An-Najah National University
Faculty of Graduate Studies

Numerical Simulation of Seawater Intrusion in Response to Climate Change Impacts in North Gaza Coastal Aquifer Using SEAWAT

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Dedication

I proudly dedicate this thesis to the soul of my father, to my beloved mother, as I always feel her prayers in all aspects of my life, and finally my husband Bashar for his great encouragement and support, and my three lovely children Ahmad, Mohammad and Abdullah.

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Reem F. Sarsak

Nablus, 2011

الإقـــرار

أنا الموقعة أدناه مقدمة الرسالة التي تحمل العنوان:

Numerical Simulation of Seawater Intrusion in Response to Climate Change Impacts in North Gaza Coastal Aquifer Using SEAWAT

دراسة تأثير التغيرات المناخية على دخول المياه المالحة الى الحوض الجوفي الساحلي في شمال غزة باستخدام SEAWAT

أقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء مـــا تمــت الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أية درجة علمية أو بحث علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's name: | **اسم الطالبة:**

Signature: | **التوقيع:**

Date: | **التاريخ:**

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ABBREVIATIONS

[Cl]	Chloride Concentration
DJF	December, January and February
EM	Eastern Mediterranean
EMCC	Engineering and Management Consulting Center
GIS	Geographical Information System
JJA	June, July, and August
l/c/d	Liter Per Capita Per Day
m^3	Cubic Meter
m^3/h	Cubic Meter Per Hour
m^3/year	Cubic Meter Per Year
MCM	Million Cubic Meter
MCM/yr	Million Cubic Meter per Year
mg/l	Mille Gram per Liter
MoA	Ministry of Agriculture
MOPIC	Ministry of Planning and International Cooperation
NOAA	National Oceanic and Atmospheric Administration
PCBS	Palestinian Central Bureau of Statistics
PWA	Palestinian Water Authority
RCM	Regional Climate Modeling
SEAWAT	A Computer Program For Simulation of Three-Dimensional Variable-Density Groundwater Flow
WHO	World Health Organization
WWTP	Wastewater Treatment Plant

NUMERICAL SIMULATION OF SEAWATER INTRUSION IN RESPONSE TO CLIMATE CHANGE IMPACTS IN NORTH GAZA COASTAL AQUIFER USING SEAWAT

By
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ABSTRACT

The development and management of fresh groundwater resources in coastal aquifers are seriously constrained by the presence of seawater intrusion. Seawater intrusion is a process that occurs in almost all coastal aquifers, where they are in hydraulic connection with seawater. Over the years, many models have been developed to simulate and study the problems related to seawater intrusion. Numerical models provide effective tool to understand groundwater problems. This research presents simulation of seawater intrusion in North Gaza coastal aquifer in response to climate change impacts using SEAWAT. Climate change is already beginning to transform life on earth. Around the globe, seasons are shifting, rainfalls are decreasing, temperatures are climbing so water demands are increasing and sea levels are raising causing seawater intrusion. If we don't act now, climate change will permanently alter the lands and waters we all depend upon for survival.

Various scenarios were simulated to study the impacts of climate change into seawater intrusion at the study area due to sea level rise, recharge and pumping rates variability.

The results show that the in-land movement for seawater intrusion for the reference scenario (Scenario 1) which reflects the continuation of the current situation is about 4,200 m with a rate of 65 m/yr. The most critical extent of salinity was found in Scenario 4 (Recharge -30%) which causes in-land intrusion movement of about 4,500m with a rate of 80 m/yr. While the in-land intrusion movement due to increasing pumping rates as in Scenario 2 (pumping +30%) was about 4,300 m with a rate of 70 m/yr. The best results for the in-land intrusion were found in Scenario 6 which considered as a management scenario since it is dealing with the proposed strategic plans that were prepared by PWA to solve the high salinity problems and water deficit in Gaza aquifer, the in-land intrusion movement for this scenario was about 2,900m with a rate of 35 m/yr.

As a result, seawater intrusion in the study area is very sensitive to recharge decrease as compared to pumping rates increase. As such, the most critical impact on seawater intrusion for the study area is recharge variability due to climate change. Therefore, it is recommended to search for new resources such as desalination of seawater and brackish water in addition to reuse of treated wastewater in order to reduce the gap in both domestic and agricultural sectors respectively in case of recharge decrease due to climate change.

CHAPTER ONE

INTRODUCTION

1.1 General Background

Global warming and climate change have been an active research topic in the last decade. Natural events and human activities are believed to be contributing to an increase in average global temperatures. This is caused primarily by increases in "greenhouse" gases such as Carbon Dioxide (CO_2) (Global Issues, 2010).

As explained by the National Oceanic and Atmospheric Administration (NOAA) in the US agency, there are seven indicators (see Figure 1) that would be expected to increase in a warming world, and three indicators would be expected to decrease. Water expands when heated, and sea levels are expected to rise due to climate change. Rising sea levels will also result as the polar caps begin to melt (Global Issues, 2010).

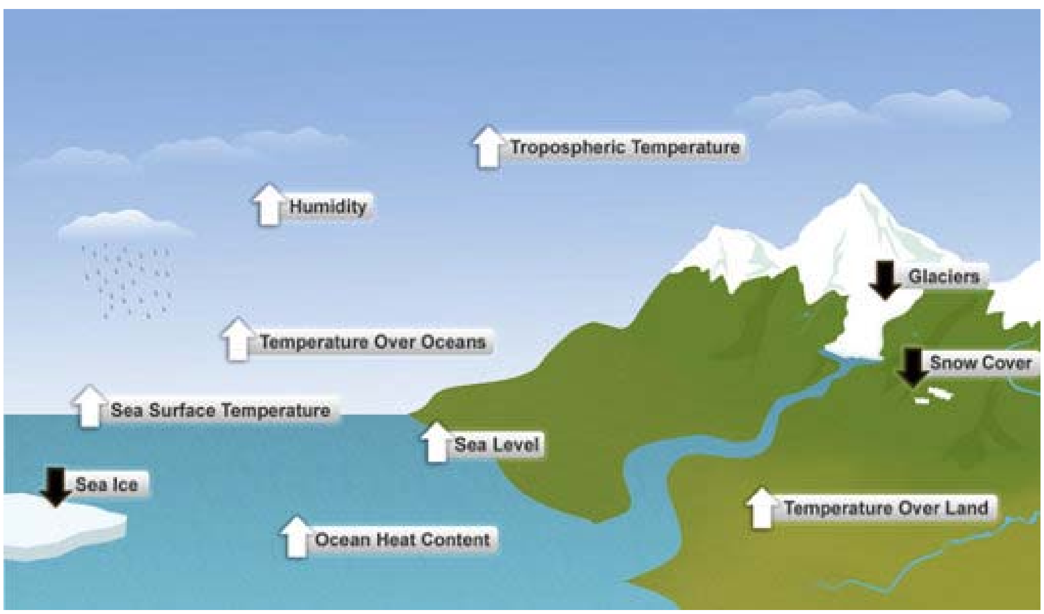


Figure (1): Warming world indicators
(Source: NOAA, July 2010)

Global climate change is interrupting the water circulation balance by changing rates of precipitation, recharge, discharge, and evapotranspiration. The Intergovernmental Panel on Climate Change (IPCC, 2007) makes “changes in rainfall pattern due to climate changes and consequent shortage of available water resource” a high priority as the weakest part among the effects of human environment caused by future climate changes. Groundwater, which occupies a considerable portion of the world’s freshwater resources, is related to climate change via surface water such as rivers, lakes, and marshes, and direct interactions, being indirectly affected through recharge (Lee, 2009).

Climate change is already beginning to transform life on earth. Around the globe, seasons are shifting, rainfalls are decreasing, temperatures are climbing so water demands are increasing and sea levels are raising causing seawater intrusion. If we don't act now, climate change will permanently alter the lands and waters we all depend upon for survival (IPCC, 2007).

Seawater intrusion is a common contamination problem in coastal areas. It affects, mainly, arid and semi-arid zones, where dense population and urban development are coupled to scarce water resources and require intense exploitation of groundwater. The Mediterranean coast is a good example (Elina, 2006).

Gaza coastal aquifer met with the above problems such as dense population semi- arid and water scarcity, for that it is a good example for seawater intrusion problem due to over pumping and climate change impacts such as recharge decrease and sea level rise.

1.2 Objectives

The main objective of this research is to assess the impacts of climate change into seawater intrusion in North Gaza coastal aquifer using SEAWAT.

The specific objectives in this research are to study the following:

- The impact of pumping rate variability.
- The impact of maximum sea level rise.
- The impact of recharge variability.
- The extreme impact of climate change due to maximum sea level rise in addition to recharge variability.
- Management solutions for water scarcity by using additional water resources.

1.3 Research Questions

The following are the research questions:

1. What is the impact of climate change on seawater intrusion in North Gaza coastal aquifer?
2. What are the potential management scenarios that can be considered for the control of seawater intrusion in North Gaza coastal aquifer?

1.4 Methodology

Figure (2) depicts the methodology that was followed in this research. The methodology starts by the collection of needed data from all available sources such as documents, reports, maps and the communication with local specialized persons from Gaza.

Data needed includes aquifer parameters such as hydraulic conductivity, total and effective porosity, specific storage, etc…, changes in rainfall patterns, and pumping rates. The population forecast was determined to estimate the water demand and the expected quantity of treated wastewater to be used in the agricultural sector at the end of the study period in order to reduce the amount of pumping water for agricultural sector. In order to reduce the amount of pumping water for domestic sector, calculations were done for desalination water quantities for both of brackish and sea water desalination plants.

The key data was obtained from MoA regarding to rainfall patterns at the study area, and from PWA which is the hydrologic data for pumping wells, this includes pumping rates and chloride concentrations for the years 2000 and 2009 for North Gaza wells, in addition to the basic needs and development ongoing and proposed projects in the PWA strategic plans such as desalination plants and wastewater treatment plants at Gaza Strip.

After preparation and processing, the data was analyzed using EXCEL. The SEAWAT code (a three dimensional model of coupled density-dependent flow and miscible salt transport), was selected to simulate solute transport in order to predict and assess the impacts of climate change on Gaza aquifer.

Six scenarios were formulated and assessed using SEAWAT to study the three climate change impacts mentioned earlier in the objectives.

The results obtained from the model runs were analyzed. Based on the research outcomes, the conclusions and recommendations were made.

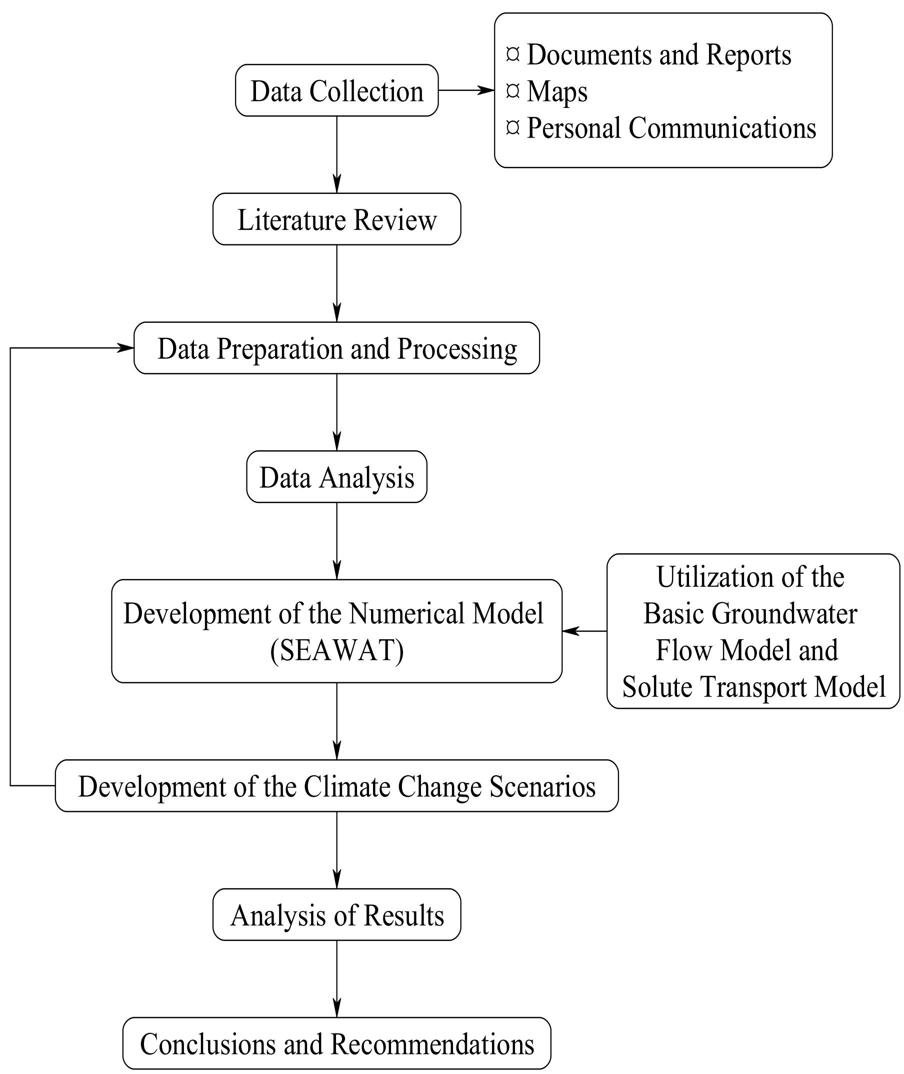


Figure (2): A Flowchart of research methodology

1.5 Thesis Outline

The thesis is organized in seven chapters as follows. Chapter 1 gives an introduction along with background information, objectives, research questions and the methodology. Chapter 2 describes the study area. Chapter 3 provides the literature review. Chapter 4 gives a general definition of climate change and its related scenarios. Chapter 5 illustrates the concept of seawater intrusion. Chapter 6 highlights the different outcomes of the climate change scenarios using SEAWAT model along with analysis. Conclusions and recommendations are furnished in Chapter 7.

CHAPTER TWO

DESCRIPTION OF THE STUDY AREA

2.1 Geographic Location

Gaza Strip is located between longitudes 31 and 25 N, and latitudes between 34 and 20 E. It is a coastal area located along the eastern Mediterranean Sea (see Figure 3). The length of the Gaza Strip is about 40 Km (coastline border), while the width varies from 6 to 12 Km. The total area of the Gaza Strip is about 360 Km^2. Because of its geographical location, Gaza Strip forms a transitional zone between the semi-humid coastal zone in the north, the semi-arid loess plains in the east, and the arid Sinai Desert in Egypt (PWA, 2001).

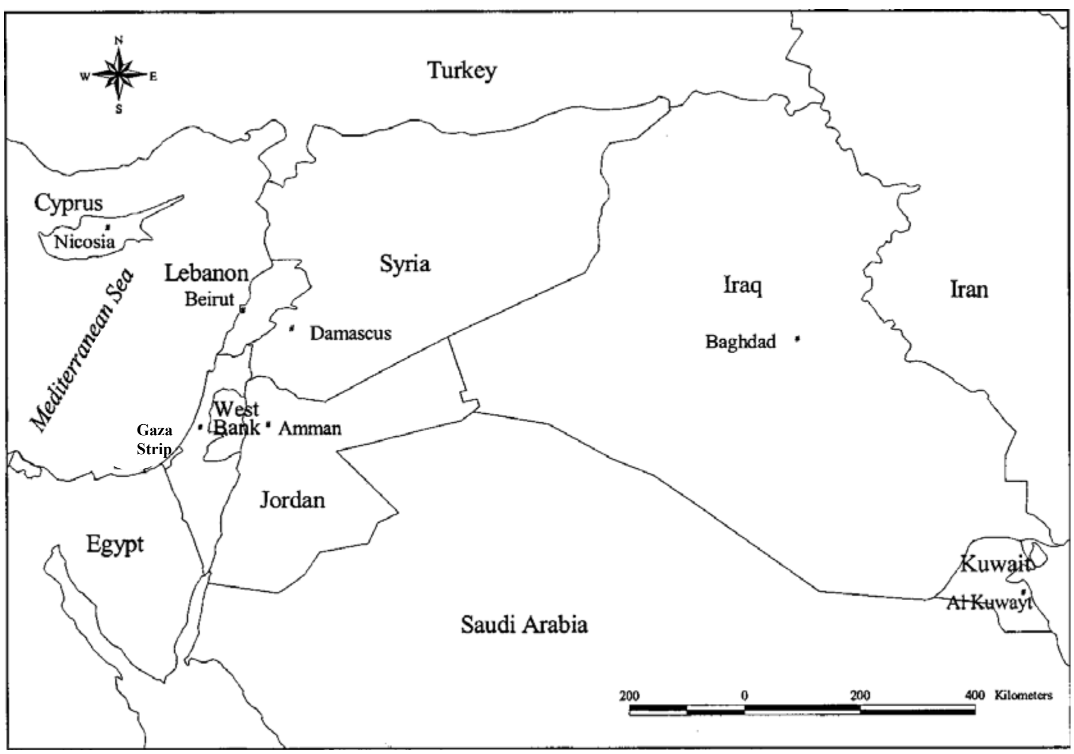


Figure (3): Regional setting of Gaza Strip

The study area is the North Gaza which consists of the Municipalities of Jabalia, Beit Lahia, Beit Hanon, Um An-Naser, and Gaza City.

2.2 Study Area Outline

Figure (4) indicates the study area and coastal aquifer boundary.

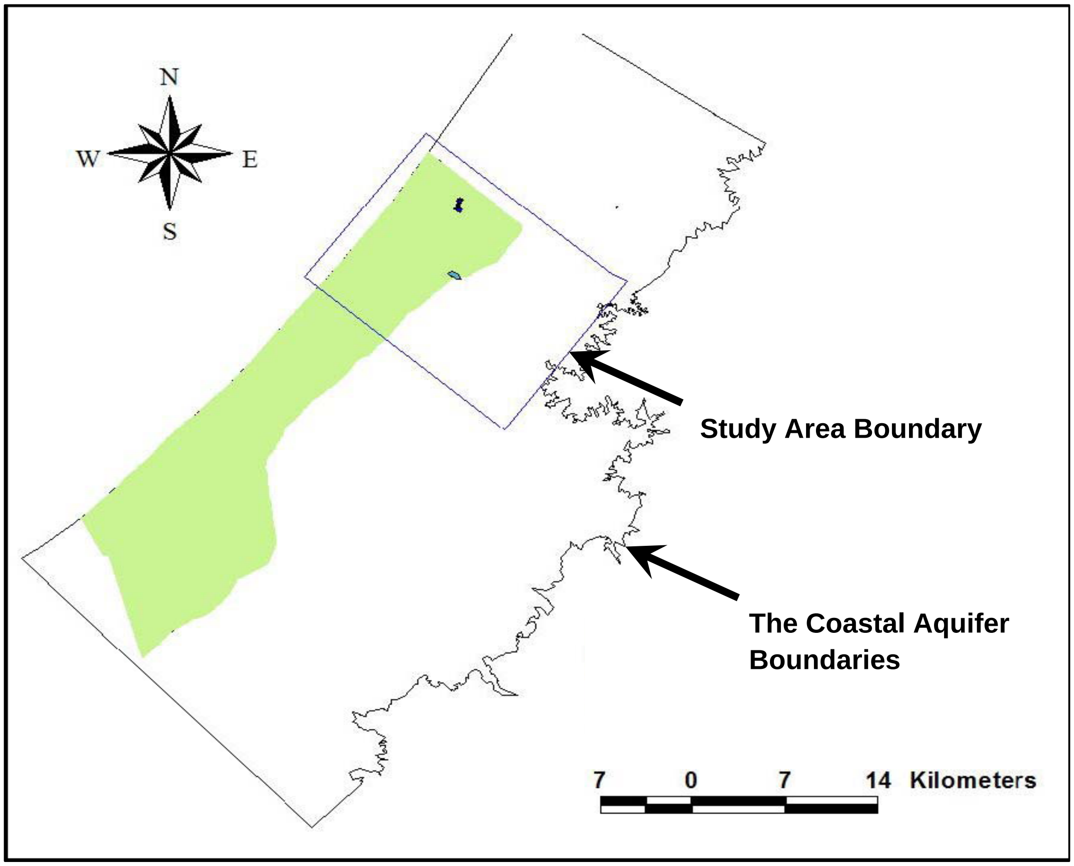


Figure (4): Study area outline

The study area was extended to include additional area outside the North Gaza borders to minimize the effects of model boundaries in the central part of the model which is the main objective for this research.

The study area was determined based on the MODFLOW model which was prepared in 2006 by PWA and EMCC (Engineering and Management Consulting Center) to study the Environmental Assessment for North Gaza Emergency Sewage Treatment Plant Project. This model was used in developing the SEAWAT model since preparing a new model again will be time consuming and is beyond the scope of this thesis.

2.3 Population

Gaza Strip is one of the most densely populated places on earth with about 1.6 million Palestinians (PCBS 2007) living over 360 Km^2 (about 4,400 capita/ Km^2).

The roots of Gaza's water problem lie in the over-population of the area due to a high influx of refugees in 1948 when approximately 200,000 people fled to Gaza Strip from Jaffa and surrounding areas (UNRWA, 2006).

The study area is the most populated area in Gaza Strip. Presently there are about 840,000 people living over 109 Km^2 (about 7,700 capita/ Km^2). The population in the study area is expected to increase to more than 1.7 million by 2035 based on PCBS expected population growth rates (see Table 1).

Table (1): Population growth rates (source: PCBS, 2008 b)

Period	Gaza Strip Growth Rate (%)
2008-2010	3.7
2010-2015	3.4
2015-2020	3.0

Total population projections in the study area for the various planning years based on the above assumptions are summarized in Table 2.

Table (2): Population projections in the study area

Year	Population					
	Beit Lahia	Beit Hanoun	Jabalia	Um An-Naser	Gaza city	Total
1997	39,456	25,540	113,827	754	353,113	**532,690**
2007	64,457	38,047	164,931	2,811	483,869	**754,115**
2010	71,880	42,428	183,924	3,135	539,590	**840,957**
2015	84,959	50,149	217,391	3,705	637,774	**993,977**
2020	98,491	58,136	252,016	4,295	739,355	**1,152,292**
2025	114,178	67,396	292,155	4,979	857,115	**1,335,823**
2030	132,363	78,130	338,688	5,772	993,631	**1,548,585**
2035	153,445	90,574	392,632	6,692	1,151,891	**1,795,234**

2.4 Geology

The coastal aquifer is the only aquifer in the Gaza Strip and consists primarily of Pleistocene age Kurkar Group deposits including calcareous and silty sandstones, silts, clays, unconsolidated sands, and conglomerates. Near the coast, coastal clays extend about 2-5 km inland, and divide the aquifer sequence into three or four sub-aquifers, depending upon location (referred to as sub aquifers A, B1, B2, and C). Towards the east, the clays pinch out and the aquifers are largely unconfined (phreatic) (HWE, 2010).

The maximum thickness of the different bearing horizons occurs in the northwest along the coast (150 m) and decreasing gradually toward the east and southeast along the eastern border of Gaza Strip to less than 10 m. The base of the coastal aquifer system is formed of impervious clay shade rocks of Neogene's age (Saqiyah formation) with a total thickness ranges between 500-1000 m (see Figure 5) (SWIMED, 2002).

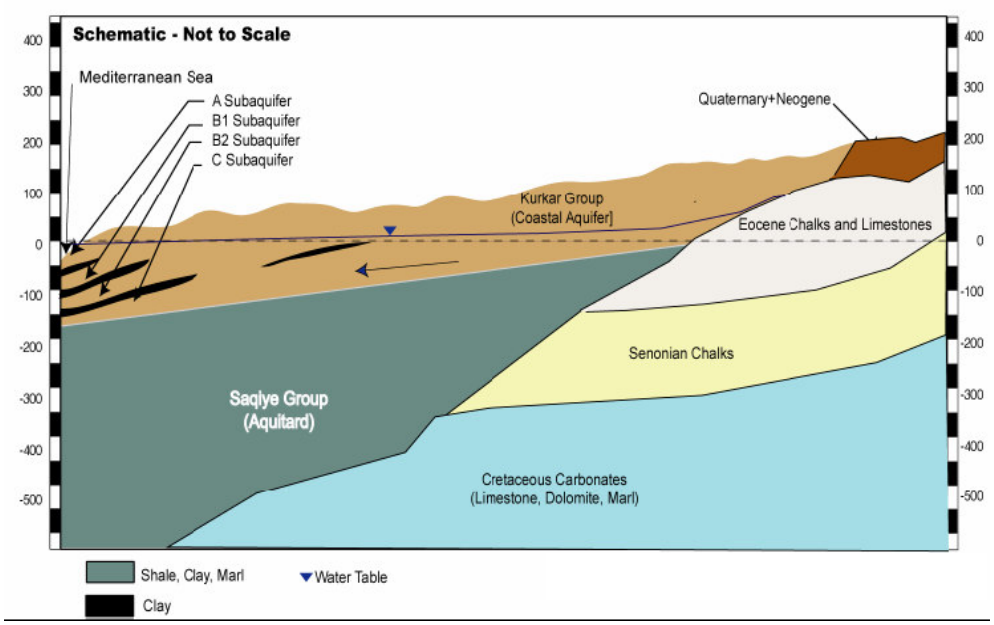


Figure (5): NW-SE Hydro-geological cross section of Gaza Strip (Source:HWE 2010)

2.5 Land Use

The study area forms about 30% of the total area of Gaza Strip. It is distributed between built-up areas (26%); agricultural lands (56%), open areas (18%).A land use map of the study area is shown in Figure 6 for the year 1998.

The types of crops planted in the study area include fruits, citrus, flowers, vegetables and rain-fed crops. Table 3 shows the agricultural production areas.

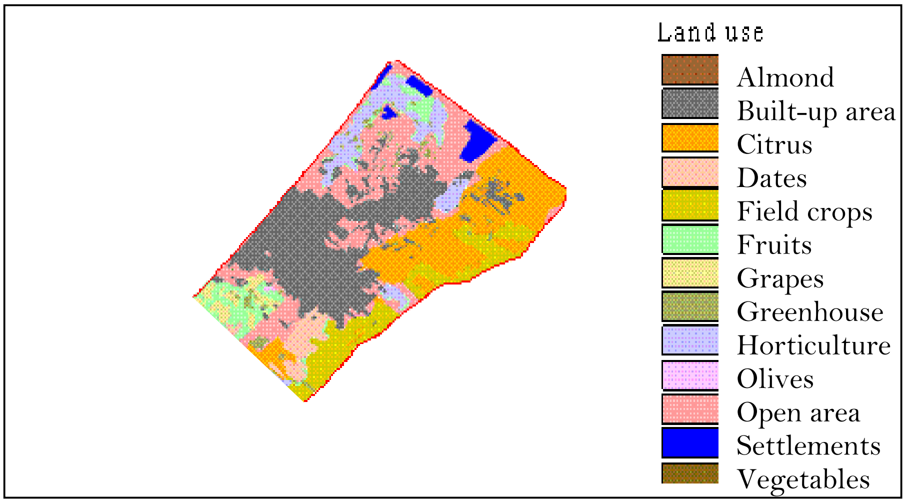


Figure (6): Land use distribution of the study area

(Source: the database of the PWA, 1998)

Table (3): Agricultural production areas (Hectares*) in North Gaza

Item	North Gaza
Vegetable	1347.4
Rained crops	861.5
Flowers	9.0
Citrus	2379.7
Fruit	1541
Total	**6139**

* : 1 hectare =10 dunums

(Source: Assessment of land based pollution sources, EQA, 2001)

2.6 Climate

As in Gaza Strip the summers are dry with a short mild rainy season. The mean temperature varies between 12-14 C° in January to 26-28 C° in June. The average annual rainfall is about 250 mm/yr, so the recharge volume is about 27 MCM/yr based on 2009/2010 rainfall data. The average annual potential evaporation is about 1400 mm/yr (SWIMED, 2002).

Figure 7 presents the average annual rainfall data of the study area obtained from 30 year records from 1980 to 2010.

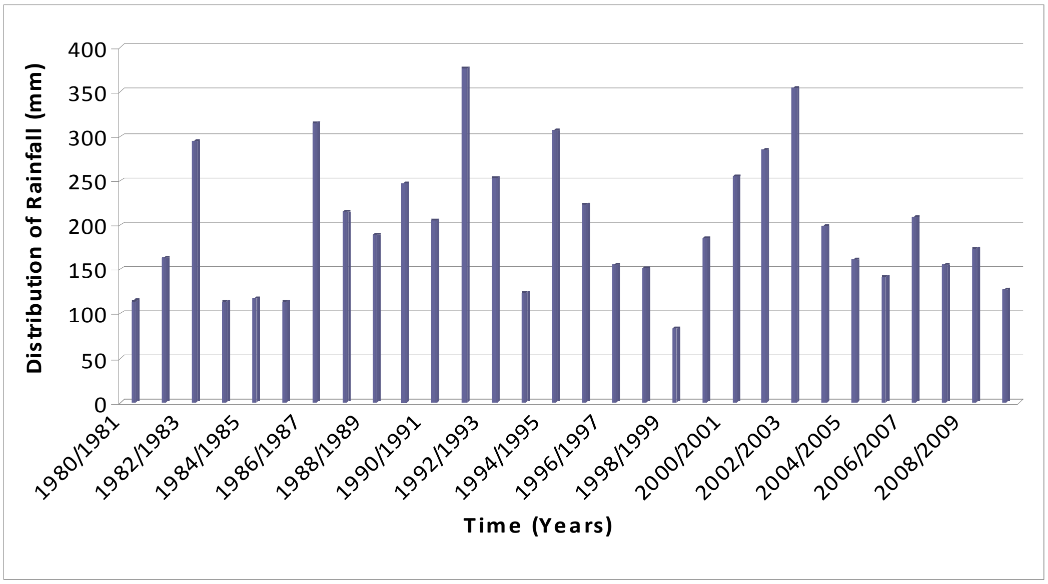


Figure (7): The average annual rainfalls of the study area (1980-2010)

(Source: MoA Reports)

2.7 Existing Water Problems in Gaza Strip

Gaza Strip faces serious problems with seawater intrusion due to over pumping, as well as aquifer contamination from agricultural and domestic wastes (SWIMED, 2002).

Figure 8 depicts the contour map for groundwater levels for the study area with clear appearance of the negative levels due to over pumping.

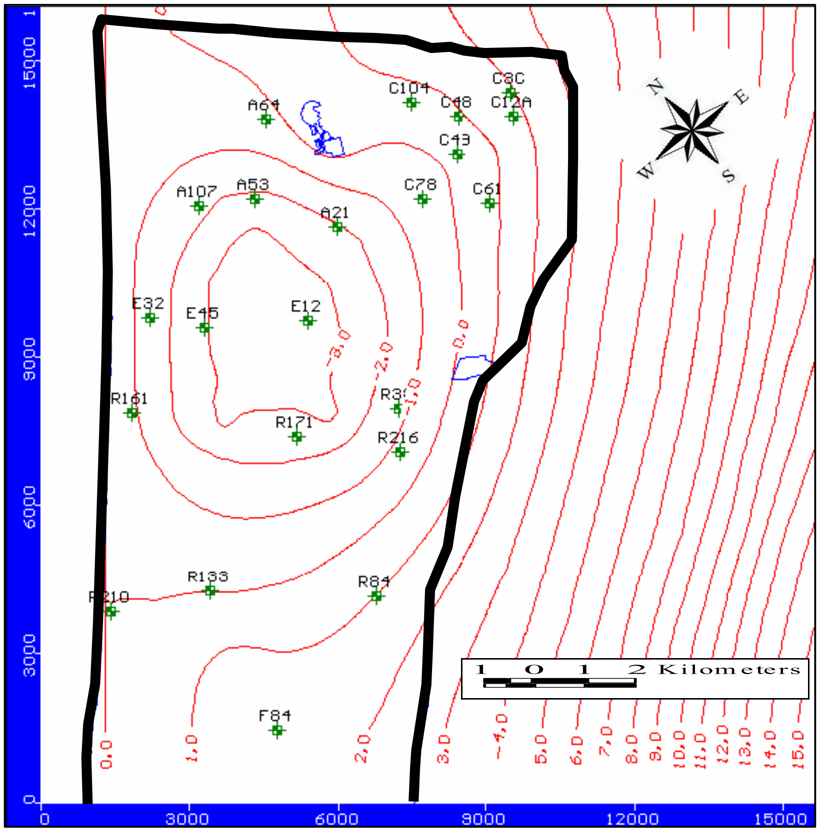


Figure (8): Steady state groundwater level contour map for the study area (Source: PWA, EMCC report 2006)

Tap water in Gaza Strip is known in general to be very salty and undrinkable. Poor groundwater quality can also be attributed to pollution from wastewater seepage and the infiltration of agricultural fertilizers according to a World Bank Report released in April 2009 (IRIN, 2009).

In addition to the previous problems, Gaza's wastewater infrastructure causes a true problem since they are provides partial and intermittent water treatment, so most of sewage goes raw to lagoons and the sea as shown in Figure 9, or seeps through the soil and reaches the aquifer, according to the World Bank report (2009).

(1) (2)

Figure (9): Wastewater problems (1): A sewage lagoon next to a sewage pumping station in Beit Lahia (2): Discharge of untreated wastewater into the sea from the existing Rafah Wastewater Treatment Plant, March 2009

2.8 Water Balance

The two largest components of the water balance are municipal and agricultural well abstraction. These exceed natural inflows (rainfall recharge and lateral inflow) therefore the present net aquifer balance is negative (water deficit). Table 4 and Table 5 summarize the recent groundwater balance for Gaza Strip and the study area, respectively.

Table (4): Water balance for hydrological year 2008/2009 for Gaza Strip, (Source: HWE, 2010)

Inflow (MCM)		Outflow (MCM)	
Rainfall Recharge Lateral Inflow Return flows	48.2 36.4 54.2	Municipal abstraction Agricultural Abstraction Lateral Outflow	94.2 80.4 2
Total	138.8		176.6
Net Balance	-37.8		

Table (5): Water balance for hydrological year 2008/2009 of the study area (Source: HWE, 2010)

Inflow (MCM)		Outflow (MCM)	
Rainfall Recharge Lateral Inflow Return flows	27.7 26.6 17.7	Municipal abstraction Agricultural Abstraction Lateral Outflow	62.8 28.9 1.92
Total	72		93.62
Net Balance	-21.62		

Under defined average climatic conditions and total abstraction and return flow, the net deficit is about 22 MCM/y (HWE, 2010). Implications of the net deficit include lowering of water level, reduction in availability of fresh groundwater, seawater intrusion, and potentially up-coning of deep brines (Qahman, 2004). The net deficit has led to a lowering of the water table in the past 30-40 years and inland migration of seawater. (Jayyousi, 2008).

Other sources of groundwater replenishment include groundwater flow from the eastern side, infiltration from surface water runoff, pipe leakage, infiltration of untreated wastewater, and return flow irrigation (MAS, 2009).

2.9 Well Status in the Study Area

Appendix A (Tables A1 to A4) summarizes the wells in the study area listed by location. The columns indicate the current pumping rates and chloride concentrations according to PWA measurements at year 2009. It was noticed that the chloride concentrations of many wells exceeds the WHO acceptable limit 250mg/l, and this is indicates that there is a seawater intrusion in a specific locations due to over pumping.

2.10 A Brief Overview of Water Quality in the Study Area

The major water quality problems in the study area are the high salinity and high nitrate concentrations; there are many reasons for this deterioration in water quality, such as increase in population and urban expansion since it is presently have about 40% of total Gaza strip population even it forms only about 30% of total Gaza strip area. In addition to improper hydrological and environmental management conditions that represented by high density of wells with high rates of abstraction, intensive agriculture activities, untreated wastewater return flow from septic tanks and networks leakage and inappropriate design of wastewater treatment plant. All these conditions beside the lateral inflow of brackish groundwater from the east, leads to accelerate salinization of this coastal aquifer with chloride, Chloride concentrations in municipal wells in 2009 are shown in Figure10.

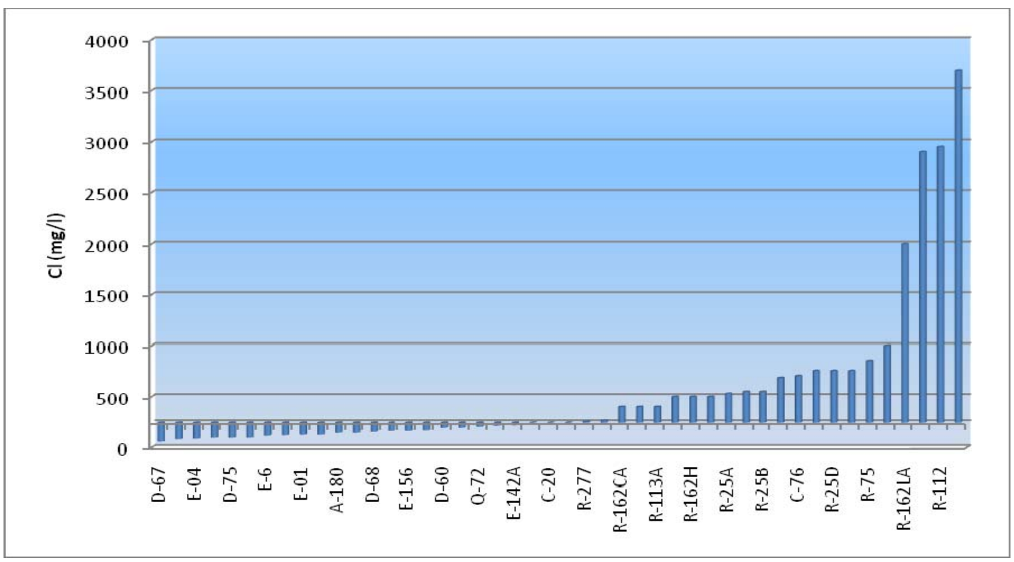


Figure (10): Chloride concentration of domestic municipal wells in the study area for year 2009
(Source: PWA reports, 2009)

The WHO drinking chloride limit is 250 mg/l. From Figure 10 it is clearly that about one half of the wells of the study area exceeded the maximum limit.

Sources of high chloride content have been determined to be seawater intrusion, lateral flow of brackish water from east and the up-coning of the brine water from the base of the aquifer.

Most municipal drinking wells in Gaza show nitrate levels in excess of the WHO drinking water standard of 50 mg/l. Figure 11 shows that nitrate concentration of 87% of the wells is exceeding the WHO drinking limit. The main sources for that are domestic sewage effluent and fertilizers. In contrast to salinity, groundwater flowing from east has relatively low nitrate levels (PWA, 2009).

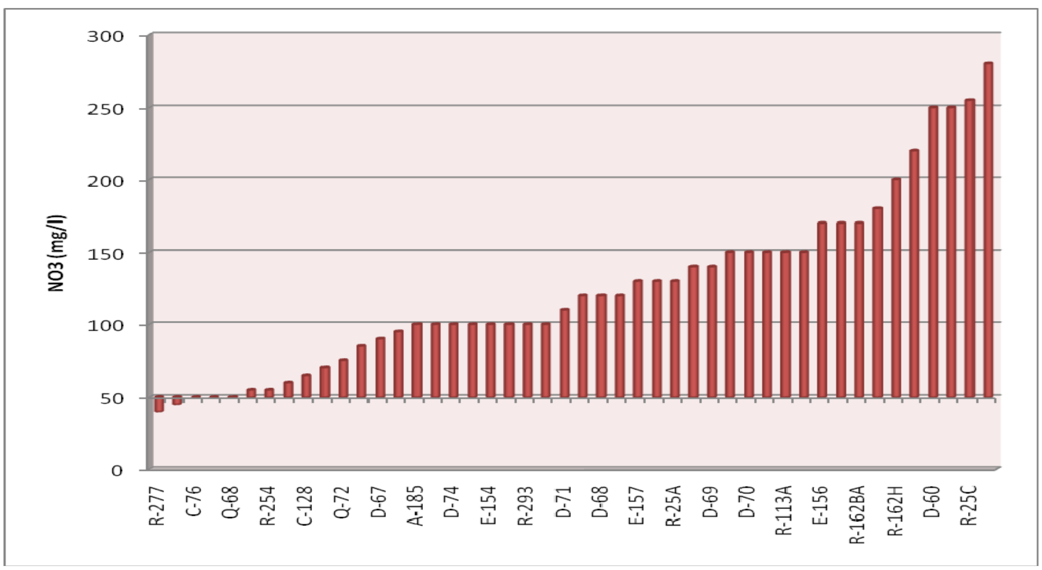


Figure (11): Nitrate concentration of domestic municipal wells in the study area for year 2009
(Source: PWA reports, 2009)

2.11 Demand Components

The principal water demand sectors in the study area are the municipal, industrial, and agricultural sectors. The municipal and industrial demands are expected to become doubled by the end of the study period, while no increase in agricultural demand is expected since there is no expansion in the agricultural lands is expected to take place.

Table 6 shows the water demands for all sectors in the study area for year 2009.

Table (6): Summary of total water demand for all sectors for 2009 in the study area, (Source: PWA reports, 2009)

Item	Demand (MCM)	Number of Wells
Municipal & Industrial Water Demand	62.8	52
Agricultural Water Demand	28.9	1002
Total Water Demand	**91.7**	

2.12 Future Municipal Water Needs

The projections of water needs are estimated based on the WHO standards of 100 L/c/d as a minimum water consumption rate and 150 L/c/d as an average domestic water consumption. Other consumption rates including commercial, industrial and livestock consumption rates are projected as a percentage of the municipal and industrial water needs (MAS, 2009). A summary of these target consumption rates are shown in APPENDIX A Table A5.

CHAPTER THREE

LITERATURE REVIEW

3.1 Introduction

There are many studies of groundwater flow models to help understand and predict the behavior of fresh and saline groundwater's under a certain type of exploitation. These studies were important to the management of groundwater. Seawater intrusion problems have been solved by using different methods, ranging from the basic Ghyben-Herzberg principle with the sharp interface models to the more sophisticated theories with the solute transport models such as SEAWAT which take into account variable densities. The groundwater flow model is always a part of any model concerned with the movement of salt-fresh water interface and/or solute transport, whereas the solute transport model is necessary for solving most of the groundwater quality problems (Thuan, 2004).

3.2 SEAWAT Application

Qahman (2004) analyzed the major-recent and (desired) future trends in water availability in Gaza Strip with a special focus on seawater intrusion and groundwater recovery for Gaza coastal aquifer. He applied MODFLOW to quantify the availability of groundwater considering the regional aquifer system and ultimately to predict the long-term groundwater behavior and the corresponding perennial yield under various strategies. The main objectives of his study was to determine a perennial yield pumping and to determine the movement of fresh/saline water interface and the corresponding threat to both freshwater storage and deterioration of water quality.

The study of Qahman (2004) used MODFLOW to set steady and transient multiple aquifer simulation models that can be used for the assessment of groundwater availability and simulation of groundwater development scenarios. A three dimensional modeling approach is selected to represent the conceptual model of the Gaza Strip. Model results indicate that most of the seawater intrusion is happened to the north of Gaza city and also near Khan-Younis city in the south. It is estimated that seawater intrusion near Jabalia at year 2003 may extend about 2 Km inland in sub aquifer B, and up to 3 Km in sub aquifer C.

Qahman and Larabi (2005) assessed numerically the seawater intrusion in Gaza Strip, applying SEAWAT. Simulation results indicate that the proposed schemes successfully simulate the intrusion mechanism. Two pumpage schemes were designed to use the model for prediction of the future changes in groundwater levels and solute concentrations over a planning period of 17 years. The results show that seawater intrusion would worsen in the aquifer if the current rates of groundwater pumpage continue. The alternatives are to moderate pumpage rates from water supply wells far from the sea shore and to increase the aquifer replenishment by encouraging the implementation of suitable solutions like artificial recharge in order to control seawater intrusion and reduce the current rate of decline of the water levels.

Alzraiee and Durnford (2009) used SEAWAT to simulate the seawater intrusion in Gaza Coastal Aquifer. The model was used to determine the extent by which seawater intrusion impacts the groundwater water quality within the next 10 years. The model was also used to determine the feasibility of different management scenarios in the future. The first scenario was the no-action scenario that simulates the continuation of the current situation for the next 10 years. The second scenario was to investigate the impact of importing water from the West Bank via a pipeline. The third scenario was the impact of the installation of injection wells line along the coast as barrier to the intrusion.

Masterson (2004) simulated interaction between freshwater and seawater and effects of changing groundwater pumping, recharge conditions and sea level change at Lower Cape Cod aquifer system, Massachusetts. SEAWAT was used to assist in the analysis of freshwater and seawater flow. Model simulations were used to determine water budgets, flow directions, and the position and movement of the freshwater/seawater interface. The depth to the freshwater/seawater interface varies throughout the study area and is directly proportional to the height of the water table above sea level. Simulated increases in sea level appear to increase water levels and stream flows throughout the Lower Cape Cod aquifer system, and yet decrease the depth to the freshwater/seawater interface. The resulting change in water levels and in the depth to the freshwater/seawater interface from sea level rise varies throughout the aquifer system. Pumping from large-capacity municipal-supply wells increases the potential for effects on surface-water bodies, which are affected by pumping and wastewater-disposal locations and rates.

Praveena and Aris (2009) presented a case study of groundwater responses towards the climate change and human pressures in Manukan Island, Malaysia. SEAWAT was used for the simulations of six scenarios representing climate change and human pressures showed changes in hydraulic heads and chloride concentrations. In general, reduction in pumping rate and an increase in recharge rate are capable to restore and protect the groundwater resources in Manukan Island. Thus, for groundwater management options in Manukan Island, scenario 2 is capable to lessen the seawater intrusion into the aquifer and sustain water resources on a long-term basis.

Langevin and Mausman (2008) used SEAWAT to predict the extent rate of saltwater intrusion at Biscayne aquifer of Broward County, Florida, in response to various sea level rise scenarios using SEAWAT. Until the date of their study (2008) there are no reported quantitative evaluations of seawater intrusion in southern Florida in response to sea-level rise. Three simulations were performed with varying rates of sea level rise. For the first simulation, the slowest sea level rise was specified at a rate of 0.9 mm/yr, estimated by IPCC. After 100 years, the 250 mg/L chloride moved inland by about 40 m. For the next simulation, sea level rise was specified at 4.8 mm/yr. For this moderate rate of sea level rise, the 250 mg/L moved inland by about 740 m after 100 years. For the fastest rate of sea level rise estimated by IPCC (8.8 mm/yr), the 250 mg/L moved inland by about 1800 m after 100 years.

As furnished in the past studies, this research deals with the climate change impacts on seawater intrusion using SEAWAT. These impacts are sea level rise using the maximum value 5.9 mm/yr that was predicted by IPCC for the Mediterranean region, in addition to recharge and pumping rates variability. The outcomes of these studies highlighted the in-land seawater intrusion and the intrusion rates in addition to the expected increase or decrease in chloride concentration at different wells locations

CHAPTER FOUR

CLIMATE CHANGE - A GENERAL BACKGROUND

4.1 Definition of Climate Change

Climate change is *"a change of climate which is attributed directly or indirectly to human activities that alter the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods"* (Pe'er and Safriel, 2000).

The average temperature of the globe has changed over the past century due to an increase in concentrations of greenhouse gases, mainly carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) (Pe'er and Safriel, 2000).

4.2 Impacts of Climate Change

The consequences of increasing temperatures, changing patterns of precipitation, and sea level rise will affect all aspects of the Earth system (IPCC 2007a; 2007b). The challenges faced by humans at the turn of the 21st century (poverty, disease, conflict, environmental degradation, and so on) may be exacerbated by climate change. In short, the implications of climate change are serious. Climate change can be considered as the biggest environmental threat in human history and as the defining human development challenge for the 21st century (IPCC 2007b; UNDP 2008).

4.3 Predictions of Climate Change for the Middle East

In a region already considered the world's most water scarce, where demand for water already outstrips supply in many places; climate models are broadly predicting a hotter, drier and less predictable climate (Alpert, 2008).

By the middle of the century, the region is expected to get hotter across all seasons models predict an increase of between 2.5 to 3.7°C in summer, and 2.0 to 3.1°C in winter (see Figure 12 and 13). (Cruz, 2007), Higher temperatures will change where rain falls, how much of it falls and how often it falls. It will also result in a global increase in sea levels; the region will get drier, with significant rainfall declines in the wet season outweighing slight increases during the drier summer months (Cruz, 2007). Meanwhile, the distribution of rains will change (moving to the north). The weather is also likely to become more unpredictable, with the region experiencing an increase in extreme rainfall events (Alpert, 2008).

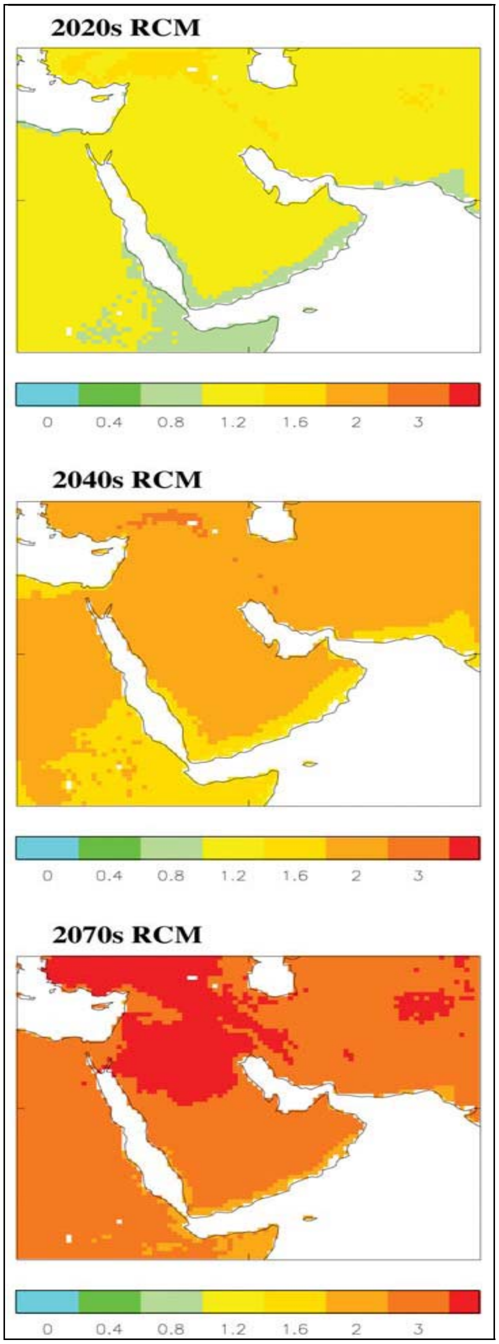


Figure (12): RCM projections of temperature changes (ºC) across the Gulf region for 2020s, 2040s and 2070s relative to the 1990s

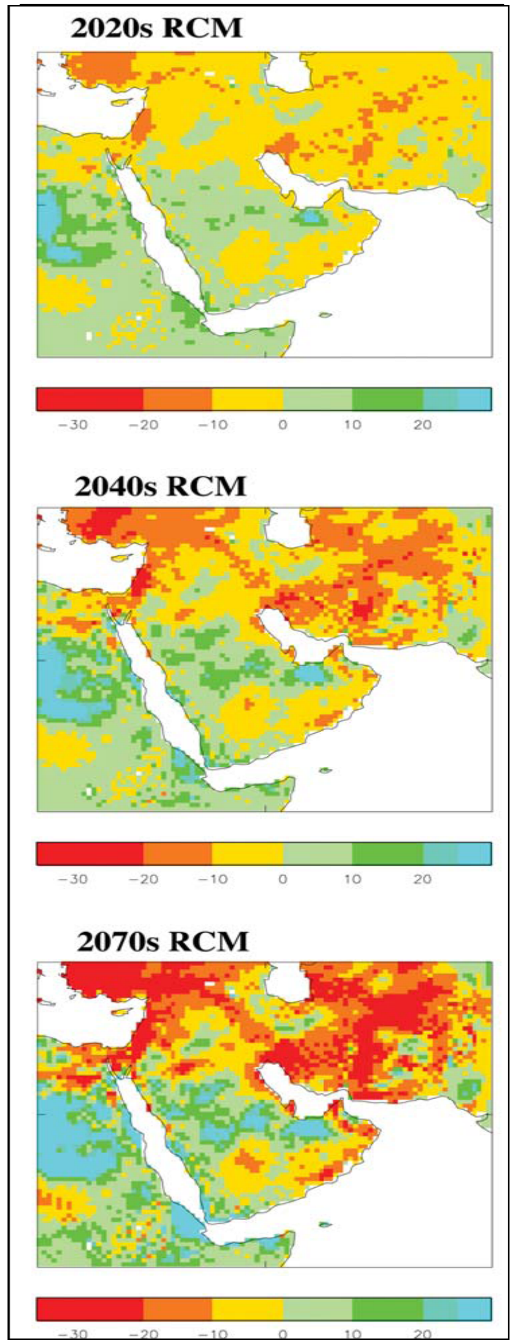


Figure (13): RCM projections of precipitation changes (%) across the Gulf region for 2020s, 2040s and 2070s relative to the 1990s

4.4 Predictions of Climate Change for the Mediterranean

Regarding the precipitation projection, the RCM (Regional Climate Models) results for 2071–2100 compared to 1961–1990 show large differences between scenarios A2 and B2 emission scenarios [(1)] (Figure 14). The black box in the figure is centered over Palestine and the Jordan River basin. In A2, most of the Eastern Mediterranean (EM) shows rainfall reduction of about 15–75 mm for DJF (December, January and February), which is equivalent to drops of about 10–30%. Model results indicate that groundwater recharge is unlikely to decrease by more than 10% until the 2050s. The DJF period covers most of the annual rain in the EM, and realistically reflects the annual rainfall changes. In scenario B2, however rainfall reductions are significantly lower and are of about 0–15% in total rainfall, while over most of Turkey significant rainfall increases are noticed. The predicted rainfall changes in B2 are similar to those observed over the EM during the recent decades (e.g., Alpert, 2004; IPCC, 2001) that also show larger precipitation decreases over the NE Mediterranean and some small increases over the SE Mediterranean (Alpert et al, 2008).

(1) The near surface air temperature differences from 2071–2100 compared to 1961–1990 are based on the RCM results for two International Panel for Climate Change (IPCC) emission scenarios A2 and B2. The A2 scenario assumes a significant increase of the GHG concentration whereas the B2 is based on less extreme estimates

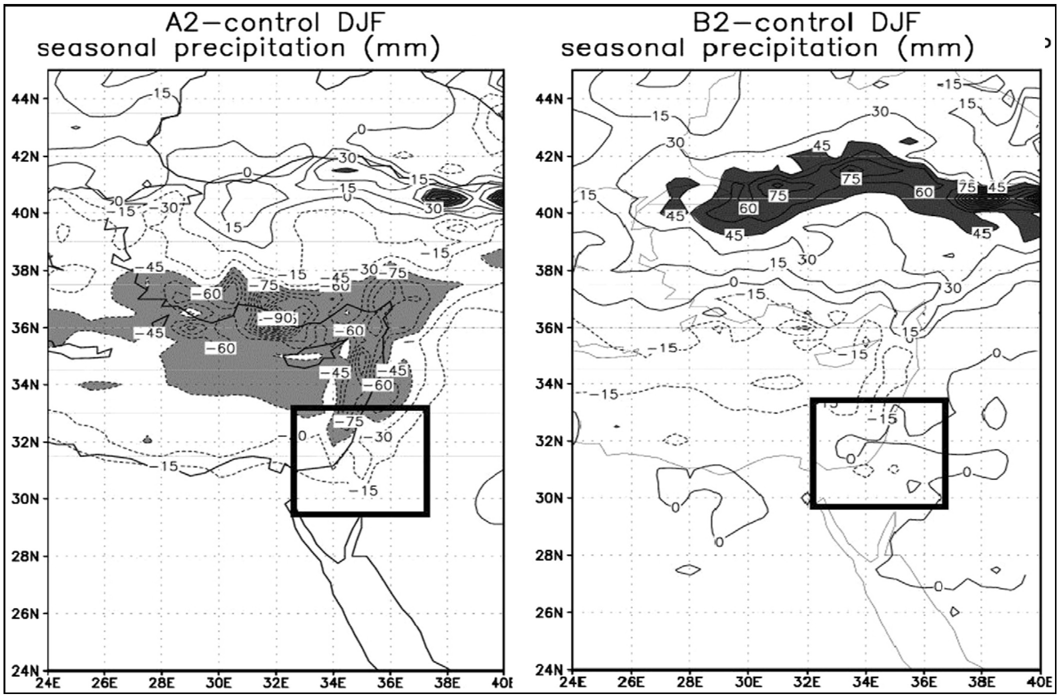


Figure (14): The winter (DJF) predicted change in the mean seasonal precipitation (mm). Differences are between A2 and B2 scenarios (2071–2100) as compared to the control run (1961–1990) values over the EM, and are based on the RCM runs.

Results of regional climate modeling performed at the International Centre for Theoretical Physics, (Trieste, Italy) are analyzed for the Mediterranean region. It is found that the average temperature over the Mediterranean area has increased by 1.5–4°C in the last 100 years. The temperature in the years 2071–2100 according to the A2 and B2 scenarios for (2071–2100) as compared to the control run (1961–1990) values over the EM, and are based on the RCM runs, as shown in Figure 15 are predicted to increase by about 4°C and 6°C, respectively over Northern Palestine in comparison with the control run for 1961–1990 (Alpert et al, 2008).

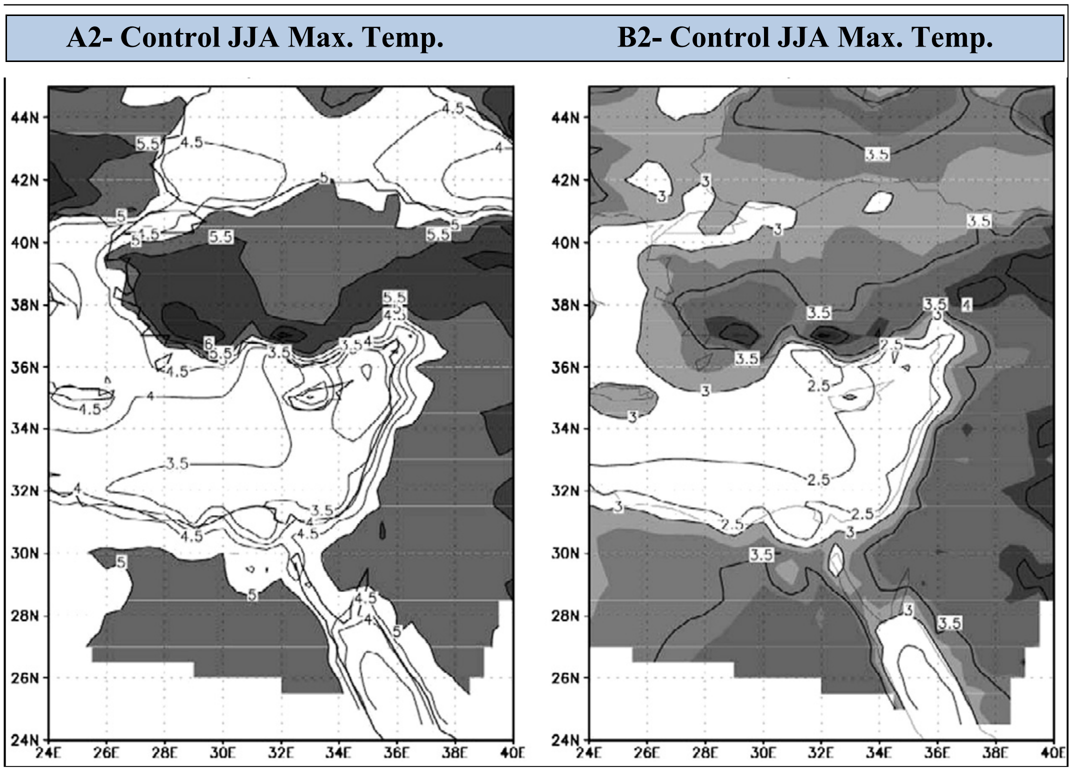


Figure (15): The summer (JJA- June, July, and August) predicted change in the daily mean maximum temperature. Differences are between A2 and B2 scenarios (2071–2100) as compared to the control run (1961–1990) values over the EM, and are based on the RCM runs.

4.5 Climate Change Scenarios

According to the IPCC predictions for the Mediterranean region the following climate scenarios are projected by the year 2100, and as Gaza Strip is part of the Mediterranean basin we can consider the same climate change scenarios for it as in the following table (see Table 7).

Table (7): Climate change projections for Gaza Strip (Source, IPCC, 2007)

Indicator	Description	Magnitude
Temperature	Increase	4° to 6°C
Precipitation	Decrease	-10% to -30%
Evapotranspiration	Increase	10%
Winter Rains	Delay	--
Rain Intensity	Increase	--
Rainy season	Shortened	--
Seasonal temperature variability	Greater	--
Sea level rise	Increase	1.8-5.9 mm/yr

4.5.1 Temperature

Price et al. (1999) observed an approximate 1^{o}C/100yr rise in annual mean temperature in Cyprus. Alpert et al. (unpublished data) observed the same warming trend in Cyprus, as well as in Italy and Spain. A relatively moderate increase in air temperature was measured in cities of the Mediterranean, primarily in winter and less in the autumn and spring (Maheras and Kutiel 1999; Kutiel and Maheras 1998). Most of the increase, however, was measured in cities undergoing urbanization (Kutiel and Maheras 1998).

4.5.2 Precipitation

Rainfall measurements at different stations in the Mediterranean region show similar declines in most regions of the basin (Paz et al. 1998a). High correlation between changes in vegetation and changes in sea level during the last decade in the Middle East suggests that the trend of decreasing precipitation in the Middle East may be attributed to global warming (Issar 1995).

Increased surface runoff will reduce aquifer recharge, transport dissolved pollutants to waters reservoirs, increase flash floods during peak water flows and damaging human structures and crops (Pe’er and Safriel, 2000).

4.5.3 Sea level rise

Climate change has a great direct effect on seawater intrusion because it leads to a rise in the global sea level and intrusion of seawater into the coastal aquifer and this will further damage groundwater. The increase in the global temperature will warm the land surface, oceans and seas. This warming will decrease the atmospheric pressure, which will in turn lead to the increase of the water level in the oceans and seas. This rise in water level will be due to a number of reasons, including thermal expansion of oceans and seas and melting of glaciers, ice caps and ice sheets (see Figure 16) (O'Brien, 2008).

Figure (16): Melting of glaciers and ice caps

Values for predicted sea level rise by the year 2100 typically range from 90 to 880 mm, with a central value of 480 mm according to IPCC, 2001. Models of glacier mass balance (the difference between melting and accumulation of snow and ice on a glacier) gives a range for sea level rise in the current century between 0.8 to 2 m, based on limitations on how quickly glaciers can melt (Wikipedia, June 2010).

According to the greenhouse gas emissions scenario, sea levels at the Mediterranean Sea are forecasted by the IPCC to rise at least 18 to 38 cm and as much as 26 to 59 cm by 2100 (Mason et al. 2009).

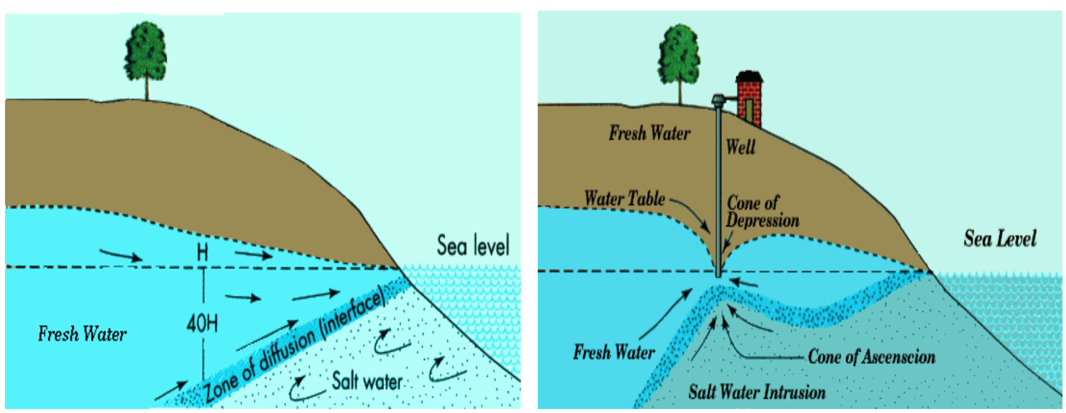
In Palestine, a local assessment of sea level rise found only a 5 cm to 10 cm rise since 1960. Tectonic movements in the eastern Mediterranean, measured through tide-gauge measurements in Haifa indicate an uplift of +2.8 mm/yr (about 3cm in a decade) (Jelgersma and Sestini 1992). Hence, long-term measurements are needed to accurately assess local changes in sea level in Palestine (Issar 1995).

CHAPTER FIVE

SEAWATER INTRUSION

5.1 General Background and Definitions

Seawater intrusion is the movement of seawater into fresh water coastal aquifers due to natural processes or human activities. Seawater intrusion is caused by decreases in groundwater levels or by rises in seawater levels. When you pump out fresh water rapidly, you lower the height of the freshwater in the aquifer forming a cone of depression. According to Ghyben-Herzberg theory the salt water rises 40 feet for every 1 foot of freshwater depression and forms a cone of ascension. Intrusion can affect the quality of water not only at the pumping well locations, but also at other well locations, by increasing salinity of the groundwater; see Figure 17 (Lenntech, 2009).



(a) (b)

Figure (17): (a): Clarifications of Ghyben-Herzberg theory, (b): effect of pumping into freshwater/seawater interface,

(Source Lenntech, 2009)

In coastal aquifers, an interface exists between fresh groundwater flowing toward the sea and saline groundwater. Across the interface, the fluid density may increase from that of freshwater (about 1,000 kg/m^3) to that of seawater (about 1,025 kg/m^3), an increase of about 2.5 percent.

An understanding of variable-density groundwater flow is important in many types of studies of coastal aquifers, such as studies of seawater intrusion, contaminated site remediation and fresh groundwater discharge into oceanic water bodies (Guo and Langevin, 2002).

5.2 Consequences and Assessments

Salinization of groundwater is considered a special category of pollution that threatens groundwater resources, because mixing of a small quantity of seawater with groundwater makes freshwater unsuitable and can result in abandonment of freshwater supply (Hany, 2009).

In coastal areas the aquifers are in hydraulic contact with the sea, and under normal conditions freshwater flows into the sea. However, over-pumping may result in inversion of the groundwater flow from the sea towards the inland, causing seawater intrusion. Therefore, seawater intrusion should be prevented or at least controlled to protect groundwater resources. In general, control can be achieved by maintaining an appropriate balance between water being pumped from the aquifer and the amount of water recharged to the aquifer. Sea level rise also threatens groundwater in coastal aquifers because it imposes an additional pressure head from the sea side which promotes the movement of seawater into the aquifer (Hany, 2009).

5.3 How to Assess Seawater Intrusion?

A complication in measuring sea level, is that the sea level does not rise by the same amount all over the globe due to the effects of the earth's rotation, local coastline variations, changes in major ocean currents, vertical movements of the earth's crust (up and down), and differences in tidal patterns and seawater density (IPCC, 2007). Today, there are two primary measurements as shown in Figure 18:

1. The first is the relative sea level (the height of the water relative to the land), measured using tide gauges (IPCC, 2007).

2. Satellite altimetry measures the distance between an Earth-orbiting satellite and the surface of the ocean (IPCC, 2007).

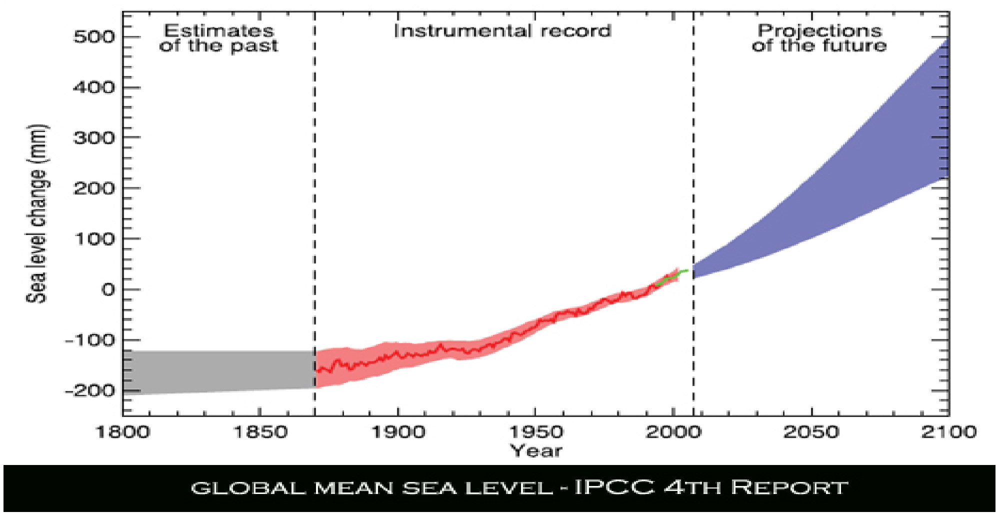


Figure (18): Time series of global mean sea levels. The grey shading shows the uncertainty in the estimated long-term rate of change. The red line is a reconstruction of global mean sea level from tide gauges. The green line shows global mean sea level observed from satellite altimetry. The blue shading represents the range of model projections for the 21st century.

The best way for assessing seawater intrusion is by monitoring the existing wells and taking samples to analyze the chloride concentration. However, these analyses are very expensive, so it is preferable to use modeling to analyze the head and concentration distributions in the coastal aquifers (Nelson, 2009).

There is a wide range of commercial and public domain computer codes that can be used to simulate variable-density groundwater flow. For example, the U.S. Geological Survey (USGS) offers the finite-element SUTRA code (Voss, 1984) and the finite-difference HST3D (Kipp, 1997) and MOCDENSE (Sanford and Konikow, 1985) codes. These codes contain powerful options for simulating a wide range of complex problems (Guo and Langevin, 2002).

With the increase in demand for fresh groundwater resources, the number of studies that require explicit representation of fluid density variation has increased. Many of these studies focus on seawater intrusion issues in coastal areas. USGS investigators have developed expertise in applying the SEAWAT computer program to a wide variety of groundwater problems which is a MODFLOW-based computer program (Langevin, 2009).

MODFLOW is the U.S. Geological Survey modular finite-difference flow model, which is a computer code that solves the groundwater flow equation. The program is used by hydrogeologists to simulate the flow of groundwater through aquifers.

5.4 SEAWAT Concept

SEAWAT was designed to simulate three-dimensional, variable-density groundwater flow in porous media coupled with multi-species solute transport. The program has been used for a wide variety of groundwater studies related to seawater intrusion. SEAWAT is relatively easy to apply because it uses the familiar MODFLOW structure. SEAWAT is a public domain computer program distributed free of charge by the U.S. Geological Survey. SEAWAT can be downloaded from the following website: *http://water.usgs.gov/ogw/seawat* (Langevin, 2009).

SEAWAT reads and writes standard MODFLOW and MT3DMS [(1)] data sets, although some extra input may be required for some SEAWAT simulations (Guo *and* Langevin, 2002).

SEAWAT is based on the concept of freshwater head, or equivalent freshwater head, in a saline groundwater environment. A thorough understanding of this concept is required in developing the equations of variable-density groundwater flow as used in the SEAWAT program and in interpreting calculated results, (Guo *and* Langevin, 2002). In order to understand the equivalent freshwater head, two piezometers open to a given point, *N*, in an aquifer containing saline water are shown in Figure 19.

Piezometer A contains freshwater and is equipped with a mechanism that prevents saline water in the aquifer from mixing with freshwater in the piezometer, while still allowing the piezometer to respond accurately to the pressure at point *N*. Piezometer B contains water identical to that present in the saline aquifer at point *N*. The height of the water level in piezometer A above point *N* is h_f. The freshwater head at point *N* is the elevation of the water level in piezometer A above datum, and thus is given by: (Guo and Langevin, 2002)

(1) A modular three-dimensional multi species transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems.

$$h_f = z + \frac{P}{\rho_f g} \qquad (1)$$

where:

h_f is the equivalent freshwater head [L]
P is the pressure at point N [$ML^{-1}T^{-2}$]
ρ_f is the density of freshwater [M/L^3]
g is the acceleration due to gravity [L/T^{-2}]
Z is the elevation of point N above datum [L]

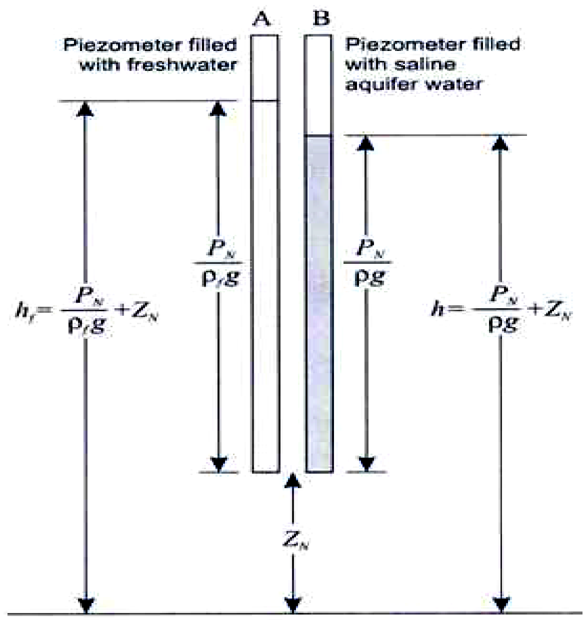


Figure (19): Two piezometers, one filled with freshwater and the other with saline aquifer water, open to the same point in the aquifer
(Source: Guo and Langevin, 2002).

5.4.1 SEAWAT procedure

The source code for SEAWAT was developed by combining MODFLOW and MT3DMS into a single program that solves the coupled flow and solute-transport equations (Guo *and* Langevin, 2002).

MODFLOW solves groundwater flow equation by solving for each time step, cell by cell flow is calculated from the fresh water head gradients and relative density difference terms, and results will give velocities and heads. While MT3DMS solves the solute transport equation by using solute transport equation based on previous MODFLOW results and repeated until stress period and simulation is complete. The numerical methods used by the MT3DMS program to simulate solute transport in a constant density flow field are directly used in SEAWAT to simulate solute transport in a variable-density flow field (Guo *and* Langevin, 2002).

5.4.2 Governing Equations

Simulation of groundwater flow is performed by numerically solving the groundwater flow and solute-transport equations. The governing flow and transport equations in SEAWAT are as in Equations 2 and 3. The SEAWAT package is very flexible and user friendly. This package has been very useful to simulate variable density flow through complex geology. One advantage of SEAWAT is that it uses MT3DMS to represent solute-transport (Guo *and* Langevin, 2002).

The groundwater flow equation can take many forms depending on the assumptions that are valid for the problem of interest. In most cases, it is assumed that the density of groundwater is spatially and temporally constant. To simulate groundwater flow in coastal environments, the assumption of constant density is not valid because seawater contains a higher concentration of dissolved salts than rainfall, which is the primary source for aquifer recharge. Fluid density is a function of dissolved salt. The density difference between fresh groundwater and seawater can greatly affect groundwater flow patterns. Accordingly, for that the groundwater flow equation used in the present study does not assume that groundwater density is constant (Guo *and* Langevin, 2002).

The groundwater flow equation is as follows: (Guo and Langevin, 2002)

$$\frac{\partial}{\partial \chi_i}\left[\rho K_f\left(\frac{\partial h_f}{\partial \chi_i}+\frac{\rho-\rho_f}{\rho_f}\frac{\partial_z}{\partial \chi_i}\right)\right]=\rho S_f\frac{\partial h_f}{\partial_t}+\theta\frac{\partial h_f}{\partial_t}+\partial\frac{\partial_\rho}{\partial_t}-\rho_s q_s \qquad (2)$$

where:

Xi	*i*th orthogonal coordinate
K_f	equivalent freshwater hydraulic conductivity (L/T)
S_f	equivalent freshwater specific storage (1/L)
h_f	equivalent freshwater head (L)
t	time (T)
θ	effective porosity (dimensionless)
ρ	is density of freshwater $[M/L^3]$
ρ_s	is density of sources and sinks $[M/L^3]$
q_s	volumetric flow rate of sources and sinks per unit volume of aquifer (1/T)

The transport equation is as follows: (Guo and Langevin, 2002)

$$\frac{\theta\left(\partial C^k\right)}{\theta_t}=\frac{\partial}{\partial_x}\left(\theta D_{ij}\frac{\partial C^k}{\partial x_j}\right)-\frac{\partial}{\partial x_i}\left(\theta v_i C^k\right)+q_s C_s^k+\sum R_n \qquad (3)$$

where:

C^k	dissolved concentration of species k $[M/L^3]$.
C^k_s	concentration of the source or sink for species k $[M/L^3]$
D_i	is the dispersion coefficient $[L^2/T]$
q_s	is the volumetric flux of a source or sink $[T^{-1}]$
R_n	the chemical reaction term (ML^3/T)

Dispersion is a physical process that tends to ‘disperse’, or spread, the contaminant mass in the X, Y and Z directions along the advective path of the plume, and acts to reduce the solute concentration. Dispersion is caused by the tortuosity of the flow paths of the groundwater as it travels through the interconnected pores of the soil.

The Dispersion inputs in Visual MODFLOW used the Longitudinal Dispersivity values in the model while MT3D calculates the Dispersion tensor for the mass transport model using the following parameters:

- Longitudinal Dispersivity for each transport grid cell
- Ratio of Horizontal to Longitudinal Dispersivity for each layer = 0.1
- Ratio of Vertical to Longitudinal Dispersivity for each layer = 0.001
- Molecular Diffusion Coefficient for each layer = 0 m^2/d

The source for species in this research is the salt, which is didn't decay or degradation for that no kinetic reactions are used.

CHAPTER SIX

DEVELOPMENT OF THE SEAWAT MODEL FOR THE NORTH GAZA AREA

6.1 Introduction

This research deals with the groundwater resources assessment and future forecasting under various scenarios. These scenarios are related to human stresses and climate changes in order to increase our understanding of the seawater intrusion in the North Gaza aquifer.

The basic groundwater flow model for this study was developed based on the MODFLOW model which was prepared by PWA and the EMCC for the purpose of study the environmental impact assessment for Beit Lahia WWTP.

6.2 Basic Groundwater Flow Model

The model domain encloses an area of 391 km^2 [(1)] in the northern part of Gaza Strip. Figure 4 in Chapter 2 shows the selected model domain which is part of the coastal aquifer. The model domain originally consists of 78 rows, 88 columns and one layer. The horizontal grid is divided into uniform cells with size of 200x200m.

For modeling purposes, the hydrologic year consists of a winter season from October to March and a summer season from April to September. Simulations started from the hydrologic year 2000.

The model boundaries can be described as follows (see Figure 20):

- West: Constant head boundary with zero head.

(1): This area includes additional area outside the North Gaza borders. The reason for expanding the model domain beyond the study area is to minimize the effects of model boundaries in the central part of the model.

- East: Constant head boundary with variable head between 11 to 18 meters. The eastern boundary was selected to minimize the boundary effects on the areas inside the aquifer (there is a considerable lateral flow from east to west at the borders with Gaza), the best selection was the outcrop of the coastal aquifer 10-15 Km east of Gaza. Near this line there are few points were the head is available, entered to the model cell by cell with a range between 11-18 m.

- North and South: Considered as no-flow boundary: Since the contour lines of the water table elevations of Gaza Coastal aquifer are parallel to the eastern and western boundaries (as shown in Figure 8, Section 2.7), then the flow will parallel to the northern and southern boundaries of the model domain and this can be considered as a no-flow boundary.

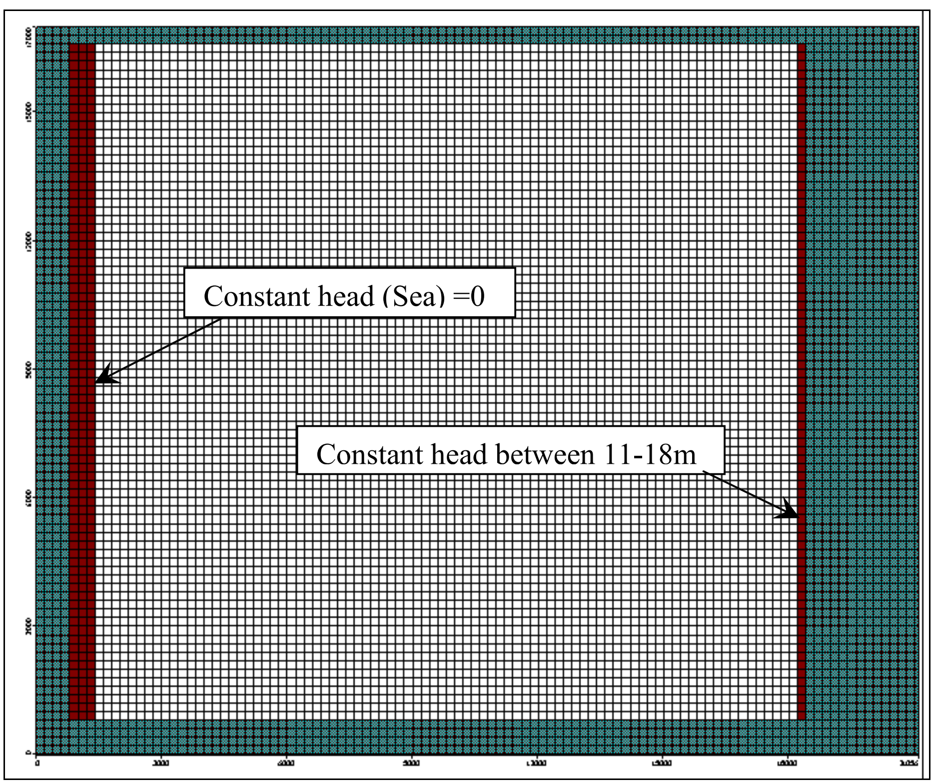


Figure (20): Model boundaries and grid

The lower boundary of the model consists of Saqiyah surface (see Figure 21).

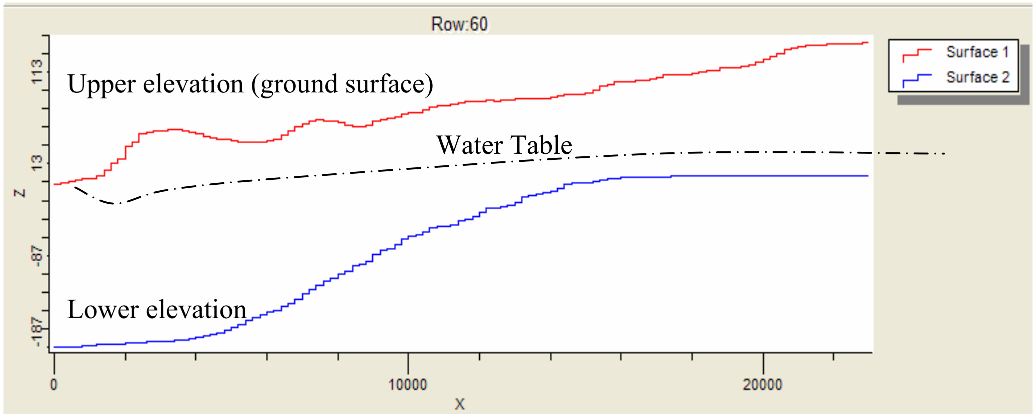


Figure (21): Bottom of the aquifer and the ground surface elevation

6.2.1 Recharge Components

The recharge was estimated based on 1999-2000 data. The net recharge for the study area is comprised of recharge from rain, irrigation return flow, water networks losses, wastewater leakages, existing treatment plants and recharges basins, and recharge from treated wastewater irrigation in the Israeli side of the model domain.

A total of 27 recharge zones were considered for the MODFLOW input. Each zone carries a different value based on the annual and seasonal recharge values (see Figure 22).

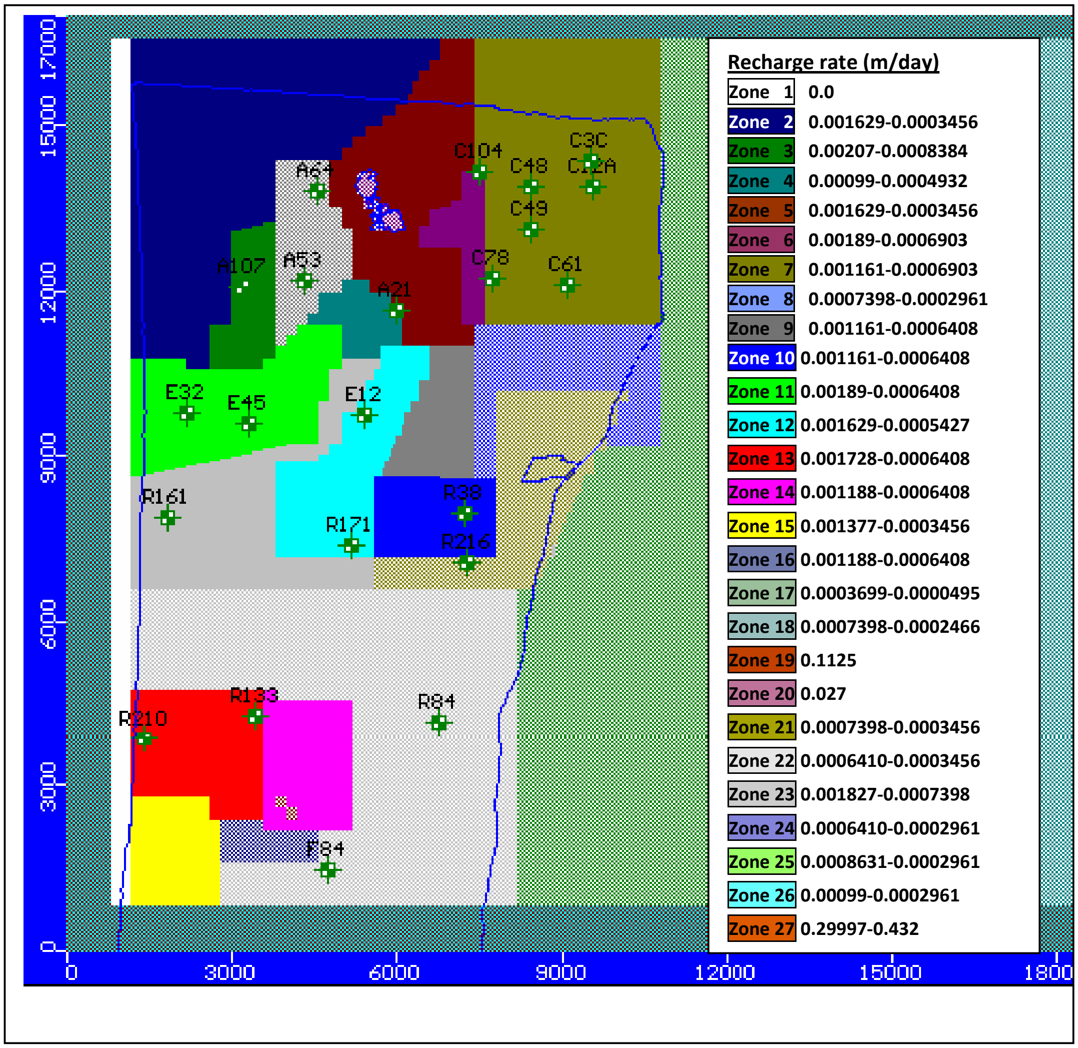


Figure (22): Head observation wells and MODFLOW recharge zones.

6.2.2 Abstraction Wells

Within the model area, there are 1,076 wells. This includes 52 domestic wells. The abstraction from domestic wells is recorded monthly. Table 8 shows the average seasonal abstraction rate from domestic wells. Data is also available for years 1998 – 2000. Very limited data is available about the agricultural wells abstraction. In the majority of the agricultural wells the abstraction rates were estimated based on information obtained from the Ministry of Agriculture about irrigated areas, crop patterns, and crop water requirements (M&E, 2000).

22 wells were selected as head observation wells for the model regional calibration (Figure 21). The selection was based on the availability of good hydrograph for these wells. More details are presented in the calibration section.

Table (8): Average Seasonal abstraction rates from the Municipal wells, (Source: PWA Data 2001-2003)

Abstraction period	QS 2001	QW 2001	QS 2002	QW 2002	QS 2003	QW 2003
Total pumping rates (m^3/day)	113,924	96,145	117,710	100,887	120,010	102,163

QS = average abstraction rate from April to September (m3/day)
QW = average abstraction rate from October to March (m3/day)

6.2.3 Simulation Period

The simulation period for the basic groundwater flow model was 8,030 days to reflect a 22 years of time starting from the hydrologic year 2000 until 2022.

6.2.4 Steady State Model Calibration

Data from year 1998 to 2000 was used for the steady state calibration. The modeled water level was then calibrated based on year 2000. Figure 8 in Chapter 2 shows the steady state water level contour map for the year 2000. In general, the modeled contour map shows a good agreement with the previous modeling results for instance the (CAMP project) for the same period.

Figure 23 compares the simulated results with the observed water level values. The modeled values show a correlation coefficient of 0.968 with the observed values.

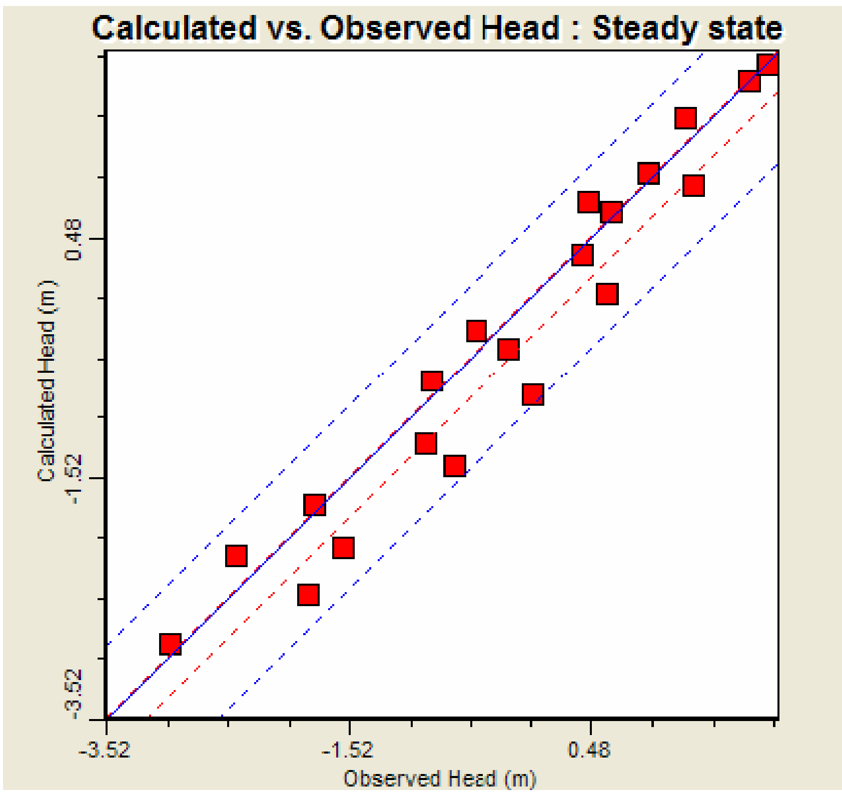


Figure (23): Steady state calibration results

6.3 SEAWAT Model Development

The SEAWAT model was first developed and later used to simulate the seawater intrusion based on the basic groundwater flow model. However many necessary adjustments were made to meet the SEAWAT requirements.

The North Gaza aquifer was vertically discretized into ten layers to better represent the vertical variability in salinity in the study area using the developed SEAWAT model.

The following flowchart depicts the procedure that was followed for the development of the seawater intrusion model for North Gaza aquifer using SEAWAT (Scenario 1). This was based on the existing conditions to continue pumping at the current rate with no consideration of climate change. The following sections provide brief information regarding the development steps of the SEAWAT model.

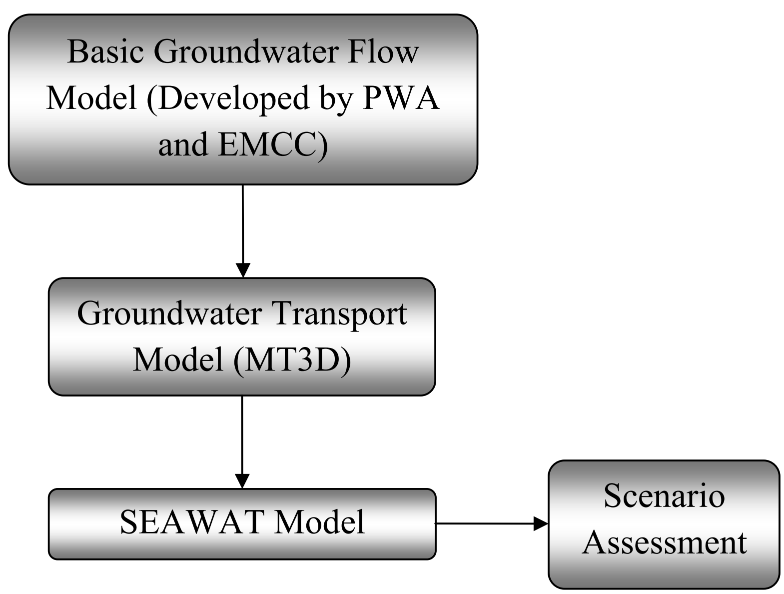


Figure (24): A Flowchart for SEAWAT development and use

6.3.1 Simulation Period for SEAWAT Model

In order to evaluate the effects of climate change and pumping on seawater intrusion, an additional simulation period of 13 years starting from 2023 until 2035 was added to the original simulation period (from 2000-2022). As such, the SEAWAT model covers 35 years (from 2000 until 2035).

6.3.2 Boundary Conditions

Constant head cells were assigned along the sea line and the deepest two layers to the east. Initial concentrations were assigned to the model according to the following assumptions (Qahman, 2004 (these values had been used by Israeli Modeling work for Gaza that had been done by Prof. Sahul Sorik from Ben Gorion University)):

- Constant concentration (western boundary) is 35,000 mg/l
- Constant concentration (eastern boundary, layers 9 and 10) is 700 mg/l
- Initial chloride concentration =102.5 mg/l (equivalent to 0.1 g/Kg) everywhere except at the specific locations of domestic wells which are exceeding this value.
- Specific chloride concentrations assigned to each domestic well location to reflect the actual conditions.
- Recharge concentration was neglected and considered 0 mg/l since the main scope of the work concentrates on salinity from seawater intrusion.

The dispersion coefficient was modified everywhere as needed to reflect the actual situation for salinity inside the model. Initial conditions (heads and concentrations) were specified using the results from a long term simulation in which the model had reached steady-state flow and transport conditions.

As there is no available data for the current sea level rise, this simulation was performed using a present day sea level of zero meters. During the simulations, a maximum sea level rise of 59 cm/100 yr was considered as appropriate (IPCC, 2007). Table 9 summarizes the input parameters for the SEAWAT model.

Table (9): Input parameters for the SEAWAT model

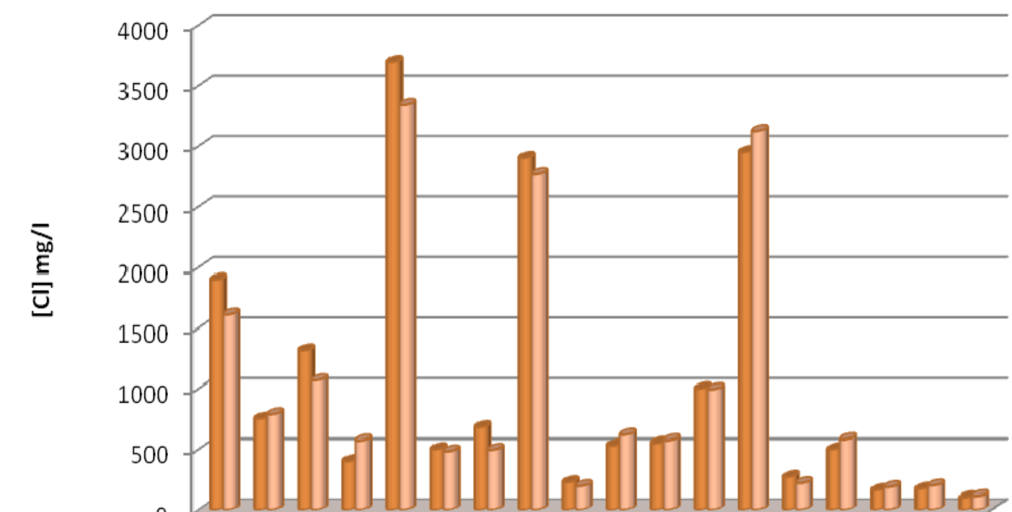
Parameter	Value
Hydraulic conductivity Kxy	35 m/d
Hydraulic conductivity Kz	3 m/d
Total porosity	0.35
Effective porosity	0.25
Specific storage	0.00002 m^{-1}
Specific yield	0.15
Longitudinal dispersivity	12 m
Horizontal transverse dispersivity	0.1 m
Vertical transverse dispersivity	0.01m

6.3.3 Calibration of the SEAWAT Model

The SEAWAT model was calibrated for chloride concentration by entering the available chloride concentrations that recorded for specific wells by PWA at year 2000, as the initial concentrations, and then the model was run to get the simulated concentrations at year 2009 which was compared with PWA observed concentrations for the same year. This was done for each of the specific well locations to meet with the needed concentrations at year 2009.

In addition to adjustment of the longitudinal dispersivity since it is the required parameter for SEAWAT simulation as discussed in the governing equations in Chapter 5.

As shown in see Figure 25 it can be concluded that there is a good match between the simulated and observed concentrations. The spearman rank correlation was 96% between the simulated concentrations and the observed ones as shown in APPENDIX A (A6).



	R 162 EA	R 162 BA	R 162 C	R 162 CA	R 162 D	R 162 H	R 162 G	E 154	E 142	R 25A	R 25B	R 25C	R 112	R 265	R 113	D68	D74	D75
Observed at year 2009	1900	750	1316	400	3700	500	680	2900	225	530	550	1000	2950	270	500	160	170	100
Simulated at year 2009	1609	786	1066	569	3337	481	494	2774	192	616	572	993	3126	216	580	184	197	111

Figure (25): Observed versus Simulated concentration for selected wells for year 2009

6.4 The Studied Scenarios

The reference scenario considered herein is Scenario 1. The studied scenarios are listed in Table 10 and are in general based on the IPCC projections for the Mediterranean coast for the next 25 years along with the PWA recommendations and projections (especially for scenario 6).

The reference scenario is based on the following assumptions:

- Current pumping rate for year 2010 is 91.7 MCM (28.9 MCM for agriculture, and 62.8 MCM for domestic).
- Current annual recharge rate (R) is 27.7 MCM
- Current sea level rise (S) is zero

In order to study the sensitivity of the aquifer for these three impacts, specialized scenarios were simulated for each impact. Scenario 2 considers the impact of increasing and decreasing pumping rates. Scenario 3 considers the impact of maximum sea level rise. Scenario 4 considers the impact of increasing and decreasing recharge rates.

Table (10): Summary description of the different scenarios simulated by the SEAWAT model

ID	Description	Q	R	S	Notes
Sc. 1	Existing conditions: **(reference scenario)**: continue pumping at the current rate with no consideration of climate change in Q, R and S [1].	No change	No change	No change	Q: current rate [2]. R: current rate S: current rate
Sc. 2	Sensitivity to pumping: take a range for changing pumping rates between -30% and +30% with no consideration of climate change.	Varies by a constant factor	No change	No change	Q: increase by 30% then decrease by 30% [3]. R: initial recharge rate= 27.7MCM/yr S: current rate
Sc. 3	Impact of sea level rise: take the maximum increase in sea level with the assumption that there is no change in both recharge and pumping rates.	No change	No change	Maximum rate	Q: current pumping rate R: initial recharge rate= 27.7MCM/yr S: maximum sea level rise = 5.9mm/yr [4].
Sc. 4	Sensitivity to recharge: take a range for changing recharge rates between -30% and+30% with no consideration of climate change.	No change	Varies by a constant factor	No change	Q: current pumping rate R: increase by 30% then decrease by 30% [5]. S: maximum sea level rise = 5.9mm/yr
Sc. 5	Extreme impacts of climate change: take the maximum rate of sea level rise and the minimum rate of recharge. No change in pumping rate is considered.	No change	Minimum rate	Maximum rate	Q: current pumping rate R: Recharge decrease by 10% [6]. S: maximum sea level rise = 5.9mm/yr
Sc. 6	Same as Sc. 4 but with decreasing pumping: this is due to the reuse of treated wastewater and desalination to cover agricultural and municipal abstraction, respectively.	decrease	Minimum rate	Maximumrat e	Q: decrease by varies factors depending on well type (domestic or agriculture use) [7]. R: Recharge decrease by 10% S: maximum sea level rise = 5.9mm/yr

(1): Q: pumping rate, R: recharge rate, S: sea level rise.

(2): In each well, the municipal abstraction increases by 3.3 % annually (same as the average population growth rate based on PCBS 2007 predictions). Also there is an upper bound for the well abstraction which is equal to 170 m^3/hour (as measured at the time of preparing the basic groundwater flow model in the year 2000) (Metcalf &Eddy, 2000). Agriculture abstraction will stay the same since there is no expansion in the agricultural lands is expected to take place.

(3): To study the seawater intrusion sensitivity to variability in pumping rates.

(4): Maximum sea level rise in the Mediterranean by 2100 according to IPCC greenhouse gas emission scenarios A2 and B2 predictions (59 cm/100 yr)

(5): To study the seawater intrusion sensitivity to the variability in recharge rates.

(6): According to IPCC greenhouse gas emission scenarios A2 and B2 prediction

(7): Presently, agricultural abstraction is 28.9 MCM/yr and the average quantity of treated wastewater that will be used for agricultural purposes is 10.98 MCM/yr. This quantity will cover part of the agricultural consumption to save about 38% of agricultural abstraction. In addition seawater desalinization plants are expected to produce an average of 34.5 MCM/yr. This quantity will cover part of municipal consumption to save about 55% of municipal abstraction (See APPENDIX A, Tables A7 to A10 for details).

6.5 Results of Scenarios simulation

6.5.1 Scenario 1: Existing Conditions

As shown in Table 10, scenario 1 reflects the continuation of the existing situation without any management or climate change effects. Figure 26 indicates the locations of domestic wells from sea shoreline, which are located between 700 and 7400 m.

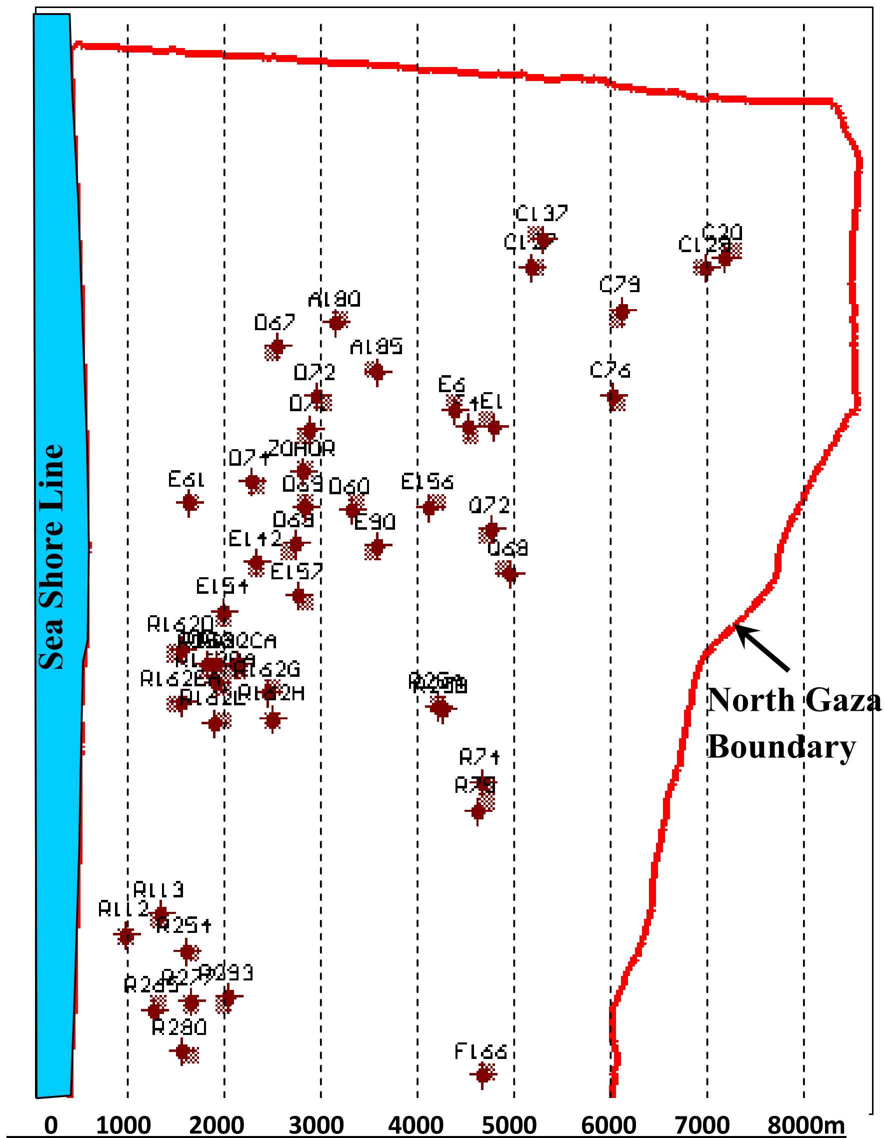


Figure (26): Locations of domestic wells from the sea shoreline

Figure 27 depicts the time series of the simulated chloride concentrations for selected wells from year 2000 until the end of year 2035 for scenario 1. These wells are selected due to their different locations in the model and their variable depth of screens to study the effect of distance and depth in terms of seawater intrusion.

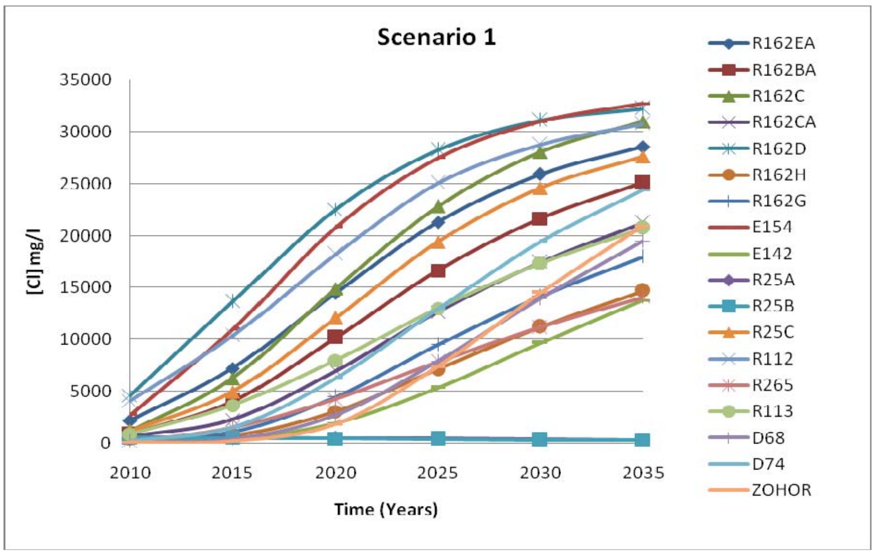


Figure (27): Simulated chloride concentration at the selected wells for Scenario1

From the two previous figures it can be clearly noticed that the concentrations decrease by increasing the distance from the sea shoreline. There are two important factors that affect the chloride concentrations of the wells. The first one is the location of the well from the sea shoreline, as in R162D and E154 which had the maximum concentrations since they are the closest to the sea shoreline and located at 1,800 m and 2,300 m respectively.

The second factor is the depth of the well screen from the ground surface, since increasing the depth of the well will increase the opportunity to pumping saline water because the bottoms of the well screen become closest to the saline water which located below fresh water due to their high density. This can be noticed clearly at R25C, R162C and R162CA. These three wells are very close to each other yet they have different concentrations due to their different depths.

The concentrations of wells R25A and R25B decrease with time. This indicates that the main source for the salinity in these two wells is not seawater intrusion since they are located at a distance of 5,000 m from sea shoreline so the effect of seawater intrusion does not reach them. This is indicated in Figure 28 which shows the in-land seawater intrusion until reaches the acceptable chloride concentration (250 mg/l) at the bottom of the model for the years from 2005 until year 2035. It shows that the most critical intrusion at 2015 happened at the first 2,400 m from the sea shoreline.

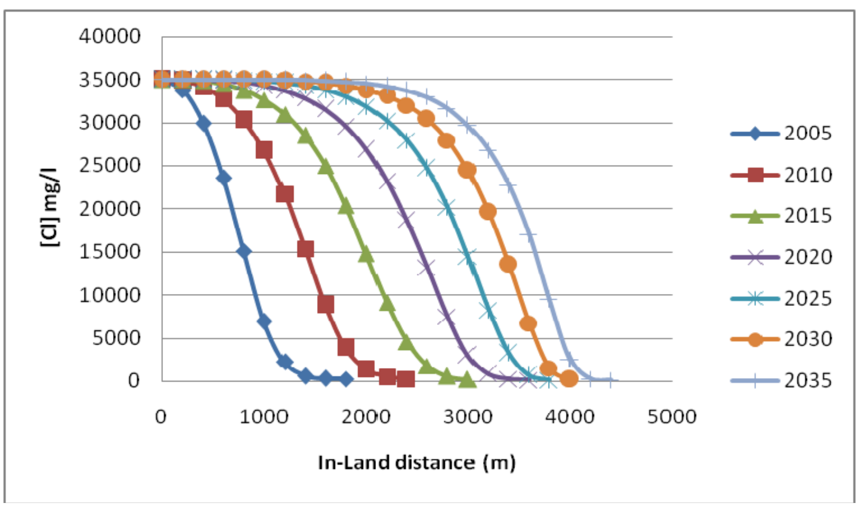


Figure (28): In-land seawater intrusion for Scenario 1

While for 2020 it will extend until 3,400 m and the in-land intrusion will continue increasing to reach 4,200 m for year 2035. This means that more than 50% of domestic wells in the study area will be affected by this intrusion and this may lead to the shutdown of the majority of these wells. The following figures indicate the maximum seawater intrusion as a plan view (Figure 29) and as cross sections (Figure 30) at 2015, 2025 and 2035. From scenario 1 results the in-land intrusion will be at a rate of about 65 m/yr.

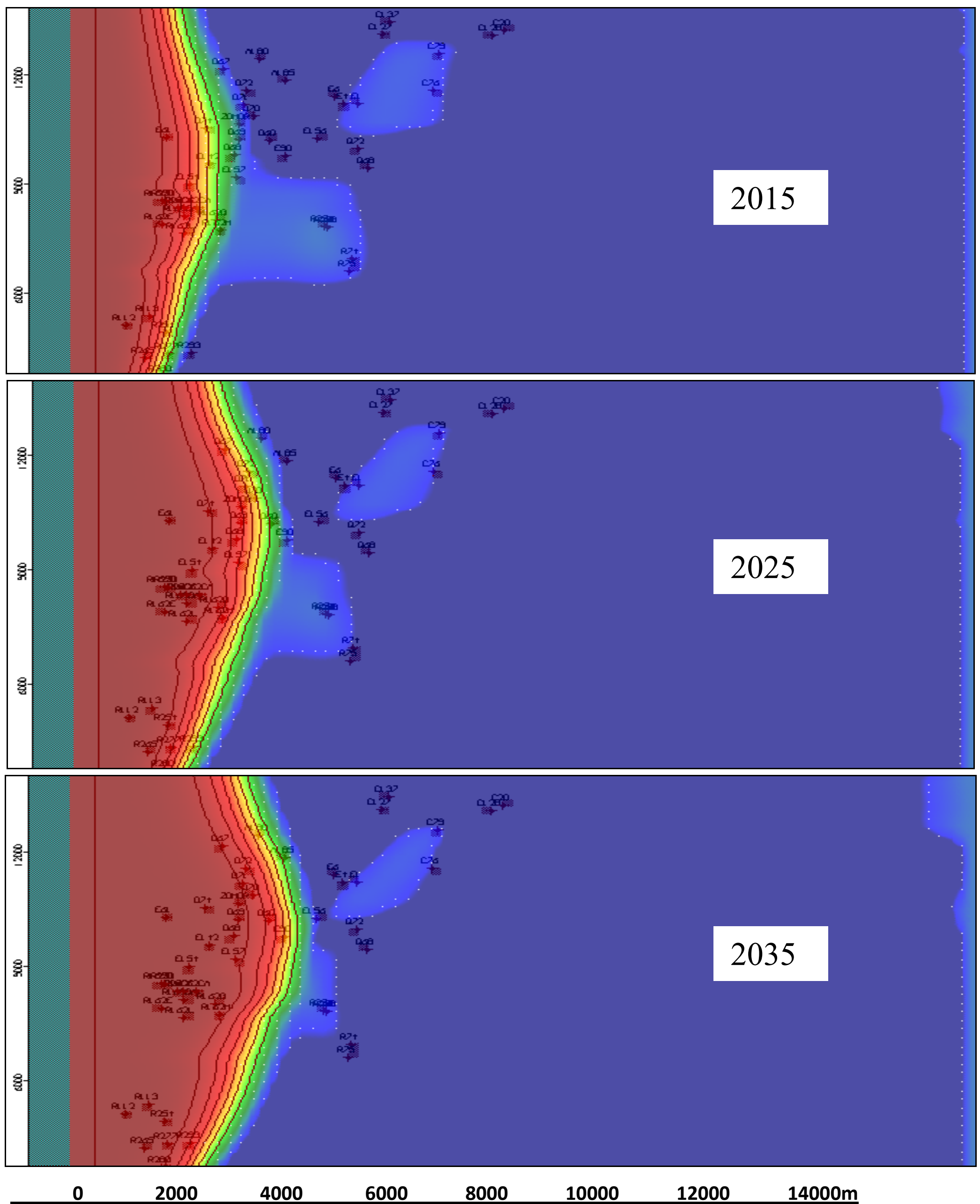


Figure (29): Plan view for seawater extent at the bottom of the aquifer for Scenario 1

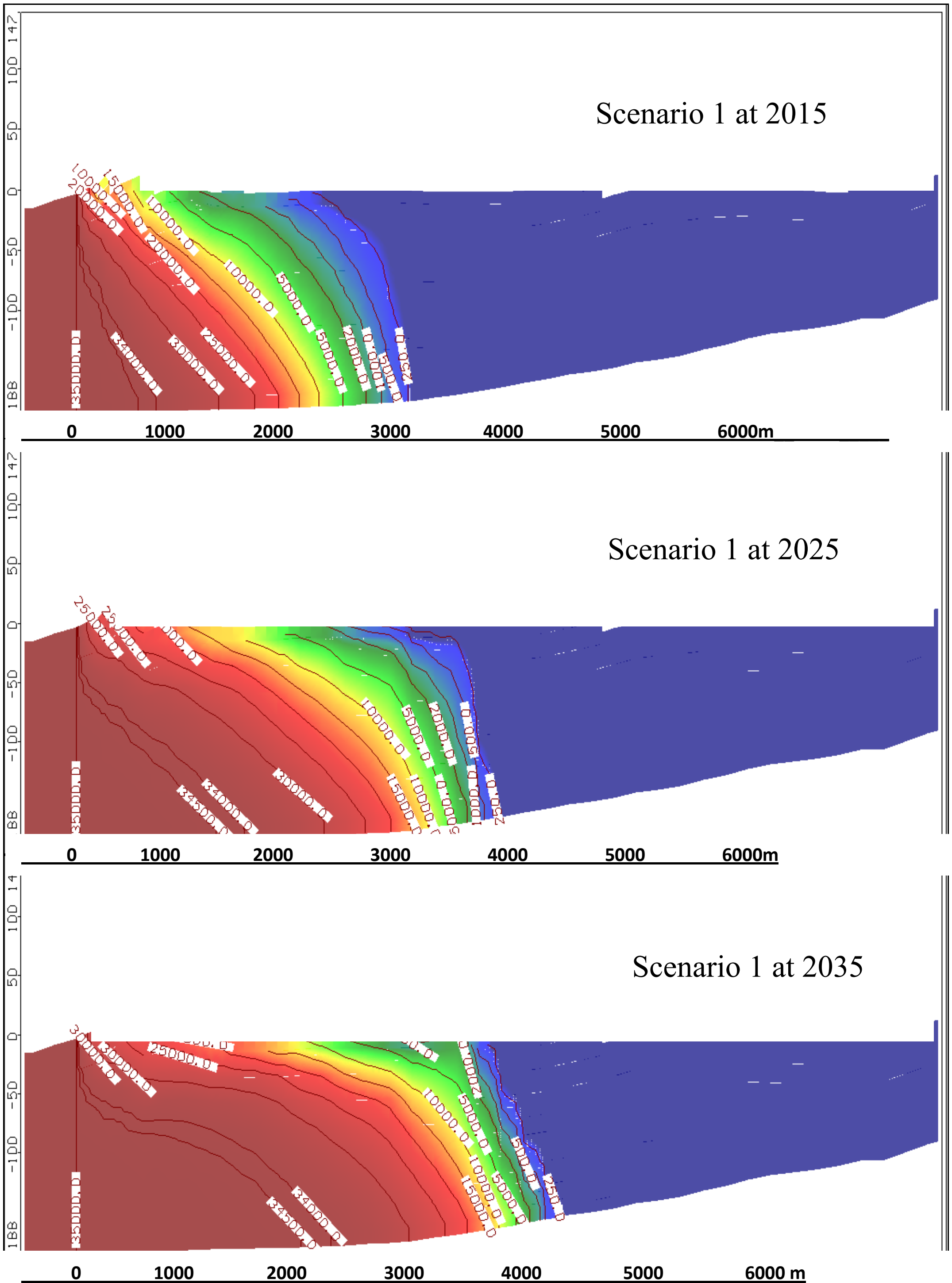


Figure (30): Cross sections for Scenario 1 indicates the maximum seawater interface at row 35

6.5.2 Scenario 2: Sensitivity to Pumping Rates

This scenario focuses on the model sensitivity to pumping rates through two sub-scenarios. Scenario 2 (-30%) is to decrease the pumping rates by 30% below the current rate in order to restore the aquifer of the study area. Scenario 2 (+30%) is to increase the current pumping rate by 30% in order to meet the future water demand.

As shown in Figure 31, for Scenario 2 (-30%) the relationship between chloride concentrations and time is approximately a linear relationship. This means that the concentrations increase gradually without a sudden change. For Scenario 2 (+30%), the concentrations increase rapidly. It was found that decreasing pumping rates by 30% will decrease concentrations by 20% to 43% as compared with the reference scenario. When increasing the pumping rates by 30% the concentrations increased by 7% to 24% depending on the well distance from the sea shoreline.

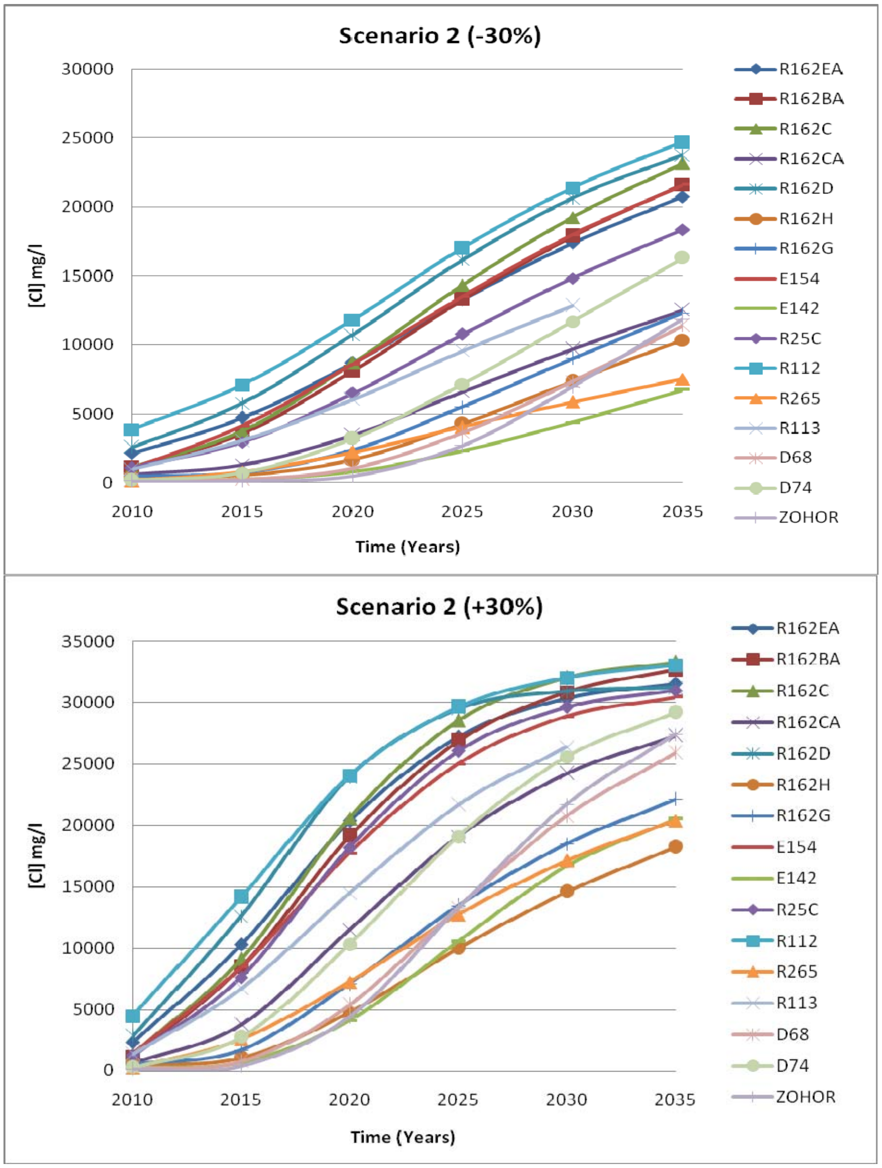


Figure (31): Simulated chloride concentration at the selected wells for Scenario 2

Figure 32 shows that the in-land distance for seawater intrusion will reach about 4,000 m at year 2035 when decreasing pumping by 30%. When the pumping increases by 30%, the intrusion will go beyond 4,300 m at year 2035. It was found that for Scenario 2 (-30%), at year 2015, the chloride concentration reached the acceptable level at a distance about 2,800 m from sea shoreline while for Scenario 2 (+30%) for the same year, the acceptable concentrations were found at a distance 3,000 m.

That means for Scenario 2 (-30%), the in-land movement of seawater intrusion will be approximately at a rate of 60 m/yr while for Scenario 2 (+30%) this rate becomes 70 m/yr.

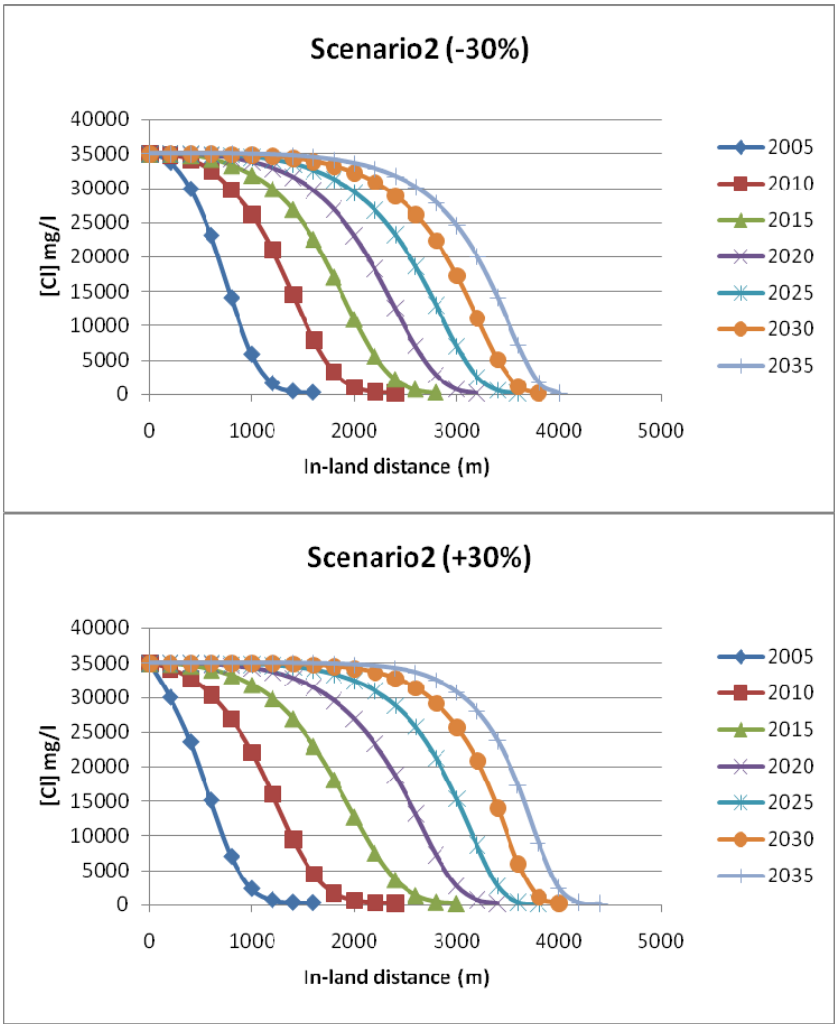
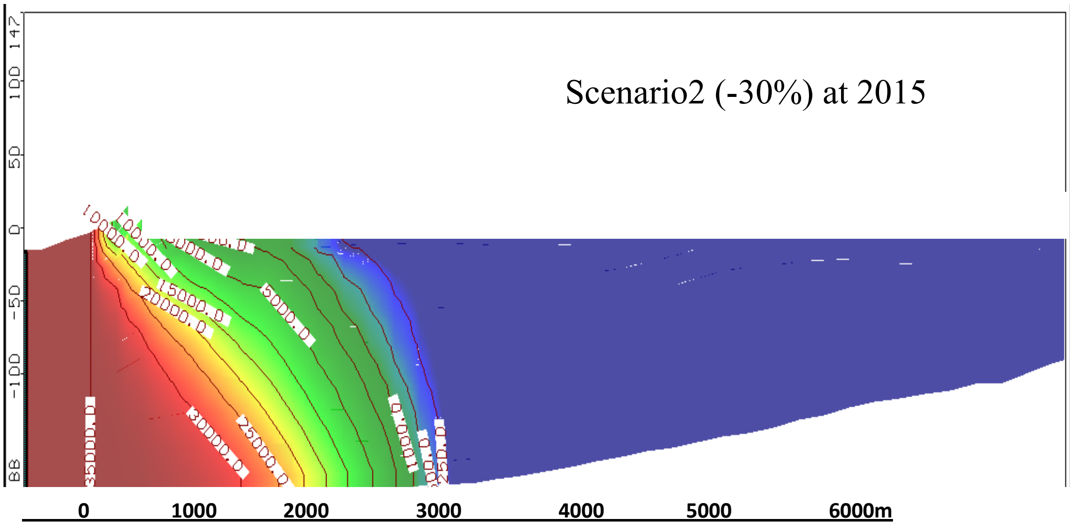
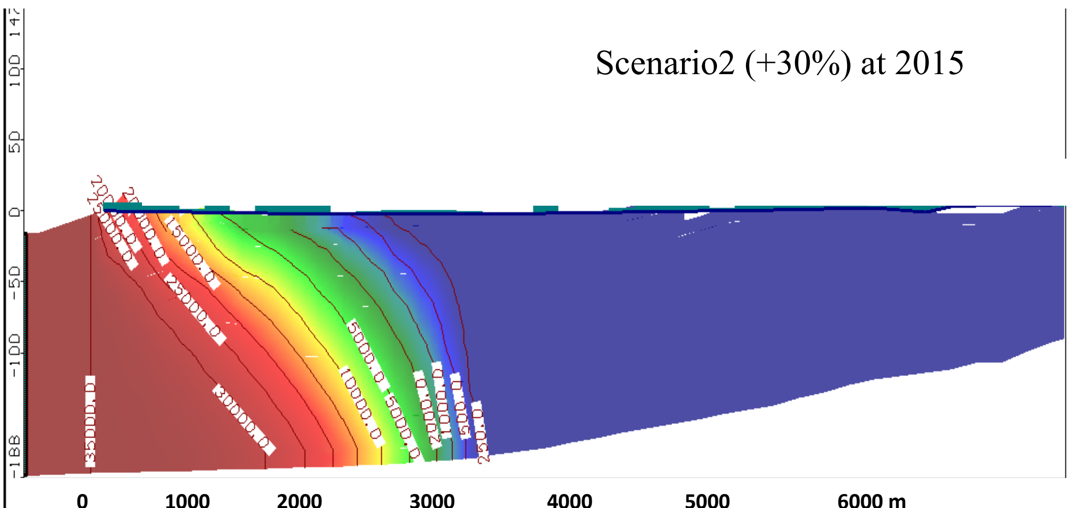
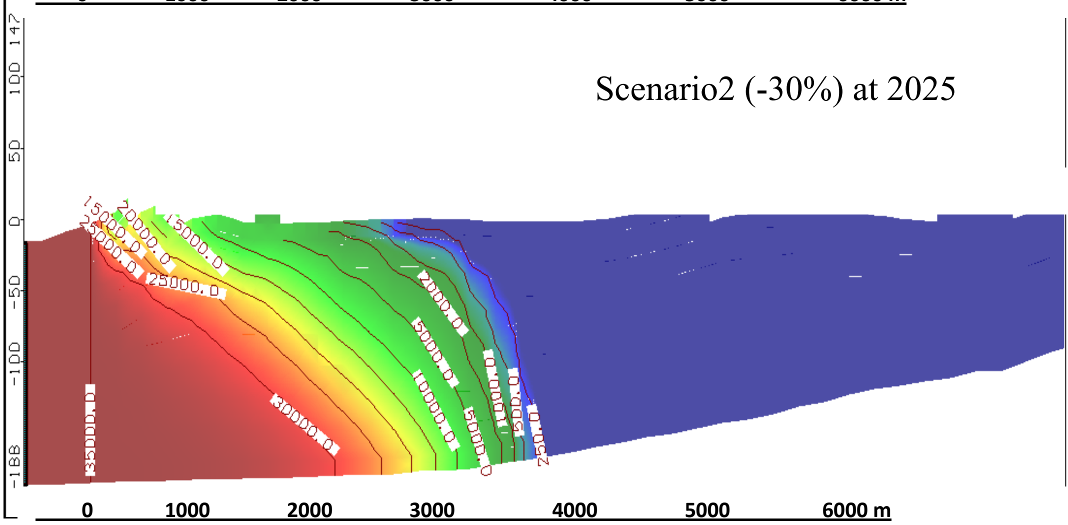


Figure (32): In-land seawater intrusion for Scenario 2

The following figure (Figure 33) depicts the seawater intrusion for different times for the two pumping scenarios.


Scenario2 (-30%) at 2015
0
1000
2000
3000
4000
5000
6000m


Scenario2 (+30%) at 2015
0
1000
2000
3000
4000
5000
6000 m


Scenario2 (-30%) at 2025
0
1000
2000
3000
4000
5000
6000 m

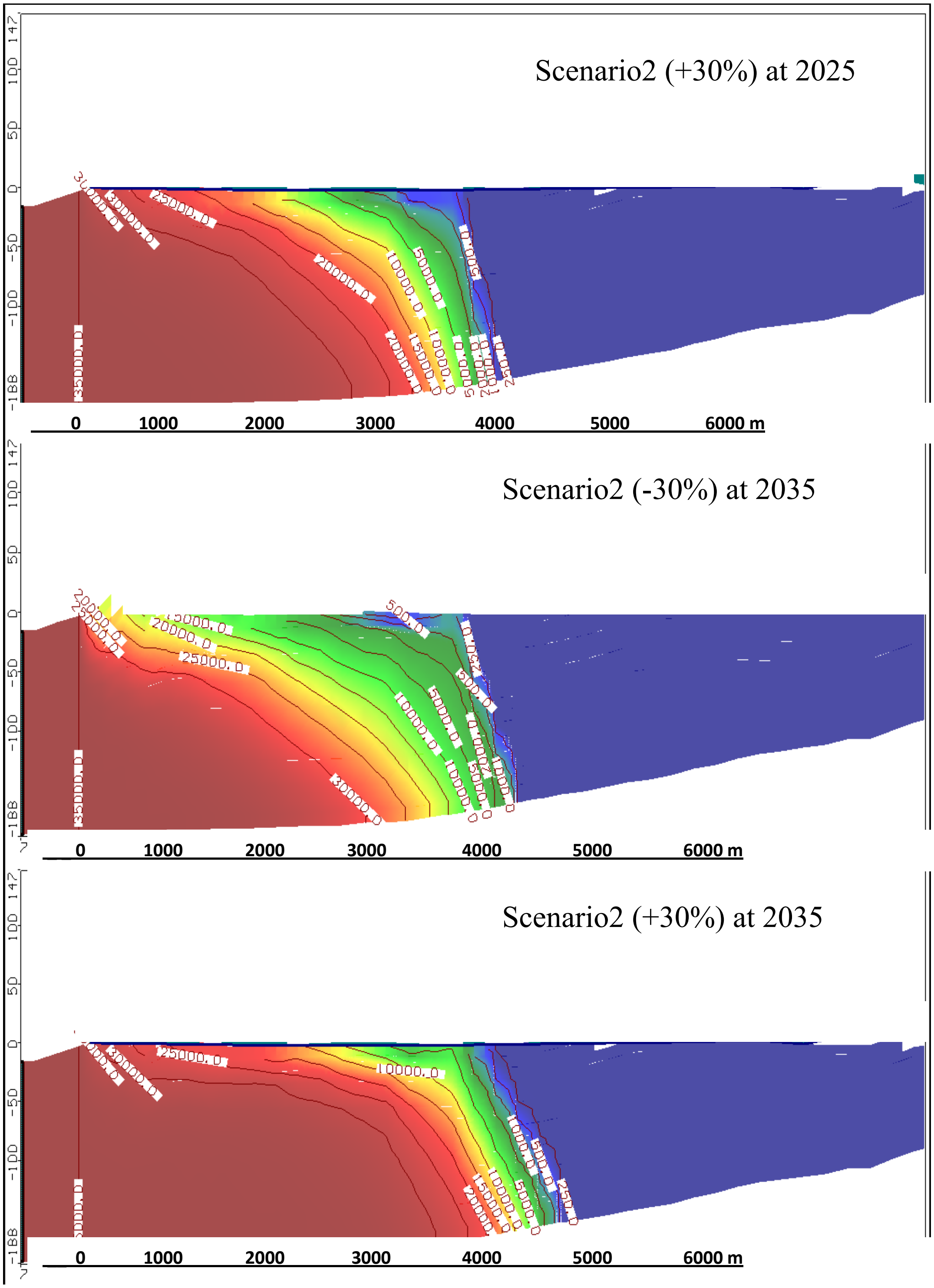


Figure (33): Cross section for Scenario 2 for the maximum seawater interface at row 35

6.5.3 Scenario 3: Impacts of Sea Level Rise

This scenario studies the impact of sea level rise on seawater intrusion with no consideration to climate change through recharge or pumping rates. According to IPCC (2007) the maximum expected sea level rise for the Mediterranean Sea is 5.9 mm/yr. Sea level rise was simulated by increasing the constant head boundary at the sea side by this value for each year until the end of the study period.

Figure 34 shows that the maximum chloride concentrations that can be encountered at year 2035 will reach 33,000 mg/l while Figure 35 shows the in-land distance for intrusion which will reach a distance of about 4,300 m by year 2035. The in-land extent for seawater intrusion will be about 70 m/yr. These results are close to the increasing pumping rates by 30% as in Scenario 2.

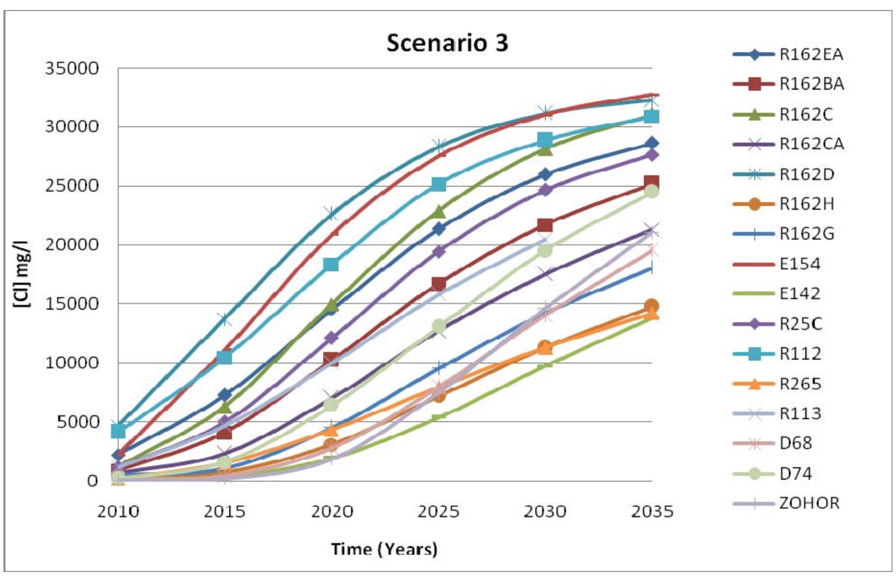


Figure (34): Simulated chloride concentration at the selected wells for Scenario 3

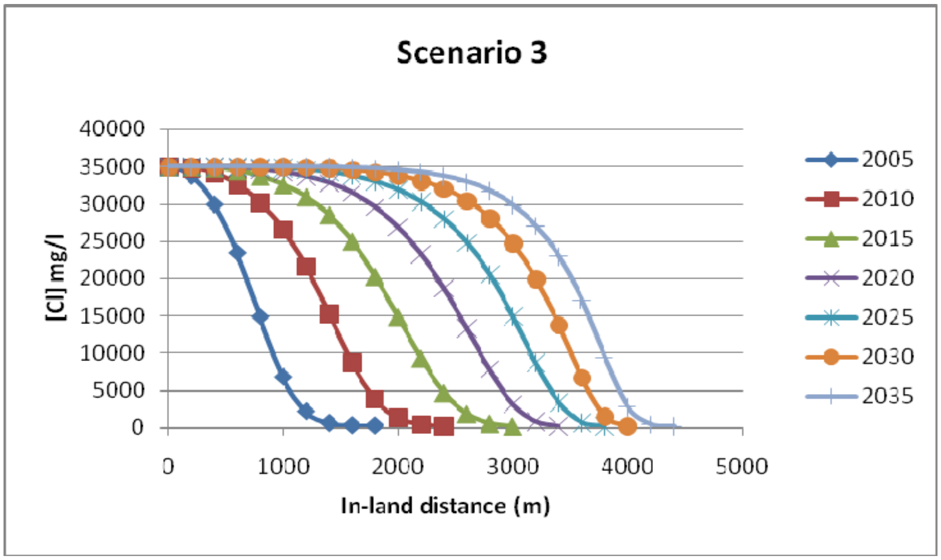


Figure (35): In-land seawater intrusion for Scenario 3

Figure 36 indicates the seawater intrusion for different times for Scenario3. As shown the results for the following figures are close to Figure 35 of the reference scenario.

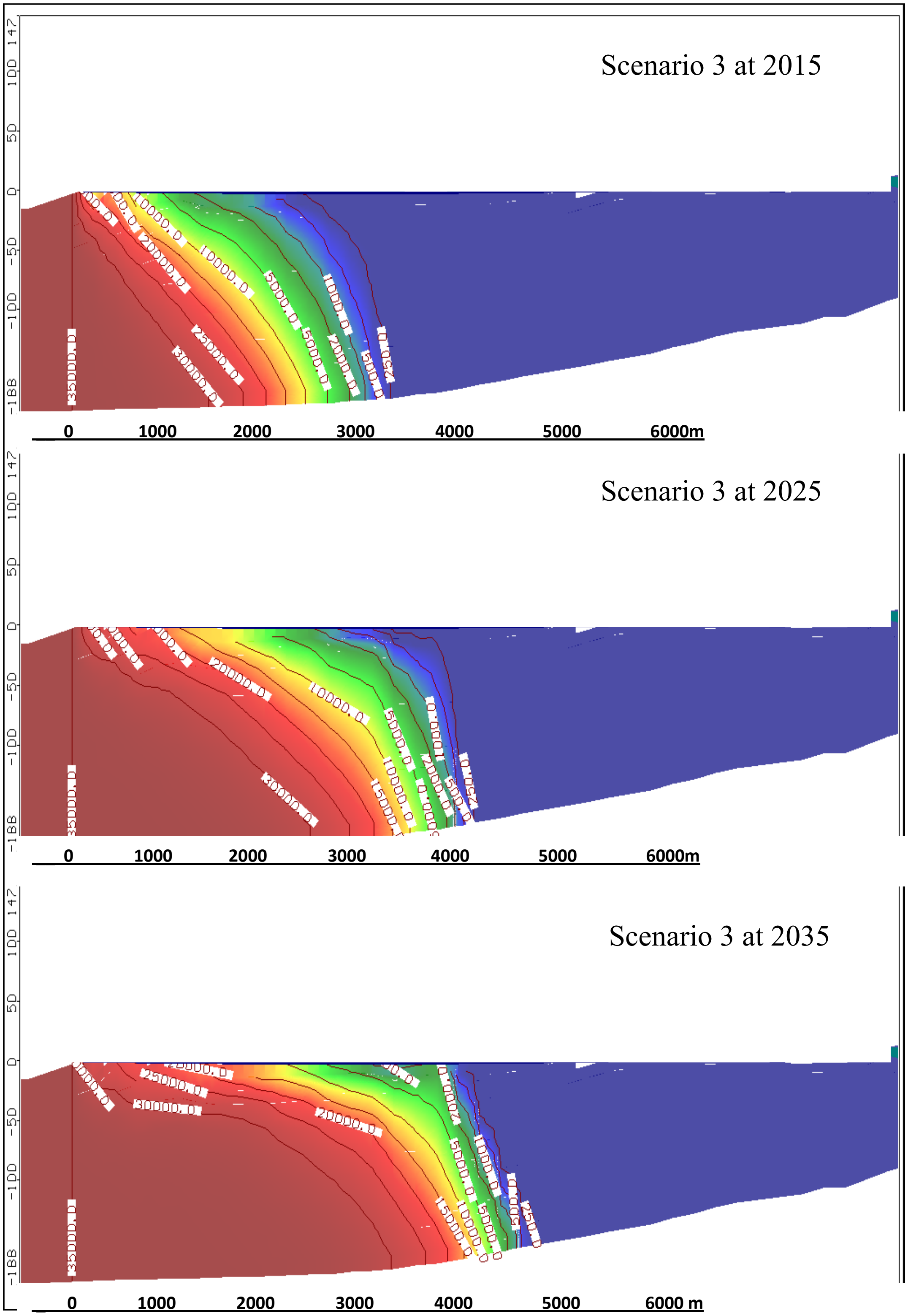


Figure (36): Cross sections for Scenario 3 indicates the maximum seawater interface at row 35

6.5.4 Scenario 4: Sensitivity to Recharge

This scenario focuses on the model sensitivity to the variability in natural recharge. This is achieved through two sub-scenarios with different uniform recharge rates. Scenario 4 (-30%) was carried out by decreasing the recharge rate by 30%, while Scenario 4 (+30%) indicates the increase in the current recharge rate by 30%.

For this scenario, the simulated chloride concentrations for selected wells are shown in Figure 37. Apparently decreasing recharge causes an increase in chloride concentrations at the specific wells by a range between 8% and 20% as compared to the reference scenario. Conversely, increasing recharge rates decreases the concentrations from 17% to 30%.

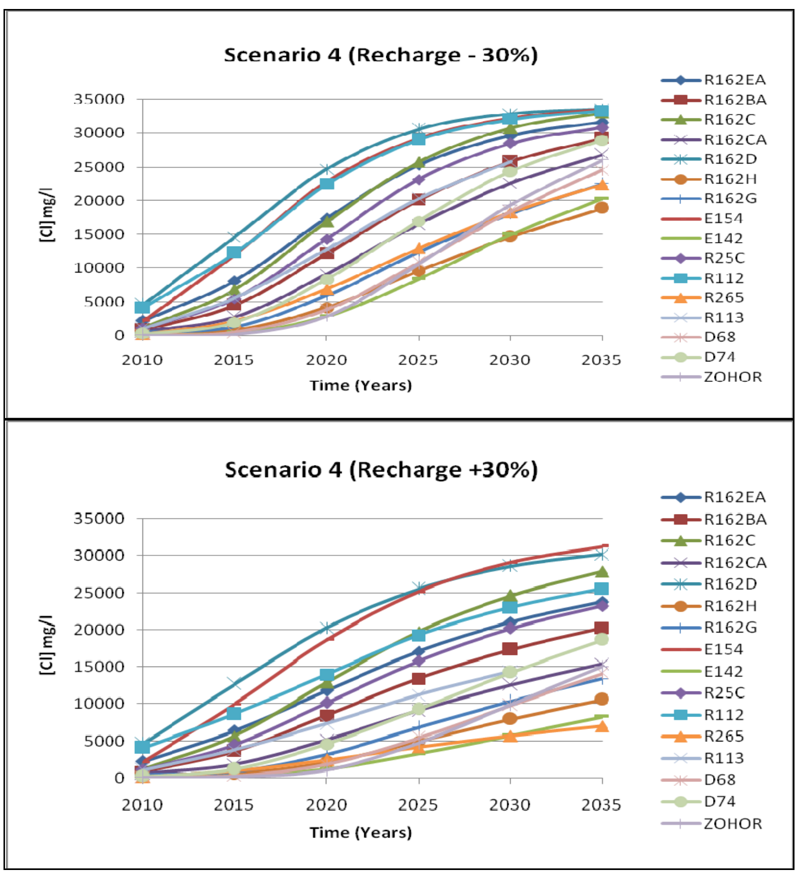
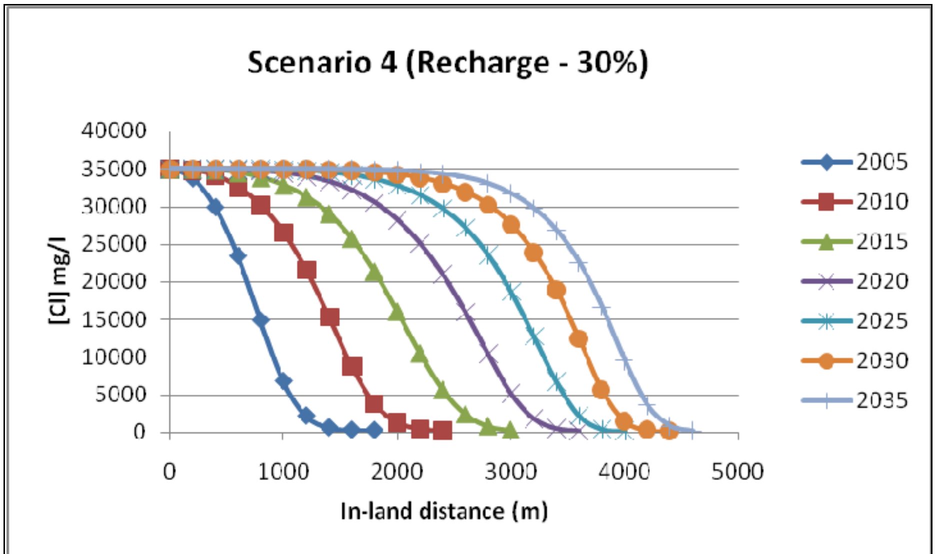


Figure (37): Simulated chloride concentration at the selected wells under Scenario 4

Figure 38 depicts the in-land seawater intrusion due to recharge variability. The intrusion occurs by the year 2035 at a distance of 3,900 m from the shoreline when increasing recharge while in the decreasing case the intrusion will reach a distance of about 4,500 m from sea shoreline. This means that the interface movement will decrease by about 10% when increasing recharge rate by 30% and it will increase by about 5% when decreasing recharge rate by 30%.



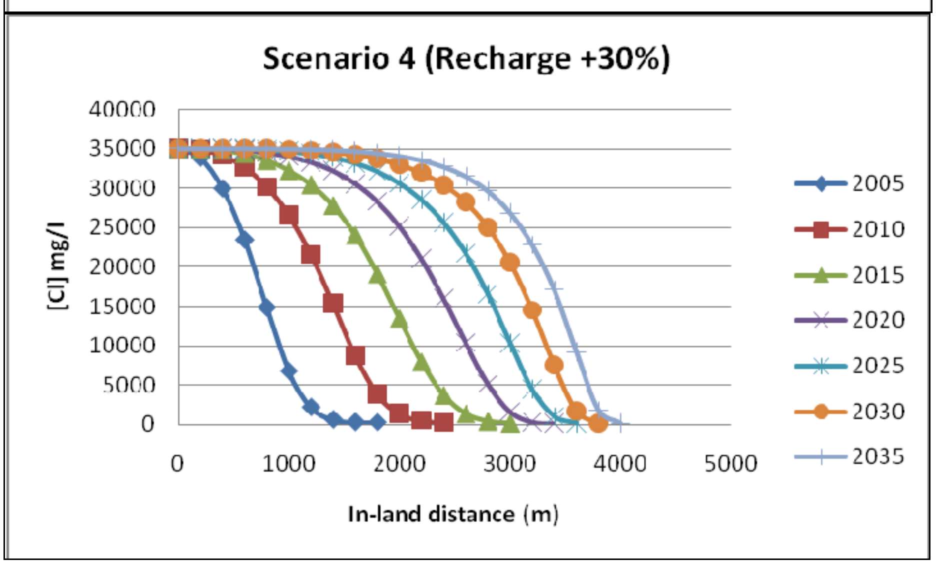
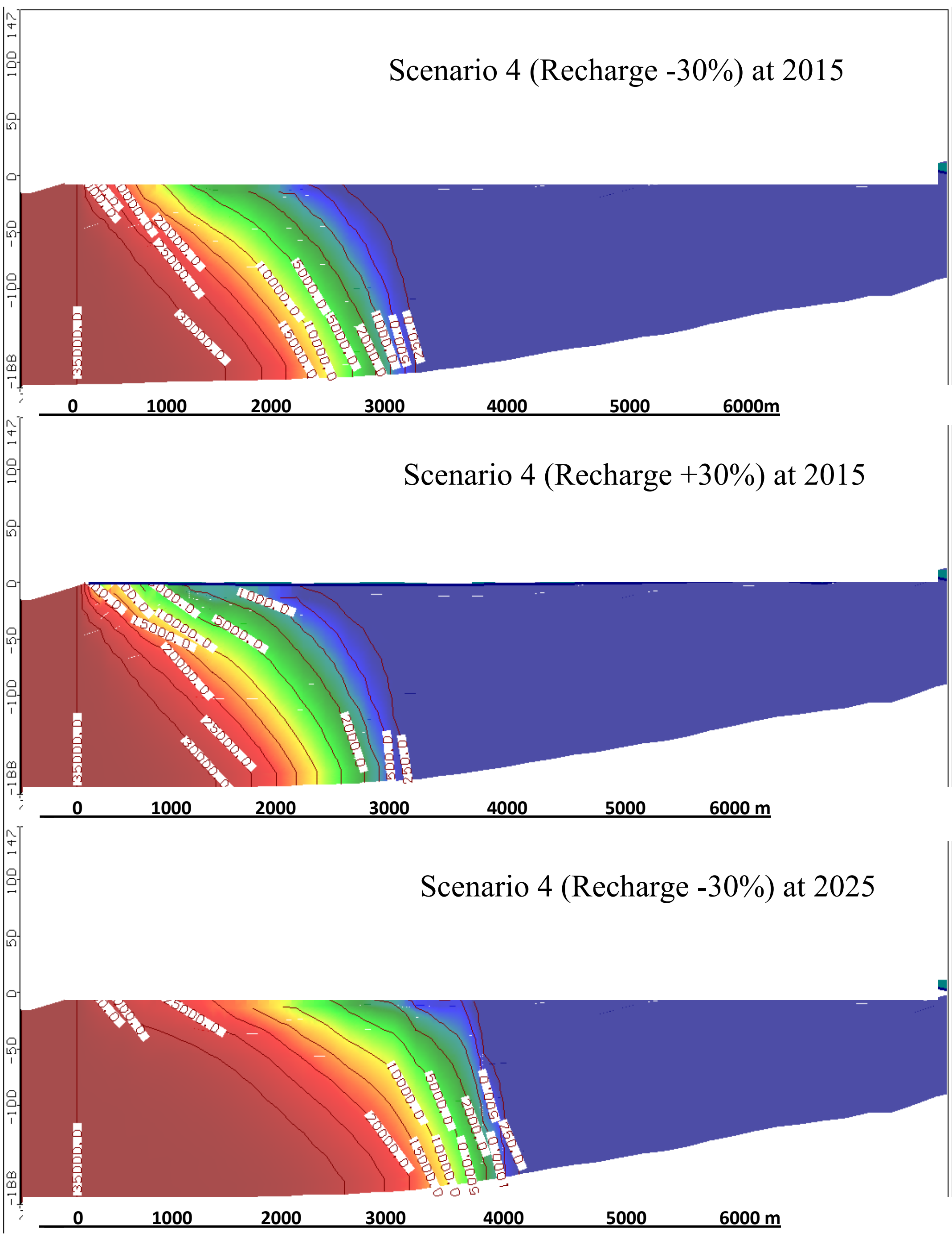


Figure (38): In-land seawater intrusion for Scenario 4

Figure 39 shows the seawater intrusion due to different recharge scenarios for different times. For Scenario 4 (Recharge -30%), the in-land movement rate of seawater intrusion will be about 80 m/yr, while for Scenario 4 (Recharge +30%), the movement rate will be about 50 m/yr.



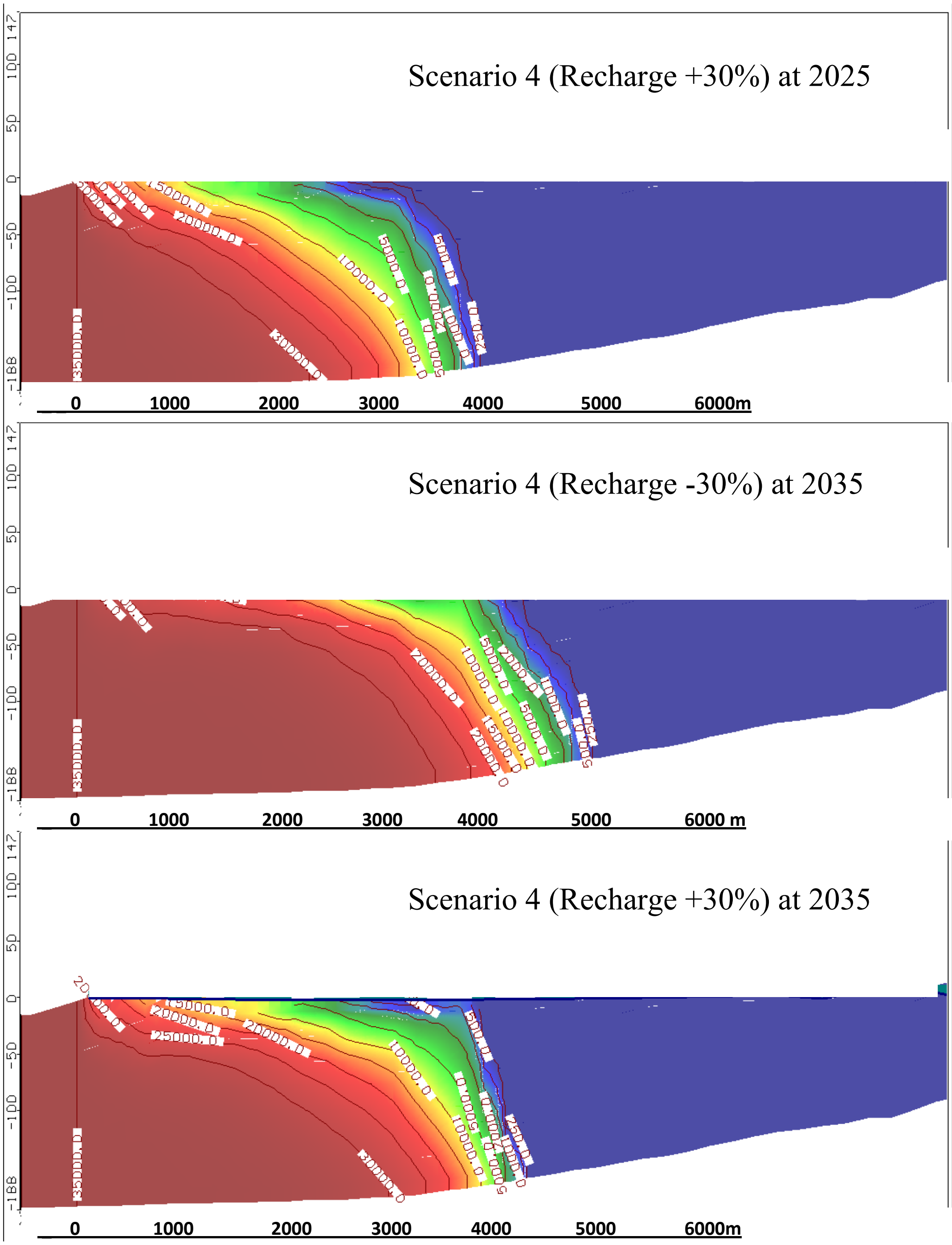


Figure (39): Cross sections for Scenario 4 depicting the maximum seawater interface at row 35

6.5.5 Scenario 5: Extreme Impacts of Climate Change

This scenario deals with the extreme impacts of climate change by combining both the maximum rates of sea level rise (59 cm/100 yr) and the minimum recharge rate (-10%) (IPCC, 2007) with no change in pumping rates. Figure 40 depicts the simulated concentrations for the selected wells.

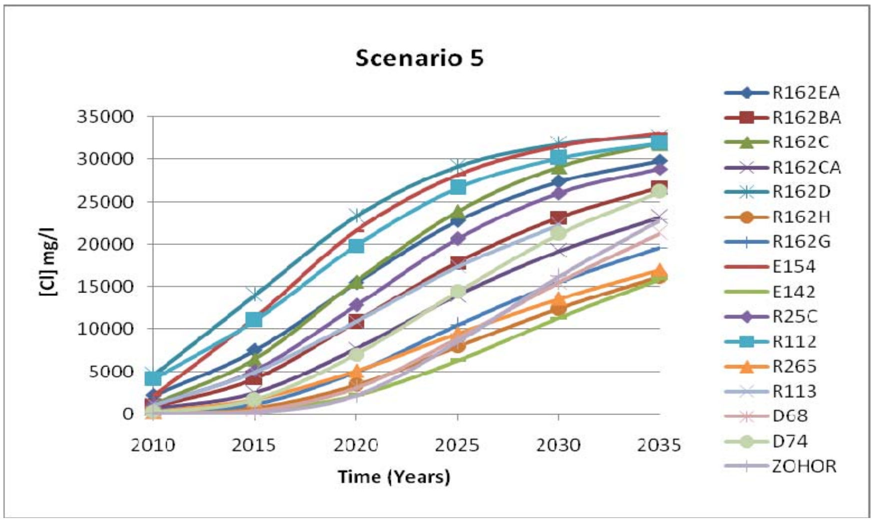


Figure (40): Simulated chloride concentration for the selected wells for Scenario 5

When comparing these concentrations with the corresponding ones of the reference scenario, we find that the increasing range of concentrations will be from 3% to 8%.

Figure 41 illustrates the in-land seawater intrusion due to the maximum sea level rise and recharge decrease. The maximum intrusion at year 2035 will occur at a distance of 4,300 m while in the reference scenario it was at a distance of 4,200 m. The two results are very close to each other since the effect of sea level rise on intrusion is very low and it can be neglected as shown in scenario 3. As such this slightly increase in the intrusion distance had occurred due to recharge decrease by 10%.

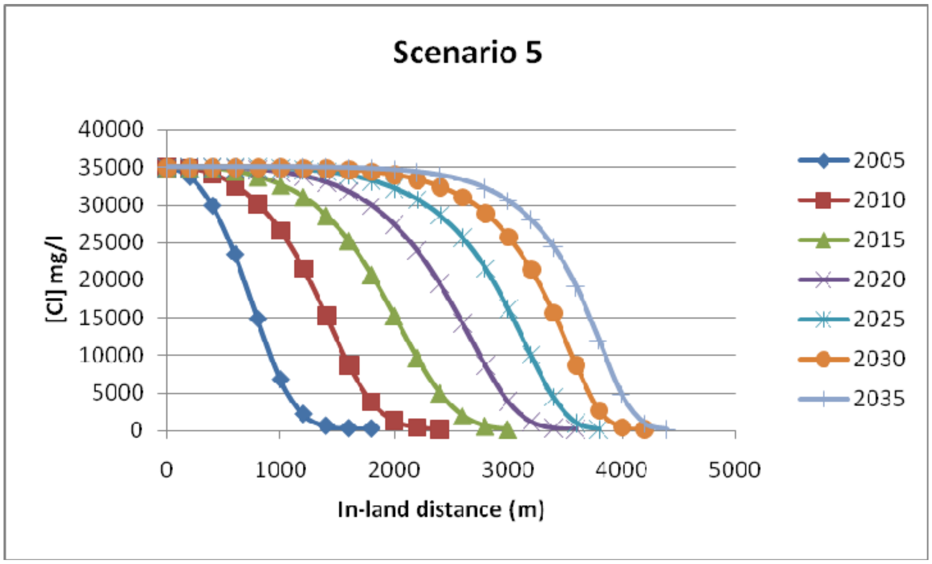


Figure (41): In-Land seawater intrusion for Scenario 5

The following figure (Figure 42) depicts the seawater intrusion for different years due to sea level rise and recharge reduction.

Due to scenario 5 results the in-land intrusion will be about 70 m/yr, which is the same distance encountered under the reference scenario.

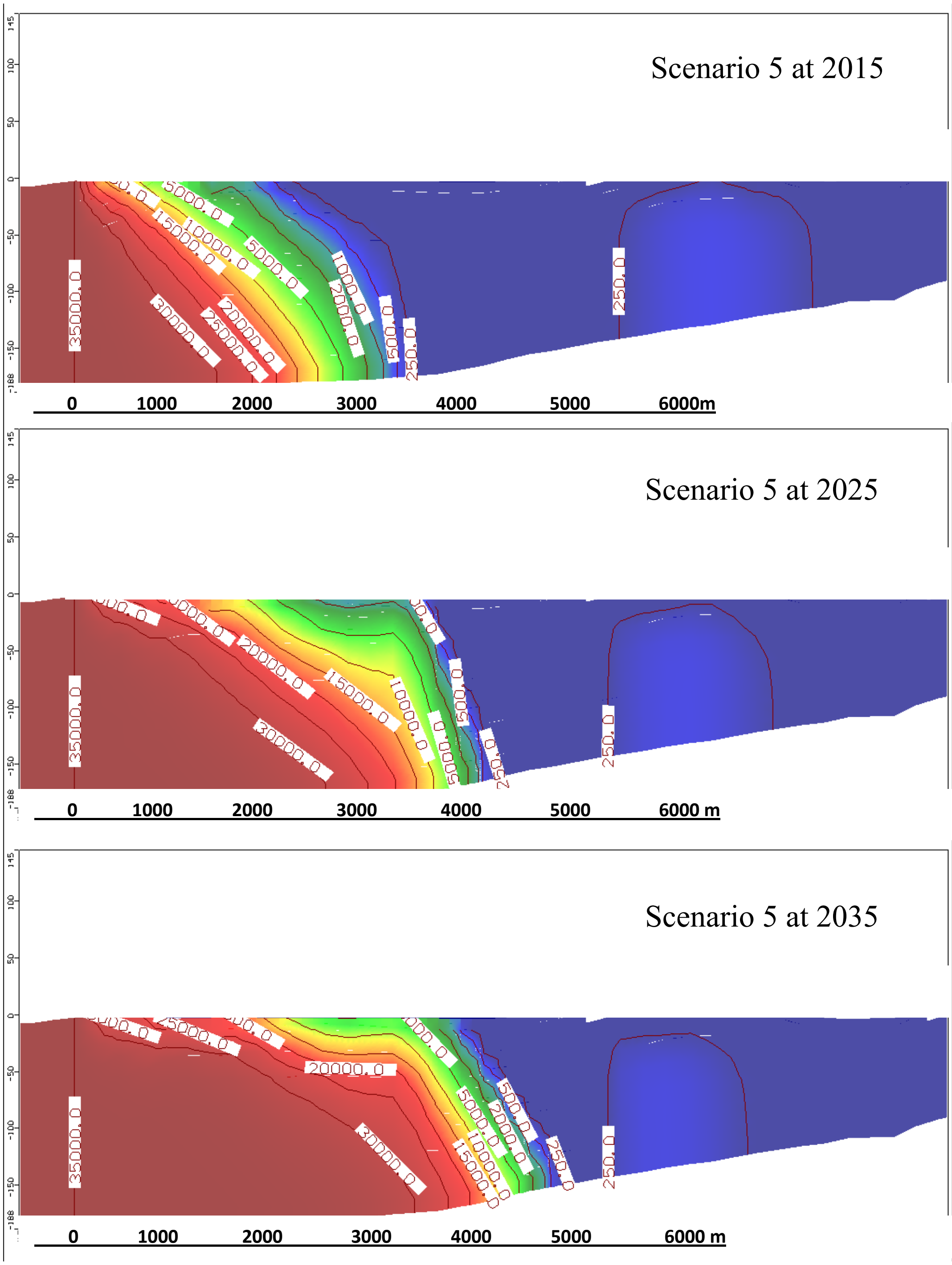


Figure (42): Cross sections for Scenario 5 signifying the maximum seawater interface at row 35

6.5.6 Scenario 6: Management Scenario

This scenario deals with the climate change impacts from both sea level rise and recharge decrease by taking into consideration the management solutions for the sea water intrusion problem. This depends on the future plans prepared by PWA to address the on-going problems in the aquifer (See APPENDIX A, Tables A6 to A9 for details).

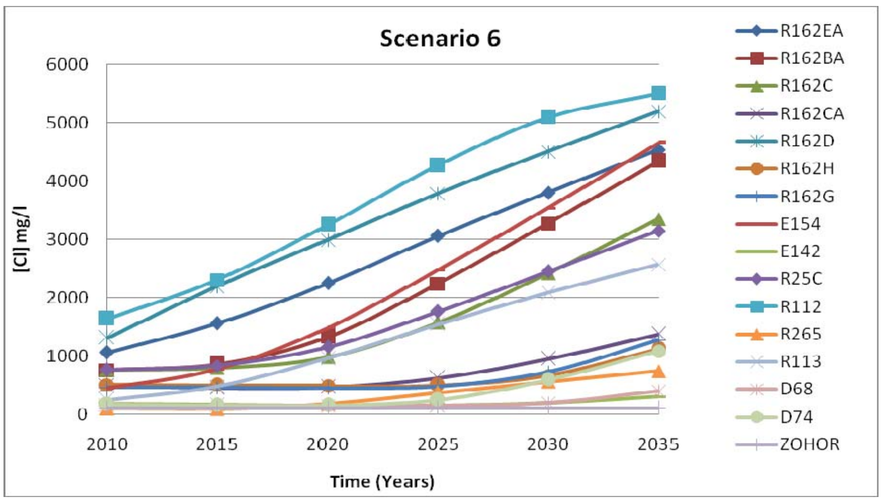


Figure (43): Simulated chloride concentration at the selected wells for Scenario 6

By comparing these results with those of the reference scenario we find that the decrease in concentrations will be between 81% and 99%. That means the PWA management plans must be activated soon.

Figure 44 depicts the in-land seawater intrusion due to scenario 6. As can be seen from Figure 49 the maximum intrusion at year 2035 will occur at a distance of 2,900 m. In the reference scenario it is at a distance of 4,200 m. As such the decreasing in the in-land intrusion will fall back about 30%.

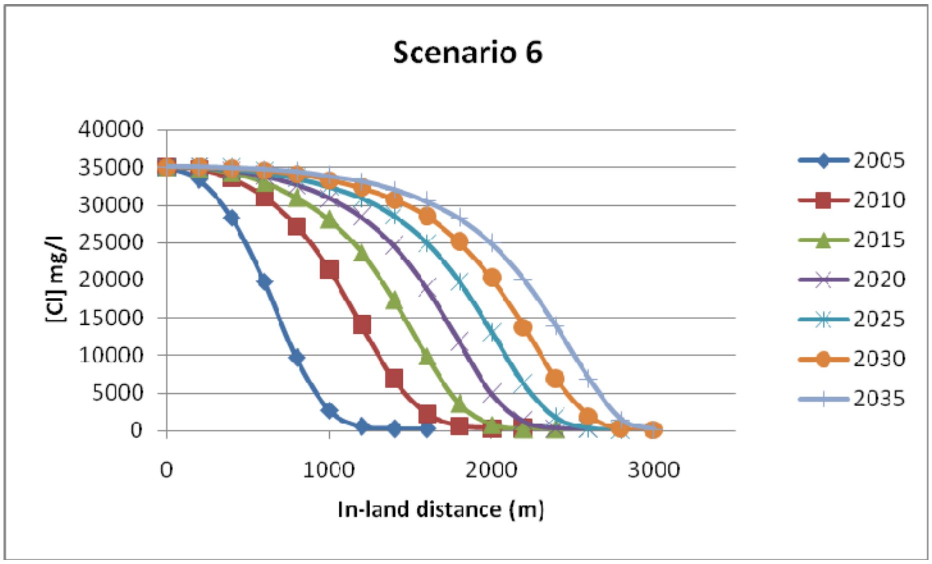


Figure (44): In-Land seawater intrusion for Scenario 6

The following figure (Figure 45) depicts the seawater intrusion for different years corresponding to Scenario 6. The maximum in-land intrusion rate will be around 35 m/yr which is the lowest among all scenarios.

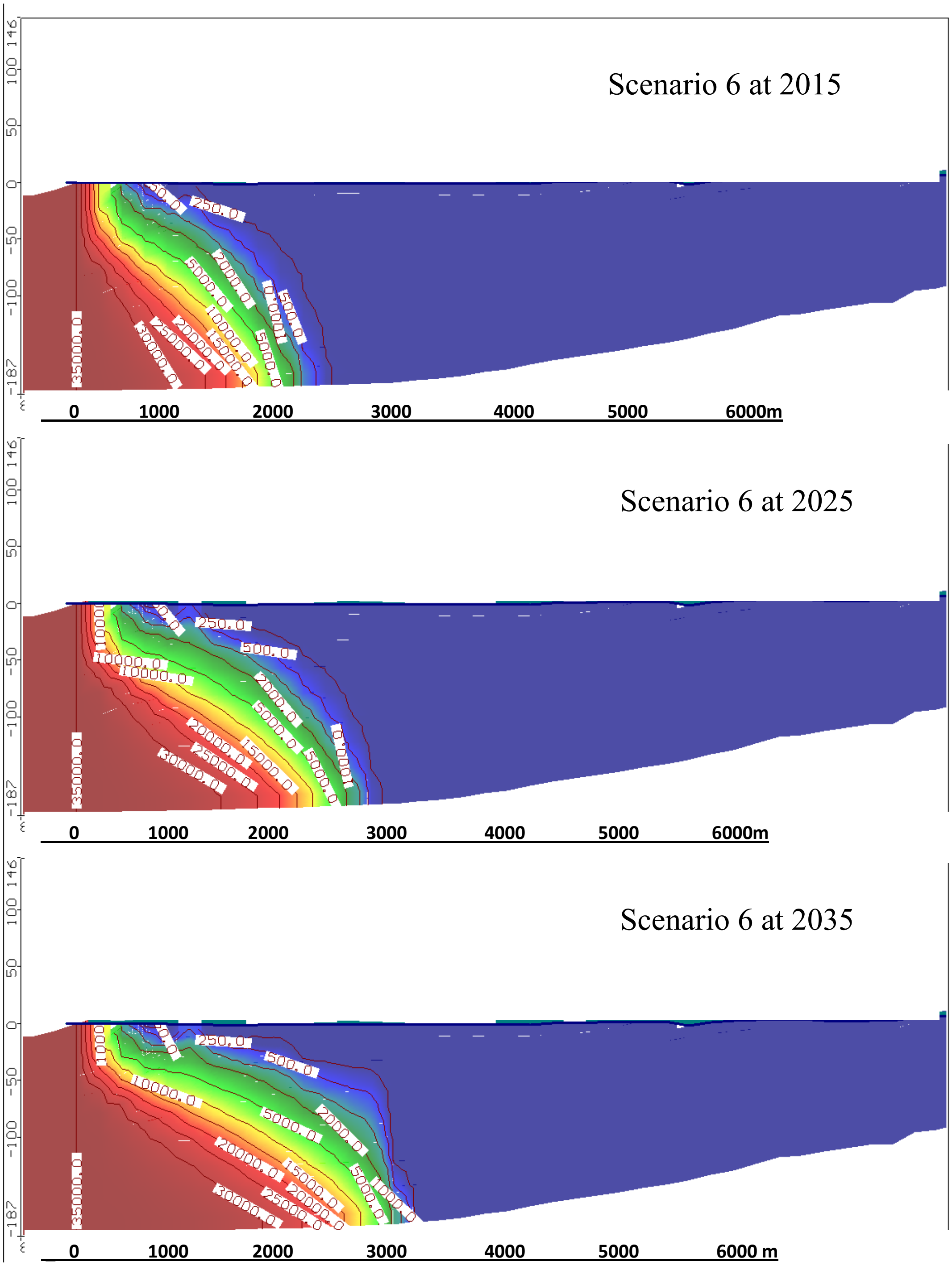


Figure (45): Cross sections for Scenario 6 with the maximum seawater interface at row 35

6.5.7 Overall Discussion

Table 11 summarizes the overall results for the six scenarios regarding to seawater intrusion.

Table 11: Summary of scenarios results by the end of simulation period (year 2035)

Indicator	Sc. 1	Sc. 2 (variable pumping rates)		Sc. 3	Sc. 4 (variable recharge rates)		Sc. 5	Sc. 6
		-30%	+30%		-30%	+30%		
[Cl] extent (m)	4,200 m	4,000 m	4,300 m	4,300 m	4,500 m	3,900 m	4,300 m	2,900 m
Seawater intrusion (m/yr)	65 m/yr	60 m/yr	70 m/yr	70 m/yr	80 m/yr	50 m/yr	70 m/yr	35 m/yr
[Cl] (±%) at wells compared to Sc. 1	--	-20% to -43%	7% to 24%	0.2% to 0.5%	8% to 20%	-17% to -30%	3% to 8%	-81% to -99%

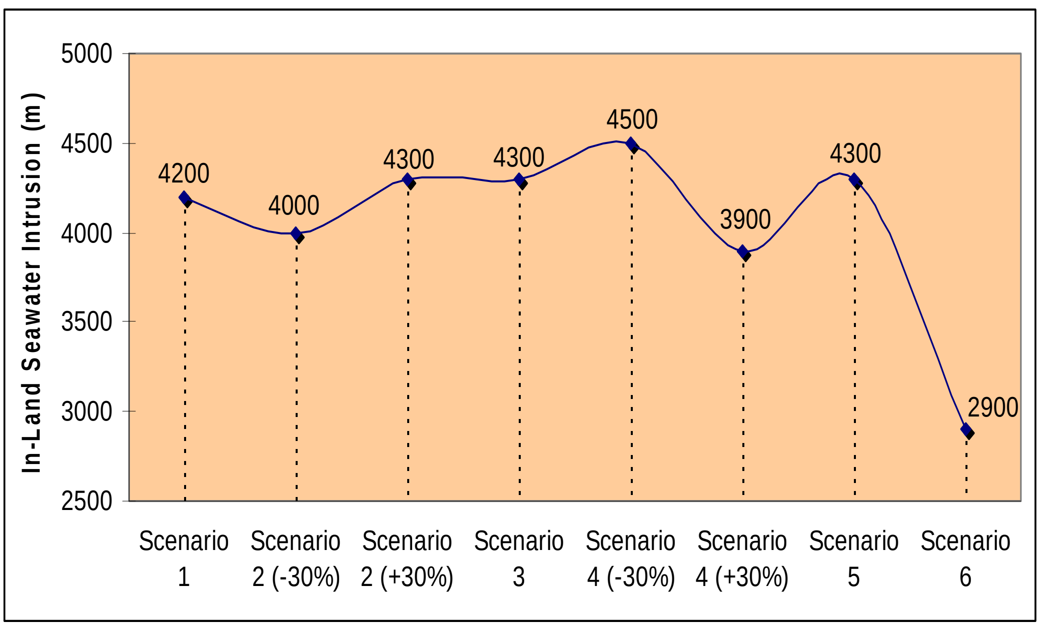


Figure (46): Seawater Intrusion results for various Scenarios

As shown in Table 11 and Figure 46, the most critical scenario for the extent of seawater is decreasing recharge by 30% since this scenario will cause an extent rate of about 80 m/yr, while the effect of scenario 2 by increasing pumping rates by 30% and scenario 3 by combining sea level rise with decreasing pumping rates by 10% was approximately the same. The management scenario (Scenario 6) is efficient and promotes the PWA strategic plan.

Seawater intrusion is more sensitive to recharge decrease by 30% (scenario 4), more than pumping rates increase by 30% (scenario 2), the reason for this that rainfall is the main recharge component for Gaza aquifer since it is the renewable resource for groundwater, so when recharge decrease with continuity of pumping as in scenario 4, so the decrease in the groundwater levels will affected from both of recharge decrease and continuity of pumping, while when pumping rates increase with keeping the current recharge rate without change as in scenario 2, so the decrease in the groundwater levels will occur due to one reason only which is pumping increase, but still renewable by another source which is rainfall which is doesn't change in this scenario.

CHAPTER SEVEN

CONCLUSINS AND RECOMMENDATIONS

7.1 Conclusions

The following are the main conclusions:

- The chloride concentrations due to seawater intrusion decrease by increasing the distance from sea shoreline with the involvement of two factors; the first is the location of the well from the sea shoreline, and the second is the depth of the well from the ground surface.

- Scenario 1 reflects the current situation without any management. Analysis results showed that the sea water intrusion will reach a distance of 4,200 m inland the aquifer, and this will cause unacceptable salinity for more than 50% of the pumping wells.

- Decreasing pumping rates as in Scenario 2 by 30% will decrease concentrations between 20% and 43% as compared to the reference scenario.

- Increasing pumping rates by 30% will cause increasing in the concentrations between 7% and 24%, depending on the well distance from sea shoreline.

- Seawater intrusion due to sea level rise as in Scenario 3, and increasing pumping rates by 30% as in Scenario 2 in addition to combining sea level rise with decreasing pumping rates by 10% as in Scenario 5 was approximately the same.

- Decreasing recharge rates by 30% as in Scenario 4 will cause an increase in chloride concentrations in the wells with a range between 8% and 20% compared to reference scenario. Increasing recharge rates will decrease the concentrations between 17% and 30%.

- By combining the two climate change elements; maximum sea level rise and the minimum recharge rates as in Scenario 5, we found that the increasing range of concentrations will be about 3% and 8% as compared to the reference scenario.

- The outcome of Scenario 6 was interesting, since it confirms the potency of PWA management plan which aim to improve the quantity and quality for groundwater aquifer at Gaza strip by restoring many alternatives to reduce the pumping rates for both municipal and agricultural sectors, and this leads to reduce the seawater intrusion movement inside the aquifer.

- Seawater intrusion is very sensitive to recharge decrease as compared to the increase in pumping rates.

- In-land intrusion rate was found to be 80 m/yr as recharge decrease by 30% and 70 m/yr as pumping rate increases by 30%.

7.2 Recommendations

The following are the key recommendations:

- PWA must go ahead in implementing the strategic plan for desalination plants for both brackish groundwater and saline seawater to cover the future water demand.

- Existing wastewater treatment plants must be developed to increase their capacity and efficiency in order to reduce the reliance on the aquifer.

- Random and illegal abstraction from both municipal and agricultural wells must stop immediately to release the stress on the aquifer.

- Improving the municipalities' water network system (system efficiency) is a considerable key to reduce losses through the water network and thus reduce pumping requirements in the end.

- Regarding the agricultural sector, it should be managed through efficient use of water, adopting new crop patterns and utilization of alternative water resources (for instance low water quality and treated wastewater).

- Injection wells of high quality treated water can reduce the seawater intrusion if they are located in a specific locations along the sea shore line, I recommend to work such idea in the future researches.

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APPENDIX A

Table A1: Jabalia wells

No.	Wells	Operation Date	Q (m^3/hr)	Cl-mg/l
1	D-74	1997	180	170
2	D-75	2003	150	100
3	E-142A	2003	100	225
4	D-60	1963	120	200
5	E-90	1974	150	220
6	E-01	1982	70	130
7	E-04	1964	100	90
8	Q-72	2003	130	210
9	E-156	1984	180	170

Table A2: Beit Hanoun wells

No.	Wells	Operation Date	Q (m^3/hr)	Cl-mg/l
1	C-128	1996	120	250
2	C-127A	2002	120	100
3	C-76	1999	80	700
4	C-79A	1999	90	500
5	C-137	2002	130	40
6	C-20	2003	110	250

Table A3: Beit Lahia wells

No.	Wells	Operation Date	Q (m^3/hr)	Cl-mg/l
1	D-67	1985	80	60
2	A-185	1987	180	175
3	A-180	1985	100	150
4	E-6	1994	100	120

Table A4: Gaza city wells

No.	Wells	Operation Date	Q (m^3/hr)	Cl-mg/l
1	R-162LA	1995	170	2000
2	R-162BA	2000	60	750
3	R-162CA	2000	60	400
4	R-162D	2001	75	3700
5	R-162H	1978	200	500
6	R-162HA	1997	120	550
7	E-154	1981	140	2900
8	E-157	1992	180	200
9	D-68	1993	170	160
10	D-69	1996	120	125
11	D-70	1996	160	130

12	R-162G	1978	210	680
13	D-71	1998	200	100
14	D-72	1998	180	85
15	R-112	1989	70	2950
16	R-254	1989	60	400
17	R-265	1999	50	270
18	R-113A	2005	70	400
19	R-277	2001	60	260
20	R-280	2003	60	150
21	R-293	2004	60	500
22	R-25B	1956	180	550
23	R-25A	1985	160	530
24	R-25C	1979	100	1000
25	R-25D	1976	180	750
26	Q-68	1999	220	250
27	R-75	1994	120	850
28	R-74	1997	100	750

Table A5: Target consumption and needs rates at the study area

Target Year	**Domestic consumption**		**Public consumption**		**Livestock consumption**		**Total Municipal Consume Rate (L/c/d)**
	Rate (L/c/d)	**(%)**	**Rate (L/c/d)**	**(%)**	**Rate (L/c/d)**	**(%)**	
2010	100	0.9	7	0.06	4	0.04	111
2015	110	0.9	9	0.07	4	0.03	122
2020	120	0.9	11	0.08	3	0.02	133
2025	130	0.9	13	0.09	1	0.01	144
2030	135	0.9	14	0.09	2	0.01	150
2035	135	0.9	14	0.09	2	0.01	150

A6: The Spearman rank correlation between Observed and simulated chloride concentrations:

```
> obs=c(100,160,170,225,270,400,500,500,530,550,680,750,1000,1316,1900,2900,2950,3700)

> cal=c(111,184,197,192,216,569,481,580,616,572,494,786,993,1066,1609,2774,3126,3337)

> rank(x)

 [1]  1.0  2.0  3.0  4.0  5.0  6.0  7.5  7.5  9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0

> rank(y)

 [1]  1  2  4  3  5  8  6 10 11  9  7 12 13 14 15 16 17 18

> cor.sp <- function(x,y) cor(rank(x),rank(y))

> cor.sp(x,y)

[1] 0.9633455
```

Table A7: Average quantity of treated wastewater

Location	Current population (2010)	Water consumption[1] L/c/d	Connection % to WW network	Losses % from Sewage Network	Losses % in distribution system & WWTP	WW production m^3/d	Total WW production m^3/d	WWTP capacity m^3/d	% of WWTP coverage	Net WW to be used for Agriculture Mcm/yr
Beit Lahia	71,880	100	83	30	25	3,341	15,021	5,000	33	0.30
Beit Hanoun	42,428	100	61.5	30	25	1,461				0.13
Jabalia	183,924	100	98.4	30	25	10,135				0.92
Um Anaser	3,135	80	60	30	25	84				0.01
Gaza city	539,590	110	99.2	30	25	32,973	32,973	50,000	100	9.03
Total	**840,957**					**47,994**				**10.40**

Location	population (2015)	Water consumption[1] L/c/d	Connection % to WW network	Losses % from Sewage Network	Losses % in distribution system & WWTP	WW production m^3/d	Total WW production m^3/d	WWTP capacity m^3/d	% of WWTP coverage	Net WW to be used for Agriculture Mcm/yr
Beit Lahia	84,959	110	83	30	25	4,344	18,335	5,000	27	0.32
Beit Hanoun	50,149	110	61.5	30	25	1,900				0.14
Jabalia	217,391	100	98.4	30	25	11,979				0.89
Um Anaser	3,705	90	60	30	25	112				0.01
Gaza city	637,774	120	99.2	30	25	42,516	42,516	50,000	100	11.64
Total	**993,977**					**60,850**				**13.01**

Location	population (2020)	Water consumption[1] L/c/d	Connection % to WW network	Losses % from Sewage Network	Losses % in distribution system & WWTP	WW production m^3/d	Total WW production m^3/d	WWTP capacity m^3/d	% of WWTP coverage	Net WW to be used for Agriculture Mcm/yr
Beit Lahia	98,491	120	83	30	25	5,493	24,705	5,000	20	0.30
Beit Hanoun	58,136	120	61.5	30	25	2,403				0.13
Jabalia	252,016	120	98.4	30	25	16,664				0.92
Um Anaser	4,295	100	60	30	25	144				0.01
Gaza city	739,355	130	99.2	30	25	53,394	53,394	50,000	100	14.62
Total	**1,152,292**					**78,099**				**15.99**

Location	population (2025)	Water consumption[1] L/c/d	Connection % to WW network	Losses % from Sewage Network	Losses % in distribution system & WWTP	WW production m^3/d	Total WW production m^3/d	WWTP capacity m^3/d	% of WWTP coverage	Net WW to be used for Agriculture Mcm/yr
Beit Lahia	114,178	120	83	30	25	6,368	28,640	5,000	17	0.30
Beit Hanoun	67,396	120	61.5	30	25	2,785				0.13
Jabalia	292,155	120	98.4	30	25	19,319				0.92
Um Anaser	4,979	100	60	30	25	167				0.01
Gaza city	857,115	130	99.2	30	25	61,899	61,899	50,000	100	16.94
Total	**1,335,823**					**90,538**				**18.31**

Location	population (2030)	Water consumption[1] L/c/d	Connection % to WW network	Losses % from Sewage Network	Losses % in distribution system & WWTP	WW production m^3/d	Total WW production m^3/d	WWTP capacity m^3/d	% of WWTP coverage	Net WW to be used for Agriculture Mcm/yr
Beit Lahia	132,363	130	83	30	25	7,998	35,971	5,000	14	0.30
Beit Hanoun	78,130	130	61.5	30	25	3,498				0.13
Jabalia	338,688	130	98.4	30	25	24,262				0.92
Um Anaser	5,772	110	60	30	25	213				0.01
Gaza city	993,631	140	99.2	30	25	77,277	77,277	50,000	65	13.69
Total	**1,548,585**					**113,249**				**15.06**

Location	population (2035)	Water consumption[1] L/c/d	Connection % to WW network	Losses % from Sewage Network	Losses % in distribution system & WWTP	WW production m^3/d	Total WW production m^3/d	WWTP capacity m^3/d	% of WWTP coverage	Net WW to be used for Agriculture Mcm/yr
Beit Lahia	153,445	140	83	30	25	9,985	44,889	5,000	11	0.30
Beit Hanoun	90,574	140	61.5	30	25	4,367				0.13
Jabalia	392,632	140	98.4	30	25	30,290				0.92
Um Anaser	6,692	110	60	30	25	247				0.01
Gaza city	1,151,891	150	99.2	30	25	95,985	95,985	50,000	52	13.69
Total	**1,795,234**					**140,874**				**15.06**
									Total	**87.81**
									Average	**10.98**

(1): MAS,2009

Table A8: Existing desalination plants production

Existing Desalination plants	m^3/d	MCM/yr
Gaza industrial zone	1080 m^3/d	0.3942
Northern desalinisation plant	phase I (Existing) = 1200 m^3/d	2.263
	phase II (Proposed) = 5000 m^3/d	
	Total	**2.6572**

Table A9: Centralized Desalination plant

Year	Proposed Desalinization quantity m^3/d	Gaza Strip Desalinization MCM/yr	North Gaza Desalination* MCM/yr
2015	320000	116.8	46.72
2020	300000	55	22.00
2025	300000	55	22.00
2030	300000	55	22.00
2035	300000	55	22.00
		Total	**134.72**
		Average	**26.94**

***: North Gaza population is about 40% of total Gaza Strip population.**

Table A10: Proposed desalination plants production

Proposed Water Resources	Gaza Strip Desalinisation MCM/yr	North Gaza Desalination MCM/yr
Mekerot	10	4.00
Beach sewater desalination plants	2.25	0.90
Total	**12.25**	**4.9**

جامعة النجاح الوطنية
كلية الدراسات العليا

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قدمت هذه الأطروحة استكمالا لمتطلبات درجة الماجستير في هندسة الميـــاه و البيئـــة بكلية الدراسات العليا، جامعة النجاح الوطنية، نابلس، فلسطين
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الملخص

تعتبر المياه الجوفية المصدر الرئيسي لسد احتياجات المواطنين في قطاع غزة سواء كان للأغراض المنزلية، الزراعية، الشرب أو الصناعية، وتغذية الحوض الجوفي هي نتاج طبيعي لرشح وتسرب جزء كبير من الأمطار خلال فصل الشتاء إلى الطبقات الصخرية مكونة ما يسمى بالحوض الجوفي.

ومن الناحية الهيدروجيولوجية فإن الحوض الجوفي في قطاع غزة يتراوح سمكه ما بين أمتار قليلة شرقاً إلى حوالي 150 متراً غرباً على طول الشريط الساحلي. ولنوعية المياه في هذا الحوض خصوصية لتأثرها بصورة مباشرة بزيادة الضخ مما يؤدي معه تدهورها نتيجة لاندفاع المياه الأكثر ملوحة من الطبقات السفلى إلى أعلى وكذلك تداخل مياه البحر المالحة في المناطق القريبة من الساحل وهذا ما حصل فعلاً خلال السنوات العشر الماضية حيث انخفض منسوب المياه الجوفية إلى معدلات عالية كنتاج طبيعي للضخ الغير المتوازن مع القدرة التجديدية للخزان.

ناهيك عن تلوث العديد من الآبار نتيجة لتسرب مياه الصرف الصحي وزيادة تركيز عنصر النترات إلى معدلات عالية جداً تفوق ما هو موصى به عالمياً. وهذا التلوث يتركز خاصة في المناطق السكنية العديدة الغير متوفر بها شبكات صرف صحي واستخدام المواطنين لحفر أرضية لتصريف هذه المياه العادمة التي تتسرب مباشرة إلى الخزان الجوفي لقربه من سطح الأرض حيث يتراوح هذا العمق ما بين أمتار قليلة في المناطق المنخفضة والقريبة من الشاطئ إلى ما يقرب من 70 متراً في المناطق الشرقية والجنوبية الشرقية.

تعتمد هذه الدراسة على نمذجة الحوض الجوفي من خلال برنامج SEAWAT وذلك لمحاولة معرفة تأثير التغير المناخي و الضخ الجائر على كفاءة الحوض الجوفي على المدى البعيد، حيث أن فترة الدراسة امتدت من سنة 2000 وهي سنة الأساس لغاية سنة 2035.

حيث أن استمرار الضخ الجائر بالاضافة لعوامل التغير المناخي والتي تتعرض لها منطقة حوض البحر المتوسط كما هو الحال في معظم أنحاء العالم، سوف يؤدي الى اغلاق حوالي 50% من الآبار الموجودة في منطقة الدراسة لعدم صلاحيتها للاستعمال البشري.

تم اعتماد خمسة سيناريوهات بفرضيات مختلفة وذلك لدراسة العوامل الثلاثة المتعلقة بالتغير المناخي وهي: ارتفاع منسوب سطح البحر،تغير كميات الضخ لتلبي الزيادة المتوقعة للسكان بالاضافة الى تغير كميات الامطار على المدى البعيد. كما تم افتراض سيناريو آخر للتعامل مع الخطة الاستراتيجية المستقبلية لقطاع غزة حسب تصور سلطة المياه حيث كانت النتائج مذهلة وتثبت فعالية هذه الخطة المقترحة من قبل سلطة المياه الفلسطينية.