بسم الله الرحمن الرحيم

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Master Thesis in Water Resources Engineering

Recharge Assessment and Modeling Issues to the north of Wadi Gaza coastal Aquifer

تقدير الحقن الصناعي ونتائج النمذجة الرياضية للخزان الجوفي الساحلي في شمال وادي غزة

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science (Water Resources Engineering Program) at the Islamic University of Gaza

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In the name of Allah, Most Gracious, Most Merciful

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"وجعلنا من الماء كل شيء حي"

القران الكريم ، سورة الأنبياء، أية 30

"We made from water all living thing"

The Holy Quran, Al-Anbiya [The Prophets] verse 30

DEDICATION

This thesis would be incomplete without a mention of the support given me by my **Beloved Parents, Wife,** and **daughters**, to whom this thesis is affectionately dedicated. They were my own "**soul out of my soul**," who kept my spirits up when the muses failed me. Without them lifting me up when this thesis seemed interminable, I doubt it should ever have been completed.

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ABSTRACT

Gaza coastal aquifer faces huge crises of the water resources scarcity and contamination by seawater intrusion. Accordingly, real concerns for planning, development, and management of available resources became so required to alleviate of such crises. This could be by searching for new additional cost effective resources. The artificial recharge using both the stormwater and the reclaimed wastewater, for instance, is one of these new alternative resources.

The main aim of the study is primarily to study the possible optimum management scenarios for study area aquifer by adopting the artificial groundwater recharge options. The first part of the research illustrates the artificial recharge background, needs, history, and sources in Gaza strip; the numerical methods for groundwater management; and Optimization-Based Groundwater Management Models. Thus possibly put our hands on the major and minor factors that are necessary to achieve the artificial recharge assessment and groundwater modeling. The second part of the study describes the study area topography, geology, soil stratification, hydrology, hydrogeology, and justification of selecting the study area. Therefore, a clear background could be built upon the area. Third part presents the two approaches which were used to record the groundwater responses once artificial recharge options were imposed. Three different locations for the artificial recharge facility were suggested in the study area with changing the recharged quantity with three different ones 0.5, 1.0, and 1.5 MCM/year for each location. The first approach was based on the simulation model alone and the second based on the simulation/optimization model with application to some parts in the Gaza aquifer.

Through the first approach, 3D coupled groundwater flow and transport model CODESA 3D (simulation model) was generated by conceptualizing the existing aquifer through constructing the 3D mesh using a pre and post processing software Argus One based upon the finite element method. Based upon different hydrological conditions for year 2008, the simulation model were generated for 1 year transient state. The current wells production was continued with the same pattern for 10 years more. The results for both scenarios were compared. The average hydraulic head at all wells after 10 years (2018) was reduced by about 9%. Moreover, based upon the simulation results, the most feasible location was identified with the effective quantity to be recharged. However, the simulation model alone can't confirm the optimum location and the optimum quantity to be recharged; therefore, the optimization model is needed to be coupled with the simulation model.

Through the second approach, the simulation model CODESA-3D was linked externally with the management (optimization) model using Genetic Algorithm (GA) technique. The optimization model aims to raise the water table by managing the groundwater pumping under various hydrological constraints. However, the study included only constraints on the volume of water extracted and the quality of water produced. Two optimization models were formulated, the first multiple- (two-) objective management model is developed for maximizing sustainable water withdrawal from the aquifer for

beneficial uses and for controlling the salinity of the water withdrawn simultaneously. Moreover, no alternative options/sources have been taken into account, i.e. no artificial recharge; therefore, the model solution came up with a new optimal spatial distribution of pumping from the existing wells only. This new pumping pattern is tested by the simulation model for one year transient state. The total pumped water reduced by 1 % only and the average improvement in hydraulic head at all wells was 10%. While the second model was similar to the management objectives of the first model with adopting the artificial recharge as a new alternative source. The application of model 2 identified the first suggested location as the optimum recharging location. Moreover, the optimum allowed pumping quantities increased among the existing situation by 126%, 151%, and 176% when 0.5, 1.0, and 1.5 MCM/yr were artificially recharged respectively.

الخـلاصة

إن خزان غزة الجوفي الساحلي يعاني من أزمة كبيرة تتمثل في الندرة الهائلة والتلوث بالملوحة الشديدة بسبب ظاهرة تسرب مياه البحر باتجاه الخزان. لذلك فإن توجيه الاهتمامات الحقيقية الخاصة بالتخطيط، والتنمية ، وإدارة الموارد المتاحة أصبحت ضرورية لتخفيف حدة هذه الأزمة، وذلك من خلال البحث عن موارد اقتصادية فاعلة. فإن الحقن الصناعي للخزان الجوفي، على سبيل المثال، باستخدام مياه الأمطار ومياه الصرف الصحي المعالجة يعتبر أحد هذه الموارد البديلة والجديدة.

إن هدف الدراسة الرئيسي هو دراسة سيناريوهات الإدارة المثلى والممكنة لخزان منطقة الدراسة باستخدام خيارات الحقن الصناعي. في جزء الدراسة الأول تم توضيح خلفية الحقن الصناعي ومدى الحاجة له، ونبذة تاريخية عنه، ومصادره المتوفرة في قطاع غزة، والنماذج الرياضية الخاصة بالإدارة المثلى للمياه الجوفية، وكيفية إعداد هذه النماذج وذللك من أجل التعرف على العوامل الرئيسية و الفرعية المؤثرة في تقييم الحقن الصناعي وفي نتائج النمذجة الرياضية على المياه الجوفية. في الجزء الثاني من الدراسة، تم وصف منطقة البحث وتضاريسها، وخصائصها الجيولوجية، والهيدرولوجية، والهيدروجيولوجية، بالإضافة إلى وصف التربة وطبقاتها، وتبريرات اختيار منطقة الدراسة. كما يعرض الجزء الثالث منهاجي البحث المستخدمين في معرفة سلوك وتصرف الخزان الجوفي أثناء استخدام الحقن الصناعي. اقترحت الدراسة ثلاثة مواقع مختلفة للمواقع الحقن الصناعي، واقترحت أيضا تغيير كمية الحقن بثلاث كميات مختلفة (0.5 ، 1.0، و1.5 مليون متر مكعب في السنة) على أن يتم حقنها في كل موقع على حدة، و أن يتم توفير كميات الحقن باستخدام مياه الأمطار المجمعة ومياه الصرف الصحي المعالجة بشرط أن تلبي نوعية هذه الكميات معايير الحقن اللازمة حسب خصائص الخزان الهيدروجيولوجية. فالمنهاج الأول قائم على استخدام نموذج المحاكاة وحده، أما المنهاج الثاني قائم على نموذج المحاكاة والاستمثال معا.

من خلال المنهاج الأول: نموذج المحاكاة وهو نموذج رياضي ثلاثي الأبعاد يحاكي تدفق المياه الجوفية وانتقال الأملاح الذائبة فيها (CODESA 3D). تم إعداد هذا النموذج من خلال تحويل حالة الخزان الحقيقية إلى الحالة التصورية عن طريق إنشاء شبكية ثلاثية الأبعاد باستخدام برنامج محوسب (pre and post processing software Argus One) يعتمد على طريقة العناصر المحددة Finite element Method. تمت محاكاة وضع الخزان الجوفي لسنة 2008 بناءا على المعلومات الهيدرولوجية المتوفرة، واعتبار حالة الخزان غير مستقرة لمدة عام فقط. كما تمت محاكاة الخزان الجوفي بعد استمرار نمط الضخ من الآبار لعام 2008 بنفس النمط لمدة 10 سنوات أي في سنة(2018). فتبين أن متوسط منسوب المياه الآبار الجوفية يهبط بمقدار 9 % في عام 2018. اعتمادا على نتائج المحاكاة، أوضحت الدراسة ما هي أكثر مواقع الحقن المقترحة جدوى وكذلك أكثر كمية المياه ملائمة للحقن، على الرغم من ذلك،فإن استخدام نموذج المحاكاة وحده لا يقوم بتحديد موقع وكمية الحقن المثالية بشكل جازم، لذا فإن من الضروري دمج نموذج المحاكاة بنموذج الاستمثال معا.

من خلال المنهاج الثاني: تم ربط نموذج المحاكاة وبنموذج الاستمثال خارجيا باستخدام تقنية اللوغاريتمات الجينية. يهدف نموذج الاستمثال لتحسين منسوب المياه الجوفية من خلال إدارة الضخ من الخزان تحت قيود هيدرولوجية خاصة بكمية المياه المستخرجة ونوعيتها فقط. تم إعداد نموذجي استمثال، النموذج الأول متعدد (اثنين) الأهداف الإدارية قائم على زيادة كمية المياه المستخرجة للحد الأقصى وجعلها مستدامة للاستخدامات المفيدة والتحكم بملوحة هذه المياه في آن واحد، دون الأخذ في الاعتبار أي خيارات بديلة أو مصادر جديدة، أي دون الاعتماد على الحقن الاصطناعي. فأوضحت الدراسة توزيع مثالي للضخ من آبار المنطقة فقط. حيث تم اختبار هذا النمط الجديد للضخ لمدة سنة واحدة باستخدام نموذج المحاكاة فتبين أن كمية المياه المستخرجة إجماليا نقصت بمقدار 1 % فقط مما أدى ذلك إلى رفع منسوب المياه الجوفية بمقدار 10%. أما بالنسبة للنموذج الثاني فهو بنفس الأهداف الإدارية للنموذج الأول ولكن تم أخذ تقنية الحقن الاصطناعي كمصدر بديل ومتجدد بعين الاعتبار. وأوضحت نتائج النموذج الثاني ما هي أفضل مواقع وكميات الحقن جدوى وفاعلية بشكل قاطع ، هذا بالإضافة إلى أن كمية الضخ المسموح بها من الآبار و بشكل مثالي زادت عما هو عليه في الوضع القائم بنسبة 126 ٪ و 151 ٪ و 176 ٪ عند حقن 0.5، و1.0، و1.5(مليون متر مكعب / سنة) على التوالي.

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Chapter 1: INTRODUCTION

1.1 BACKGROUND

Freshwater quality and availability are one of the most critical environmental and sustainability issues of the twenty-first century **(UNEP, 2002a; Prieto, 2005).** As common to all, water is one of the most crucial resources and a vital commodity to the human beings' life.

Gaza coastal aquifer is the main source of water for supplying agriculture, domestic, and industrial purposes. The surface water is very limited or almost neglected, which represented by some valleys. The main valley is Wadi Gaza, which is almost dry as results to the Israel dams built on the upper stream at the eastern border of the Gaza Strip **(Abu Heen & Lubbad, 2005; UN, 2007).** Gaza coastal aquifer extensively suffers many problems regarding the seawater intrusion **(Qahman, 2004; Al Yaqoubi, 2007).**

Recently, Gaza coastal aquifer faces huge crises of the scarcity and contamination by seawater intrusion; these crises are going to agglomerate due to the increased demand on water resources resulted from the rapid growth of the population and the enhancement of the living standards. Accordingly, any new groundwater development should focus and concentrate on alleviation of such problems.

The proper management of the groundwater coastal aquifer should take into account the searching for new additional resources by adopting, for instance, the artificial recharge using both the stormwater and the reclaimed wastewater. These new alternative resources may relieve and narrow the huge gap and deficit between the demand and the available scarce supply.

Good management should develop a tool which can provide helpful information by certain prediction regarding the response of the groundwater aquifer during the employment of the different available alternatives. These alternatives are related to both pumping and recharging respectively. The response of the aquifer may take the form of changes in the water levels, changes in water quality, or land subsidence. Such information about the response of the aquifer system could be acquired by developing certain models **(Qahman, 2004)**.

In recent years, the numerical groundwater simulation model, that predicts system responses, has been combined with techniques of optimization that computes the best strategy for the problem, scenario, or formulation, to address important groundwater management problems. The combined simulation and optimization model accounts for the complex behavior of the groundwater system and identifies the best management strategy under consideration of the management objectives and constraints.

The simulation model can be combined with the management model either by using the governing equations as binding constraints in the optimization model or by using a response matrix **(Qahman, 2004)** or an external simulation model **(Dasi & Datta, 2001).**

The model sentence consists of physical and managerial constraints on heads, hydraulic gradients, velocities or pumping/injection rates, drawdowns, groundwater velocities, and solute concentrations can be incorporated easily. Some of the unknown groundwater variables, i.e. hydraulic heads, source/sink rates, existing solute concentrations, solute concentrations of the source/sink at each node may become decision variables in the optimization problem **(Dasi & Datta, 2001; Qahman, 2004).**

The optimum scenario for pumping from the aquifer depends on both the hydrogeological restrictions on water quantity and quality; and the cost/benefit of providing water with acceptable quality limits according to required demand. This means that maximizing the extraction from the aquifer may not be the optimum one **(Qahman & Zhou, 2001).**

Qahman (2004) used the externally combined the 3D simulation model (CODESA-3D) with the genetic algorithm (GA) optimization model to achieve the optimum options for the groundwater abstraction with some constraints on the abstracted groundwater quantity and quality.

Qahman (2004) presented the desalination option as the possible optimum option in order to fulfill the restriction requirements in case of the quality of the abstracted water to produce water of certain concentration and does not exceed the quality restriction limits. This certainly leads to increase the price of the abstracted water keeping the restrictions on the quantity constant.

This study, however, will set the artificial recharge in the study area to be the possible optimum scenario to satisfy the requirements of the quantity and quality restrictions.

1.2 Research Problem Identification

The major source of new groundwater in the aquifer is rainfall. This Rainfall, unfortunately, is sporadic across Gaza and generally varies from 400 mm/yr in the north to about 200 mm/yr in the south **(Aish & De Smedt, 2004)**. The lateral inflow to the aquifer is estimated at 10- 15 MCM/yr. Some recharge is available from the major surface flow (Wadi Gaza). However, because of the extensive extraction from Wadi Gaza in Israel, this recharge is limited to, at its best 1.5- 2 MCM during the ten to 50 days the Wadi actually flows in a normal year. As a result, the total freshwater recharge at present is limited to approximately 55-65 MCM/yr **(El Sheikh & Hamdan, 2002).**

This overexploitation of the coastal aquifer leads to a real drop in the water level by about 20-30 cm per annum is occurred **(PWA, Data bank 2003).** This also makes the aquifer strongly susceptible to seawater intrusion. Therefore, the seawater intrusion has deteriorated in the quality of aquifers besides the overuse of fertilizers and pesticides in the agricultural activities. As 2% of seawater mixed in a freshwater makes it unsuitable for the human drinking purposes besides other agricultural and industrial purposes **(Qahman & Zhou, 2001; Ismail, 2003).**

Figure 1.1 represents the groundwater level that indicating the seawater intrusion of the coastal aquifer. This, therefore, requires immediate and concentrated efforts to improve the current situation of the water supplies.

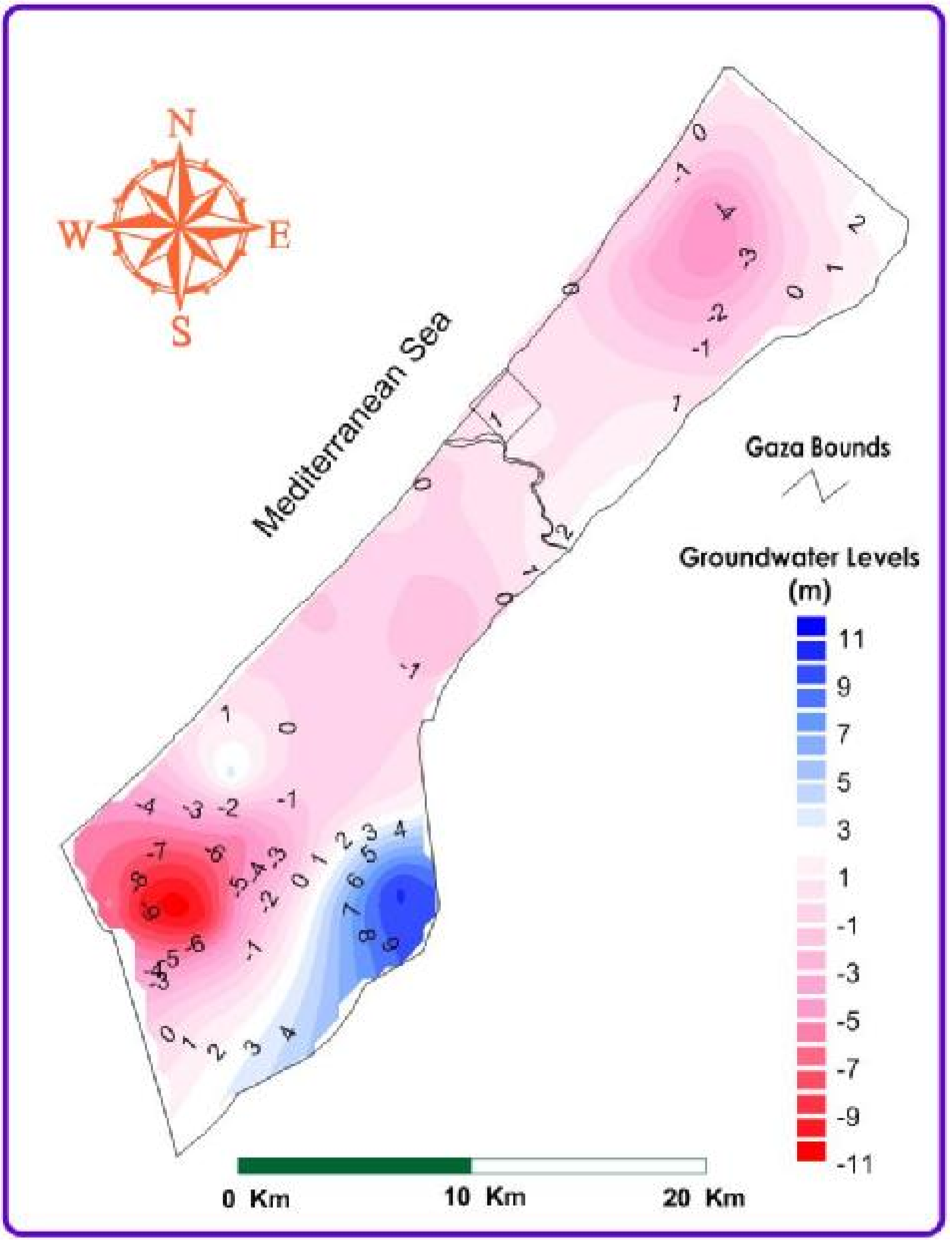

Figure (1.1): Gaza groundwater level in year 2006 (PWA 2008)

1.3 Objectives

1.3.1 The main objective

To study the possible optimum management scenario to the north of Wadi Gaza aquifer by adopting the artificial groundwater recharge scenario to subsidize any decided national plan/policy regarding the achievable solutions for water resource crises.

1.3.2 Specific objectives

1. To study the capabilities of establishment of seawater intrusion hydraulic barrier in the study area aquifer using the artificial recharge, i.e. the stormwater and the reclaimed wastewater through alleviating the overpumping of groundwater and its effects that causes the seawater intrusion problems.

2. To determine the most optimal location of the artificial recharging basin and to find out the optimal quantity of accepted quality to be recharged artificially.

Chapter 2: LITERATURE REVIEW

2.1 INTRODUCTION

The provision of safe and high quality drinking water is essential and fundamental to having a high quality of life. However, the water resources in Gaza Strip are threatened by two main crises, which are stated in the form of scarcity in groundwater quantity and degradation in the groundwater quality.

In Gaza strip, the groundwater crises' causes are many, where the main causes are the overexploitation of the groundwater and the overuse of the chemical fertilizers in the agricultural purposes, in addition to the non/partially wastewater treatment and a lack in the wastewater collection systems.

Overexploitations of groundwater resources and as a consequence decline in the water table are causes of serious concern in Gaza Strip. Unfortunately, this leads the coastal aquifer to extensively suffer from the scarcity and the salinity contamination by the seawater intrusion and up-coning. This Overexploitation was recorded since at least 50 years ago, due to the clear deficit in the available water resources. This deficit is going to agglomerate with time sequence due to the rapid increase in the population and the development of living standards, whereas the water demand doubled the available water resources. Therefore, in the context of this increasing deficit pressure, there should be an increasing requirement to alleviate and reduce this huge gap by developing new resources to create a basis for a provision of safe and high quality drinking water.

The development of new resources such as groundwater artificial recharge could be implemented in Gaza strip beside the desalination of the brackish/seawater and the reuse of the wastewater in the agricultural activities **(Qahman, 2004).**

Good management should develop a tool that can provide helpful information by certain prediction regarding the response of the groundwater aquifer during the employment of such available alternatives. Such information could be acquired by developing certain models. In recent years, the numerical groundwater simulation model has been combined with techniques of optimization in order to determine the possible optimum solutions for the problem, scenario, or formulation.

This chapter will review the literatures regarding the implementation of the available alternatives such as the artificial recharge to augment the available scarce water supply. Moreover, to illustrate the different available numerical models that could be used in this context.

The simulation and optimization models besides the combination of both models could be used to identify the best management strategy under consideration of the management objectives and constraints for the complex behavior of the groundwater system **(Dasi & Datta, 2001).**

2.2 ARTIFICIAL RECHARGE OF GROUNDWATER

2.2.1 Background

Artificial recharge of groundwater is one of the important tools towards achieving the sustainability of groundwater reservoir **(Zubiller et al., 2002).** The water to be recharged can be clean water i.e. storm water, water surpluses, surface water, imported water…etc.; saline/brackish water, or treated effluent.

There are several artificial recharge techniques which have been widely employed in arid and semi-arid zones. Main recharge methods are: infiltration basins, bank filtration, sink-pits and canals, and injection wells. Their usage depends on: the type of water or effluent; the soils and ground geologic profile; hydraulic underground characteristics; the availability of land for such projects; the proximity of contamination sources; and the risk of seawater in coastal aquifers. **(Rusteberg, 2006).** Artificial recharge techniques normally address the following issues:

1) To enhance the sustainable yield in areas where over development has depleted the aquifer.
2) Conservation and storage of excess surface water for future requirements, since these requirements often changes within a season or a period.
3) To improve the quality of existing groundwater through dilution.
4) To remove bacteriological and other impurities from sewage and wastewater so that water is suitable for re-use.

The basic purpose of artificial recharge of groundwater is to restore supplies from aquifers depleted due to excessive groundwater development. **(CGWB, 2000)** Accordingly, problems related to scarcity of the available water resources can be alleviated by searching for additional water sources that can be used economically and effectively to promote further development. These additional resources can be (partially) achieved by artificial recharge using stormwater and treated wastewater which is considered as a viable means of reducing Palestine's water deficit and limiting the seawater intrusion **(El Sheikh & Hamdan, 2002)**.

2.2.2 History

According to **Aish & De Smedt (2004,** cited in **Glover, 1961; Marmion, 1962; Marino,1967, 1974; Hantush, 1967; Bianchi and Muckel, 1970; Rao and Sarma, 1983; and Latinopoulos, 1986),** theoretical and experimental studies were carried on the subject of groundwater artificial recharge through the surface spreading.

Artificial recharge has been practiced for a number of years in many countries and for a wide variety of water resources management purposes. For example, Finland was the first European country to introduce artificial recharge at a large scale. Currently, there are 28 systems of this type with a total capacity of 21,000 m^3/day. In the Netherlands AR concepts are highly developed and contribute with 65% to the public water supply. In Spain, the artificial recharge is practiced at several locations. Water from the Lobregat River (Barcelona) is being injected for water storage and for seawater intrusion control 2.5 to 15 MCM/yr. Water supply to Budapest is guaranteed by infiltration of water from the Danube River of about 180 MCM/yr. In Canada, about 34,000 m^3/day infiltrated in spread basins, while in Germany, about 20% of the public water supply. The same is in Sweden (25%). The largest artificial recharge projects are known to function mostly in the western United States and Israel **(Rusteberg, 2006).**

In Gaza Strip, the first experience was applied in the early 1990s, where about 80 dunms basin was constructed in the Gaza city to collect the stormwater and divert it to this basin, where water was supposed to be injected through special wells close to the basin. Unfortunately, the wastewater mixed with the stormwater due to the improper collection of wastewater. However, this reservoir is known as Sheikh Radwan basin, which has been rehabilitated by the Palestinian Authority. The wastewater has been diverted to the wastewater pipes' network. However, minor quantity of the collected stormwater infiltrated downward due to the impermeability of soil at the bottom of the pool. While, unfortunately the large excess of collected stormwater is wasted through pumping to the sea.

In 1997 and 1998, two projects are established, the first one in Gaza city treatment plant, where part of the effluent of treated wastewater is diverted to infiltration basins the infiltration capacity was less than that of the effluent flow, therefore, the rest of effluent is pumped to the sea. The second project is the stormwater collection in North Gaza, where stormwater is collected in the retention basin constructed in Jabalia City and then this water pumped to infiltration basins located close to the existing wastewater treatment plant at Beit Lahia **(Hamdan & Jaber, 2001).**

During September 2001 to August 2002, A project of implementing a pilot artificial recharge system for recharging the treated wastewater to groundwater. The project is located in the north of Gaza city, east of Jabalia town, next to the eastern border of the Gaza Strip. An area of about 212,000 m^2 was used for a treatment plant and artificial recharge basin. **(Qahman, 2004).** This project aims to enclose the wastewater of the north Governorates. The first phase was accomplished, in which the percolation ponds were constructed and started receiving the treated wastewater from the Beit-Lahia wastewater treatment plant (WWTP) by a range of 15,000 - 17,000 m^3/day since May 2009. About 2.50 MCM was diverted to the percolation ponds in the new project from the treated wastewater pond in Beit-Lahia WWTP, till it became semi dry in September 2009 **(CWMU, 2009).**

2.2.3 Sources of Artificial Recharge

The sources of water to be artificially recharged are mainly from stormwater, urban runoff and reclaimed wastewater.

1. Stormwater

The Gaza Strip receives an average rainfall range from 400mm/yr in the north to 200mm/yr in the south. The average annual volume of rainfall is about 110-125 MCM/yr, whereas, more than 40% of total stormwater either discharge to the sea by natural flow or pumped to protect the residential areas from flooding **(UNEP, 2002b) and (Aish & De Smedt, 2004)**. Spatial distribution of average annual rainfall in different areas of the Gaza Strip (period 1998-2007) is shown in figure. 2.1

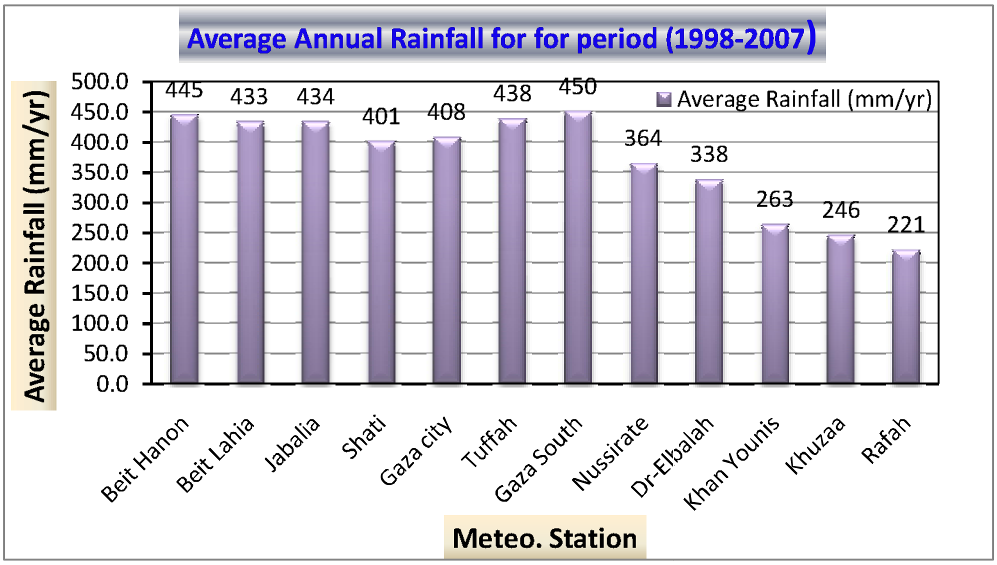

Figure (2.1): Spatial distribution of average annual rainfall in different location of Gaza strip (period 1998-2007) (PWA, 2008)

The potential natural recharge is between 40 to 46 MCM/yr **(PWA, Data bank 2003).** The runoff amounts have been estimated to be 37 MCM in the existing land use and will reach 43 MCM for planned land use, i.e. urban development expansion **(Hamdan et al., 2007).**

The urbanized area represented around 16% in the year 1998; and 20% in the year 2004, and expected to increase in the next years due to the rapidly increasing in population growth to represent 33%, and 44.5% for the years 2015, 2025 respectively. The total amount of rainwater losses due to urbanization as surface run-off estimated to be 14.5 MCM in the year 1998 and expected to increase to be about 20 MCM, 35 MCM, and 52 MCM for the years 2005, 2015, and 2025 respectively **(Al Yaqoubi, 2007).**

Actually, because of the steadily development of the urbanization, the amounts of natural recharge of rainfall are going to decrease while excess urban stormwater are expected to occur. Therefore, utilizing of such excess of stormwater become an argent and necessary to do not waste this important considerable resource. This utilization could be by implementing an artificial recharge system in order to collect such a runoff and diverting it to infiltration basins. Meanwhile, the current situation is regrettable as large quantities of stormwater are wasted either by mixing the wastewater collection networks or by naturally flooding to the sea every rainy season **(Hamdan & Jaber, 2001).**

According to **El-Nakhal (2004,** cited on **Sogreah, et.al, 1999; PECDAR, 2000; Metcalf and Eddy,2000)**, the existing storm water systems in Gaza Strip are as following:

- In Jabalia, the stormwater converges towards Abu Rashid pond which capacity of 47,000 m^3; while in Gaza city, stormwater in the coastal zone naturally floods to the sea.
- The Gaza city having two Storm water reservoirs, which are:
  1. Sheikh Radwan Reservoir: It receives the stormwater from its catchment of about 9,000 dunums plus over flow from Waqf reservoir, which serves a catchment of 9,500 dunums. The storage capacity of Sheikh Radwan reservoir is about 560,000 m^3.
  2. Waqf Reservoir: It is located at a low point in the Asqoula area of the city. Its storage capacity is about 34,000 m^3.
- A part of KhanYounis stormwater is drained towards a depression in the town center near the municipal office, another to the EL-Katiba depression. This depression is flooded during rainy days.
- Rafah is divided into 15 catchment areas, each catchment has a depression into which the storm water drains**.**

2. Reclaimed Wastewater

In Gaza Strip, using treated wastewater could be one of the main options to develop the water resources as it represents an additional renewable and reliable water source **(Afifi, 2006)**.

In Gaza strip, access to sewerage facilities varies from areas where more than 80 % of the households are served by sewerage systems, to areas where no sewerage systems at all. On average, it is estimated about 60 % of the population is connected to sewerage networks. Table 2.1 outlines the percentage of different governorates of Gaza Strip served by wastewater networks for year 2006. ***The study area*** is located in some parts of Wadi Gaza, Al-Zahra and Mughraka**,** the areas where no sewerage systems is available. Instead of, cesspits and/or boreholes are the wastewater disposal systems table 2.2 represents the wastewater situation in Gaza governorate for year 2006.

Table (2.1): Coverage of Wastewater Network in Gaza Strip

Governorate	Population (capita)	Coverage %
North Area	298,125	68.51%
Gaza	546,959	79%
Middle area	223,679	64%
Khanyounis	299,918	20.60%
Rafah	183,649	59.79%
Total	1,552,330	61.26%

Source: (PWA / IRCB, 2007)

The total annual wastewater production in Gaza strip is estimated to be 32.75 MCM, of which 20 MCM passes into sewerage networks and the rest to cesspits or pit latrines. Approximately, 70-80 % of the domestic wastewater produced in Gaza is discharged into the environment without treatment, either directly after collection in cesspits, or through leakages and overloaded treatment plants.

Table (2.2): Wastewater Situation in Gaza Governorate

City	Population capita	Coverage (%)	Wastewater (m^3/day)
Gaza	533092	80	47765
Al-Zahra	5000	95	456
Mughraka	5439	5	21.8
Wadi Gaza	3428	0	0

Source: (PWA / IRCB, 2007)

2.2.4 Needs for Artificial Recharge in the Gaza Strip

Artificial recharge using stormwater and reclaimed wastewater is considered as a viable and feasible means for reducing Gaza's water deficit in the form of both quantity and quality, especially:

1. To fulfill domestic and agriculture demand,
2. For the recovery of the Coastal Aquifer, and
3. To solve the wastewater disposal problem.

1. To Fulfill Domestic, Industrial, and Agriculture Demand

In Gaza strip, the water resources are limited to the coastal groundwater Aquifer. Surface water is so limited and no longer available with exception of wastewater flow in Wadi Gaza, which ultimately reaches the Sea or infiltrates to the underlying aquifer.

The total abstraction from about 4,600 wells in 2006 was about 164.6 MCM for both domestic and agricultural purposes. In addition, three small brackish water desalination plants each of which produce between 45 and 75 m^3/hr (i.e. average of 1.6 MCM/yr), and 4 MCM/yr supplied from Israeli Water Mekorot **(PWA, 2007).** Figure 2.2 illustrates the different water supply sectors and the total abstraction in Gaza strip.

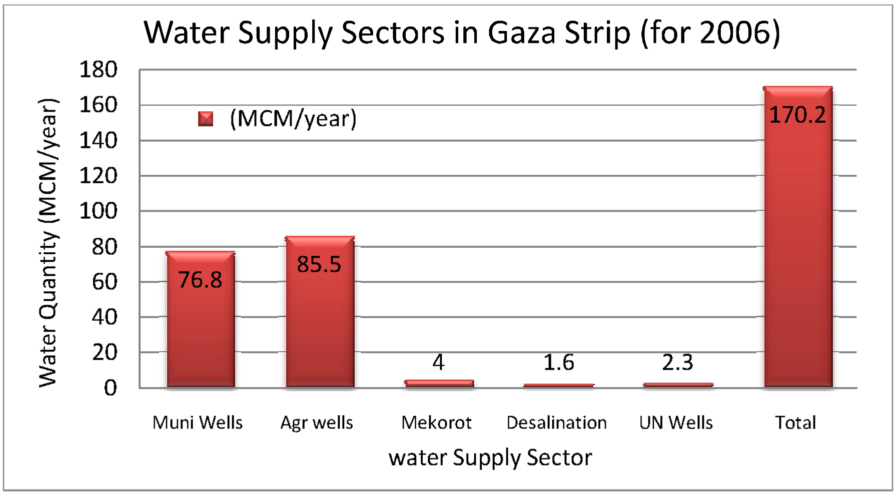

Figure (2.2): Different water supply sectors in Gaza strip for year 2006

This overall consumption induces a huge deficit between the water demand and the available resources. Therefore, artificial recharge using the stormwater and reclaimed wastewater besides the desalination options could be the feasible means to reduce and alleviate this deficit/gap.

2. Recovery of the Coastal Aquifer

In order to recover or stop deterioration of the coastal aquifer, artificial recharge is utilized. As common to all, the recharged water to the groundwater aquifer is much lesser than the abstracted water for different purposes. Groundwater overexploitation to fulfill this deficit is the responsible for declining the water level by about 20-30 cm/yr. Moreover, this prompts the seawater and brackish water from deep aquifers intrudes inland to the fresh water.

Consequently, the continuous deterioration of the water quality is prospected. Therefore, a contingency requirement for securing new alternatives for water resources is intensively urgent. The artificial recharge is one of these new suggested alternatives for mitigating water scarcity in Gaza strip.

3. To solve the wastewater disposal problem in Gaza Strip

Because of the extensive increase in water consumption, larger wastewater quantities will be generated and needed a safe health and environmental disposal. The quality of the water is mainly impacted by untreated and/or partially treated wastewater that percolated to the sub-aquifer, besides, up-coning of brackish groundwater and seawater intrusion because of excessive abstraction.

The urgent problem related to the disposal of about 24 MCM/yr of partially treated wastewater from the three-wastewater treatment plants. About 42% of this wastewater infiltrates to the ground without any further treatment, while the rest of this wastewater is diverted to the sea. Moreover, the raw wastewater that directly infiltrates until reaches the groundwater in the areas where now sewer collection networks are available. Therefore, the artificial recharge projects using the treated wastewater will alleviate and solve the problem of wastewater disposal. Moreover, the benefit of the treated wastewater became as a new water resource **(Sánchez-Vila & Barbieri, 2005).**

2.3 Numerical & Optimization Models for GW Management

Increasing demands on the groundwater resources are creating a need for improving the scientific information and analysis techniques to better understand and manage the groundwater systems/responses.

Since the 1960s, numerical simulation models have been important tools for groundwater development strategies. Commonly, the simulation models provide only localized information regarding, for instance, the response of the groundwater system to pumping and/or artificial recharge.

Because of the complex nature of groundwater systems, the process of selecting a best operating procedure or policy can be extremely difficult by using the simulation models alone as they require many numbers of trials and hence lead to enormous computing time. While using the optimization techniques alone is not feasible as they may necessitate conceptual assumptions, or they suffer from the dimensionality problem. Therefore, groundwater simulation models have been linked with optimization modeling techniques in a single framework to overcome the weakness of using simulation or optimization alone. As the combined simulation and optimization (S/O) models greatly enhances the utility of simulation models alone by directly incorporating management goals and constraints into the modeling process and determining the best (or optimal) management strategies from many possible strategies as shown in figure 2.3 **(Sreejith & Mohan, 2002; Barlow, 2005).**

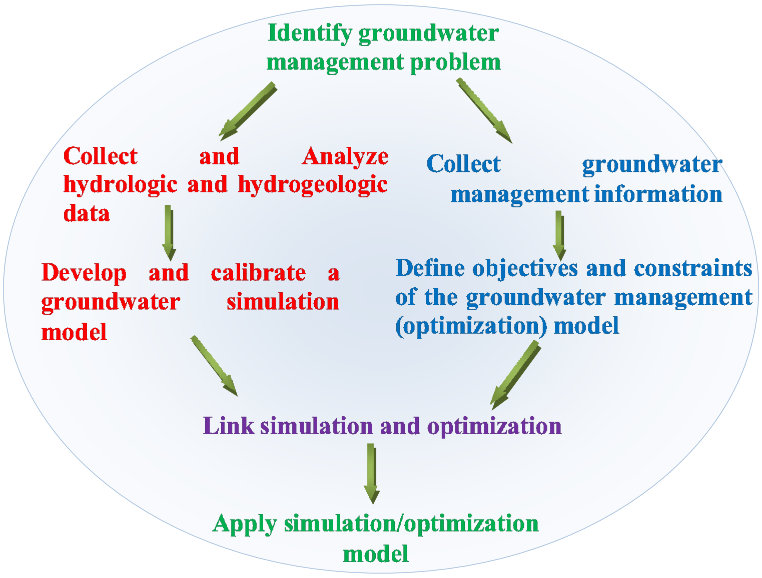

Figure (2.3): Principal steps in the development and application of a groundwater simulation-optimization model.

2.3.1 Numerical methods for groundwater management

The development of numerical simulation models in the early 1960s provided the resource planner with important tools for managing the groundwater system by understanding groundwater flow and saltwater movement in coastal aquifers.

The numerical models represent the key features in the complex groundwater systems by mathematical governing equations which solved by numerical techniques (such as finite-difference, finite-element, boundary finite element, or finite volume methods) using some computer codes. The analysis of groundwater flow and saltwater movement in coastal aquifers cannot be accomplished by field studies alone. Therefore, groundwater numerical simulation models to simulate either groundwater flow or combination of the flow and solute transport. However, the numerical models that simulate groundwater flow and solute transport are more difficult to develop and to solve than those that simulate groundwater flow alone.

In Coastal aquifers, the density of the water and the concentrations of dissolved chemicals that may vary substantially throughout the modeled area cause this difficulty.

To address these difficulties, two approaches generally are used to simulate freshwater-saltwater interactions (**Barlow, 2005)**

1. Sharp Interface Approach

The employment of the sharp-interface model is based on the Ghyben-Herzberg (GH) (1888-1901). The GH-relationship was conceptualized by assuming hydrostatic balance. I.e. the width of the freshwater saltwater mixing zone is much smaller than the thickness of the aquifer, and therefore it can be assumed that freshwater and saltwater are two immiscible fluids of different types but constant densities separated by an interface , as shown in figure 2.4 **(Das & Datta, 2001; Camas, 2007).**

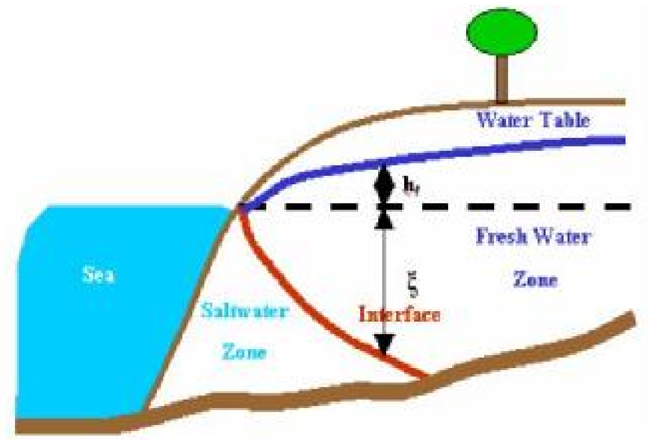

Figure (2.4): Saltwater - Freshwater sharp interface

According to **Camas (2007); and Arlai (2007,** cited in **Mercer et al., 1980)**, a numerical model that solves the partial differential equations through describing the motion of saltwater and freshwater separated by such a sharp interface was presented. His 2D areal approach was based on the Dupuit approximation**.**

According to **Das & Datta (1999,** cited in **Finney et al., 1992)**, development and application of a quasi three-dimensional optimal control model for groundwater management in the Jakarta coastal aquifer basin was presented. The movement of the freshwater-seawater interface was again based on the sharp interface assumption**.**

According to **Das & Datta (2001,** cited in **Polo and Ramis,1983; Larabi and De Smedt, 1994, 1994, 1997; and Naji et al., 1998, 1998, 1999),** Numerical models based on the sharp interface approach were also reported**.**

According to **Arlai (2007,** cited in **Bakker, 2003)**, the Dupuit approximation for the simulation of three-dimensional regional seawater intrusion was adopted, but diffusion and dispersion were not taken into account. The formulation was based on a vertical discretization of the groundwater into zones of either constant density (stratified flow) or continuously varying density (piecewise linear in the vertical direction)**.**

Significant improvements were reached on the sharp-interface model under the Dupuit assumption, which assumes that equipotential lines are vertical, the flow is horizontal, and the specific discharge is uniform along the vertical direction. However, the Dupuit assumption is not reasonable in the general case. The density-dependent model better describes the real saltwater intrusion mechanism due to strong saltwater hydrodynamic dispersion and the existence of a wide transition zone, which is evident in real coastal aquifers. The density-dependent model considers freshwater and saltwater mixing and explicitly allows change in water density by solving coupled flow and transport equations simultaneously **(Camas, 2007).**

2. Density-Dependent Miscible Flow and Transport (Diffuse interface) Approach

In coastal aquifers, the real saltwater mechanism could be debited by the strong saltwater hydrodynamics dispersion that allows mixing of the freshwater and saltwater; and develops a transition zone of considerable extent in both directions i.e. the vertical and the horizontal directions. In addition to explicitly allowance of change in water density, the freshwater and saltwater are considered being a single fluid having a spatially variable salt concentration influences the water density as shown in figure 2.5.

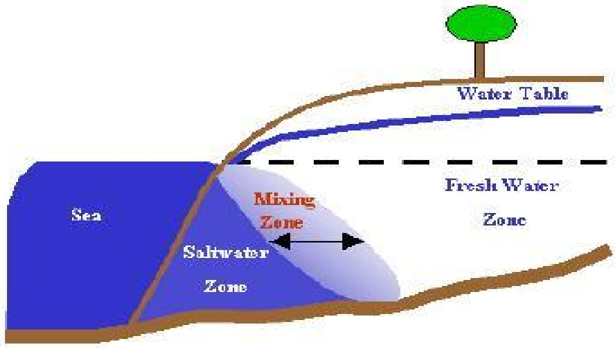

Figure (2.5): Density-dependent miscible saltwater-freshwater system

The good management of the seawater intrusion, therefore, that meets water quality requirements by incorporating simulation of both the density-dependent miscible flow and transport of seawater in coastal aquifers **(Das & Datta, 1999;Camas, 2007).**

According to **Papadopoulou et al. (2005); and Camas (2007,** cited in **Pinder and Cooper, 1970),** successfully applied the method of characteristics to track the saltwater front for saline concentrations no larger than concentration in the seawater. Under this assumption, the transport equation is hyperbolic and the method of characteristics can be used to track the position of the saltwater**.**

According to **Das & Datta (2001); and Qahman (2004,** cited in **Huyakorn et al., 1987; Galeati et al., 1992; Putti & Paniconi, 1995; Das & Datta, 1995, 2000; Langevin & Guo 2002; Aharmouch and Larabi,2004)**, some of the recently developed simulation models for seawater intrusion, which were based on density dependent miscible flow and transport approach were presented **.**

According **to Camas (2007,** cited in **Simpson and Clement, 2004)**, an improved computation of the Henry (1964) analytical solution was presented, in which the isochors are smooth and reach the upper boundary. Moreover, a decrease in the freshwater inflow was proposed to improve the Henry problem as a test of buoyancy effects due to the variability of water density.

According to **Perera et al., (2008,** cited in **Perera et al.,2008)**, a model based on the transition zone approach which couples the groundwater flow and mass transport equation to solve the density dependent flow have been developed. They simulated the seawater intrusion phenomenon in a three dimensional point of view under the density dependent flow effect in a coastal area of Motooka, Japan.

CODESA -3D as a Numerical (Computer) Code

Complex numerical models and advanced computing and networking tools provide scientific and technological basis to support the decisions in sustainable development of coastal zones.

Recently, several solute transport models suitable for the simulation of seawater intrusion and up-conning of saline water beneath pumping sites were developed. These include the used code in this study. As any other computer codes, CODESA-3D code is a 3D simulation model that provides solution of two simultaneous, non-linear, partial differential equations. These equations describe the conservation of "mass of fluid" and "conservation of mass of solute" in porous media **(Qahman, 2004).**

Paniconi et al., (2001) used a CODESA-3D numerical model that treats density-dependent variably saturated flow and miscible salt transport to investigate the occurrence of seawater intrusion in the 'Korba' aquifer of the eastern coast of Cap-Bon in northern Tunisia. The exploratory simulations suggest interesting interactions between the unsaturated zone and the saltwater–freshwater interface with possible implications for groundwater exploitation from shallow unconfined coastal aquifers.

CAU et al., (2002) used a three-dimensional finite element model (CODESA 3D) to simulate coupled flow and solute transport processes in variably saturated porous in Oristano plain - Sardinia, Italy. The study aim was to investigate the causes of saltwater intrusion by developing a model supported by a geographic information system.

CAU et al., (2006) used the finite element CODESA-3D model has been applied to simulate 3D density-dependent groundwater flow and contaminant transport in the subsurface of the Muravera-Flumendosa coastal basin (SE Sardinia, Italy). As the aquifer was being threatened by seawater intrusion, the study aim was to improve the understanding of the groundwater degradation mechanism in a complex hydrodynamic environment diverted upstream surface waters, lagoons and channels and to support the decision between alternative remediation scenarios.

2.3.2 Optimization-Based Groundwater Management Models

It is no doubt true that unless the demand is more than the supply, and the economic value of the water resources is being considered, optimization is more or less meaningless.

Although simulation models provide the water resources planners with important tools for managing the groundwater system, this predictive models do not identify the optimal groundwater development, design, or operational policies for an aquifer system **(Qahman et al., 2005).**

Optimization tools are utilized to facilitate optimal decision making in the planning, design and operation of especially large-scale water resources systems. The use of optimization tools for evolving economically efficient management strategies is considered as the most important component of decision support systems that are not confined only to the quantity aspect of water, but also the quality aspects.

Optimization-based models for management are comprised of three parts:

(1) The objectives that form the basis of management,
(2) The constraints that limit the realization of the management objectives,
(3) The decision variables that control the management process **(Bhattacharjya & Datta, 2005b).**

In optimization-based approaches, the decision variables are adjusted with the goal to maximize (or minimize) the objectives that subjected to meet the specified constraints. These constraints may include mass balance equation, maximum and minimum permissible recharge and discharge as function of time, legal and institutional constraints, and other physical bounds such as demands. The objective function value represents the level of performance of the system for assigned values of the decision variables, often in terms of economic units **(Uddameri et al., 2006).**

A good and appropriate management technique should control the intrusion of seawater into the coastal aquifer by determining the optimum freshwater supply strategies that will satisfy various hydrological and environmental restrictions. However, the optimization technique alone may necessitate conceptual assumptions or they suffer from dimensionality problem. While the simulation model alone requires higher number of trials and hence leads to enormous computing time. But these problems can be solved in a more efficient manner by a way of combining simulation (that predicts system responses), and optimization (that computes the best strategy for the problem, scenario, or formulation) in a single framework. Moreover, the combined use of simulation and optimization techniques have been demonstrated to be powerful and useful methods in determining planning and management strategies for optimal development and operation of groundwater systems **(Sreejith & Mohan, 2002; Peralta, 2004).**

Several computer codes have been developed during the past two decades to facilitate ground-water simulation-optimization modeling **(Barlow, 2005).**

1. Mathematical Programming Techniques

In order to solve optimization-based groundwater management models, some kind of mathematical programming techniques have been used such as linear programming (LP), dynamic programming (DP), nonlinear programming (NLP), and their variations in the seawater intrusion management **(Das & Datta, 2001).**

Linear programming (LP)

No doubt, in all the optimization methods, LP was found to be the maximum widespread in the groundwater management field due to the associated ease in solution, capacity to solve large-scale problems; guarantee global optimal solutions; and easily available computer codes. Moreover, LP models can be utilized for solving groundwater management problems when the imposed physical and managerial constraints and the objective function are linear ones. However, LP models are extended by incorporating uncertainties in the modeling process in "Chance constrained LP" **(Das & Datta, 2001; Bhattacharjya & Datta, 2005b).**

Dynamic Programming (DP)

According to **Das & Datta (2001,** cited in **Buras, 1966)**, dynamic programming (DP) is used extensively in the optimization of groundwater resource systems), which used to solve multistage decision problems, formulated largely by Bellman R. (1957)

In the dynamic programming technique, a multistage decision problem is decomposed into a sequence of single-stage decision problems (i.e. DP effectively decomposes highly complex problems with a large number of decision variables into a series of sub-problems that can be solved recursively). Individual single-stage problems may be solved by any method of optimization. The advantage of using the dynamic programming technique is that it can deal with discrete variables, non-convex, non-continuous and non-differentiable functions. It can also take into account nonlinear constraints and objectives and stochastic or random variables in the DP formulation of the management or planning problem.

Dynamic programming, however, suffers from a major drawback known as the curse of dimensionality. Therefore, many modifications of the discrete DP concept were proposed to make this technique more efficient. Such modifications include differential dynamic programming which overcomes the curse of dimensionality (I) because the discretization of the control and state vector is not required, and (II) by stage wise decomposition. Other modifications such as constrained differential DP, reliability constrained DP and stochastic DP. Stochastic DP is more suitable for long term planning **(Das & Datta, 2001; Bhattacharjya & Datta, 2005b).**

An important element of any DP model is the state transition equations of the system. The response or transfer equations, which can be developed using finite difference or finite element methods, define how the system state variables change over successive stages or time periods **(Qahman, 2004).**

Nonlinear programming

Many groundwater planning and management models involve nonlinearities in the objective function and constraints. These nonlinearities may arise due to various causes such as (i) nonlinear cost functions, (ii) nonlinear equations governing the flow particularly for unconfined aquifers, (iii) nonlinearities in the governing equations for solute transport in groundwater, and (iv) other types of nonlinear physical and managerial objective functions and constraints. These nonlinear management problems can be solved using nonlinear programming (NLP) algorithms **(Dasi & Datta, 2001).** These nonlinearities make the optimization process more slow and requires large amounts of computer storage and time when compared with linear programming. The mathematics involved in the formulation and solutions of nonlinear models is much more complicated than in the linear case. Nonlinear programming, unlike DP, cannot easily accommodate stochastic or random variables. However, nonlinear programming can effectively handle non-separable objective functions and nonlinear constraints. Furthermore, NLP, such as quadratic programming or separable programs, can be used iteratively as a master program or subprograms in large-scale system problems.

Many groundwater management problems can be represented as constrained nonlinear programming problem. Where, the constraints define the hydraulic or water quality response equations of the aquifer system and water demand requirements.

According to **Dasi & Datta (2001,** cited in **Gorelick et al., 1984)**, a general modeling approach was presented to determine the optimal design of reclamation schemes for contaminated groundwater systems. The planning model combined a nonlinear, distributed parameter groundwater flow and solute transport simulation model (SUTRA) with a nonlinear optimization method (MINOS). They used the embedding technique. The planning model was applied for a steady-state aquifer reclamation and transient flow and transport.

According to **Sreejith & Mohan (2002,** cited in **Das & Datta, 1999, 2000),** demonstrated the application of the nonlinear programming technique to solve the highly nonlinear problem of seawater intrusion management in coastal aquifers. They considered the density-dependent miscible transport case of seawater intrusion in coastal aquifers. They used the embedding technique to incorporate the finite-difference-approximated simulation model within the optimization model.

2. Mathematic Programming Variations:

One of the optimization tools applications is the management of coastal aquifers. Therefore, the literature is replete with applications of combined simulation optimization approaches for the control of seawater intrusion **(Uddameri et al., 2006).**

There are some modifications/variations are performed on some mathematic programming, these modifications are according the variations on the decision variables and objective function and the constraints in the optimal management model. Such of these variations: Stochastic linear programming, and Quadratic programming…etc. In the stochastic linear programming, extension for linear programming, groundwater problems are often characterized by random variables (i.e. the water demand, groundwater recharge, or transmissivity and storage parameters may be random variables or processes). In a quadratic programming (QP), groundwater problems are nonlinear programming problems characterized by linear constraints and an objective function that is the sum of a linear and a quadratic form **(Qahman, 2004).**

Quadratic optimization model was used for the management of the aquifer system by minimization of the total pumping costs. They used MINOS algorithm **(Dasi & Datta, 2001; Sreejith & Mohan, 2002).**

According to **Bhattacharjya & Datta (2005b,** cited in **Das and Datta,1999, 2000)**, a number of nonlinear optimization based multi objective management models for sustainable utilization of coastal aquifer was presented. **Bhattacharjya and Datta (2004)** linked simulation-optimization based multi-objective management model for coastal aquifer management.

Qahman el al (2005) developed four non-linear optimization models under steady state condition; two of them multi-objective management models were applied on a local-area selected from the Gaza coastal regional aquifer. The results show that using optimization/simulation approach in the Gaza Strip can improve planning and management policies and can give better decision for aquifer utilization. The results of application on this part of the Gaza aquifer show that the optimum pumping rate ranges from 26%-34% of the total natural replenishment**.**

3. Evolutionary Techniques via Combination Algorithms

One of the most important steps of coupling the simulation and optimization models is the linkage technique between these models and to represent the simulation constraints within the optimization models. Generally, the simulation model can be combined with the management (optimization) model either by using the governing equations as binding constraints in the optimization model (Embedding technique) or by using a response matrix **(Ndambukiet al., 2000; Yang et al., 2001),** or an external linkage of simulation optimization model **(Dasi & Datta, 2001; Mohan et al., 2007).**

1. Embedding Technique

According to **Das & Datta (1999); and Tran (2004,** cited in **Aguado and Remson, 1974),** the embedding method was firstly presented, in which the discretization was based on the finite difference or the finite element method. The finite difference or finite element form of the governing groundwater flow and solute transport equations were directly incorporated as part of the constraint set in a formal mathematical programming-based management model.

Other physical and managerial constraints on heads, gradient, velocities, or pumping/injection rates can be incorporated easily. Some of the unknown groundwater variables, i.e. hydraulic heads, source/sink rates, existing solute concentrations, solute concentrations of the source/sink at each node may become decision variables in the optimization problem **(Das & Datta, 1999; Tran, 2004).** This method, not only solves the problem once i.e. not solved iteratively (as opposed to the response matrix approach), but also provides lots of information regarding the behavior of the aquifer **(Tran, 2004).** Moreover, when large numbers of pumping cells are used and steady state management policies are desired, the embedding technique requires less computer memory and processing time than the response matrix approach **(Dasi & Datta, 2001).**

For nonlinear systems, the response matrix approach is not applicable and use of embedding technique becomes necessary. However, for transient cases, the time step used in the embedding approach for transient problems may require a larger number of variables and constraints for accuracy of the solution. This may result in computational problems. Consequently, the technique is restricted to the application of a small scale and steady state problems **(Das & Datta, 1999; Mohan et al., 2007)**.

2. Response Matrix

The response matrix approach is based on principle of superposition which is used to determine the total response at the pre-selected observation points such as well location. Furthermore, the principle of superposition assumes the system linearity and boundary condition homogeneity. Therefore, the response matrix is only good for linear or slightly nonlinear systems. However, in nonlinear systems, the response matrix approach is not applicable in a strict sense; as the iterative response matrix approach may be adopted as an approximation. While for highly nonlinear systems, such as those involving density dependent transport models, the response matrix approach is not applicable because, the development of a response matrix requires several executions of the numerical simulation model; moreover, a management model even for a small study area may become dimensionally large and solving such models becomes difficult **(Das & Datta, 1999; Qahman, 2004).**

In the response matrix approach, the influence of a unit change in an independent decision variable such as pumping or recharge at a pre-selected well location upon a variety of dependent variables like drawdown and velocity at specified observation points is determined. These unit changes or responses are used to construct the response matrix that is then used to generate constraints for the optimization model. Superposition is then performed to calculate their total response at specified points resulting from all decision variables. Since the procedure is carried out only for selected observation points, i.e. well location, this method is generally more economical and requires less computational effort. However, its main drawback is the number of simulations required to generate the responses as well as recalculate the response matrix when the boundary conditions and well locations are changed. This approach has been used by many researchers **(Ndambukiet al., 2000).**

According to **Yang et al. (2001,** cited **in Peralta et al.,1991)**, a steady-state embedding model required less processing time than a response matrix model. However, for regional problems with a greater number of objectives, the embedding model is not suitable because the constraint matrix may become too large. The researcher reported that the response matrix model was more flexible and memory saving for the multi-period, multi-objective programming of the regional water resources management and was thereby used to couple the groundwater simulations into the multi-objective optimization model.

3. Simulation/Optimization Approach

Due to the nature of groundwater systems is very complex, moreover, the large number of engineering, legal, and economic factors that often affect groundwater development and management as especially for controlling the saltwater intrusion in the coastal aquifers. Therefore, the process of obtaining physically meaningful optimal management strategies or selecting a best operating procedure or policy can be extremely difficult because the physical processes, i.e. the involved density-dependent flow and solute transport are needed to be simulated while deriving the optimal management strategies. To address this difficulty, groundwater simulation models have been linked with optimization modeling techniques to determine best (or optimal) management strategies from many possible strategies. However, for the existing case of seawater intrusion, incorporation of the simulation model within an optimization-based management model using the embedding approach is very complex and difficult. All embedded models become dimensionally large even for a very advanced computer, and higher resolution along the spatial and temporal ones may not be possible for a large system. Therefore, as an alternative, it is possible to link a simulation model externally with an optimization based management model **(Barlow, 2005; Bhattacharjya & Datta, 2005a)**, as shown in figure 2.6 **(Bhattacharjya & Datta, 2005b).**

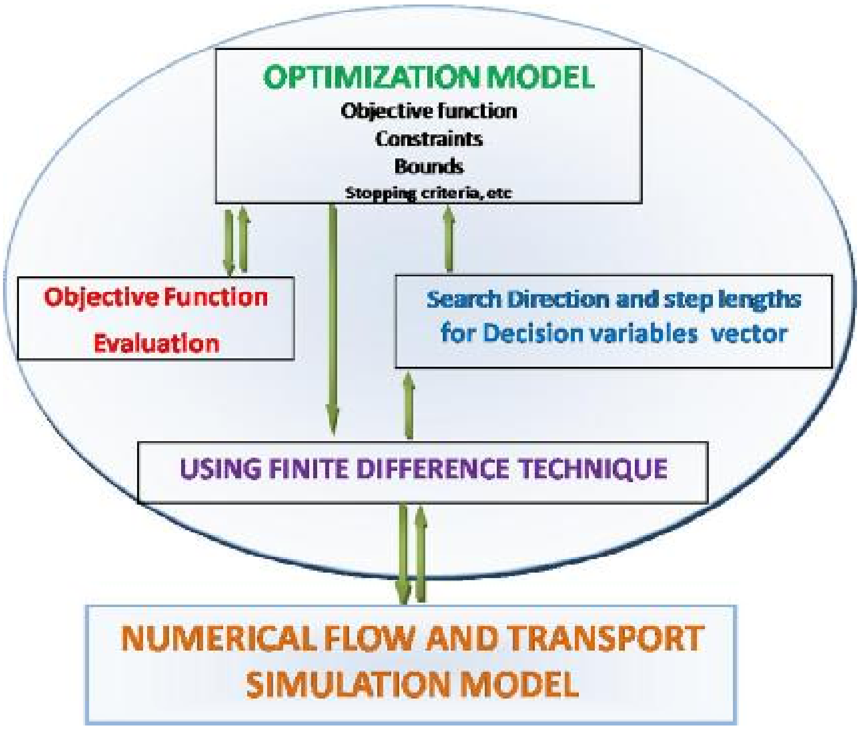

Figure (2.6): the schematic representation of a linked simulation optimization approach.

The use of combined simulation-optimization models, that include both simulation abilities and optimization algorithms, greatly enhances the utility of simulation models alone by directly incorporating management goals and constraints into the modeling process (figure 2.3). In the simulation-optimization approach, the modeler specifies the desired attributes of the hydrologic and water resource management systems (such as minimum stream flow requirements or maximum allowed groundwater level declines) and the model determines from a set of several possible strategies, a single management strategy that best meets the desired attributes **(Peralta et al., 2003).** The simulation model is repeatedly called by the optimization model in order to compute state (decision) variable values and gradients **(Qahman, 2004).**

2.3.3 Linkage of simulation model to optimization model

The Genetic Algorithm (GA) based optimization approach is especially suitable for externally linking the numerical simulation model within the optimization model. Further efficiency in computational procedure can be achieved for such a linked model, if the simulation process can be simplified by approximation, as very large number of iterations between the optimization and simulation model is generally necessary to evolve an optimal management strategy. A possible approach for approximating the simulation model is to use a trained Artificial Neural Network (ANN) as the approximate simulator. Therefore, an ANN model is trained as an approximator of the three dimensional density-dependent flow and transport processes in a coastal aquifer. A linked simulation /optimization model is then developed to link the trained ANN with the GA-based optimization model for solving saltwater management problems **(Bhattacharjya & Datta, 2005a).**

According to **Bhattacharjya & Datta (2005b,** cited in **Singh and Datta, 2003, 2004)**, an artificial neural network (ANN) based methodology was proposed, and a genetic algorithm (GA) based linked simulation optimization methodology that would facilitate optimal identification for unknown groundwater pollution sources using concentration measurement data. Each methodology requires a groundwater flow and contaminant transport simulation model to simulate the physical processes in the aquifer system. The GA based simulation optimization approach uses the simulation model for fitness evaluation for the population of potential pollution sources evolved by GA**.**

Qahman (2004) proposed the linked simulation-optimization approach to incorporate the 3D flow and transport simulation model (CODESA 3D) with the nonlinear optimization model Genetic algorithm (GA) in order to obtain an optimal pumping strategies for a part of Gaza coastal aquifer and hence alleviating the seawater intrusion problem**.**

2.4 OPTIMIZATION ALGORITHM:

Most real world optimization problems involve complexities like discrete, continuous or mixed variables, multiple conflicting objectives, non-linearity, discontinuity and non-convex region. The search space (design space) may be so large that global optimum cannot be found in a reasonable time. The existing linear or nonlinear methods may not be efficient or computationally inexpensive for solving such problems. Various stochastic search methods like simulated annealing, evolutionary algorithms (EA) or hill climbing can be used in such situations. EAs have the advantage of being applicable to any combination of complexities (multi-objective, non-linearity etc) and also can be combined with any existing local search or other methods. The most popular technique which makes use of EA approach is Genetic Algorithms (GA) which operates mainly on a population search basis **(Deb, 2002).**

2.4.1 Genetic Algorithm as optimization technique:

The GAs are recognized as powerful search algorithms and offer nice alternative to conventional optimization technique. They are based on the mechanics of natural selection and natural genetics Goldberg (1989). A genetic algorithm allows a population composed of many individuals to evolve under specified selection rules to a state that maximizes the ''fitness'' (i.e. minimizes/maximize the objective function). The method was developed by J. Holland (1975) and finally popularized by one of his students, David Goldberg (1989) **(Benhachmi et al., 2001).**

The genetic algorithm begins, like any other optimization, by defining the optimization parameters, the objective function. It ends like other optimization algorithms too, by testing for convergence **(Benhachmi et al., 2001).**

Simple GA evolves new designs from a population of trial designs, each of which is encoded as a binary string, using evolutionary principles. However, simple genetic algorithms cannot explicitly consider uncertainty. Stacking methods or chance constraints can be used to incorporate uncertainty within a genetic algorithm, but these methods either require substantial computational effort or simplifications regarding the uncertainty form **(Krishnamurthy, 2003).**

GAs have been used extensively within the groundwater management field such as pipe network optimization; groundwater parameter determination; and groundwater cleanup **(Qahman, 2004; Krishnamurthy, 2003).**

Genetic algorithm differs from conventional optimization techniques in following ways:

1. GAs operate with coded versions of the problem parameters rather than parameters themselves i.e., GA works with the coding of solution set and not with the solution itself.
2. Almost all conventional optimization techniques search from a single point but GAs always operate on a whole population of points (strings), i.e. GA uses population of solutions rather than a single solution from searching. This plays a major role to the robustness of genetic algorithms. It improves the chance of reaching the global optimum and also helps in avoiding local stationary point.
3. GA uses fitness function for evaluation rather than derivatives. As a result, they can be applied to any kind of continuous or discrete optimization problem. The key point to be performed here is to identify and specify a meaningful decoding function. **(Krishnamurthy, 2003; Qahman, 2004)**
4. GAs use probabilistic transition operates while conventional methods for continuous optimization apply deterministic transition operates, i.e. GAs do not use deterministic rules. **(Krishnamurthy, 2003)**

These are the major differences that exist between Genetic Algorithm and conventional optimization techniques.

2.4.2 Advantages and Limitations of Genetic Algorithm

The advantages of genetic algorithm include,

1. Parallelism
2. Liability
3. Solution space is wider

4. The fitness landscape is complex
5. Easy to discover global optimum
6. The problem has multi objective function
7. Only uses function evaluations.
8. Easily modified for different problems.
9. Handles noisy functions well.
10. Handles large, poorly understood search spaces easily
11. Good for multi-modal problems
12. Returns a suite of solutions.
13. Very robust to difficulties in the evaluation of the objective function.
14. They require no knowledge or gradient information about the response surface
15. Discontinuities present on the response surface have little effect on overall optimization performance.
16. They are resistant to becoming trapped in local optima.
17. They perform very well for large-scale optimization problems.
18. Can be employed for a wide variety of optimization problems.

The limitations of genetic algorithm include,

1. The difficulty of identifying fitness function
2. The difficulty of choosing the various parameters like the size of the population, mutation rate, cross over rate, the selection method and its strength.
3. Cannot use gradients, and cannot easily incorporate specific information in the problem.
4. Not good at identifying local optima.
5. Needs to be coupled with a local search technique.
6. Require large number of response (fitness) function evaluations.
7. Configuration is not straightforward **(Sivanandam & Deepa, 2008).**

Chapter 3: DESCRIPTION OF THE STUDY AREA

3.1 DESCRIPTION OF THE STUDY AREA

The selected area for accomplishment of this study falls within Gaza strip boundaries. This area of Study is located to the north-west of Wadi Gaza and it overlooks to the Mediterranean Sea with 2000m in both dimensions and it falls parallel to the coastline as shown in figure 3.1.

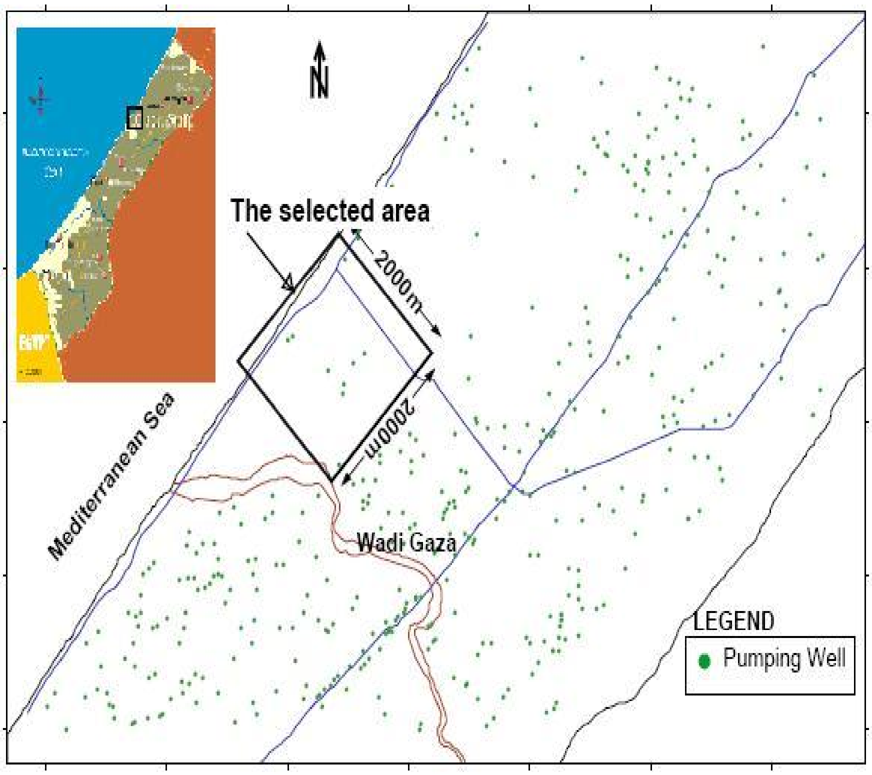

Figure (3.1): location of study area within Gaza strip boundaries

3.1.1 Previous Studies Justifications for Area Selection

In previous literatures, there were some criteria used to select this area of study. Such criteria could be represented by the properties of this specified location which lead to select this part of the Gaza aquifer. These properties can be summarized as follows:

- This area falls parallel to the coastline. Therefore, the occurrence of seawater intrusion may ensured while the occurrence of extensive pumping.
- According to the water level contour map for year 2000 in previous researches:
  1. This area is in 'steady state' condition because water level did not vary very much since year 1969, and the water level contour line of 1 m above the mean sea level AMSL still parallel to the coastline.

2. The groundwater salinity in this area in general is relatively good, so its high capability to install new pumping wells in the future.
3. The density of existing pumping wells is low which mean that the number of decision variables in the objective function is small **(Qahman, 2004).**

3.1.2 Area Reselection Justifications

The above mentioned criteria used to select the area of study were applicable in the period of the existence of the Israeli occupation, while after the Israeli military withdrawn from Gaza strip in September 2005, this area had some new modifications such as installing new pumping wells and constructing new civil structures… etc. therefore, some of the above criteria may not applicable to the area nowadays.

The justifications of reselecting this area to be the area of the study are as following:

1. This study will followed up the previous studies by Qahman (2004) on the same area due to :
   1. Previous Data Availability
   2. Applicability of some previous selection criteria such as: the area under the steady state as the natural recharge quantities still greater than the current demand till now; and the limited decision variables (wells).
2. The study results could be applicable in some Gaza strip areas which have similar hydrogeological properties, especially in the x-settlements in Khan Younis and Rafah and the north of Gaza city.

3.2 Geography

Gaza Strip is a part of the Palestinian coastal plain in the south west of Palestine, where it forms a long and narrow rectangle. Gaza Strip is located on the most southeastern coast of Palestine on the Mediterranean Sea, between longitudes 34° 2" and 34° 25" east, and latitudes 31° 16" and 31° 45" north **(Aish, 2004)**. The location of the Gaza Strip is shown in figure 3.2.

It is bordered by occupied Palestine by Israel to the east and north, Egypt to south. The total area is estimated about 365Km^2. Its length along the coast is 45km from Beit Hanoun town in the north to Rafah city in the south, and its width ranges from 6 to 13 Km **(Assaf, 2001; Aish, 2004).**

Three valleys/Wadis are crossing Beit Hanoun, Gaza, Salga areas forming the hydrological feature of the area. Wadi has a river cross-section and shape. The Wadi Gaza is the biggest one. It runs in the central part of the Gaza Strip and discharges into the Mediterranean Sea. Israel has retained and changed the course of the three Wadis and they became dry **(Ismail, 2003).**

Figure (3.2): Location map of the Gaza Strip

3.2 POPULATION

The total Palestinian population in Gaza strip by the end of 1997 was approximately 1.02 millions. The population increased by 39% by the year 2007 increasing the total to about 1.42 million with the population density 3.882 capita/km^2 of the total build-up area in Gaza strip, making it one of the most overcrowded areas in the world **(PCBS, 2006)**.

The population growth rate is around 3.8%. The total fertility rate is 5.8 children in 2003 and 5.4 children in 2006 **(PCBS, 2006).** This rate plays a big role in the planning and management of water resources **(Ismail, 2003).** Table 3.1 represents the comparison between the population in 1997 and 2007 in the different governorates of Gaza strip.

Table (3.1): Population in Gaza strip Governorate for 1997, 2007

Govern-orate	Number of Population	
	2007	1997
Gaza Strip	**1,416,539**	**1,022,207**
North Gaza	270,245	183,373
Gaza	496,410	367,388
Dier Al-Balah	205,534	147,877
Khan Younis	270,979	200,704
Rafah	173,371	122,865

***The Palestinian Central Bureau of Statistics (PCBS, 2008)**

3.3 Climate

The Gaza Strip has a semi-arid Mediterranean climate with a long hot and dry summer, and short cool and rainy winter. Gaza strip is located in the transitional zone between a temperate Mediterranean climate in the west and north, and an arid desert climate of the Sinai Peninsula in the east and south **(Dudeen, 2001; Aish, 2004).**

3.4 Temperature, Humidity and Solar Radiation

The annual mean of air temperature, annual mean of maximum air temperature, and the annual mean of minimum air temperature was 21.0 ºC, 23.6 ºC, and 17.7 ºC respectively as observed in the meteorological station of Gaza city in 2005 **(PCBS, 2006)**. Temperature gradually changes throughout the year, and reaches its maximum in August (summer) and its minimum in January (winter), average of the monthly maximum temperature ranges from about 17.6 ºC for January to 29.4 C° for August. The average of the monthly minimum temperature for January is about 9.6 ºC and 22.7 ºC for August **(Ismail, 2003; Aish, 2004)**. The average monthly air temperatures as observed in the meteorological station of Gaza city for the period lasting from 1999 until 2005 is represented in figure 3.3.

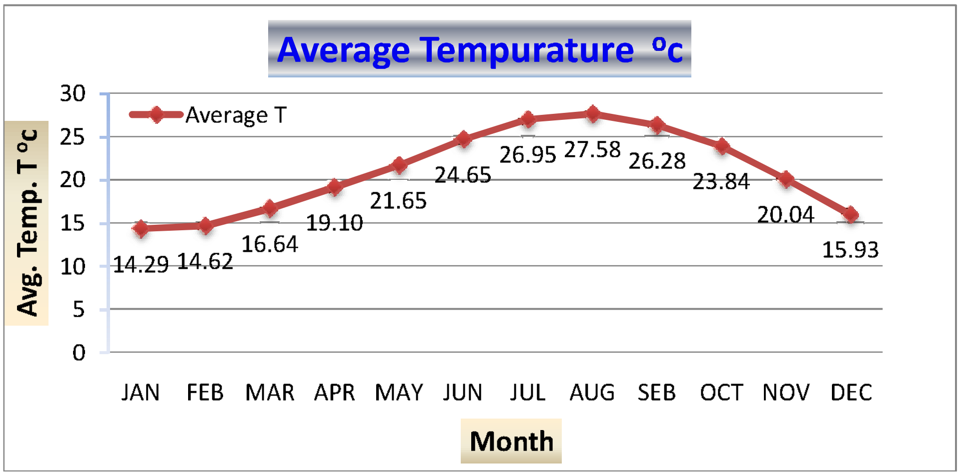

Figure (3.3): Avg. temperature for Gaza Strip (period 1999 - 2005) (PWA, 2006)

For Gaza, the most annual mean of relative humidity in 2005 was 66%. The average relative humidity as observed in the meteorological station of Gaza city for the period lasting from 1999 until 2005 is represented in figure 3.4. The mean annual solar radiation amounts to 2,200 J/cm^2/day.

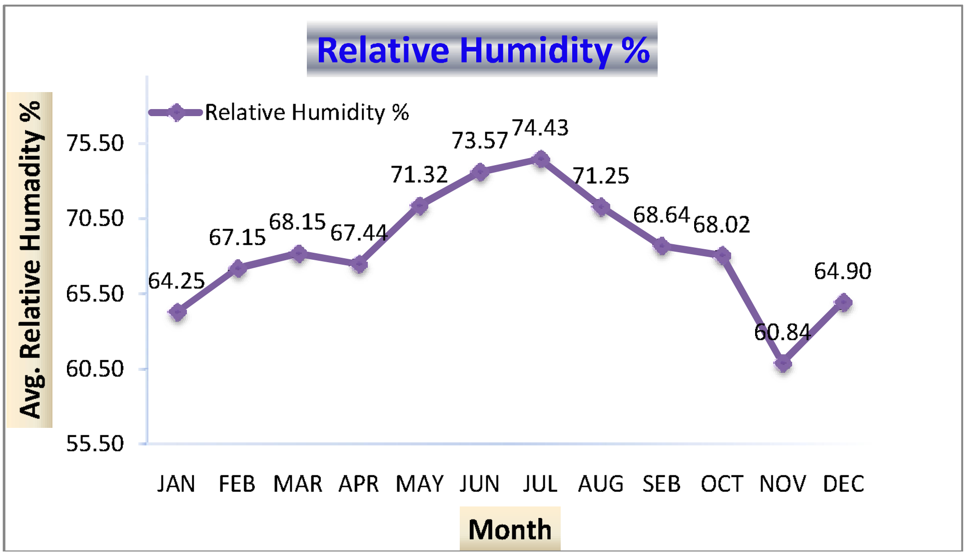

Figure (3.4): Average relative humidity (%) for the Gaza Strip (1999 -2005) (PWA, 2006)

3.5 RAINFALL

Rainfall is almost the main source of all water in Gaza strip. According to the available historical data, the average rainfall ranges from 400 mm/yr in north to 200mm/yr in south. In addition, there are 9 rain gauge stations distributed on different locations on Gaza strip. Other 3 new rain gauge stations are installed in Tuffah area, Jabalia, and Khuzaa in 1998.

Mostly, rainfall occurs in the period from October to March, the rest of the year is completely dry. Precipitation patterns are classified as thunderstorms and rain showers, with exception of the few rainy days in the wet months almost in the December and January.

Figure 3.5 represents the variation of the annual rainfall for the whole Gaza strip with daily data, and the spatial distribution of average annual rainfall in the meteorological stations of Gaza strip for the period (1985-2007) respectively.

The peak of rainfall takes place during December and January. The rainy days range from 45 to 50 days. The average annual volume of rainfall is about 110-115 MCM/yr, and the potential recharge is between 40 to 46 MCM/yr **(PWA. Data bank, 2003).**

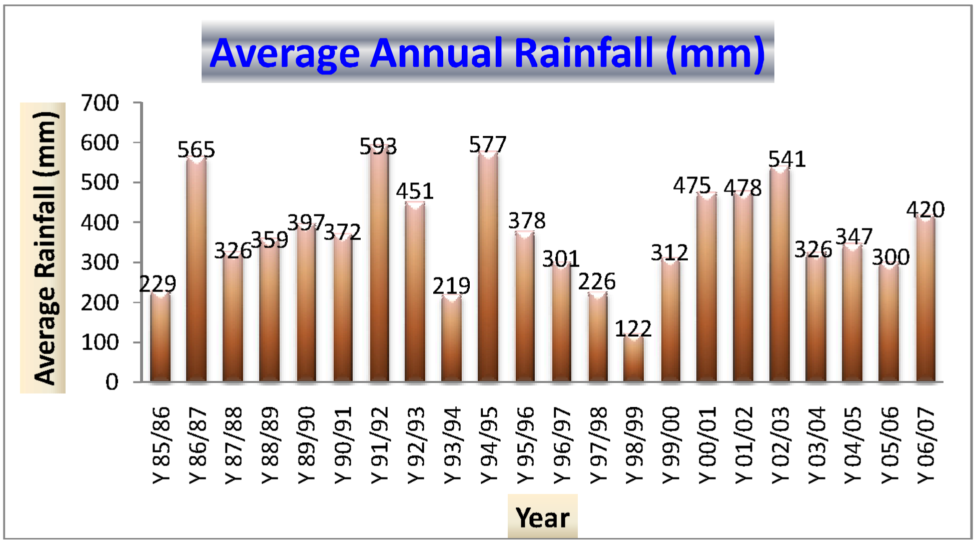

Figure (3.5): Spatial variation of average annual rainfall in the Gaza Strip for Period (1985-2007)

Figure 3.6: shows the location of the various metrological stations in the various governorates of Gaza strip.

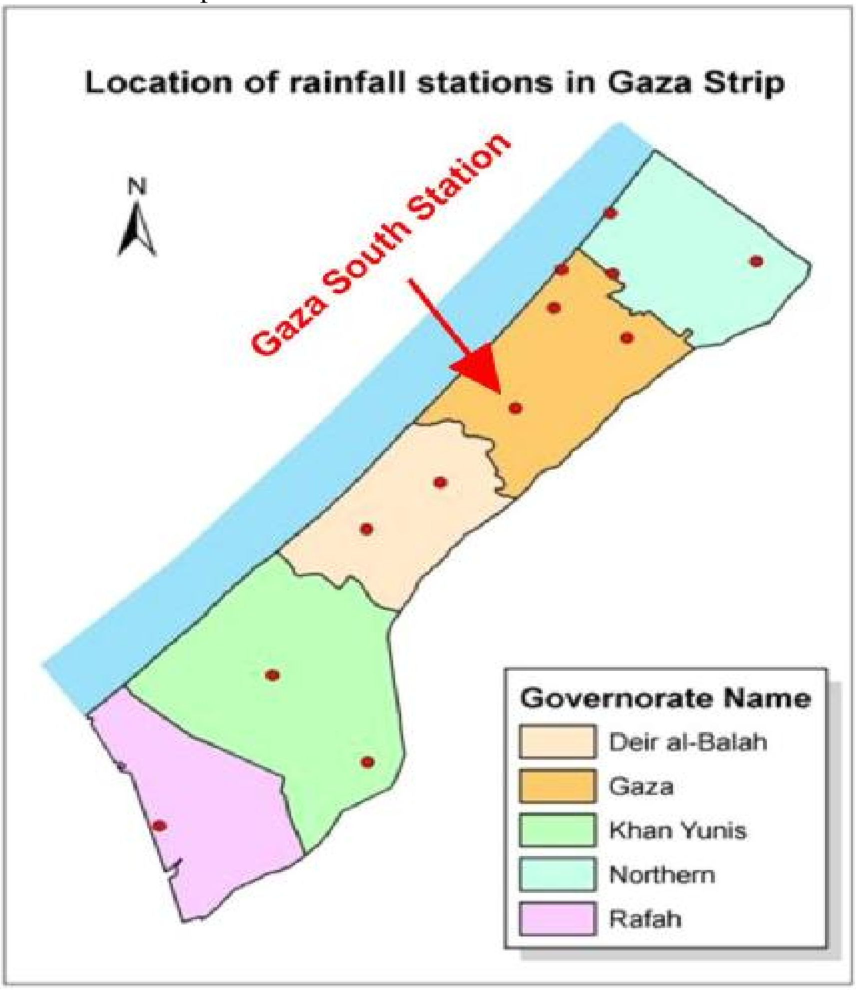

Figure (3.6): Location of the metrological stations in Gaza Strip Governorates

Figure 3.7: shows the annual accumulated rainfall for the south Gaza strip rainfall station. The study area falls within the range of this station.

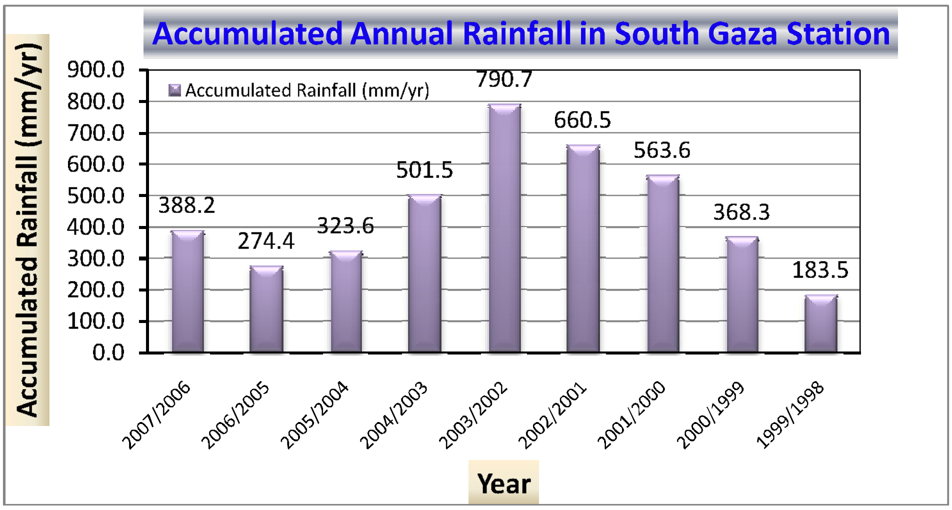

Figure (3.7): Annual accumulated rainfall in the Gaza south station (Period 1998 - 2007)

3.6 Evapotranspiration (ET)

The aerial variation is less in evapotranspiration (ET) compared with that in rainfall in the Gaza Strip. ET measurements and calculations indicate that the average annual ET for the Gaza Strip in the period from 1999 till 2005 is around 1,660 mm/yr.

Figure 3.8 represents the average annual ET for the period of 1999-2005. The average ET in the summer months reaches its maximum value around 195 mm/month [June to September] , while such a value is reduced in the winter months to around 80 mm/month [November to February] relatively low pan-evaporation values of around 70 mm/month were measured during the months December to January **(Aish, 2004).**

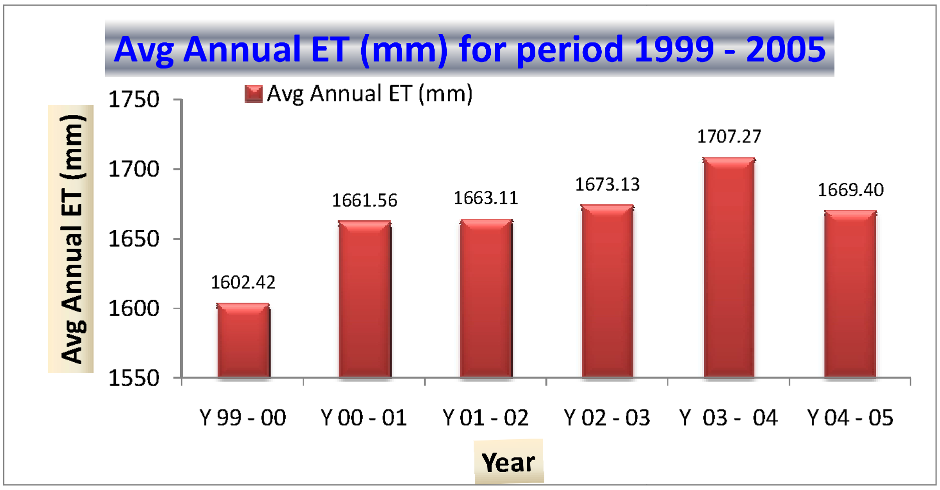

Figure (3.8): The average annual ET for the period of 1999-2005

3.7 TOPOGRAPHY

Generally, Gaza strip is largely flat and dunes, with dunes pushing in from the coast (west) towards the east, particularly in the south of Gaza strip. In details, Gaza topography is characterized by elongated ridges and depressions, dry streambeds and shifting sand dunes. The ridges and depression generally extend in a NNE-SSW direction, parallel to the coastline. They are narrow and consist primarily of sandstone (Kurkar). In the south, these features tend to be covered by sand dunes **(Aish, 2004).**

Gaza's topography gradually slopes downwards from east to west with the land surface elevation varying between 20 m above sea level in the west to 110 m above Mean Sea Level (AMSL) in the east. Thus, without any intervention, much of the rainwater in the urbanized areas will simply run straight towards the sea, without giving enough time for infiltration to the groundwater. Figure 3.9 represents the 3D topography of the study area. The surface elevation near the coast reaches its lowest value of about -2 m AMSL and its highest elevation towards the landward of about 22 m AMSL.

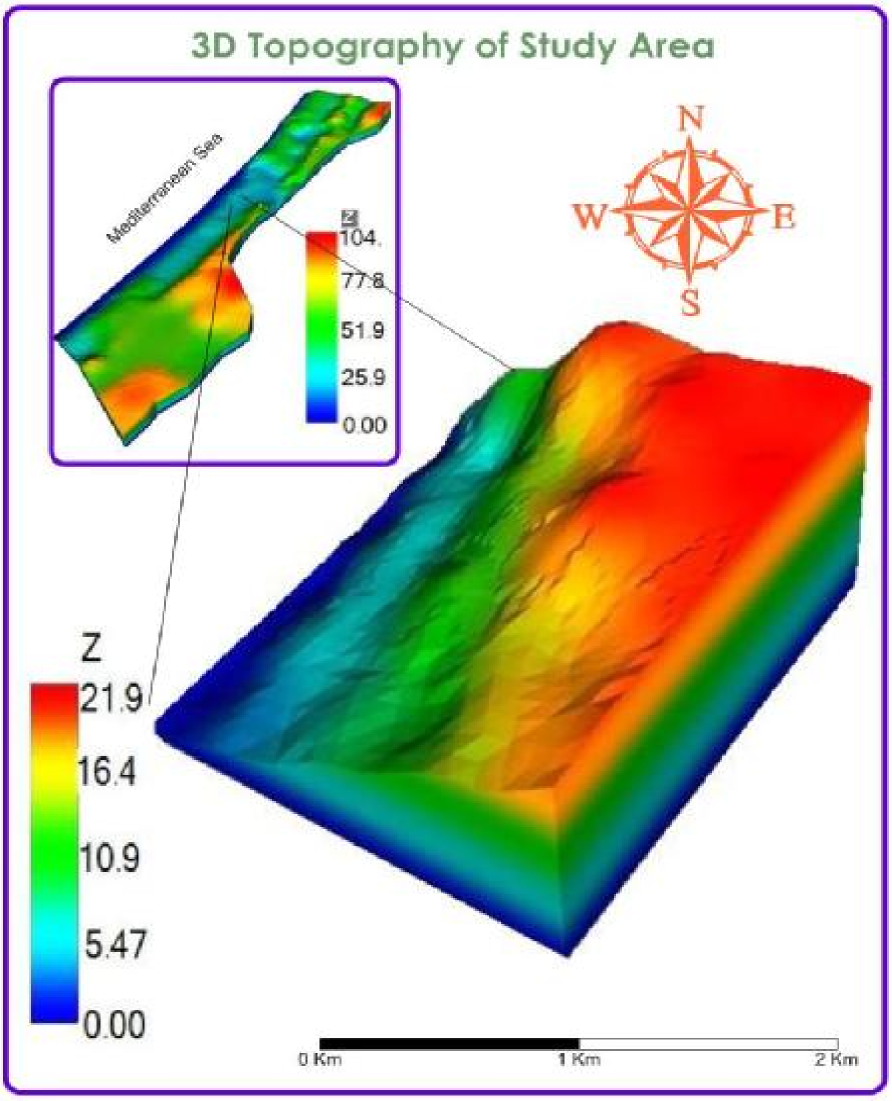

Figure (3.9): 3D Topography of the Study Area (m)

In Gaza strip, the sand dunes are 30-60 m above sea level; cover a total area of 70 km^2. Moreover, Lucite soil, which is a mixture of sand and loam, is widespread in the middle of the Gaza Strip. The surface elevations of individual ridges range between 20 m and 90 m above MSL **(Adeloye & Al-Najar, 2005)**.

3.8 SOIL

The soil in the Gaza Strip is composed mainly of three types: sands, clay and loess. The sandy soil is found along the coastline extending from south to outside the northern border of the Strip, at the form of sand dunes which are overlying alluvial soils in a shallow layer creating ideal conditions for fruit plantations. The thickness of sand fluctuates from 2 m to about 50m due to the hilly shape of the dunes. Clay soil is found in the north eastern part of the Gaza Strip. Loess soil is found around Wadis, where the approximate thickness reaches about 25 to 30 m. (Jury and Gardner,1991).

Figure 3.10 shows the soil map of the study area which mainly consists of two types: sand and clay.

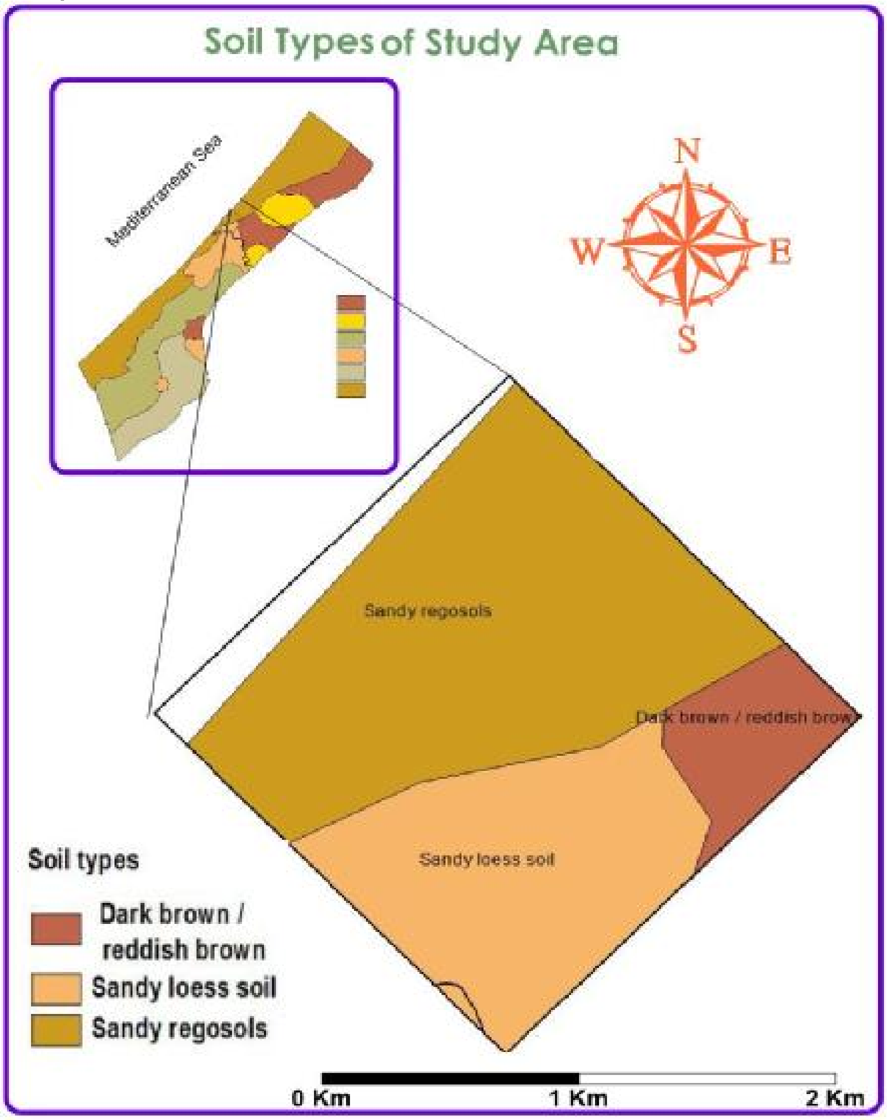

Figure (3.10): Soil map of the study area

The sand forms the majority of the area as around 90 % of total area. The sand in study area is further of two types: regosols and sandy loess while the clay is of dark brown or reddish brown type.

Along the coast there is a zone of varying thickness with rather uniform dune sands while more inland there are zones consisting of loess loamy soils. The sand dunes extend up from 4 to 5 km inland, and are wider in the north and in the south than in the center. Further inland to the east, the soil becomes less sandy with more silt, clay, and loess **(Dudeen, 2001; Shomar et al, 2004).**

3.9 GEOLOGY

The Geology of Gaza area is a part of the coastal plain geology, which consists of a series of geological formations sloping gradually from East towards the West as shown in figure 3.11. These geological formations are mainly from the Tertiary and Quaternary eras. The Important part of these formations is the coastal aquifer of the Gaza area which consists of the Pleistocene age Kurkar Group and recent (Holocene age) sand dunes. The Kurkar Group includes marine and eolian calcareous sandstone ("kurkar"), reddish silty sandstone ('hamra'), silts, clays, unconsolidated sands, and conglomerates.

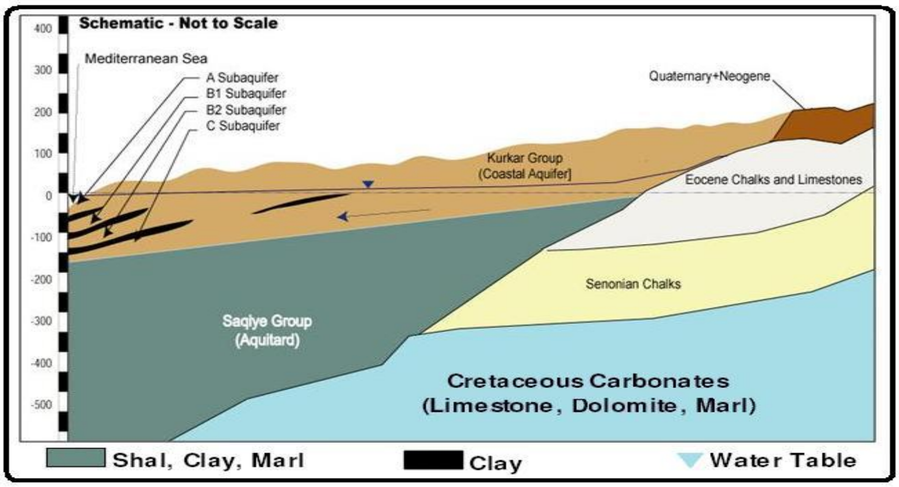

Figure (3.11): Typical hydrogeological section of Gaza aquifer (Sorek, S. et al., 1997)

3.10 HYDROGEOLOGY

The Gaza Strip aquifer is an extension of the Mediterranean seashore coastal aquifer. It extends from Ashqelon in the North to Rafah in the South, and from the seashore to 10 km inland **(Aish, 2004).**

The coastal aquifer 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 **(Shomar et al, 2005).** The Gaza aquifer is divided into three sub-aquifers. These sub-aquifers overlay each other and are separated by impervious and semi-pervious clayey layers **(Dudeen, 2001; Shomar et al, 2005).**

The regional groundwater flow is mainly westward towards the Mediterranean Sea. The total saturated thickness of the Kurkar Group is about 100 m at the shore in the south, and about 200 m near Gaza City. At the eastern Gaza border, the saturated thickness is about 60– 70 m in the north, and only a few meters in the south near Rafah. Local perched water conditions exist throughout the Gaza Strip due to the presence of shallow clays **(Shomar et al, 2005).** Most of the recharge is from dune areas near the west coast. **(Dudeen, 2001).**

3.10.1 Hydraulic Properties of Gaza Aquifer

The hydraulic properties of the aquifer system were determined by a pumping test, transmissivity values range between 700 and 5,000 m^2/day. Corresponding values of hydraulic conductivity (K) are mostly within a relatively narrow range, 20-80 m/day. Specific yield values are estimated to be about 15–30% while specific storativity is about 10^{-4} m^{-1} **(PWA/USAID, CAMP, 2000).**

Most of the wells that have been tested are municipal wells screened across more than one sub-aquifer. Hence, little is known about any differences in hydraulic properties between these sub-aquifers **(Dudeen, 2001; Shomar et al, 2005).**

3.10.2 Groundwater Balance

Estimating all water inflows and outflows to the aquifer has developed to assess the water balance of the Gaza coastal aquifer. The Gaza coastal aquifer is extremely overexploited in the last few decades. This overexploitation makes the aquifer strongly susceptible to seawater intrusion **(Qahman & Zhou, 2001; Ismail, 2003).** Under the current inflow and outflow conditions as shown in table 3.2; the net deficit is about 40-50 MCM/y **(Dudeen, 2001).**

Table (3.2): The recent groundwater balance of the Gaza Strip aquifer

Inflow	Min	Max	Outflows^{2006}	Max
	MCM/y			MCM/y
Effective Recharge (from Rainfall)	40	45	Municipal Abstraction	79.1
Lateral Inflow	20	35	Agricultural Abstraction	85.5
Salt-Water Intrusion - Shallow	10	15	Mekorot Abstraction	4
Leakage from Water Distribution System	10	15		
Wastewater Return Flow (Pipes)	1.6	1.6		
Wastewater Return Flow (Septic Systems)	8.9	8.9		
Recharge from WWTPs (e.g., Jabalya)	2	2		
Recharge from Wadi Gaza	1.5	1.5		
Agricultural/Irrigation Return	20	25		
Loss of Aquifer Storage	2.1	3.2		
Subtotals	**116.1**	**152.2**	**Total**	**168.6**

(PWA/USAID/CAMP 2000, PWA 2007)

3.10.3 Groundwater Levels

Under natural conditions, groundwater flow in the Gaza strip is towards the Mediterranean Sea. However, long term abstraction of groundwater has significantly disturbed the natural flow patterns. The groundwater levels ware dropped by 8 m between year 1935 and 1969. This drop increased to reach in some areas to -11 m in year 2007. Figure 3.12 represents the groundwater level for study area coastal aquifer in year 2007, which ranges from 0.15 m AMSL near the coast to about 1.50 m landward.

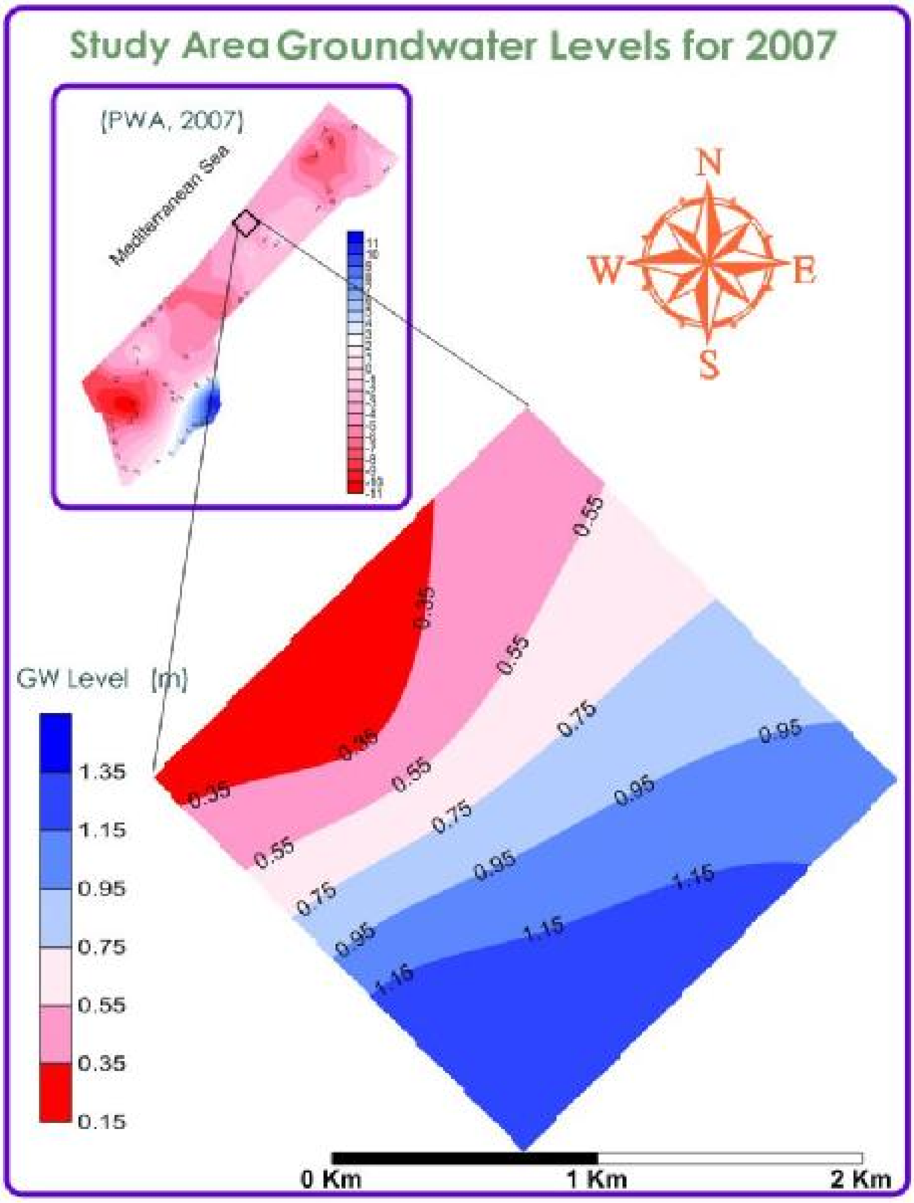

Figure (3.12): Groundwater levels in study area coastal Aquifer in year 2007

In all the Gaza Strip, between years 1970 and 1993 groundwater levels dropped by almost 2 meters on average **(Shomar et al, 2005).** The water level dropped by about 2-3 m from the 1994-2003 **(Qahman & Zhou, 2001; PWA, Data bank 2003).**

3.10.4 Groundwater Quality

Decades of huge overpumping from the aquifer has resulted in drawdown of the groundwater with resulting intrusion of seawater and up-coning of the underlying saline water. Therefore, around only 5% of the public water supply complies with safe water drinking quality (WHO) standards (i.e. more than 250 mg/l). The primary causes of concern are the unacceptable levels of salinity and nitrate in the groundwater supply **(Al Yaqoubi, 2007).**

1. Chloride

Salinity in the Gaza coastal aquifer is most often described by the concentration of chloride in groundwater. Sources of high chloride content have been determined to be: seawater intrusion, lateral flow of brackish water, and up-coning of the brine water from the base of the aquifer **(Al Yaqoubi, 2007).** Figure 3.13 represents the chloride concentration levels in the study areas, which reaches above 800 mg/l in some areas near the coast and 340 mg/l towards the land side.

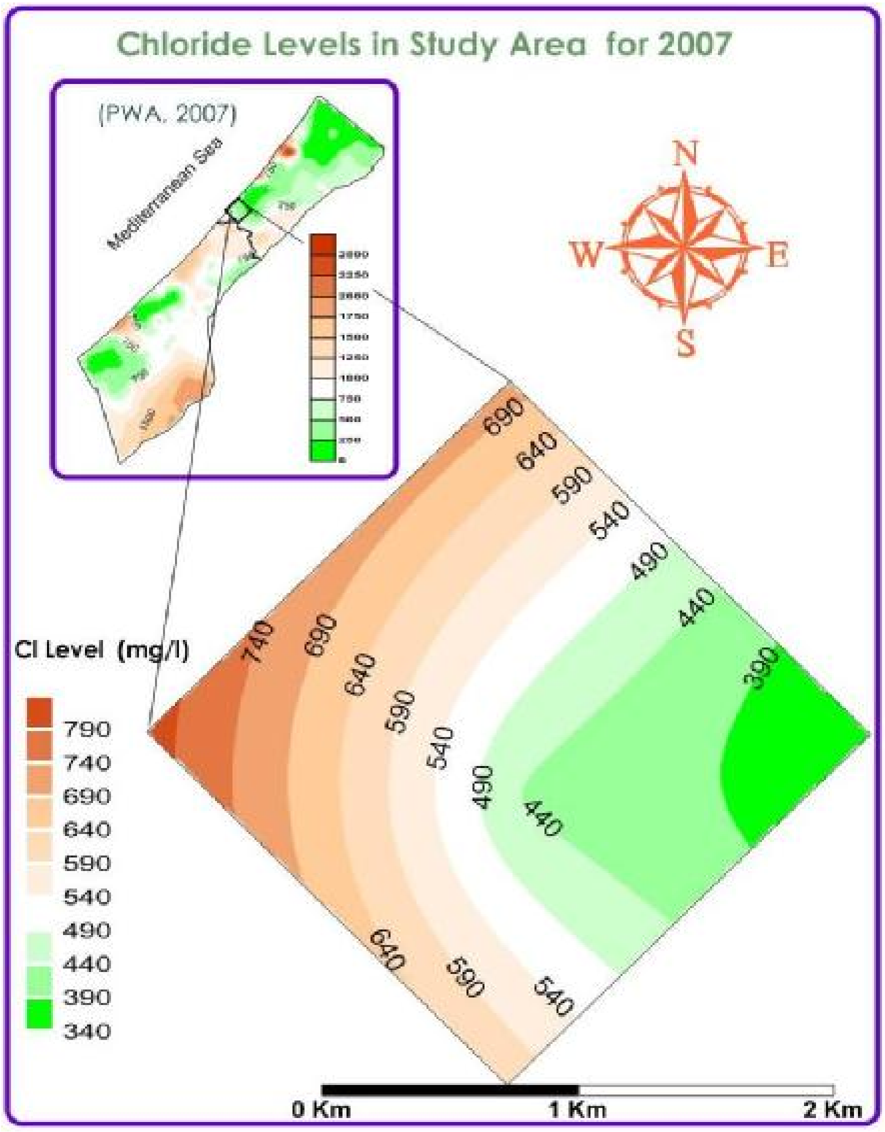

Figure (3.13): Chloride Levels (mg/l) in Study Area in 2007

The coastal groundwater aquifer holds approximately 5,000 MCM of different quality. However, only 1,400 MCM of this is “fresh water”, with chloride content of less than 500 mg/l (70% is brackish or saline water and 30% is fresh water) **(Al Yaqoubi, 2007).**

2. Nitrate

Nitrate is the most important pollutant of the groundwater aquifers. Most municipal drinking wells in the Gaza Strip show the nitrate level that exceeds the WHO drinking water standard of 50 mg/l with exception of 10 % of Gaza municipal wells remain unaffected by high nitrate concentrations **(PWA/USAID, CAMP, 2000).**

Figure 3.14 indicates the nitrate concentration levels in the study areas which extend from 30 mg/l near the land side to 90 mg/l near the sea side.

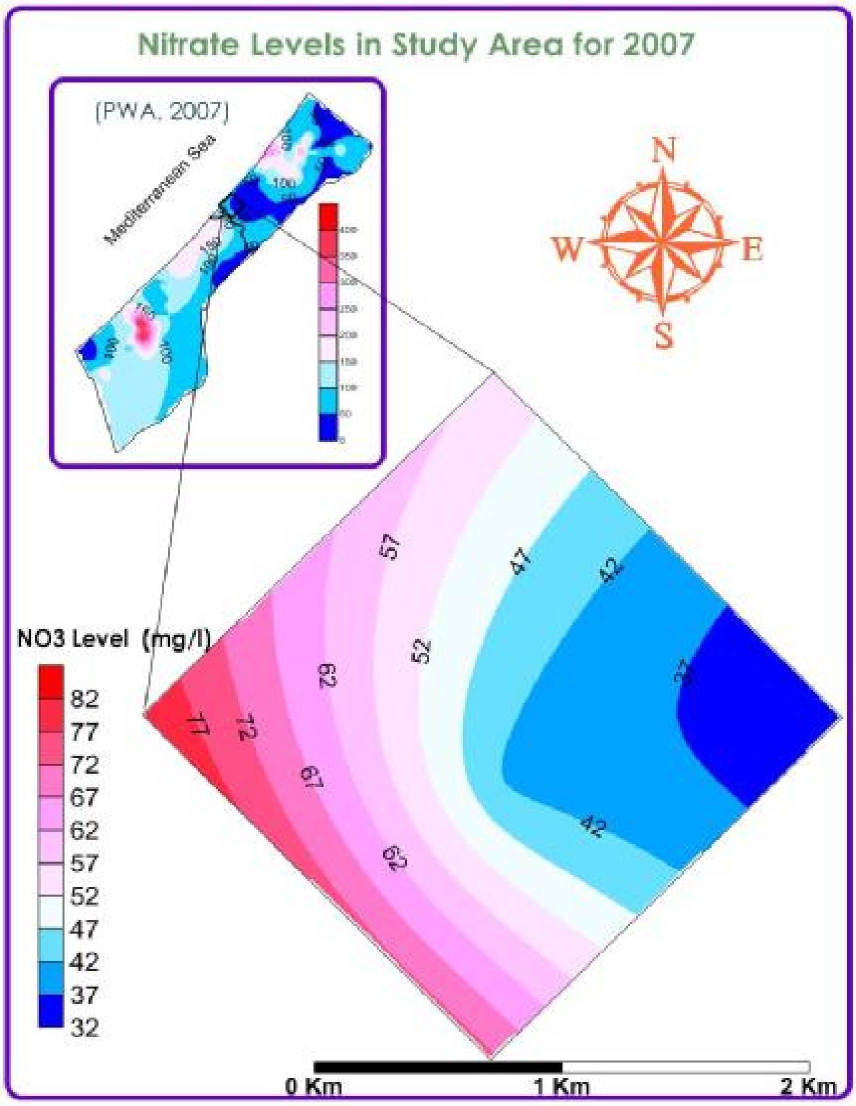

Figure (3.14): Nitrate levels of study area wells in year 2007

In Gaza urban centers nitrate concentrations range from 0 to 450 mg/l. They are also increasing at rates up to 10 mg/l per year. Sources of high nitrate concentrations have been determined to be: untreated domestic sewage effluent, and uncontrolled use of pesticides and fertilizers in the agriculture **(Al Yaqoubi, 2007).**

3.10.5 Water Demands:

Actually, the water demand for different uses is mainly controlled by the population growth and socio-economic development **(Hamdan & Jaber, 2001).** Gaza Strip has a severe crisis on water resources due to the rapid increase of water demand for both domestic and agriculture purposes **(Ismail, 2003).**

1. Domestic and Industrial Water Demand (D&I):

The D&I demand includes net demand for domestic, industrial, public customers and livestock water supply. Water losses through a transmission pipeline and a water distribution system are also included **(Al Yaqoubi, 2007).**

The domestic water demand in 1990 was estimated at 25MCM/yr, **(Hamdan & Jaber, 2001)** While it is estimated at 46 MCM for year 1995. The amount of water used for domestic is averaged 150 l/capita/day. However, the actual water that reaches the users is much less; about 55 to 80 l/capita/day. **(LYSA, 1995; Qahman, 2004).**

In 1999 and 2000, it was estimated that a proximately 140 MCM/yr of water was pumped from about 4,000 wells. Of which, about 50 MCM/yr were pumped for domestic and industrial from 90 municipal wells. It is estimated that 80 l/capita/d was actually made available to consumers **(PWA/USAID, SAMP, 2000).** While the water consumption for industry was estimated at 3 MCM/yr **(Aish & De Smedt, 2004).**

By year 2002, average per capita consumption for both domestic and industrial was estimated at 91 l/capita/d including the livestock **(PWA, LEKA 2003)**. While, in 2003, it was estimated that approximately 150 MCM/yr of water was pumped from about 4,100 wells. Of which, about 60 MCM/yr was pumped for domestic and industrial from 100 municipal wells **(Al Yaqoubi, 2007).**

In the year 2006, all of the water extracted by the municipalities from 126 wells distributed all over the Gaza Strip, is about 76.8 MCM, while Mekorot water supply was about 4 MCM, and the UN-wells pumped about 2.3 MCM from 10 wells for the refugees camps, with a total demand of 83.1 MCM.

Table 3.5 represents the groundwater production from the municipal wells over the period 2000 to 2006 and the total consumption from the same wells over the period. This table also represents the consumption/production ration (efficiency of the water pipe network) and the people requirements along the period taking care of the population increment.

Table (3.3): Comparison of Water Consumption in different years

Item	Year 2000	Year 2001	Year 2002	Year 2003	Year 2004	Year 2005	Year 2006
Total municipal well Production ($\times 10^3$ m^3)	57,015	59,143	62,680	68,065	71,082	74,600	76,807
Total billed water Consumption, ($\times 10^3$ m^3)	35,055	37,840	39,718	42,290	44,114	45,342	46,593
Efficiency %	61.5	64.0	63.4	60.4	60.3	58.7	57.7
Population	1,167,359	1,229,250	1,299,403	1,370,345	1,443,737	1389789	1,443,814
L/c/d	82	84	84	85	84	89	84

(PWA, 2007)

Figure 3.15 indicates the yearly municipal water well production and consumption which are continually increasing with time increment.

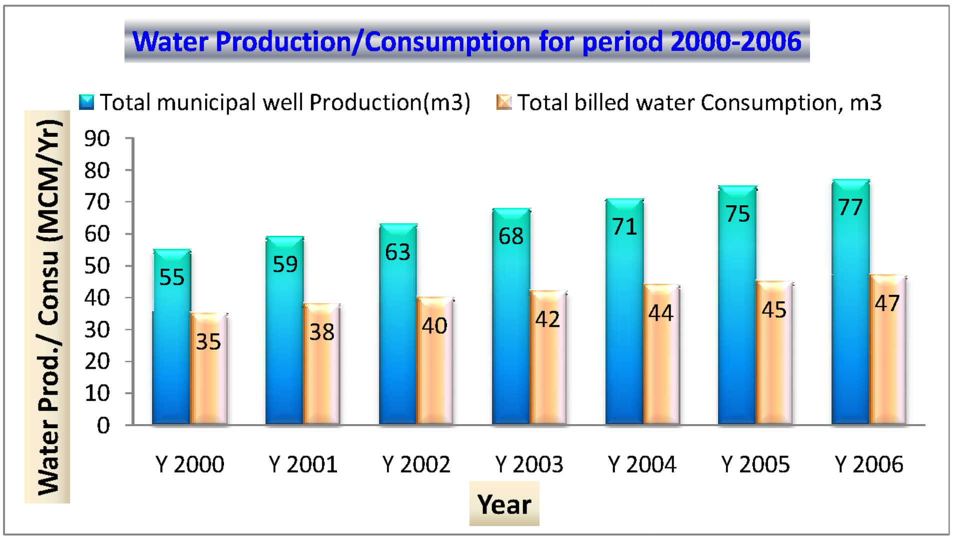

Figure (3.15): Yearly municipal water well production and consumption (Period 2000-2006)

2. Agricultural water Demand

The agricultural sector is considered as a heavy consumer, which requires high quantities of water for food production in the Gaza Strip. If the agricultural water demand is calculated on the basis of the food requirements for growing population which will be doubled in 2020, it appears that the agricultural demand will be increased from about 90 MCM/yr to185 MCM/yr. However this projection is not realistic for Gaza, because neither the water nor the land is available to support this growth **(Al Yaqoubi, 2007).**

In 1975, the total water use (agriculture and domestic combined) was 110 MCM, with a drop in the 1990's to 80 MCM due to improved irrigation efficiency **(Melloul, 1994).** In 1999-2000, it was estimated that a proximately 140 MCM/yr of water was pumped from about 4,000 wells. Of which, about 90 MCM/yr of water uses was used for irrigation. **(Ismail, 2003).**

In 2003, it was estimated that approximately 150 MCM/yr of water was pumped from about 4100 wells. Of which, about 90 MCM/yr of water was used for irrigation **(Al Yaqoubi, 2007).** While in 2006, the approximate estimation of irrigation water demand is about 85.5 MCM/yr of water abstracted form more than 4,600 agricultural wells distributed all over Gaza Strip as shown in table 3.4 and figure 3.16 **(PWA, Data Bank 2007).**

Table (3.4): Fluctuation of Cultivated Areas and Related Water Demand in Gaza Governorates for period 2002 till 2006

Year	Total Cultivated Area, Dunam	Total Estimated Agricultural Water Demand, MCM/Year
2002	167,016	79.5
2003	158,055	77.5
2004	154,000	73.5
2005	167,861	80
2006	175,755	85.5

Source: Ministry of Agriculture Reports (2002-2006)

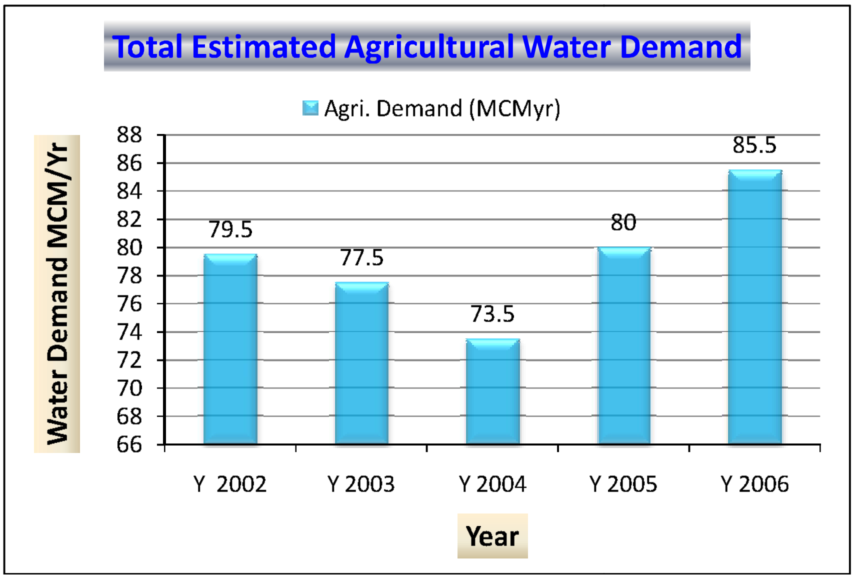

Figure (3.16): Total estimated agricultural water demand, MCM/Year

3. Overall future water demand in the Gaza Strip

The overall projected water demand in Gaza Strip was estimated to increase from about 162.3 MCM in year 2006 to about 262 MCM by year 2020. This includes domestic and industrial demands at water supply source and agriculture use as well.

According to the Water National Plan and the **(CAMP, 2000)** reports, there is dramatic increase in the water balance by year 2020. Table 3.5 illustrates over all water demand in domestic and agriculture sectors and the gap in water resources for both to the year 2020 without incorporating the management options **(PWA/USAID, CAMP 2000).**

Table (3.5): Overall projection water demand in the Gaza Strip

Year	Agricult-ure water demand	D&I water demand	Total demand	Available resources	Gap
2000	91	55	146	109	-37
2005	92	100	192	131	-61
2010	88	125	213	137	-76
2015	86	152	238	145	-93
2020	80	182	262	155	-107

Source: (PWA/USAID, CAMP, 2000)

Accordingly, the water deficit, as shown in figure 3.17, will result in more declining in the groundwater level and the continuous deterioration in the water quality of the aquifer due to seawater intrusion and upcoming saline water from deep aquifer. These impacts will add to more threats to overall development and sustainability.

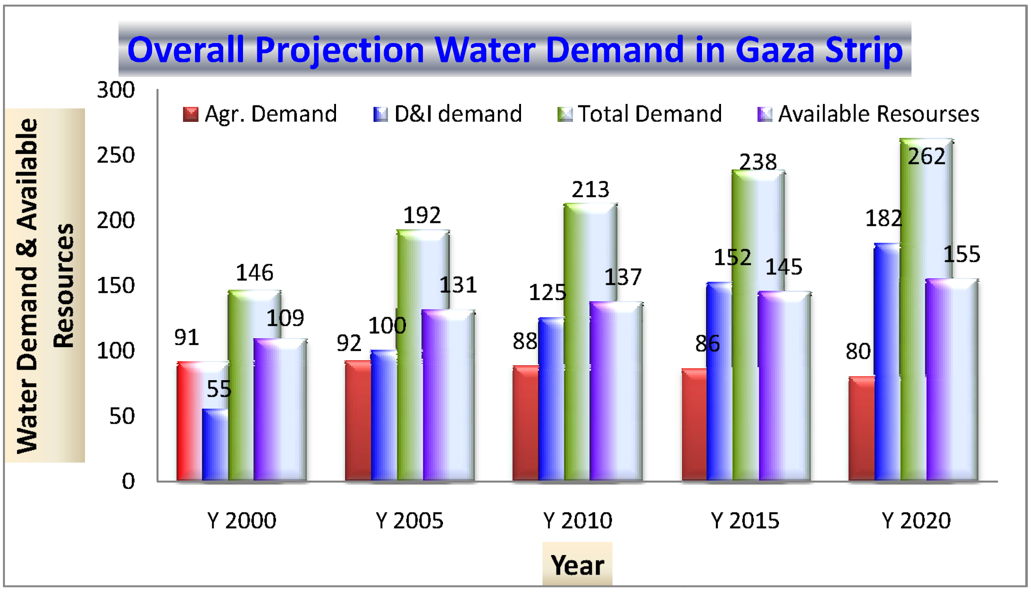

Figure (3.17): Overall Projection Water Demand, MCM/Yr for (2000-2020)

Chapter 4: METHODOLOGY

4.1 INTRODUCTION

This chapter mainly focused on the adopted methodology that used in achieving the main and specific research objectives. This study stood up on the simulation and optimization modeling techniques, therefore, this chapter was subdivided into two main parts that highlighted the imposed tools and the utilized computing software's. The technique used for coupling the simulation and optimization models was also taken into consideration. The data representing and analyzing tools used to incorporate the geographically distributed information with the inputs and outputs of the adopted models was also highlighted herein after. This besides the results demonstration and outcomes visualization tools.

This study mainly concentrated on simulating the coastal aquifer of a specific area in Gaza strip, the northern west of Wadi Gaza. The study also attempted for providing possible optimal scenarios to well manage the coastal aquifer and to provide reasonable solutions for the seawater intrusion problems. This could be by adopting the artificial recharge in which the storm water and/or treated wastewater options could be used. However, related data was required to be collected from different sources in order to satisfy the research requirement and S/O models setup.

4.2 DATA COLLECTION

The related data was collected about the groundwater hydrology, hydrogeology, geology, water subtraction, soil types, natural and artificial recharge, and essential maps. The related data was requested from the involved ministries and related local institutions such as Palestinian Water Authority (PWA), Agricultural Ministry, local municipalities. Some needed data was collected from the published reports and available researches in the local libraries and Internet.

Shortage in and out of date data collected, however, forced on to adopt an effective and economical data collection methods. The field survey method in which the questionnaire is the main instrument was adopted. This method is selected due to the various advantages of using questionnaire technique like wide coverage, facilitating analysis, saving resources, keeping confidentiality and limited researchers **(Mohammed, 2007).**

The prepared questionnaire was distributed among the wells owners in the study area to collect data regarding the water production and well depths, etc. “See appendix I: The used questionnaire form and collected data”

4.3 SET-UP OF SIMULATION/OPTIMIZATION MODELS

A groundwater model application could be of two distinct processes as shown in figure 4.1 **(Kumar, 2002).** First process is the model development resulting in utilizing a software product such as the CODESA -3D, and second process is the application of that product for a specific purpose. Groundwater models are most efficiently developed in a logical sequence

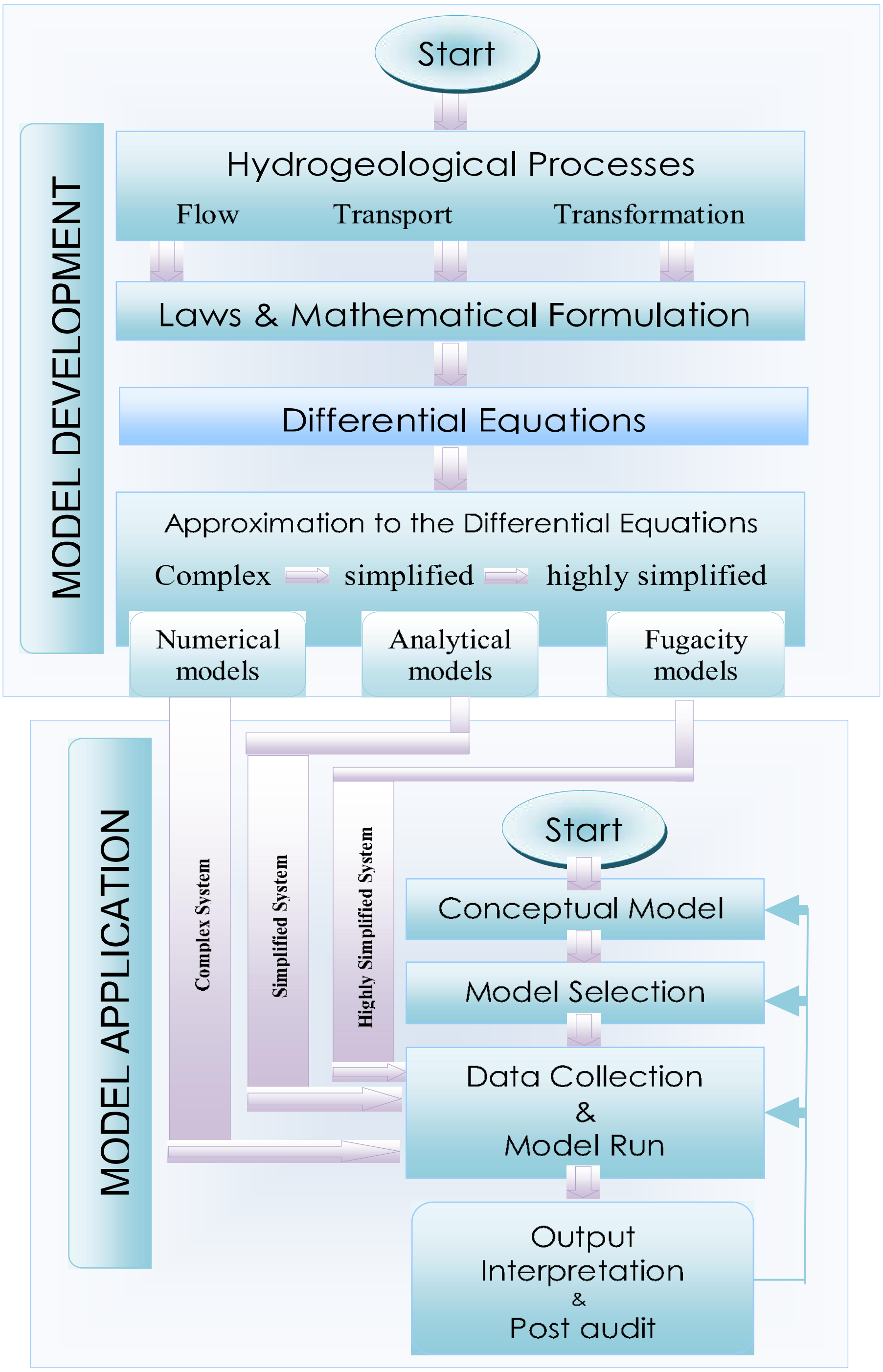

Figure (4.1): Development Process of a Model (Kumar, 2002)

The scarcity of natural water from both quantity and quality perspectives directly resulted from the overexploitation of Gaza coastal aquifer. Therefore, a real need to develop comprehensive scientific information and to improve analysis techniques in order to better understand and to well manage the groundwater systems becomes so important necessity.

Recent technical applications demonstrated that the combined simulation and optimization (S/O) models, retained within a single framework, greatly enhanced the utility of simulation models by directly incorporating management goals and constraints into the modeling process and determining the optimal management strategies from many available ones **(Sreejith & Mohan, 2002; Barlow, 2005).**

The simulation optimization approach was used to solve the optimization problem by linking externally the 3D simulation model with the optimization model. **(Bhattacharjya & Datta, 2005a).**

4.3.1 Simulation Model Setup

The groundwater numerical simulation model (CODESA 3D) was used in this study to represent the key features in groundwater system by solving certain mathematical governing equations; i.e. the numerical simulation model was used to simulate groundwater flow and solute transport.

CODESA 3D (COupled variable DEnsity and SAturation 3-Dimentional) model is a three dimensional finite element simulator for flow and transport in variably saturated porous media on unstructured domain. The flow and salt transport processes are coupled through the variable density of the filtrating mixture made of water and dissolved matter (salt, pollutants). The flow model simulates the flow movement in the porous medium, taking into account different forcing input: infiltration/evaporation, recharge/discharge, withdrawal/injection, etc.; while the transport module computes the migration of the salty plume due to advection and diffusion processes.

The CODESA-3D code is born from the integration of two parent codes:

- STAC3D: SATurated Coupled flow and transport 3-Dimensional model;
- FLOW3D: variably saturated FLOW 3-Dimentional model.

These two computer codes were developed, during the 1990s, by the Department of Applied Mathematics of the University of Padova in collaboration with Environment Group of Centre for Advanced Studies, Research and Development (CRS4) in Sardinia, Italy **(Lecca, 2000).**

Like any saturated coupled flow and miscible transport simulator, CODESA-3D is a coupled flow and transport simulator, but in addition it allows for a variably saturated flow regime. In doing this extension, CODESA-3D incorporates the pre-existing freshwater flow model FLOW3D and integrates it with the presence of the diluted salt, thus giving rise to a flow simulator for a variably dense fluid in a variably saturated porous medium as shown in figure 4.2. The integration required model extensions both in the incorporated flow module, due to the introduction of the salt concentration terms which affected water density, and in the transport module, which conversely deals with a variably saturated flow field **(Gambolati et al., 1999) and (Lecca, 2000).**

Recently, CODESA-3D model was upgraded to deal with the real world topography of the study area, besides, the sub-aquifer layers and their thicknesses and the well screens depths.

Using CODESA-3D in this study backed to the availability of the source code of this model. Qahman (2004) with the cooperation of CRS4 used this model_through their research titled:" Aspects of Hydrogeology, Modeling, and Management of Seawater intrusion for Gaza aquifer Moreover, Afifi and Qahman still have a very good cooperation and contact with CRS4 – Italy and have the access to use this code.

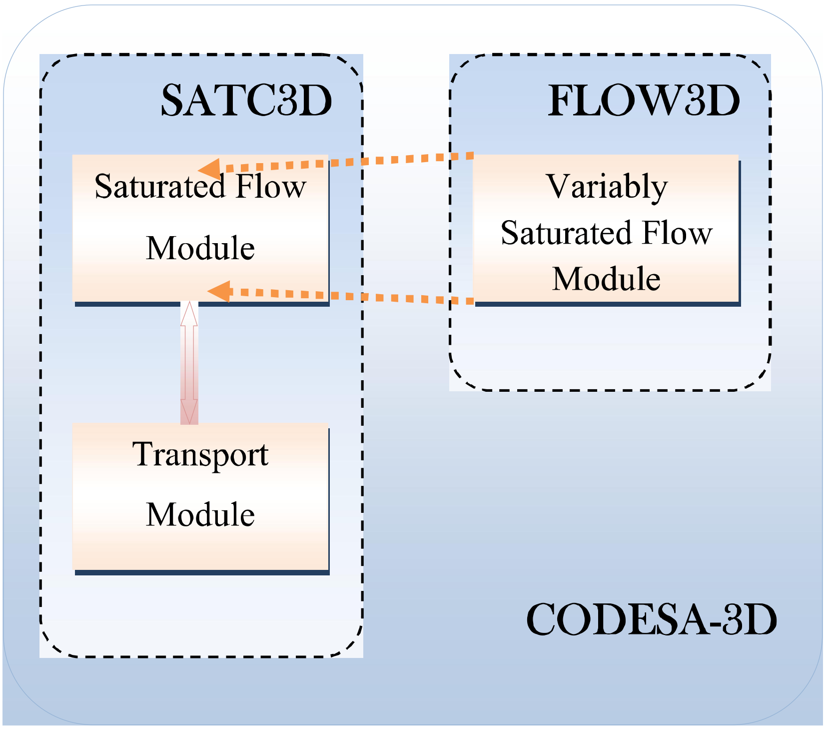

Figure (4.2): integration of FLOW3D variably saturated flow module in with SATC3D Saturated Coupled flow and transport for the creation of CODES-3D model (Lecca, 2000)

A visit to CRS4 – Italy was arranged in the period 19/4/2009 to 16/5/2009. Through this visit, the simulation model was performed and carried out. The simulation model also was linked with GA externally. The results of the combined model were achieved using the multi- processors computer to run a great number of independent problems on a great number of processors in a concurrent way. The platform is a high performance computing platform running Linux Operating System and PGI fortran90.

The PGI Fortran90 was used to compile and build the source code files of CODESA 3D into an executable file. The utilization of Fortran Developer is because the parent codes (SATC3D, FLOW3D) which were written in Fortran Language V. 77. Figure 4.3 represents the 3D simulation model CODESA-3D flow chart.

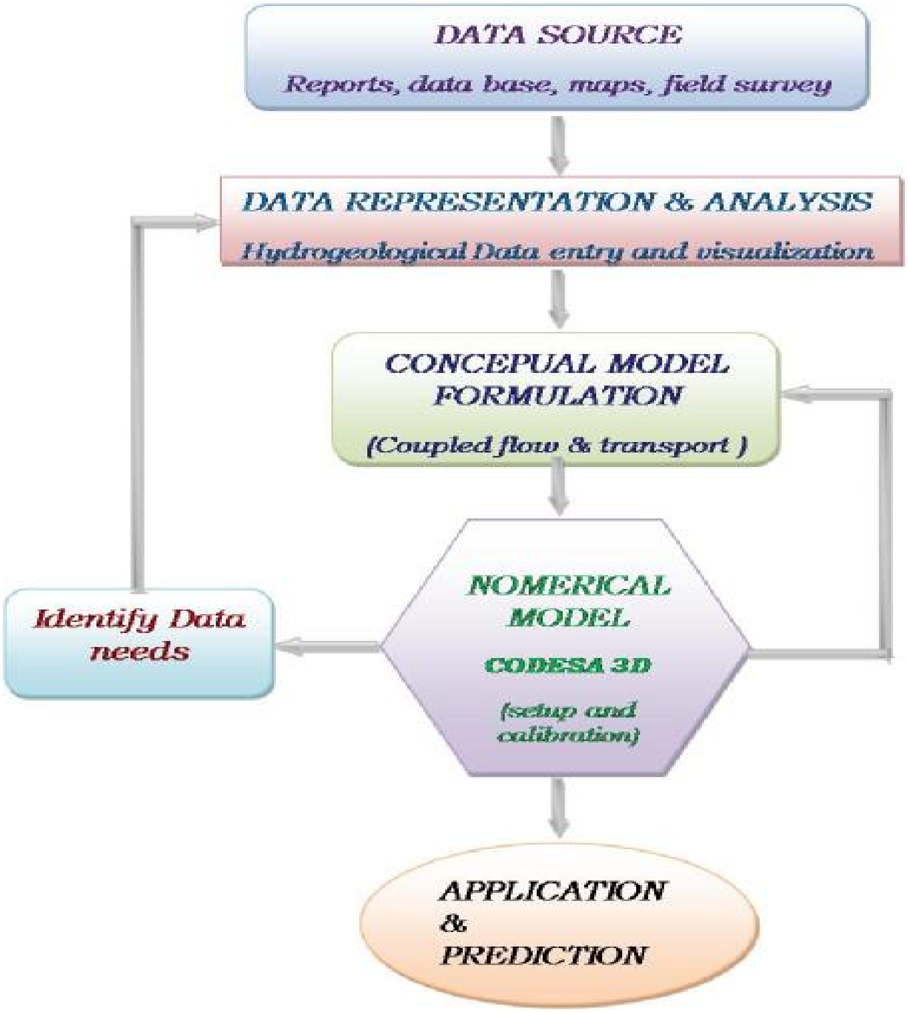

Figure (4.3): The 3D simulation model procedure

4.3.2 Optimization Model Setup

Although simulation models provide the resource planners with important tools for managing the groundwater system, which provide localized information regarding the response of the groundwater system to pumping and/or artificial recharge only (Willis and Yeh, 1987); nevertheless, because of the complex nature of groundwater systems, these predictive models don't identify the optimal groundwater development, design, or operational policies for an aquifer system as they require more number of trials and enormous computing time **(Sreejith & Mohan, 2002 and Barlow, 2005).**

Optimization techniques are, however, utilized to facilitate optimal decision making in the planning, design and operation of especially large-scale water resources systems. In spite of this, they are not feasible to be used alone as they may necessitate conceptual assumptions or they suffer from dimensionality problem. However, these problems could be solved in a more efficient manner by a way of combining simulation (that predicts system responses), and optimization (that computes the best strategy for the problem, scenario, or formulation) in a single framework to overcome the usage of simulation or optimization alone.

The combination of simulation and optimization techniques have been demonstrated to be powerful and useful methods in determining, planning, and managing most feasible strategies for the optimal development and operation of groundwater systems **(Das & Datta, 2001 and Peralta, 2004).**

In this study, the simulation model CODESA-3D was linked externally with optimization model as which genetic algorithm (GA) version (1.7a) known as D.L. Carroll's FORTRAN Genetic Algorithm Driver (Carroll, 2001) was utilized as shown in figure 4.4 **(Qahman, 2004).**

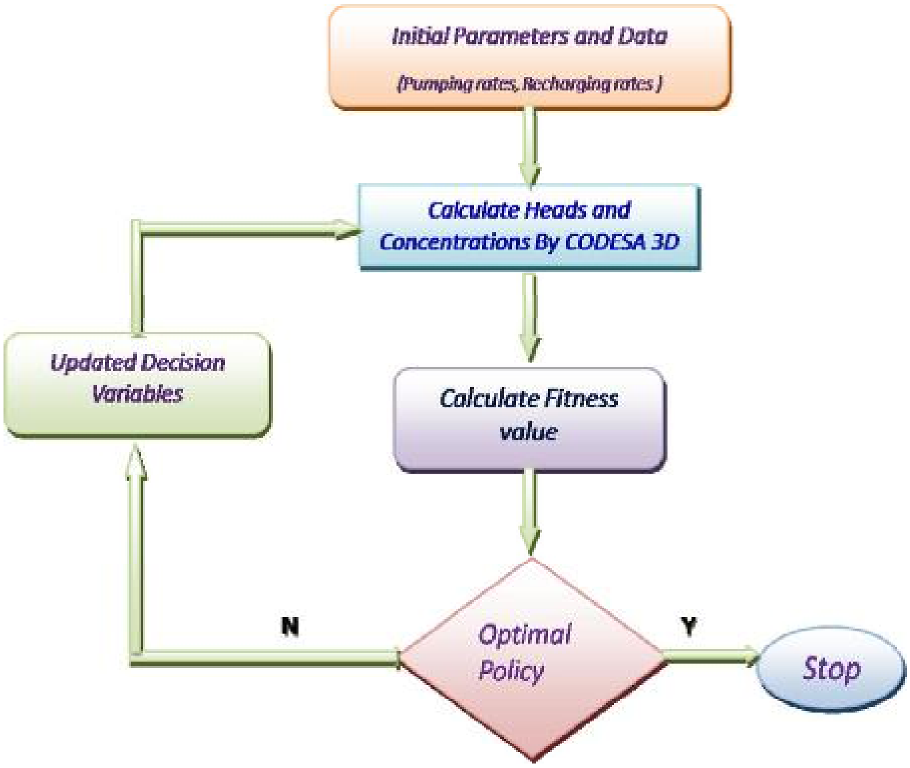

Figure (4.4): The Optimization- Simulation Solution Procedure (Qahman, 2004)

Figure 4.5 represents the flow chart of simple GA optimization model with CODESA - 3D simulation model in more details in order to highlight the sequence of the Genetic Algorithm main processes such as selection, crossover, and mutation. For more details see chapter 5 in this study.

4.4 DATA REPRESENTATION AND ANALYSIS

The collected data included information on the regional distribution of basic and hydrologic parameters, as topography, soil types, geological conditions, population density, infiltration/annual recharge, evapotranspiration, groundwater flow, etc., and other derived parameters such as water budget, consumption use, water reserves, wastewater production etc. Some of collected data were transformed into GIS form with the help of the ArcView GIS v. 3.3 and Surfer v.9 computer software.

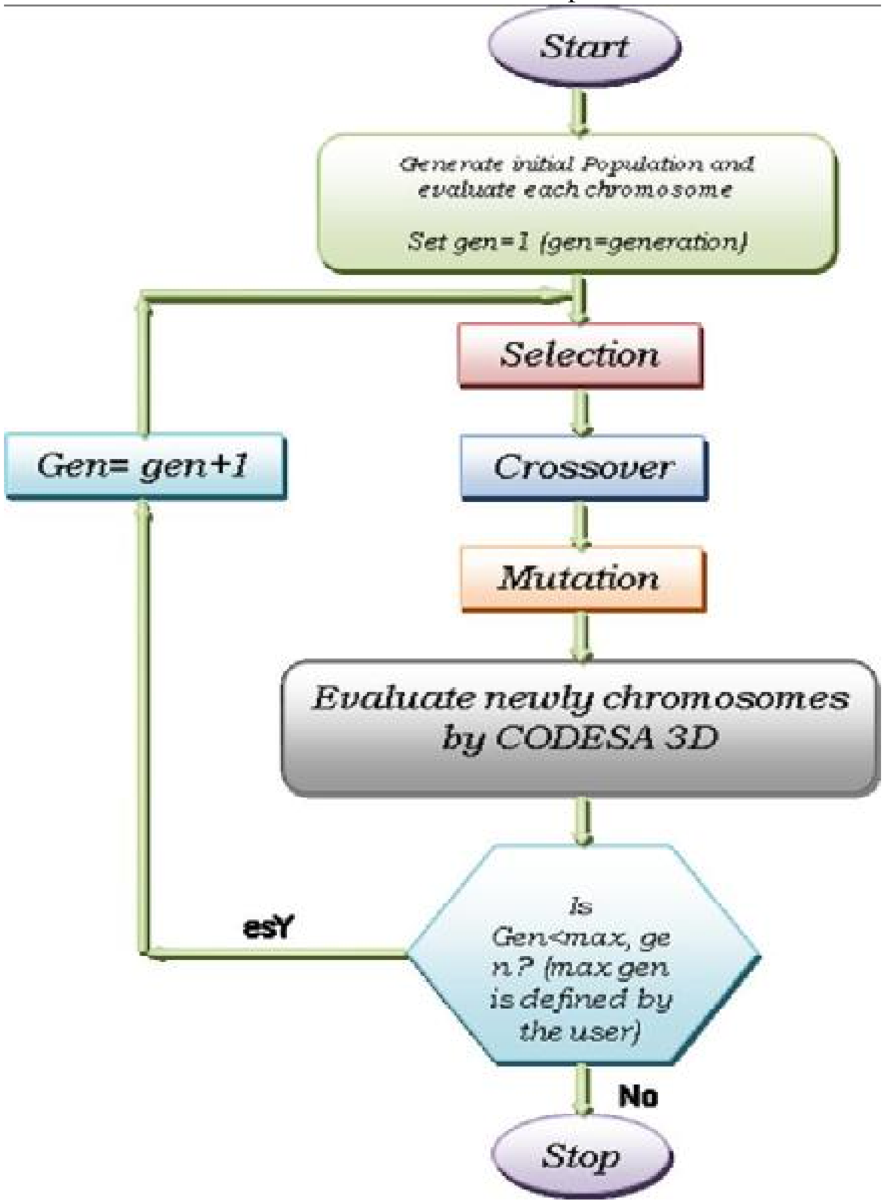

Figure (4.5): flow chart of simple (GA) linked with CODESA-3D (Qahman, 2004)

This transformed data into Geographical Information System (GIS) format was mainly used to represent the existing situation of the geological conditions and groundwater system in Gaza strip in general and the study area in special; such as the topography, sub-aquifers layers inclination, the soil types map, groundwater levels, the chloride and nitrate concentrations, and natural recharge/infiltration, etc.

Some modeling related data was analyzed using Argus ONE v. 4.0 pre and post processor software. Using a conceptual model approach, combined with export scripting capabilities and plug-in support, Argus ONE is an application of development environment for developing and deploying graphical user interfaces for CODESA-3d numerical model. Using Argus ONE, the conceptual model was constructed by creating the finite element mesh; boundary conditions were defined; initial conditions were manipulated; and adding parameters to the model grid. The modeling data was exported by using Argus ONE into an input data format used for the simulation model (GODESA-3D)

4.5 Result Demonstration

The results of both externally linked models i.e. 3D simulation model (CODESA-3D) and the optimization model are visualized into a three dimension using the ParaView V. 3.0.2 Open-source, multi-platform visualization application. Some of the results were represented using the ArcView V. 3.3 and Surfer V. 9 Geographical information systems (GIS) software's. As GIS software's are suitable tool for recording geographically the distributed information and to incorporate this information with the input or output of groundwater modeling (**Barakat, 2005).** Visualizing and GIS processing of the results allow better demonstration for the outcomes and enhance better read for these results.

The whole methodology steps and utilized tools and techniques in this work could be summarized and represented as in figure 4.6.

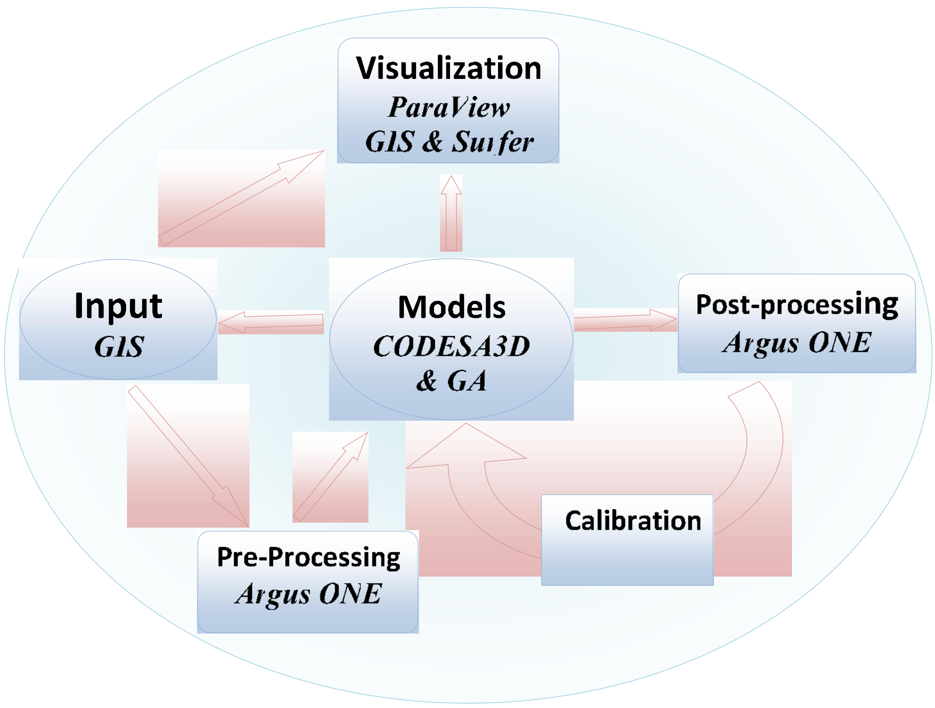

Figure (4.6): the overall methodology layout

Chapter 5: SIMULATION & OPTIMIZATION MODELS SETUP

5.1 INTRODUCTION

The combination of a simulation model with an optimization model in a single multi objective management model is applied for groundwater aquifer management. This multi objective model is applied basically for prevention of the seawater intrusion in the study area, in addition to the duplication possibilities of a such model to all areas of similar hydrogeological in Gaza strip in the future.

The simulation of groundwater was conducted to provide a hydrological data that can be used in the groundwater resources management scheme. Such groundwater models have been applied to investigate a wide variety of hydrogeological conditions; whereas the considered parameters in such models include the groundwater level, the flow direction and concentration, the groundwater balance, and other parameters of the aquifer. However, the considered parameters in the study models are the flow and concentration only.

The use of optimization tools for evolving economically efficient management strategies, especially large-scale water resources systems, is considered as the most important component of Decision Support Systems that are not confined only to the quantity aspect of water, but also the quality aspects **(Bhattacharjya & Datta, 2005b).**

This chapter represents the simulation model application and setup which included the conceptual model development, boundary and initial conditions, and grid design, besides the model calibration. In addition to the setup of the simulation optimization models and their formulation processes and considerations.

5.2 SIMULATION MODEL

5.2.1 Mathematical Model and Governing Equations

The CODESA-3D (COupled variable DEnsity and SAturation) code is used to simulate the variable density effect on the aquifer groundwater. It is a distributed, fully three dimensional, variably saturated flow and miscible transport model that accounts for spatial and temporal variability of parameters and boundary conditions. The wide applicability of the model allows investigation of a number of important scenarios for study area, such as the effects of aquifer heterogeneity, location and rate of pumping, natural recharge, and unsaturated zone characteristics. The full coupling between water flow and salt transport components makes it possible to examine in detail the density effects and interactions between pressure head and salt concentration fields, in order to derive from these fields, the water table levels, groundwater velocities and saltwater-freshwater mixing zone.

The CODESA-3D mathematical model is based on two coupled equations assessing for fixed control volume immersed in the flow domain (figure 5.1), the mass conservation principle both for water (equation 1) and dissolved salt (equation 2). The first mass balance equation is referred further as flow equation and the second one as transport equation or the advection- dispersion equation.

In what follows $[x, y, z]^T$ is the Cartesian spatial coordinate vector where the superscript T is the transpose operation, with z vertical coordinate directed upward, and t is the time.

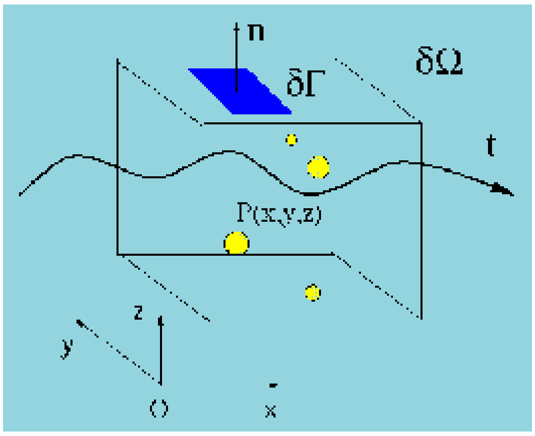

Figure (5.1): control volume centered at point P(x,y,z) of domain Ω and crossed by the water flow at time t. the salt dissolved in water is represented by yellow particles.

The mathematical model is formulated in terms of **two unknowns**:

$$\psi(x,y,z,t) = \frac{p}{\rho_0 g} \qquad \text{Equivalent freshwater pressure head}$$

$$c(x,y,z,t) = \frac{\tilde{c}}{\tilde{c}_s} \qquad \text{Normalized concentration of salt}$$

The mathematical model of density-dependent flow and transport in groundwater is expressed in terms of an equivalent freshwater total head:

$$h = \psi + z \quad ,$$

$$\psi = \frac{p}{\rho_0 g}$$

Where:

h = the equivalent freshwater total head;
z = the vertical coordinate directed upward;
ψ = the equivalent freshwater pressure head;
p = the fluid pressure;
ρ_0 = the freshwater density; and
g = the acceleration of gravity.

The normalized concentration (c) is a non dimensional variable ($0 \le c \le 1$) defined as the ratio between the actual $\tilde{c}$ and maximum $\tilde{c}_s$ absolute concentrations of salt in water. The maximum absolute concentration $\tilde{c}_s$ is a characteristic parameter of the numerical applications: for seawater intrusion problems $\tilde{c}_s$ is usually in the range of (25-35) x 10^{-3} (g/l), which corresponds to an average salt concentration of seawater.

In this model the variable density of the solution is expressed as a linear function of the normalized salt concentration (c):

$$\rho = \rho_0(1 + \varepsilon .\ c),$$

Where:

ρ_0 = the reference density,

c = the relative salt concentration, normalized with respect to the maximum salt concentration of seawater (30 grams/liter [g/l]),

ε = the density difference ratio which is expressed by:

$$\varepsilon = (\rho_s - \rho_0)/\rho_0 \ll 1$$

Where: ρ_s = the maximum density of seawater.

With these definitions, the coupled system of variably saturated flow and miscible salt transport equations is:

$$\begin{cases} \sigma \dfrac{\partial \psi}{\partial t} = -\nabla .\ v - \phi S_w \varepsilon \dfrac{\partial c}{\partial t} + \dfrac{\rho}{\rho_0} q & (eq\ 1)\ \ flow\ equation \\ \phi \dfrac{\partial (S_w c)}{\partial t} = \nabla .\ (D \nabla c) - \nabla .(cv) + qc^* + f & (eq\ 2)\ \ Transport\ equation \end{cases}$$

All terms in above equations (1 & 2) are time inverse [T^{-1}] and the symbol ∇ is gradient operator, e.g. $\nabla_z = [0, 0, 1]^T$ is the unit vertical vector.

In equation (*eq.* 1), the term $-\nabla .\ v$ express the divergence of water flux in the control volume. In equation (*eq.* 2), the term $-\nabla .(cv)$ expresses the advective flux, i.e. the flux carried by the water at its average velocity. While the term $\nabla .\ (D\nabla c)$ expresses the dispersive flux, linearly proportional to the gradient of concentration, which takes place from high concentration to low ones. The dispersive flux is macroscopic effect resulting from local velocity fluctuations, accounting both for mechanical dispersion and molecular diffusion.

In the flow equation (*eq.* 1):

- v is the Darcy velocity vector [*L/T*];

  $$v = -K[\nabla \psi + (1 + \varepsilon c)\nabla z] \qquad \text{With}$$
  $$K = k_{rw} K'_s$$

  Where:

  K = the variably saturated hydraulic conductivity tensor [*L/T*],

  k_{rw} = the relative permeability *[/]*; being k is the intrinsic medium permeability *[L²], and*

  $$K'_s = \rho g k/\mu \qquad \text{where:}$$

  K'_s = the saturated hydraulic conductivity tensor [*L/T*]

  Incorporating constitutive equations for density and viscosity, K'_s becomes:

  $$K'_s = \frac{(1+\epsilon c)}{(1+\epsilon' c)} K_s \qquad \text{where:}$$

  K_s = the saturated hydraulic conductivity tensor at reference conditions μ_0 and ρ_0;

- $\sigma(\psi, c)$ is the overall storage coefficient [L^{-1}];

- ϕ is the porosity [/];
- S_w is the water saturation [/] i.e. the ratio between the volume of water and the volume of voids in the representative elementary volume (REV) of porous medium. Obviously $S_w = 1$ in a water saturated porous medium;
- q is the injected (+ive) / extracted (-ive) volumetric flow rate [T^{-1}].

In the transport equation (*eq.* 2):

- D is the hydrodynamic dispersion tensor [T^{-1}];
- c^* is the normalized concentration of salt in the injected (+ive) / extracted (-ive) fluid [/];
- f is the volumetric rate of injected (+ive) / extracted (-ive) solute, in a limited quantity not capable to affect the flow field [T^{-1}].

Coupling the flow and transport equations is due to the concentration terms that appears in flow equation and, conversely, the head terms that appear in the transport equation via the Darcy velocities. As can be seen the coupling terms contain nonlinear expressions of the unknowns both in the flow and transport equations. An additional source of nonlinearity is introduced in the flow equation by the coefficients σ and k_{rw} that are highly nonlinear function of the pressure head ψ, when the water flow develops in the unsaturated zone where ψ, now called the suction head, becomes lesser than zero, due to the capillarity effect.

The initial conditions (IC's) and Dirichlet, Neumann, or Cauchy boundary conditions (BC's) must be added to complete the mathematical formulation of the density – dependent flow and transport problem expressed as follows in:

The **flow boundary conditions** are:

$$\begin{aligned} \psi(x,y,z,t=0) &= \psi_o(x,y,z) && \text{on } \Omega \text{ (flow IC's)} \\ \psi(\bar{x},\bar{y},\bar{z},t) &= \bar{\psi}(\bar{x},\bar{y},\bar{z},t && \text{on } \Gamma_1 \text{ (flow BC's)} \\ v\,.\,n &= -q_n(\bar{x},\bar{y},\bar{z},t) && \text{on } \Gamma_2 \end{aligned}$$

Where:

Ω = the whole 3-D computational domain;

Γ = the domain boundaries;

ψ_o= the prescribed pressure head at initial time (zero) for all the points belonging to the volume Ω.

$\bar{\psi}$ = the prescribed pressure head on the Dirichlet boundary segment Γ_1 of the surface Γ.

q_n = the prescribed flux across the Neumann boundary segment Γ_2, whose outward normal unit vector is n

The **transport boundary conditions** are:

$$\begin{aligned} c(x,y,z,t=0) &= c_o(x,y,z) && \text{on } \Omega \text{ (transport IC's)} \\ c(\bar{x},\bar{y},\bar{z},t) &= \bar{c}(\bar{x},\bar{y},\bar{z},t) && \text{on } \Gamma_3 \text{ (transport BC's)} \\ D\nabla c\,.\,n &= q_d(\bar{x},\bar{y},\bar{z},t) && \text{on } \Gamma_4 \\ (vc - D\nabla c)\,.\,n &= -\,q_c(\bar{x},\bar{y},\bar{z},t) && \text{on } \Gamma_5 \end{aligned}$$

Where:

c_o = the initial concentration at time zero;

$\bar{c}$ = the prescribed concentration on the Dirichlet boundary segment Γ_3;

q_d = the prescribed dispersive flux across the Neumann boundary segment Γ_4 ; and

q_c = the prescribed total flux (advective plus dispersive) of solute across the Cauchy boundary segment Γ_5.

Figure 5.2 shows typical boundary conditions for a coastal aquifer, contaminated by seawater intrusion due to inland over-pumping. The prescribed pressure (on boundaries Γ_1) and the concentration (on Γ_3) also are considered as Dirichlet boundaries at the sea side. Impervious boundary (no water flux ($q_n = 0$)) at the aquifer bottom (Γ_{2a}) assumed distributed influx (q) (infiltration) along the soil surface (Γ_{2b}) and exploitation or water outflow (Q) (withdrawal) at wells (on Γ_{2b}).

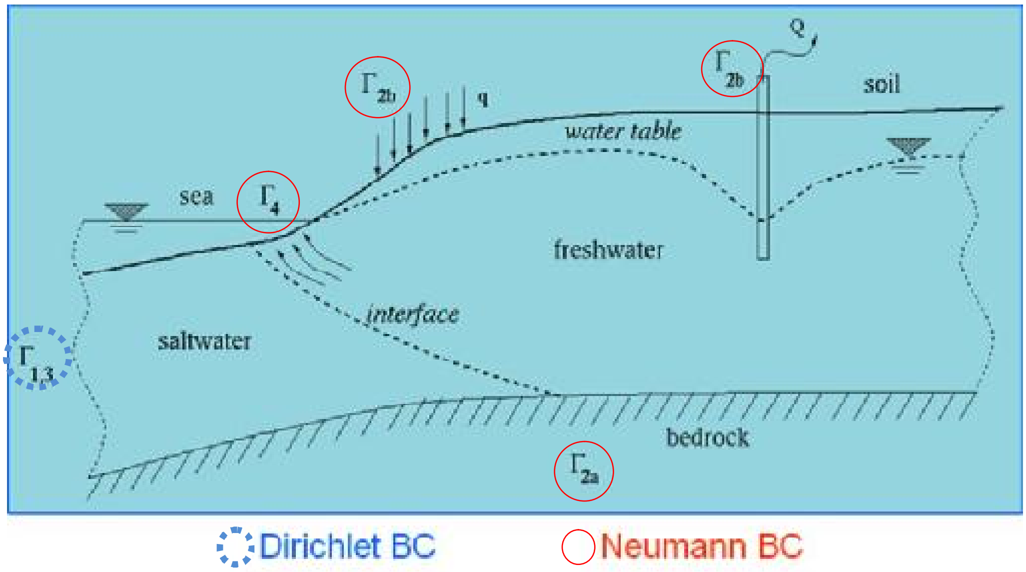

Figure (5.2): cross-section of the flow domain Ω representing a costal aquifer, contaminated by seawater intrusion.

5.2.2 Numerical simulation Model Setup

1. The conceptual model and grid design

The model domain encloses a square area of 2.0 km X 2.0 km sided from the west by the Mediterranean Sea coast. This domain was adequately discretized using Argus One, pre and post processor computer software based on the finite element method. The 3D mesh of the aquifer system contained 13,096 nodes and 25,280 tetrahedral. This mesh was built from the layer-by-layer replication of a 2D triangulation made of 3160 tetrahedral and 1637 nodes as shown in Figure 5.3. In this model, three zones were considered according to the soil map of the study area (figure 3.9)

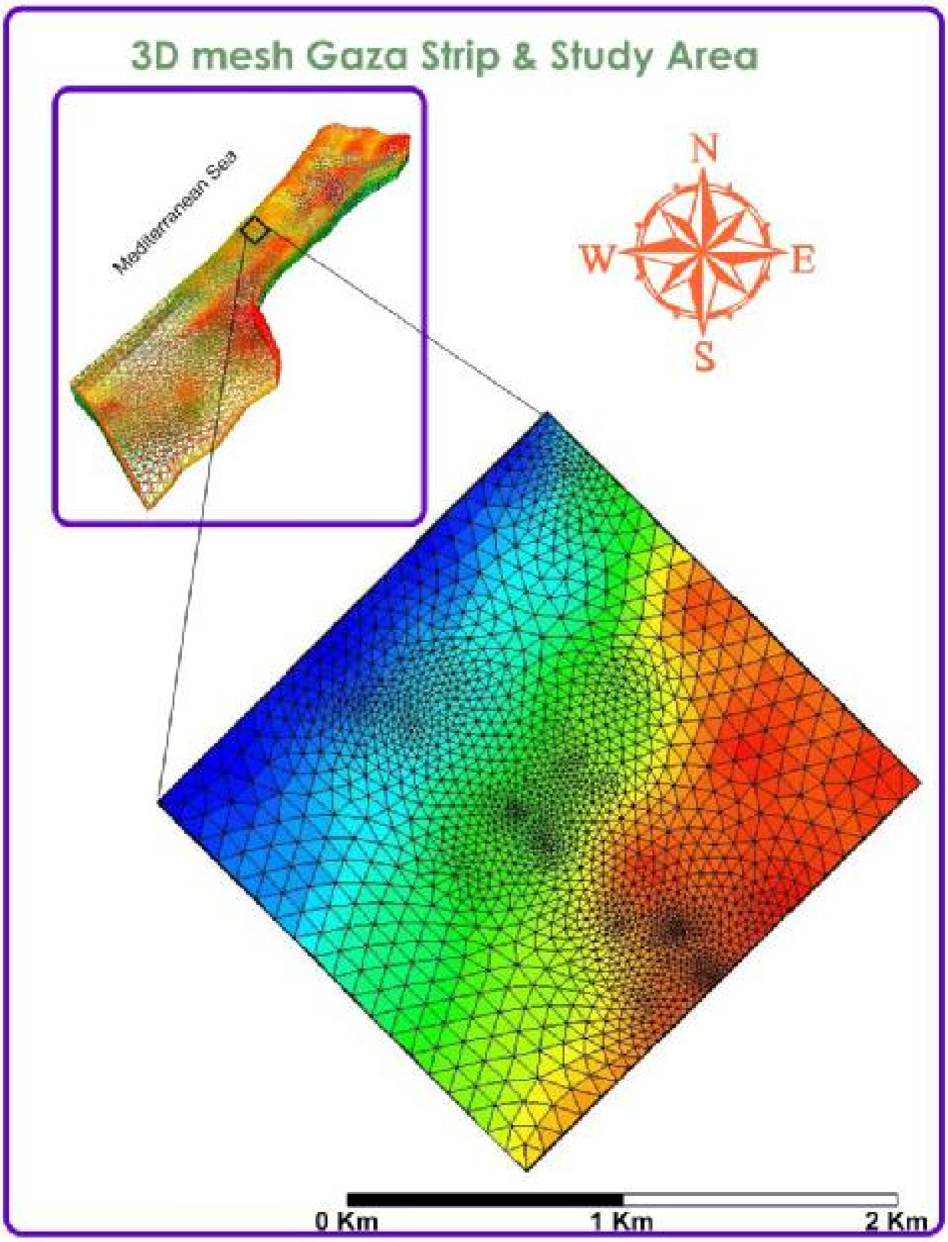

Figure (5.3): 2D surface mesh of the study area

2. Model construction

A cross sectional simulation model represents the study area in northern west of Wadi Gaza section was developed based on the available borehole details for the whole Gaza strip in the previous studies. The aquifer system was considered as an aquifer with a stratigraphy of 7 layers 4 of which are sub-aquifer: A, B1, B2, and C which are classified as dunes sand, sandstone, calcareous sandstone, and silt respectively with alternating finer and coarser unconsolidated sediments belonging to the sandstone (Kurkar) formation. The minimum thickness of the seven vertical strata was 1.98 m while the maximum thickness was 51.75 m. Schematization of the hydrogeological cross section of the Gaza Strip aquifer is shown in figure 3.10. It is implied that sub-aquifer A is phreatic, whereas sub-aquifers B1, B2, and C become increasingly confined towards the sea.

The model was discretized vertically into 8 layers of different thickness as shown in figure 5.4, corresponding to 7 hydrogeological units: phreatic aquifer (unit 1), aquifers (units 3, 5 and 7) and aquitards (units 2, 4, and 6). The top elevation of the first layer is spatially variable and corresponds with land surface elevation. The aquifer domain overlies marine clay of Neogene's age, known as the Saqyia Clay aquiclude **(EC, 2000)**. The layers are approximately horizontal with a small inclination towards the sea **(Aish & De Smedt, 2004).**

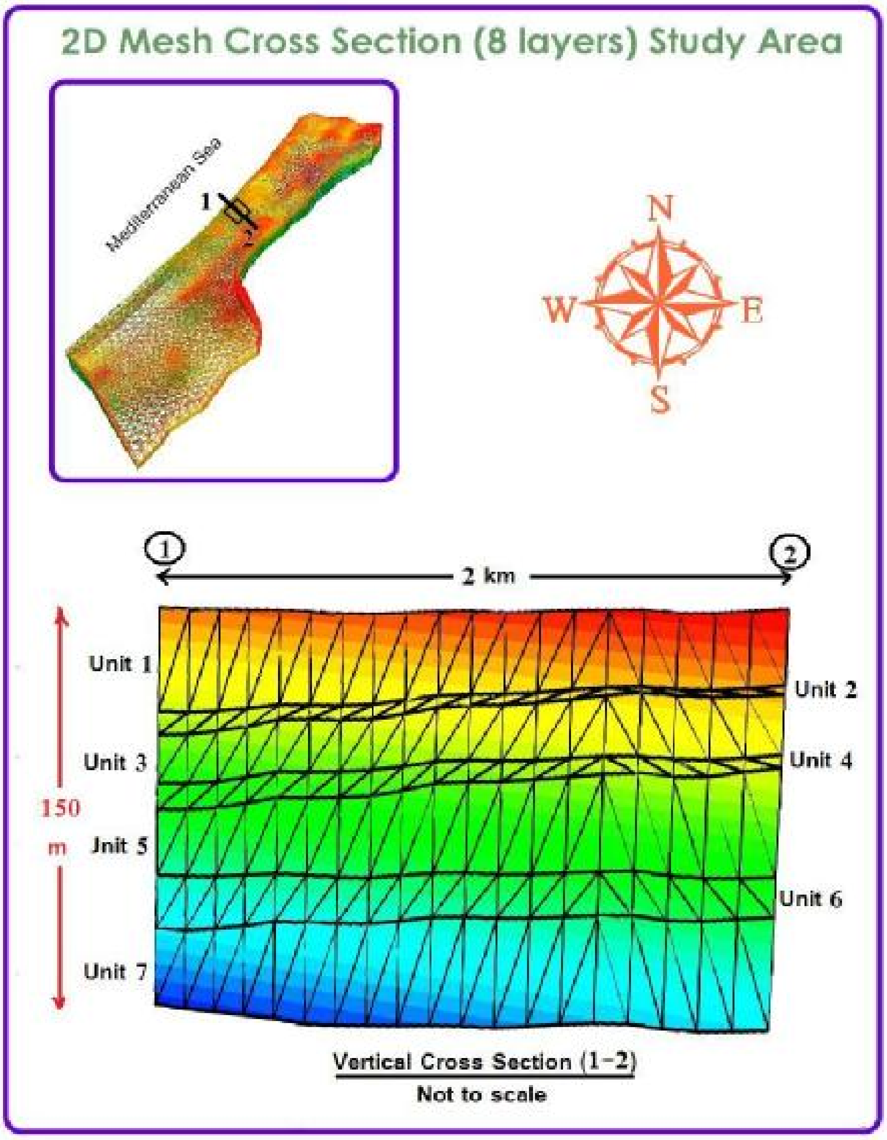

Figure (5.4): the 2D mesh vertical cross section of the study area

For 1 year transient state simulation:
Running the simulation model CODESA-3D for 1 year transient state condition was performed for 6 time steps in total with 1 year time period at the end of the simulation. The minimum time step size was taken as 2.628 x 10^{+5} second (3 days) and the

maximum size as 3.153 x 10^{+7} (1 year). The CPU time for each step was 3.67 seconds. The total CPU time for the simulation was 22 seconds.

For 10 years transient state simulation:
Running CODESA-3D for 10 year transient state condition was performed for 38 time steps in total with 10 years' time period at the end of the simulation. The minimum time step size was taken as 2.628 x 10^{+5} second (3 days) and the maximum size as 3.153 x 10^{+7} (1 year). The CPU time for each step was 4.87 seconds. The total CPU time for the simulation was 185 seconds.

3. Boundary conditions and internal sinks

A Neumann-type of no-flux boundary conditions was assigned to the bottom of the aquifer (aquiclude); since it is assumed that this sub-aquifer is sealed from the sea (Guo and Langevin 2002), while the top of the aquifer was considered as a recharge boundary by the direct infiltration.

Zero flux boundary conditions were imposed on part of the northern and southern domain boundaries regarded as groundwater divides, assuming that the flow lines are parallel to them under natural conditions. However, the exact position of this boundary is not known due to the scarcity and uncertainty of data. This assumption could be changed in case the water level data are obtained **(Qahman & Larabi, 2005).**

A Dirichlet-type of boundary condition was assigned to the residual parts of the left and right boundaries besides the remaining part in the northern side i.e. the flow in which was allowed. For the flow problem, hydrostatic pressure was assumed along the vertical boundary of the sea side, while the aquifer was charged with freshwater by a constant flux from the inland side.

A constant head boundary was prescribed for each layer and the water density for left (seaside) and right (landside) boundaries were (1025 and 1000 kg/m^3) respectively. For the transport problem, at the inland side the concentration was zero (freshwater condition). While at the coastal side, the aquifer system was subjected to seawater intrusion. The relative concentration of seawater is imposed for a height of 150 m from the aquifer bottom.

4. Aquifer Input Parameters

In the simulation model, the study area aquifer is considered as unconfined, heterogeneous and an anisotropy with respect to freshwater hydraulic conductivities, molecular diffusion, and longitudinal and transverse dispersivities as each sub aquifer has its own hydrogeological parameters. The aquifer parameters used in the simulations are summarized in table 5.1, which were assigned based on the hydrogeological investigation, i.e. the pumping tests in the Gaza Strip, previous modeling studies by Israeli organizations in the coastal plain, and related literatures .

The hydraulic conductivity ranges obtained by tests carried out in Gaza showed that values were 20–80 m/day. The hydraulic conductivity was assumed to be constant for units (1, 3, 5, and 7) which are sub aquifers, while another hydraulic conductivity value was assigned to the aquitards units (2, 4, and 6). The vertical hydraulic conductivity of the unsaturated zone for the soil types investigated is 18 m/d for sand with fine gravel and 0.3 m/d for clay. The vertical conductivity was set to be 10% of the horizontal hydraulic conductivity **(Qahman & Larabi, 2005).**

Table (5.1): Hydraulic parameters value for model inputs

parameter	Sub Aquifers			Aquitard	unit
	sandy regosols	sandy loess	Dark brown sandy loess	Clay	
Do (molecular diffusion	7.7E-6	7.7E-6	7.7E-6	7.7E-6	m^2/s
g (gravitational constant)	9.81	9.81	9.81	9.81	m/s^2
K_{sx} (saturated hydraulic conductivity in the x direction)	9 E-4	5 E-4	2 E-4	2 E-6	m/s
K_{sy} (saturated hydraulic conductivity in the y direction)	9 E-4	5 E-4	2 E-4	2 E-6	m/s
K_{sz} (saturated hydraulic conductivity in the z direction)	9 E-5	5 E-5	2 E-5	2 E-7	m/s
α_L (longitudinal dispersivity)	50	50	50	50	m
α_T (transversal dispersivity)	10	10	10	10	m
q_n (lateral freshwater flux)	76 E-3	76 E-3	76 E-3	0	m^3/s
Φ (effective porosity)	0.34	0.34	0.34	0.26	
Spatial infiltration (recharge)	6.8 E-8	2.9 E-9	2.4 E-10	0	m/s

Pumping tests carried out to date in the Gaza Strip have yielded unreliable values of storage coefficient; hence values were obtained from the literature for similar types of sediments, as well as results from previous studies **(PWA/USAID, CAMP 2000).** Specific yield values are estimated to be about 15–30 percent while specific storage is about 10^{-4} m^{-1} from tests conducted in Gaza **(Qahman & Larabi, 2005).**

The estimated range for the transport equation parameters, i.e., the longitudinal and vertical transverse dispersivities, is obtained from published data in the literature **(EC, 2000)**. In addition, all parameter values were adjusted during the model calibration in order to make the model adequately reflected the observed water level distribution and interpreted flow patterns throughout the aquifer.

5. Internal hydrologic stresses

The internal hydrologic stresses used in the simulation process are presented with boundary conditions in the model domain. These internal hydrologic stresses include: recharge from rainfall, lateral flow, and municipal and agricultural withdrawals.

I. Recharge/Infiltration

The recharge from rainfall replenishes the groundwater aquifer through the infiltration and percolation to the sub surface soil layers. This recharge is specified with a low salt concentration of 0.085 kg/m^3 **(Qahman, 2004).** A Neumann-influx boundary condition was assigned at the land surface. The recharge to the aquifer varied spatially due to the difference in soil type, land use, relief and topography and temporally depending on the amount of rainfall. The recharge is generally estimated from the rainfall (figure 3.7) based upon the recharge coefficient according to the soil types and the area of such soil.

The average water flux was estimated for each soil type as shown in figure 3.10. This estimation of infiltration is based on the long term annual average of rainfall data available for the period 1998 till 2007 as shown in table 5.2. The infiltration of rainfall for different types of soil in the area is estimated using the following equation **(Widagda & Jagranatha, 2005):**

$$R = P_A \times A \times C$$

Where:

R = mean annual groundwater recharge (m^3/year)

A = surface area of recharge zone (km^2)

P_A = mean annual precipitation recharge zone (mm/year)

c = recharge coefficient for the area (%).

Table (5.2): Estimation of Infiltration quantity for (Period 1998 – 2007).

Stations	Soil types	Area (km^2)	Average annual Rainfall (mm/year)	Average annual ET (mm/year)	Net average annual rainfall (mm/year)	Recharge coefficient* (%)	mean annual recharge (m^3/yr) $*10^3$
(1)	(2)	(3)	(4)	(5)	(6) =(4-5)	(7)	(8)=(6*7)
Study Area (Gaza South)	Dark brown / reddish brown	0.41	450.47	143.85	306.62	0.025	3.14
	Sandy regosols	2.19	450.47	143.85	306.62	0.7	470.05
	Sandy loess soil	1.40	450.47	143.85	306.62	0.3	128.79
Sum		4.0					601.98

*** (PWA, 2008)**

II. The groundwater lateral flow

The lateral flow of from the inland perimeter of the model was calculated from the available water level contour maps of 2007 by using the Darcy's low to be 3,560 m^3/day. Taking into consideration that the hydraulic conductivity as 35m/day and the aquifer thickness as 105m. The value of lateral flow was adjusted during the model run and calibration. The boundary conditions were established to represent as closely as possible the conceptual model of the flow system.

III. Municipal and agricultural well fields

According to the collected data, there are around 16 pumping wells in the model domain used for different purposes: municipal and agricultural, as represented in figure 5.5.

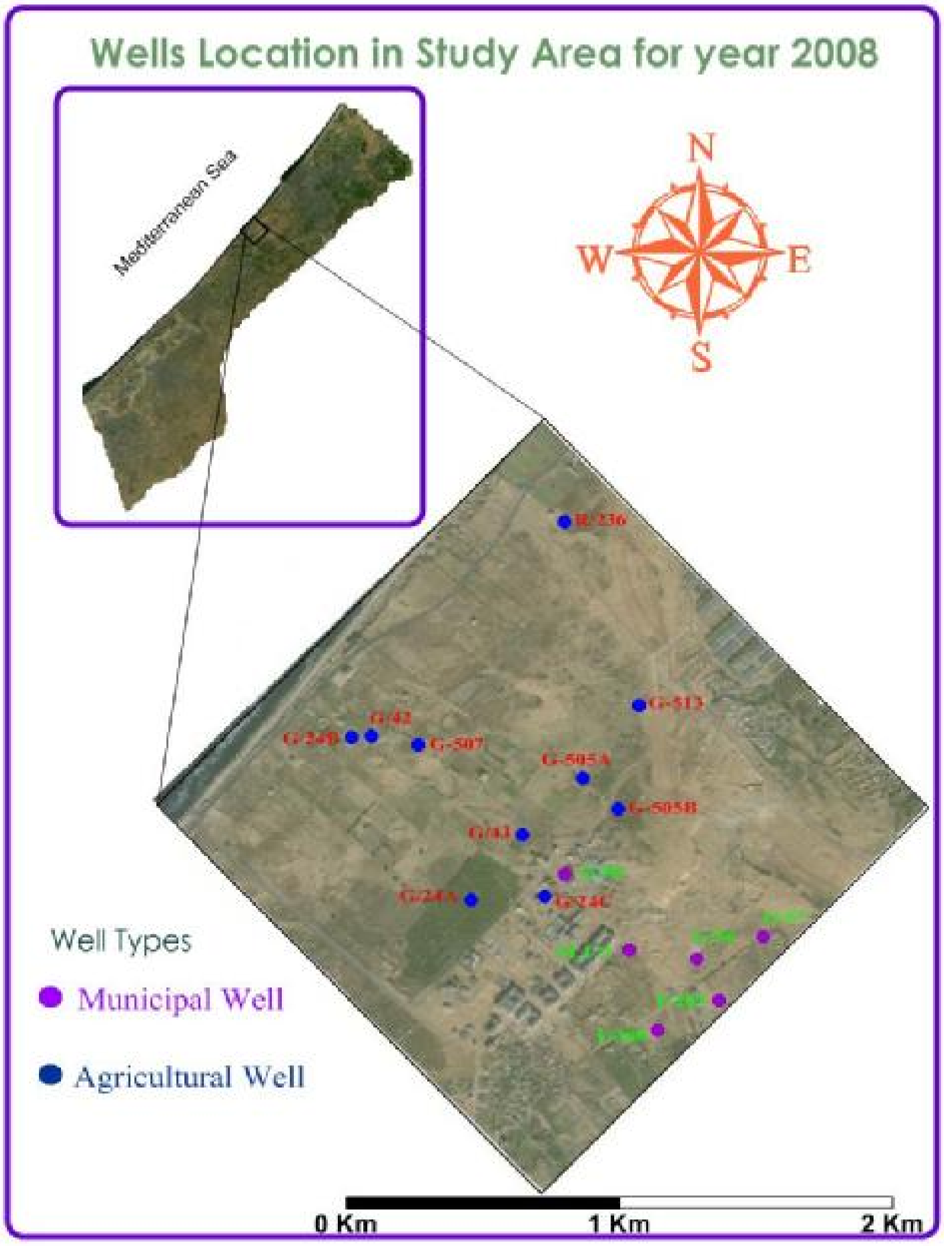

Figure (5.5): Wells type and location in study area

The groundwater abstraction rate from these wells is illustrated in table 5.3. This estimated rate was done according to the field survey i.e. questionnaire applied in the model domain in year 2008. Figure 5.6 represents the wells discretization in the model domain.

6. Initial conditions

A steady state simulation was performed for year 2008 hydrologic conditions. The results (water level and concentrations) from the steady state simulation were used as initial conditions for transient simulation **(Qahman & Larabi, 2005).**

Table (5.3): The wells location, average annual production and type in study area

WELL_ID	X_GPS	Y_GPS	Avg. PRO (m^3/Yr)	Q (m^3/Hr)	Type
F/208	93493	97839	151,200	60	Municipal
G/56	93640	98098	108,000	50	Municipal
G/57	93880	98181	108,000	50	Municipal
G/50	93154	98411	144,000	50	Municipal
F/203	93720	97945	463,680	92	Municipal
Mid.171	93392	98133	172,800	60	Municipal
G/24A	92814	98316	100,800	50	Agriculture
G/24B	92377	98909	72,000	50	Agriculture
G/24C	93082	98327	161,280	80	Agriculture
G/42	92448	98910	18,360	45	Agriculture
G/43	92999	98553	24,480	60	Agriculture
G-505-A	93220	98760	54,000	60	Agriculture
G-505-B	93350	98649	69,120	60	Agriculture
G-507	92618	98881	25,920	45	Agriculture
G-513	93429	99023	43,200	50	Agriculture
R/236	93213	99822	113,400	45	Agriculture
	Total		**1,830,240**		

(PWA 2008 , Questionnaire –Appendix I)

7. Calibration and verification

Model calibration is an essential process needed to assure that the simulation outputs are close to real observations **(Hammouri & El-Naq, 2007).** Once a model was developed and simulated for the initial parameter estimation, it was calibrated and verified using the same hydrogeological parameters of the calibrated model run by **Qahman (2005).**

5.3 Optimization model

Aquifer management models that combine simulation with optimization help in understanding how social and economic forces interact with the water resource allocation. Just as a simulation model is a tool to understand the physical/chemical behavior of an aquifer system, a management model can be thought of as a tool, which provides insight into the economic and social consequences of institutional changes **(Ndambukiet al., 2000).**

In this case study, the 3D coupled flow and transport simulation model (CODESA 3D) which used to simulate the density dependent flow and transport processes in the coastal aquifer is linked with a based management model externally using the Genetic Algorithm (GA). Because, this approach is powerful when there are a large number of state variables; a small number of control variables; and complex physics need to be modeled. Moreover, this linked simulation optimization approach is used to obtain an optimal aquifer management that supports the decision making process and alleviates of the seawater intrusion problem. Thus the optimal pumping strategy for the available wells in the study area could be adopted based on two conflicting objectives considered are: (i) the total withdrawal from the entire region should satisfy all the purposes (i.e. demotic, municipal, and agricultural, etc.); and (ii) the concentration of a conservative pollutant (chloride) occurring in the groundwater should be within the acceptable ranges (below 500 g/l) as stated by PWA (**PWA, 2003**).

5.3.1 Optimization Algorithm

Most real world optimization problems involve complexities like discrete, continuous or mixed variables, multiple conflicting objectives, non-linearity, discontinuity and non-convex region. The most popular technique which makes use of EA approach is Genetic Algorithms (GA) which operates mainly on a population search basis **(Deb, 2002).**

1. Genetic Algorithm as optimization technique

The GAs are recognized as powerful search algorithms and offer nice alternative to conventional optimization technique. They are based on the mechanics of natural selection and natural genetics (Goldberg, 1989). A genetic algorithm allows a population composed of many individuals to evolve under specified selection rules to a state that maximizes the ”fitness’’ (i.e. minimizes/maximize the objective function). The method was developed by J. Holland (1975) and finally popularized by one of his students, David Goldberg (1989) **(Benhachmi et al., 2001).**

2. My Genetic Algorithm

This study performs a combination of groundwater simulation models with GAs, search algorithms based on the mechanics of natural selection, to help search for optimal (or, at least near optimal) groundwater system designs.

In this study, the version (1.7a) of the GA, known as D.L. Carroll's FORTRAN Genetic Algorithm Driver (Carroll, 2001) is used. This program is a FORTRAN version of a genetic algorithm driver **(Qahman, 2004).**

It is to be known that before using a genetic algorithm to solve any problem, a way must be found of encoding any potential solution to the problem. Encoding is a process of representing individual genes. The process can be performed using bits, numbers, trees, arrays, lists or any other objects. For example, one can encode directly real or integer numbers **(Sivanandam & Deepa, 2008).**

I. Binary Encoding

The most common way of encoding is a binary string **(Sivanandam & Deepa, 2008),** which is the only option with D.L. Carroll's FORTRAN Genetic Algorithm Driver

(Carroll, 1996). Each chromosome encodes a binary (bit) string. Each bit in the string can represent some characteristics of the solution. Every bit string, therefore, is a solution but not necessarily the best solution. Another possibility is that the whole string can represent a number. The way bit strings can code, differs from problem to problem. Binary coded strings with 1s and 0s are mostly used. Binary encoding would be represented as in figure 5.6 **(Sivanandam & Deepa, 2008).**

Chromosome 1	1101100100110110
Chromosome 2	1101111000011110

Figure (5.6): binary Encoding

In the binary representation of the simple genetic algorithm, the design variables (M, number of wells) are represented in a binary form. The length of the design variables depend on the required precision (n_i i.e. the number of digits after the decimal point). Each design variable (x_i) belongs to an interval $[a_i, b_i]$. As the length of the string bits (l_i) depends on the accuracy, it could be computed if the equation (1)

$$[(b_i - b_i) \times 10^{n_i} \leq 2^{l_i} - 1] \text{ is satisfied for } (l_i) \qquad (1)$$

Where:
a_i = minimum pumping rates = 0
b_i= maximum pumping rates = (safe yield (m^3/sec) / no. of wells)

The length of the individual (i.e. maximum no. of chromosomes) which represent the entire design variable is equal to $(l) = \sum_{i=1}^{M} l_i$ **(Alvarez, 2002).**

In this optimization model, the design variables = no. of wells = 16. The number of digits after the decimal point was taken (n_i) as 4 digits. The length of the string bits (chromosome) per the individual was estimated according to equation (2) to be 6. Therefore, the length of the individual (maximum no. of chromosomes) = 6 x 16 =96.

II. Population Size

Ideally, the population size (npopsize) should be large enough to guarantee adequate genetic diversity yet small enough for efficient processing. In particular, the number of cost-function evaluations is proportional to the population size. Equation 2 corresponds to Goldberg's criterion (Goldberg, 1989b) of increasing the population size exponentially with the increase in the number of model parameters (for binary encoding).

$$npopsize = order\,[(l/k)(2^k)] \qquad (2)$$

Where:
l = the number of bits in the chromosome and,
k = the order of the schemata of interest (effectively the average number of bits per parameter, i.e. approximately equal to (no. of chromosomes /no. of parameters), rounded to the nearest integer).

This criterion, however, may result in populations too large when the number of model parameters and so the length of the chromosome is large. Moreover, when the uniform crossover and niching are turned on (which are recommended to be adopted), this scaling law is usually overkill, i.e. it is most likely to reduce the population size at least twice as small. This large population, however, may require many cost-function evaluations and a lot of memory. Most applications reported in the literature use population sizes between 50 and 200 **(Alvarez, 2002).** While Carroll (1996) recommended using population size of 5 when the micro Genetic algorithm is adopted**.**

In this optimization model, the micro GA was adopted. The population size was set as 5 while the maximum number of individuals (i.e. max. population size) was estimated according to equation (2) to be 1000. Based upon the Carroll (1996) recommendations, the uniform crossover and niching were taken into account, therefore the max. # of individuals was divided by 5 times to be 200.

In order to carry out the S/O model, around 1000 iterations i.e. [(max. # of individuals = 200) x (the population size 50)]. The total CPU time required to carry out the simulation problem was 1000 x 22 sec. = 22000 sec. (6.11 hr) for one year transient state condition as for each GA iteration evaluated the state variables with the simulation model CODESA -3D. Running 10 Configuration/scenarios of different recharging options took 61.1 hrs (2.55 days) of CPU time.

III. Breeding

The breeding process is the heart of the genetic algorithm. It is, in this process, the search process that creates new and hopefully fitter individuals. The breeding cycle consists of three steps:

a. Selecting parents.
b. Crossing the parents to create new individuals (offspring or children).
c. Replacing old individuals in the population with the new ones **(Sivanandam & Deepa, 2008).**

The success and performance of GAs are dependent on several parameters: population size, number of generations, and the probabilities of crossover and mutation. Goldberg, (1989) suggested that good GA performance requires the choice of high-crossover and low-mutation probabilities and a moderate population size **(Krishnamurthy, 2003).**

A. <u>Selection</u>

Selection is the process of choosing two parents from the population for crossing as shown in figure 5.7. After deciding on an encoding, the next step is to decide how to perform selection, i.e. how to choose individuals in the population that will create offspring for the next generation and how many offspring each will create. The purpose of selection is to emphasize fitter individuals in the population in hopes that their off springs have higher fitness. Chromosomes are selected from the initial population to be parents for reproduction. The problem is how to select these chromosomes. According to Darwin's theory of evolution the best ones survive to create new offspring.

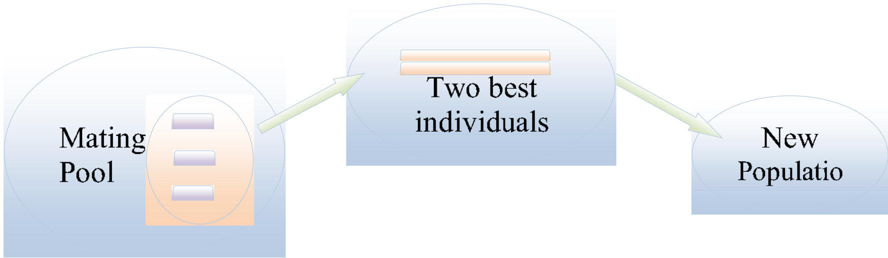

Figure (5.7): the basic selection process.

Selection is a method that randomly picks chromosomes out of the population according to their evaluation function. The higher the fitness function, the more chance an individual has to be selected. The selection pressure is defined as the degree to which the better individuals are favored. The higher the selection pressured, the more the better individuals are favored **(Sivanandam & Deepa, 2008).**

There are many methods how to select the best chromosomes, for example roulette wheel selection, Boltzman selection, tournament selection, rank selection, steady state selection and some others **(Deb, 2002).** Tournament selection is the only option with D.L. Carroll's FORTRAN Genetic Algorithm Driver **(Carroll, 1996).** Tournament selection, proposed by (Wetzel 1983) and studied by (Brindle, 1981), is one of the most popular and effective selection schemes **(Weise et al., 2008).** Moreover, it is an important mechanism for GAs. It is simple to code; easy to implement; robust in the presence of noise; and has adjustable pressure **(Sivanandam & Deepa, 2008).**

B. Crossover (Recombination)

Crossover is the process of taking two parent solutions and producing from them a child. After the selection (reproduction) process, the population is enriched with better individuals. Reproduction makes clones of good strings but does not create new ones. Crossover operator is applied to the mating pool with the hope that it creates a better offspring **(Sivanandam & Deepa, 2008).** The Type and implementation of crossover operators depends on encoding and also on a problem **(Obitko, 1998).**

That is, the simplest way how to do that is to choose randomly some crossover point and copy everything before this point from the first parent and then copy everything after the crossover point from the other parent as shown in figure 5.8 Crossover can then look like this (| is the crossover point) **(Sivanandam & Deepa, 2008)**:

Chromosome 1	11011 | 00100110110
Chromosome 2	11011 | 11000011110
Offspring 1	11011 | 11000011110
Offspring 2	11011 | 00100110110

Figure (5.8): Crossover (Recombination)

There are other ways how to make crossover, for example we can choose more crossover points. Crossover can be rather complicated and very depends on encoding of the chromosomes. Specific crossover made for a specific problem can improve performance of the genetic algorithm. There are many ways how to do crossover such as: Single/One-point crossover, two-point crossover, Tree crossover, uniform crossover, and Arithmetic crossover **(Obitko, 1998).** In D.L. Carroll's FORTRAN Genetic Algorithm Driver, the GA routine includes binary coding for the individuals, and the option for single-point or uniform crossover, while the uniform crossover is recommended by Carroll (1996) and being used in this study.

In the uniform crossover, each gene of the offspring is selected randomly from the corresponding genes of the parents. Unlike One-point and two-point crossover produce two offspring, whilst uniform crossover produces only one. Figure 5.9 shows the uniform crossover. **(Obitko, 1998)**

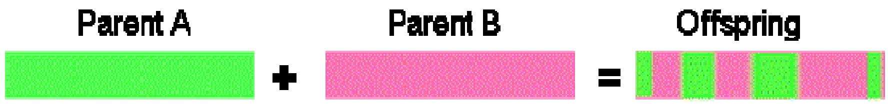

Figure (5.9): uniform crossover

Uniform crossover is probably the most wildly used crossover operator because of its efficiency in not only identifying, inheriting and protecting common genes, but also re-combining non-common genes. The uniform crossover is obviously much more powerful than the one position split crossover in terms of exploiting all possibilities of recombining non-common genes **(Hu & Di Paolo, 2007).** Moreover, there is another sense in which uniform crossover is unbiased **(Whitley, 1994).**

The basic parameter in crossover technique is the crossover probability. It is recommended to have a value of 0.5 once using the uniform crossover in D.L. Carroll's FORTRAN Genetic Algorithm Driver **(Carroll, 1996).** Crossover probability is a parameter to describe how often crossover will be performed. If crossover probability is 100%, then all offspring are made by crossover. If it is 0%, whole new generations are made from exact copies of chromosomes from old population, but this does not mean that the new generation is the same. **(Sivanandam & Deepa, 2008).**

C. Mutation

After crossover, the strings are subjected to mutation. Mutation plays the role of recovering the lost genetic materials as well as for randomly disturbing genetic information. Mutation changes randomly the new offspring. It is an insurance policy against the irreversible loss of genetic material. Mutation has traditionally considered as a simple search operator. Mutation helps escape from local minima’s trap and maintains diversity in the population **(Sivanandam & Deepa, 2008).**

For binary encoding, a few randomly chosen bits could be switched from 1 to 0 or from 0 to 1. Mutation can then be as shown in figure 5.10 **(Obitko, 1998).**

Original offspring 1	1101111000011110
Original offspring 2	1101100100110110
Mutated offspring 1	1100111000011110
Mutated offspring 2	1101101100110110

Figure: (5.10): mutation

There are many different forms of mutation for the different kinds of representation. For binary representation, there are two types of mutation operators the standard jump mutation that acts on the chromosome, sometimes called genotype and creep mutations that act on the decoded individual, sometimes called henotype. In any case, the mutation probabilities are expected to be low, which is usually taken about 1/L, where L is the length of the chromosome, since high values may cause strong disruption and may reduce the diversity in the population and makes the algorithm converge toward some local optima **(Sivanandam & Deepa, 2008).**

In D.L. Carroll's FORTRAN Genetic Algorithm Driver, the GA routine includes binary coding for the individuals jump mutation, and creep mutation **(Carroll, 1996).** The important parameter in the mutation technique is the mutation probability. The mutation probability decides how often parts of chromosome will be mutated. If mutation probability is 100%, whole chromosome is changed, if it is 0%, nothing is changed. Mutation generally prevents the GA from falling into local extremes. Mutation should not occur very often, because then GA will in fact change to random search **(Sivanandam & Deepa, 2008).**

The same number of creep mutations and jump mutations per generation could be used. However, (Carroll, 2001) recommended to use jump mutation probability equal to (1/no. of population size) (large populations have larger genetic diversity and so less need for jump mutation) and creep mutation probability equal to the number of bits per model parameter times the jump mutation rate **(Alvarez, 2002).**

IV. The GA process summary

The GAs used in existing simulations can be described by the following steps:

1. An initial population of ‘’strings’’ which represent realizations of the set of decision variables, is randomly generated. A binary encoding is used, in which each string has values of 0s and 1s for their alleles (the values at particular locations on the string).
2. The ‘’fitness’’ of search string in the population is evaluated, based on the objective function and constraints. The strings are then mapped to a ranking fitness value in which the strings are sorted linearly by order of decreasing evaluation value. Selection of the strings that continue onto the mating pool is done by Tournament selection method.
3. The strings selected are then randomly assigned a mating partner from within the mating pool, and the random crossover locations on the strings pairs are determined. Mating between two strings occurs with the probability (P_{cross}). If the strings pairs were determined to mate, a uniform crossover then occurs in which information is exchanged between two parent strings as the crossover locations.
   This results in the formation of children strings. The population size remains constant through the generations, or iterations, by replacing the parent strings with the new children strings. If no crossover between parent strings takes place, then these strings are copied to new population.
4. To prevent premature convergence to local optima, some alleles on the strings are randomly muted so that allele values of 0 are changed to 1 and vice versa. This occurs with the probability (P_{mut}).

5. This process of selection, crossover, and mutation (Steps 2-4) is repeated for many generations until a stopping criterion is met. As the maximum value of the fitness value is not known only a maximum number of iterations are specified to stop the process and the best strings within these iterations can be selected as the optimum solution of the problem.

For most real-world problems, these pseudo-optimal solutions are still much better than using less robust methods **(Benhachmi et al., 2001).** The GA must have some control parameters such as population size (n) which usually rangers from 20 to 100 while in this study n = 5 as recommended for the micro GA; the probabilities for applying genetic operators, e.g. crossover probability (P_{cross}) usually ranges from 0.7 to 1 while, in this study (P_{cross}) = 0.5 as suggested for uniform crossover; and creep mutation probability (P_{mut}) is usually from 0.01 to 0.05, while for this study (P_{mut}) = 0.0234. Moreover, Dejong (1975) originally suggested that a jump mutation probability inversely proportional to the population size would be enough to prevent the search from locking onto a local optimum **(Krishnamurthy, 2003),** therefore it typically equals (1/200) = 0.005 in this study.

5.3.2 Optimization models Application

1. Considerations for optimization model setup

a. Setting up the optimization model, the optimization model should honor the total water balance.
b. The model should take account of the current water table, which is shallow, and consider that the extensive withdrawal from the coastal aquifer is the most significant component of the seawater intrusion and the groundwater imbalance. The optimization model, therefore, aims to raise the water table by managing the groundwater pumping, under various hydrological constraints which may include the volume of water extracted, the quality of water produced, the profit from selling the water, the cost of producing, treating, storing, and conveying the water, the operational restrictions, the environmental and social–economic costs, the conjunctive use of surface and subsurface water, etc. **(Qahman et al., 2005).** Thus the seawater intrusion in the coastal aquifer could be reduced.
c. The model should also consider the real demand among the available groundwater for the various purposes: municipal, irrigation, and domestic. Therefore, the groundwater development strategies should also reflect this actual groundwater demand for these different purposes.
d. Precipitation is the primary source of natural groundwater recharge besides the lateral flow to the coastal aquifer.
e. The artificial recharge to the groundwater is considered as a feasible alternative source to raising the current water table and thus to reduce the seawater intrusion in the study area. The proper location and quantity of accepted water quality to recharge the groundwater artificially, i.e. stormwater and treated wastewater, were determined. In searching for the optimal groundwater pumping strategy, one assumes that the combined use of groundwater and artificially recharged water will meet the current and future water demand.
f. Management of seawater intrusion is a multi objective decision problem. The most rigorous modeling approaches for the seawater intrusion phenomena are the density-dependent flow and transport techniques. The problem is

formulated as a multi objective optimization problem consisting of two objectives such as maximization of pumping and minimization of the maximum salt concentration at specified observation points considering the constraints on water levels and concentration **(Mohan & Pramada, 2005).**

The threat of groundwater contamination by the seawater intrusion in the coastal aquifers as a direct result of the overexploitation of the groundwater encourages the in deep search for the possible optimum alternative sources such as the groundwater artificial recharge either by the stormwater or the treated wastewater , and yet artificially recharged water is still a much less costly option than other alternatives such as the seawater desalination; therefore, the formulation of the optimization can go in two objectives to maximize the amount of groundwater pumping within hydrological and hydrogeological constraints, so that as required artificially recharged water as possible is used to meet the local water demand with keeping the chloride concentration as minimum as recommended by the WHO, i.e. 250 mg/l.

In the following sections, two optimization models are formulated, which search for optimal groundwater development strategies for both scenarios.

2. Optimization model formulation

The coastal aquifer management model is developed for sustainable water withdrawal from the aquifer for beneficial uses **(Benhachmi et al., 2001).**Therefore, coastal aquifer management for sustainable beneficial uses may require consideration of conflict multiple objectives **(Das & Datta, 1999).** Due to application of spatially distributed pumping strategy, the seawater intrusion takes place, and the salinity of the pumped water varies with the magnitude and location of pumping in the three-dimensional space domain of the aquifer **(Benhachmi et al., 2001; Qahman, 2004).**

The management model objective is to obtain an optimal pumping policy by maximizing the net benefit, subject to constraints of no intrusion of saltwater front to the wells, and pumping capacity limits restrictions. The solution of the model determines the optimal sustainable spatial distribution of the pumping for beneficial uses from a specified set of potential locations, both the discharge wells and the artificial groundwater recharge basin, while trying to minimize the saltwater intrusion contamination as possible.

Two nonlinear optimization models are formulated to demonstrate the development of coastal aquifer management models for sustainable beneficial use. The models as formulated here do not explicitly incorporate economic values. However, decision variables such as the quantity of withdrawal, artificially recharged water to sub aquifer, and the associated salinities can be easily conceived as surrogate economic variables. Explicit consideration of economic values requires the definition of cost and benefit functions. This aspect is not included in these models.

Application of this model is illustrated for an existing case three-dimensional coastal aquifer system in the northern west of Wadi Gaza. These models are solved for transient state of one year time period.

I. Management model 1

The first multiple- (two-) objective management model is developed for maximizing sustainable water withdrawal from the aquifer for beneficial uses and for controlling the salinity of the water withdrawn simultaneously. Multiple, often conflicting objectives arise naturally in most real-world optimization scenarios **(Mohan & Pramada, 2005).** Management of coastal aquifers for beneficial uses often requires consideration of multiple objectives. **(Qahman, 2004)**

This optimization model has two conflicting objectives. The first objective is to maximize the total water withdrawal for beneficial uses from specified existing wells locations within the aquifer region under a transient state flow. The second objective seeks to minimize the salinity concentration in order to control seawater intrusions. No alternative options/scenarios have been taken into account; therefore, the model solution has determined the optimal spatial distribution of pumping for both beneficial uses and seawater intrusion control from the existing wells only in the study area.

The general mathematical expression of these two objective functions of this model can be written as:

i. to maximize the total withdrawal (Z) from the aquifer:

$$Max\ Z = \sum_{i=1}^{n} Q_i \tag{1}$$

ii. to minimize the salinity of the water withdrawn (Z) from the aquifer:

$$Min\ Z = \sum_{i=1}^{n} Q_i\ C_i \tag{2}$$

Where:

Q_i = the discharge at well Q_i and n is the total number of pumping wells in the coastal aquifer.

The objective functions were subject to some constraints: First, the discharge of each well should stay within the specified limits; the aquifer safe yield (S) divided by the number of pumping wells ($Q_{min} = \text{zero}$) for the upper limit and no pumping ($Q_{min} = \text{zero}$) for the lower limit. This can be written as:

$$Q_{min} \leq Q_i \leq Q_{max} \tag{3}$$

Second constraint, the salinity of the pumped water (C_i) at the pumping well must not exceed a specified salinity level (C_{max}) defined as;

$$C_i \leq C_{max} \tag{4}$$

As common, in the pumping management problem, the design variables are the pumping rates. These rates to be optimized are encoded as binary string within the well capacity constraints. Each population contains strings to represent all design variables. GAs are ideally suited for unconstrained optimization problems. The present problem is a constrained one, i.e. two objective functions and constrains illustrated in (1), (2), (3) and (4). Therefore, converting this problem to an unconstrained one is a must. **(Benhachmi et al., 2001; Krishnamurthy, 2003).**

To do this extension, according to **Qahman (2004, cited in park and Aral,2004),** the weighed sum method is used to incorporate early mentioned objective functions (1) and (2) in a single scalar objective function. However, adjusting the weight of each objective, which finally treated to be a managerial decision, is difficult to be handled. In addition, the generation of objective function in a single scalar function is not capable of representing the vector tendency of each objective. Nevertheless, for the simplicity, the single scalar objective function approach is used here. This approach was used by many researchers as Gordon (2001), Park and Aral (2004), and Qahman (2004). **(Qahman,2004).**

Equations (1) and (2) are then modified to accommodate constraints (3) and (4). The final unconstrained model is presented as follows:

$$\text{Max } Z = P_1 \sum_{i=1}^{n} Q_i - P_2 \sum_{i=1}^{n} Q_i C_i \qquad (5)$$

Where:

P_1 and P_2 are the objective function weighting parameters. The constraint in equation (2) is automatically satisfied by definition of population space in GA.

Adopting the feasible salinity weighing parameter P_2 was required to run the final management model. To do this extension, the model was run eight times with different values for the salinity parameter P_2 while the pumping weighing parameter P_1=1 was kept constant for all runs.

Table 5.4 represents the optimal results of total pumping and total salt mass extracted corresponding to different salinity weighting P_2 values. Using these results, a trade-off between the total withdrawal and salinity was made. The feasible and unfeasible zones for the P_2 were determined as shown in figure 5.11.

Table (5.4): Optimal results of total pumping and total salt mass extracted corresponding to different parameter P_2

Pt (1)	Weighing Parameter (P_2) (2)	Total Pumping (m^3/s) (3)	Total Pumping (m^3/d) (4)	Total salt mass extracted (normalized/s) (5)	Weighted salt mass extracted (normalized/s) (6)=(5)/(2)	Total salt mass extracted (kg/d) (7)=(6)*(3) *2.16E+6	% of total pumping to Safe yield (S) (8)
1	1	0.05964	5152.526	0.13913	0.13913	17921.97	94.36%
2	3	0.05937	5129.511	0.13913	0.04638	17841.91	93.94%
3	5	0.05919	5114.168	0.13848	0.02770	17705.56	93.66%
4	10	0.05875	5075.810	0.13679	0.01368	17358.34	92.96%
5	25	0.05745	4963.584	0.13473	0.00539	16718.65	90.90%
6	50	0.05449	4707.887	0.13455	0.00269	15835.65	86.22%
7	100	0.05035	4350.234	0.13351	0.00134	14519.96	79.67%
8	200	0.04579	3956.461	0.13226	0.00066	13081.95	72.46%

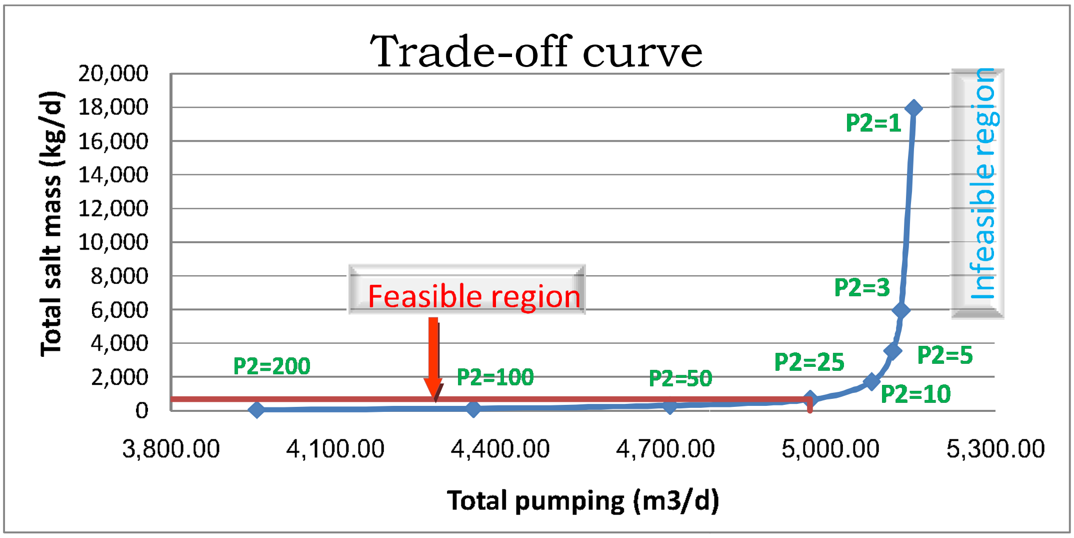

Figure (5.11): Trade-off curve between optimal results of total pumping and total salt mass extracted

Referring to table 5.4 and figure 5.11; increasing the pumping normally leaded to increase the salinity and vice versa. In addition, increasing the salinity weighing parameter P_2 from 1 to 200 reduced the total salt mass extracted which leaded to reduce the pumping.

Considering high weights to the salinity corresponding to pumping, the salinity weighing parameter P_2 was set equal to the withdrawal one $P_1 = 1$. The model allowed high water quantity to be pumped from aquifer. However, according to the pumping constraint, the allowed pumped quantity never exceeded the safe yield. The percent of the total pumping by the model to the safe yield reached its maximum value of 94.36%.

Setting up the salinity weights lesser than that of the withdrawal by 200 times, P_2 value was increased from 1 to 200. Reduction in the salinity weights reduced the total abstracted water. The percent of total allowed water quantity to be pumped by model to the natural safe yield reduced from 94.36% to 72.46%.

In fact, the most cost effective and most feasible salinity weight is the point which represents high pumping quantities with reasonable salinity. From point 1 to 5, where the salinity had high weights corresponding to the withdrawals, there were small reduction in total withdrawal about (3.81%) resulted in reduction of the total weighted salinity by a factor of (25.82). While, from point 5 to 8, where the total weighted salinity was reduced by small amount (factor 4.04), however, the reduction in total pumping was so high (25.46%).

Therefore, the most feasible value for the salinity weight was by setting up its weighing parameter $P_2 = 25$ as the maximum pumping was ensured and the salinity was still within the reasonable limits.

II. Management model 2

The second multiple- (two-) objective management model is similar to that of model 1 with some modification by taking into consideration the artificial recharge as new alternative source, i.e. for maximizing sustainable water withdrawal from the aquifer for beneficial uses and simultaneously controlling the salinity of the water withdrawn by adding new quantities to the aquifer artificially besides the natural ones.

The first objective is to maximize the total water withdrawal for beneficial uses from the existing wells whereas the artificial recharge to the groundwater as an alternative resource was considered in the simulation model. While the second objective seeks to minimize the salinity concentration in order to control seawater intrusions.

The model solution has determined the optimal spatial distribution of the pumping for both beneficial uses and seawater intrusion control from existing wells besides the proposed artificially recharged facility in the study area.

Through the model, (9) nine configurations for the artificial recharge were generated to assess the most effective and less expensive strategy for artificially groundwater recharging. Three different locations for the recharging basin were proposed with three different quantities 0.5, 1.0, and 1.5 MCM/yr injected through each location separately. In each location, the injected quantities were added to the total safe yield in order to get benefit of these quantities. In addition, the model was allowed to pump the total natural and artificial recharged quantity.

The general mathematical expression of these two objective functions of this model were similar to that in the first management model; in addition these objective functions were subject to the same constraints of management model 1.

5.4 SUMMARY

5.4.1 Simulation Model Summery

Gaza coastal aquifer is one of many coastal aquifers susceptible to the deterioration by the seawater intrusion due to the extensive uncontrolled pumping and limitation of renewable water resources naturally. Therefore, searching for new coast effective and socio-economic resources/alternatives could partially solve this significant crisis. To this extension, the artificial recharge was adopted on a small area in Gaza strip. Three locations for the recharging basin were proposed at the study area. These locations were injected separately with three different quantities of water 0.5, 1.0, & 1.5 MCM/yr respectively. The main purpose for generating and simulating these nine configurations is to come up with the most feasible location for recharging with the most cost effective quantity.

The simulation model, therefore, using CODESA-3D code was applied. The model domain was adequately discretized using Argus One, pre and post processor computer software based on the finite element method. The 3D mesh of the aquifer system was built from the layer-by-layer replication of a 2D triangulation made of 3160 tetrahedral and 1637 nodes. In this model, three zones were considered according to the soil map of the study area. The model was discretized vertically into 8 layers of different thickness based on the available borehole details. The layers are approximately horizontal, with a small inclination towards the sea.

A Neumann-type of no-flux boundary conditions was assigned to the bottom of the aquifer (aquiclude); while the top of the aquifer was considered as a recharge boundary by the direct infiltration. Although the exact position of this boundary is not known due to the scarcity and uncertainty of data, zero flux boundary conditions were imposed on part of the northern and southern domain boundaries. A Dirichlet-type of boundary condition was assigned to the residual parts of the left and right boundaries besides the remaining part in the northern side i.e. the flow in which was allowed.

In the simulation model, the study area aquifer is considered as unconfined, heterogeneous and an anisotropy. The aquifer parameters were assigned based on the hydrogeological investigation, i.e. the pumping tests in the Gaza Strip, previous modeling studies by Israeli organizations in the coastal plain and related literatures. The internal hydrologic stresses used in the simulation process are presented with boundary conditions in the model domain. These Internal hydrologic stresses include: recharge from rainfall, lateral flow, and municipal and agricultural withdrawals.

5.4.2 Optimization Model Summery

Optimization tools are utilized to facilitate optimal decision making in the planning, design and operation of especially large-scale water resources systems. The use of optimization tools for evolving economically efficient management strategies is considered as the most important component of Decision Support Systems that are not confined only to the quantity aspect of water, but also the quality aspects. Aquifer management models that combine simulation with optimization help in understanding how social and economic forces interact with the water resource allocation. One of the most important steps of coupling the simulation and optimization models is the linkage technique between these models and to represent the simulation constraints within the optimization models. Generally, the simulation model can be combined with the management (optimization) model either by using the governing equations as binding constraints in the optimization model (Embedding technique) or by using a response matrix or an external linkage of simulation optimization model.

In this case study, the 3D coupled flow and transport simulation model (CODESA 3D) which used to simulate the density dependent flow and transport processes in the coastal aquifer is linked with a based management model externally using the Genetic Algorithm (GA). Because, this approach is powerful when there are a large number of state variables; a small number of control variables; and complex physics need to be modeled. Moreover, this linked simulation optimization approach is used to obtain an optimal aquifer management that supports the decision making process and alleviates of the seawater intrusion problem. Thus the optimal pumping strategy for the available wells in the study area could be adopted based on two conflicting objectives considered are: (i) the total withdrawal from the entire region should satisfy all the purposes (i.e. demotic, municipal, and agricultural, etc.); and (ii) the concentration of a conservative pollutant (chloride) occurring in the groundwater should be within the acceptable ranges (below 500 g/l) as stated by PWA**.**

In this study, the version (1.7a) of the GA, known as D.L. Carroll's FORTRAN Genetic Algorithm Driver is used. This program is a FORTRAN version of a genetic algorithm driver. It is to be known that before using a genetic algorithm to solve any problem, a way must be found to encode any potential solution to the problem; and to convert the constrained problems i.e. multi objective models into unconstrained ones. Therefore, the weighted sum method is used. In which two weighing parameters for the pumping and salinity were adopted. The pumping weighing parameter was constant and equal one, while the salinity related parameter was changed 8 times with different values. Therefore, the model is generated 8 times. The best salinity weighing parameter was found to be 25 at which the maximum pumping and minimum concentration were satisfied.

Two management models were formulated with similar multi (two) objectives with exception to some differences in the alternative sources adaptation. The first model without any alternatives while the second with the artificial recharge as an alternative source/option.

Chapter 6: SIMULATION AND OPTIMIZATION RESULTS

6.1 INTRODUCTION

The sustainable management of groundwater resources has gained increased attention in recent times, especially in the arid and semi-arid areas. The threat of large-scale unregulated pumping has urged the real attention towards the groundwater management in order to regulate the underlying aquifer resources in an efficient manner.

Artificial recharge of groundwater is one of the important tools towards achieving the sustainability of groundwater reservoir. Artificial recharge also has been practiced for a number of years in many countries and for a wide variety of groundwater resources management purposes (**Zubiller et al., 2002).**

This chapter includes the simulation model results discussion for the existing and predicted scenarios of adopting the artificial recharge techniques. In addition, the simulation/optimization model results which the optimal pumping strategy for both existing and artificial recharge situations. This strategy can protect the groundwater from probable deterioration by seawater intrusion in case of current pumping pattern continued unmanaged.

6.2 SIMULATION RESULTS DISCUSSION

Simulation of the flow and salt mass transport for the study area groundwater aquifer was mainly accomplished to obtain a clear image for the existing situation of the aquifer, besides this, executing management model could help the decision makers to build their decisions to well manage this important source.

6.2.1 Existing Case -No Recharge

Simulation of the study area groundwater aquifer was performed using a 3D groundwater simulation model (CODESA-3D). A transient state of one year time period "2008" and 10 years "2018" was adopted to obtain a neat comparison and to predict the aquifer current status in 2008 and after 10 years more, i.e. 2018 keeping the current pumping pattern as constant. Figure 6.1 represents the hydraulic/potential head in year 2008 and compares it with that in year 2018.

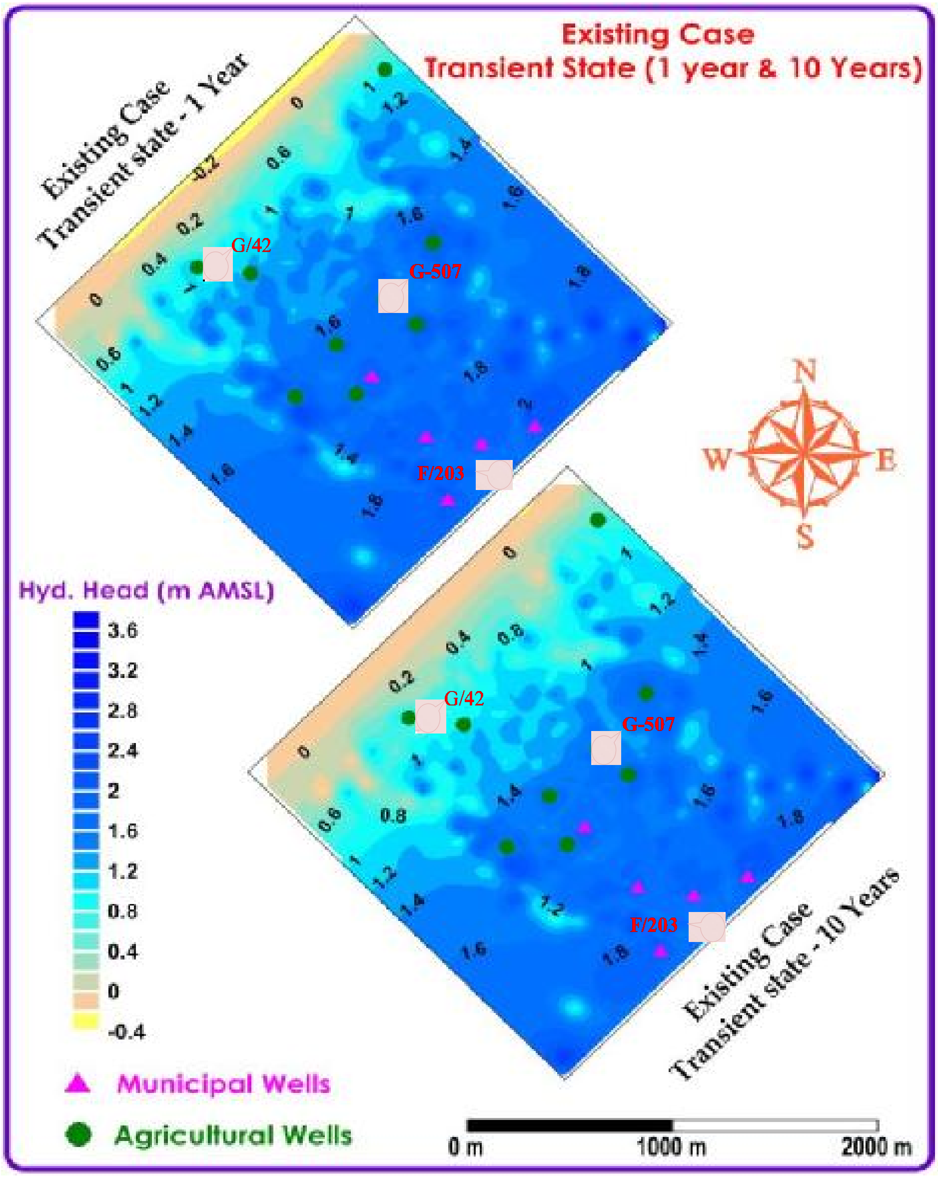

Figure (6.1): the aquifer hydraulic head for existing case in 2008 and 2018

As shown in the above figure, the hydraulic head in year 2008 had lowered significantly in the majority of the study area. Few wells' points that could represent the whole area were selected to compare the head in year 2008 and 2018. In well *F/203*, the head was 0.02 m AMSL in year 2008, this head at the same well had lowered to -0.04 m AMSL after 10 years "2018" of keeping the pumping scenario constant along the whole period, i.e. the head reduced by 323.33 %. The head at well *G-507* also had reduced by fewer amounts as 8.61%. Also, clear drop in the well *G/42* head had occurred i.e. the head lowered by 20.70%. This conclusion leads those two main factors affecting the reduction of hydraulic head: the location of wells near the coast had affected as less natural recharged quantities could reach this area; and the high pumping rates.

6.2.2 Artificial Recharge Case "9 scenarios"

Gaza coastal aquifer is one of many coastal aquifers susceptible to the deterioration by the seawater intrusion due to the extensive uncontrolled pumping. This overexploitation backs to limitation of renewable water resources naturally comparing with the real demand. Therefore, searching for new cost effective and socio-economic resources/alternatives could partially solve this significant crisis. To this extension, the artificial recharge was adopted to fulfill this purpose.

Three locations for the recharging basin were proposed at the study area. These locations were almost at the center of the north south direction. The first location was near the landside boundary; the second was almost at the middle; and the third was away from the coast by 200 m. Three different quantities of water that, either from the stormwater or the reclaimed wastewater, are feasible to be recharged to the aquifer. These quantities were 0.5, 1.0, & 1.5 MCM respectively. Each location was proposed to be injected with the three different pumping scenarios separately, so nine recharging configurations were generated and simulated.

The main purpose for generating these nine configurations is to come up with the most feasible location for recharging with the most cost effective quantity to be recharged.

The obtained results from the simulation model were for the hydraulic/potential head, normalized concentration, and the groundwater pressure for all scenarios. Same quantity was injected through the three locations separately. The achieved results from injecting this constant quantity to these locations were compared among each other in addition to the existing case of no injection with transient state of only one year time period. To do this extension of comparison, each three scenarios of the total nine will be compared together according to the quantity of injected water.

1. First three scenarios of recharging 0.5 MCM/yr artificially

In first three scenarios, each proposed location was recharged with 0.5 MCM/yr once. The gotten results of the potential head, normalized concentration, and groundwater pressure were compared with the no injection case as shown in figure 6.2. From the figure, the head was increased near the recharging basin; in addition, the head increase covered almost all the area.

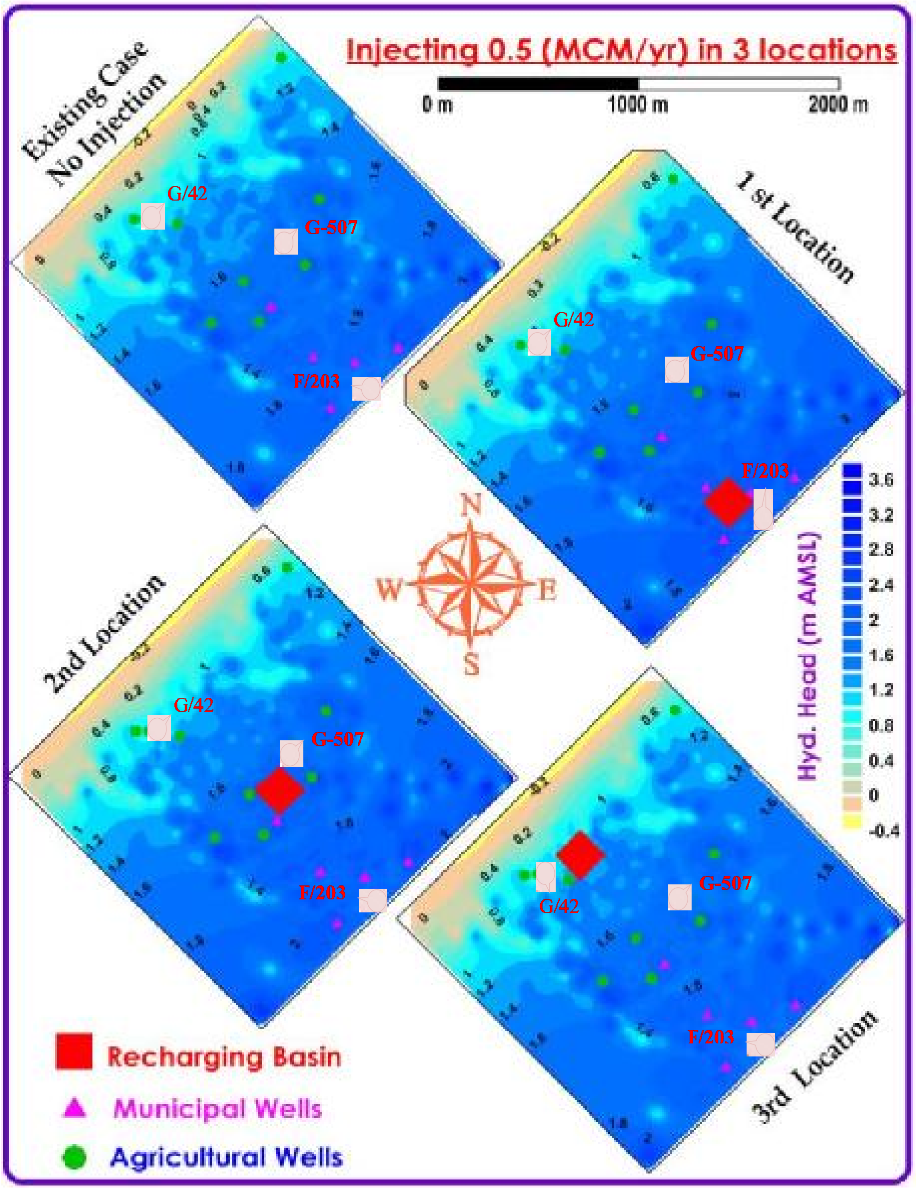

Figure (6.2): hydraulic heads in 3 recharging locations injected with 0.5 MCM/yr

For more details, the hydraulic head increased with different values in the already three wells that were selected to represent the whole area. The head at well F/203 when recharging in the first location "near the landside boundary" increased more than the existing case by 0.27 m (from 0.02 to 0.29 m); it also slightly improved by around 0.1m and 0.03m when recharging in the second and the third locations respectively.

The head at well G-507 have rose by 0.03, 0.04, and 0.04 m when injecting in the first, second, and third location respectively. While at well G/42 about 0.02 was added to the existing case head once injecting in the three locations respectively. The head increment was almost constant.

The significant increment in the head values in well F/203 could be due to the high pumping quantities and the closeness to the injection location, while almost constant head at wells G-507 and G/42 could be resulted from the less pumped quantities and the screen depths in addition to the aquifer strata inclination.

Figure 6.3 shows the hydraulic head at every well in the study area and compares the head of the existing situation with that once the location of the recharging basin was changed and injected by constant quantity of 0.5 MCM/yr.

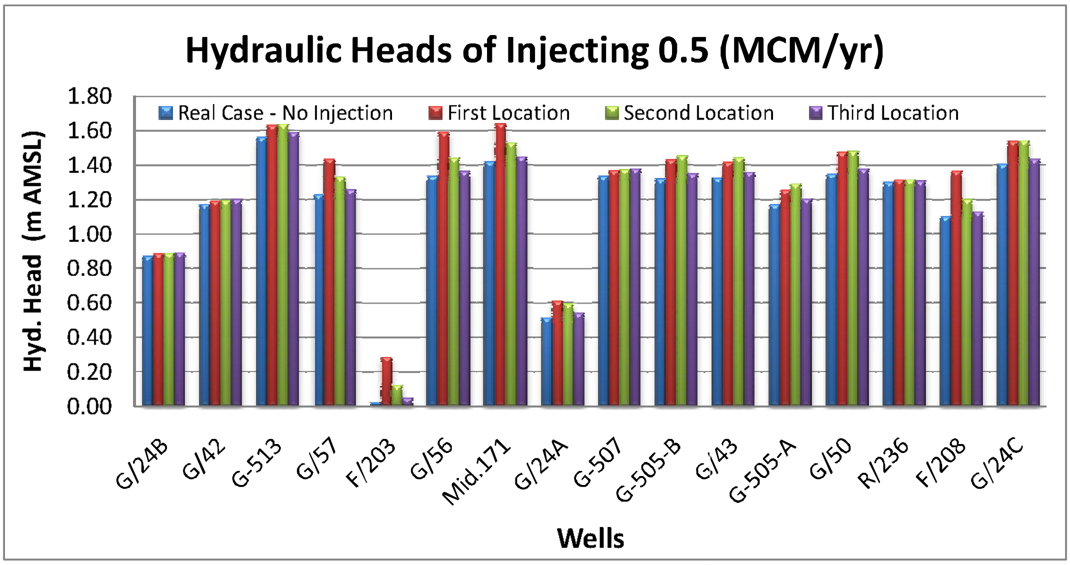

Figure (6.3): Hydraulic heads at wells in 3 recharging locations injected with 0.5 MCM/yr

At almost all wells, the hydraulic head was improved and rose as a direct result of establishing the artificial recharge facility and injecting 0.5 MCM/yr. however there were no significant changes and improvements in heads for the alteration of recharging location.

The average of potential head at all wells for the existing case has increased by 110.92% when the recharged quantity was injected through the first location and by 107.92 % and 102.44 % for the second and third locations respectively.

The selection of the first recharging location "near the landside boundary" was the most cost effective location as the hydraulic head was slightly improved in all wells by an average of 103.1% among the second location and by 108.3% among the third one. This could back to the location of the pumping wells and their distributions near the first location.

Figure 6.4 represents and compares the simulated normalized concentration of the groundwater in the existing case and in the three different recharging locations once keeping the recharged quantity const of 0.5 MCM/yr.

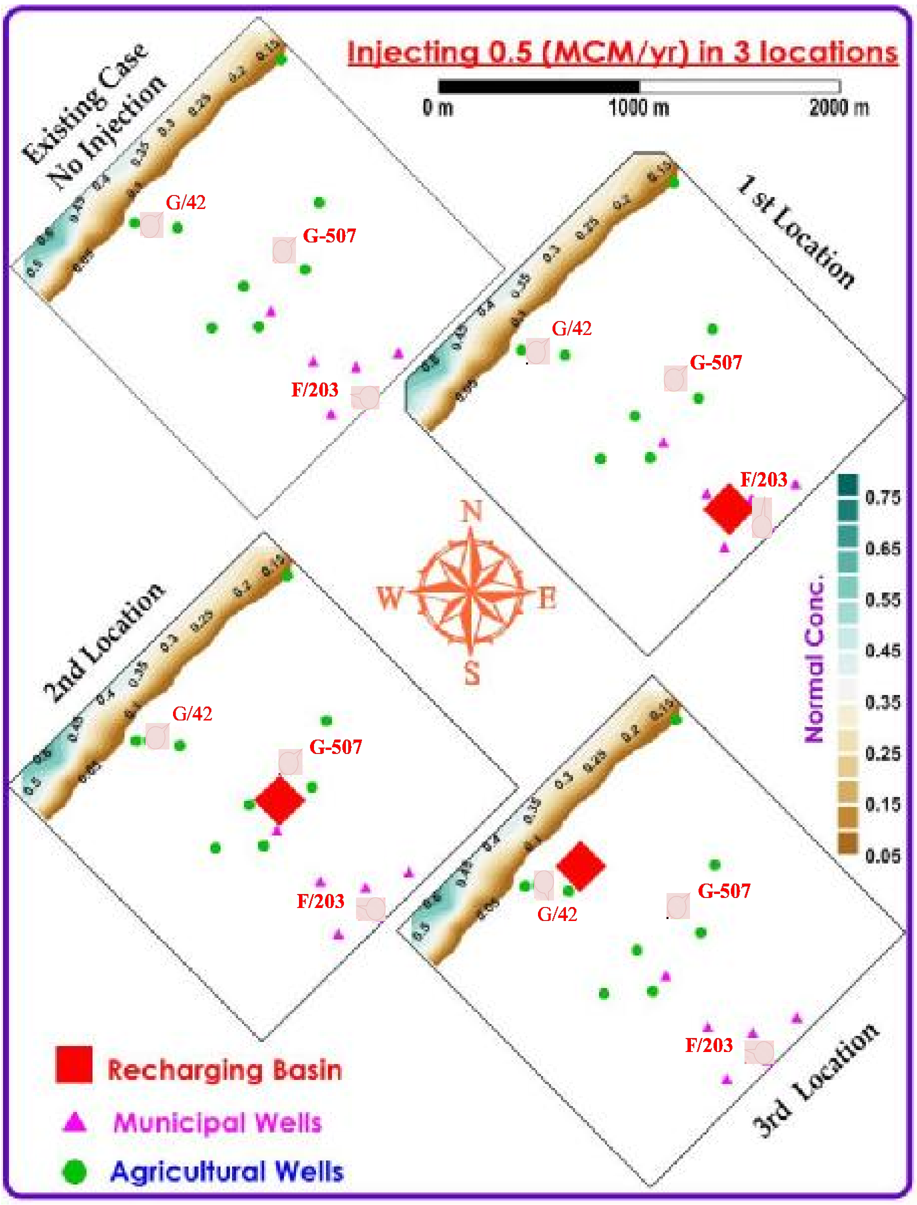

Figure (6.4): Normalized Conc. once injecting 0.5 MCM/yr in 3 recharging locations

The normalized concentration results were utilized to represent the total dissolved solids (TDS) in the groundwater and to indicate the seawater intrusion situation. As shown in figure 6.4, the salt concentration at well *F/203* was almost zero in all cases. The salt concentration at well *G-507* was reduced among the existing case by 11.6%, 12.6%, and 15.2% at first, second, and third injecting locations respectively. While the salt concentration at well *G/42* decreased with the changing the injection location, It was reduced among the no recharge case by around 6.2%, 6.4%, and 8.5% for the injecting locations first, second, and third respectively. Therefore, there were no significant changes in the normalized concentration in almost all the area once injecting same quantity to the different locations. This could be due to the small time period of one year used in the simulation, in addition to the small recharged quantity that could induce significant changes to push back the seawater intrusion through this period.

Figure 6.5 represented and compared the simulated groundwater pressure in the existing case and the three different artificial recharge locations.

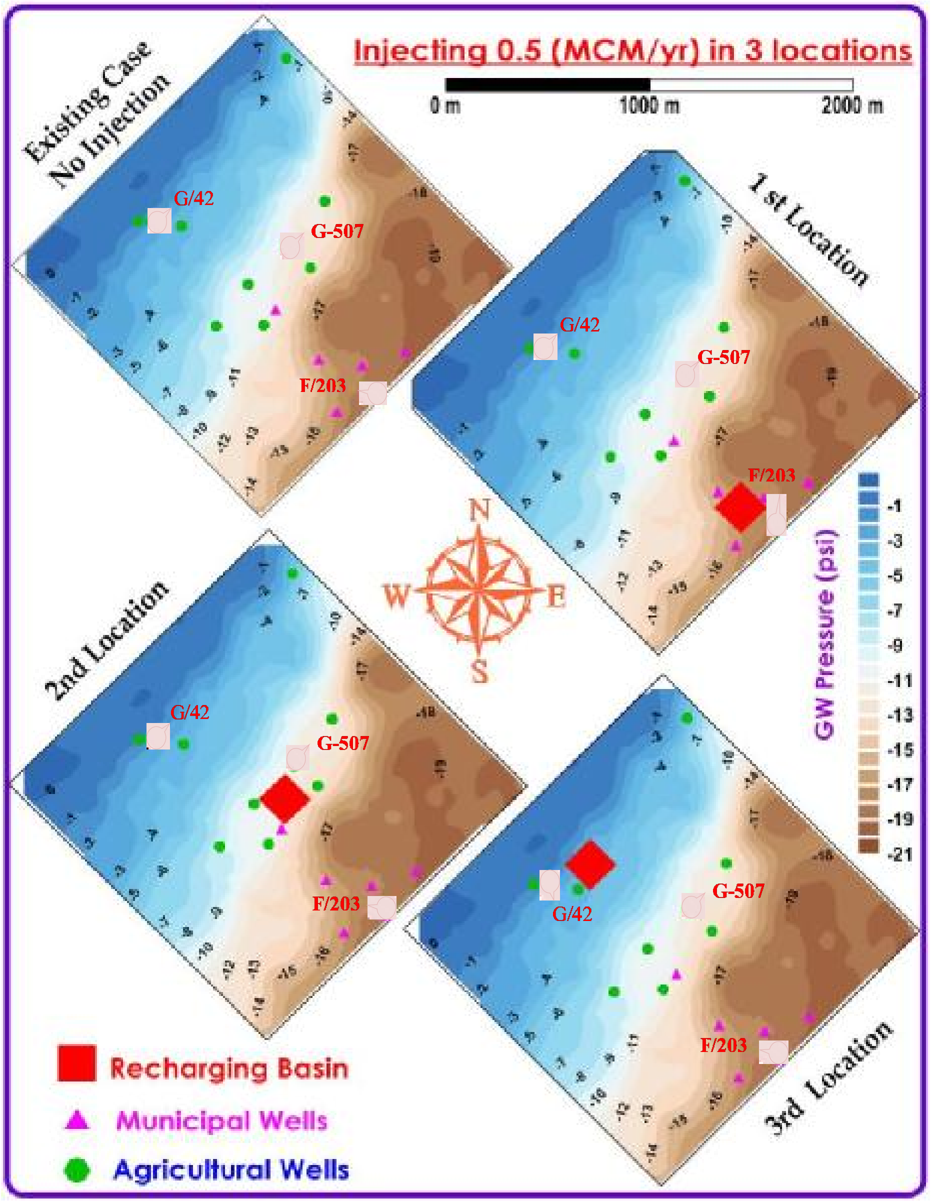

Figure (6.5): GW Pressure once injecting 0.5 MCM/yr in 3 recharging locations

In this figure, the groundwater pressure is increased near the recharging basin location; however, there were no significant increment among the different recharging locations and the existing case. This was resulted from the small time period of one year utilized in the transient simulation model. *For more details about the groundwater pressure comparisons for the other scenarios, i.e. injecting 1.0 MCM/yr and 1.5 MCM/yr, see appendix II.*

A cross section was made in the domain area far away from the sea side by about 200 m in order to check the normalized concentration of the sub aquifer groundwater as shown in figure 6.6. The normalized concentration at this section acted as an indicator for the seawater that perhaps intrudes into the land side.

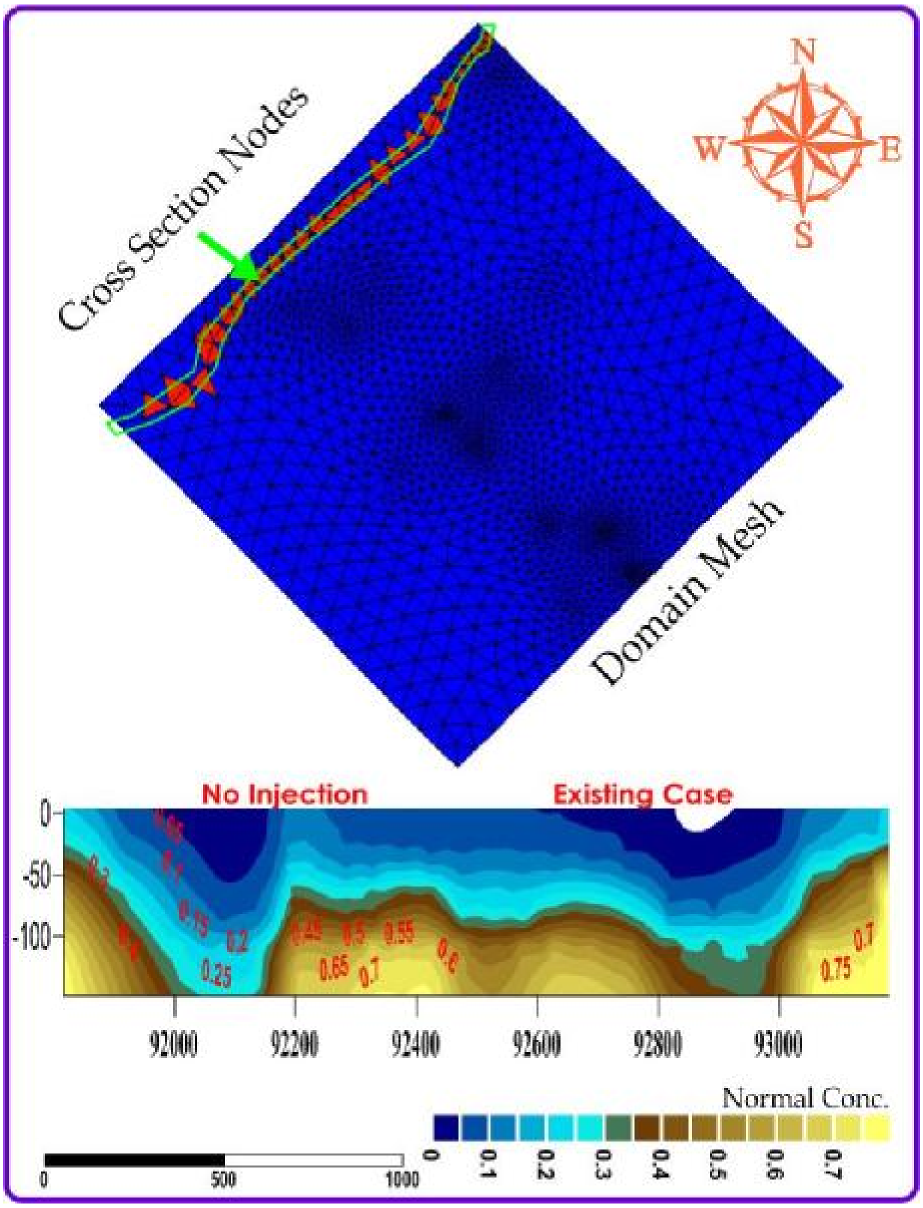

Figure (6.6): the Cross section location in the study area domain.

Through the simulation model, the normalized concentration was computed at this section for existing case as well as the nine scenarios of the artificial recharge; i.e. the three different locations for the recharging basin with other options of three different quantities to recharged in each location.

Figure 6.7 represents the simulated normalized concentration at the cross section of different sub aquifer depths. This figure also compares the groundwater normalized concentration for the existing case and for the other recharging basin locations.

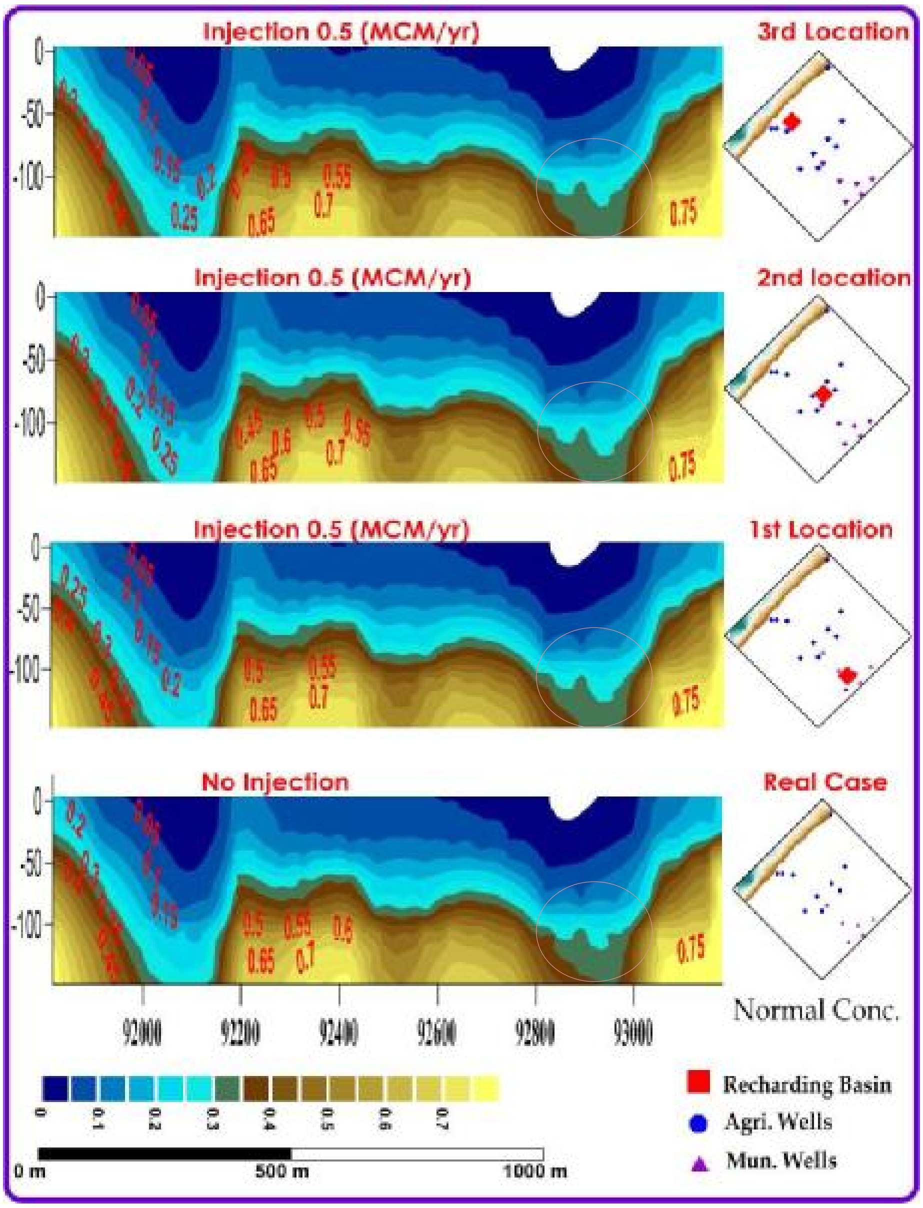

Figure (6.7): Normalized Concentration at the cross section for three recharging locations injected with 0.5 MCM/yr

There was a clear reduction in the groundwater concentration of the existing case when injected water through the different locations; however, there were slight changes when the three injection scenarios were compared with each other. This leaded to the feasibility of the recharging basin and its different locations in the study area. For more details about the normalized concentration for the other two injecting scenarios, i.e. 1.0 and 1.5 MCM/yr, see appendix III.

2. Second three scenarios of recharging 1.0 MCM/yr artificially

In second three scenarios, each proposed location was recharged with 1.0 MCM/yr once. The gotten results of the potential head, normalized concentration, and groundwater pressure were compared with the no injection case as shown in figure 6.8.

From the figure, the head was increased near the recharging basin; in addition, the head increase covered almost all the area.

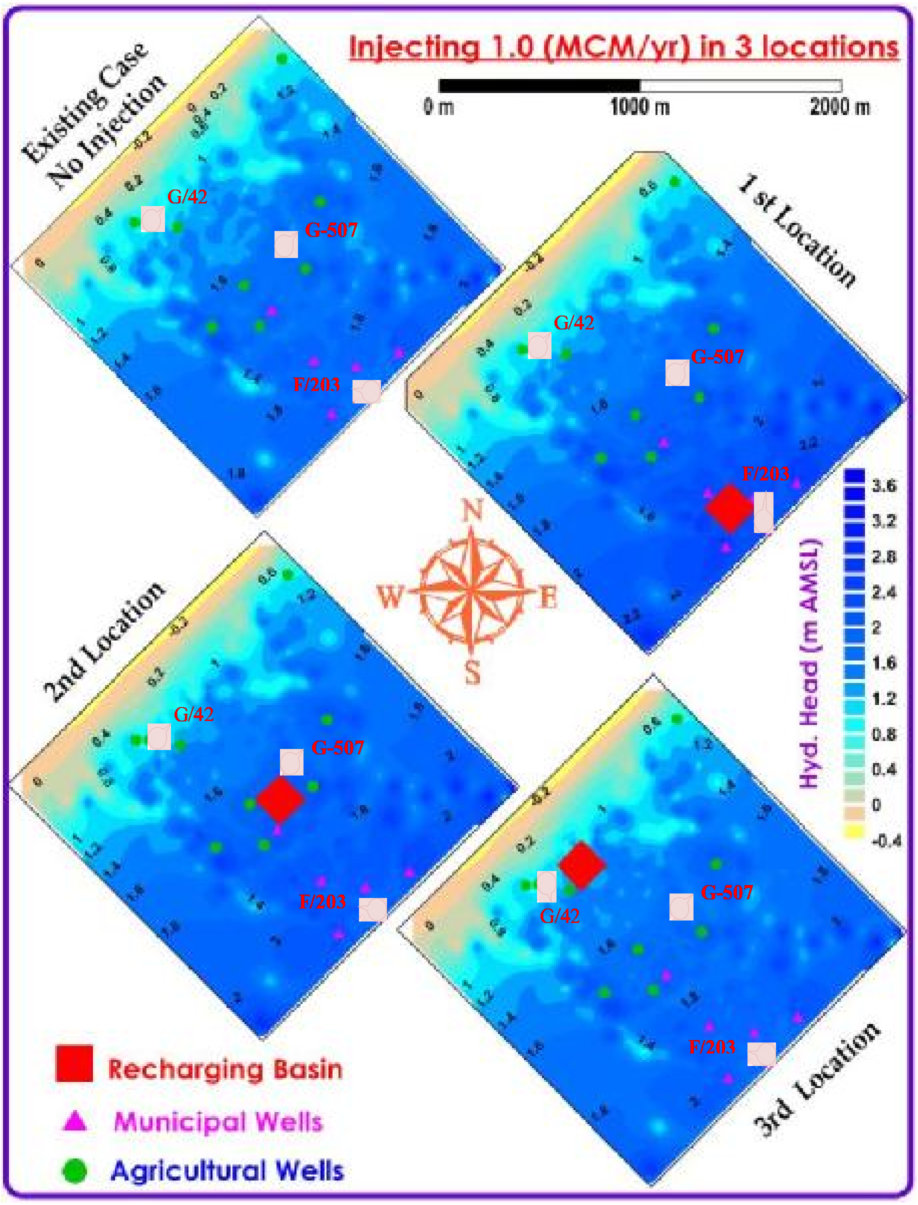

Figure (6.8): hydraulic heads in 3 recharging locations injected with 1.0 MCM/yr

For more details, the hydraulic head increased with different values in the already three wells points that were selected to represent the whole area. The head at well *F/203* when recharging in the first location increased from the existing case by 0.53 m; it also had rose by less amount of 0.21 m and 0.06 m when recharging in the second and the third locations respectively. The high difference in the head increment among recharging location could be explained due to the closeness of the well to the recharging location. The head at well *G-507* have improved by small amount of 0.07, 0.08, and 0.09 m (around 5 % in average) when injecting in the first, second, and third location respectively. While at well *G/42,* the head was improved by about 3.3 % in the first, second, and third locations respectively. The almost constant improvement to the head at wells *G-507* and *G/42* could be resulted from the less pumped quantities and the screen depths in addition to the aquifer strata inclination.

Figure 6.9 represents the hydraulic head at every well in the study area and compares the head of the existing situation with that once the location of the recharging basin was changed and injected by constant quantity of 1.0 MCM/yr.

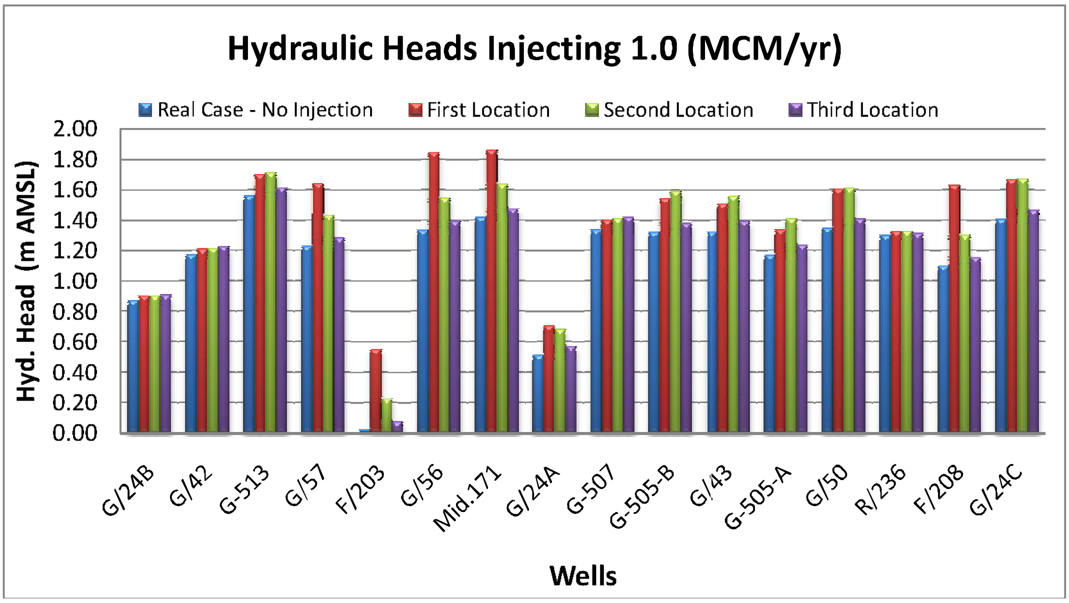

Figure (6.9): Hydraulic heads at wells in 3 recharging locations injected with 1.0 MCM/yr

At almost all wells, the hydraulic head was improved and rose as a direct result of establishing the artificial recharge facility and injecting 1.0 MCM/yr. however there were no significant changes and improvements in heads for the alteration of recharging location.

Choosing the first recharging location was the most cost effective location as the wells hydraulic head was improved more in average by 121.83% among the existing case and by105.73 on the second and by 116.2% on the third locations. This could back to the location of the pumping wells and their distributions near the first location.

Figure 6.10 represented and compared the simulated normalized concentration of the groundwater in the existing case and in the three different recharging locations once keeping the recharged quantity const of 1.0 MCM/yr.

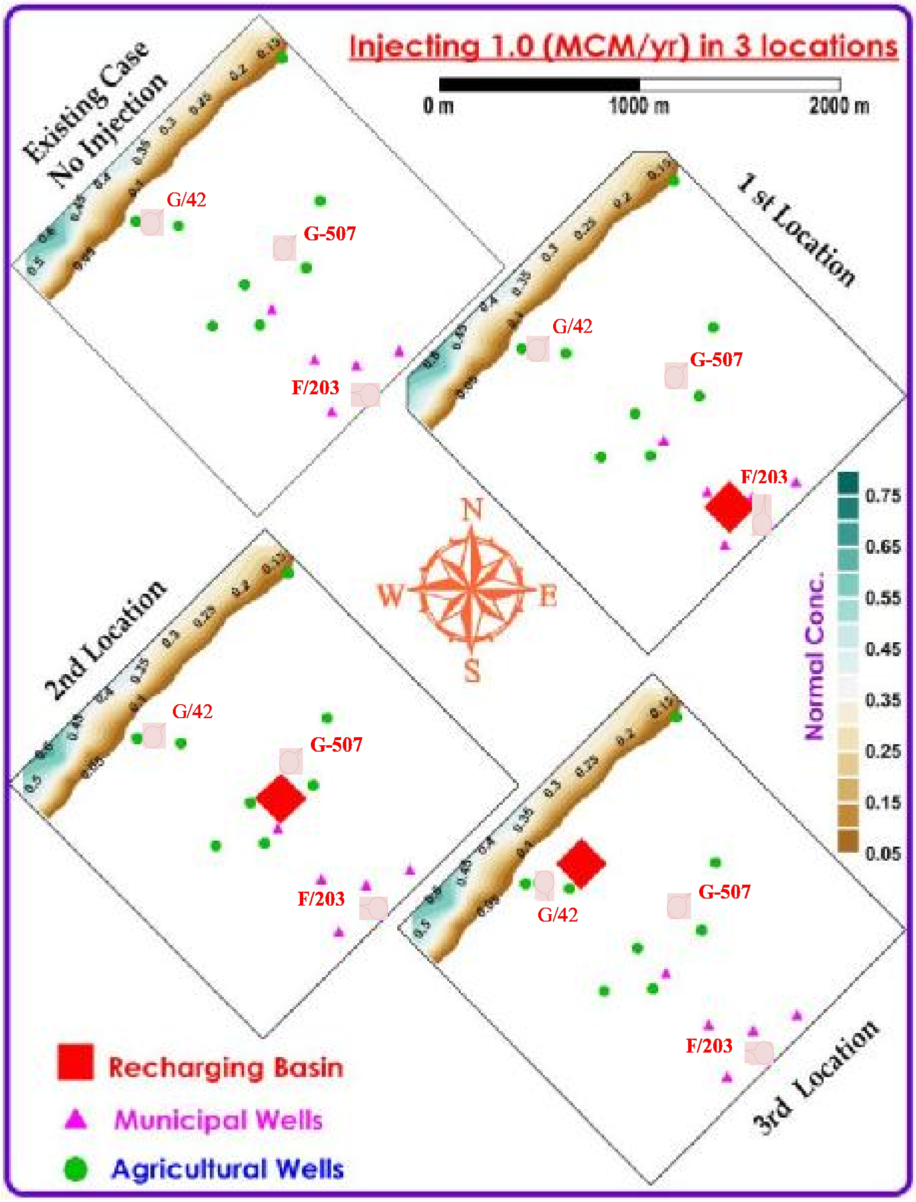

Figure (6.10): Normalized Conc. once injecting 1.0 MCM/yr in 3 injection locations

The normalized concentration results were utilized to represent the total dissolved solids (TDS) in the groundwater and to indicate the seawater intrusion situation. As shown in figure 6.10, the salt concentration at well *F/203* was almost zero in all cases. The salt concentration at well *G-507* was reduced among the existing case by 22.0%, 23.7%, and 30.2% at first, second, and third injecting locations respectively. While the salt concentration at well *G/42* decreased with changing of the injection location by 11.7%, 12.2%, and 16.0% for the injecting locations sequence first, second, and third respectively. Again, there were no significant changes in the normalized concentration in almost all the area once injecting same quantity to the different locations. The relatively high value of the salt concentration in well G/42 had back to closeness to the coast.

3. Third three scenarios of recharging 1.5 MCM/yr artificially

The gotten results of the potential head were compared with the no injection case as shown in figure 6.11. From the figure, the head was increased near the recharging basin; in addition, the head increase covered almost all the area

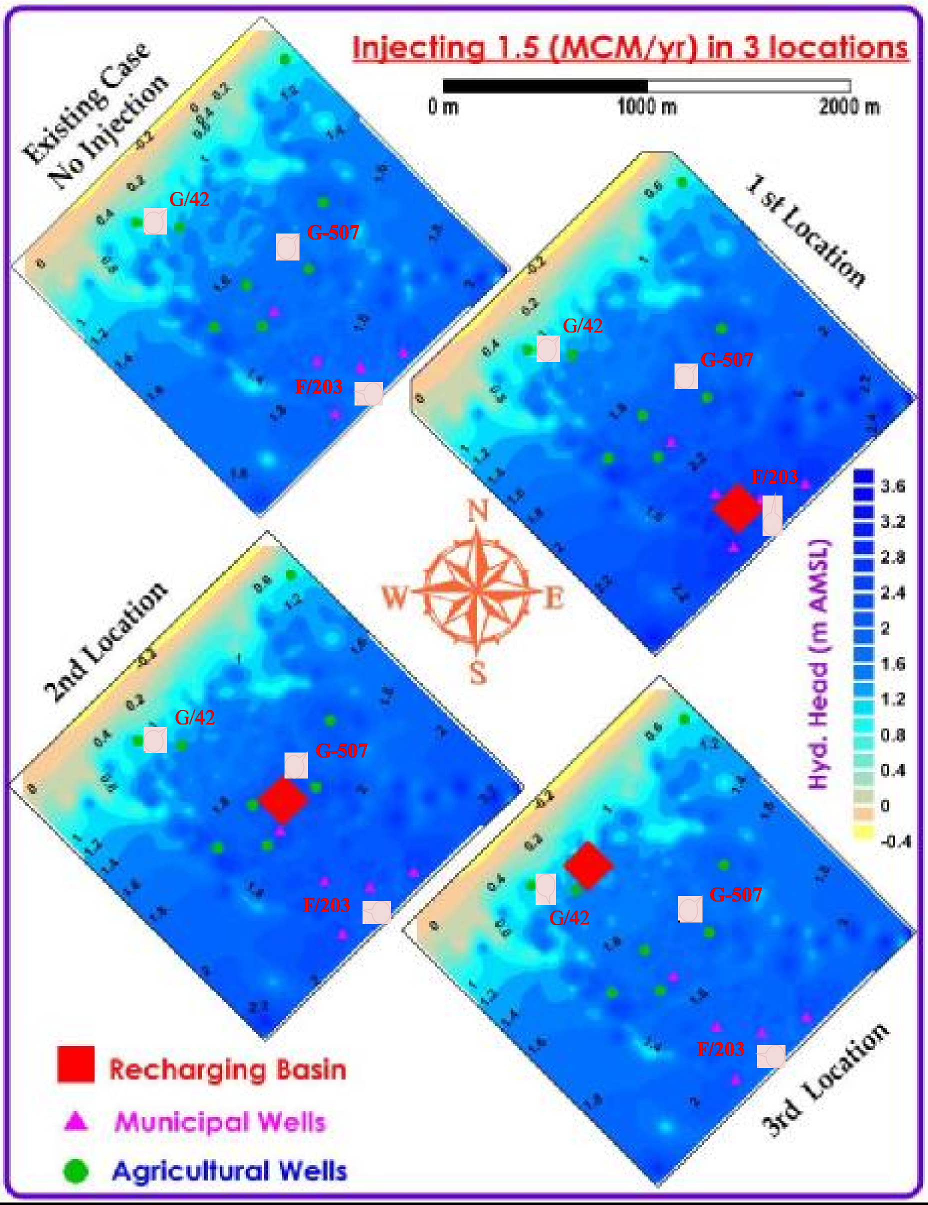

Figure (6.11): hydraulic heads in 3 recharging locations injected with 1.5 MCM/yr

For more details, the hydraulic head increased with different values in the already selected three wells that represented the whole area. The head at well *F/203* when recharging in the first location increased from existing case by 0.80 m; it also had improved by 0.31 m and 0.08 m when recharging in the second and the third locations respectively. The high difference in the head increment among recharging location could be explained due to the near distance of the well from the recharging location. The head at well *G-507* have improved by small amount 0.10, 0.11, and 0.12 m when injecting in the first, second, and third location respectively. While at well *G/42,* the head was improved by about 4.6 % in the first, second, and third locations respectively. The almost constant improvement to the head at wells *G-507* and *G/42* could be resulted from the less pumped quantities and the screen depths in addition to the aquifer strata inclination.

Figure 6.12 represents the hydraulic head at every well in the study area and compares the head of the existing situation with that once the location of the recharging basin was changed and injected by constant quantity of 1.5 MCM/yr.

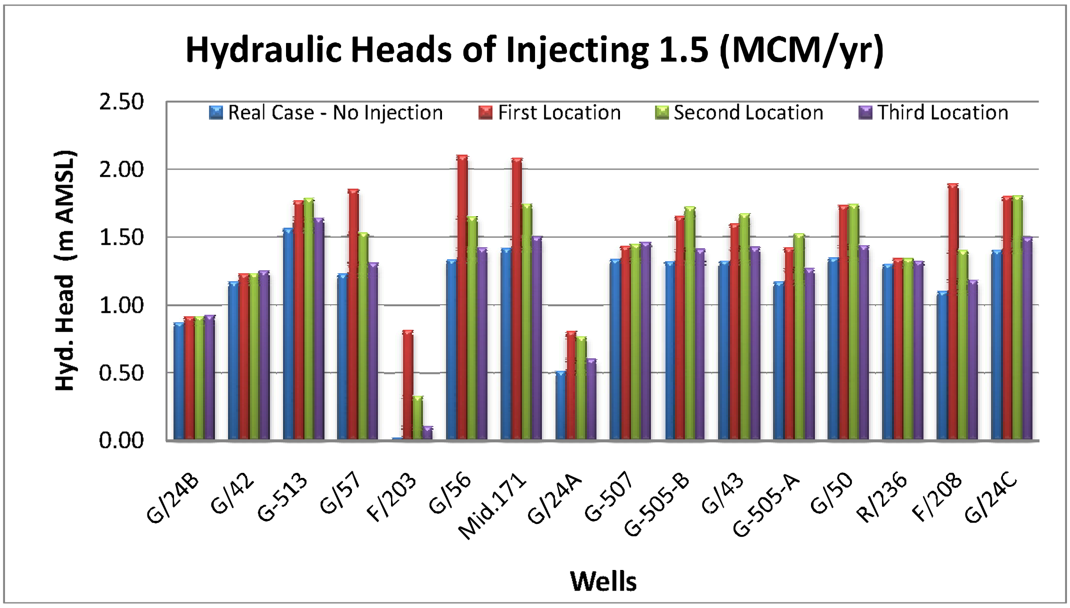

Figure (6.12): Hydraulic heads at wells in 3 recharging locations injected with 1.5 MCM/yr

At almost all wells, the hydraulic head was improved and rose as a direct result of establishing the artificial recharge facility and injecting 1.0 MCM/yr. however there were no significant changes and improvements in heads for the alteration of recharging location.

Deciding on the first recharging location was the most cost effective location as the hydraulic head was improved more in all wells by 100% on the second and on the third locations.

In addition, the average of potential head in all wells when the recharged quantity injected through the first location has increased 130.62% among the existing case and by108.06 on the second and by 123.70 % on the third locations. This could also back to the location of the pumping wells and their distributions near the first location.

Figure 6.13 represented and compared the simulated normalized concentration of the groundwater in the existing case and in the three different recharging locations once keeping the recharged quantity const of 1.5 MCM/yr.

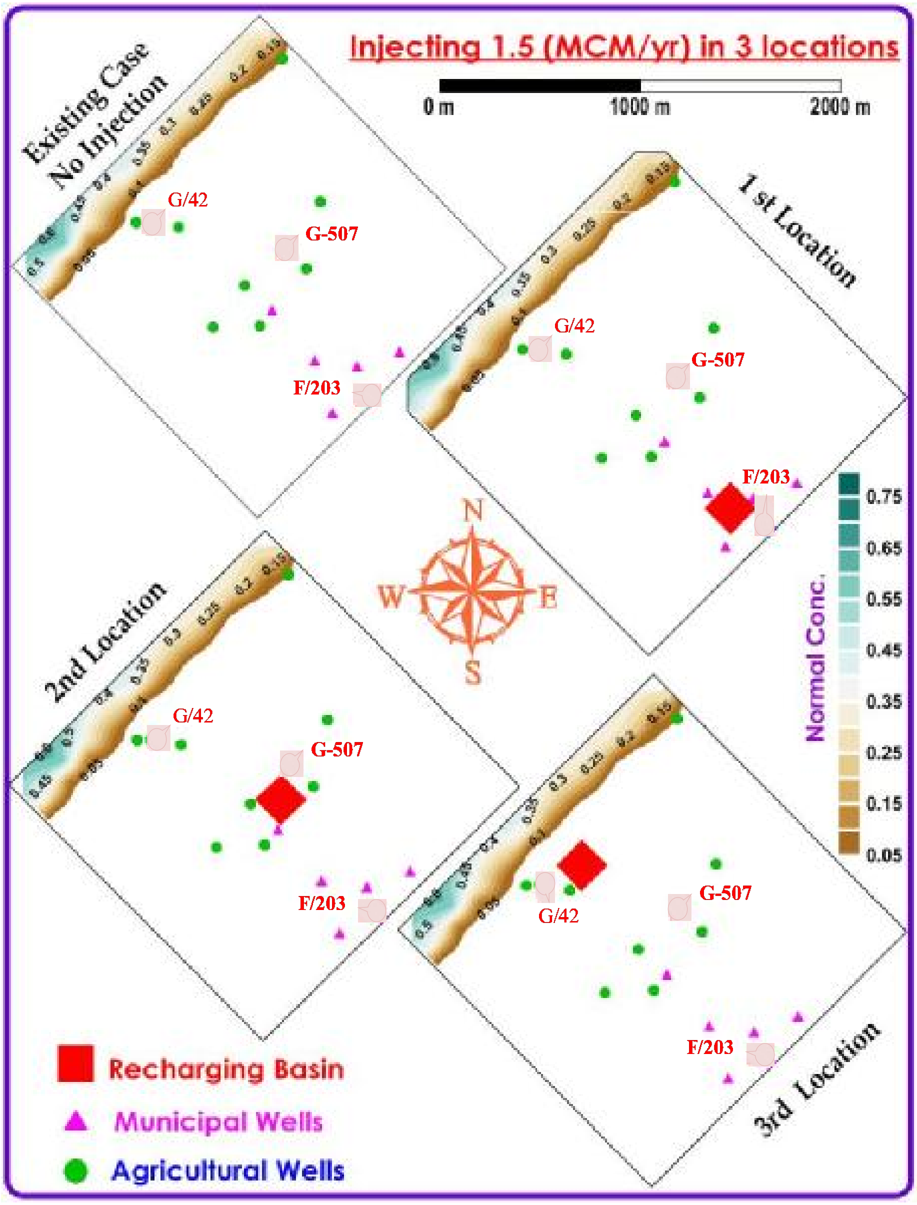

Figure (6.13): Normalized Conc. once injecting 1.5 MCM/yr in 3 injection locations

The normalized concentration results were utilized to represent the total dissolved solids (TDS) in the groundwater and to indicate the seawater intrusion situation. As shown in figure 5.13, the salt concentration at well *F/203* was almost zero in all cases. The salt concentration at well *G-507* was reduced among the existing case by 31.0%, 33.3%, 42.70% at first, second, and third injecting locations respectively. While the salt concentration at well *G/42* decreased with the changing of the injection location by 16.8%, 17.5%, and 22.5% for the injecting locations sequence first, second, and third respectively. Again, there were no significant changes in the normalized concentration in almost all the area once injecting same quantity to the different locations. The relatively high value of the salt concentration in well G/42 had back to closeness to the coast.

6.2.3 More Simulation Comparisons

In the above figures, the recharged quantity was constant and the location of the recharging basin varied. This was to decide the best and most feasible location out of the three options. However, comparing the results from the prospect of altering between the different three recharging quantities (0.5, 1.0, and 1.5 MCM/yr) was to decide the best and most cost effective quantity out of them; when the location was kept constant and the recharged quantity changes.

Recharging through first location scenarios, the proposed first location was kept constant and recharging it with different quantities 0.5, 1.0, and 1.5 MCM/yr. The attained results of the potential head and normalized concentration were compared with the no injection case as shown in figure 6.14. From figure, the head was increased by increasing the recharged quantity; in addition, the head enhancement covered almost all the area.

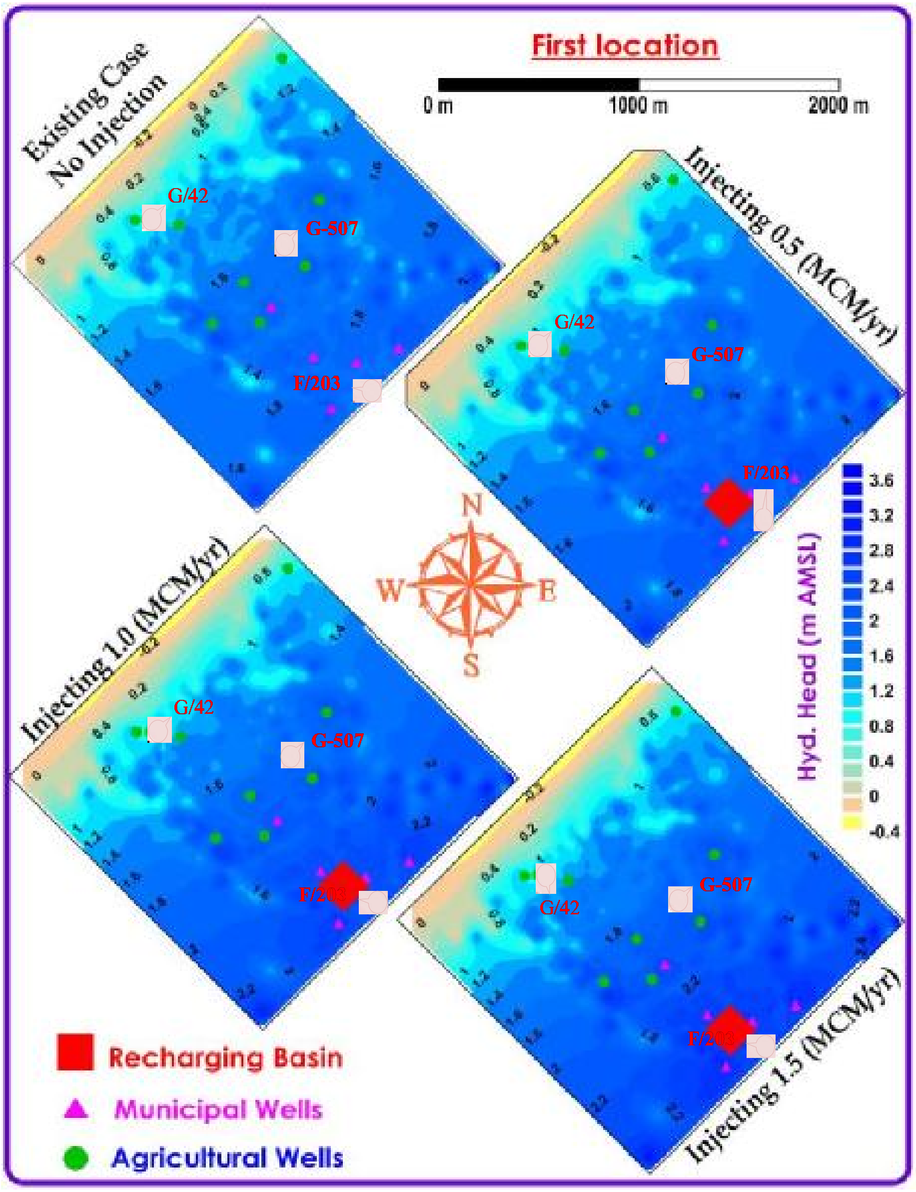

Figure (6.14): hydraulic heads in first recharging locations injected with 0.5, 1.0, and 1.5 MCM/yr

The hydraulic head had increased by different values in the already three selected wells. The head at well F/203 increased by 0.26 m as a result of changing the injected quantity from 0.5 to 1.0 MCM/yr and by same amount when altering the quantity from 1.0 to 1.5 MCM/yr.

The head at well G-507 had risen by 0.03 m when the quantity changed from 0.5 to 1.0 and from 1.0 to 1.5 MCM/yr. While at well G/42 about 0.02m was added to the head once varying from 0.5 to 1.0 and from 1.0 to 1.5 MCM/yr.

This could lead to a constant head increment when changing the quantities from one to the other. The constant increment in the head values could be due to the constant quantity increment of 0.5 MCM in each scenario, i.e. from 0.5 to 1.0 MCM is equal to 1.0 to 1.5 MCM.

The above conclusion was feasible for the results obtained by the simulator for the hydraulic head in the other two recharging locations "second and third". For more details about the head comparisons, see A IV

The hydraulic heads at every well in the study area were compared with that of the existing situation and the different injected quantity scenarios in figure 6.15

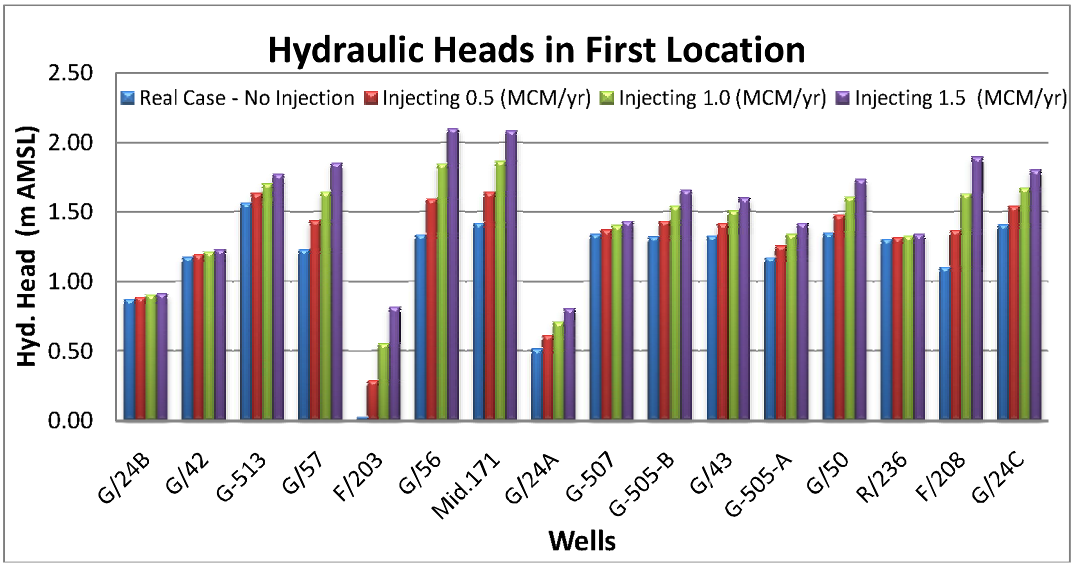

Figure (6.15): Hydraulic heads comparison at wells when first recharging locations injected with 0.5, 1.0, and 1.5 MCM/yr

At almost all wells, the hydraulic head was improved and rose by different amounts from the existing case due to the artificial recharge according to the quantity recharged. However, there were no significant improvements in heads due to the alteration in the recharged quantities.

Choosing of the 1.5 MCM/yr recharging quantity was the most cost effective location as the hydraulic head was improved more in all wells by 100% on 0.5 and 1.0 MCM injection options.

In addition, the average of hydraulic head in all wells had increased by same percent of 4.5% when the injected quantity varied from 0.5 to 1.0 and from 1.0 to 1.5 MCM/yr. This could back to the increase of the recharging quantity.

Figure 6.16 represents and compares the simulated normalized concentration of the groundwater at the proposed cross section in the existing case and in the three different injecting quantity options for the first location. For more details about the normalized concentration at the proposed cross section for the other two locations, see Appendix V.

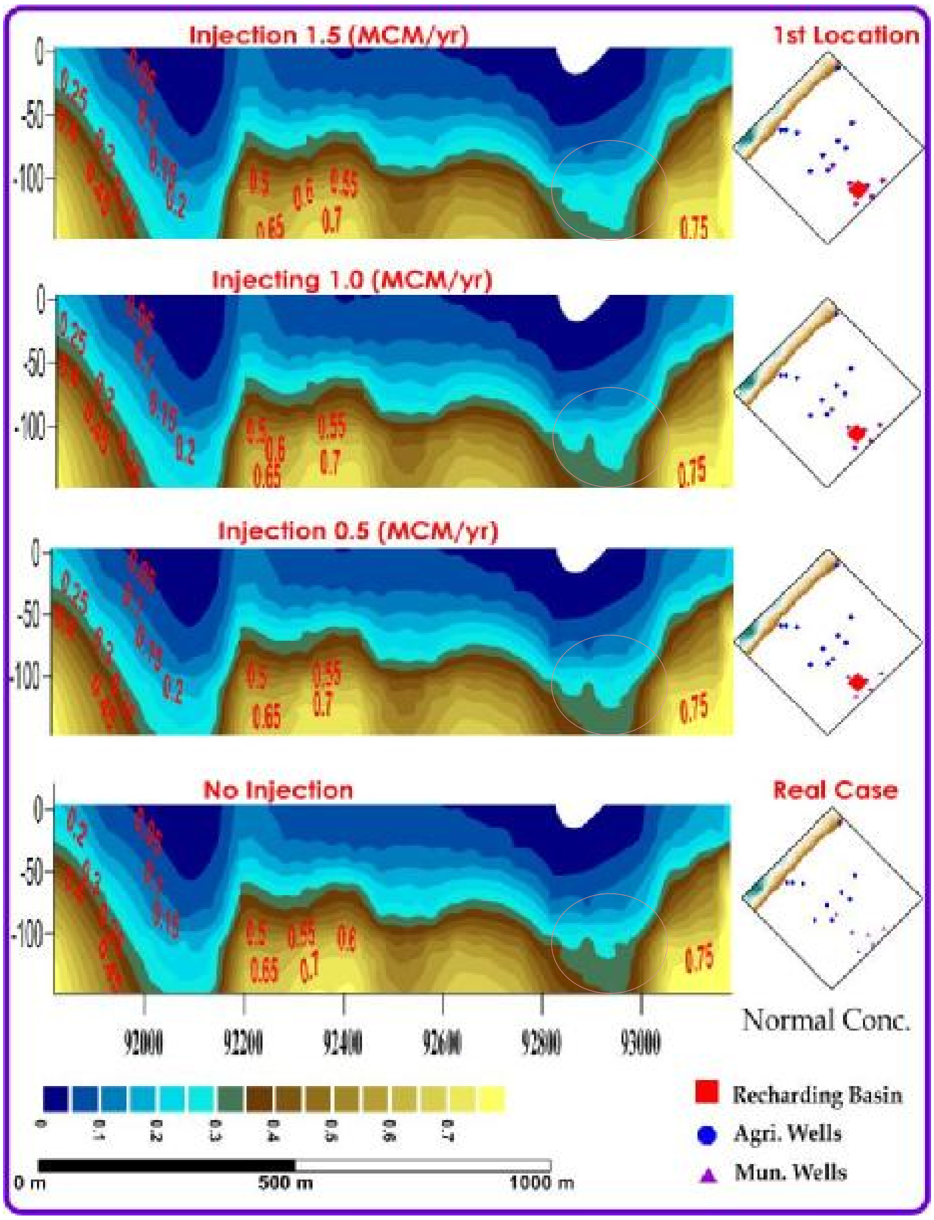

Figure (6.16): Normalized Conc. at cross section when the first location is injected with different quantities 0.5, 1.0, and 1.5 MCM/yr

Injecting water of accepted quality of about 1.5 MCM/yr reduced the normalized concentration more than the other two options: 0.5 MCM/yr and 1.0MCM respectively. This could be logic as pushing the salt water-fresh water transition zone needs more water quantities of accepted quality. However, the simulation model alone can't confirm the optimum location and the optimum quantity to be recharged; therefore the optimization model through Genetic Algorithm GA was coupled with this simulation model. For more details see chapter 6 "Groundwater Optimization Management".

6.3 Results of Management Models Application

6.3.1 Management model 1

Running the management model with the final format for the objective function (eq. 5) was based upon justifying the feasible value of salinity weighing parameter (P2= 25). Table 6.1 denotes the optimal pumping quantities that ensure the minimization of the salinity "objective function", as well as maximization of the actual annual production.

Table (6.1): Actual annual production, obtained optimum annual pumping, and the optimal pumping strategy pumping for the existing wells

Well Id. # (1)	Actual Production (m^3/yr) (2)	Optimized production quantities (m^3/yr) (3)	Optimal Strategy Increasing/Decreasing Pumping (m^3/yr) (4)= (3)-(2)
R/236	113,400	6,314	-107,086
G/57	108,000	120,078	12,078
F/203	463,680	116,527	-347,153
F/208	151,200	122,431	-28,769
G/24B	72,000	124,541	52,541
G/42	18,360	108,600	90,240
G/56	108,000	123,286	15286
Mid.171	172,800	122,955	-49,845
G/24A	100,800	122,963	22,163
G-507	25,920	123,883	97,963
G/24C	161,280	113,117	-48,163
G-513	43,200	123,849	80,649
G-505-B	69,120	121,013	51,893
G/43	24,480	124,024	99,544
G-505-A	54,000	121,218	67,218
G/50	144,000	116,911	-27,089
Total	**1,830,240**	**1,811,710**	**-18,530**

Obtaining the optimum pumping results from the management model maintains the optimal pumping strategy for the existing wells by either increasing or decreasing the actual productions according to the optimum ones.

As seen in table 6.1, an optimal pumping strategy for the study area wells was sustained. For instance, the actual annual production for well F203 was 463,680 (m^3/yr) should be reduced by 347,153 (m^3/yr) to fulfill the attained optimal pumping from the management model. While, for well G/43, the actual pumping of 24,480 (m^3/yr) is needed to be increased by 99,544 (m^3/yr) to become 124,024 (m^3/yr) as optimum pumping.

The total optimum pumping was about (88.30 %) of the total safe yield. This total also was reduced by a small quantity of about 18,530 (m^3/yr) as compared with the actual ones, i.e. (99.00 %) of the total actual productions.

Based upon the attained optimum pumping for the study area wells using the coupled simulation optimization (S/O) model, the spatial distribution of the total hydraulic/potential heads at the upper layer were simulated. The heads exposed the optimal pumping strategy. For comparison purposes, the simulated real heads based upon the current pumping using the simulation model alone were compared with that achieved using the S/O model as shown in figure 6.17.

As shown in figure 6.17, the hydraulic heads had increased in the majority of the study area as soon as the S/O model was carried out as compared with the simulated ones using the simulation model alone. For evaluation purposes, some representative wells points were selected. In well *F/203*, the head had increased by 1.54 m, i.e. from 0.018 to 1.56 m AMSL by utilizing S/O model instead of the simulation one alone. However, the head at well *G-507* also had reduced by small amount of 0.22 m and in the well *G/42* by 0.11 m only.

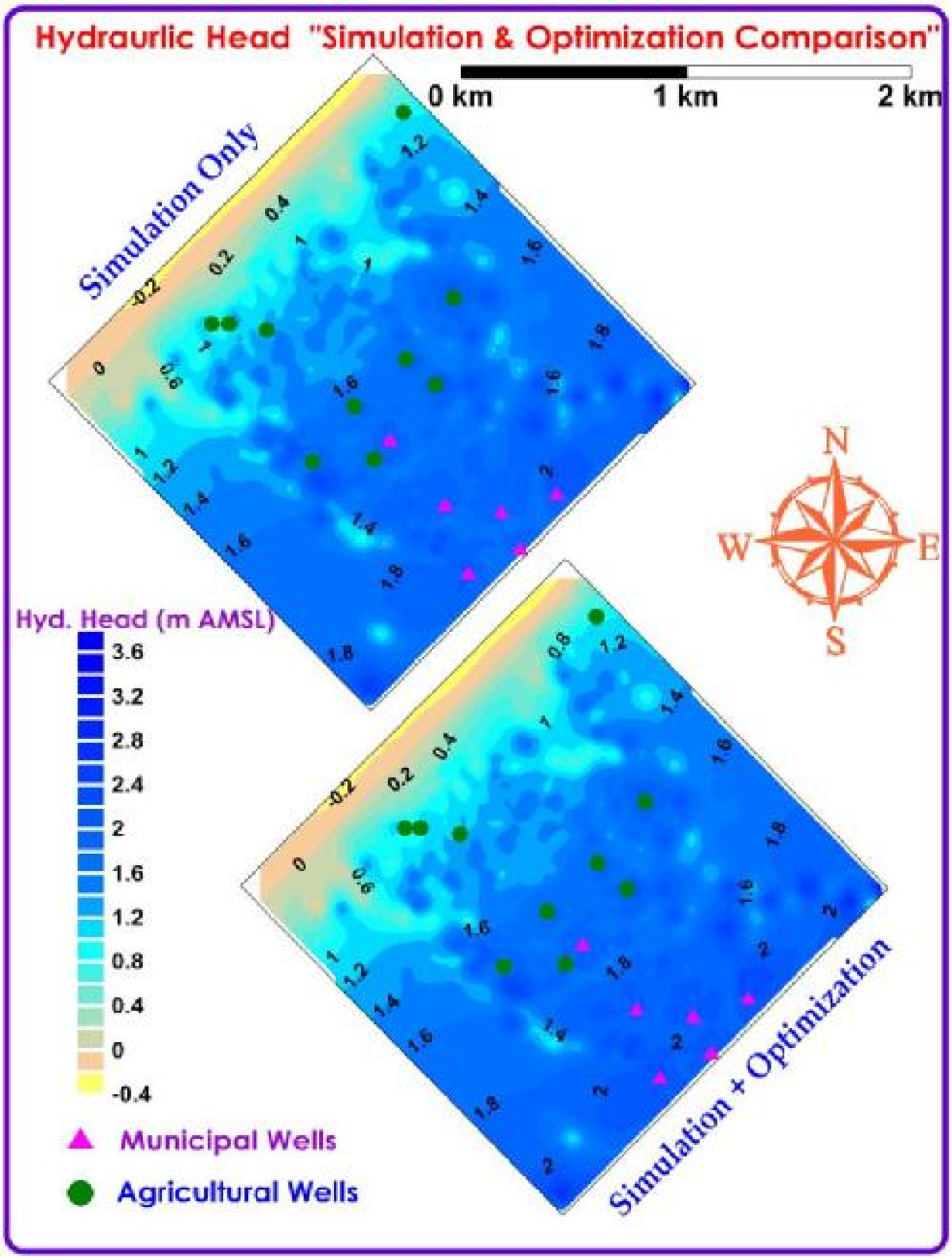

Figure (6.17): the spatial distribution of total hydraulic heads at the upper layer obtained by both simulation model and S/O model.

Figure 6.18 represents and compares the normalized concentration contours when the simulation model was executed alone as well as the S/O model.

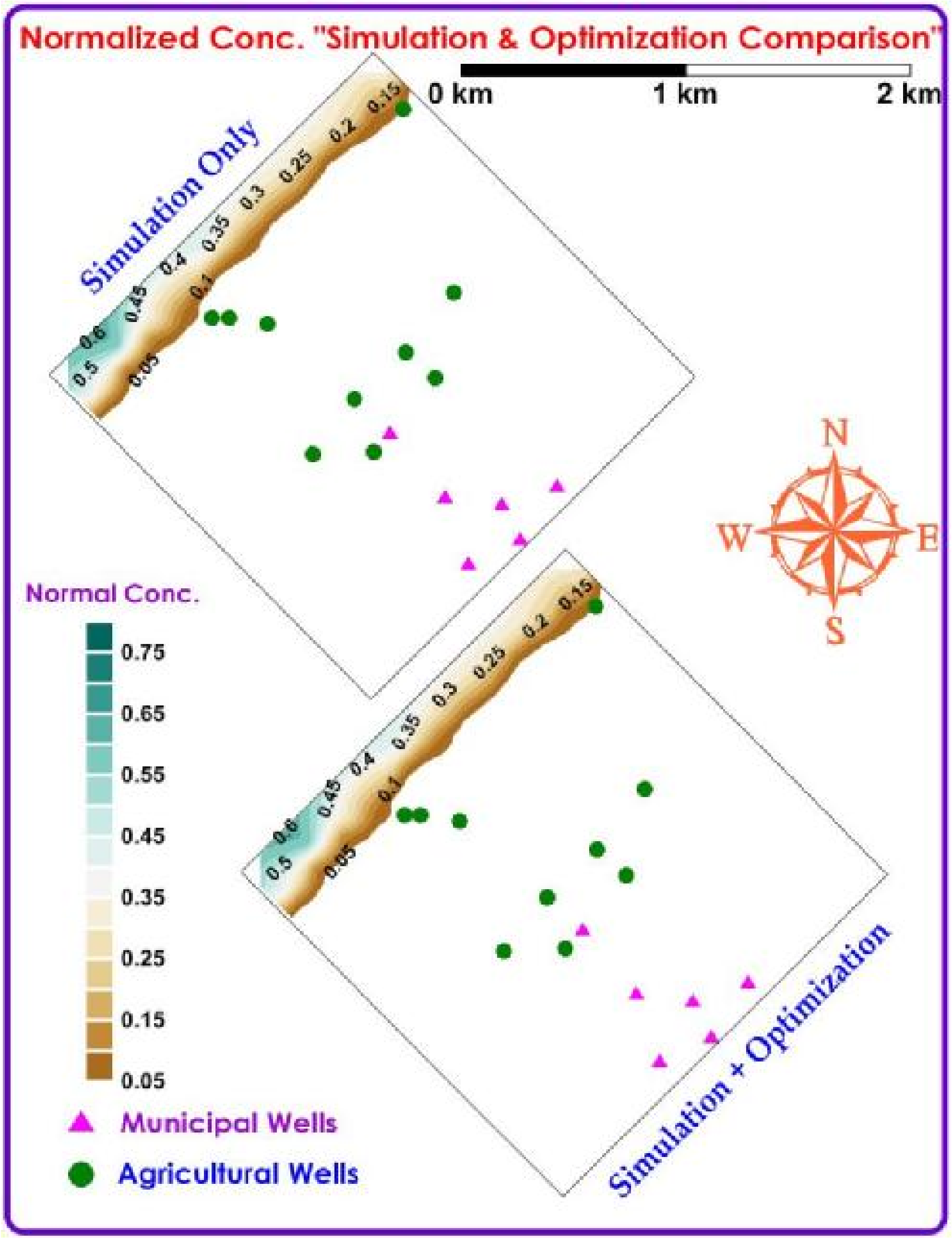

Figure (6.18): Normalized Concentration contours when the simulation model was executed alone as well as the S/O model.

The normalized concentration results were utilized to represent the total dissolved solids (TDS) in the groundwater and to indicate the seawater intrusion situation. As shown in figure 6.18 and for the contrasting needs, the salt concentration at well F/203 was almost zero in both cases. The salt concentration at well G-507 was increased from 0.60

to 3.6 kg/d by alerting from the only simulation model to S/O model. This increase in the salt concentration is due to the increase of pumping quantity by 6 times the actual pumping. However, the salt concentration at well F/236 was decreased from 43.34 to 814.32 kg/d when the optimizer identified the optimum pumping rates by reducing the pumping quantity by 107,086 m^3/yr.

Significant reductions in the normalized concentrations in almost all the area was occurred by adopting the S/O model instead of depending upon the simulation model alone. Therefore, It is worth enough to utilize the S/O techniques as a robust alternative to the simulation models alone in the groundwater management.

6.3.2 Management model 2

Through the model 2, nine adopted scenarios of the artificial recharge had been developed. Optimum pumping scenarios for each proposed location of the three artificial recharging facilities that injected by three different quantities separately were acquired as illustrated in table 6.2.

Table (6.2): Study area wells optimum pumping for 9 artificial recharge scenarios

Injection Quantity	0.5 MCM			1.0 MCM			1.5 MCM		
Location	1st	2nd	3rd	1st	2nd	3rd L	1st	2nd	3rd
Wells ID	Pumping quantity			Pumping quantity			Pumping quantity		
R/236	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002	0.0004	0.0004	0.0003
G/57	0.0048	0.0048	0.0048	0.0057	0.0057	0.0059	0.0067	0.0067	0.0069
F/203	0.0046	0.0046	0.0046	0.0055	0.0055	0.0052	0.0065	0.0065	0.0061
F/208	0.0049	0.0049	0.0049	0.0058	0.0058	0.0056	0.0068	0.0068	0.0066
G/24B	0.0049	0.0049	0.0049	0.0059	0.0059	0.0058	0.0069	0.0069	0.0068
G/42	0.0043	0.0043	0.0043	0.0052	0.0052	0.0059	0.0060	0.0060	0.0069
G/56	0.0049	0.0049	0.0049	0.0059	0.0059	0.0057	0.0068	0.0068	0.0066
Mid.171	0.0049	0.0049	0.0049	0.0059	0.0059	0.0058	0.0068	0.0068	0.0068
G/24A	0.0049	0.0049	0.0049	0.0059	0.0059	0.0058	0.0068	0.0068	0.0067
G-507	0.0049	0.0049	0.0049	0.0059	0.0059	0.0057	0.0069	0.0069	0.0067
G/24C	0.0045	0.0045	0.0045	0.0054	0.0054	0.0055	0.0063	0.0063	0.0064
G-513	0.0049	0.0049	0.0049	0.0059	0.0059	0.0052	0.0069	0.0069	0.0060
G-505-B	0.0048	0.0048	0.0048	0.0058	0.0058	0.0055	0.0067	0.0067	0.0064
G/43	0.0049	0.0049	0.0049	0.0059	0.0059	0.0055	0.0069	0.0069	0.0065
G-505-A	0.0048	0.0048	0.0048	0.0058	0.0058	0.0058	0.0067	0.0067	0.0067
G/50	0.0046	0.0046	0.0046	0.0056	0.0056	0.0057	0.0065	0.0065	0.0066
Total pumping (m^3/sec)	**0.0719**	**0.0719**	**0.0719**	**0.0864**	**0.0864**	**0.0848**	**0.1006**	**0.1006**	**0.099**

The three proposed quantities of the artificial recharge were added to the total natural safe yield. The model allowed pumping all the natural and artificial recharge quantity in every case. Table 6.3 represents the total pumped quantities by model and total allowed pumping quantity for all wells when the different artificial recharging scenarios were proposed; in addition to the percent of the total pumped to the total allowed pumping quantities.

Table (6.3): Total pumped quantities and total allowed pumping quantities

Injection Quantity	0.5 MCM			1.0 MCM			1.5 MCM		
Location	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Wells ID	Pumping quantity			Pumping quantity			Pumping quantity		
Total pumping (m^3/sec)	0.0719	0.0719	0.0719	0.0864	0.0864	0.0848	0.1006	0.1006	0.099
Total pumping MCM/yr)	2.267	2.267	2.267	2.725	2.725	2.674	3.173	3.173	3.122
Allowed pumping for each well (MCM/yr)*	0.1557*			0.188			0.2183		
Total Allowed pumping (MCM/yr)	2.491			2.992			3.493		
%age of total safe yield	91.03 %	91.03 %	91.03 %	91.07 %	91.07 %	89.38 %	90.83 %	90.83 %	89.38 %

*** Total allowed pumping for each well=**

= safe yield/no. of wells + injected quantity (ex. 0.5MCM/yr)/no. of wells

= 0.0632/16+0.0158/16=0.00493 m3/sec

= 0.1557 MCM/yr.

Referring to table 6.2 and 6.3, comparing the total pumped water quantities which obtained through changing the location of the artificial recharge was accomplished to identify the most cost effective location. Through all injection quantities scenarios, the *first and second locations* had allowed the maximum pumped quantities as compared with that allowed by the third location. These two locations (first and second) were located near the western land boarder and the middle of the study area.

Concentrating on the results obtained by adopting best location "the first and second" is in order to identify the achieved improvements in the existing pumping pattern. Table 6.4 represents the pumping pattern for each well in the area and compares it with that when different recharged quantities were injected in best locations.

As seen in table 6.4, the percentage increase in total pumped quantity in the first scenario i.e. recharging with 0.5 MCM as compared with the actual pumping was 25.70%. In the second scenario (recharging 1.0MCM/yr) the percent increase was 51.06%; while in the third scenario (recharging 1.5 MCM/r) was 75.87%.

Table (6.4): Total pumped quantities in 1st and 2nd locations injected with 3 quantities

Well Id #	Injected quantities			
	No injection	0.5 MCM	1.0 MCM	1.5 MCM
R/236	0.0002	0.0003	0.0003	0.0004
G/57	0.0038	0.0048	0.0057	0.0067
F/203	0.0037	0.0046	0.0055	0.0065
F/208	0.0039	0.0049	0.0058	0.0068
G/24B	0.0039	0.0049	0.0059	0.0069
G/42	0.0034	0.0043	0.0052	0.0060
G/56	0.0039	0.0049	0.0059	0.0068
Mid.171	0.0039	0.0049	0.0059	0.0068
G/24A	0.0039	0.0049	0.0059	0.0068
G-507	0.0039	0.0049	0.0059	0.0069
G/24C	0.0036	0.0045	0.0054	0.0063
G-513	0.0039	0.0049	0.0059	0.0069
G-505-B	0.0038	0.0048	0.0058	0.0067
G/43	0.0039	0.0049	0.0059	0.0069
G-505-A	0.0038	0.0048	0.0058	0.0067
G/50	0.0037	0.0046	0.0056	0.0065
Total pumping (m3/sec)	**0.0572**	**0.0719**	**0.0864**	**0.1006**
Total pumping (MCM/yr)	**1.8039**	**2.2674**	**2.7247**	**3.1725**
% increase	**100%**	**125.70%**	**151.05%**	**175.87%**

After decide the best locations (first and second), the optimized pumping rates for the area wells were simulated using the CODESA-3D model. The spatial distribution of hydraulic head was simulated when three different recharging quantities 0.5, 1.0, and 1.5 MCM/yr were injected to the aquifer. Figures 6.19 represented the hydraulic head when the various quantities were injected.

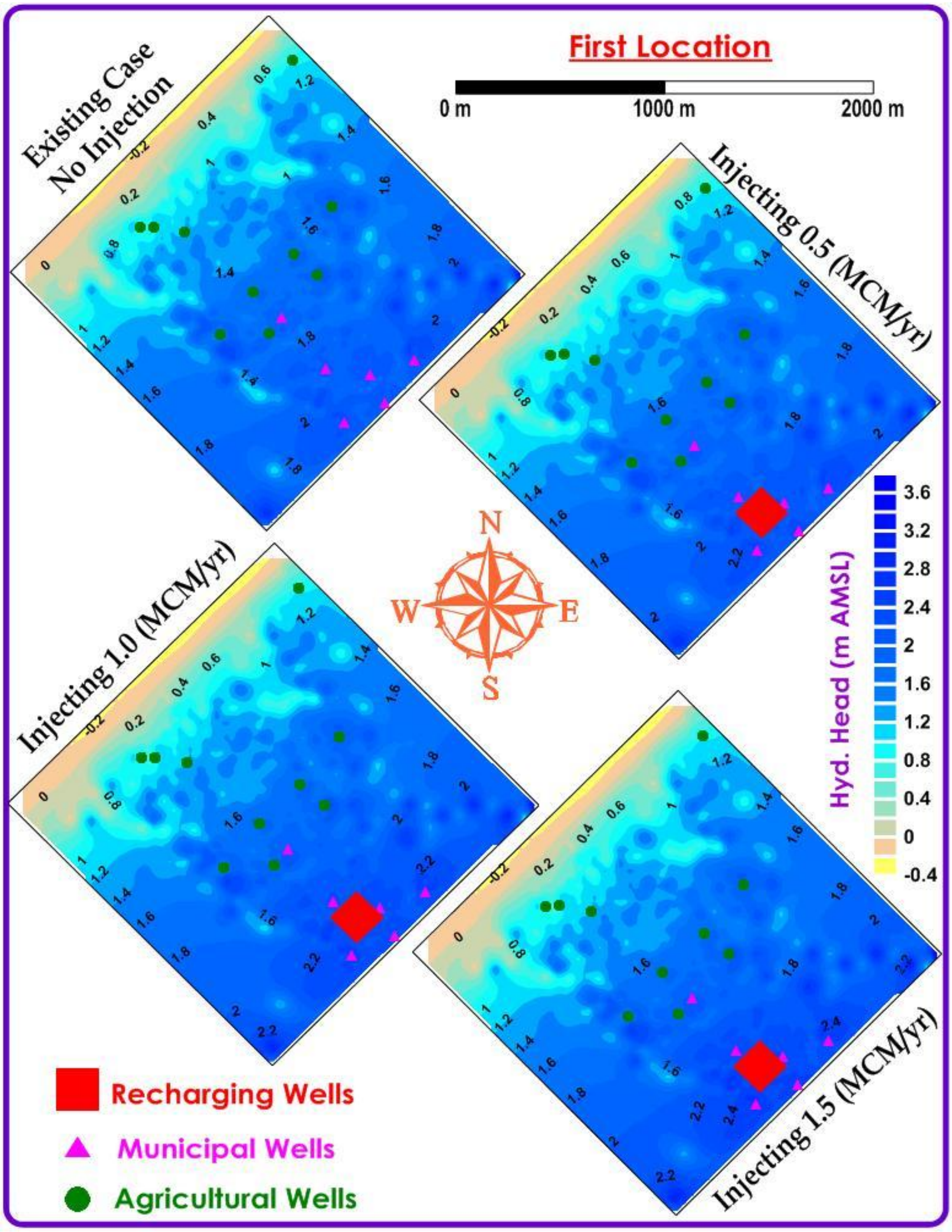

Figure (6.19): spatial distribution for hydraulic heads in first recharging locations injected with 0.5, 1.0, and 1.5 MCM/yr

For evaluation purposes, three wells points were selected to cover changes in study area. The current hydraulic head at well F/203 increased by very small amount of 0.02 m as a result of injecting 0.5 MCM/yr, i.e. from 1.56 to 1.58 m AMSL. Moreover, the head increased by 0.04 m by increasing the recharged quantity to 1.0 MCM/yr and by 0.06 m for 1.5MCM/yr.

For well G-507, the head had decreased by 0.07 m when the recharged quantity was 0.5 MCM/yr. while, the head reduced by 0.13 m and 0.20 m when the recharged quantity was increased to 1.0 and 1.5 MCM/yr respectively. While at well G/42 about 0.04 m was lowered to the head once 0.5 MCM was injected. The head reduced also by 0.07 m and 0.10 recharging for injecting 1.0 and 1.5 MCM/yr respectively.

The insignificant head increase or decrease; specially, when the injected quantity increased could be explained as a result of high increase in the pumped quantities from the total allowed quantities which equals the natural and artificial recharge quantities. In addition to the some farness of the well location to the recharging location

Figure 6.20 shows the hydraulic head at every well in the study area and compares the existing situation head with resulted heads once the first location of the recharging basin was injected by different quantities of 0.5, 1.0, and 1.5 MCM/yr.

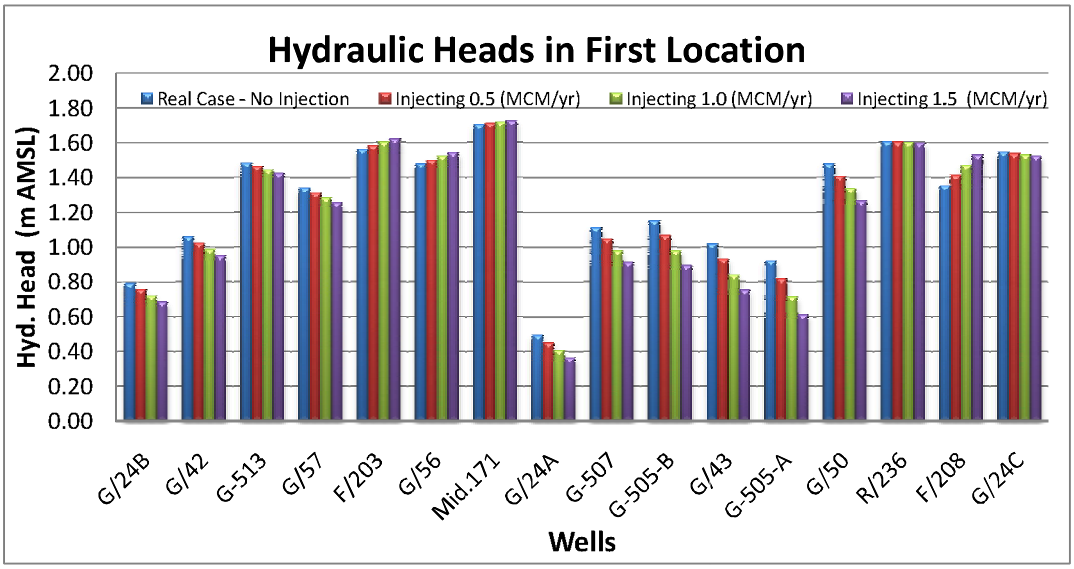

Figure (6.20): Hydraulic heads comparison at wells when second recharging location injected with 0.5, 1.0, and 1.5 MCM/yr

Figure 6.21 represents and compares the spatial concentration of the groundwater normalized concentration in the existing case and once the three different recharging quantities were injected through the first location.

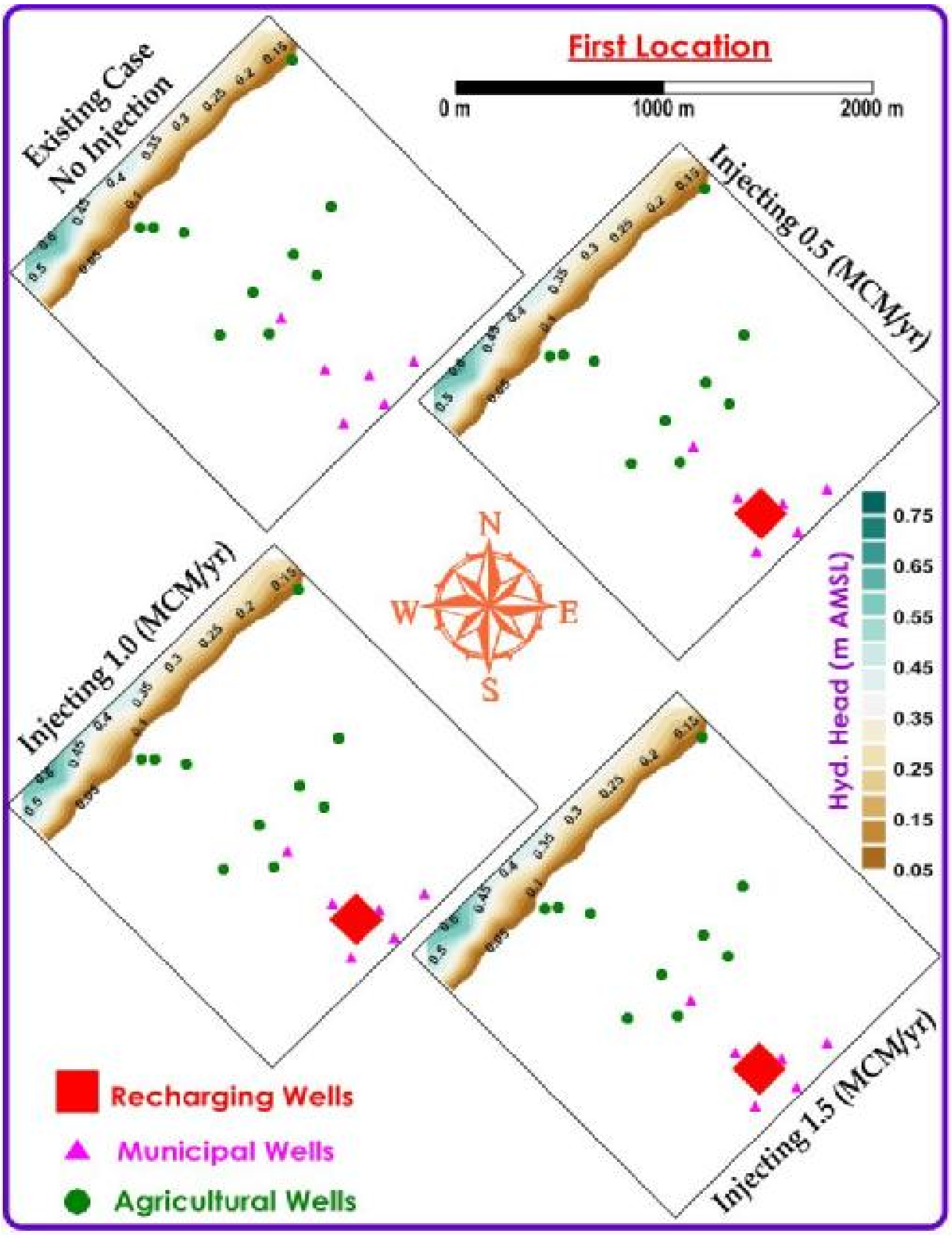

Figure (6.21): Normalized Conc. when the first location was injecting by 0.5, 1.0, and 1.5 MCM/yr

As shown in figure 6.21, the salt concentration at well F/203 was almost zero in all cases. The salt concentration at well G-507 was increased by small amount of 0.12 kg/d i.e. from 3.67 to 3.55 kg/d when 0.5 MCM/yr was injected. It also increased to 3.79, and 3.91 kg/d when 1.0 and 1.5MCM/yr were injected respectively. While the salt concentration at well G/42 increased with changing the injected quantities, for no injection existing case, concentration was 74.84 kg/d. for the injection cases; it was 75.54, 76.32, and 77.16 kg/d for the injecting quantities 0.5, 1.0, and 1.5 MCM/yr respectively. Therefore, the insignificant reduction in the salt concentration occurred in almost all the area once injecting different quantity to first location. This could be due to the small time period of one year used in the simulation, in addition to the small recharged quantities that could induce significant changes to push back the seawater intrusion.

6.3.3 More Optimization Comparisons

1. Deciding the best location option of the recharging basin

To decide the best location out of the first and Second ones, the optimized pumping rates for the area wells were simulated using the CODESA-3D model. The simulated hydraulic head was compared for both options when three different recharging quantities 0.5, 1.0, and 1.5 MCM/yr were injected to the aquifer. Figures 6.22 represented the hydraulic head when the various quantities were injected through the first and second locations respectively.

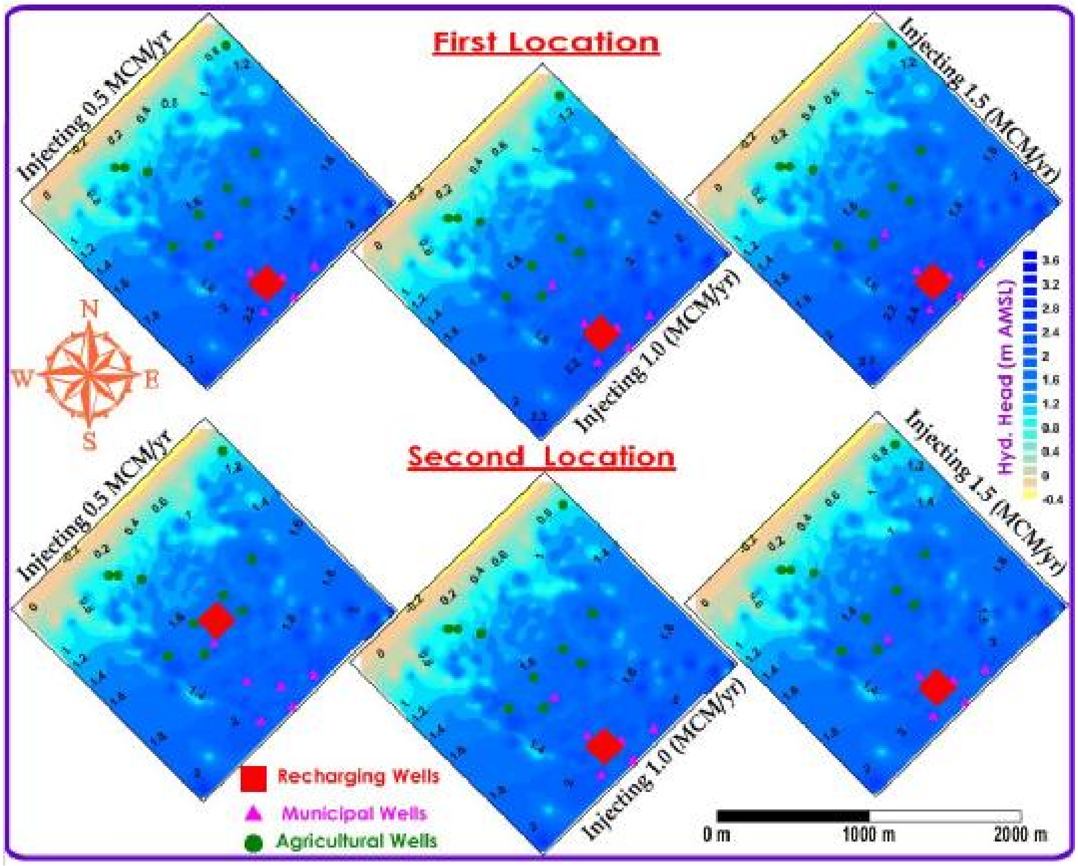

Figure (6.22): comparison between spatial distribution for hydraulic heads in first and second recharging locations once injected with 0.5, 1.0, and 1.5 MCM/yr.

Through the Comparison of the hydraulic head spatial distribution results obtained when the first and second recharging locations were adopted when injected with three different quantities; the first location is the best one as the average head in all wells is greater than that of the second location by 3.4 % when 0.5 MCM/yr was injected, and by 7.1% and 11.1% when 1.0 and 1.5 MCM/yr were injected respectively.

Therefore, the best location of recharging basin is the first one. The obtained results from the S/O is supporting the conclusion of the simulation one regarding the selection of the best location as depending upon the simulation model alone could not judge perfectly.

2. Comparing the simulation alone with the S/O for spatial distribution of hydraulic head when recharging 0.5 MCM/yr artificially

Figure 6.23 represents and compares the spatial distribution of the hydraulic head obtained by recharging 0.5 MCM/yr in the three different locations when the simulation model was executed alone and when the S/O model was run.

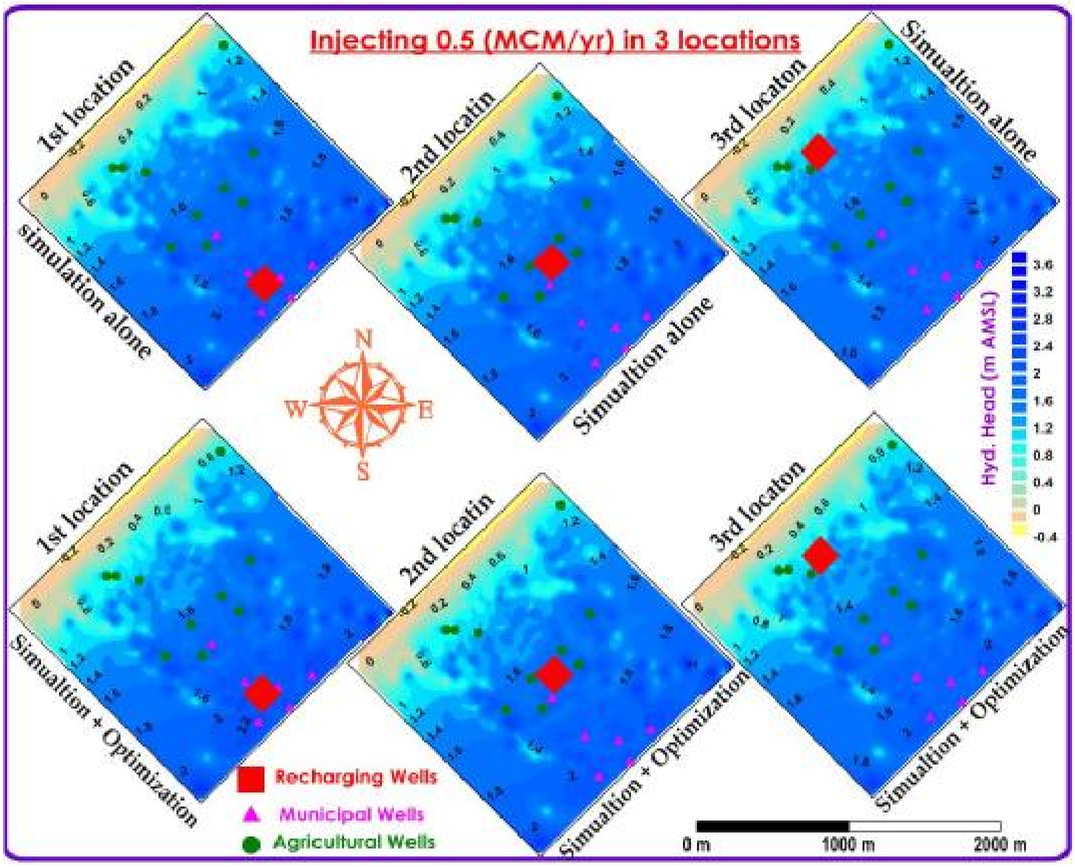

Figure (6.23): comparing spatial distribution of hydraulic head obtained by simulation model alone and S/O model when 3 different locations were recharged with 0.5 MCM/yr.

As shown in figure, there were no significant changes when comparing the obtained results by executing the simulation model with the S/O model. Although, the pumping pattern was kept constant as in the existing situation once the running the simulation model and this pattern was changed by increasing the allowed pumping quantities to include the artificially recharged quantities once executing the S/O model. This could back to the small difference in the two pumping patterns in the two models.

6.4 RESULTS SUMMARY

6.4.2 Results Summery of the Simulation Model

A steady state simulation was performed for year 2008 hydrologic conditions. The results (water level and concentrations) from the steady state simulation were used as initial conditions for transient simulation. After the model development and simulation for the initial parameter estimation, it was calibrated using the same hydrogeological parameters of the calibrated model run by (Qahman, 2005).

A transient stat of one year time period "2008" and 10 years "2018" was adopted to predict the aquifer current status in 2008 and after 10 years more, i.e. 2018 keeping the current pumping pattern as constant.

As obtained from results, the hydraulic head in year 2008 had lowered significantly in the majority of the study area in general. Two main factors affecting the reduction of hydraulic head: the location of wells near the coast had affected as less natural recharged quantities could reach this area; and the high pumping rates.

The obtained results from the simulation model were for the hydraulic/potential head, normalized concentration, and the groundwater pressure for all scenarios. Same quantity was injected through the three locations separately. The achieved results from injecting this constant quantity to these locations were compared among each other in addition to the existing case of no injection with transient state of only one year time period.

Through the adopted nine scenarios, the head was increased near the recharging basin and in almost all the area. Both considerable and slight increase in the head is explained by the closeness of the pumping well and its pumping rate in addition to screen depths and the aquifer strata inclination. Increasing the recharging quantity directly improves the head.

The average of potential head at all wells for the existing case have increased by 110.92% when the recharged quantity was injected by 0.5 MCM through the first location and by 107.92 % and 102.44 % for the second and third locations respectively. when the recharged quantity was increased to 1.0 MCM, the average wells hydraulic head was improved more in average by 121.83% among the existing case and by105.73% on the second and by 116.2% on the third locations. While increasing the recharged quantity to reach 1.5 MCM/yr improves the average of potential head in all wells as the recharged quantity injected through the first location has increased 130.62% among the existing case and by108.06% on the second and by 123.70 % on the third locations. Moreover, a constant head increment when changing the quantities from one to the other. The constant increment in the head values could be due to the constant quantity increment of 0.5 MCM in each scenario, i.e. from 0.5 to 1.0 MCM is equal to 1.0 to 1.5 MCM

The normalized concentration results were utilized to represent the total dissolved solids (TDS) in the groundwater and to indicate the seawater intrusion situation. The average salt concentration was reduced among the existing case, the closeness of the location of recharging basin, and the increase of the recharging quantity. However, there were no significant changes in the normalized concentration in almost all the area once injecting same quantity to the different locations. This could be due to the small time period of one year used in the simulation, in addition to the small recharged quantity that could induce significant changes to push back the seawater intrusion through this period. Table 6.5 summarized the obtained results for the hydraulic head and the salt concentration.

Table (6.5): Results summary for the hydraulic head and the salt concentration

Injection Quantity	No re-charge	0.5 MCM			1.0 MCM			1.5 MCM		
Location		1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Avg. head	1.15	1.28	1.24	1.18	1.40	1.32	1.21	1.52	1.41	1.23
% increase	-	10.92	7.62	2.44	21.83	15.22	4.85	32.62	22.74	7.22
Avg. CL	423	403	404	404	385	386	387	368	369	371
% decrease	-	4.74	4.56	4.44	9.02	8.73	8.49	12.98	12.73	12.38

Based upon table 6.5, selection of the first recharging location could be the most cost effective location, however, the simulation model alone can't confirm the optimum location and the optimum quantity to be recharged; therefore, the optimization model through Genetic Algorithm GA was coupled with this simulation model.

6.4.2 Results Summery of the Optimization Model

Through this study, two nonlinear optimization models are formulated to demonstrate the development of coastal aquifer management models for sustainable beneficial use. Application of this model is illustrated for a real case three-dimensional coastal aquifer system in the northern west of Wadi Gaza. These models are solved for transient state of one year time period.

The first multiple- (two-) objective management model is developed for maximizing sustainable water withdrawal from the aquifer for beneficial uses and for controlling the salinity of the water withdrawn simultaneously. Multiple, often conflicting objectives arise naturally in most real-world optimization scenarios. Management of coastal aquifers for beneficial uses often requires consideration of multiple objectives.

The second multiple- (two-) objective management model is similar to that of model 1 with some modification by taking into consideration the artificial recharge as new alternative source, i.e. for maximizing sustainable water withdrawal from the aquifer for beneficial uses and simultaneously controlling the salinity of the water withdrawn by adding new quantities to the aquifer artificially besides the natural ones.

Through this model, (9) nine configurations for the artificial recharge were generated to assess the most effective and less expensive strategy for artificially groundwater recharging. Three different locations for the recharging basin were proposed with three different quantities 0.5, 1.0, and 1.5 MCM/yr injected through each location separately. In each location, the injected quantities were added to the total safe yield in order to get benefit of these quantities. In addition, the model was allowed to pump the total natural and artificial recharged quantity.

Running the management model with the final format for the objective function (eq. 5) was based upon justifying the feasible value of salinity weighing parameter (P2= 25). Table 6.2 denotes the optimal pumping quantities that ensure the minimization of the salinity "objective function", as well as the actual annual production. Obtaining the optimum pumping results from the management model maintains the optimal pumping strategy for the existing wells by either increasing or decreasing the actual productions according to the optimum ones.

First, the application of model 1; based upon the attained optimum pumping for the study area wells using the coupled simulation optimization (S/O) model, the spatial distribution of the total hydraulic/potential heads at the upper layer were simulated. The heads exposed the optimal pumping strategy. The hydraulic heads had increased in the majority of the study area as soon as the S/O model was carried out as compared with the simulated ones using the simulation model alone.

The normalized concentration results were utilized to represent the total dissolved solids (TDS) in the groundwater and to indicate the seawater intrusion situation. The salt concentration at some wells was increased by alerting from the only simulation model to S/O model. This increase in the salt concentration is due to the increase of pumping quantities more than the actual pumping. However, the salt concentration at some wells was decreased when the optimizer identified the optimum pumping rates by reducing the pumping quantities. Insignificant reductions in the normalized concentrations in almost all the area was occurred by adopting the S/O model instead of depending upon the simulation model alone. Therefore, it is worth enough to utilize the S/O techniques as a robust alternative to the simulation models alone in the groundwater management.

Through the application of model 2, nine adopted scenarios of the artificial recharge had been developed. Optimum pumping scenarios for each proposed location of the three artificial recharging facilities that injected by three different quantities separately were acquired. The three proposed quantities of the artificial recharge were added to the total natural safe yield. The model allowed pumping all the natural and artificial recharge quantity in every case.

Comparing the obtained results through changing the location of the artificial recharge identified the most cost effective location. Through all injection quantities scenarios, the *first and second locations* had allowed the maximum pumped quantities as compared with that allowed by the third location. The current hydraulic head at some wells increased by very small amount; however, in some wells the head had decreased. The insignificant head increase or decrease; specially, when the injected quantity increased could be explained as a result of high increase in the pumped quantities from the total allowed quantities which equals the natural and artificial recharge quantities. In addition to the some farness of the well location to the recharging location; the insignificant reduction occurred in the salt concentration in almost all the area once injecting different quantity to first location. This could be due to the small time period of one year used in the simulation, in addition to the small recharged quantities that could induce significant changes to push back the seawater intrusion.

In order to decide the best location out of the first and Second ones, the optimized pumping rates for the area wells were simulated using the CODESA-3D model. the simulated hydraulic head was compared for both options when three different recharging quantities 0.5, 1.0, and 1.5 MCM/yr were injected to the aquifer. Through the comparison of the hydraulic head spatial distribution results obtained when the first and second recharging locations were adopted when injected with three different quantities; the first location is the best one as the average head in all wells is greater than that of the second location. Therefore, the best location of recharging basin is the first one. The obtained results from the S/O is supporting the conclusion of the simulation one regarding the selection of the best location as depending upon the simulation model alone could not judge perfectly.

Chapter 7: CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION

Recently, Gaza coastal aquifer faced huge crises regarding the water resources scarcity and contamination by seawater intrusion. Accordingly, real concerns for planning, development, and management of available resources became so required to alleviate of such crises through searching for new additional resources. The artificial recharge technique is one of these new alternative resources.

Many studies internationally tried to manage the coastal aquifers by providing possible solutions for the seawater intrusion problems through prospective of artificial recharge techniques. These studies developed many tools/models to acquire helpful information by prediction of the aquifer responses regarding the adoption of artificial recharge. Through this study, the aquifer response took the form of water levels and salinity changes.

The developed groundwater simulation models can provide the resource planner with important tools for managing the groundwater system, however, as a result of groundwater complex nature , achieving best management options could be so difficult by using the simulation models alone due to their requirements to high number trials which need enormous computing time and effort. Therefore, the numerical groundwater simulation model has been combined with optimization models in order to identify the best management strategy under consideration of the management objectives and constraints. In addition, there are many ways to combine both simulation and optimization models in single frameworks such as Genetic Algorithms (GAs).

Through this study, two approaches were used to record the groundwater responses once artificial recharge options were imposed. Three different locations for the artificial recharge facility were suggested in the study area with changing the recharged quantity with three different ones 0.5, 1.0, and 1.5 MCM/year for each location. The recharging quantities could be provided through the annual storm water and the reclaimed wastewater. However, quality of these quantities should satisfy the recharging standards for similar aquifer hydrogeological properties. The first approach was based on the simulation model alone and the second based on simulation/optimization model with application to the Gaza aquifer.

Through the first approach, 3D coupled groundwater flow and transport model CODESA 3D (simulation model) was generated by conceptualizing the real word aquifer by constructing the 3D mesh using a pre and post processing software Argus One based upon the finite difference method.

In the simulation model, the input data was collected from the related literatures and requested from related institutes, however a field survey was applied to overcome the shortage and to update the old ones .

The developed model was used to predict the potential hydraulic head and the normalized concentration of groundwater which is the representative of the seawater intrusion phenomenon, during both current situations (no recharge options were adopted) and imposing artificial recharge sceneries.

For the real world simulation, the results of the simulation obtained for year 2008 was compared with the predicted results for year 2018 (10 years later). The results indicated that the hydraulic heads were dropped by average of 9.30 % in almost all the area, although the well pumping pattern was kept constant along the whole period. Therefore, the uncontrolled pumping scenario is definitely leading to the water level drops with respect to the time increment. This also is potentially making the aquifer susceptible to seawater intrusion contamination.

For the artificial recharge scenarios, the obtained simulation results were first compared with the existing situation of no artificial recharge. The results showed that the adoption of the artificial recharge facility in any location (3 locations) is much better than the current situation with respect to both hydraulic head and normalized concentration, although, the well pumping pattern scenario was kept constant i.e. the abstraction from the aquifer was kept constant for both cases. Whereas, for instance, the average of potential head at all wells for the existing situation have increased by 110.92% when the 0.5 MCM/yr was injected through the first location and by 107.6 % and 102.5 % for the second and third locations respectively. Farther more, this average was increased more by increasing the recharging quantity, till the head improvement reached 132.62% for the first location injected with 1.5 MCM/yr

In addition, the simulation results obtained from the artificial recharge scenarios were compared among each others for prospective of variety of recharging basin locations. The recharging quantity was kept constant for the three different locations for each comparison. The results comparison mainly performed to preliminarily assess the cost effective location of the artificial recharge facility in the study area. The first location (near the landside boundary) was indicated as the best location among other two locations. The hydraulic head, although, was slightly improved in all wells by an average of 3.07% among the second location and by 8.3% among the third one when the recharging quantity was 0.5 MCM/Yr. This could back to the location of the pumping wells and their distributions near the first location.

The recharged quantity was increased two times from 0.5 to 1.0 MCM/yr and from 1.0 to 1.5 MCM/yr. This increment was generated to assess the coast effective quantity that the aquifer needs to satisfy the agglomerated demand without posing the aquifer to the seawater intrusion contamination. For example, the average hydraulic head was improved by 9.85 % when the quantity increased from 0.5 to 1.0 MCM/yr for the first location and by 7.06 % and 2.35 % for the second and third locations respectively. The maximum increase in the hydraulic head was achieved for the first location among the other two locations when the recharged quantity was increased. This also leads to the most feasibility of the first location. Moreover, the average head was raised by 8.86 %, 6.52 %, and 2.26 % when the injected quantity was augmented from 1.0 to 1.5 MCM/yr for the locations first, second, and third respectively.

A cross section was made in the domain area far away from the sea side by about 200 m in order to check the normalized concentration of the sub aquifer groundwater. The normalized concentration was computed at this section for existing case as well as for the nine recharging scenarios. The results obtained from the simulation model for the current situation was compared with that for the recharging options. There was a clear reduction in the groundwater concentration of the existing case when injected water through the different locations; however, there were slight changes when the three injection scenarios were compared with each other. This could indicate the feasibility of the recharging basin and its different locations in the study area as an alternative to protect the aquifer for possible deterioration by seawater intrusion.

The second approach was based on simulation/optimization model. The groundwater simulation model CODESA-3D was linked externally with the management (optimization) model using Genetic Algorithm GA technique. Through this management model, two optimization models were formulated, the first multiple-(two-) objective management model is developed for maximizing sustainable water withdrawal from the aquifer for beneficial uses and for controlling the salinity of the water withdrawn simultaneously. Moreover, no alternative options/sources have been taken into account, i.e. no artificial recharge was adopted; therefore, the model solution has determined the optimal spatial distribution of pumping for both beneficial uses and seawater intrusion control from the existing wells only. While the second multiple-(two-) objective management model is similar to the first model with a modification by adopting the artificial recharge as new alternative source, i.e. for maximizing sustainable water withdrawal from the aquifer for beneficial uses and simultaneously controlling the salinity of the water withdrawn by adding new quantities to the aquifer artificially besides the natural ones. the injected quantities were added to the total safe yield in order to get benefit of these quantities i.e. the model was allowed to pump the total natural and artificial recharged quantity.

As common, in the multiple (two-) objective management problem that uses the genetic algorithm techniques to optimize the design variables (the pumping rates) by encoding them as binary string within the well capacity constraints. GAs are ideally suited for unconstrained optimization problems. While the present constrained problem, i.e. two objective functions (maximize pumping and minimize salinity) and constrains (max. pumping and min. salinity). Therefore, converting constrained problem to an unconstrained one is a must. To do this extension, the weighed sum method is used to incorporate the available objective functions in a single scalar objective function. In which, two weighing parameters were required to be determined i.e. the pumping and salinity weighing parameters. The model was run eight times with different salinity weighing parameter to identify the feasible value that could viably run the final management model; while the pumping weighing parameter was kept constant for all runs. The most cost effective and most feasible salinity weight is the point which represents high pumping quantities with reasonable salinity. Setting up its weighing parameter equals 10 satisfied this condition as the maximum pumping was ensured and the salinity was still within the reasonable limits.

The results of the management model 1 indicated the optimal spatial distribution for the study area wells by assessing the maximum allowed quantity to be pumped. The current uncontrolled and unplanned well pumping pattern is needed to be reallocated according to these results as no new alternatives of artificial recharged was adopted.

By comparing the results of the management model 2 obtained by adopting three different recharging locations distributed in the study area, the second location (at the middle of the area) was the best cost effective as the maximum allowed pumping by the aquifer was greater than that obtained when the first and third locations (near the land side boundary and sea side boundary) were adopted respectively. Moreover, Based upon the attained optimum pumping for the study area wells using the coupled simulation optimization (S/O) model, the spatial distribution of the hydraulic/potential heads and the normalized concentrated at the upper layer were simulated. The heads exposed the optimal pumping strategy taking into consideration controlling the seawater intrusion phenomenon.

Three different quantities to be recharged 0.5, 1.0, and 1.5 MCM/yr through the recharging basin installed in the three location were adopted separately. However, results obtained by adopting these quantities injected into the best location "the first" were to identify the most cost effective quantity. Comparing these results could help in deciding the best improvements achieved on both aquifer capacity to receive more quantities and the current pumping pattern.

Although the increase of recharging quantity in the second scenario was doubled the quantity of the first; the percent increase in the pumped quantity among the existing case was improved from 26.0% to 51% (almost double). This means that the aquifer still needs more recharging quantities. In addition, the increase of recharging quantity in the third scenario was three times greater than that of the first scenario; the percent increase was raided from 26% to 76% (almost three times). This means that the aquifer still needs more quantities of water to be recharge. This could conclude that the best quantity is 1.5 MCM/yr recharged in the first location.

7.2 RECOMMENDATION

Based on the achieved results the study recommends the following:

1. Appropriate effort is highly required for recording the hydrological data such as the spatial distribution of available wells water levels, production, quality parameters such as chloride and nitrate concentration. A strong data base using these data could be built.

2. Urgent interventions should be carried out to protect the groundwater aquifer from probable contamination by seawater intrusion. This could be by searching for socio economic sources alternatives such as the artificial recharge in order to compensate the huge gap between the rapid increase demand and the available supply. Moreover, using the artificial recharge options could partially alleviate the crisis of aquifer contamination by seawater intrusion.

3. Coupling CODESA-3D miscible flow and solute transport groundwater simulation model with the optimization (management) model through the Genetic Algorithm GA technique is one of the effective models for managing the seawater intrusion problems in the coastal areas.

4. The used management model in this study was based on maximizing the pumped water for beneficial uses and minimizing the salinity using the artificial recharge options only, other possible alternatives could be incorporated in this model such as the desalination. Moreover, the cost prices of adopting either the artificial recharge or any other incorporated alternatives should be taken into account in further studies.

5. The time period used in the management model was one year; therefore, the model could be rerun for different long term periods in order to attain certain long term management plan.

6. Further studies and research are required to investigate the proper quality of recharged water either by the storm water, the reclaimed wastewater or both.

7. It is recommended to replicate the work taking the model specific recommendation for areas in Gaza strip that has similar hydrological and hydrogeological properties of study area.

8. It is recommended also to rerun the model with increasing the area of the study, moreover, make the model to determine the optimal locations for the groundwater abstraction (wells).

REFERENCES

Abu Heen Z. and Lubbad S. (2005), Assessment of Groundwater Quality in Gaza City (South Of Palestine) during the period (1994-2004) /Ninth International Water Technology Conference, IWTC9, Sharm El-Sheikh, Egypt. 2005 [Cited at 2008, march.13] Available: http://www.angelfire.com/pro2/iwtc/2005_pdf/06-6.pdf

Adeloye B. and Al-Najar H. (2005) , The effect of urban expansion on groundwater as a renewable resource in the Gaza Strip, RICS Research paper series Volume 5, Number 8. April, 2005 [Cited at 2008, Sep .8] Available: http://www.foeme.org/docs/Gaza_groundwater.pdf

Afifi S. (2006), Wastewater reuse status in Gaza Strip: Palestine, Int. J. Environment and Pollution (IJEP), Vol. 28, No. 1/2, 2006.

Aish A. (2004), Hydrogeological Study and Artificial Recharge Modeling of the Gaza Coastal Aquifer Using GIS and MODFLOW , Department of Hydrology and Hydraulic Engineering, Vrije Universiteit Brussel, PHD research, Nov. 2004 [Cited at 2008, Jul. 02] Available: http://twws6.vub.ac.be/hydr/download/AdnanAish.pdf

Aish, A., and F. De Smedt (2004), Modeling of a Groundwater Mound Resulting From Artificial Recharge in the Gaza Strip, Palestine, Proceedings of the Second Israeli-Palestinian International Conference on Water for Life in the Middle East, October 10-14, 2004, Turkey, pp. 114-122, [cited at 2008, Jan .03] Available: http://www.ipcri.org/watconf/papers/adnan.pdf

Al Yaqoubi A. (2007), Country Paper: Water Resources Statistical Records in Palestine ,Economic and Social Commission for Western Asia, Cairo, Egypt. June 5-, 2007 [Cited at 2008, march .13] Available: http://www.escwa.un.org/divisions/events/Countrypapers/5june07Palestine.pdf

Alvarez G. (2002), Can we make genetic algorithms work in high-dimensionality problems?, Stanford University, Stanford, California, USA. Nov. 2002 [Cited at 2009, May. 11] Available: http://sepwww.stanford.edu/public/docs/sep112/gabriel1/paper_html/

Arlai Ph. (2007), Numerical Modeling of possible Saltwater Intrusion Mechanisms in the Multiple-Layer Coastal Aquifer System of the Gulf of Thailand, kassel university press GmbH, Kassel. April 2007 [Cited at 2008, May .22] Available: http://www.upress.uni-kassel.de/online/frei/978-3-89958-293-2.volltext.frei.pdf

Assaf S. (2001), Existing and the future planned desalination facilities in the Gaza Strip of Palestine and their socio-economic and environmental impact, European Conference on Desalination and the Environment, Desalination 138, pp 17–28, Elsevier Science B.V. May 2001

B. Datta and V.Harikrishna, "Optimization Applications in Water Resources Systems Engineering" www.iitk.ac.in/directions/directsept04/bithin~new.pdf

Barakat M. (2005), Optimal water resources Management in the southern Gaza strip, Master of since in water resources management, Islamic university, Gaza, Palestine.

Barlow P. (2005),Use of Simulation-Optimization Modeling to Assess Regional Ground-Water Systems, U.S. Department of the Interior-U.S. Geological Survey, Fact Sheet 2005–3095, August 2005 [Cited at 2008, Oct .13]
Available: http://pubs.usgs.gov/fs/2005/3095/pdf/factsheet.pdf

Benhachmi M., Ouazar D., Naji A., Cheng A., and EL Harrouni K. (2001), Optimal Management in Saltwater-Intruded Coastal Aquifers By Simple Genetic Algorithm , First International Conference on Saltwater Intrusion and Coastal Aquifers—Monitoring, Modeling, and Management. Essaouira, Morocco, April 23–25, 2001 [Cited at 2009, May. 03]
Available: http://www.olemiss.edu/sciencenet/saltnet/swica1/Benhachmi-Ouazar-Naji-paper-2.pdf

Bhattacharjya R. and Datta B. (2005), Optimal Management of Coastal Aquifers Using Linked Simulation Optimization Approach, Water Resources Management, Springer 19: pp. 295–320.

Bhattacharjya R. and Datta B.(2004), An ANN-GA Approach for Solving Saltwater Intrusion Management Problems in Coastal Aquifers ,8th SWIM, Cartagena (Spain), 31 May - 3 June 2004. [Cited at 2008, April .03]
Available: http://www.geo.vu.nl/users/swim/pdf/swim18/Bhattacharjya.pdf

Bhattacharjya, R., and Datta, B. (2005), Optimal management of coastal aquifer using linked simulation optimization approach, Water Resources Management, 19(3), pp. 295-320.

Camas B. (2007), Saltwater Intrusion Simulation In Heterogeneous Aquifer Using Lattice Boltzmann Method, Master study research, Polytechnic University of Madrid, Spain. May 2007 [Cited at 2008, Jun .12]
Available:http://etd.lsu.edu/docs/available/…./unrestricted/BORJA_THESIS.pdf

Carroll, D. L.(1996), "Genetic Algorithms and Optimizing Chemical Oxygen-Iodine Lasers," Developments in Theoretical and Applied Mechanics, Vol. XVIII, eds. H.B. Wilson, R.C. Batra, C.W. Bert, A.M.J. Davis, R.A. Schapery, D.S. Stewart, and F.F. Swinson, School of Engineering, The University of Alabama, 1996, pp.411-424.

Cau P., Lecca G., Ardau F. (2006), Automatic calibration of a 3D groundwater model applied to the Muravera-Flumendosa coastal aquifer, SE Sardinia, Italy, CMWR-XVI International Conference 18-22 June 2006, Copenhagen, Denmark

Cau P., Lecca G., Muscas L., Barrocu G., and Uras G. (2002), Seawater Intrusion In The Plain Of Oristano -Sardinia, Italy, 17th Salt Water Intrusion Meeting, Delft, The Netherlands, 6-10 May 2002.

Central Ground Water Board (CGWB). (2000), GUIDE on ARTIFICIAL RECHARGE to GROUND WATER, MINISTRY OF WATER RESOURCES, NEW DELHI , India. May 2000 [Cited at 2008, Dec .22]
Available: http://cgwb.gov.in/documents/Guide_on_ArtificialRecharge.pdf

Cheng, A. H.-D, Halhal D., Naji A., and Ouazar D., (2000), Pumping optimization in saltwater-intruded coastal aquifers , Water Resource. Res., 36(8), pp. 2155-2165.

Das A., and Datta B. (1999), Development Of Management Models For Sustainable Use Of Coastal Aquifers, Journal of Irrigation and Drainage Engineering, Vol. 125, No. 3, Paper No. 17391, ASCE. June,1999 [Cited at 2008, April .11]
Available: http://www.ksu.edu.sa/sites/Colleges/Papers/Papers/sustainUse.pdf

Das A., and Datta B. (2001), Simulation of seawater intrusion in coastal aquifers: Some typical responses" Sadhana, Vol. 26, Part 4, August 2001, pp. 317–352. [Cited at 2008, Oct .22]
Available: http://www.ias.ac.in/sadhana/Pdf2001Aug/pe866.pdf

Das A. and Datta B. (2001), Application of optimisation techniques in groundwater quantity and quality management , S. adhan. , Vol. 26, Part 4, pp. 293-316. [Cited at 2008, April .02]
Available: http://www.ias.ac.in/sadhana/Pdf2001Aug/pe865.pdf

Deb K. (2002), Multi-Objective Optimization using Evolutionary Algorithms, Multi-Objective Optimization using Evolutionary Algorithms, First Edition, John Wiley & Sons Pte Ltd, 2002. [Cited at 2009, May. 03]
Available: http://www.iitk.ac.in/kangal/papers/nbook.pdf

Dudeen B. (2001), Soil resources of Southern and Eastern Mediterranean countries: The Soils of Palestine (The West Bank and Gaza Strip) Current Status and Future Perspectives, IAM-BARI- Options Méditerranéennes. Série B, no. 34. [Cited at 2008, Sep .12]
Available: http://www.lrcj.org/Studies/Soil_of_Palestine/Soils%20of%20Palestine.pdf

EC Initiative AVICENNA (AVI-CT95-73), (2000), Salt Water Intrusion Management in Coastal Aquifers, European Commission, pp. 238-254.

El Sheikh, R. & S. Hamdan. (2002), Artificial recharge in Palestine: A new technique to overcome water deficit, In Dillon (Ed) Management of Aquifer Recharge for Sustainability, Proceedings of the fourth International Symposium On Artificial Recharge, ISAR 4, Adelaide, 22-25 Sept. 2002

El-Nakhal H. (2004), Alternatives to tap water: a case study of the Gaza Strip, Palestine, Springer-Verlag 2004, 19 April 2004 [Cited at 2008, Jul .02] Available: http://www.springerlink.com/index/6XK821RQPTW85E69.pdf

Gambolati G., Putti M., and Paniconi C. (1999) , Three dimensional model of couple density dependent flow and miscible salt transport in groundwater : seawater intrusion in coastal aquifers - concepts , methods, and practices, in: J. Bear, A. D. cheng, S.

Sorek, D. Ouazar, I. Herrera, eds., Kluwer Academic Publisher, Dordrecht, The Netherlands, pp 315-362

Hamdan S. and Jaber I. (2001), Artificial Infiltration of Groundwater: A Tool towards the Sustainability of Water Resources in the Gaza Strip, Sixth International Water Technology Conference, IWTC, Alexandria, Egypt 2001. [Cited at 2008, mar .13] Available: http://www.angelfire.com/pro2/iwtc/2001_pdf/03-5.pdf

Hamdan S., Troeger U., Nassar A. (2007), Stormwater availability in the Gaza Strip, Palestine, International Journal of Environment and Health, Volume 1, Number 4 / 2007, pp. 580 – 594 [Cited at 2008, April. 28] Available: http://inderscience.metapress.com/index/X0M48X7102827585.pdf

Hammouri N. and El-Naq A. (2007), Hydrological modeling of ungauged wadis in arid environments using GIS: a case study of Wadi Madoneh in Jordan, Revista Mexicana de Ciencias Geologicas, v.24, no. 2, 2007, pp. 185-196 [Cited at 2008, March. 09] Available: http://rmcg.unam.mx/24-2/(5)Hammouri.pdf

Hu X. , and Di Paolo E. (2007), An Efficient Genetic Algorithm with Uniform Crossover for the Multi-Objective Airport Gate Assignment Problem, IEEE Congress on Evolutionary Computation, CEC 2007, Singapore, September 25-28, 2007 [Cited at 2009, Jan. 21]
Available: http://www.secse.net/publications/docs/sussex/hu07d.pdf

Ismail M. (2003), Prospects of Water Desalination in the Gaza Strip, TRITA-LWR Master of Science Thesis, Stockholm 2003, [cited at 2008, Feb. 10]
Available: http://www.lwr.kth.se/Publikationer/PDF_Files/LWR_EX_04_10.PDF

Krishnamurthy S. (2003), Optimization of Natural Attenuation with Active Remediation under uncertainty using a multi-objective genetic algorithm, M.Sc. Thesis, Civil and Environmental Engineering Department, the Florida State University. Dec. 2003. [Cited at 2009, May. 03]
Available: http://etd.lib.fsu.edu/theses/available/.../unrestricted/05chapter3.pdf

Kumar C. (2002), Groundwater Flow Models, Technical note, National Institute of Hydrology, Roorkee , India (2002) [Cited at 2008, March. 29]
Available: http://www.docstoc.com/docs/3365196/Groundwater-Flow-Models

Lecca G. (2000), Implementation and testing of the CODESA-3D model for density dependent flow and transport problems in porous media, Center for Advanced studies, Research, and development (CRS4),Sardinia, Italy. July 2000

Lecca G., Paniconi C., Bettio F., Muscas L., and Leonardi E. (1998), A Modular approach to the KORBA aquifer seawater intrusino study, simualtion, Data manipulation and visulaization for the 3-D model, Center for Advanced studies, Research, and development (CRS4),Sardinia, Italy.

Lyonnaise des Eaux (LYSA). (1995), Assessment of Water and sewage public services in the Gaza Strip, Prepared to the Palestinian Authority. Gaza- Palestine.

Mohammed A. (2007), Prospects of private sector Participation for sustainable water and sanitation services in the Gaza strip" M.Sc. Research, Engineering Faculty, Islamic university –Gaza, Palestine. January 2007

Mohan S., and Pramada S. (2005), Multi Objective Optimisation to seawater Intrusion Problem in South Chennai Aquifer System, Asia Oceania Geosciences Society, Singapore. 2005 [Cited at 2009, May. 11]
Available: http://www.asiaoceania.org/abstract/hs/58-HS-A0793.pdf

Mohan S., Sreejith P., and Pramada S. (2007), Optimization of Open-Pit Mine Depressurization System Using Simulated Annealing Technique, Technical Notes, Journal Of Hydraulic Engineering, ASCE. July, 2007 [Cited at 2009, April. 30] Available: http://hal.iwr.uni-heidelberg.de/~sreejith/QHY000825.pdf

Ndambuki, Otieno, Stroet, and Veling (2000), Groundwater management under uncertainty: A multi-objective approach, Water SA Vol. 26 No. 1, ISSN 0378-4738, January 2000. [Cited at 2009, April. 18]
Available:
http://www.wrc.org.za/archives/watersa%20archive/2000/January/jan00_p35.pdf

Obitko M. (1998), Introduction to Genetic Algorithms, Hochschule für Technik und Wirtschaft Dresden (FH) (University of Applied Sciences) , September 1998 [Cited at 2009, Jan. 21]
Available:http://saba.kntu.ac.ir/eecd/Fatehi/Lectures/Intelligent%20Systems/GeneticAlgorithms/ga_pdf.pdf

Palestinian Central Bureau of Statistics (PCBS). (2008), Press Conference on the Preliminary Findings (Population, Buildings, Housing Units and Establishments), PCBS, Ramallah, Palestine. February, 2008

Palestinian Central Bureau of Statistics (PCBS). (2006) , The Press Release in the Occasion of the World Meteorological Day, 23/03/2006, PCBS, Palestine. March 2006

Palestinian Water Authority (PWA)/ USAID (2000), Coastal Aquifer Management Program (CAMP), Final Model Report (task 7). PWA, Palestine.

Palestinian Water Authority (PWA) /Data Bank Department. (2003), Yearly Data Books. PWA. Gaza. Palestine,

Palestinian Water Authority (PWA) /Data Bank Department. (2008), Yearly Data Books. PWA. Gaza. Palestine.

Palestinian Water Authority (PWA) and Lyonnaise des Eaux, Khatib &Alami (LEKA). (2003), Financial Data for the fiscal year 2002. PWA, LEKA. Yearly report. Gaza, January 2003.

Palestinian Water Authority (PWA). (2007), Agricultural And Municipal Water Demand In Gaza Governorates For 2006, PWA, Gaza, Palestine. August 2007.

Palestinian Water Authority (PWA)/ Institutional Reform and Capacity Building Component , 0206 (IRCB). (2007), wastewater Situation in Gaza Governorates (Facts and Challenges), November, 2007

Paniconi C., Khlaifi I. Lecca G. , Giacomelli A. and Tarhouni J. (2001), Modeling and Analysis of Seawater Intrusion in the Coastal Aquifer of Eastern Cap-Bon, Tunisia, Springer, Earth and Environmental Science, Volume 43, Number 1 / April, 2001, Netherlands.

Papadopoulou M., Karatzas G., Koukadaki M., and Trichakis Y. (2005) , Modeling the Saltwater Intrusion Phenomenon in Coastal Aquifers - a case study in the industrial zone of herakleio in crete, Global NEST Journal, Greece. Vol. 7, No 2, pp. 197-203, 2005 [Cited at 2008, May .15]
Available:http://www.gnest.org/journal/Vol7_No2.asp?url=Vol7_No2/paper_6_papadopoulou_335.pdf

Peralta R. (2004), Optimizing management of nonlinear flow and transport in groundwater and surface water systems, Utah State University, Utah 84322-4105, USA [Cited at 2008, Oct .22]
Available:http://www.usurf.org/units/wdl/somos-downloads/optimization-management-of-nonlinear-flow.pdf

Peralta R., Kalwij I., and Shengjun I. (2003), Practical Simulation / Optimization Modeling for Groundwater Quality and Quantity Management, International Ground Water Modeling Center [Cited at 2009, May. 03]
Available:http://www.usurf.org/units/wdl/somos-downloads/modflow2003ProcV2.pdf

Perera E., Jinno K., Tsutsumi A., and Hiroshiro Y. (2008), Development and Verification of a Three Dimensional Density Dependent Solute Transport Model for Seawater Intrusion, Memoirs of the Faculty of Engineering, Kyushu University, Vol. 68, No.2, June 2008.

Prasad K. and Rastogi A. (2001), Estimation of Net Groundwater Recharge in Large Aquifer Systems By Genetic Algorithm: A Case Study, Korea Water Resources Association- Water Engineering Research, Volume 2, No. 3, pp. 161-169, 2001. [Cited at 2009, May. 04]
Available: http://kfki.baw.de/conferences/ICHE/2000-Seoul/pdf/101/PAP_135.PDF

Prieto C. (2005), Groundwater-seawater Interactions: Seawater intrusion, submarine Groundwater discharge and temporal Variability and randomness effects ,TRITA-LWR PhD Thesis, ISSN 1650-8602 [Cited at 2008, march .13] Available: http://www.lwr.kth.se/Publikationer/PDF_Files/LWR_PHD_1019.pdf

Qahman K. (2004), Aspects of Hydrogeology, Modeling, and Management of Seawater Intrusion for Gaza Aquifer – Palestine , PhD Thesis.

Qahman K. and Zhou Y.(2001), Monitoring of Seawater Intrusion in the Gaza Strip, Palestine First International conference on Saltwater Intrusion and Coastal Aquifers Monitoring, Modeling, and Management. Essaouira, Morocco, April 23-25, 2001.

Qahman K. and Larabi A. (2005) , Evaluation and numerical modeling of seawater intrusion in the Gaza aquifer (Palestine) Hydrogeology Journal, Springer-Verlag. September 2005

Qahman K., Larabi A., Ouazar D., Naji A., & Cheng A.(2005), Optimal and sustainable extraction of groundwater in coastal aquifers, Springer-Verlag & Stoch Environ Res Risk Assess,3 Feb 2005.

Rusteberg B. (2006), Groundwater Artificial Recharge by Alternative Sources of Water to guarantee Water Supply in the Future: The European Research Project GABARDINE, Geoscience Center - University of Gottingen, Germany.2006. [Cited at 2008, April .02]
Available: http://www.srcosmos.gr/srcosmos/showpub.aspx?aa=8758

Sánchez-Vila X., Barbieri M. (2005) , Groundwater artificial recharge based on alternative sources of water: advanced integrated technologies and management, sixth framework programme -gabardine project, Universitat Politècnica de Catalunya (UPC), Nov. 2005

Shomar B., Muller G., and Yahya A. (2004), Geochemical features of topsoils in the Gaza Strip: Natural occurrence and anthropogenic inputs, Elsevier, Environmental Research 98 (2005) pp 372–382 . December 2004 [Cited at 2008, Sep .22]
Available:http://www.rzuser.uni-heidelberg.de/…/Basem/Soilgeochemistry.pdf

Shomar B., Muller G., and Yahya A. (2005), Geochemical Characterization of Soil and Water From a Wastewater Treatment Plant in Gaza" Taylor & Francis Inc. Soil & Sediment Contamination, 14: pp 309–327 [Cited at 2008, Oct. 01]
Available: http://www.rzuser.uni-heidelberg.de/~i02/muelhome/Basem/Soilprofile.pdf

Sivanandam S., and Deepa S. (2008), Introduction to Genetic Algorithms, ISBN 978-3-540-73189-4, Springer Berlin Heidelberg, New York, USA.

Sreejith P. and Mohan S. (2002), A Combined Simulation-Optimization Approach for Saltwater Intrusion Control: a case study, Chennai.2002. [Cited at 2008, April.02] Available: http://hal.iwr.uni-heidelberg.de/~sreejith/Hydro-2002-Sreejith.pdf

Tran T. (2004), Multi-Objective Management of Saltwater Intrusion in Groundwater: Optimization under Uncertainty, Delft University Press, The Netherlands. Apr,2004 [Cited at 2008, Aug .25] Available : http://www.olemiss.edu/sciencenet/saltnet/thesis/tran.pdf

Uddameri V., Kuchanur M. , and Balija N. (2006), Aquifers of the Gulf Coast of Texas: Optimization-Based Approaches for Groundwater Management, Texas Water Development Board, Report 365. Feb, 2006 [Cited at 2008, Aug .05]
Available:http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/R365/R365_Composite.pdf

United Nation(UN). (2007), Gaza Strip Humanitarian Fact Sheet [cited at 2008, Jan. 8]
Available:http://www.ochaopt.org/documents/GazaStripHumanitarianFactSheet_2007_11_28.pdf

United Nations Environment Program (UNEP). (2002), Desk Study on the Environment in the Occupied Palestinian Territories, Global Ministerial Environment Forum in Cartagena, Colombia. 2002, Feb. 15, [cited at 2008, Feb. 20]
Available: http://postconflict.unep.ch/publications/INF-31-WebOPT.pdf

United Nations Environment Programme (UNEP). (2002a), Global Environment Outlook (GEO-3), p. 416 .

Weise Th., Skubch H., Zapf M., and Geihs K. (2008) ,Global Optimization Algorithms and their Application to Distributed Systems, Distributed Systems Group, Fachbereich 16: Elektrotechnik/Informatik, University of Kassel, Germany. October 2008 [Cited at 2009, Jan. 21]
Available:http://www.it-weise.de/documents/files/…/WSZG2008GOAATATDS.pdf

Whitley D. (1994), A Genetic Algorithm Toturial, Computer sicence department, Colorado State University. Statistics and Computing , 4: pp. 65-85. 1994 [Cited at 2009, Jan. 21]
Available: http://www.cs.uga.edu/~potter/CompIntell/ga_tutorial.pdf

Widagda L. and Jagranatha I. (2005), Recharge Calculation of Lahendong Geothermal Field in North Sulawesi-Indonesia, Proceedings World Geothermal Congress, Antalya, Turkey, 24-29 April 2005 [Cited at 2009, March. 29] Available: http://iga.igg.cnr.it/pdf/WGC/2005/1940.pdf

Yakirevich A , Melloul A., Sorek S., Shaat S. (1998), Simulation of seawater intrusion into the Khan Yunis area of the Gaza Strip coastal ,J. of Hydrogeology 6: pp. 549-559.

Yang Y., Kalin M., Zhang Y., Lin X., and Zou L. (2001), Multi-objective optimization for sustainable groundwater resource management in a semiarid catchment, Hydrological Sciences-Journal-des Sciences Hydrologiques, 46(1) Feb. 2001. [Cited at 2008, April. 27] Available: https://www.itia.ntua.gr/hsj/46/hysj_46_01_0055.pdf

Zubiller C., Affifi S., Nasser A. , Al Baz I., Henzler M., Mostert C. (2002), Guidelines for Wastewater Reuse in the Gaza-Strip, Palestine, LIFECY/99/GA/141 Programme of the European Commission, Adelphi Research. Aug 2002, [cited at 2008, Ian. 18] Available: http://www.adelphi-research.de/projektberichte/Guidelines_Palestine.pdf

APPENDIXES

Appendix 1 – "The used questionnaire for collecting Data about groundwater wells in the study area"

Questionnaire - Groundwater Wells Details in the Study Area			
	Islamic University - Gaza Water Resources Engineering Master Programme		2008-2009
	Recharge Assessment and Modeling Issues to the north of Wadi Gaza costal Aquifer		Prepared by: Samir Alnahhal

ID	707	
Agriculture No.	F - 208	
Name-Arabic	-	
Owner Name	Mughraga F- 208	
Governorate	Gaza	
Municipality	Mughraga	
General Data	**Type**	Municipal
	X GPS	93493
	Y GPS	97839
	'Z GPS	21
	Initial Depth	-
	Establish Date	-
Mechanical Data	**Total Depth**	40 m
	Type of Pump	Vertical
	Pump capacity	40 Hp
	Pipe Diameter	4”
	Casing Dia.	-
	Screen Dia.	-
Operation Data	**Operation days/ month**	30 Days
	Operation hours/ day	7 Hr “average”
Hydraulic Data	**Flow , Q (m3/hr)**	60
	WL , MSL (M)	-
	TDS	-
	Cl, mg/l	-
	NO3, mg/l	-
Remarks		

Questionnaire - Groundwater Wells Details in the Study Area

	Islamic University - Gaza Water Resources Engineering Master Programme	2008-2009
	Recharge Assessment and Modeling Issues to the north of Wadi Gaza costal Aquifer	Prepared by: Samir Alnahhal

ID	-	
Agriculture No.	G - 56	
Name-Arabic	-	
Owner Name	Mughraga G - 56	
Governorate	Gaza	
Municipality	Mughraga	
General Data	**Type**	Municipal
	X GPS	93640
	Y GPS	98098
	'Z GPS	18.30
	Initial Depth	-
	Establish Date	-
Mechanical Data	**Total Depth**	30 m
	Type of Pump	Vertical
	Pump capacity	40 Hp
	Pipe Diameter	4”
	Casing Dia.	-
	Screen Dia.	-
Operation Data	**Operation days/ month**	30 Days
	Operation hours/ day	6 Hrs
Hydraulic Data	**Flow , Q (m3/hr)**	50
	WL , MSL (M)	-
	TDS	-
	Cl, mg/l	-
	NO3, mg/l	-
Remarks	Used for Municipal and agricultural purposes	

Questionnaire - Groundwater Wells Details in the Study Area		
	Islamic University - Gaza Water Resources Engineering Master Programme	2008-2009
	Recharge Assessment and Modeling Issues to the north of Wadi Gaza costal Aquifer	Prepared by: Samir Alnahhal

ID	-	
Agriculture No.	G - 57	
Name-Arabic	-	
Owner Name	Mughraga G - 57	
Governorate	Gaza	
Municipality	Mughraga	
General Data	**Type**	Municipal
	X GPS	93880
	Y GPS	98181
	'Z GPS	19.30
	Initial Depth	-
	Establish Date	-
Mechanical Data	**Total Depth**	30 m
	Type of Pump	Vertical
	Pump capacity	40 Hp
	Pipe Diameter	4"
	Casing Dia.	-
	Screen Dia.	-
Operation Data	**Operation days/ month**	30 Days
	Operation hours/ day	6 Hrs
Hydraulic Data	**Flow , Q (m3/hr)**	50
	WL , MSL (M)	-
	TDS	-
	Cl, mg/l	-
	NO3, mg/l	-
Remarks	Used for Municipal and agricultural purposes	

Questionnaire - Groundwater Wells Details in the Study Area

	Islamic University - Gaza Water Resources Engineering Master Programme	2008-2009
	Recharge Assessment and Modeling Issues to the north of Wadi Gaza costal Aquifer	Prepared by: Samir Alnahhal

ID	-	
Agriculture No.	G/50	
Name-Arabic	بئر بلدية الزهرة رقم 1	
Owner Name	Al-Zahra Well no. 1	
Governorate	Gaza	
Municipality	Al Zahra	
General Data	**Type**	Municipal
	X GPS	93154
	Y GPS	98411
	'Z GPS	10.90
	Initial Depth	30 m
	Establish Date	1999
Mechanical Data	**Total Depth**	30 m
	Type of Pump	Vertical
	Pump capacity	40 Hp
	Pipe Diameter	4”
	Casing Dia.	-
	Screen Dia.	-
Operation Data	**Operation days/ month**	30
	Operation hours/ day	8
Hydraulic Data	**Flow , Q (m3/hr)**	60
	WL , MSL (M)	-
	TDS	-
	Cl, mg/l	-
	NO3, mg/l	-
Remarks	Average annual production = 152496 m^3 (CMWU 2008)	

Questionnaire - Groundwater Wells Details in the Study Area		
	Islamic University - Gaza Water Resources Engineering Master Programme	2008-2009
	Recharge Assessment and Modeling Issues to the north of Wadi Gaza costal Aquifer	Prepared by: Samir Alnahhal

ID	-	
Agriculture No.	F/203	
Name-Arabic	بئر بلدية المغراقة	
Owner Name	Mughraga F/203	
Governorate	Gaza	
Municipality	Mughraga	
General Data	**Type**	Municipal
	X GPS	93720
	Y GPS	97945
	'Z GPS	24.11
	Initial Depth	30 m
	Establish Date	2003
Mechanical Data	**Total Depth**	30 m
	Type of Pump	Vertical
	Pump capacity	60 Hp
	Pipe Diameter	6”
	Casing Dia.	-
	Screen Dia.	-
Operation Data	**Operation days/ month**	30
	Operation hours/ day	14
Hydraulic Data	**Flow , Q (m3/hr)**	92
	WL , MSL (M)	-
	TDS	951 (2006)
	Cl, mg/l	300 (2006)
	NO3, mg/l	-
Remarks		

Questionnaire - Groundwater Wells Details in the Study Area		
	Islamic University - Gaza Water Resources Engineering Master Programme	2008-2009
	Recharge Assessment and Modeling Issues to the north of Wadi Gaza costal Aquifer	Prepared by: Samir Alnahhal

ID	838	
Agriculture No.	G/24A	
Name-Arabic	علي فريح أبو مدين	
Owner Name	Ali.-F.-Abu-Meden-	
Governorate	Gaza	
Municipality	Al Zahra	
General Data	**Type**	Agricultural
	X GPS	92814
	Y GPS	98316
	'Z GPS	-
	Initial Depth	33 m
	Establish Date	1973
Mechanical Data	**Total Depth**	33 m
	Type of Pump	Vertical
	Pump capacity	40 Hp
	Pipe Diameter	4.0”
	Casing Dia.	6”
	Screen Dia.	6”
Operation Data	**Operation days/ month**	21
	Operation hours/ day	8
Hydraulic Data	**Flow , Q (m3/hr)**	50
	WL , MSL (M)	-
	TDS	-
	Cl, mg/l	-
	NO3, mg/l	-
Remarks		

Questionnaire - Groundwater Wells Details in the Study Area		
	Islamic University – Gaza Water Resources Engineering Master Programme	2008-2009
	Recharge Assessment and Modeling Issues to the north of Wadi Gaza costal Aquifer	Prepared by: Samir Alnahhal

ID	839	
Agriculture No.	G/24B	
Name-Arabic	علي فريج أبو مدين	
Owner Name	Ali.-F.-Abu-Meden-	
Governorate	Gaza	
Municipality	Al Zahra	
General Data	**Type**	Agricultural
	X GPS	92377
	Y GPS	98909
	'Z GPS	14.744
	Initial Depth	30 m
	Establish Date	1981
Mechanical Data	**Total Depth**	30 m
	Type of Pump	Vertical
	Pump capacity	40 Hp
	Pipe Diameter	4"
	Casing Dia.	6"
	Screen Dia.	6"
Operation Data	**Operation days/ month**	20
	Operation hours/ day	6
Hydraulic Data	**Flow , Q (m3/hr)**	50
	WL , MSL (M)	-
	TDS	-
	Cl, mg/l	489 (Camp, 2000)
	NO3, mg/l	94 (Camp, 2000)
Remarks		

Questionnaire - Groundwater Wells Details in the Study Area		
	Islamic University - Gaza Water Resources Engineering Master Programme	2008-2009
	Recharge Assessment and Modeling Issues to the north of Wadi Gaza costal Aquifer	Prepared by: Samir Alnahhal

ID	840	
Agriculture No.	G/24C	
Name-Arabic	علي فريح أبو مدين	
Owner Name	Ali.-F.-Abu-Meden-	
Governorate	Gaza	
Municipality	Al Zahra	
General Data	**Type**	Agricultural
	X GPS	93082
	Y GPS	98327
	'Z GPS	-
	Initial Depth	30 m
	Establish Date	1973
Mechanical Data	**Total Depth**	53 m
	Type of Pump	Vertical
	Pump capacity	40 Hp
	Pipe Diameter	6"
	Casing Dia.	10"
	Screen Dia.	10"
Operation Data	**Operation days/ month**	21
	Operation hours/ day	8
Hydraulic Data	**Flow , Q (m3/hr)**	80
	WL , MSL (M)	-
	TDS	-
	Cl, mg/l	623 (PWA, 2003)
	NO3, mg/l	-
Remarks		

Appendix II

"The groundwater pressure comparisons for the other scenarios, i.e. injecting 1.0 MCM/yr and 1.5 MCM/yr"

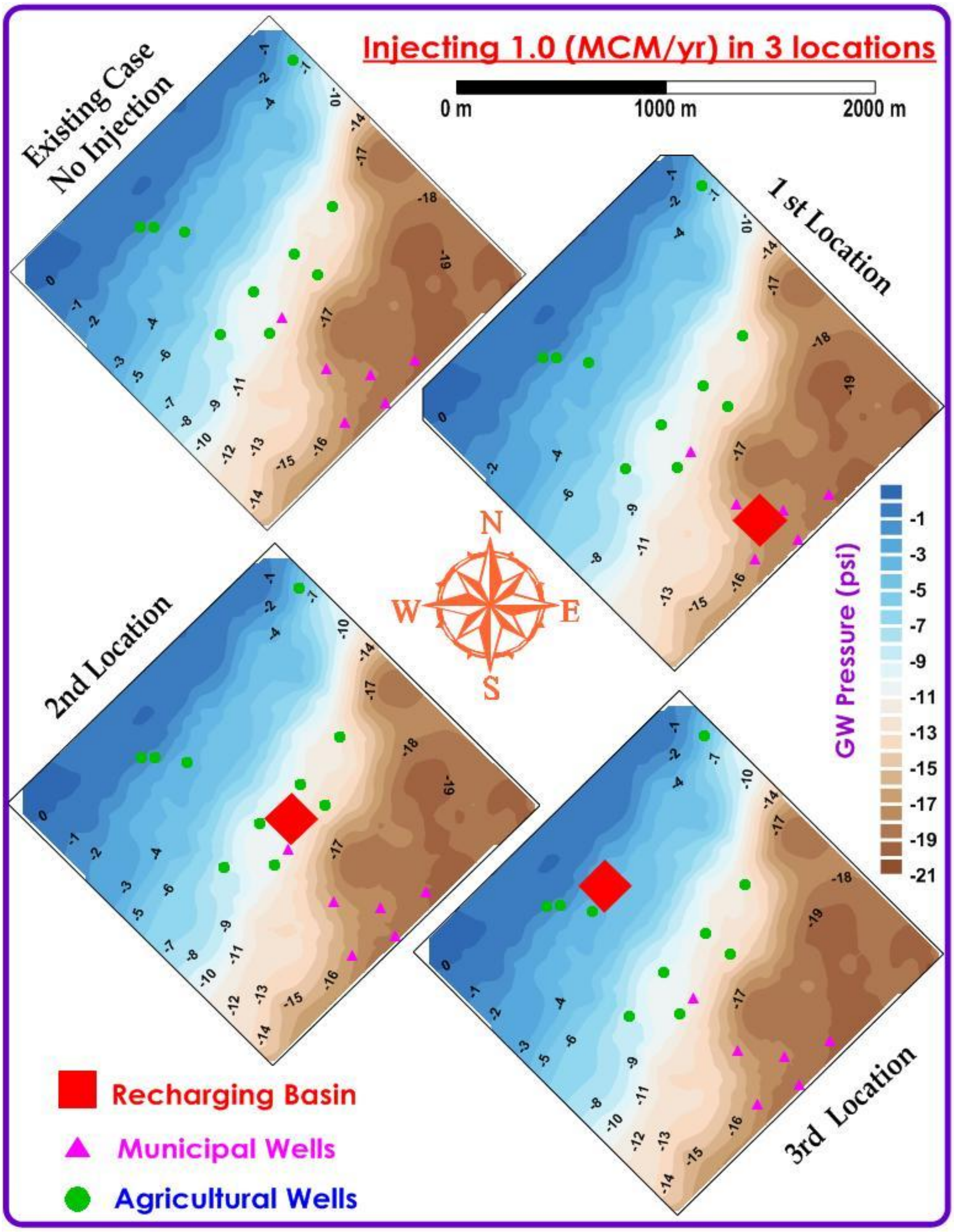

Figure (App . 1): GW Pressure once injecting 1.0 MCM/yr in 3 recharging locations

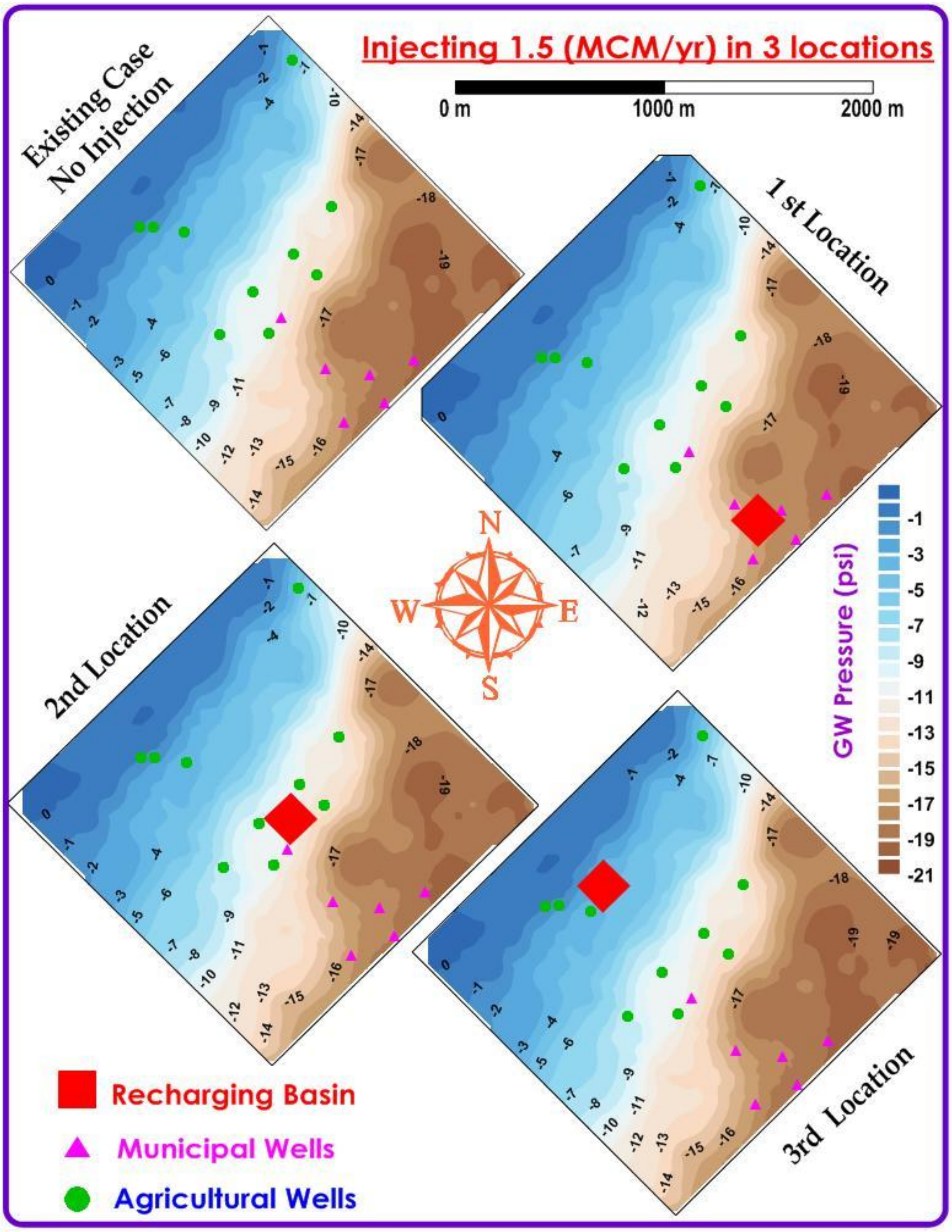

Figure (App . 2): GW Pressure once injecting 1.5 MCM/yr in 3 recharging locations

Appendix III

"The normalized concentration at cross section for the other two injecting scenarios, i.e. 1.0 and 1.5 MCM/yr"

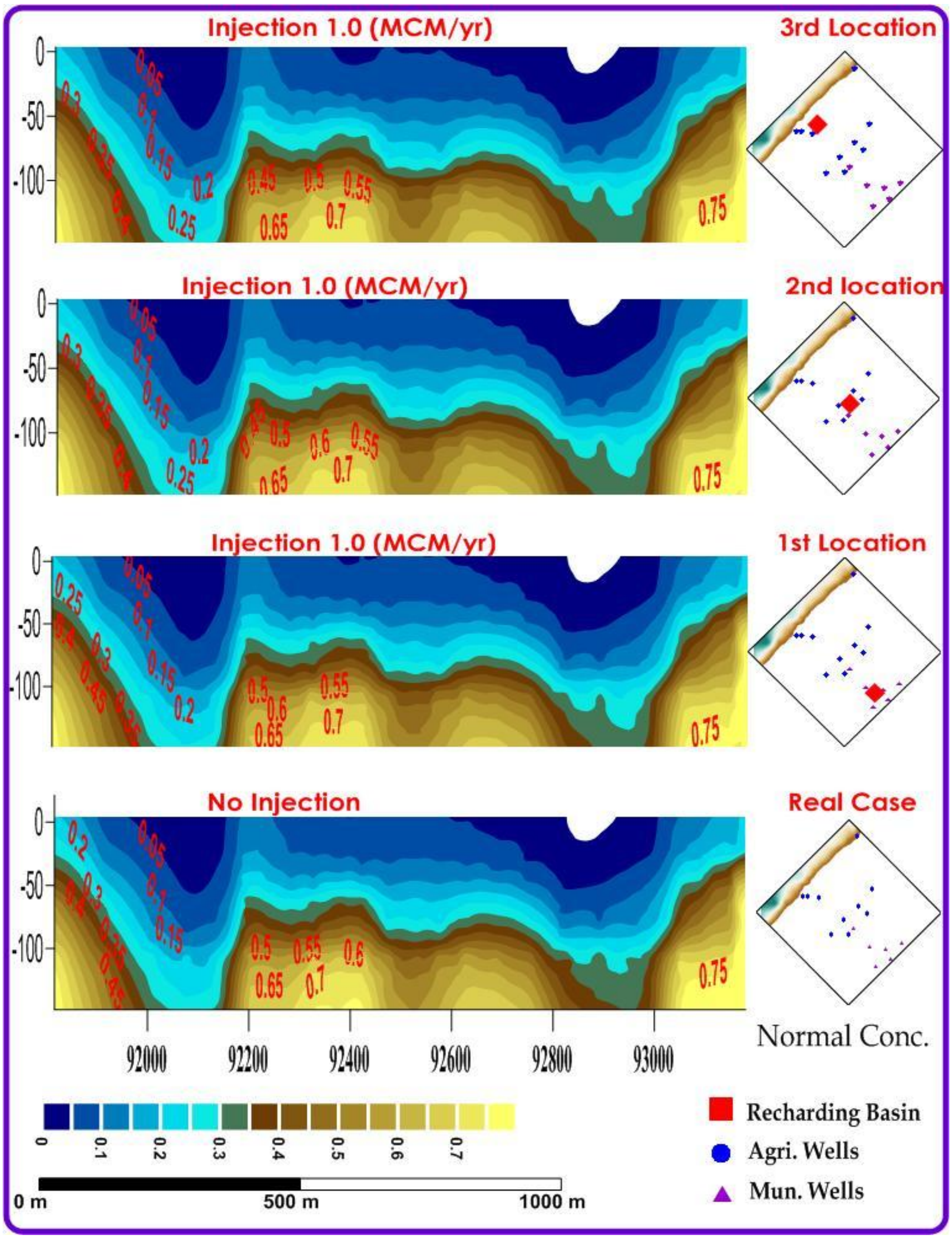

Figure (App. 3): Normalized Concentration at the cross section for three recharging locations injected with 1.0 MCM/yr

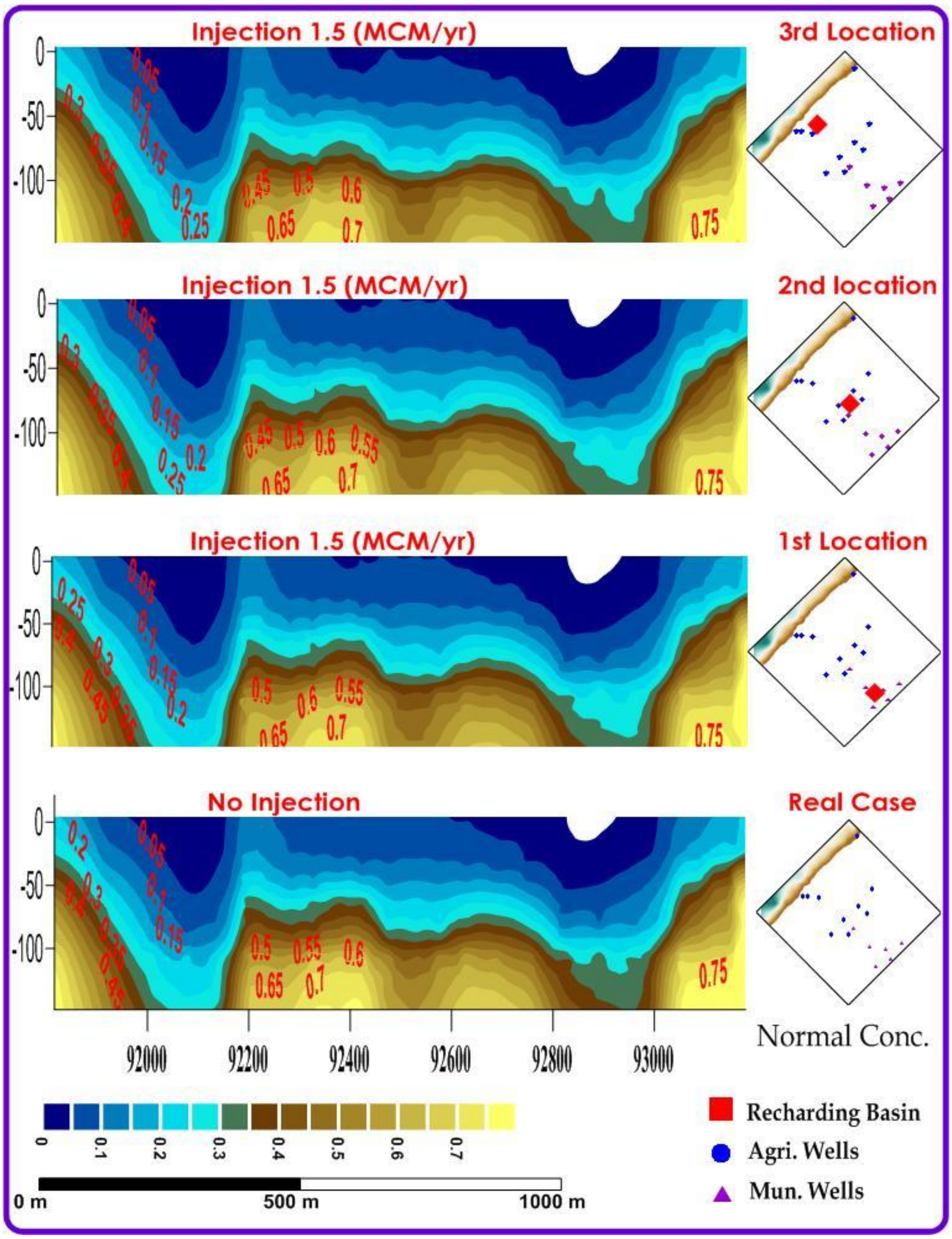

Figure (App. 4): Normalized Concentration at the cross section for three recharging locations injected with 1.5 MCM/yr

Appendix IV

"The hydraulic head in the other two recharging locations "second and third while injected with 0.5, 1.0, 1.5 MCM/yr"

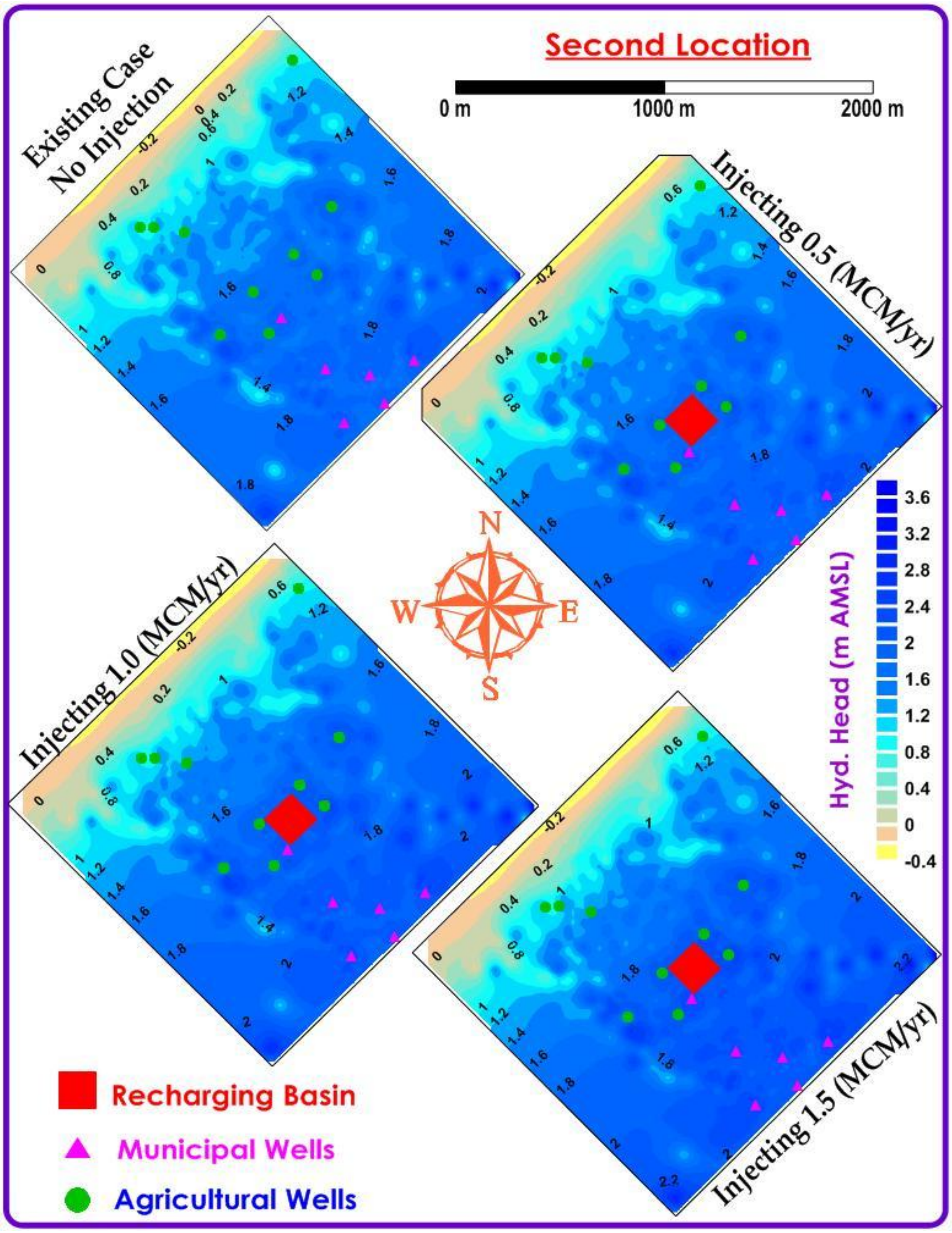

Figure (App. 5): hydraulic heads in second recharging locations injected with 0.5, 1.0, and 1.5 MCM/yr

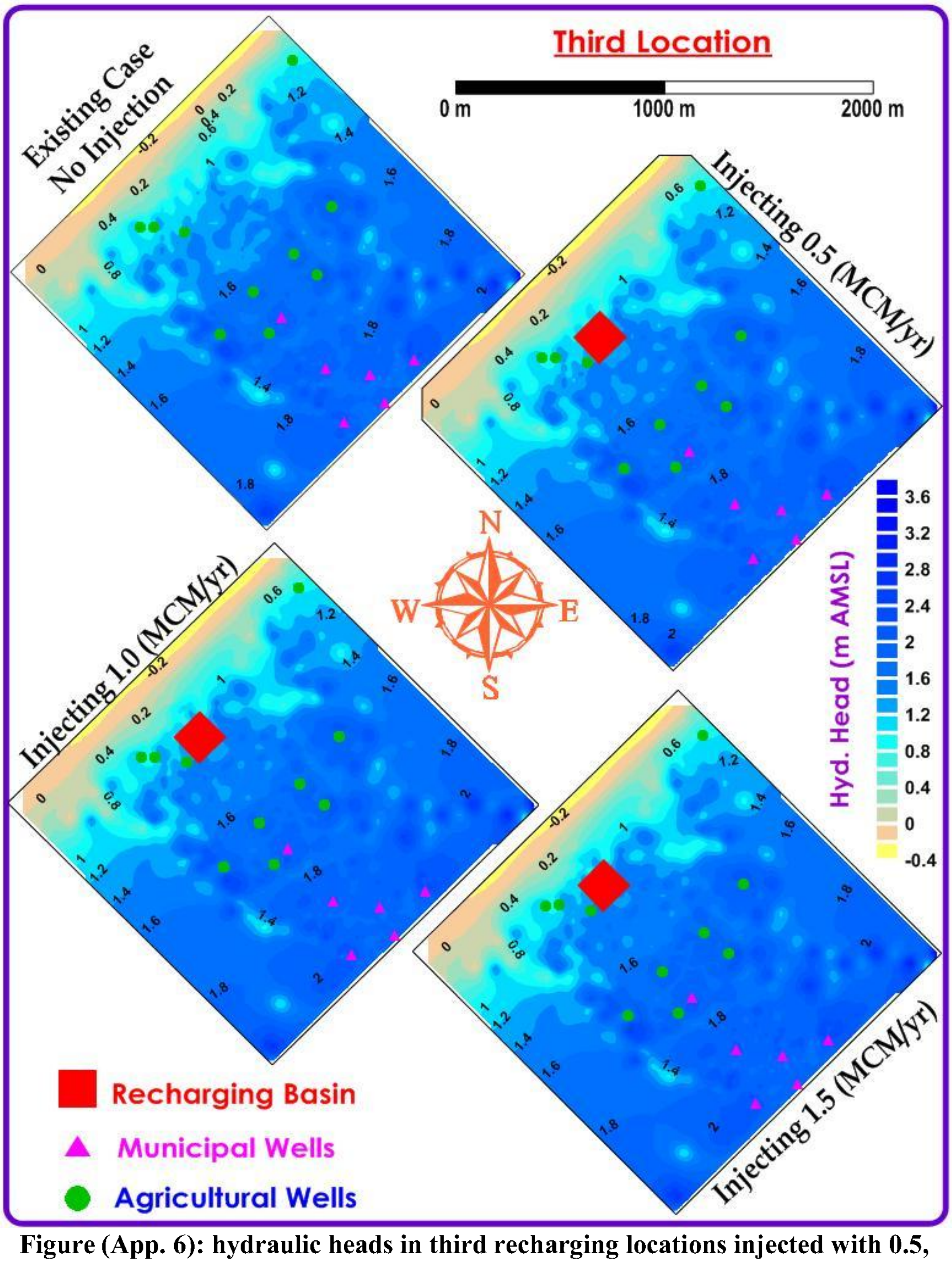

Figure (App. 6): hydraulic heads in third recharging locations injected with 0.5, 1.0, and 1.5 MCM/yr

Appendix V

"The normalized concentration at cross section for the other two locations (second and third)

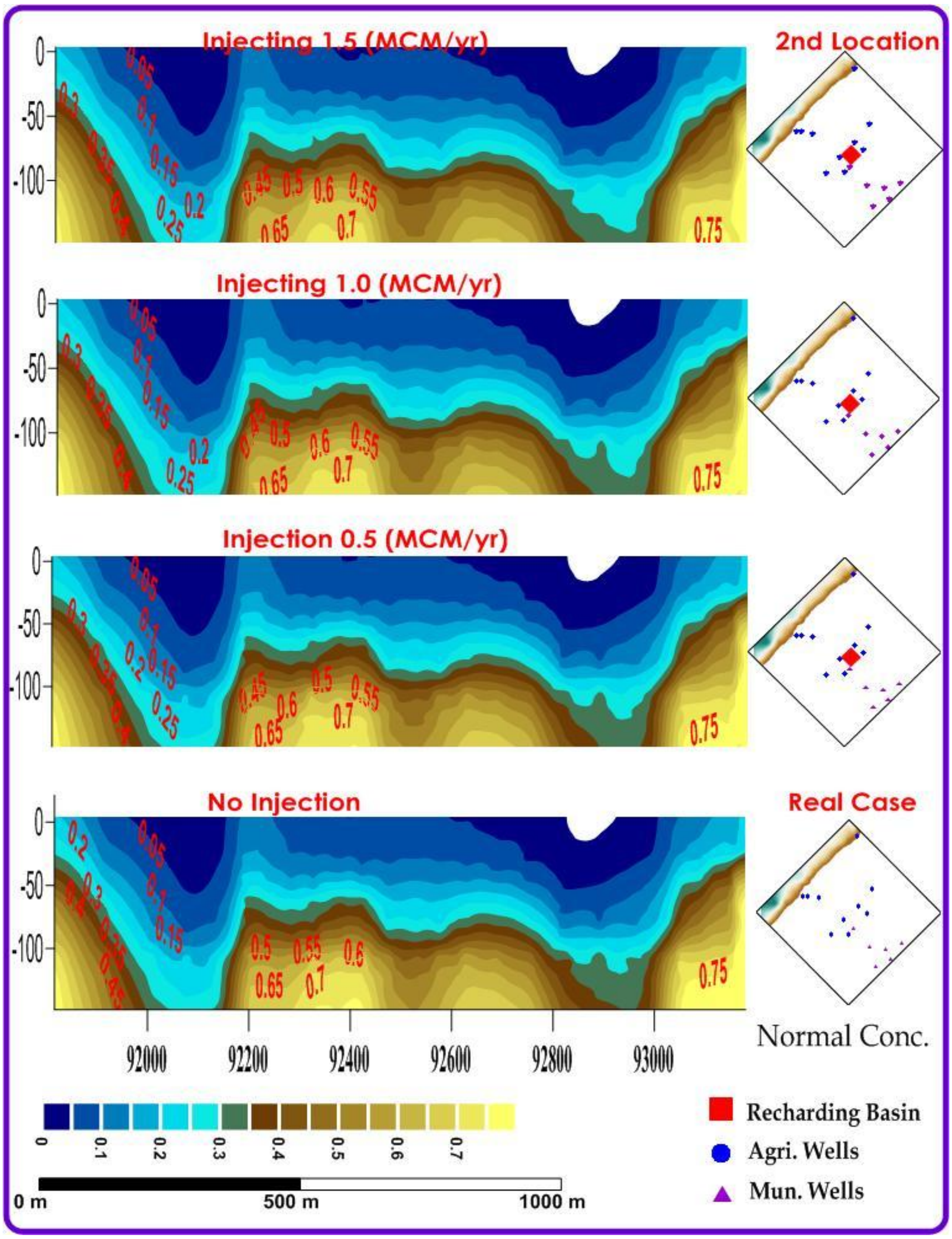

Figure (App.7): Normalized Conc. at cross section when the second location is injected with different quantities 0.5, 1.0, and 1.5 MCM/yr

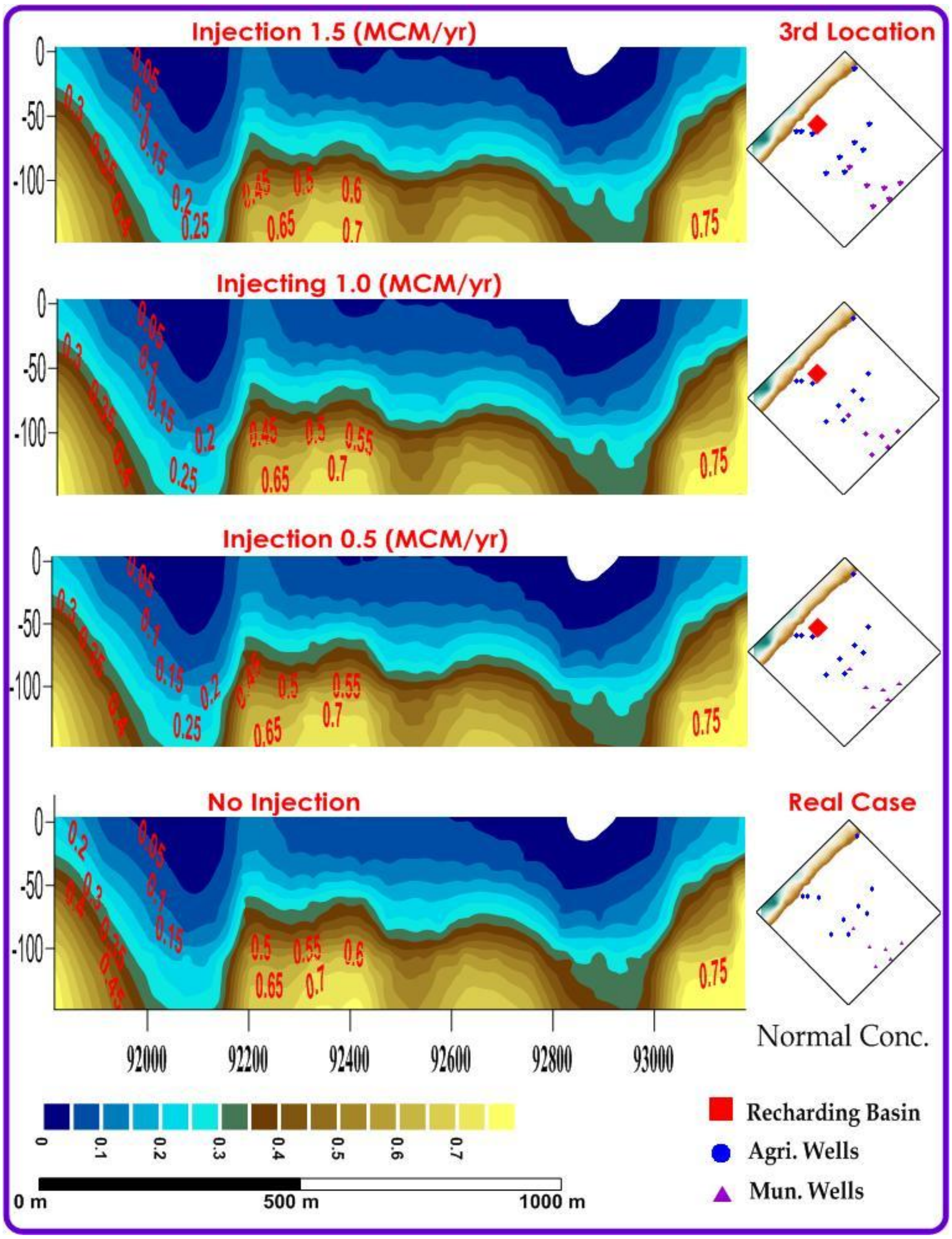

Figure (App. 8): Normalized Conc. at cross section when the third location is injected with different quantities 0.5, 1.0, and 1.5 MCM/yr

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الكاتب:	EngrSamir
الكلمات الأساسية:	
تعليقات:	
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