,000	Commenced operation in	0.56
Ashkelon, Israel	272,000	Under construction, to be	0.54

3.2.3 Energy

In any desalination technology applied, certain energy requirements need to be met. Over the past century, the desalination costs have been decreased dramatically. The availability of energy resources would be a playing factor in determining the desalination technology to be used. Non-oil rich countries such as the Mediterranean countries keep to invest in the reverse osmosis technology. Meanwhile, the oil rich countries such as the Gulf states are still biased to the desalination technologies based on thermal processes **(DHV Water BV et al., 2004)**.

Renewable energy might be an option in coupling energy sources for running desalination plants particularly for small scale plants in remote areas with no available power grid. Moreover, the awareness of the impacts generated from the consumption of fossil fuels on the climate and environment in general is driving the efforts to encourage the application of renewable energy sources.**(DHV Water BV et al., 2004)**.

3.2.4 Desalination Process Comparison and Choice

The selection of the appropriate and most efficient desalination technology is a decision that depends on a number of factors including but not limited to: **(DHV Water BV et al., 2004)**

- The quality of feedwater, see figure (3-16)
- Co-generation possibility of power and water
- Availability of local energy resources
- Plant size and aimed capacities

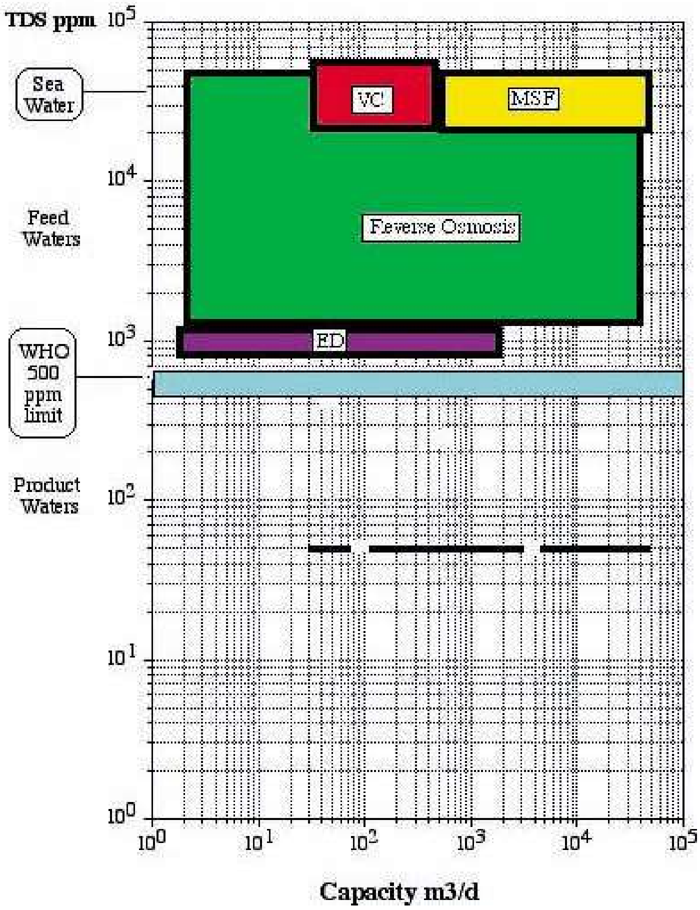


Figure (3-16): Desalination technologies applicability with regard to the feed water quality (DHV Water BV et al., 2004)

3.3 Neighboring Regional Desalination Experiences

3.3.1 Israeli Experience

3.3.1.1 Overview of Israeli Desalination Practices

Israel has developed a program called the Sea Water Reverse Osmosis (SWRO) desalination program with an initial target of 400 MCM in 2002 and aiming to reach 750 MCM by the year 2020. This program will to encourage the investment and to allow for establishing new water sources to meet the ongoing increasing demands **(Tenne, 2010).**

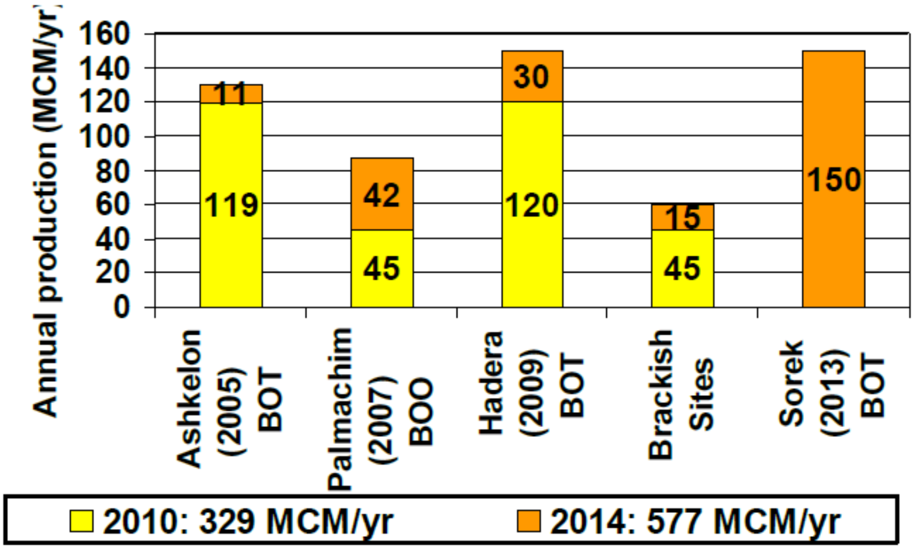


Figure (3-17): The annual Israeli production of major desalination plants (Tenne, 2010)

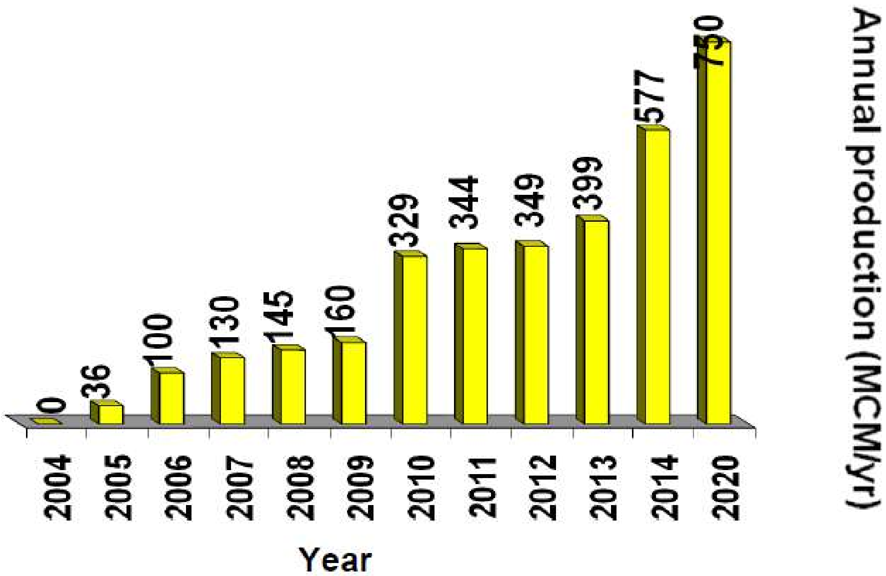


Figure (3-18): The overall annual Israeli production of desalinated water (Tenne, 2010)

3.3.1.2 Desalination of Brackish Water

“In Israel several smaller desalination facilities desalinate brackish water from groundwater wells, rather than sea water (Figure 3-19). Such facilities exist in Eilat, the Arava, and the southern coastal plain of the Carmel. Total production of desalinated water from brackish sources is currently 30 MCM/year, and planned production is expected to reach 60 MCM/year, and 80-90 MCM/year by the years 2013 and 2020, respectively” **(Tenne, 2010).**

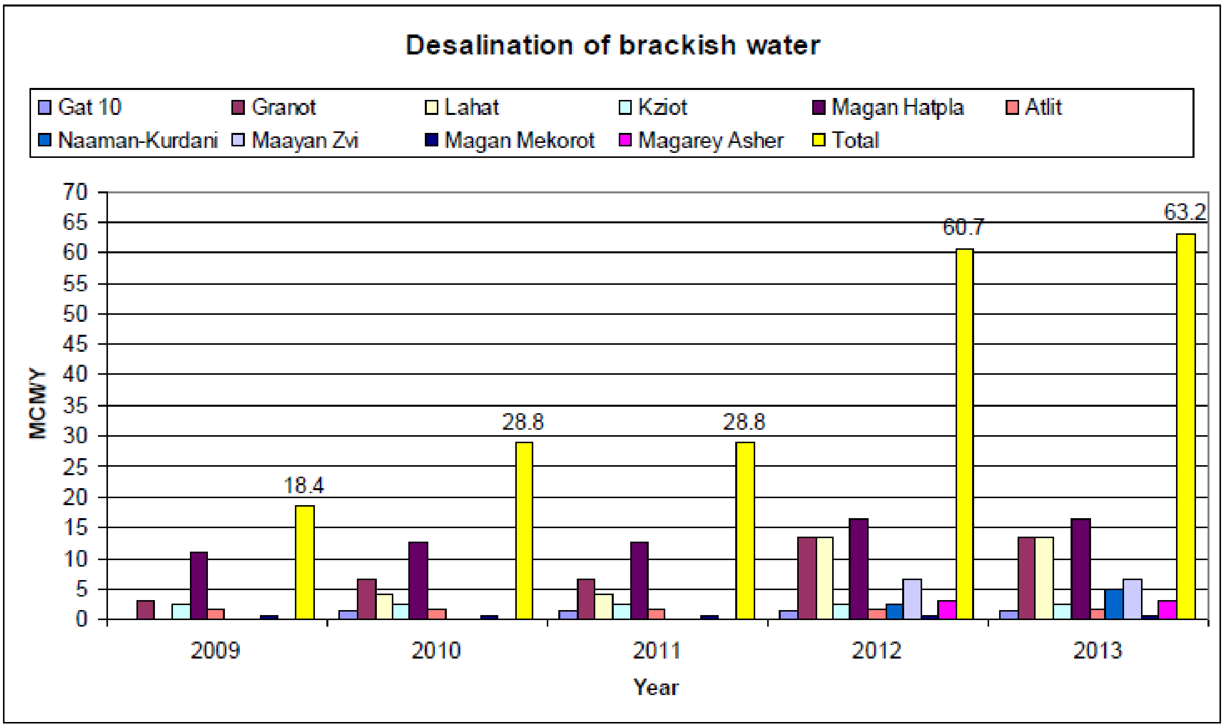


Figure (3-19): The Israeli Brackish Water Desalination Program (Tenne, 2010)

Figure (3-20) shows that Israel’s large desalination facilities has one of the lowest prices worldwide due to the local technological advances and supporting governmental policies **(Tenne, 2010).**

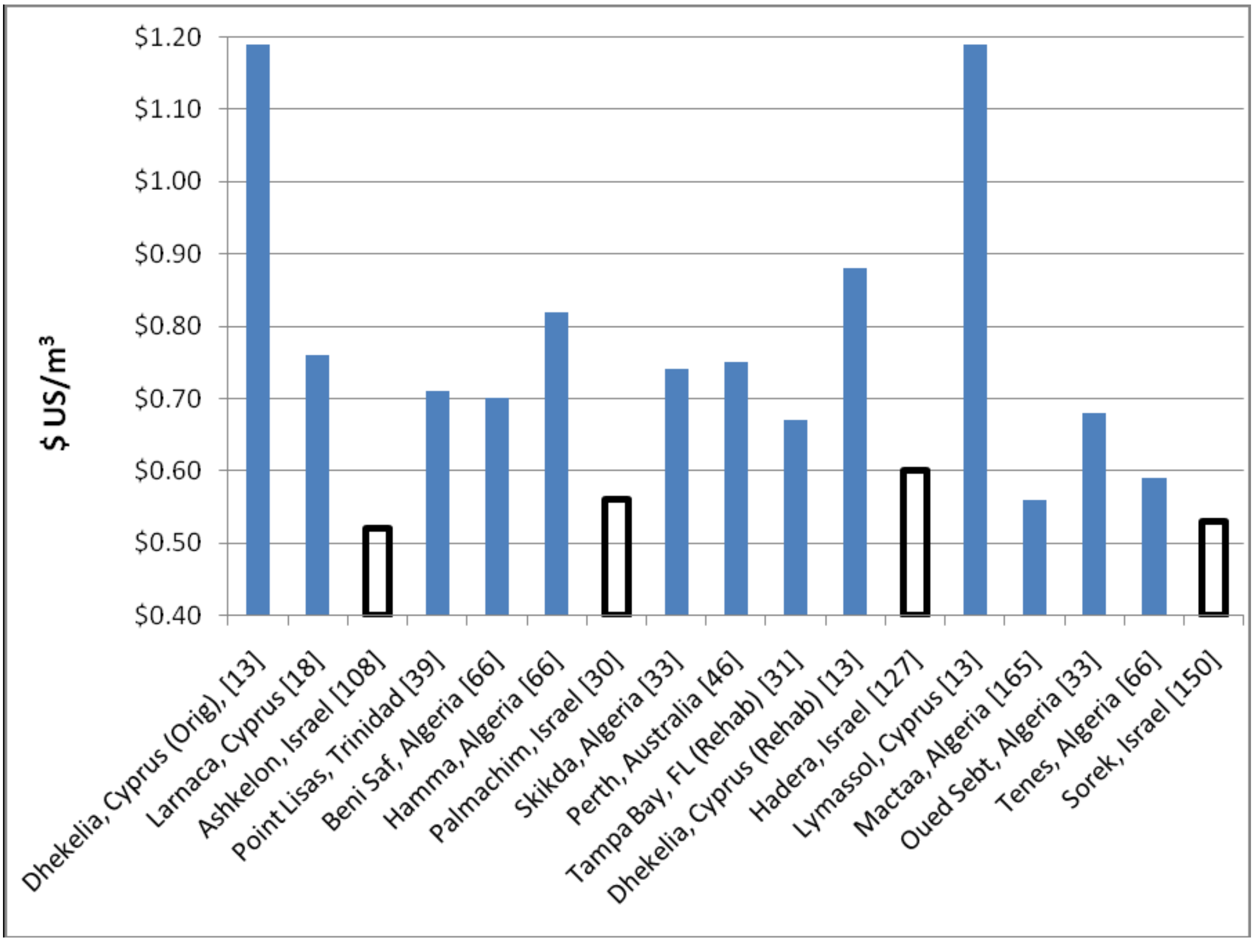


Figure (3-20): Cost of desalinated water in a number of desalination plants worldwide in comparison to the major Israeli plants (Tenne, 2010)

[Annual production volumes are indicated within square-brackets on the x-axis, in millions of cubic meters]

For future implementation, some Israeli local companies proposed the prices of US$ 0.65–0.70/$m^3$to desalinate seawater **(Mohsen, 2007).**

3.3.1.3 Ashkelon Seawater Desalination Project

"The Ashkelon seawater desalination project is a Build, Operate and Transfer (BOT) Project which consists of the financing, design, construction, operation and transfer of a sea-water desalination plant with guaranteed production capacity of up to 100 MCM/year. This plant is located at the Ashkelon site of the Eilat-Ashkelon Pipeline Corporation, 30 km south of Tel-Aviv" (**Velter, 2004**).

The Project will use the Membrane Reverse Osmosis (RO) technology. Several factors contribute to the low water price offered by the Consortium (0.527 $\$/m^3$) **(Kronenberg, 2004)**:

1. Contractual Structure with proper risks allocation
2. Adaptation of SWRO technology for large-scale plants (pressure centers concept)
3. Advance Energy Recovery System (low energy consumption)
4. Self-Generating Energy Supply System (low electricity cost)

The Ashkelon desalination plant's projected benefits are **(Dreizin, 2004):**

1. Improvements in municipal water supply quality
2. Savings in pumping energy required to deliver water from the north
3. Increased water supply reliability

Site Description

"The desalination plant is located at the Ashkelon Industrial zone, 700 meters north of an existing IEC (Israel Electrical Company) power station, within the EAP (Eilat-Ashkelon Pipeline Corp.) facility. The feed water to the plant is pumped from the Mediterranean Sea. The pumping station is located on the sea shore, 200 meters from the Site. The water quality is typical Mediterranean Sea water. The desalinated water delivery point is at the site battery limit. The brine (concentrated feed water) will be discharged back to the sea diluted with the coolant outfall of the adjacent IEC Power Plant. The electrical power for the plant will be provided from two independent sources: overhead line from the national grid and self-generating energy supply system (IPP) installed at the site" **(Kronenberg, 2004)**.

Technology and Design Process

The basic concept for the construction of 100 million m^3/year plant is to have two plants of 50 million m^3/year able to operate separately and independently from each other. Most subsystems will be double (one for each 50 million m^3/year plant), with the exception of the Intake System, the Post-treatment and the Independent Power Plant. Those systems will be unified for the whole 100 million m^3/year plant, but are designed with the required redundancy to serve each plant separately **(Kronenberg, 2004)**.

Energy Supply

The power needed to run the project is provided from two sources: self-generating system and by overhead connection from the Israeli grid **(Kronenberg, 2004)**.

Management of the Project:

The project was implemented following a Build, Operate and Transfer (BOT) contract signed by a consortium of international companies and the Israeli Water Authority. The contract has a period of 24 years.

3.3.2 Jordan

In Jordan, the seawater from the red sea and the brackish water basins are the potential sources of water desalination (**Mohsen and Jayyousi, 1999**). The Jordanian experience in the desalination field is relatively limited as most of the existing plants are of small scale and of industrial or commercial purposes **(Mohsen, 2007).**

The available brackish water in Jordan are groundwater basins near the Dead Sea with yield of 60 MCM/yr. “Other resources are the saline springs east and west of the Jordan Valley with the capacity of about 10 MCM/y. The third source is brackish water distributed all over the country estimated at hundreds of millions m^{3}" **(Mohsen and Gammoh, 2010).**

Due to the lack of the existing energy sources in Jordan, the reverse osmosis technology is considered to be the optimum process for large-scale desalination **(Mohsen and Gammoh, 2010).**

"The WadiMa'in, Zara and Mujib desalination plant was officially inaugurated in November 2007, the water production started in August 2006. Desalination is carried out using the reverse osmosis (RO) techniques. This is a Design-Build-Operate contract. The plant includes desalination of 55 MCM per year of water with a salinity of 1500–2000 mg/l. It shall provide Amman with 38 MCM per year with a TDS of 250 mg/l" **(Mohsen and Gammoh, 2010).**

"Currently, there are few, very small desalination plants which are used for industrial purposes. Technologies used in these plants are RO and ED, i.e., Hussein thermal station (0.97 US$/$m^3$), oil refinery, Electricity Authority, and medical industries" **(Mohsen and Gammoh, 2010).**

"Recently, the Ministry of Water and Irrigation (MWI) has developed two large desalination projects, the RO plant at Abu Zighan and Wadi Ma'in, Zara and Mujib desalination plants. The Abu Zighan plant delivers some 40,000 m^3/d (18 MCM at maximum capacity). The TDS of the feed water for this plant is around 7000 ppm. The Ministry of Water and Irrigation (MWI) and Jordan Water Authority (WAJ) have signed the construction agreement for the Wadi Ma'in, Zara and Mujib desalination plant and conveyance project in September 2003. The desalination is carried using the reverse osmosis (RO) techniques. This is a Design-Build-Operate contract. The plant will be operated for 2 years before being handed over to the Government. The plant includes desalination of 55 MCM per year of water with a salinity of 1500–2000 mg/l. It shall provide Amman with 38 MCM per year with a TDS of 250 mg/l. In this way more drinking water can be supplied to major water consumers" **(Mohsen and Gammoh, 2010).**

"MWI studies estimated the capital cost for a brackish water treatment plant of a 20 MCM/y capacity and inflow TDS not exceeding 5000 ppm to be US$ 35 million; and the annual operating and maintenance costs to be US$ 8 million. So, the production cost of such a plant was estimated to be 0.4 US$/$m^3$ of water produced. In these costs, pretreatment, produced water storage if needed, and brine disposal facilities were not included because they vary from one source to another, the energy required was estimated to be 1.9-3.2 kwh/m^3 of water produced depending on quality of inflow water and the required TDS of outflow" (**Mohsen and Jayyousi, 1999**).

According to **(Mohsen, 2007)**, Jordan does not have high potential to invest in large-scale seawater desalination as the available potential water sources for desalination are not in close proximity to the populated areas. While, implementing small scale desalination projects for industrial, commercial and touristic activities may be a valid option.

3.4 Management of Desalination Projects

The planning, development and investment in desalination projects can have an essential role in bridging the water supply/demand gap. The government's decision to invest in desalination technologies needs strategic and holistic analysis amongst the local water resources management practices. The relatively high costs and the needed specific know-how and management of such non-conventional projects may be real challenges in the application of the desalination projects.

3.4.1 Private Sector Participation (PSP)

Private sector participation in infrastructure projects is usually referred to privatization. Privatization is a general term encompassing a variety of arrangements that allocate to the private sector selected responsibilities for operating, and sometimes ownership of public assets **(Deane, 2002)**. In water sector, privatization involves transferring some or all of the assets or operation of public water systems to private companies **(Cooly et al., 2006).** Political sensitivity is always considered as an issue for implementing private sector participation in the water sector due to the vital value of water as a community owned asset. The trend has been focusing on limiting the private sector's responsibility as operator of the system not owning the assets of the system. **(Deane, 2002).**

3.4.1.1 Rationale for Private Sector Participation in Desalination Projects

In many countries around the world, the water sector is under the direct control of the national government or public entities due to the social and economic attributes of water. Desalination projects are considered non-traditional infrastructural projects that entail high technology, large capital investments and high energy requirements and for such reasons the public institutions tend to lack the ability to operate and maintain such relatively complicated projects. Therefore; public-private partnerships are commonly established to run such projects (**Tsiourtis, 2004**).

Public-private partnerships save the public entities and governments from direct allocation of high amounts of funds to establish such large scheme projects. Meanwhile it allows maintaining proper operation of such complicated facilities (**Tsiourtis, 2004**). Moreover, this introduces higher efficiency gains due to the participation of the private sector that may reach 10-30% on average in utility sectors **(DHV Water BV et al., 2004)**.

Reasons behind the involvement of private sector in such large water schemes projects may include the following: provision of modern and technological capacities, encouraging the investment climate, enhancing the operational efficiency, improving the quality of service **(DHV Water BV et al., 2004)**.

3.4.1.2 Structure of Private Sector Partnership

The first step towards the development of private sector participation process is the development of a policy framework of private sector participation (PSP)/public private partnership (PPP). This policy should show the government's obligation to encourage the investment climate, improve the current policies and systems and establish a transparent process in conducting such partnerships for the benefit of the public **(DHV Water BV et al., 2004)**.

The above mentioned ideal process towards private sector participation can be represented in the figure below.

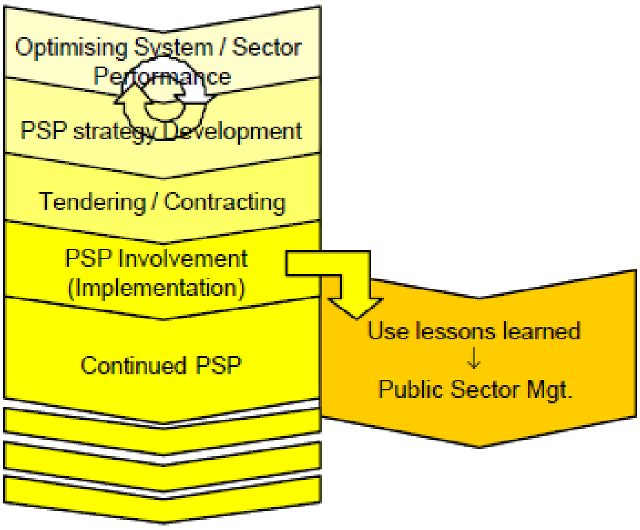


Figure (3-21): Path towards Private Sector Involvement (DHV Water BV et al., 2004)

The establishment of clear and solid policy addressing the public-private partnerships aims to: encourage and attract new investments, identify new partners, ensure its applicability among different sectors, establish communication approaches and implementation procedures and highlight potential risks and concerns **(DHV Water BV et al., 2004)**.

As previously discussed, this anticipated partnership is usually made from public entity and private partner. The partnership will impose certain commitments on both sides under certain conditions. In desalination projects, the public partner usually transfers the responsibility of the provision of the technical designs and know-how and expertise in constructing the associated infrastructure and then the operation of the facility to the private partner. While the public partner remains committed to purchase the desalinated water at an agreed price. (**Tsiourtis, 2004**).

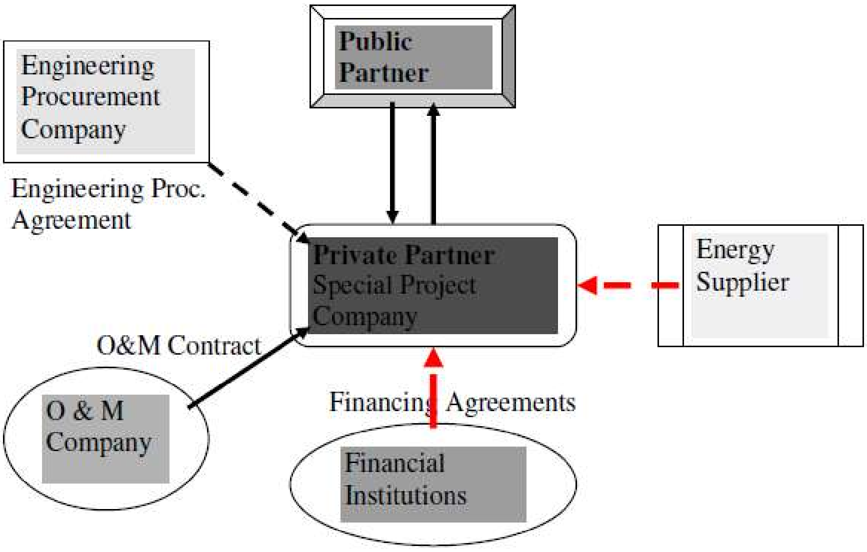


Figure (3-22): Overview of the PPP model under a Desalination Project (Tsiourtis, 2004).

3.4.1.3 Types of Private Sector Partnership

There are a number of different types of contracts to establish private sector participation in desalination projects. This partnership depends on the commitments set for each partner at different phases of implementing the project from design, construction then to operation. Different forms of partnerships will impose different roles of each partner and eventually variable risks to consider.

Brief description of different types of public private partnership is discussed below:

Service Contracts

Service contracts include "supply and civil work contracts, technical assistance contracts, plus sub-contracting or contracting out aspects of the water supply service" **(Deane, 2002)**. These types of contracts may be initially introduced when the PPP is not well-experienced by the public agencies and will gradually introduce this concept to the community **(DHV Water BV et al., 2004)**.

Management Contracts

These types of contracts are relatively similar to service contracts **(DHV Water BV et al., 2004)**.. Higher risks remain at the public entity as the private partner is only providing the overall management services of the facility **(Deane, 2002)**.

Lease Contracts

"Lease contracts include the transfer of the entire operation of a utility in a certain area to a private party. The utility leases its infrastructure to an operator against a lease fee, while the operator, in exchange, gets the right to collect water charges from consumers for its own account." **(DHV Water BV et al., 2004)**.

Build Operate Transfer (BOT) Type Contracts

These types of contracts are the most predominant in the establishment of new large water and wastewater schemes and typically have a contract period of 10 to 30 years. Build-Operate-Transfer (BOT) are widely used in the bulk water provision projects **(DHV Water BV et al., 2004)**.

As indicated from its name, the BOT contract entails that the private partner is responsible to prepare the technical designs of the facility, construct and build all the associated infrastructure, and then **O**perate the project facilities for the contract specified duration, and then **T**ransfer all the facilities to the public partner. Whilst, the public partner will be committed during the contract implementation to buy specified amounts of the produced water with the signed price (**Tsiourtis, 2004**).

Concession Contracts (full utility / retail)

In this type of contracts, the private partner entails the overall capital investment with the possibility of using already built infrastructure to provide the anticipated service. Concession contracts can be considered as a combination of the build-operate-transfer contracts and lease contracts with a typical duration of 25 years **(DHV Water BV et al., 2004)**.

Divestiture / Full privatization (retail)

Under these types of contracts the private partner assumes the highest responsibility in the public-private partnerships. The ownership of the facilities are transferred from the public partner to the private partner imposing full responsibility over the operation, maintenance and future improvement of the facility **(DHV Water BV et al., 2004)**.

3.4.2 Institutional Framework in the Local Water Sector

Different authorities and institutions are playing integrated role in governing the water sector in Palestine. A brief role about each authority/institutions is shown below. Table (3-9) describes the Institutional framework of the water and wastewater sector in Palestine.

Table (3-9): Institutional Framework of the Water and Wastewater Sector (source: researcher)

Cabinet of Ministers	**Decision Level**
Water Sector Regulatory Council	
Palestinian Water Authority	Regulatory Level
National Water Company (NWC) **(**formerly, **West Bank Water Department - WBWD)**	Bulk Water Supply
Water and Wastewater Sub-Utilities, Municipal Water Departments, Joint Service Councils, Village Councils	Operational Level (Water and wastewater sectors)
Water Users' Associations, Farmers Unions, Cooperatives, Farmers	Operational Level (Agricultural Sector)

3.4.2.1 The Water Sector Regulatory Council

Currently, and after the endorsement of the new Palestinian water law, the Water Sector Regulatory Council has been established by a decision of the cabinet of ministers. The objective of the council is to monitor all matters related to the operation of the water service providers including production, transportation, distribution, consumption and wastewater management with the aim of ensuring water and wastewater service quality and efficiency to consumers in Palestine at affordable prices.

3.4.2.2 Palestinian Water Authority (PWA)

It is the main authority responsible of water related issues in Palestine. Consequently, it is considered the main source of data related to water sector in the Palestinian territories as a whole. PWA fields of responsibilities include planning, licensing and implementation of water related projects and infrastructure. Due to this important role played by PWA it is considered as one of the important authorities that are to be involved in water desalination projects. Its role will be important in analyzing monitoring, controlling, assessing, planning and defining the potential brackish water sources and its treatment.

3.4.2.3 National Water Company (NWC)

Based on the policy of the Palestinian Water Authority and the recently endorsed water law, the National Water Company (NWC) will be established and owned by the State of Palestine. The National Water Company will be responsible for the supply and sale of bulk water to water undertakings, local authorities, joint water councils and associations. In addition, it will be responsible for the extraction of water resources, desalination of water, and bulk water transmission **(PWA, 2014)**.

3.4.2.4 Environmental Quality Authority (EQA)

EQA seeks to promote sustainable environmental development of the Palestinian society. The main goal of EQA is the protection of all elements of environment as well as preventing health risks facing all organisms.

3.4.2.5 Ministry of Local Government (MoLG)

It is the main source of local communities' sectors data. It is responsible on the physical planning for the expansion of the built up areas. MoLG by its law is the governmental body responsible in providing the municipalities and village council with financial and administrative assistance.

3.4.2.6 Local Government Units (LGU)

It is the responsibility of the LGU to provide citizens with drinkable water and for any other use and specify its requirements such as pipes, meters, etc. and organize its distribution, specify its tariff and connection fees, and prevent the contamination of water resources.

3.4.2.7 Ministry of Agriculture (MoA)

MoA is the responsible governmental entity to regulate the agricultural sector in the Palestine. The main goal of it is to improve and develop the agricultural sector in Palestine. Desalinated water is considered as a non-conventional source for irrigation purposes.

3.4.2.8 Ministry of Health (MoH)

The MoH is responsible for the public health of the Palestinian people. Therefore, it is involved in the control and monitoring of potable water quality, food quality, wastewater related diseases etc.

3.4.2.9 Ministry of Finance (MoF)

It controls the financial activities of the Palestinian National Authority (PNA) and its expenditure. It also performs supervision and organizing monetary funds and the economic and political analysis of financial aid directed towards the PNA.

3.4.2.10 Palestine Standard Institute (PSI)

It is the main and official institute of accreditation of standards and specifications for water wastewater qualities and reuse.

3.4.2.11 Palestinian Central Bureau of Statistic (PCBS)

It is the main source of information and data about the Palestinian. Its responsibilities include the provision of relevant data population, economy as well as physical aspects in the form of statistical databases.

3.4.2.12 Non-Governmental Organizations (NGOs)

Numerous water and agricultural related Palestinian NGOs are contributing to the water treatment and reuse sector through implementation of pilot projects or provision of support to farmers.

3.4.2.13 Water Users Associations (WUAs)

WUAs are representing the end users of treated water consists of groups of farmers who have shared interests. They are generally small and loosely organized. But they can act as focal point for the operator of the desalinated water distribution systems, or operation and maintenance and billing issues.

Chapter Four: Approach and Methodology

This chapter presents the approach and methodology adopted and applied throughout the implementation of this research work. The research methodology was established to respond to the stated research questions that were previously discussed in chapter one. This chapter gives detailed overview and discusses the research approach from the data collection phase to the data analysis and decision making phases.

4.1 Research Approach

The overall research method used in this study is based on an interdisciplinary and integrated combination of approaches. Scholarly articles and books consist of literature studies of published materials and data in line with the area of interest were reviewed. The literature sources were concerning the available technologies, economic assessments and management framework of desalination projects. Interviews were also carried out with relevant stakeholders and authorities. Research data was sourced, collected and collated accordingly.

Figure (4-1) summarizes the methodology of this research and shows the key steps in the research approach process.

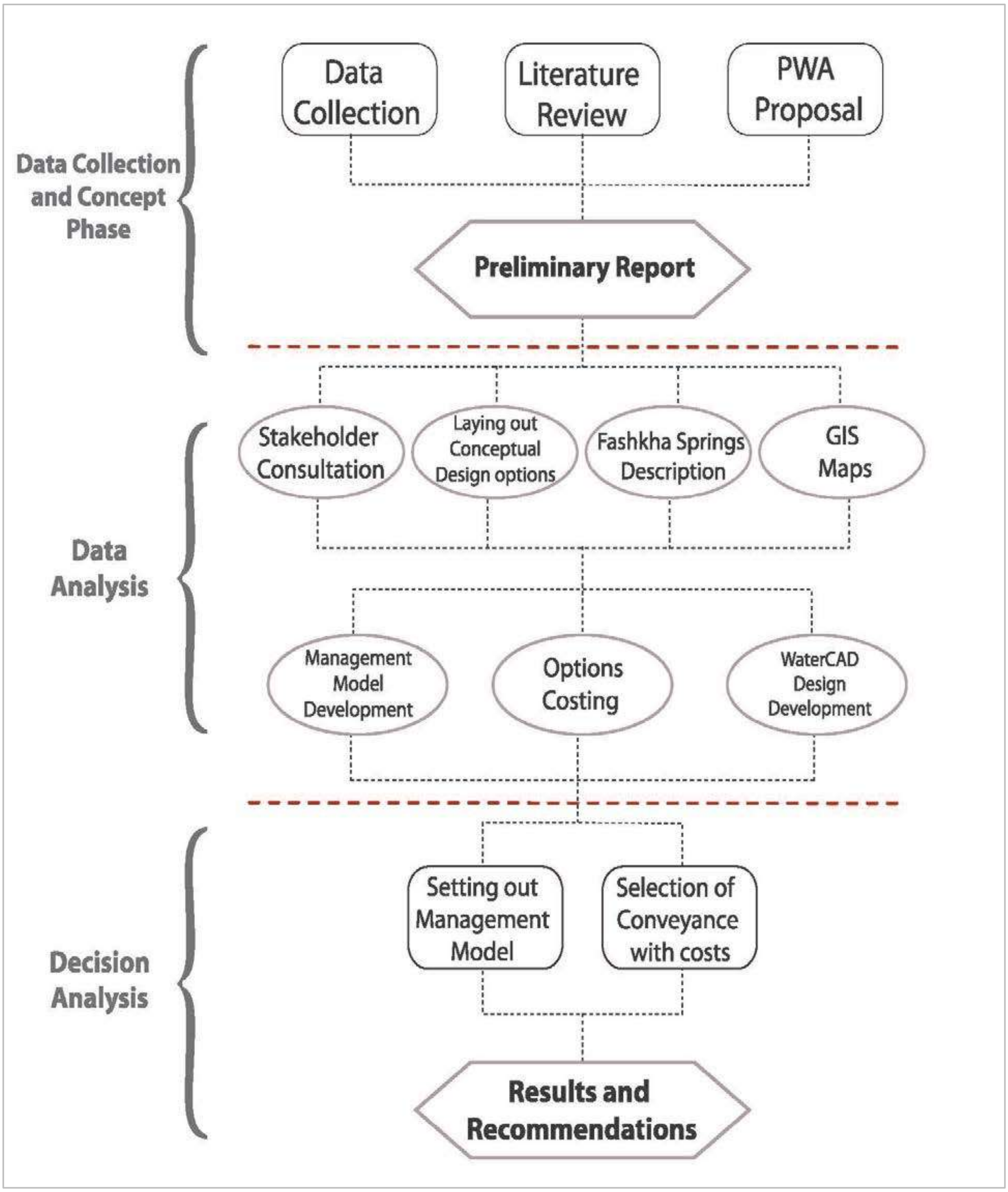


Figure (4-1): Key Steps in the Research Approach Methodology (source: Researcher)

4.2 Data Collection

4.2.1 Literature Review

The first phase of initiating this research was the Concept and Data Collection Phase; mainly consisted of data collection from relevant authorities and published scholarly work. All available data, reports and literature documents were thoroughly reviewed and linked together and integrated further in this research work.

4.2.2 Stakeholders Consultation

To identify the issues and concerns to be addressed in this research, several consultative interviews were conducted with the Palestinian ministries and authorities which mainly included the Palestinian Water Authority (PWA) and Ministry of Agriculture (MoA). The general opinions of other authorities were also incorporated in this research from personnel who have previously commented on this research at early stages. In the interviews, the Al Fashkha desalination project was briefly described to the consulted parties, and feedback, comments, and concerns were considered and constantly integrated to the research report.

4.3 Analytical Procedures

The analysis adopted in this research is generally inspired by the Palestinian Water Authority (PWA) strategic project of Dead Sea springs and future national water strategies and policies. Thus it begins with the process of proposing and laying out conceptual design for the conveyance systems of the desalinated water from Al Fashkha springs that was done in constant stakeholder consultation mainly with PWA and the Ministry of Agriculture (MoA) to identify the direct beneficiary communities from this proposed project. After setting out the conceptual designs, detailed hydraulic designs were developed with more than one option using the WaterCAD V8i software program that was companied with conducting costing analysis for the proposed options to account for the capital and operational costs of each option.

On the other hand, along with the technical work done to establish the engineering designs and their costs, another analysis was done to establish management framework for establishing and running such a non-conventional large scheme project that was done in direct consultation with relevant authorities and stakeholders. This work investigated available scenarios to run such a project and the development of the possible management models was done.

4.3.1 Design of Conveyance System Options for Al Fashkha Springs Desalinated Water

4.3.1.1 Introduction

This section technically discusses the water conveyance system of the desalination project that the Palestinian Water Authority (PWA) proposed for Al Fashkha springs as part of the PWA strategic project of Dead Sea springs. It shows the preliminary scope of the project as proposed by the PWA and the utilization options for the desalinated water that entails the establishment of water conveyance systems for the benefited communities. In this research, and after discussion and agreement from PWA, two options have been analyzed including the “Al Fashkha - Jericho” in Jericho Governorate and “Al Fashkha – Al Ubedeyya” in Bethlehem Governorate. PWA nominated these two communities as they are the closest main urban areas to Al Fashkha springs and they have potential to use the desalinated water for domestic and agricultural purposes.

4.3.1.2 PWA Strategic Project of Dead Sea Springs

The Palestinian Water Authority (PWA) is developing plans to utilize Al Fashkha springs (brackish) for domestic and agricultural uses by proposing a desalination plant for Al Fashkha springs which is considered one of the prioritized strategic projects for Palestinian National Authority in the water sector **(PNA, 2010)**. This proposal supports the PWA plans and will further extend the idea to develop a plan to drill wells in the Pleistocene aquifer to extract brackish water for agriculture use **(Aliewi, 2010)**. Much of the water in the Dead Sea springs is discharged haphazardly without any real benefit derived to the surrounding environment. Aimed at utilizing this discharge, this proposal involves the construction of a desalination plant capable of desalinating the brackish water discharge, as well as purifying the available freshwater. Reverse Osmosis (RO) is recommended as the most suitable approach to desalinate brackish springs. As a tentative estimate, the design capacity of such a desalination plant will be 22 MCM per year (60,000 m^3/day) which was adopted in this research for the development of the designs of the conveyance system **(PWA, 2012).** The tentative cost of the project is roughly reaching US$100 million **(Abdelghafour, 2009).** The suggested cost of one cubic meter of the desalinated water ranges from 0.45-0.7 U.S dollars **(HWE, 2009)**.

4.3.1.3 Conceptual Design of the Proposed Conveyance Systems

In this research, conceptual engineering designs of the conveyance systems for the utilization options of the desalinated water were developed. This includes the proposal of the pipeline routes, size and material. Moreover, the conceptual designs proposed the associated facilities like the pumping stations and the storage reservoirs in terms of capacity and location.

The main concern was the challenge in pumping the desalinated water along the pipeline route due to length of the route and the high difference in the topographical elevation between the water source (-350 mbsl) at the level of the desalination plant to the final destination that reach up to (+600 masl) at the storage reservoir in Al Ubedeyya option.

4.3.1.4 Design Criteria and Hydraulic Model

The objective of the hydraulic analysis done is to determine the most appropriate diameter for the main transmission pipes and check the nominal pressure in the pipes resulting from the operation of the transmission pipelines and pumping stations for the established design flow rates. In order to achieve this purpose and study the adequacy of the proposed system, a Hydraulic Model was built out and analyzed using WarerCAD V8i Software.

The following hydraulic equation was used to determine pipelines sizes:

$$Q=V*A$$

Where:

Q: Volumetric Flow Rate, m^3/h

V: mean Velocity, m/s

A: Radius Sectional area, m^2

Hazen-William equation was used in the hydraulic analysis to calculate the friction loss in the forced main pipes:

$$H_f= (6.79L/D^{1.16}) (V/C)^{1.85}$$

Where:

$H_{f:}$ head loss in (m)

L: pipe length in (m)

D: pipe diameter in (m)

V: velocity in (m/s)

C: Hazen-Williams friction coefficient = 130 for Steel cement lined

The friction loss through fittings is calculated using the following formula:

Friction Loss= Hl =K(V^2/2g)

g: Gravitational constant = 9.81 m/s^2

V: velocity in m/s

K: Head loss coefficient of fitting

Pipes were selected to maintain velocities and pressure heads within acceptable limits. The transmission pipeline diameters were selected ensuring that the maximum velocity is below 2.5 m/s. This maximum velocity was maintained to minimize pumping costs as increasing the velocity beyond this value will result in increasing friction losses and increasing the pumping costs significantly.

Transmission pipelines were designed to deliver water at demands points with a minimum pressure of 1.5 bars at connection points, while the maximum pressure was maintained at 40 bars which is the maximum rating of locally available pipe fittings.

Pipeline Routing

The pipeline routing was chosen to follow the existing roads to the extent possible to avoid encroachment on private property and for easier construction.

Pipelines Material

Steel cement lined pipes for the transmission pipelines were selected in this research. These pipes are considered strong, durable, withstand high pressure and have reasonable chemical resistance. Moreover, there is a considerable local experience in installing and laying out steel pipes in the West Bank with availability of technicians and workers experienced in welding steel pipes. In addition to that, the local engineers are also experienced in the installation and inspection of steel pipes and their welding. Moreover, this will simplify the construction and operation and maintenance for the water system in the future given the complicated topography of the project area.

Chapter Five: Results and Discussion

This chapter discusses the results of the conceptual designs of the proposed water conveyance systems to utilize the desalinated water from Al Fashkha springs and their associated capital and running costs. Two conveyance routes were designed for each option (Jericho and Al Ubedeyya options). Moreover, this chapter presents and discusses the proposed management model and framework to run the proposed Al Fashkha desalination project.

5.1Desalinated Water Utilization Options

5.1.1 Option (A) – (Al Fashkha – Jericho)

This option proposes conveying the desalinated water from Al Fashkha springs to Jericho Governorate. Jericho is the nearest urban area to Al Fashkha springs and it also has large areas of non-reclaimed agricultural lands. Supplying Jericho with new source of water would allow for high potential for agricultural activities especially in the southern part of Jericho. Moreover, technically speaking, this option provides the most feasible conveyance system in terms of constructability due to the easiness of the topography of the area in addition it provides the shortest pipeline route with the least elevation difference that directly impacts the capital and operational costs of the system.

According to the records of Jericho municipality, the total water consumption during 2009 in Jericho was around (2,770,500) m^3 with a total population supplied by water of around (31,509) inhabitants; in Jericho (18,346) inhabitants and Aqbet Jaber Camp (7,163) inhabitants and the Palestinian Military Camps (6,000). The average per capita consumption was around (206) lit/capita/day. The main source of water in Jericho is Ein Sultan spring which has an annual flow of 5.5 MCM/year used for domestic (42%) and agricultural (58%) purposes (**Jericho Municipality, 2014**).

5.1.1.1 Route Alternative # 1 (A-1)

In this alternative the pipeline route passes in parallel to the existing main paved road that connects Al Fashkha to Jericho city. The total length of the pipeline route is around 20.5 km. The elevation at the source point is 380 mbsl at Al Fashkha springs and reaches up to 238 mbsl at the end point in Jericho.

Two pumping stations were utilized in this option. The first pumping station is located at the desalination plant at Al Fashkha springs area while the other one is located within the pipeline route to Jericho as indicated in the figure below. Each pumping station contains 12 pumps (10 working and 2 standby). The characteristics of the used pumps were chosen from the available local market and shown in Table (5-1) and Annex (D).

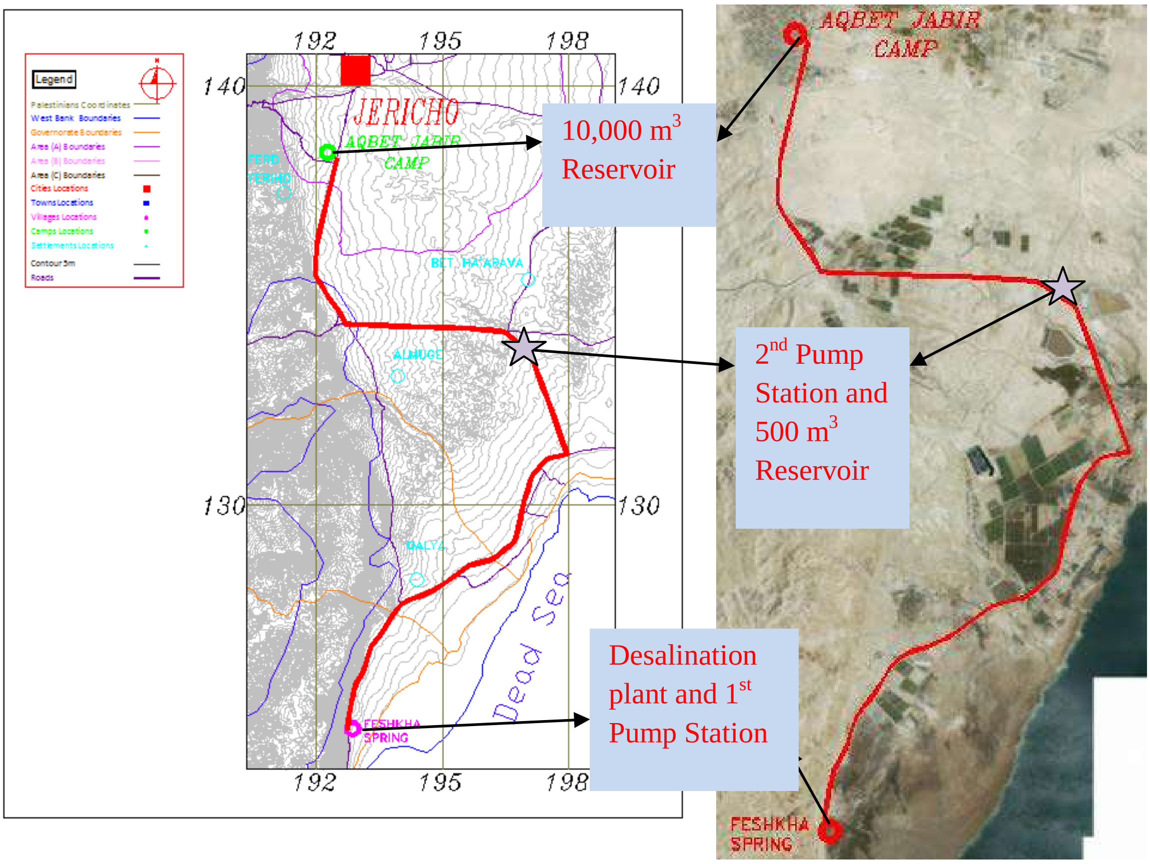


Figure (5-1): Al Fashkha – Jericho Option, Alternative Route #1 (A-1)

Table (5-1): Selected Pump Schedule - Option (A-1)

Ref.	Type	Rate Flow (m^3/hr)	Total Dynamic Head (m)	Rate Efficiency	Best Efficiency Point	Shut Off Head	Speed (RPM)
P1 to P12	Centrifugal vertical multistage	250	150	>70%	within 15% of rated flow	200 (m)	2900

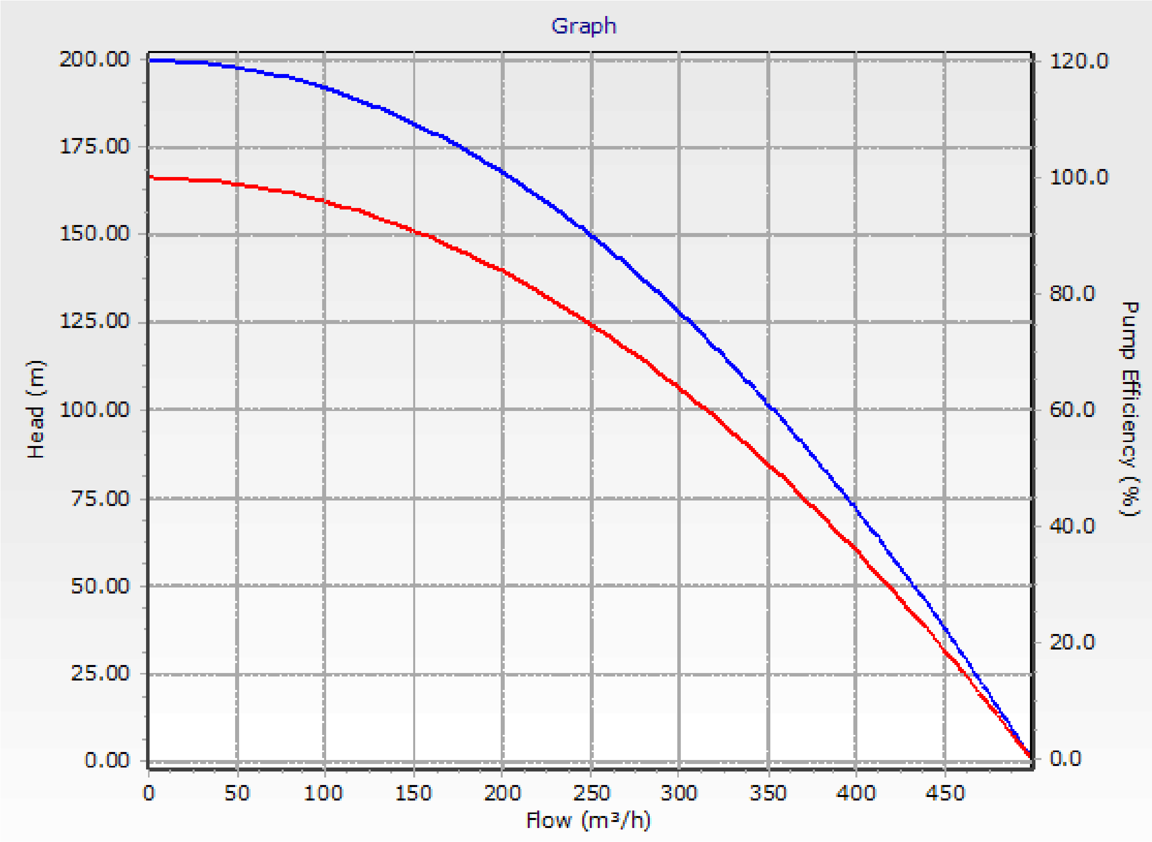


Figure 5-2: Performance or Characteristic Curve of the Selected Pump - Option (A-1)

The hydraulic analysis results of the transmission main joints and pipes are shown in Annex (B).

Costs estimates

Cost estimations were calculated for the different components of the conveyance system including the construction costs based on the local market prices.

Table (5-2): Cost Estimations of the Conveyance System Components of Option (A-1)

Item	Element	Unit	Quantity	Unit price ($)	Cost ($)	Notes
1.	Transmission pipelines (600 mm)	m	20,440	100	2,044,000	Prices include all costs as ,coating, excavation of trench, bedding, pipes, fittings, backfilling, flushing, testing, fittings etc.
2.	Pumps	No.	24	45,000	1,080,000	10 operational and 2 stand by in each pumping station
3.	Pumping station	No.	2	200,000	400,000	Includes: civil, mechanical and electrical works, valves, pipes and fittings).
4.	Water Balance Reservoir (Concrete- On Ground 500 m^3)	No.	1	300,000	300,000	Price includes excavations, reinforced concrete, plastering, testing, valves (water meter, check, gate, strainer, etc), fittings, pipes, covers, etc
5.	Water Storage Reservoir (Concrete- On Ground 10,000 m^3)	No.	1	2,220,000	2,220,000	Price includes excavations, reinforced concrete, plastering, testing, valves (water meter, check, gate, strainer, etc), fittings, pipes, covers, etc
TOTAL					**6,044,000**	

Pumping costs

Table (5-3): Estimations of Pumping Costs of Option (A-1)

Power for one pump (kw)	Hours of day (h)	No. of Pumps in operation	price for electrical load (NIS/KWH)	TOTAL COST (NIS)	TOTAL COST ($/day)
250	24	20	0.5	60000	17,140

5.1.1.2 Route Alternative # 2 (A-2)

In this alternative the pipeline route partly passes in parallel to the existing main paved road that connects Al Fashkha to Jericho city then it takes a shorter unpaved route that passes through agricultural lands and at certain point it crosses an existing wadi. The total length of the pipeline route is around 15 km. The elevation at the source point is 380 mbsl at Al Fashkha springs and reaches up to 238 mbsl at the end point in Jericho.

Two pumping stations were utilized in this option. The first pumping station is located at the desalination plant at Al Fashkha springs area while the other one is located within the pipeline route to Jericho as indicated in the figure below. Each pumping station contains 12 pumps (10 working and 2 standby). The characteristics of the used pumps were chosen from the available local market and shown in Table (5-4) and Annex (D).

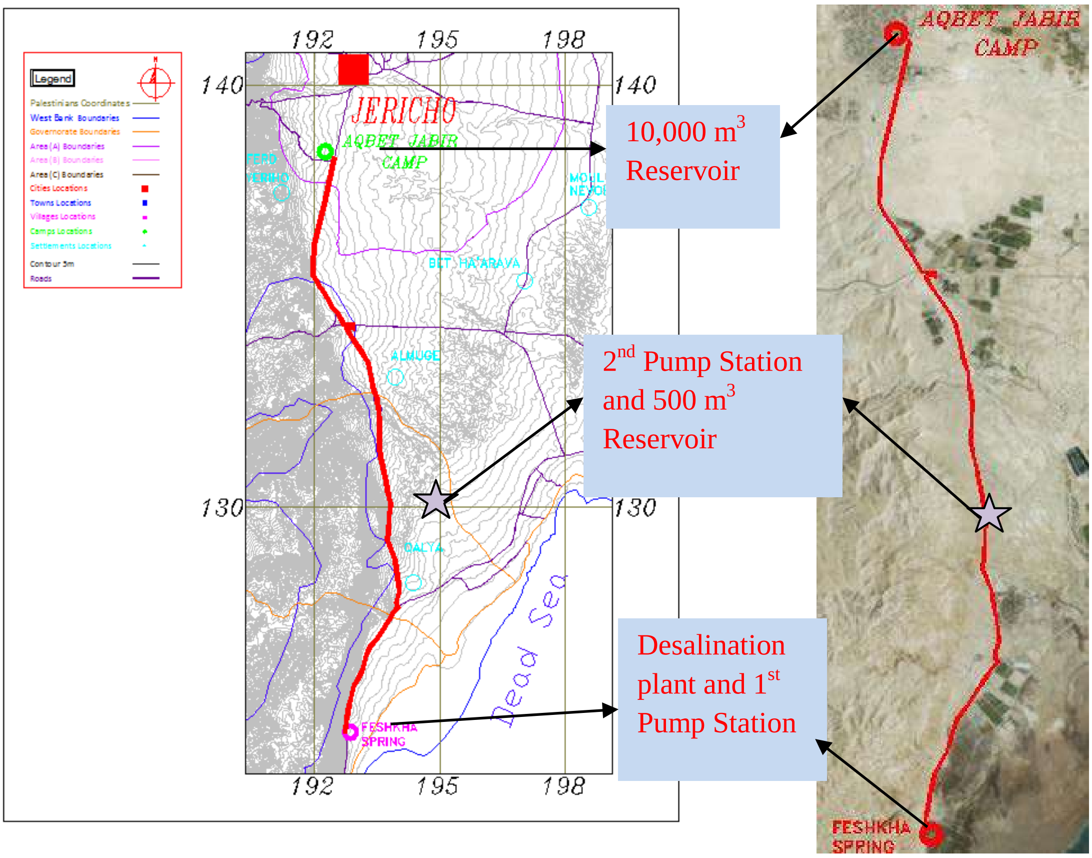


Figure (5-3): Al Fashkha – Jericho Option, Alternative Route #2 (A-2)

Table (5-4): Selected Pump Schedule - Option (A-2)

Ref.	Type	Rate Flow (m^3/hr)	Total Dynamic Head (m)	Rate Efficiency	Best Efficiency Point	Shut Off Head	Speed (RPM)
P1 to P12	Centrifugal vertical multistage	250	130	>70%	within 15% of rated flow	173.3 (m)	2900

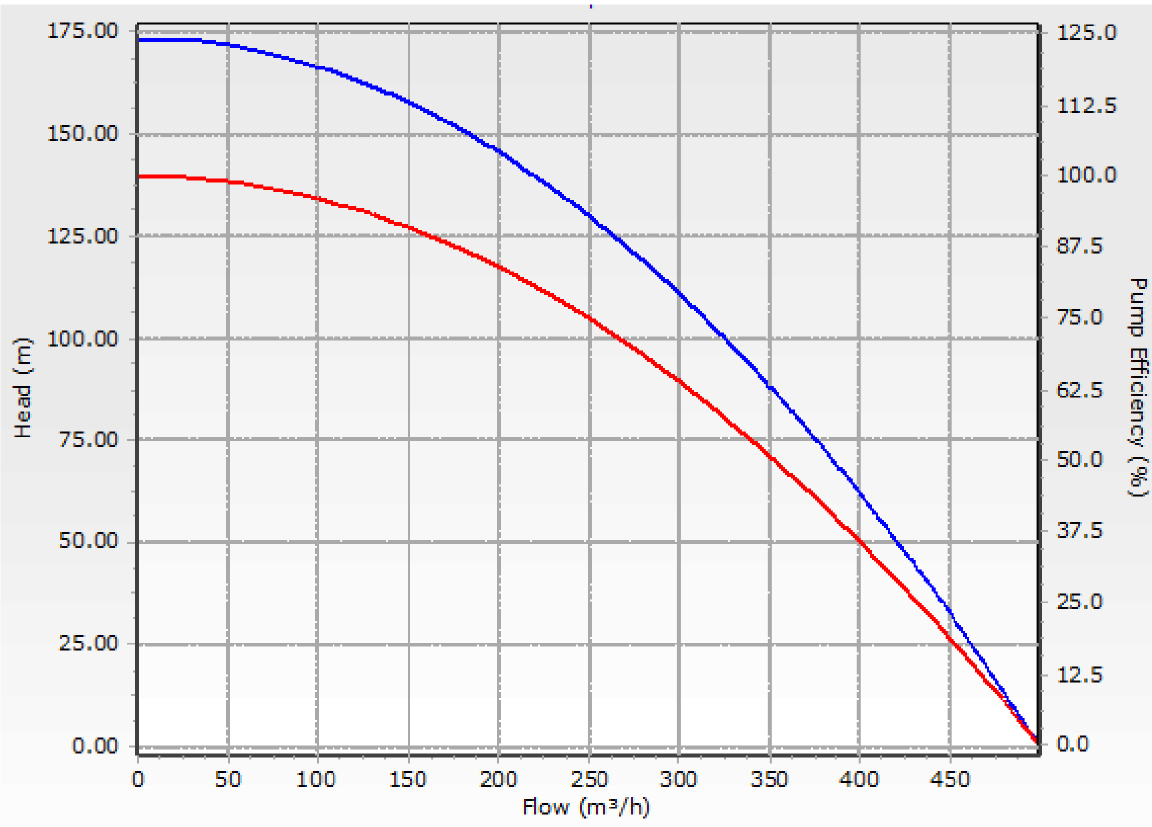


Figure (5-4): Performance or Characteristic Curve of the Selected Pump - Option (A-2)

The hydraulic analysis results of the transmission main joints and pipes are shown in Annex (B).

Costs Estimates

Cost estimations were calculated for the different components of the conveyance systems including the construction costs based on the local market prices.

Table (5-5): Cost Estimations of the Conveyance System Components of Option (A-2)

Item	Element	Unit	Quantity	Unit price ($)	Cost ($)	Notes
1.	Transmission pipelines (600 mm)	m	14,860	100	1,486,000	Prices include all costs as ,coating, excavation of trench, bedding, pipes, fittings, backfilling, flushing, testing, fittings etc.
2.	Pumps	No.	24	40,000	960,000	10 operational and 2 stand by in each pumping station
3.	Pumping station	No	2	200,000	400,000	Includes: civil, mechanical and electrical works, valves, pipes and fittings).
4.	Water Balance Reservoir (Concrete- On Ground 500 m^3)	No	1	300,000	300,000	Price includes excavations, reinforced concrete, plastering, testing, valves (water meter, check, gate, strainer, etc), fittings, pipes, covers, etc
5.	Water Storage Reservoir (Concrete- On Ground 10,000 m^3)	No	1	2,220,000	2,220,000	Price includes excavations, reinforced concrete, plastering, testing, valves (water meter, check, gate, strainer, etc), fittings, pipes, covers, etc
TOTAL					**5,366,000**	

Pumping costs

Table (5-6): Estimations of Pumping Costs of Option (A-2)

Power for one pump (kw)	Hours of day (h)	No. of Pumps in operation	price for electrical load (NIS/KWH)	TOTAL COST (NIS)	TOTAL COST ($/day)
250	24	20	0.5	60000	17,140

5.1.1.3 Selected Route

Given that the variance in the capital costs between the two routes is not major ($0.7 million) and the running costs are the same, the route alternative (A-1) is recommended as the selected route for the Al Fashkha – Jericho option as it passes in parallel to the existing paved road and avoid passing over existing wadis. This will avoid constructability challenges on the ground that may require more retaining structures and civil works. Moreover, this route will minimize the disturbance to the existing environment and wildlife.

5.1.1.4 Calculated Costs

The costs of the conveyed desalinated water will include the following:

Total Cost = desalination cost + conveyance system capital cost + daily pumping cost

Desalination Costs

After discussions with PWA and comparing desalination costs of regional experiences using Reverse Osmosis and the ongoing improvement in this technology, the desalination cost is assumed to be 0.55 $\$/m^3$.

Conveyance System Capital Cost

The payback period of the capital cost of the conveyance system is assumed to be 12 years.

Then, cost per year = 6,044,000/12 = 0.504 M$/year

Cost per cubic meter = 0.504/22 = 0.02 $\$/m^3$

Daily Pumping Cost

The daily pumping capacity is assumed to be 60,000 m^3/day

Daily pumping costs = 60000 NIS

US$/NIS conversion rate used = 3.5

Converted daily pumping costs = 17,140 $

Then, pumping cost per cubic meter = 17,140/60,000 = 0.28 $\$/m^3$

Total cost = 0.55 + 0.02 + 0.28 = 0.85 $\$/m^3$

5.1.2 Option (B) – (Al Fashkha – Al Ubedeyya)

This option proposes conveying the desalinated water from Al Fashkha springs to Bethlehem Governorate. Al Ubedeyya would be the nearest major urban area to Al Fashkha springs and it also has large areas of non-reclaimed agricultural lands. Moreover, Al Ubedeyya and the neighboring communities suffer from a shortage in water supply. Supplying Al Ubedeyya with new source of water would allow for better water security in the area and improves the public health and hygienic situation for the communities there. Moreover, it allows for high potential for agricultural activities especially in the eastern and southern parts of Al Ubedeyya.

According to the records of Al Ubedeyya municipality, the total water consumption during 2008 in Jericho was around (522,338) m^3 with a total population supplied by water of around (10,106) capita. The average per capita consumption was around (81) liter/capita/day. The main source of water in Al Ubedeyya is from Em-Tobah well which located Jerusalem Governorate which is under Israeli control and the water is supplied to Al Ubedeyya through Mekorot connection (**Al Ubedeyya Municipality, 2014**).

5.1.2.1 Route Alternative # 1 (B-1)

In this alternative the pipeline route passes in parallel to the existing main paved road that connects Al Fashkha springs to Al Ubedeyya town. The total length of the pipeline route is around 44.5 km. The elevation at the source point is 380 mbsl at Al Fashkha springs and reaches up to 555 masl at the end point in Al Ubedeyya.

Three pumping stations were utilized in this option. The first pumping station is located at the desalination plant at Al Fashkha springs area while the other two are located within the pipeline route to Al Ubedeyya as indicated in the figure below. Each pumping station contains 10 pumps (8 working and 2 standby). The characteristics of the used pumps were chosen from the available local market and shown in Table (5-7) and Annex (D).

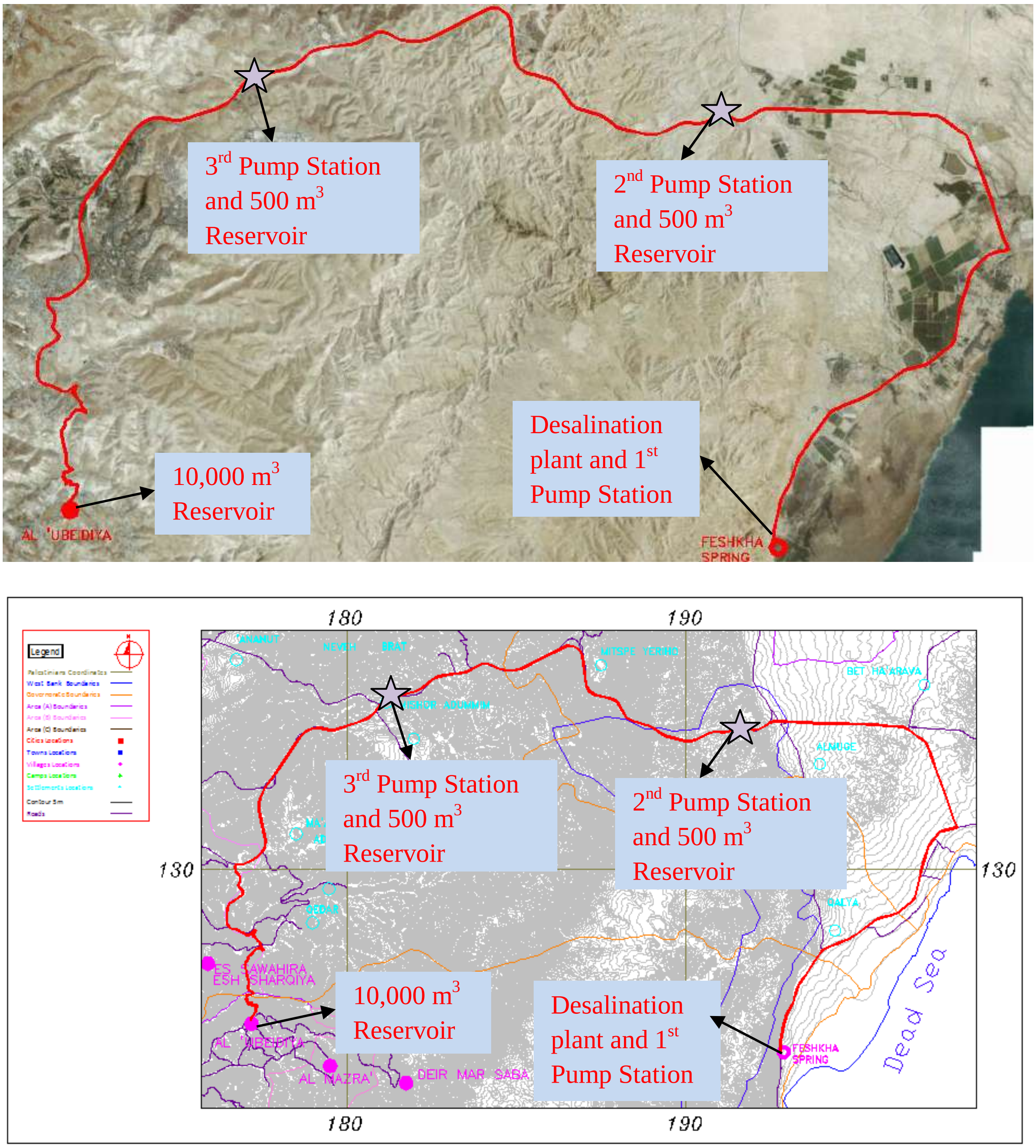


Figure (5-5): Al Fashkha – Al Ubedeyya Option, Alternative Route #1 (B-1)

Table (5-7): Selected Pump Schedule - Option (B-1)

Ref.	Type	Rate Flow (m^3/hr)	Total Dynamic Head (m)	Rate Efficiency	Best Efficiency Point	Shut Off Head	Speed (RPM)
P1 to P10	Centrifugal vertical multistage	313	494	>70%	within 15% of rated flow	658.7 (m)	2900

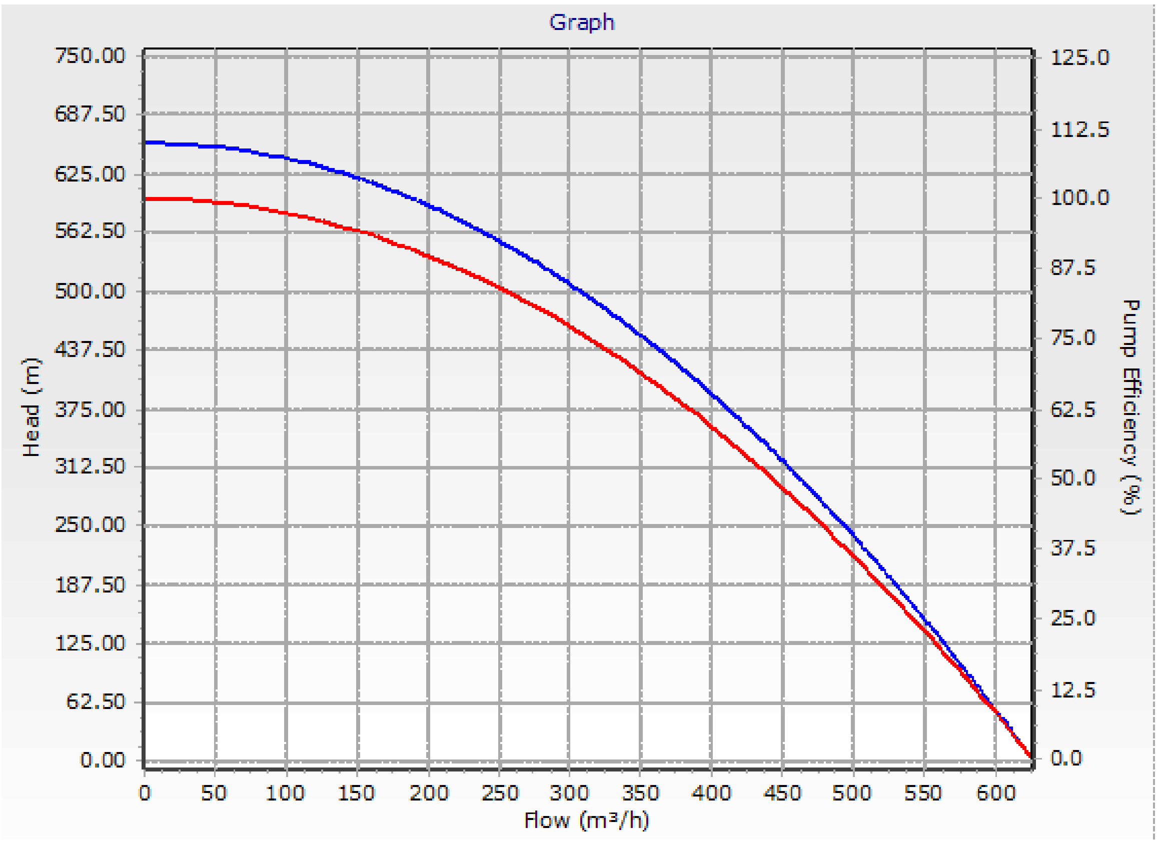


Figure (5-6): Performance or Characteristic Curve of the Selected Pump - Option (B-1)

The hydraulic analysis results of the transmission main joints and pipes are shown in Annex (C).

Costs estimates

Cost estimations were calculated for the different components of the conveyance systems including the construction costs based on the local market prices.

Table (5-8): Cost Estimations of the Conveyance System Components of Option (B-1)

Item	Element	Unit	Quantity	Unit price ($)	Cost ($)	Notes
1.	Transmission pipelines (600 mm)	m	44,430	100	4,443,000	Prices include all costs as ,coating, excavation of trench, bedding, pipes, fittings, backfilling, flushing, testing, fittings etc.
2.	Pumps	No.	30	104,000	3,120,000	10 operational and 2 stand by in each pumping station
3.	Pumping station	No	3	200,000	600,000	Includes: civil, mechanical and electrical works, valves, pipes and fittings).
4.	Water Balance Tank (Concrete- On Ground 500 m^3)	No	2	300,000	600,000	Price includes excavations, reinforced concrete, plastering, testing, valves (water meter, check, gate, strainer, etc), fittings, pipes, covers, etc
5.	Water Storage Reservoir (Concrete- On Ground 10,000 m^3)	No	1	2,220,000	2,220,000	Price includes excavations, reinforced concrete, plastering, testing, valves (water meter, check, gate, strainer, etc), fittings, pipes, covers, etc
TOTAL					**10,983,000**	

Pumping costs

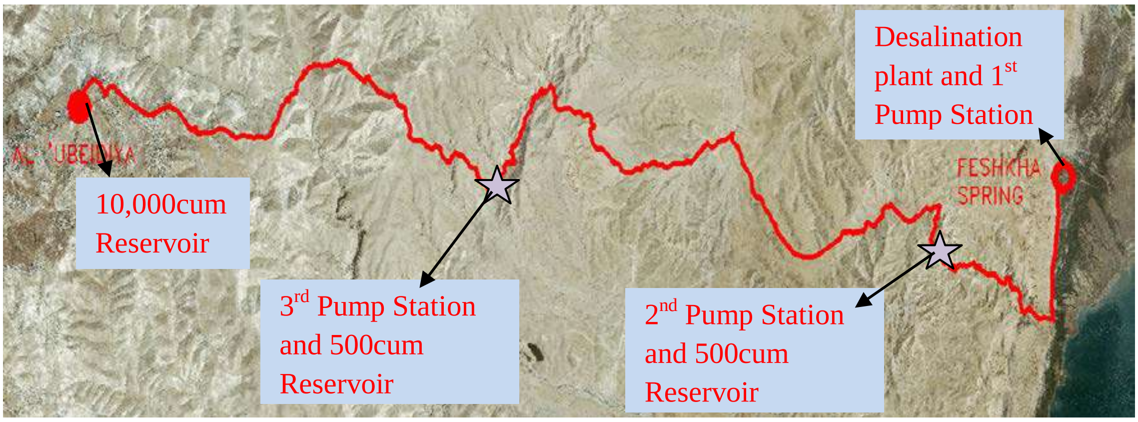
Table (5-9): Estimations of Pumping Costs of Option (B-1)

Power for one pump (kw)	Hours of day (h)	No. of Pumps in operation	price for electrical load (NIS/KWH)	TOTAL COST (NIS)	TOTAL COST ($/day)
355	24	24	0.5	102,240	29,211

5.1.2.2 Route Alternative # 2 (B-2)

In this alternative the pipeline route passes in parallel to the existing main paved road that runs to the south towards the Dead Sea then it goes along the wadi path upward to reach Al Ubedeyya. The total length of the pipeline route is around 24.4 km. The elevation at the source point is 380 mbsl at Al Fashkha springs and reaches up to 555 masl at the end point in Al Ubedeyya.

Three pumping stations were utilized in this option. The first pumping station is located at the desalination plant at Al Fashkha springs area while the other two are located within the pipeline route to Al Ubedeyya as indicated in the figure below. Each pumping station contains 10 pumps (8 working and 2 standby). The characteristics of the used pumps were chosen from the available local market and are shown in Table (5-10) and Annex (D).



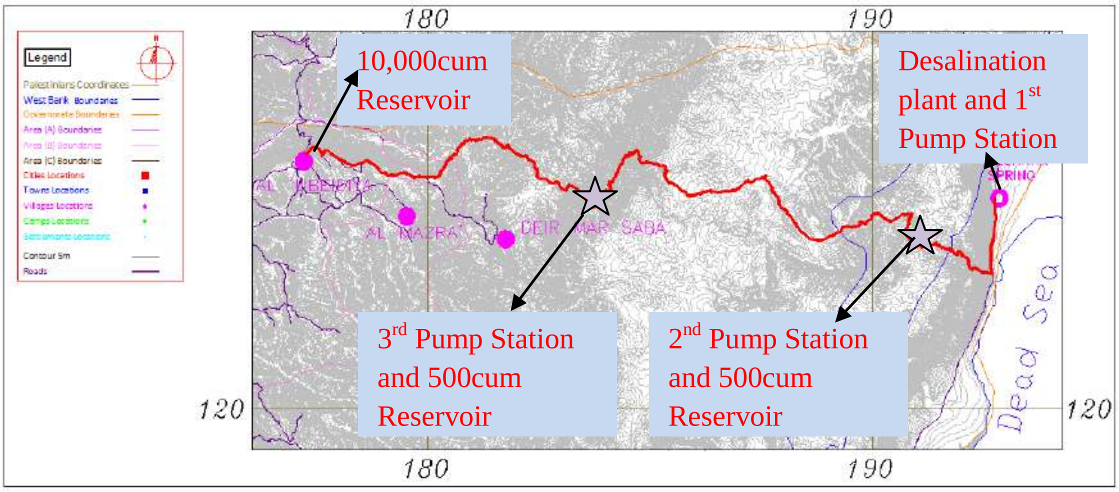


Figure (5-7): Al Fashkha – Al Ubedeyya Option, Alternative Route #2 (B-2)

Table (5-10): Selected Pump Schedule - Option (B-2)

Ref.	Type	Rate Flow (m^3/hr)	Total Dynamic Head (m)	Rate Efficiency	Best Efficiency Point	Shut Off Head	Speed (RPM)
P1 to P10	Centrifugal vertical multistage	313	405	>70%	within 15% of rated flow	504 (m)	2900

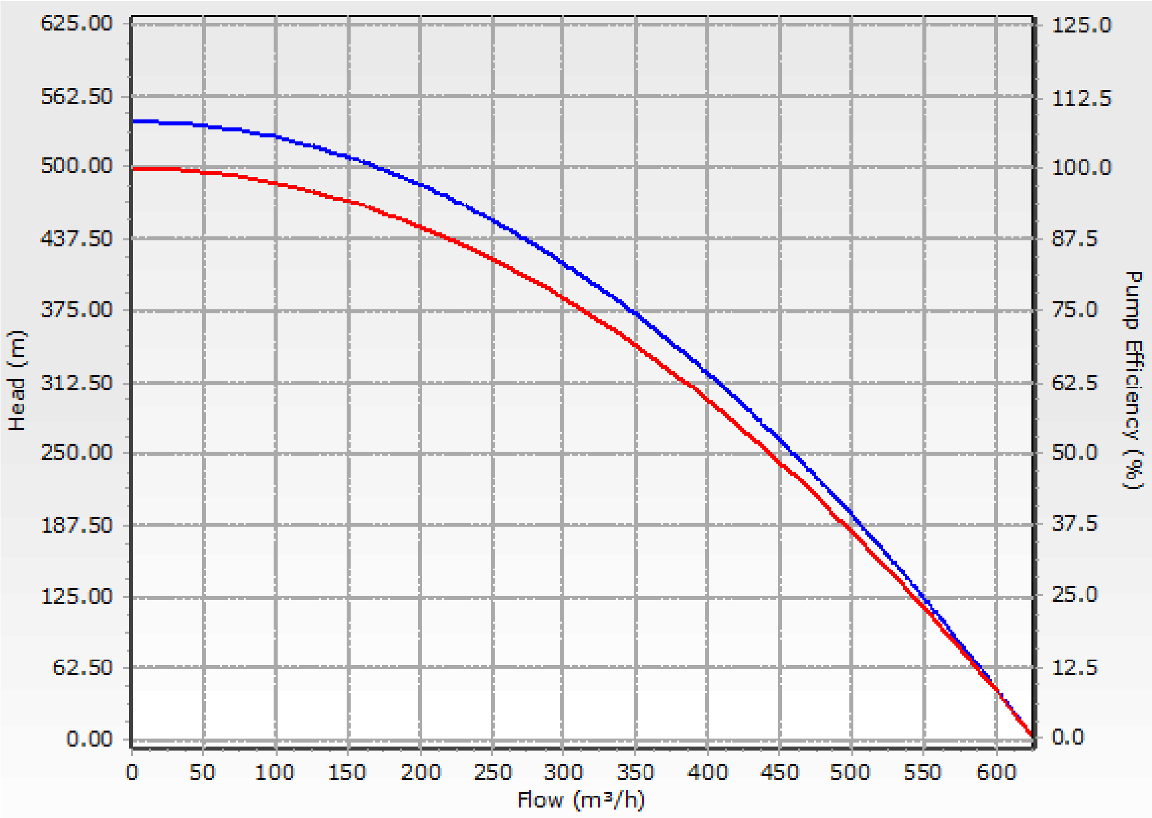


Figure (5-8): Performance or Characteristic Curve of the Selected Pump - Option (B-2)

The hydraulic analysis results of the transmission main joints and pipes are shown in Annex (C).

Costs estimates

Cost estimations were calculated for the different components of the conveyance systems including the construction costs based on the local market prices.

Table (5-11): Cost Estimations of the Conveyance System Components of Option (B-2)

Item	Element	Unit	Quantity	Unit price ($)	Cost ($)	Notes
1.	Transmission pipelines (600 mm)	m	24,370	100	2,437,000	Prices include all costs as ,coating, excavation of trench, bedding, pipes, fittings, backfilling, flushing, testing, fittings etc.
2.	Pumps	No.	30	98,000	2,940,000	10 operational and 2 stand by in each pumping station
3.	Pumping station	No	3	200,000	600,000	Includes: civil, mechanical and electrical works, valves, pipes and fittings).
4.	Water Balance Tank (Concrete- On Ground 500 m^3)	No	2	300,000	600,000	Price includes excavations, reinforced concrete, plastering, testing, valves (water meter, check, gate, strainer, etc), fittings, pipes, covers, etc
5.	Water Storage Reservoir (Concrete- On Ground 10,000 m^3)	No	1	2,220,000	2,220,000	Price includes excavations, reinforced concrete, plastering, testing, valves (water meter, check, gate, strainer, etc), fittings, pipes, covers, etc
TOTAL					**8,797,000**	

Pumping costs

Table (5-12): Estimations of Pumping Costs of Option (B-2)

Power for one pump (kw)	Hours of day (h)	No. of Pumps in operation	price for electrical load (NIS/KWH)	TOTAL COST (NIS)	TOTAL COST ($/day)
355	24	24	0.5	102,240	29,211

5.1.2.3 Selected Route

The route alternative (B-2) is recommended as the selected route for the Al Fashkha – Al Ubedeyya option as it requires less infrastructure and civil works due to its considerably shorter route length (20 km difference). This has direct impact on the capital cost as this option will roughly save the PWA $2.5 million. Moreover, this route will require less maintenance costs and fittings replacement due to its considerably shorter length. On the other hand, this route has political importance as it supports the Palestinian rights and presence in the eastern side of the West Bank towards the Dead Sea.

5.1.2.4 Calculated Costs

The costs of the conveyed desalinated water will include the following:

Total Cost = desalination cost + conveyance system capital cost + daily pumping cost

Desalination Costs

After discussions with PWA and comparing desalination costs of regional experiences using Reverse Osmosis and the ongoing improvement in this technology, the desalination cost is assumed to be 0.55 $\$/m^3$.

Conveyance System Capital Cost

The payback period of the capital cost of the conveyance system is assumed to be 12 years.

Then, cost per year = 8,797,000/12 = 0.733 M$/year
Cost per cubic meter = 0.733/22 = 0.03 $/m^3

Daily Pumping Cost

The daily pumping capacity is assumed to be 60,000 m^3/day

Daily pumping costs = 102,240 NIS

US$/NIS conversion rate used = 3.5

Converted daily pumping costs = 29,211 $

Then, pumping cost per cubic meter = 29,211/60,000 = 0.48 $/m^3

Total cost = 0.55 + 0.03 + 0.48 = 1.06 $/m^3

5.2 Management Model of Al Fashkha Desalination Project

5.2.1 Proposed Management Options

The proposed Al Fashkha springs desalination project has the following components:

- The desalination plant
- The transmission pipelines from the desalination plant to the storage reservoirs for distribution
- The pumping stations and balance tanks along the transmission pipelines
- The water supply and irrigation networks

So far the PWA has not set a clear vision for the anticipated management framework for the proposed Al Fashkha springs desalination project due to the difficulty of the political situation and the constraints due to the critical geo-political conditions of the site of Al Fashkha springs and the surrounding areas.

Certainly PWA needs to formulate a public-private partnership to run this particular non-traditional project. PWA as a governmental body cannot handle the daily operations and associated costs of such a complicated project **(Samhan, 2014)**.

Based on the policy of the Palestinian Water Authority and the recently endorsed water law, the National Water Company (NWC) will be established and owned by the State of Palestine. The National Water Company will be responsible for the supply and sale of bulk water to water undertakings, local authorities, joint water councils and associations. In addition, it will be responsible for the extraction of water resources, desalination of water, and bulk water transmission **(PWA, 2014)**. Accordingly, this National Water Company is supposed to manage the establishment and operation of this desalination project. Moreover, under this new law, regional water utilities will be established and will be responsible for the provision of water and wastewater each within its specified administrative and geographical scope **(PWA, 2014)**. Jericho and Jordan Valley Water Utility will be established to operate the water supply sector in that area so that this potential utility will manage the provision of the desalinated water from Al Fashkha springs **(Kittaneh, 2014)**. Another valid vision is that PWA will establish three main bulk water utilities in the West Bank (North, South, and Middle). In this case, the Middle West Bank Bulk Water Utility will be the one to take over the management of the provision of desalinated water produced from this project. This utility will be the expanded version of the already existing Jerusalem Water Undertaking (JWU) that currently operates in Jerusalem and Ramallah & Al Bireh governorates.

The potential National Water Company, that is assumed to manage the implementation of this project, is supposed to go through a Public-Private Partnership (PPP) to effectively implement such a non-conventional project in the Palestinian context. As illustrated earlier in chapter three, a number of public-private-partnerships are available to manage this type of projects. But the Build-Operate-Transfer (BOT) is the most common partnership in such desalination projects and showed to be the recent global trend to implement projects in this sector.

The desalinated water produced from this proposed project will create a new significant source of water that might be used for both domestic water supply in the beneficiary communities and irrigation purposes for the agricultural activities in the serviced areas. The National Water Company will coordinate with the PWA and the local municipalities for the water supply management options and for possible reallocation of utilized water resources so that the available water resources will be used at the most optimal manner allowing for the best service for the beneficiary populations.

Other than being a water source for domestic use, the desalinated water produced from this project will create a new water source to be used for agricultural and irrigation purposes. This will allow for the reclamation of agricultural lands that are not cultivated due to the lack of the available water. Such lands are available in both Jericho and Al Ubedeyya areas which are the suggested direct beneficiary communities from this project. For the management of the water used for agricultural purposes, it is suggested to form Water Users Associations (WUAs) in the targeted communities that include the farmers and the land owners which will function in full coordination with Ministry of Agriculture (MoA) and PWA. WUAs, which are established according to the new water law to manage the service of supplying irrigation water at the local level in a sustainable manner, will work for the establishment of irrigation systems and allocation of agricultural water shares between farmers. While MoA will constantly work to elevate the capacity of such associations **(MoA, 2014)**.

Moreover, other relevant authorities would play a role in the management of this project. The Ministry of Health (MoH) would have a monitoring program for desalinated water quality that has to be in compliance with the standards set by the Palestinian Standards Institute (PSI). Moreover, the Environment Quality Authority (EQA) would constantly monitor the operation of the desalination plant to investigate for any associated impacts downstream at the desalination plant level or at the upstream level where the desalinated water is utilized particularly for agricultural purposes. The Ministry of Local Government (MoLG) would also have a role in managing this large scheme project through the existing municipalities and local councils by setting out new physical master plans and directing the new built up expansion in the area to integrate the overall goals of this desalination project.

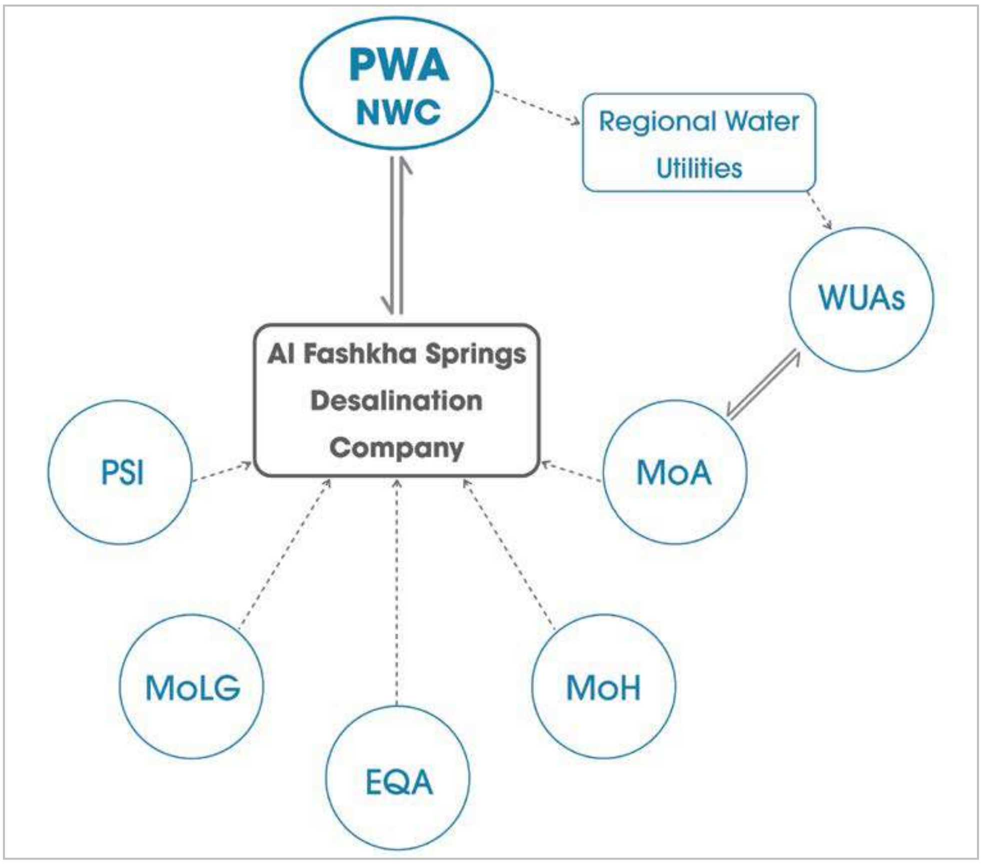


Figure (5-9): Authorities and institutions relevant to the management of the Al Fashkha Springs Desalination Project (source: researcher)

5.2.2 Proposed Project Model Structure

Private sector participation is suggested to establish the structure of this non-conventional project. Build-Operate-Transfer (BOT) agreement is suggested to govern the project. BOT contracts are particularly utilized worldwide in bulk water supply schemes and used for new infrastructure to be built and operated which is the case of the Al Fashkha Springs Desalination project. Such partnership entails that the private partner will provide, on his own human and capital resources, the know-how and expertise to develop, design, construct, operate and maintain the desalination facility and associated infrastructure. This will lower responsibility on the PWA side and transfer it to be higher at the private partner's side in running this non-conventional project. Such responsibility arrangement will give higher potential for the successful management of this project given the public partner (PWA) will still keep a margin of control for this national resource which might be lost under other management options like full privatization (divestiture).

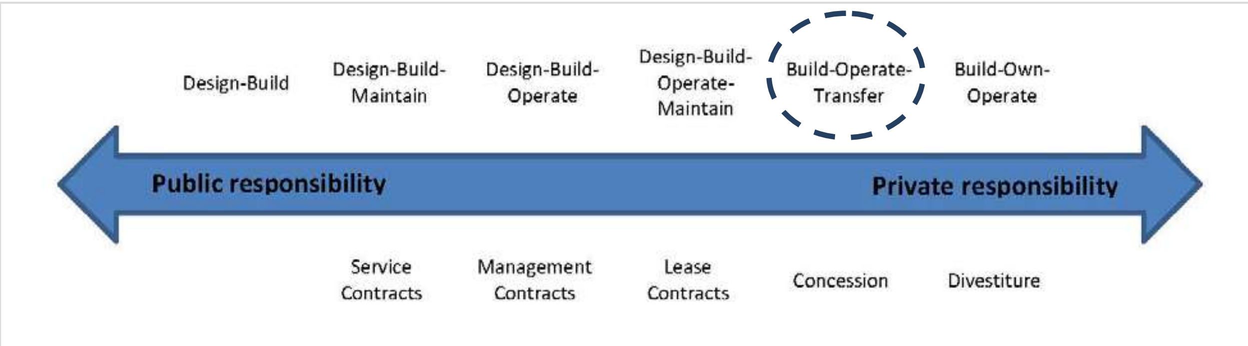


Figure (5-10): Spectrum of responsibilities in PPP contracts (source: researcher)

The BOT agreement is suggested be signed between potential Consortium of international companies (Al Fashkha Springs Desalination Company) and a government agency, which is the Palestinian Water Authority (PWA) or the potential National Water Company. The agreement is proposed to have a period of 25 years. The production of the Plant will be sold to the PWA or the potential National Water Company within the project site where the water company then distributes to the respective community via the established regional water utility through the constructed conveyance system.

Construction of the desalination plant is suggested to go through two phases; 11 MCM/year facility for each. The construction of the first 11 MCM/year is proposed to last 12 months and for the second 11 MCM/year, additional 6 months (total 18 months). The Construction of the facility to be undertaken under an Engineering and Procurement Contract ("EPC Contract") between the Consortium and the Construction Company. The operations and maintenance of the proposed desalination facility will be governed by an Operation & Maintenance Agreement ("O&M Agreement") entered between the Consortium and the Operating and Maintenance Company. The power supply will be secured through a Power Purchase Agreement ("PPA") between the Consortium and the Electricity Company and establishment of self-generating energy supply system onsite. Financial Agreement(s) between the Consortium and external sponsors may be established to secure the require funds to run the project components at different stages.

The diagram in figure (5-11) illustrates the proposed management model for the proposed Al Fashkha desalination project.

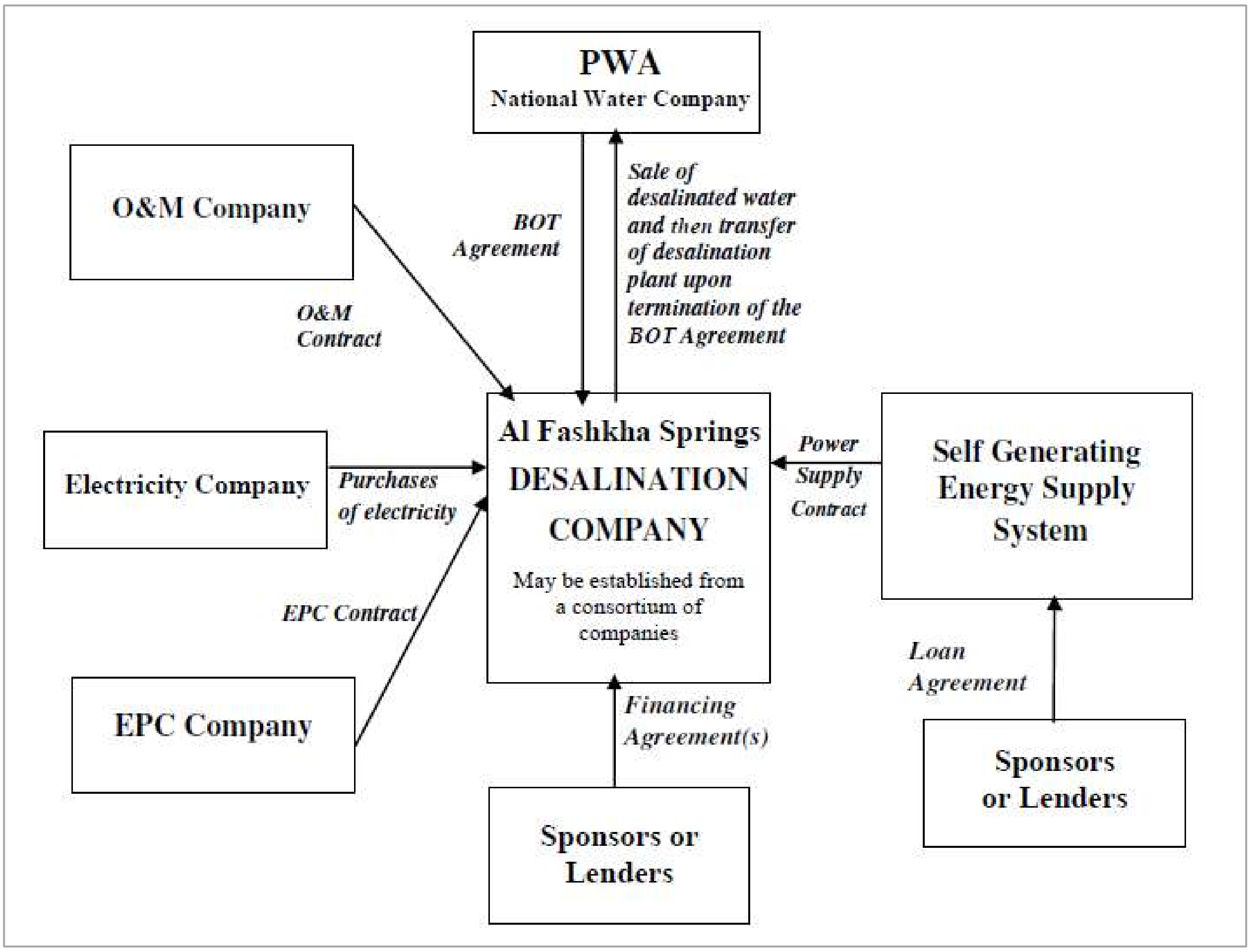


Figure (5-11): Proposed Management Model of Al Fashkha Springs Desalination Project

(Source: researcher)

Chapter Six: Conclusions and Recommendations

6.1 Conclusions

Palestine is currently suffering from a significant gap in the available water supply sources and acute demand needs. Palestinians should look for developing new non-conventional water resources to alleviate the current pressure on the available water resources and to lessen the gap in the supply/demand balance. Such non-conventional resources may include: seawater and brackish water desalination.

The main objective of this research is to assess the financial feasibility and propose management model of the utilization options of the PWA proposed reverse osmosis desalination project for Al Fashkha Springs. In this research, and after discussion and agreement with PWA, two options of utilizing the desalinated water have been analyzed including the “Al Fashkha - Jericho” in Jericho Governorate and “Al Fashkha – Al Ubedeyya” in Bethlehem Governorate. PWA nominated these two communities as they are the closest main urban areas to Al Fashkha springs and they have potential to use the desalinated water for domestic and agricultural purposes.

The Dead Sea springs are considered among the most important springs in the West Bank of which the main group is called Al Fashkha springs. These springs comprise the main amount of brackish water located in the Jordan valley. Al Fashkha springs are located at the north western side of the Dead Sea within a nature reserve that is under control of the Israeli occupation. They are composed of ten springs within close proximity to each other; the volume of water discharged by these springs could be around 80 MCM per year which runs eastwards towards the Dead Sea.

Available records show that Al Fashkha springs have relatively high values of Total Dissolved Solids (TDS) ranging from 1500 to 5000 (mg/l) making them considered as brackish water. During the course of this research work, three water samples were taken from Al Fashkha springs and were tested at PWA and gave the following average results: TDS (2087 mg/l), Salinity (1700 mg/l) and EC (3810 µS/cm). These results show that the water of Ein Al Fashkha is considered as brackish water.

The Al Fashkha – Jericho selected conveyance route has an overall estimated length of (20.5 km) and estimated elevation difference of (150 m) with an overall estimated construction cost of ($6 millions) associated with daily operational non-stopping pumping costs of ($17,000) based on the capacity of the plant to desalinate and pump 22 MCM per year (60,000 m^3/day). The calculated overall cost (desalination and conveyance) per cubic meter is 0.85 $/$m^3$.

The Al Fashkha – Al Ubedeyya selected conveyance route has an overall estimated length of (24.5 km) and estimated elevation difference of (950 m) with an overall estimated construction cost of ($8.8 millions) associated with daily operational non-stopping pumping costs of ($29,000) based on the capacity of the plant to desalinate and pump 22 MCM per year (60,000 m^3/day). The calculated overall cost (desalination and conveyance) per cubic meter is 1.06 $/$m^3$.

High capital investment, specific high-tech knowledge requirement, and lack of local experience could be real challenges in Palestine to manage such non-conventional project. Therefore; a realistic option might be to turn towards the private sector as a provider of both capital and knowledge. Build-Operate-Transfer (BOT) contract is suggested to govern the management of this project.

The BOT agreement is suggested to be signed between potential Consortium of international companies (Al Fashkha Springs Desalination Company) and a government agency, which is the Palestinian Water Authority (PWA) or the potential National Water Company. The agreement is proposed to have a period of 25 years. The production of the Plant will be sold to the PWA or the potential National Water Company within the project site where the water company then distributes to the respective community via the established regional water utility through the constructed conveyance system.

Al Fashkha springs desalination project will be functioning under direct monitoring from the National Water Company and the PWA. But other relevant authorities will be constantly involved throughout the life of the project including but not limited to; MoA, EQA, MoH, MoLG PSI and WUAs.

Construction of the desalination plant is suggested to go through two phases; 11 MCM/year facility for each. The construction of the first 11 MCM/year is proposed to last 12 months and for the second 11 MCM/year, additional 6 months (total 18 months). The Construction of the facility to be undertaken under an Engineering and Procurement Contract ("EPC Contract") between the Consortium and the Construction Company. The operations and maintenance of the proposed desalination facility will be governed by an Operation & Maintenance Agreement ("O&M Agreement") between the Consortium and the Operating and Maintenance Company.

6.2 Recommendations

The main recommendations that came out of this research work are summarized as the following:

- PWA to work on establishing an ongoing monitoring program for implementing quantitative and qualitative analysis of Al Fashkha springs yield water.
- PWA to implement an institutional reform for the water sector according to the endorsed new water law and to work constantly to expedite the establishment of the proposed National Water Company and the proposed regional water utilities.
- PWA to establish in cooperation with the private sector capacity building program in the desalination field and exchange experiences internationally
- Palestinian government to encourage and support the investment in the desalination technologies manufacturing and particularly in the reverse osmosis field
- PWA to create an institutional framework or steering committee that include all relevant authorities to follow up on the development and progress of the Al Fashkha Springs Desalination project
- MoA to introduce the concept of this project to the farmers associations in the targeted communities and work to establish and organize water users associations in these areas
- PWA to work closely with local NGOs to mainstream and integrate the local efforts to support the overall vision of this project.

6.3 Future Research

This study has provided a discussion of financial feasibility and management model of the utilizing options of Al Fashkha Desalination project. As with any study, further research is required to reveal additional information and to take this study to the next level. Some possible further research, which would elaborate on certain issues mentioned throughout this study, may be as follows:

- Study on the technical designs of Al Fashkha Springs desalination plant and associated costs.
- Study on the environmental impacts of the desalination project on the nearby environment
- Studies to track the yield and quality of Al Fashkha springs.
- Studies on the water resources management scenarios and swap options with the availability of the desalinated water from Al Fashkha springs.
- Study on the options of potential crops to be irrigated by desalinated water and the change in the cultivation patterns in the targeted areas of Al Fashkha Springs Desalination project
- Study on the willingness to invest in the agricultural sector in the beneficiary areas from the Al Fashkha desalination project.

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ANNEXES

ANNEX (A)

Site Photographs

(Al Fashkha Springs Nature Reserve)

SITE PHOTOGRAPHS

Al Fashkha Springs Nature Reserve

Photo 1: Entry sign at the Ein Al Fashkha Nature Reserve – Arabic Language

Photo 2: Entry sign at the Ein Al Fashkha Nature Reserve – English Language

Photo 3: The Ein Fashkha Nature Reserve

Photo 4: The source of Ein Al Fashkha at the visitors section in the nature reserve

Photo 5: Swimming pools filled by the Ein Al Fashkha springs water

Photo 6: The Ein Fashkha Nature Reserve – visitors section

Photo 7: Ein Al Fashkha running stream

Photo 8: Water ponds along the route of the Ein Fashkha springs stream

Photo 9: The researcher taking water samples from the Ein Al Fashkha springs source in the visitors section

Photo 10: Water sampling at Ein Al Fashkha

Photo 11: Reeds along the route of the Ein Al Fashkha springs stream to the Dead Sea

Photo 12: The Dead Sea downstream the Ein Al Fashkha springs

ANNEX (B)

Hydraulic Analysis

(Option A: Al Fashkha - Jericho)

ANNEX (B): Hydraulic Analysis

Al Fashkha - Jericho Option – Route #1

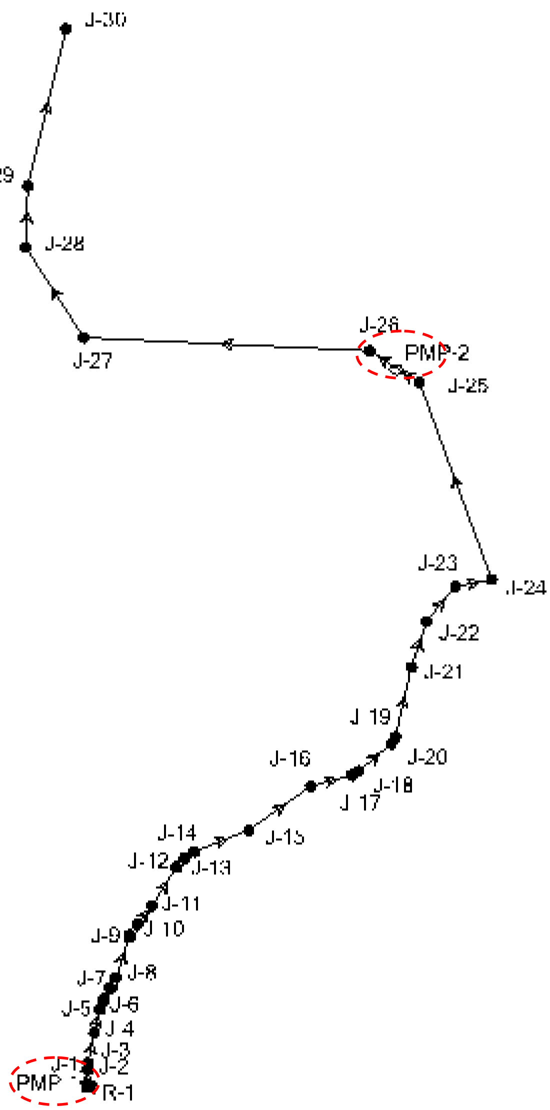


Figure (B-1): Junction Numbers and Location of Pump Stations

Figure (B-2) below shows the pressure and elevation along the path of the transmission pipeline from the desalination plant to Jericho.

Figure (B-2): Pressure and elevation along the path of the transmission pipeline

Table (B-1): Hydraulic Results for Junctions

Label	X (m)	Y (m)	Elevation (m)	Demand (m^3/h)	Hydraulic Grade (m)	Pressure (bars)
J-1	192,767.78	124,707.84	-380.23	0	-231.7	14.54
J-2	192,768.87	124,922.16	-376.14	0	-233.08	14
J-3	192,779.76	125,009.24	-372.78	0	-233.72	13.61
J-4	192,858.67	125,400.79	-371.79	0	-236.66	13.22
J-5	192,923.66	125,698.87	-368.62	0	-238.91	12.7
J-6	192,966.63	125,806.29	-370.21	0	-239.76	12.77
J-7	193,061.98	125,968.09	-367.39	0	-241.14	12.36
J-8	193,136.23	126,111.09	-372.42	0	-242.33	12.73
J-9	193,298.25	126,629.29	-375.01	0	-246.32	12.59
J-10	193,413.64	126,797.13	-374.23	0	-247.82	12.37
J-11	193,597.38	127,030.61	-374.08	0	-250.01	12.14
J-12	193,906.21	127,527.43	-371.31	0	-254.31	11.45
J-13	194,010.27	127,641.56	-371.09	0	-255.45	11.32
J-14	194,141.19	127,728.84	-374.15	0	-256.61	11.5
J-15	194,842.30	128,007.58	-378.33	0	-262.16	11.37
J-16	195,638.15	128,572.49	-385.37	0	-269.34	11.36
J-17	196,166.85	128,715.16	-388.28	0	-273.37	11.25
J-18	196,254.97	128,765.51	-387.76	0	-274.11	11.12
J-19	196,674.09	129,117.40	-388.52	0	-278.14	10.8
J-20	196,727.80	129,204.68	-389.01	0	-278.9	10.78

J-21	196,932.98	130,100.71	-381.78	0	-285.66	9.41
J-22	197,121.48	130,694.34	-379.7	0	-290.24	8.76
J-23	197,493.88	131,140.17	-379.55	0	-294.52	8.32
J-24	197,960.67	131,232.48	-387.48	0	-298.02	8.76
J-25	197,029.78	133,774.34	-343.36	0	-317.94	2.49
J-26	196,393.48	134,175.28	-315	0	-173.47	13.85
J-27	192,722.95	134,344.89	-222.49	0	-200.51	2.15
J-28	191,977.33	135,505.04	-220.07	0	-210.66	0.92
J-29	192,002.72	136,294.94	-220.87	0	-216.47	0.43
J-30	192,495.08	138,317.15	-238.35	2,500	-231.78	0.64

Table (B-2): Hydraulic Results for Pipes

Label	Start Node	Stop Node	Diameter (in)	Length (Scaled) (m)	Material	Flow (m^3/h)	Velocity (m/s)	Headloss (m)	Headloss Gradient (m/m)
P-2	J-1	J-2	24	214	Steel	2500	2.38	1.37	0.006
P-3	J-2	J-3	24	88	Steel	2500	2.38	0.65	0.007
P-4	J-3	J-4	24	399	Steel	2500	2.38	2.94	0.007
P-5	J-4	J-5	24	305	Steel	2500	2.38	2.24	0.007
P-6	J-5	J-6	24	116	Steel	2500	2.38	0.85	0.007
P-7	J-6	J-7	24	188	Steel	2500	2.38	1.38	0.007
P-8	J-7	J-8	24	161	Steel	2500	2.38	1.19	0.007
P-9	J-8	J-9	24	543	Steel	2500	2.38	4	0.007
P-10	J-9	J-10	24	204	Steel	2500	2.38	1.5	0.007
P-11	J-10	J-11	24	297	Steel	2500	2.38	2.19	0.007
P-12	J-11	J-12	24	585	Steel	2500	2.38	4.3	0.007
P-13	J-12	J-13	24	154	Steel	2500	2.38	1.14	0.007
P-14	J-13	J-14	24	157	Steel	2500	2.38	1.16	0.007
P-15	J-14	J-15	24	754	Steel	2500	2.38	5.55	0.007
P-16	J-15	J-16	24	976	Steel	2500	2.38	7.18	0.007
P-17	J-16	J-17	24	548	Steel	2500	2.38	4.03	0.007
P-18	J-17	J-18	24	101	Steel	2500	2.38	0.75	0.007
P-19	J-18	J-19	24	547	Steel	2500	2.38	4.03	0.007
P-20	J-19	J-20	24	102	Steel	2500	2.38	0.75	0.007
P-21	J-20	J-21	24	919	Steel	2500	2.38	6.76	0.007
P-22	J-21	J-22	24	623	Steel	2500	2.38	4.58	0.007
P-23	J-22	J-23	24	581	Steel	2500	2.38	4.27	0.007
P-24	J-23	J-24	24	476	Steel	2500	2.38	3.5	0.007
P-25	J-24	J-25	24	2707	Steel	2500	2.38	19.92	0.007
P-27	J-26	J-27	24	3674	Steel	2500	2.38	27.04	0.007
P-28	J-27	J-28	24	1379	Steel	2500	2.38	10.15	0.007

P-29	J-28	J-29	24	790	Steel	2500	2.38	5.82	0.007
P-30	J-29	J-30	24	2081	Steel	2500	2.38	15.31	0.007
P-31	R-1	PMP-1	24	3	Steel	2500	2.38	0.02	0.007
P-32	PMP-1	J-1	24	22	Steel	2500	2.38	0.16	0.007
P-33	J-25	PMP-2	24	335	Steel	2500	2.38	2.47	0.007
P-34	PMP-2	J-26	24	417	Steel	2500	2.38	3.07	0.007

<u>Jericho Option – Route# 2</u>

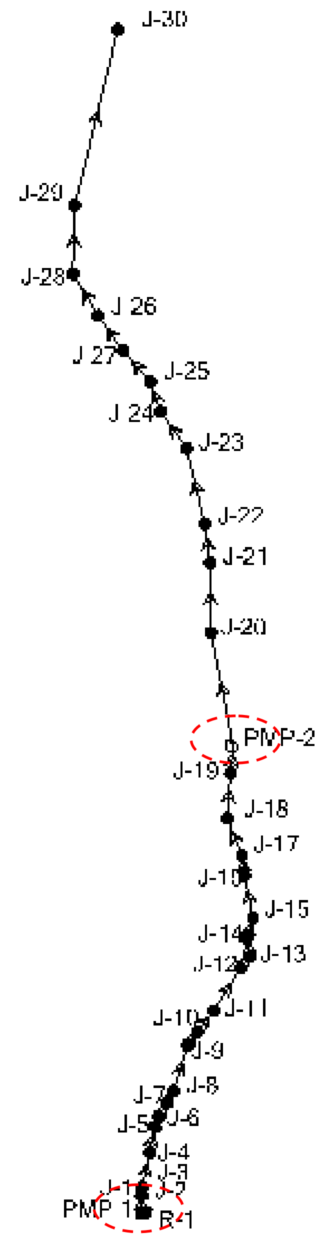


Figure (B-3): Junction Numbers and Location of Pump Stations

Figure (B-4) below shows the pressure and elevation along the path of the transmission pipeline from the desalination plant to Jericho.

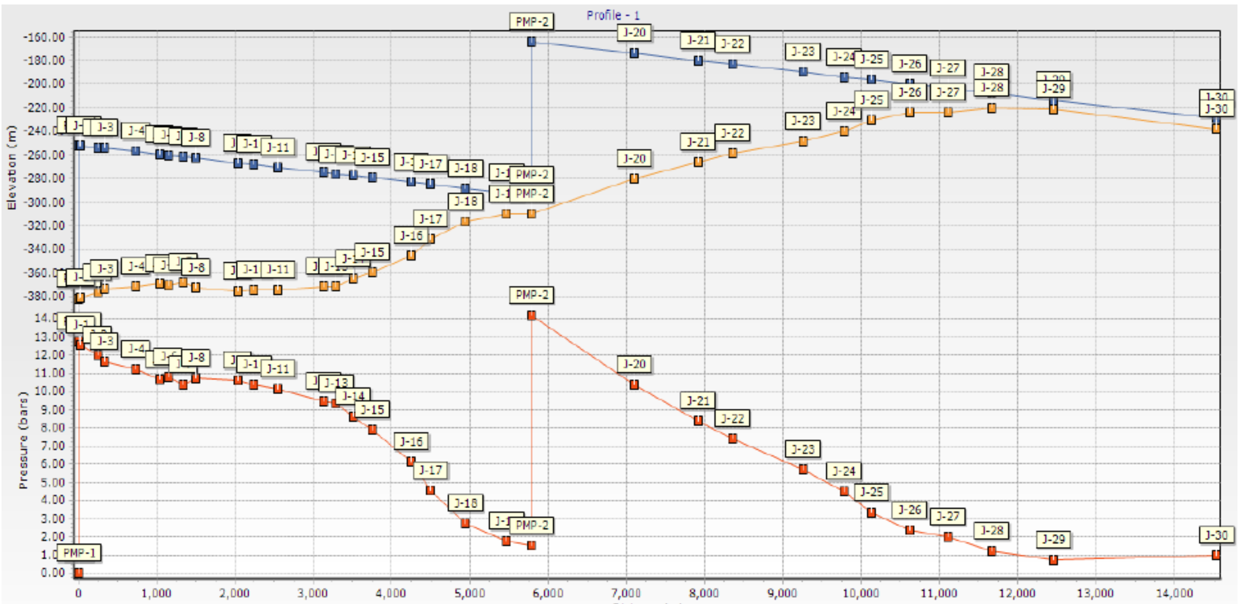


Figure (B-4): Pressure and elevation along the path of the transmission pipeline

Table (B-3): Hydraulic Results for Junctions

Label	X (m)	Y (m)	Elevation (m)	Demand (m^3/h)	Hydraulic Grade (m)	Pressure (bars)
J-1	192,767.78	124,707.84	-380.23	0	-251.7	12.58
J-2	192,768.87	124,922.16	-376.14	0	-253.28	12.02
J-3	192,779.76	125,009.24	-372.78	0	-253.93	11.63
J-4	192,858.67	125,400.79	-371.79	0	-256.87	11.25
J-5	192,923.66	125,698.87	-368.62	0	-259.11	10.72
J-6	192,966.63	125,806.29	-370.21	0	-259.96	10.79
J-7	193,061.98	125,968.09	-367.39	0	-261.34	10.38
J-8	193,136.23	126,111.09	-372.42	0	-262.53	10.76
J-9	193,298.25	126,629.29	-375.01	0	-266.52	10.62
J-10	193,413.64	126,797.13	-374.23	0	-268.02	10.39
J-11	193,597.38	127,030.61	-374.08	0	-270.21	10.17
J-12	193,906.21	127,527.43	-371.31	0	-274.51	9.47
J-13	194,019.33	127,653.63	-371.08	0	-275.76	9.33
J-14	193,981.27	127,861.60	-365.19	0	-277.32	8.6
J-15	194,048.75	128,101.11	-359.6	0	-279.15	7.87

J-16	193,954.48	128,587.58	-345.47	0	-282.79	6.13
J-17	193,922.72	128,823.59	-331.24	0	-284.55	4.57
J-18	193,748.37	129,242.98	-316.07	0	-287.89	2.76
J-19	193,790.40	129,766.04	-309.68	0	-291.75	1.75
J-20	193,567.82	131,376.72	-280.17	0	-173.79	10.41
J-21	193,557.64	132,185.15	-265.4	0	-179.74	8.38
J-22	193,497.15	132,624.36	-258.7	0	-183.01	7.41
J-23	193,285.76	133,500.40	-248.04	0	-189.64	5.72
J-24	192,984.29	133,928.18	-239.58	0	-193.49	4.51
J-25	192,872.34	134,266.35	-230.08	0	-196.11	3.32
J-26	192,549.37	134,624.63	-223.76	0	-199.66	2.36
J-27	192,270.35	135,023.79	-223.83	0	-203.24	2.02
J-28	191,977.33	135,505.04	-220.07	0	-207.39	1.24
J-29	192,002.72	136,294.94	-220.87	0	-213.2	0.75
J-30	192,495.08	138,317.15	-238.28	2,500	-228.52	0.96

Table (B-4): Hydraulic Results for Pipes

Label	Start Node	Stop Node	Diameter (in)	Length (Scaled) (m)	Material	Flow (m^3/h)	Velocity (m/s)	Headloss (m)	Headloss Gradient (m/m)
P-2	J-1	J-2	24	214	Steel	2,500	2.38	1.58	0.007
P-3	J-2	J-3	24	88	Steel	2,500	2.38	0.65	0.007
P-4	J-3	J-4	24	399	Steel	2,500	2.38	2.94	0.007
P-5	J-4	J-5	24	305	Steel	2,500	2.38	2.24	0.007
P-6	J-5	J-6	24	116	Steel	2,500	2.38	0.85	0.007
P-7	J-6	J-7	24	188	Steel	2,500	2.38	1.38	0.007
P-8	J-7	J-8	24	161	Steel	2,500	2.38	1.19	0.007
P-9	J-8	J-9	24	543	Steel	2,500	2.38	4	0.007
P-10	J-9	J-10	24	204	Steel	2,500	2.38	1.5	0.007
P-11	J-10	J-11	24	297	Steel	2,500	2.38	2.19	0.007
P-12	J-11	J-12	24	585	Steel	2,500	2.38	4.3	0.007
P-13	J-12	J-13	24	169	Steel	2,500	2.38	1.25	0.007
P-14	J-13	J-14	24	211	Steel	2,500	2.38	1.56	0.007
P-15	J-14	J-15	24	249	Steel	2,500	2.38	1.83	0.007
P-16	J-15	J-16	24	496	Steel	2,500	2.38	3.65	0.007
P-17	J-16	J-17	24	238	Steel	2,500	2.38	1.75	0.007
P-18	J-17	J-18	24	454	Steel	2,500	2.38	3.34	0.007
P-19	J-18	J-19	24	525	Steel	2,500	2.38	3.86	0.007
P-21	J-20	J-21	24	809	Steel	2,500	2.38	5.95	0.007
P-22	J-21	J-22	24	443	Steel	2,500	2.38	3.26	0.007
P-23	J-22	J-23	24	901	Steel	2,500	2.38	6.63	0.007

P-24	J-23	J-24	24	523	Steel	2,500	2.38	3.85	0.007
P-25	J-24	J-25	24	356	Steel	2,500	2.38	2.62	0.007
P-27	J-26	J-27	24	487	Steel	2,500	2.38	3.58	0.007
P-28	J-27	J-28	24	563	Steel	2,500	2.38	4.15	0.007
P-29	J-28	J-29	24	790	Steel	2,500	2.38	5.82	0.007
P-30	J-29	J-30	24	2,081	Steel	2,500	2.38	15.31	0.007
P-31	R-1	PMP-1	24	3	Steel	2,500	2.38	0.02	0.007
P-32	PMP-1	J-1	24	22	Steel	2,500	2.38	0.16	0.007
P-35	J-25	J-26	24	482	Steel	2,500	2.38	3.55	0.007
P-36	J-19	PMP-2	24	314	Steel	2,500	2.38	2.31	0.007
P-37	PMP-2	J-20	24	1,323	Steel	2,500	2.38	9.73	0.007

ANNEX (C)

Hydraulic Analysis

(Option B: Al Fashkha–Al Ubedeyya)

ANNEX (C): Hydraulic Analysis

Al Fashkha - Ubedeyya Option – Route #1

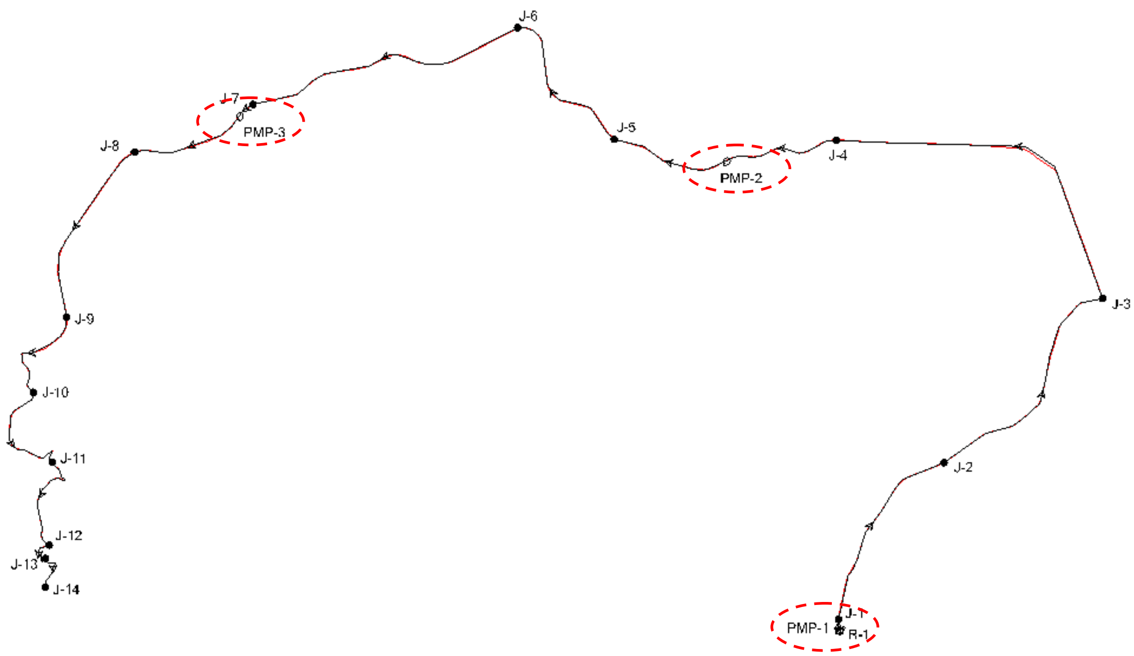


Figure (C-1): Junction Numbers and Location of Pump Stations

Figure (C-2) below is shown the pressure and elevation along the path of the transmission pipeline from the desalination plant to Ubedeyya.

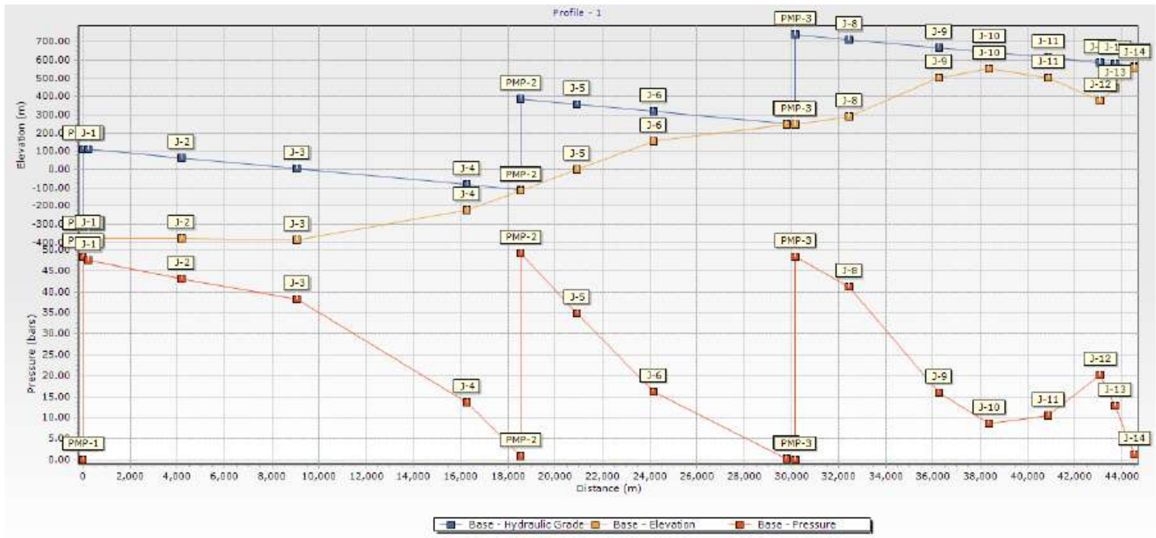


Figure (C-2): Pressure and elevation along the path of the transmission pipeline

Table (C-1): Hydraulic Results for Junctions

Label	X (m)	Y (m)	Elevation (m)	Demand (m³/h)	Hydraulic Grade (m)	Pressure (bars)
J-1	192,768.87	124,922.16	-376.14	0	109.62	47.54
J-2	194,842.30	128,007.58	-378.33	0	62.31	43.13
J-3	197,960.67	131,232.48	-387.48	0	3.95	38.31
J-4	192,722.95	134,344.89	-222.49	0	-81.94	13.76
J-5	188,357.51	134,363.17	-0.14	0	356.23	34.88
J-6	186,460.24	136,557.29	152.69	0	317.37	16.12
J-7	181,254.69	135,049.14	248.28	0	250.02	0.17
J-8	178,924.84	134,112.07	292.17	0	712.31	41.12
J-9	177,592.92	130,864.21	503.41	0	667.09	16.02
J-10	176,937.32	129,389.06	553.41	0	641.64	8.64
J-11	177,309.27	128,009.93	504.29	0	611.67	10.51
J-12	177,246.22	126,385.39	378.66	0	585.45	20.24
J-13	177,172.89	126,124.12	446.77	0	577.69	12.81
J-14	177,166.54	125,561.33	554.56	2,500	567.9	1.3

Table (C-2): Hydraulic Results for Pipes

Label	Start Node	Stop Node	Diameter (in)	Length (Scaled) (m)	Material	Flow (m³/h)	Velocity (m/s)	Headloss (m)	Headloss Gradient (m/m)
P-31	R-1	PMP-1	24	3	Steel	2,500	2.38	0.03	0.012
P-35	J-1	J-2	24	3,955	Steel	2,500	2.38	47.31	0.012
P-36	J-2	J-3	24	4,879	Steel	2,500	2.38	58.36	0.012
P-37	J-3	J-4	24	7,180	Steel	2,500	2.38	85.88	0.012
P-39	J-5	J-6	24	3,248	Steel	2,500	2.38	38.86	0.012
P-40	J-6	J-7	24	5,630	Steel	2,500	2.38	67.35	0.012
P-42	J-8	J-9	24	3,780	Steel	2,500	2.38	45.22	0.012
P-43	J-9	J-10	24	2,127	Steel	2,500	2.38	25.44	0.012
P-44	J-10	J-11	24	2,506	Steel	2,500	2.38	29.97	0.012
P-45	J-11	J-12	24	2,192	Steel	2,500	2.38	26.22	0.012
P-46	J-12	J-13	24	649	Steel	2,500	2.38	7.76	0.012
P-47	J-13	J-14	24	819	Steel	2,500	2.38	9.79	0.012
P-48	PMP-1	J-1	24	236	Steel	2,500	2.38	2.82	0.012
P-49	J-4	PMP-2	24	2,291	Steel	2,500	2.38	27.4	0.012
P-50	PMP-2	J-5	24	2,377	Steel	2,500	2.38	28.44	0.012
P-51	J-7	PMP-3	24	361	Steel	2,500	2.38	4.32	0.012
P-52	PMP-3	J-8	24	2,291	Steel	2,500	2.38	27.4	0.012

Ubedeyya Option – Route #2

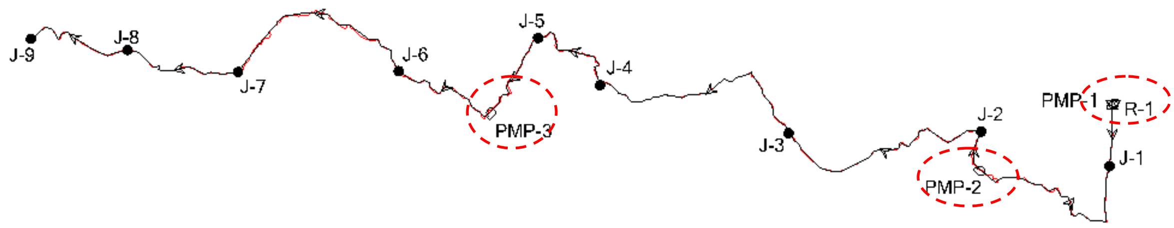


Figure (C-3): Junction Numbers and Location of Pump Station

Figure (C-4) below shows the pressure and elevation along the path of the transmission pipeline from the desalination plant to Ubedeyya.

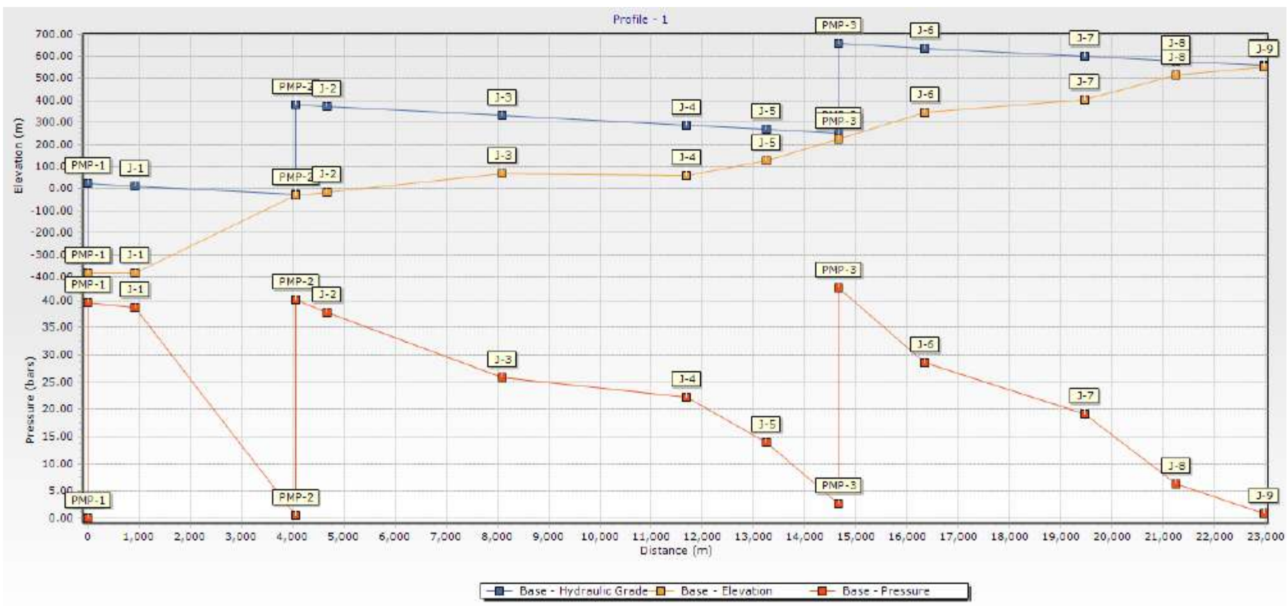


Figure (C-4): Pressure and elevation along the path of the transmission pipeline

Table (C-3): Hydraulic Results for Junctions

Label	X (m)	Y (m)	Elevation (m)	Demand (m^3/h)	Hydraulic Grade (m)	Pressure (bars)
J-1	192,742.31	123,805.21	-382.52	0	12.36	38.65
J-2	190,891.36	124,303.51	-14.32	0	372.58	37.87
J-3	188,120.79	124,280.80	67.01	0	331.53	25.89
J-4	185,405.66	124,973.77	61.89	0	288.5	22.18
J-5	184,512.01	125,652.55	127.88	0	269.91	13.9
J-6	182,503.87	125,177.02	345	0	637.79	28.65
J-7	180,192.56	125,162.89	404.28	0	600.53	19.21
J-8	178,598.88	125,479.31	513.61	0	579.14	6.41
J-9	177,209.08	125,640.34	550.13	2,500	558.71	0.84

Table (C-4): Hydraulic Results for Pipes

Label	Start Node	Stop Node	Diameter (in)	Length (Scaled) (m)	Material	Flow (m^3/h)	Velocity (m/s)	Headloss (m)	Headloss Gradient (m/m)
P-31	R-1	PMP-1	24	3	Steel	2,500	2.38	0.03	0.012
P-48	PMP-1	J-1	24	927	Steel	2,500	2.38	11.08	0.012
P-57	J-6	J-7	24	3,115	Steel	2,500	2.38	37.26	0.012
P-59	J-8	J-9	24	1,708	Steel	2,500	2.38	20.43	0.012
P-60	J-4	J-5	24	1,554	Steel	2,500	2.38	18.58	0.012
P-65	J-2	J-3	24	3,432	Steel	2,500	2.38	41.05	0.012
P-66	J-3	J-4	24	3,597	Steel	2,500	2.38	43.03	0.012
P-67	J-1	PMP-2	24	3,132	Steel	2,500	2.38	37.47	0.012
P-68	PMP-2	J-2	24	611	Steel	2,500	2.38	7.31	0.012
P-69	J-7	J-8	24	1,788	Steel	2,500	2.38	21.39	0.012
P-70	J-5	PMP-3	24	1,401	Steel	2,500	2.38	16.76	0.012
P-71	PMP-3	J-6	24	1,703	Steel	2,500	2.38	20.37	0.012

ANNEX (D)

Pumps Characteristics

caprari
pumping power

Technical data

COMPANY WITH INTEGRATED MANAGEMENT SYSTEM CERTIFIED BY DNV
= ISO 9001:2000 =
ISO 14001:2004

PM 125/ 5 A

Requested data

Flow	87 l/s
Head	494 m
Fluid	Clean Water
Pumpe type	Single head pump
No. of pumps	1

Operating pump data

Flow	85.5 l/s
Head	476 m
Shaft power	524 kW
Efficiency	76.1%
Head H(Q=0)	653 m
Discharge connection	DN 125 (UNI PN40)

Motor data

Frequency	50 Hz
Rated voltage	400 V
Nominal speed	2950 1/min
Number of poles	2
Rated power P2	355 kW
Rated current	0 A
Motor type	3~
Insulation class	F
Degree of protection	IP 55

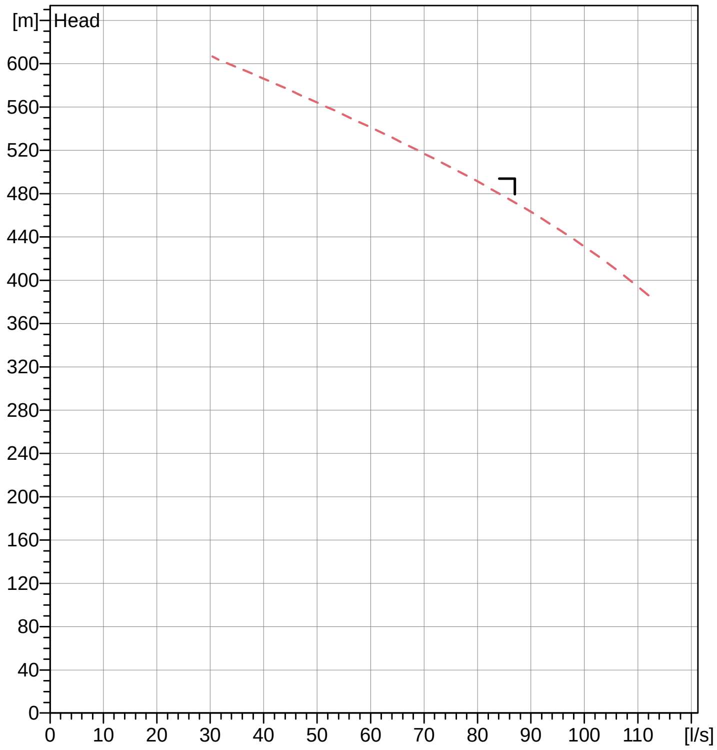
Operating limits

Starts per hour max.	5
Maximum temperature of pumped fluid	90 °C
Maximum content of solid	20 g/m³
Max. Density	998 kg/m³
Max. viscosity	1 mm²/s
P2 Max shaft power	

General data

Weight	2675 kg

Materials

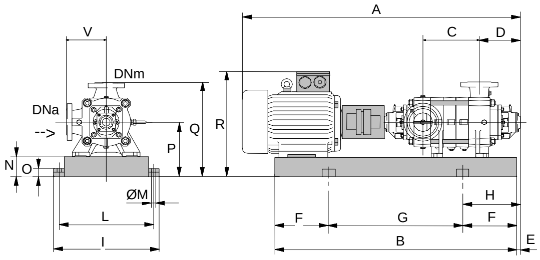


Operating data ISO 9906 GRADE 2

Q [l/s]	H [m]	P [kW]	Eff. [%]	NPSH [m]

Dimensions mm

A = 2937
B = 2680
C = 545
D = 337
DNa = 150/PN8-25
DNm = DN 125 (UNI PN40)
E = 181
F = 400
G = 1880
H = 581
I = 870
L = 820
M = 22
N = 180
O = 50
P = 535
Q = 855
R = 1080
V = 320



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caprari
pumping power

Technical data

COMPANY WITH INTEGRATED MANAGEMENT SYSTEM CERTIFIED BY DNV
= ISO 9001:2000 =
ISO 14001:2004

PMS 125/ 4 A

Requested data

Flow	87 l/s
Head	405 m
Fluid	Clean Water
Pumpe type	Single head pump
No. of pumps	1

Operating pump data

Flow	84.5 l/s
Head	383 m
Shaft power	417 kW
Efficiency	76.2%
Head H(Q=0)	523 m
Discharge connection	DN 125 (UNI PN64)

Motor data

Frequency	50 Hz
Rated voltage	400 V
Nominal speed	2950 1/min
Number of poles	2
Rated power P2	355 kW
Rated current	0 A
Motor type	3~
Insulation class	F
Degree of protection	IP 55

Operating limits

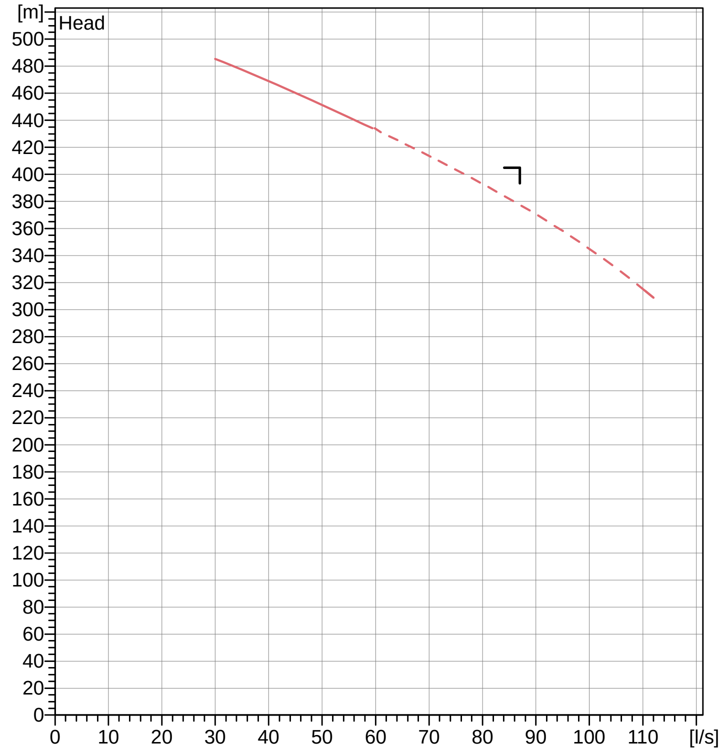
Starts per hour max.	5
Maximum temperature of pumped fluid	90 °C
Maximum content of solid	20 g/m³
Max. Density	998 kg/m³
Max. viscosity	1 mm²/s
P2 Max shaft power	522 kW

General data

Weight	2635 kg

Materials

Delivery casing (PMS)	Nodular cast iron
Suction casing	Cast iron
Impeller	Cast iron
Wear ring	Cast iron
Intermediate bowl	Cast iron
Casing	Nodular cast iron
Shaft	Stainless steel
Shaft bush	Stainless steel
Seal ring	Nitrile rubber
Ball bearings	Steel
Stuffing box	Cast iron
Packing	Graphited cord



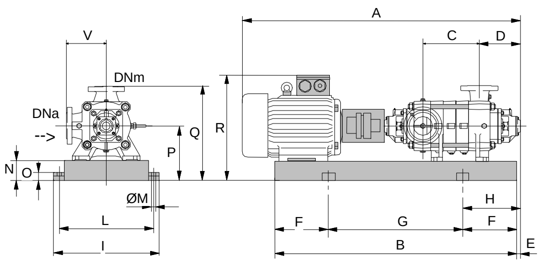
Operating data

ISO 9906 GRADE 2

Q [l/s]	H [m]	P [kW]	Eff. [%]	NPSH [m]

Dimensions mm

A = 2837
B = 2180
C = 445
D = 337
DNa = 150/PN8-25
DNm = DN 125 (UNI PN64)
E = 181
F = 350
G = 1480
H = 531
I = 870
L = 820
M = 22
N = 180
O = 50
P = 535
Q = 855
R = 1080
V = 320



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PumpTutor Version 3.2 - 30.01.2008 (Build 30)

Please check no. of line shafts and critical speed.

P16C/10/55/6A

Requested data

Flow	96.4 l/s
Head	150 m
Fluid	Clean Water
Pumpe type	Single head pump
No. of pumps	1

Operating pump data

Flow	96.8 l/s
Head	151 m
Shaft power	194 kW
Efficiency	73%
Head H(Q=0)	174 m
Discharge connection	DN250

Motor data

Frequency	50 Hz
Rated voltage	400 V
Nominal speed	1450 1/min
Number of poles	4
Rated power P2	250 kW
Rated current	0 A
Motor type	3~
Insulation class	F
Degree of protection	IP 55

Operating limits

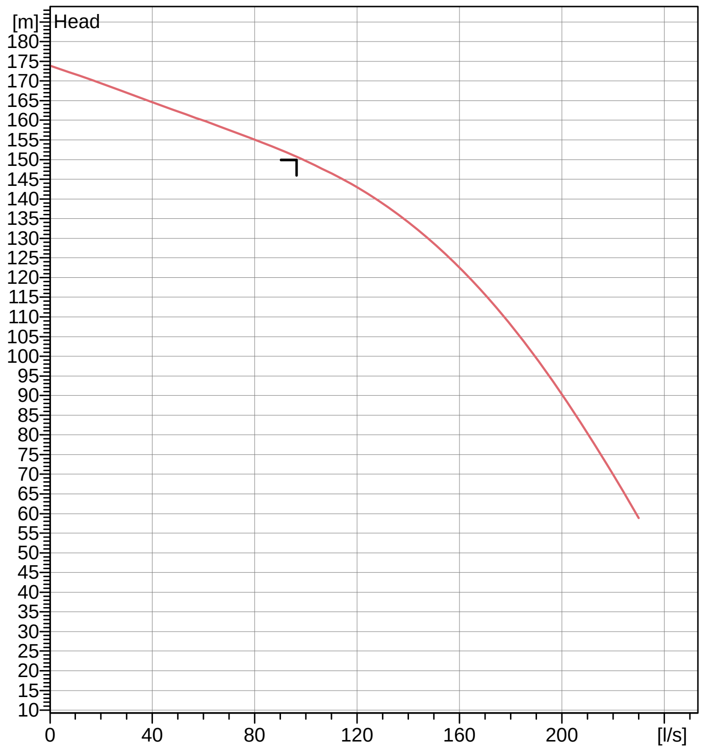
Starts per hour max.	20
Maximum temperature of pumped fluid	40 °C
Maximum content of solid	40 g/m³
Max. Density	998 kg/m³
Max. viscosity	1 mm²/s

General data

Weight	2923 kg

Materials

PUMP CONSTRUCTION	.
Delivery casing	Cast iron
Suction casing	Cast iron
Intermediate casing	Cast iron
Impeller	Cast iron
Wear ring	Cast iron
Pump shaft	Steel
Journal bearing	Rubber
LINE SHAFT CONSTR.	.
Column pipe	Steel
Shaft	Steel
Shaft bush	Chrome plated steel
Box coupling	Stainless steel
Line ball bearing	Rubber
DRIVE UNIT CONSTR.	.
Base	Cast iron or Steel
Drive unit latern bracket	Cast iron or Steel
Strainer	Galvanized Steel



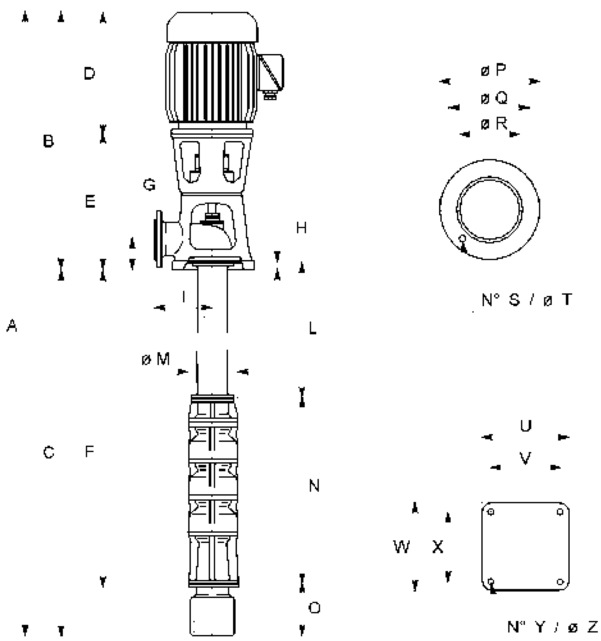
Operating data

ISO 9906 GRADE 2

Q [l/s]	H [m]	P [kW]	Eff. [%]	NPSH [m]

Dimensions mm

A = 7094
B = 2210
C = 4836
D = 1190
DN = 250
E = 1020
F = 4520
G = 220
H = 48
I = 400
L = 2500
M = 384
N = 2020
No S = 12
No Y = 4
O = 364
P = 405
Q = 355
R = 250
T = 25
U = 640
V = 550
W = 640
X = 550
Z = 30



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