Economics of Using Desalinated Sea Water and Brackish Water in Supplementary Irrigation

By

Somea Ibrahim Khoder
B.Sc. Civil Engineering**,** Syria

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
Irrigation and Hydraulics
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Summary. At present, about 40% of the world's population is suffering from serious water shortages. This is because of the rapid increase of population, and pollution that limit the use of fresh water resources. In addition, according to IPCC the rainfall and water resources will decrease significantly because of climate change. Concerns about the sustainability of freshwater supplies are fostering the interest in desalination as a one possible solution to the increased water demand especially in agriculture sector. This study investigates the economics of using the desalinated salt water and brackish water especially in supplementary irrigation. To find an optimum solution linking the economic cost of the desalination plant technology with the economic return of water used in supplementary irrigation by finding breakeven curves for each crop and analysis for change variables. Desalination presents the main opportunity to meet the increased demand and reduce the food gap by providing freshwater not only from the sea, but also from brackish groundwater. This research offers solution to cover loss in cost due to reduction of water, using supplement irrigation.

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Finally, this work is dedicated to the spirit of my mother, and Jasmine's land, cradle of civilization my home SYRIA.

Somea

ABSTRACT

Only 6 percent of all the Earth's water is fresh, while 94 percent is salt water from the oceans. At present, about 40% of the world's population is suffering from serious water shortages. This is because of the rapid increase of population and pollution that limit the use of fresh water resources. In addition, according to the Intergovernmental Panel on Climate Change (IPCC) the rainfall and water resources will decrease significantly in the Arab countries because of the expected increase in temperature that will lead to increasing evaporation losses, losses in soil moisture, and decrease in the groundwater levels. Concerns about the sustainability of freshwater supplies are fostering the interest in desalination as a one possible solution to increase water demand. It is expected that the agricultural sector will be significantly affected and the water availability for this sector will be decreased. In the Arab Region, desalination presents the main opportunity to meet the increased demand and reduce the food gap by providing freshwater not only from the sea, but also from brackish groundwater. This study investigates the economics of using the desalinated sea water and brackish water especially in supplementary irrigation to find a solution linking the economic cost of the desalination plant technology used in the region with the economic return of water used in supplementary irrigation. This has been achieved by studying the economics of using the desalinated water in supplementary irrigation and the influence of variables change (cultivated area, maximum yield, feed salinity, and crop sale price) on the cost by calculating breakeven curve for every crop.

First, cost equations of desalination are fitted as a function of capacity and degree of feed salinity using regression analysis by using Excel. Next, yield reduction under stress of water shortage is studied for different stages of growth, and its influence on the loss of profit was assessed by using the CROPWAT program. Finally, breakeven curves for each crop are established and compared. This research offers a solution to cover loss in profit due to lack of sufficient water resources, using supplementary irrigation. Desalination offers a good benefit, especially for large capacity and large

area of relatively profitable crops. Future studies must focus on reduction the cost of desalination.

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Symbols

BEP	Breakeven point($/$m^3$)
C	Capacity (m^3/day)
CG	Crop gain due to water deficit in each stage
CG max	Maximum crop gain due to ET_{max}
CWR	Crop water requirements (m^3)
Dr	Root zone depletion [mm].
ea	Actual vapors pressure [kPa],
es- ea	Saturation vapour pressure deficits [kPa],
es	Saturation vapors pressure [kPa],
ET0	The reference evaporation (mm/day)
Eta	Actual crop evaportranspiration (mm/day)
ETc	(ET_{max}) is daily evaportransporation (Et_c in mm) of crop under irrigation or Maximum evapotranspiration.
Etm	crop evaportransporation for standard conditions (no water stress) (mm/day)
ETm	Refers to conditions when water is adequate for unrestricted growth and development.
G	Soil heat flux density [MJ m^{-2} day^{-1}],
ha	Hectare (area unit)
Ks	A dimensionless transpiration reduction factor dependent on available soil water [0 - 1].
n	The number of data
p	Fraction of TAW that a crop can extract from the root zone without suffering water stress.
Q mix	The amount of water that is mixed with salt water to get proper salinity of plant. (m^3/day).
RAW	Readily available water
Rn	Net radiation at the crop surface [MJ m^{-2} day^{-1}],
SI	Supplementary irrigation (m^3)
T	Air temperature at 2 m height above ground level [°C],
TAW	Total available soil water in the root zone [mm].
U2	Wind speed at 2 m height [m s^{-1}],
Y a	Actual crop yield (ton/hectare)
Y m	Maximum expected crop yield for standard conditions(ton/hectare)

$\boldsymbol{Y}_{\mathbf{cal}}$	Predicted data
$\boldsymbol{Y}_{\mathbf{obs}}$	Observed data
YR	Yield reduction
lp	Length of growing period in days
γ	Phycrometic constant ([kPa °C^{-1}].)
Δ	Slop vapour pressure curve [kPa °C^{-1}],

Abbreviations

ABVC	Absorption Vapor Compression
ADVC	Adsorption Vapor Compression
BW	Brackish water
CVC	Chemaical Vapor Compression
ED	Electro-Dialysis
FAO	Food and Agriculture Organization
HDH	Humidification - Dehumidification
HBW	High brackish water
IDA	International Desalination Association
IPCC	Intergovernmental Panel on Climate Change
MED	Multi Effect Desalination
MEE	Multi Effect Evaporation
MSF	Multi Stage Flash
MVC	Mechanical Vapor Compression
RO	Reserve Osomosis
SEE	Single Effect Evaporation
TDS	Total disolved solids
TVC	Thermal Vapor Compression

CHAPTER ONE

Introduction

1-1 General:

As a result of increasing population growth, some Arab countries with relatively existing sufficient water resources (such as Lebanon, Egypt, Morocco, Syria) will suffer from severe water problems and will join the countries under the water poverty limit by the year 2050. Also, the Inter-governmental Panel on Climate Change (IPCC) has noticed that the rainfall and water resources will decrease significantly in the Arab countries by the year 2050 (IPCC, 2009). IPCC (Inter-governmental Panel on Climate Change) suggested that the expected increase in temperature will lead to increase in evaporation losses, loss in soil moisture, and decrease in groundwater levels. As a result of the future shortage in water resources in these Arab countries, it is expected that the agricultural sector will be significantly affected and water availability for this sector will decrease. Accordingly, the development of non-conventional water resources such as desalination of both sea water and brackish water is of great importance in meeting the water needs of the Arab countries.

Desalination of sea water and brackish groundwater for public drinking water supply is adopted in many parts of the world in areas where the demand is increasing beyond the supply. A seawater desalination process separates saline seawater into two streams: a fresh water stream containing a low concentration of dissolved salts and a concentrated brine stream. Salt water is divided on the basis of the total amount of water-soluble salts in parts per million as shown in Table (1-1).

Table (1-1) Water salinity classification

Fresh water	**Brackish water**	**salt water**	**Brine Water**
<500 ppm	500-20,000 ppm	20,000-50,000 ppm	>50,000 ppm

There are many techniques used for the desalination of sea water, including thermal methods, flash evaporation method, multi-stage distillation, multi-effect distillation using solar energy, steam distillation, and membranes methods (e.g., electric power methods sorting membrane dialysis and reverse electricdialysis). The technology used for desalination depends on the quality of the water source and the desired degree of desalination of produced water. The salinity of seawater ranges from 20,000 to 50,000 ppm, and the salinity of the brackish groundwater ranges from 500 to 20,000 ppm. In order to select the adequate technology to desalinate water, consideration should be taken into accounts, which are:

- The quality of feed water source and the concentration of total dissolved solids (TDS)
- Sources of energy available, such as oil, electricity, gas, or renewable sources (e.g., wind, solar energy).
- Desalination plant to be close to the usage area.
- Expected uses of water (industrial, agriculture, domestic ...etc).

1-2 Problem Definition:

Concerns about the sustainability of freshwater supplies are fostering the interest in desalination as one possible solution to the increased water demand. Sandia National Laboratories announced that more than 70 billion dollars will be spent worldwide over the next 20 years to design and build new desalination plants and facilities. In the Arab Region, desalination presents the main opportunity to meet the increased demand and reduce the food gap by providing freshwater not only from the sea, but also from brackish groundwater. Unfortunately, previous studies did not thoroughly investigate the economics of using the desalinated salt water and brackish water especially in supplementary irrigation. Accordingly, this study aimed at providing some efforts in this regard.

1-3 Research Objectives:

The main objective of this research is to link the economic cost of the desalination plant technologies used in the region with the economic return of water used in supplementary irrigation. This could be obtained by achieving the following specific objectives:

- Establishing a relation between the cost of desalination process and the capacity of feed salinity for different desalination techniques in the region.
- Examining the economics of using desalinated sea water and brackish water in supplementary irrigation, for different crops.
- Deriving curves that represent breakeven between the amounts of available water with the cost of water, for getting optimum profit for each crop. Therefore assessing the feasibility of using desalination for supplementary irrigation.

1-4 Outlines of the Thesis:

This thesis consists of seven chapters, the details of each chapter and their interrelations are as follows:

- **Chapter (1): Introduction**

This Chapter presents general information about the research point, problem definition, objectives and the thesis contents.

- **Chapter (2): Desalination Processes**

This chapter covers the definition of desalination, overview of desalination technologies, types of desalination processes, factors affecting technology selections and product cost, elements of economic calculations, advantages and disadvantages of each type of technology, ranges of salinity of sea water and brackish water, and limits of product salinity for different uses in each sector (municipal, agriculture, industrial.....etc).

- **<u>Chapter (3): Supplementary Irrigation</u>**

This chapter illustrates information about crops, factors affecting crop water requirements and supplementary irrigation, yield reduction based on CROPWAT computer program, and equations developed in previous studies.

- **<u>Chapter (4): Literature Review</u>**:

This chapter gives a review of previous studies related to desalination processes as well as supplementary irrigation.

- **<u>Chapter (5): Methodology:</u>**

This chapter describes the methodology used in this research:

1. Compiling all available data about methods and techniques of desalination and their cost. This is conducted by using internet resources and communication with different desalination companies in Egypt.
2. Constructing cost curves for each desalination technique showing the cost of desalination as a function of the quantity of water and the degree of feed salinity.
3. A synthetic analysis is conducted to study the economics of using desalinated water in the supplementary irrigation. In this analysis different crops will be selected and the feasibility for preventing yield loss by using supplementary irrigation will be evaluated at different levels of supplementary water requirements.
4. Effect of the price, maximum yield, and the amount of reduction of water as decision variables on the economic return is also studied.

- **<u>Chapter (6): Application and Results Analysis:</u>**

This chapter presents the results of analysis:

- Establish curves that can be used to relate the cost of desalination to the quantity of water for each degree of feed salinity.

- Provide a decision tool that could examine the economics of using desalinated salt water or brackish water in supplementary irrigation.

- **<u>Chapter (7): Conclusions and Recommendations :</u>**

This chapter gives the main study conclusions, general remarks, and recommendations for future research.