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Delineation of Wellhead Protection Plans for Municipal Supply Wells in Gaza Governorate

تصميم خطط لحماية حرم آبار مياه الشرب في محافظة غزة

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QURAAN

بسم الله الرحمن الرحيم

(وَقَالَ رَبِّ أَوْزِعْنِي أَنْ أَشْكُرَ نِعْمَتَكَ الَّتِي أَنْعَمْتَ عَلَيَّ وَعَلَى وَالِدَيَّ وَأَنْ أَعْمَلَ صَالِحًا تَرْضَاهُ

وَأَدْخِلْنِي بِرَحْمَتِكَ فِي عِبَادِكَ الصَّالِحِينَ) النمل (**19**)

DEDICATED TO:

"God's mercy upon "Soul of My Mother Fahima

My Father

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ABSTRACT

Groundwater is the only source of fresh water in Gaza Strip while its inhabitants and its water consumption increased rapidly.

This study aims at preserving and protecting the groundwater from any pollutants caused by industrial installations through the work of delineation of Wellhead Protection Areas (WHPA) for Municipal Supply Wells in Gaza Governorate boundaries.

WHPA has been determined in three different methods: Calculated Fixed-Radius Method (CFR), Analytical Method (AM), and Wellhead Analytic Element Model (WhAEM2000) which is currently used by the United States Environmental Protection Agency (EPA). These methods mainly depend on the time it takes groundwater to travel a specified horizontal distance. Three well zones were delineated for each municipal production well, the first zone is 50 days time of travel (TOT), the second zone is 2 years TOT and the third zone is 5 years TOT.

All industrial installations with high pollution that fall in the well zones were investigated. The exact location of 141 industrial installations that were previously adopted by Environment Quality Authority (EQA) were determined by using handheld Global Positioning System (GPS). Installation sites were located and signed on maps by using GPS.

Results showed that when CFR method was used on total 2 industrial installations lie in WHPA for 50 days TOT where the average of the radius is about 71 m, 13 industrial installations lie in WHPA for 2 years TOT where the average of the radius is about 217 m, and 32 industrial installations lie in WHPA for 5 years TOT where the average of the radius is about 429 m. From the results, it can be recommended that by using CFR method any industrial installation should be prohibited in any distance less than 430 m from the well.

Analytical Method showed that are no industrial installations lie in WHPA for 50 days TOT, 2 industrial installations lie in WHPA for 2 years TOT, and 10 industrial installations lie in WHPA for 5 years TOT. From the results, it can be recommended that by using analytical method, any industrial installation should be prohibited in any ellipse radiuses r_{max}, r_{min}, and r_p less than 862 m, 150 m, and 223 m respectively around the well.

Sensitivity analysis for analytical method showed that there are no upper or lower limits on values of gradient, extraction rate, hydraulic conductivity, and aquifer thickness. The only witnessed anomalies are when using low values of effective porosity. If not using effective porosities smaller than 0.1 however, the calculation of r should be correct. Effective porosities smaller than 0.1 are uncommon for aquifers.

Wellhead Analytic Element Model revealed that there are no industrial installations lie in WHPA for 50 days TOT, 3 industrial installations lie in WHPA for 2 years TOT, and 5 industrial installations lie in WHPA for 5 years TOT. From the results, it can be recommended that by using WhAEM2000 method any industrial installation should be prohibited in any boat shaped radiuses L_u, L_s and Y_{max} are 454 m, 79 m, 250 m respectively around the well.

CFR method is the weakest method because it does not take into account regional groundwater flow, causing a hydraulic gradient. WHPAs identified by these methods may be either too large or too small, resulting in wellhead overprotection or under protection. Analytical Method incorporates hydrogeologic characteristics of the aquifer, groundwater flow, and hydrogeologic boundaries into the model. Often produces a WHPA that is smaller than the one produced using CRF. WhAEM2000 method is the best method because it uses a hydrogeological computer model of groundwater flow and it provides a more accurate delineation of the WHPA. It often produces a smaller area to manage than other methods.

Nahawnd Company for Plastic Industry has been selected as a case study were field visit was carried out to investigate the availability of the mitigation measures in the site. The company is very close to (R/25A, R/25B, R/25C, and R/25 D) well field. From this study it is clear that no mitigation measures have been identified as necessary to reduce the anticipated groundwater impacts of the industry.

The study concluded that all the industrial installations located in the WHPA should be carefully checked and investigated by EQA. Mitigation measures for pollutants caused by these industrial installations should be identified. In addition, EQA must give licenses for the establishment of any new industrial installations based on the delineation of WHPAs using the previously mentioned methods.

الملخص

المياه الجوفية هي المصدر الوحيد للمياه العذبة في قطاع غزة، في حين أن السكان والاستهلاك للمياه يزيد بشكل سريع.

هذه الدراسة تهدف إلى حفظ وحماية المياه الجوفية من التلوث الناجم عن المنشآت الصناعية من خلال تصميم خطط لحماية حرم آبار مياه الشرب في حدود محافظة غزة.

وقد تم استخدام ثلاث طرق مختلفة : طريقة حساب القطر الثابت، والطريقة التحليلية ، و طريقة النمذجة التحليلية لعناصر حرم البئر الذي تستخدم حالياً من قبل وكالة حماية البيئة في الولايات المتحدة الأمريكية. هذه الطرق في المقام الأول تعتمد على الوقت الذي يستغرقه انتقال ملوثات المياه في الجوفية وخاصة المسافة الأفقية. تم تصميم ورسم خرائط لثلاث مناطق لكل بئر من آبار الشرب، حيث يكون وقت انتقال الملوثات في المنطقة الأولى 50 يوماً، أما في المنطقة الثانية يكون الوقت سنتين وفي المنطقة الثالثة والأخيرة يكون الوقت خمس سنوات.

جميع المنشآت الصناعية عالية التلوث والتي تقع في منطقة الدراسة تم تحيدها مسبقاً من قبل سلطة جودة البيئة. حيث تم تحديد مواقع المنشآت الصناعية بدقة باستخدام جهاز النظام العالمي لتحديد المواقع يدوياً. بناءً علي الدراسة الحالية 141 موقع منشأة صناعية وقعت على الخرائط بدقة باستخدام النظام العالمي لتحديد المواقع يدوياً.

أظهرت النتائج أنه عندما استخدام طريقة حساب القطر الثابت فإن منشأتين صناعيتين تقع في منطقة حماية حرم البئر عندما يكون وقت انتقال الملوثات 50 يوماً حيث أن متوسط نصف القطر 71 متراً، 13 منشأة صناعية تقع في منطقة حماية حرم البئر عندما يكون الوقت سنتين حيث أن متوسط نصف القطر 217 متراً ، و 32 منشأة صناعية تقع في منطقة حماية حرم البئر عندما يكون الوقت 5 سنوات حيث أن متوسط نصف القطر 429 متراً. من النتائج التي وجدت عند استخدام طريقة حساب القطر الثابت أنه يجب أن يحظر وقوع المنشآت الصناعية علي أي مسافة أقل من 430 متر من البئر.

وتبين من استخدام الطريقة التحليلية أنه لا تقع أي منشأة صناعية داخل منطقة حماية حرم البئر عندما يكون وقت انتقال الملوثات 50 يوماً، منشأتين صناعيتين تقع في منطقة حماية حرم البئر عندما يكون الوقت سنتين و 10 منشآت صناعية تقع داخل منطقة حماية حرم البئر عندما يكون الوقت 5 سنوات. من النتائج التي وجدت عند استخدام الطريقة التحليلية أنه يجب أن يحظر وقوع المنشآت الصناعية عند أي مسافة أقل من أنصاف أقطار الشكل البيضاوي r_{max} ، r_{min}، r_p 862 م ، 150 م ، و 223 م على التوالي حول البئر. ويتضح من نتائج تحليل الحساسية للطريقة التحليلية أنه لا توجد أعلى أو أدنى قيود على قيم معامل الانحدار الهيدروليكي ، معدل الاستخراج ، التوصيل الهيدروليكي وسمك طبقة المياه الجوفية. وشهدت المفارقات الوحيدة هي عند استخدام انخفاض قيم المسامية الفعالة. إذا لم تكن المسامية الفعالة أقل من 0.1 فان الأقطار ينبغي أن تكون صحيحة. المساميات الفعالة التي تكون أقل من 0.1 لطبقات المياه الجوفية غير شائعة.

طريقة النمذجة التحليلية لعناصر حرم البئر تكشف أنه لا توجد منشآت صناعية تقع في داخل منطقة حماية حرم البئر عندما يكون وقت انتقال الملوثات 50 يوماً، 3 منشآت صناعية تقع داخل منطقة حماية حرم البئر عندما يكون وقت انتقال الملوثات سنتين، و 5 منشآت صناعية تقع في داخل منطقة حماية حرم البئر عندما يكون الوقت 5 سنوات. من النتائج التي وجدت في هذا الإطار عند استخدام طريقة النمذجة التحليلية لعناصر حرم البئر أنه يجب أن يحظر وقوع المنشآت الصناعية علي أي مسافة أقل من أنصاف أقطار الشكل القاربي وهي L_u ، L_s, Y_{max} 454 م , 79م , 250م على التوالي حول البئر.

طريقة حساب القطر الثابت هي الأضعف لأنها لا تأخذ في الاعتبار اتجاه الجريان في المياه الجوفية الذي يسببه الانحدار الهيدروليكي. ومن خلال استخدام هذه الطريقة يتبين أن منطقة حماية حرم البئر إما أن تكون كبيرة جداً أو صغيرة جداً مما يؤدي إلي حماية أقل أو حماية مفرطة. الطريقة التحليلية تتضمن خصائص طبقات المياه الجوفية، جريان المياه الجوفية و حدود المياه الجوفية داخل النموذج. و غالباً ما تكون منطقة حماية حرم البئر أقل من طريقة القطر الثابت. طريقة النمذجة التحليلية لعناصر حرم البئر هي أفضل طريقة لأنها تشكل نموذج حاسوبي لجريان المياه الجوفية ، وتعتبر هذه الطريقة الأكثر دقة لتحديد منطقة حماية حرم البئر. و غالباً ما توفر هذه الطريقة أصغر منطقة لحماية حرم البئر.

شركة النهاوند لصناعة البلاستيك تم اختيارها كدراسة حالة و أجريت زيارة ميدانية للتحقيق في مدى توافر تدابير التخفيف في الموقع. الشركة تقع على مسافة قريبة جداً من الآبار التالية (R/25A، R/25B، R/25C، R/25D). ومن خلال هذه الدراسة من الواضح أنه لا يوجد أي احتياج ضروري لتدابير التخفيف للحد من الآثار المتوقعة علي المياه الجوفية من المصنع.

وخلصت الدراسة إلى أن جميع المنشآت الصناعية الواقعة داخل منطقة حماية حرم البئر ينبغي دراستها وفحصها من خلال المؤسسات المعنية كسلطة جودة البيئة. ينبغي أيضاً تحديد تدابير التخفيف والحد من الملوثات الناجمة عن هذه المنشآت الصناعية. هذا بالإضافة إلي أن سلطة جودة البيئية يجب أن تعطي تراخيص لإقامة منشآت صناعية جديدة بناءً علي تحديد مناطق حماية حرم ا الآبار باستخدام الطرق التي استخدمت في هذه الدراسة.

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ACRONYMS AND ABBREVIATIONS

Analytical Method	AM
Before Christ	BC
Coastal Aquifer Management Program	CAMP
Coastal Municipal Water Utility	CMWU
Cubic meters per hour	m^3/hr
Calculated Fixed-Radius Method	CFR
Digital Line Graph	DLG
Environment Quality Authority	EQA
Ground Water Protection Regulation	GWPR
Global Positioning System	GPS
Group Pollutants A	GA
Group Pollutants B	GB
Group Pollutants C	GC
Group Pollutants D	GD
Group Pollutants E	GE
Gaza Meteorological Station	GMS
Lyonnaise des Eaux and Khatib and Alami	LEKA
Mean Sea Level	MSL
Meter per day	m/day
Ministry Of Planning and International Corporation.	MOPIC
Millgrams per Liter	mg/l
Millimeter	mm
Milllion Cubic Meter per year	Mm^3/y
Ministry of Agriculture	MoA
Ministry of Health	MOH
National Environmental Action Plan	NEAP
National Water Council	NWC
Non-Governmental Organization	NGO

North North East	NNE
Palestinian Authority	PA
Palestinian Central Bureau of Statistics	PCBS
Palestinian Environmental Strategy	PES
Palestinian National Authority	PNA
Palestinian Water Authority	PWA
Source Water Assessment Planning	SWAP
South South West	SSW
Square Kilometer	km^2
Square Meter per Day	m^2/day
Time Of Travel	TOT
United State	U.S.
United States Environmental Protection Agency	US EPA
Washington State Department of Health	WSDOH
Wastewater Treatment Plant	WWTP
Wellhead Analytic Element Model 2000	WhAEM2000
Wellhead Protection	WHP
Wellhead Protection Area	WHPA
Wellhead Protection Programs	WHPP
World Health Organization	WHO
Year	Yr

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Chapter (1)

Introduction

1.1 General

Water is the most important natural resource on our planet and perhaps the scarcest commodity of the 21st Century. Groundwater is the most important component of the freshwater resources of the world. It is the cleanest, the most reliable, and often the least expensive source of water. It usually requires less treatment than surface water, and the supply is less sensitive to drought conditions. A clean, dependable source of groundwater is a necessity to sustain agriculture, industry, community growth, and human life itself.

In addition to the problems of over-abstraction and salination, the groundwater resources are also threatened by pollution as a result of uncontrolled solid waste disposal and discharge of untreated wastewater, and extensive use of fertilizers and Pesticides **(PWA, 2005).** Gasoline or oil stored in damaged or rusting underground storage tanks can also pollute groundwater. The sources of pollution are many, and the problem of contaminated groundwater is extreme.

Groundwater is a renewable resource that provides a continuous source of fresh water for consumption. Even when no immediate water related concern appears to exist, communities need to be knowledgeable about their drinking water resources for a number of reasons:

- To minimize the potential risks to the health and vitality of the community;
- To avoid the potential costs associated with cleaning up contaminated groundwater and providing alternate supplies of water; and
- To avoid the negative economic impacts on a community that groundwater contamination could cause.

Many efforts are introduced in local and regional scales to protect the valuable groundwater recourses. The efforts continue monitoring of groundwater and isolation of the pollution sources. One method of groundwater protection is to minimize the potential of groundwater contamination is to protect a portion of the land area supplying water to the well as a wellhead protection area (WHPA). After determining the area to be protected, a community will be able to focus pollution prevention efforts. A community can then create a management plan to control land use within the protection area to minimize the potential for groundwater contamination. Wellhead protection (WHP) is a progressive pollution prevention tool that has the potential to save each community many thousands of dollars and provide a quality drinking-water supply for the future.

The U.S. Environmental Protection Agency (U.S. EPA) defines a wellhead protection area as the "surface or subsurface area surrounding a water well or wellfield supplying a public water system, through which contaminants are reasonably likely to move toward and reach such well or wellfield" **(EPA, 1987).** Delineation of the wellhead protection area is the process of determining what geographic area should be included in a wellhead protection program. This area of land is then managed to minimize the potential of groundwater contamination by human activities that occur on the land surface or in the subsurface.

1.2 Problem Identification

A comprehensive and effective legislative framework is essential for the smooth operation of the water sector and for it to meet its goal of providing an adequate water supply. The policy statement should also clearly highlight source protection, minimum treatment requirements and water supply monitoring that is expected from the different institutions.

This thesis studies the delineation of wellhead protection areas for the municipal supply wells in Gaza Governorate because there is no study that covers the protection of municipal wells from potential sources of pollutions by considering the Groundwater Protection Regulation (GWPR) developed by Palestinian Water Authority (PWA). The study illustrates the level of influence of all potential sources of pollutions about municipal wells.

1.3 Study Area

The study is applied on Gaza Governorate, which is the largest Governorate **(74 km²)** in the Gaza Strip **(365 km^2)** and the Palestinian territories . The Gaza Governorate has a population of approximately **409,680 (2007)** in the inner city and, which has been inhabited since 3000BC and the number of municipal wells in Gaza Governorate is 47 well **(PCBS, 2007).**

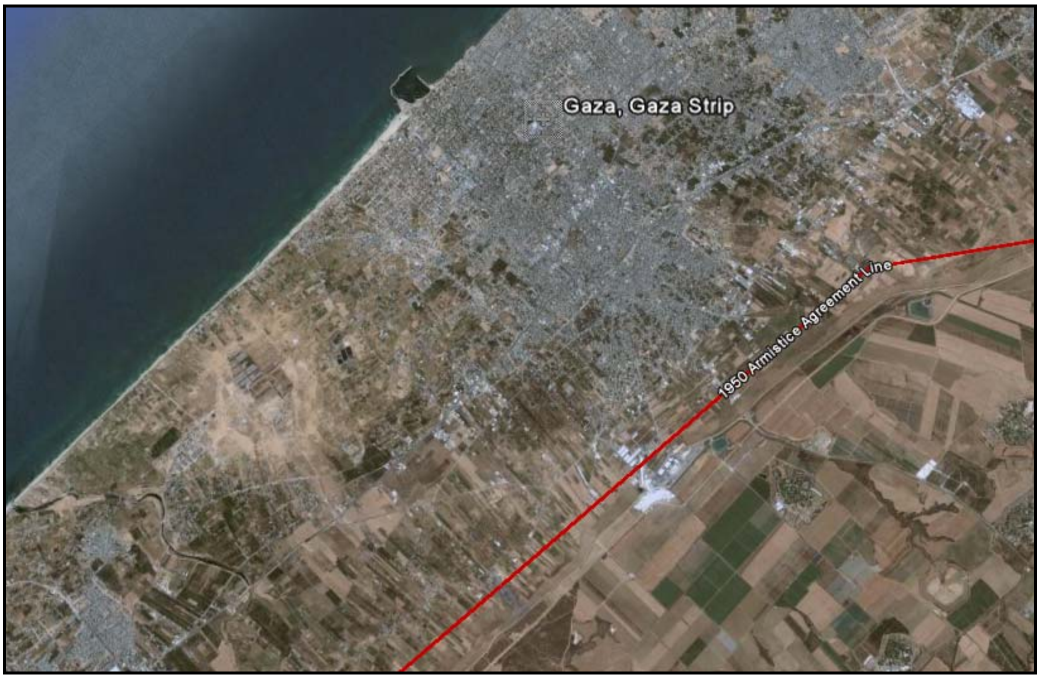


Figure 1.1: *Study area - Gaza Governorate - .*

1.4 Aim

This thesis aims at providing specifications and guidelines that can be used for groundwater pollution control regulations which can be part of PWA water regulations and delineation of Wellhead Protection (WHP) plans in Gaza Governorate.

1.5 Objectives

The main objectives of this thesis can be summarized as follows:

- Mapping of all types of pollutants which affect the groundwater. Using handheld Global Positioning System GPS.
- Mapping of WHPA to all drinking water wells located within the borders of Gaza Governorate.
- Identifying and presenting all the Industrial installations that fall within WHPA and recommending appropriate solutions to preserve groundwater from pollutions.

1.6 Methodology

To achieve the objectives of this study, the following methodology has been considered:

- Collect information about the present hydrogeological conditions, groundwater contours, and water abstraction and recharge conditions, water quality developments, location, and capacity of existing municipal wells.
- Identification of activities and use of substances that are potential sources of pollutions in the wellhead protection zones.
- Determine the wellhead zoning areas by using three methods and all potential sources of pollutions and drawing on maps.
- Present review and land-uses planning with respect to possible groundwater uses and pollutions risks, and identify remedial actions, development restrictions, and additional land-use regulations.

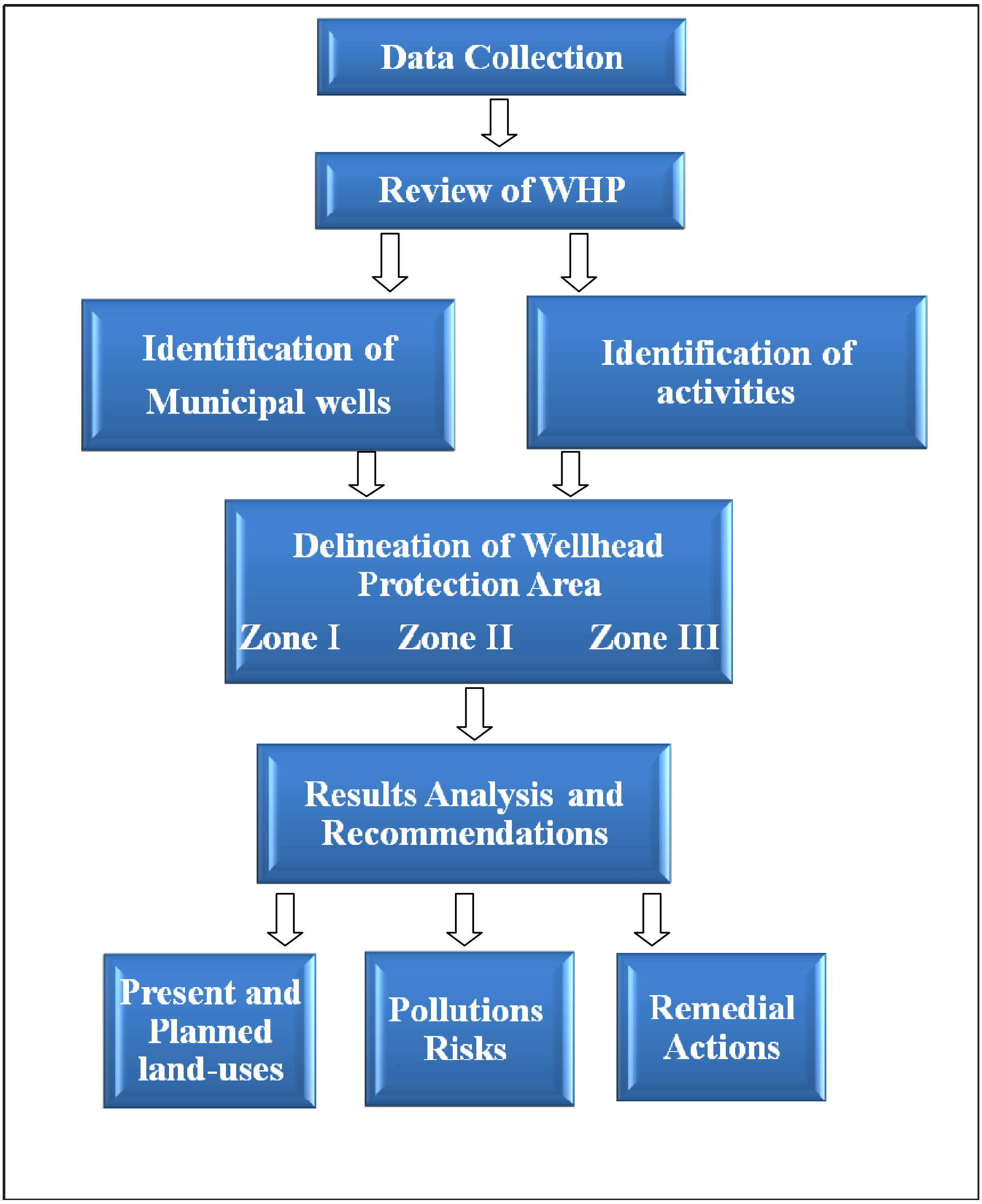


Figure 1.2: *Flow chart for the methodology.*

1.7 Thesis Outline

This study consists of seven chapters:

- **Chapter One (Introduction):** general introduction is followed by problem identification, study objectives, methodology, and tools used in order to achieve the objectives and finally, a plan for thesis outline.
- **Chapter Two (Literature Review):** covers a general literature review on international attempts for groundwater protection and groundwater protection in Gaza strip. The literature review which highlights on wellhead protection in international level and in Gaza strip. It also describes methods of determining the zoning dimension. Finally, the literature review presents Potential Contaminant Sources.
- **Chapter Three (Legislative Frameworks for the Water Sector in Palestine):** highlights on the key elements of legislation which includes Policy Statement, Institutional roles, Palestinian Water and Environmental laws, and Regulatory Framework.
- **Chapter Four (Description of Study Area):** describes the study area with respect to its geography, geology, hydrology and hydrogeology, and land use. The available studies on groundwater situation and available data in the study area.
- **Chapter Five (Application of the Methods):** discusses the methods of determining the zoning dimension by three methods which are calculated fixed-radius method (CFR), analytical method, and wellhead analytic element model (WhAEM2000) by using different softwares Surfer version 8, AutoCAD 2009, WhAEM2000 and Excel. Finally, this chapter evaluated the three methods.
- **Chapter Six (Monitoring and Evaluation):** describes Hazardous material and waste, evaluation, remedial Action, and monitoring. Finally, Nahawnd Company was used as a case study.
- **Chapter Seven (Conclusions and Recommendations):** The conclusions and recommendations of the study are stated in this chapter of the thesis.

Chapter (2)

Literature Review

2.1 Introduction

The prediction that more than a third of the world's population will not have access to sufficient freshwater by 2025 and cannot be ignored this advocates that, rather than trying to satisfy projected future increases in demand, it is better to meet needs with currently available water resources, while preserving the ecosystems that are part of our well-being. In essence, this is a call for sustainable development. From the survey of papers presented in this chapter. It can be seen that the defining feature of sustainable groundwater development at global and local scales is not the balancing of available aquifer storage to satisfy a single aim such as meeting water users' demands, but the maintenance and protection of the groundwater resource to balance economic, environmental, and social human requirements **(Hiscock et al., 2002).**

Water demand in Palestine, in general and in the Gaza strip, in particular is rapidly increasing. The water resources are limited, compared to the continuous of groundwater that much exceeds the renewable amount that replenishes the groundwater reservoir. This leds to continuous decline of groundwater levels and deterioration of water quality from both seawater intrusion and deep salt-water upconing .To achieve sustainable use of groundwater system, there is a need to reach balance between the water discharge, naturally to sea and across the border, and artificially by human activities, and water recharge, also natural and artificial **(PWA, 2004).**

The groundwater resources of Gaza are by large restricted to the so-termed shallow aquifer. This shallow aquifer contains the only known fresh groundwater. Gaza aquifer is part of the coastal aquifer from Sinai Peninsula in the south to Mount Carmel in Haifa City in the north. The shallow aquifer that mean the sand (stone) and the clay layers located on the top of the so-term Saqiya formation **(PWA, 2004).**

Any changes on groundwater chemical quality can lead to contamination and pollution and consequently can have serious consequences on ecosystem health and function and can cause problems for water use. So, it is important to preserve and monitor groundwater quality for early warnings of change and to detect its sources either from natural systems and/or resulting from human activities. Also, it is important to know the factors that affecting on the changes in groundwater quality **(PWA, 2004).**

2.2 Groundwater Protection

Groundwater protection means to protect the remained amount of groundwater in the aquifer from pollution and to prevent if possible the pollution to spread out in large areas.

2.2.1 International Attempts for Groundwater Protection

Groundwater is an important source of drinking-water. In its natural state, groundwater is generally high microbiological quality with little or no contamination, although some groundwater does have high levels of harmful chemicals such as fluoride and arsenic. The relative purity of groundwater in its natural state is largely the result of infiltration through the soil and unsaturated layers of rock. During infiltration processes such as sorption, mechanical filtration and ion exchange operate which remove bacteria and some chemicals, particularly metals, from the water. However, some chemical compounds, such as nitrate, are not easily attenuated, and once in the sub-surface aquatic environment are highly persistent and mobile.

Once an aquifer is contaminated, as the movement of water through sub-surface systems relative to their volume is slow and residence times are lengthy, the natural processes of removal by dilution and discharge to surface waters may be extremely long (decades, centuries or millennium). Thus prevention of contamination of groundwater by persistent mobile contaminants is an essential element in the protection of groundwater resources. A further complication is that many processes in the saturated zone are reversible and whilst initially contaminants may be removed from solution through, for instance sorption, at a later date they may be desorbed and re-enter the water. This is a common problem in industrial cities in Western Europe, where initial development led to a decrease in the water and subsequent attenuation of contaminants in the unsaturated zone. Subsequent development has occurred elsewhere using different water sources leading to a recovery of groundwater levels and desorption of contaminants and groundwater pollution **(EA, 1996).**

Generally, where aquifers are overlain by a substantial unsaturated zone and have high primary porosity and reasonable permeability, they tend to be less vulnerable to pollution. Aquifers where water is primarily held in secondary porosity (fissures and joints) tend to be more vulnerable to contamination as the water has less opportunity to undergo processes which remove contaminants.

This has led the concept of "Groundwater Protection Zones" where acceptable land uses are defined in order to protect the underlying groundwater. These zones were originally developed in Western Europe, particularly Germany, and the Netherlands, to prevent contamination of groundwater supplies by pathogens and thus reduce the incidence of water borne diarrheal diseases. The delineation of groundwater protection zones is done by establishing the length of time a substance or organism takes to become non-harmful and the distance this represents underground flow conditions.

Microbiological groundwater protection zone are established on the basis that the vast majority of pathogenic bacteria die off within 50 days of being in groundwater under normal conditions. Thus by establishing the distance travelled by groundwater in 50 days for a particular area, a zone can be defined from the abstraction point.

The definition of zones for chemical protection has also been attempted but this has been far less successful than the delineation of microbiological zones. This is because, unlike microbiological survival rates, it has proved extremely difficult to establish or even estimate the half-life of many chemicals in groundwater. Not only is there a vast number of chemical compounds which may be found in water, but groundwater and aquifers (particularly hard rock aquifers) frequently have a complicated chemistry themselves which may interact with pollutants and extend or reduce half-life. A 400-day isochron has been suggested in some quarters as being sufficient, but in reality far more work is needed in this area and chemical persistence will vary with different chemicals and aquifers **(EA, 1996).**

Groundwater Protection Zones may take many shapes. They are very rarely simple circles drawn with an abstraction point as the centre. There are many factors which will influence the shape of the zone: the nature of the aquifer (which are very rarely isotropic); the number of rivers in the zone; the condition of rivers (whether influent, effluent, perched, or changing); and the number and location of other abstraction points within the zone. Within the protection zone, land use may be restricted to non-polluting activities and ensure that any discharges within the zone meet stringent quality standards. This may be problematic where there is intensive agriculture with widespread use of inorganic fertilizers and pesticides **(EA, 1996).**

Groundwater either the main source of water or a complementary source to surface water. It can be renewable or fossil. Therefore, groundwater resources protection should receive high attention in such regions to ensure sustainability of developments. Groundwater deterioration occurs in various forms, namely, pollution, excessive draw downs, seawater intrusion, etc. Due to the low travel velocity of groundwater, deterioration may not be detected at real times; and when detected, rehabilitation may either be impossible or very costly. Accordingly, monitoring is one essential activity in the process of groundwater protection. Monitoring of groundwater should be carried out in the framework of integrated systems rather than simple networks. Important tools in this process are databases, geographic information systems, and numerical models. Groundwater management generally aims at the protection of the resource in the framework of integrated water management. Groundwater management is the second important step after the formulation of water policy in each region/ country. Groundwater management deals with both the hardware and the software. The hardware constitutes of various elements, namely, assessment, planning, and research implementation; while the software consists of the human resources, institutions, the public, and the legislation. All together form a package that aims at the protection of the resource **(Weshah, 2002).**

The key to a successful groundwater management policy is an understanding of recharge and recharge processes. This depends heavily on good quality quaternary mapping, but this is not yet universally available. Together with aquifer vulnerability zoning, these zones enable suitable control measures to be applied in order to safeguard groundwater from pollution. All groundwater protection policies must be reviewed from time to time. As technology advances, and as understanding of groundwater processes allows, the existing policies will be adapted to provide the best possible and most suitable policies for resource and source management. Perhaps the concept of mapping the susceptibility of aquifers to over-exploitation may become an important future management tool, although it is most likely to be applicable in regions of new and rapid groundwater development. The current policy and strategy for groundwater protection in the United Kingdom, and the policy now recommended in the Republic of Ireland, represent the state of the art and provide the best possible and best practical means of managing both resources and sources at the moment **(Robins, 1998).**

Groundwater is a vast resource that underlies the Earth's surface. Nearly half of the United States (U.S.) population uses groundwater for their drinking water source, including virtually all rural residents. In addition, groundwater provides much of the water used for irrigation and for industry. On average, about 40 percent of the annual stream flow in the U.S. is comprised of groundwater seepage, although in some areas more than three-fourths of the average stream flow, including virtually all fair weather flow, comes from groundwater seepage into streambeds.

States have traditionally regulated water withdrawals and the permitting of water wells. The states have generally been the first to regulate activities which could adversely impact groundwater; virtually all the states have either developed groundwater quality protection policies or are formulating or revising such policies.

States have traditionally managed water development including regulating drillers, well construction and decommissioning, and water withdrawals. Such state efforts should continue to be encouraged and promoted. States should determine the level of protection afforded to groundwater. This level may vary with the use and value of the resource **(NGWA, 1996).**

Local governments control land use, which is an essential element in protecting groundwater and preventing inappropriate uses of sites where the potential for exposure to wastes and/or contaminated groundwater exists. Federal and state groundwater protection and management efforts should recognize the need for land use controls and coordinate groundwater management with local governments **(NGWA, 1996).**

On the European level, the base of legislation is the water framework directive. This directive has to be transformed into national legislation by all European Union (EU) member states. It is also a part of the general provisions of becoming member states of the accession countries. The key objectives of the directive at European level are general protection of the aquatic ecology, specific protection of unique and valuable habitats, protection of drinking water resources, and protection of bathing water. All these objectives must be integrated for each river basin. On the effects side, it co-ordinates all the environmental objectives in existing legislation, and provides a new overall objective of good status for all waters, and requires that where the measures taken on the source side are not sufficient to achieve these objectives, additional ones are required **(Kollarits et al., 2003).**

There are various types of groundwater protection measures which are used in different part of the world. Each measure has its strength and weaknesses. Consequently, there is not one measure which can be universally adopted to protect Australia's groundwater. Each State and Territory will need to examine the range of, measures available and adapt one or more of these measures to their particular circumstances and local needs. The choice of suitable measures will not only depend on the physical properties of the groundwater body and the nature and type of contamination, but also can legislative, financial, social, environmental, and political considerations. This legislation can be grouped under three broad headings:

- Groundwater Management.

- Land-use Planning.
- Environment Protection (MCOA, 1995).

2.2.2 Groundwater in Gaza strip

Groundwater is the only source of water in the Gaza Strip. Municipal groundwater wells are currently being used for drinking and domestic purposes while private wells are being used for irrigation. The Gaza Strip is one of the most densely populated areas in the world 2,638 people/km^2 **(PCBS, 2000).** More than 90% of the population is connected to the municipal drinking water network while the other 10% of the rural areas is dependent on the private wells **(Shomar, 2006).** In addition to the problems of over-abstraction and salination, the groundwater resources are also threatened by pollution as result of uncontrolled solid waste disposal and discharge of untreated wastewater, and extensive use of fertilizers and pesticides **(PWA, 2005).**

The water quality in Gaza is affected by many different water sources including soil/water interaction in the unsaturated zone due to recharge and return flows, mobilization of deep brines, sea water intrusion or upconing and disposal of domestic and industrial wastes into the aquifer **(Ghabayen et al., 2006)**

Under natural conditions, groundwater flow in the Gaza Strip is towards the Mediterranean Sea, where fresh groundwater discharges into the sea. However, natural flow patterns have been significantly disturbed by pumping and artificial sources of recharge over the past 40 years **(MEnA, 2000).** Within the Gaza Strip, large cones of depression have formed over extensive areas in the north and south. Water levels are presently below mean sea level in many places, inducing a hydraulic gradient from the Mediterranean Sea towards the major pumping centers and municipal supply wells **(PEPA, 1996).**

Between 1970 and 1993, water levels dropped 1.6 m on average, mostly in the south. This is equivalent to 5 million cubic meters per year (Mm^3/yr) decline in aquifer storage on average using a specific yield of 0.2 (**Baalousha, 2005).** More than 89% of the groundwater wells are not suitable for drinking purposes because of high concentrations of NO3, Cl and F and some trace metals which exceed 2–7 times the WHO standards and private wells exposed to contamination sources of solid waste dumping sites, wastewater and manure disposal sites showed high concentrations of Zn, Pb, As and Cd **(Shomar, 2006).**

The Gaza coastal aquifer is the primary water source for the Gaza Strip, but it is in danger of becoming unusable. Metcalf and Eddy developed an integrated 20-year plan for managing Gaza's water resources. It covers the engineering, financial, and institutional aspects of water supply, treatment, and distribution; wastewater collection, treatment, and recharge; and agricultural irrigation with reclaimed water. The plan includes schedules and costs for the phased construction of major infrastructure facilities requiring the investment of some 1.5 billion dollar over the next 20 years **(PWA, 2000a).**

2.3 Wellhead Protection (WHP)

2.3.1 Wellhead protection in international level

The purpose of wellhead protection is to prevent the contamination of groundwater used for drinking water. A wellhead protection area (WHPA) is the area surrounding a public water supply well from which water and contaminants are likely to reach the well. Delineation is the process of identifying the wellhead protection area. There are several methods for delineating WHPAs for public water supply wells. The methods range from simple and inexpensive to complex and costly **(DWGB, 2007).**

A guideline for delineation of WHPA summarizes various technical approaches. The goal of delineation is simple; to identify an area around a potable water wellhead that, when properly managed, will provide a high degree of protection for the quality of water produced by that well. Ideally, delineation activities incorporate both the physical processes that control groundwater flow and transport, and local hydrogeologic information **(Bates and Evans, 1996).**

A WHPA can be delineated utilizing several different standards or criteria. Five criteria that may form the basis of WHPA delineation are identified. Numerous methods are available to determine WHPA specifications based on chosen criteria. The criteria are:

*distance, drawdown, time-of-travel (TOT), flow boundaries, assimilative capacity (its capacity to receive waste waters or toxic materials without deleterious effects and without damage to aquatic life or humans who consume the water).*The distance criterions delineate the WHPA by assigning a radius or other variable dimension from a pumping well. The drawdown criterion establishes the WHPA based on the magnitude of water level drawdown caused by the pumping well. Utilizing the TOT criterion, the WHPA boundary is determined based on time required for water or conservative contaminants to travel through the aquifer and reach the well. The flow boundary criterion incorporates the locations of physical or hydraulic features that control groundwater movement such as a groundwater divide or known discharge area. The assimilative capacity criterion incorporates the geologic formations capacity to dilute or attenuate contaminants to acceptable levels before they reach the supply well **(Bates and Evans, 1996).**

A WHPA based on time of travel is the area surrounding a well or well field that contributes groundwater flow to the well within a specified period of time. As example of using WHPA under Ohio's WHP Program suppliers delineate WHP areas based on a five-year time-of-travel. In other words, if drops of groundwater located at the well could backtrack to where they were located five years ago, these locations would mark the five-year time-of-travel boundary of the WHPA. The five-year time of travel criterion fulfills Ohio's WHP Program objectives by allowing a supplier time to respond to groundwater contamination reaching the WHPA. Theoretically, if a spill occurs just outside the controlled zone and results in groundwater contamination, a supplier still has five years to try to control or remove the plume, put in a treatment system, or develop an alternate supply before the contaminants reach the pumping well. The five-year time-of-travel area also provides a manageable area on which suppliers can focus their pollution prevention activities **(Bates and Evans, 1996).**

The first step in developing a wellhead protection program is to identify the land area around each well from which groundwater may be flowing to the source. These areas are the most likely to contribute pollutants to the groundwater and are referred to as zones of contribution. Zones of contribution require proper land use management to minimize the potential of contaminants entering the groundwater system **(Gray and Osborne, 2002).**

Protection zones can be monitored for detecting approaching contaminants and their growth, through natural or human processes. It is important to estimate accurately the limit of protection zones, since within them; limitations are imposed, concerning land use. If a small part of larger protection zone is taken, it may involve dire economic and environmental consequences **(Krijgsman and Ferreira, 2001).**

A wellhead protection area (WHPA) must be delineated separately for each municipal well and well-field to which the requirement to delineate this area applies. The WHPA represents a surface projection of the entire 3-dimensional capture area from which the water that is pumped from the well or well-field originates. Each WHPA should be sub-divided into well capture zones to distinguish among the areas of different potential risks posed to well water quality from various types of microbiological and chemical contaminants that could enter the water table and/or move with the groundwater flow to the well, and to facilitate effective and economical management of those risks .This variation in the risk potential throughout the WHPA results from the fact that bacteria have a limited life span and an adequate travel time from the point of entrance to the well may effectively inactivate these organisms. Similarly, over time, some chemical contaminants degrade into lower risk compounds or are absorbed by the geological materials encountered along the flow path. On the other hand, other chemicals are stable in a groundwater setting and the risk from their presence may only be attenuated through dilution along the flow path **(OMOE, 2001).**

At a minimum, three well capture zones should be delineated for each municipal production well/well field:

1) Zone 1: 0 to 2 year saturated travel time (TOT). Land uses in this zone need to be managed to avoid all possible risks, including those from bacteria and viruses.

2) Zone 2: 2 to 10 year TOT. The main focus of the land use management in this zone should be to minimize risks from all chemical contaminants; however, the bacterial and viral risks may still be a concern.

3) Zone 3: 10 to 25 year TOT / Zone of Contribution. The land use management in this zone needs to address risks from persistent and hazardous contaminants.

In addition, within Zone 1, a 50-day TOT area should be identified to recognize potential risks from day-to-day activities of the water utility itself or other contaminant sources **(OMOE, 2001).**

The protection zone is the area around the well in which installations or activities susceptible to polluting groundwater resources are prohibited or restricted. In the new Portuguese law, there are three zones defined as shown in **Figure (2.1):**

a) **Zone of immediate protection** is an area around the well in which in principal all activities are prohibited, except those for conservation, maintenance or better exploration of the aquifer.

b) **Zone of intermediate protection** is an area around the zone of immediate protection with variable extension, depending on the geological conditions and structure of the aquifer system, in which the objective is to reduce or eliminate pollution of the groundwater resources. In this area installations or activities susceptible to polluting groundwater resources are prohibited or restricted. It includes infiltrating pollutants or favouring the infiltration in the zone close to the well.

c) **Extended zone of protection** is an area around the zone of intermediate protection, in which activities or installations are prohibited or restricted that are capable of polluting the groundwater resources with persistent pollutants, like organic compounds, radioactive substances, heavy metals, hydrocarbons and nitrates, taking into account the nature of the terrain, the nature and quantity of pollutants as well as the way of emission of these pollutants **(Krijgsman and Ferreira, 2001).**

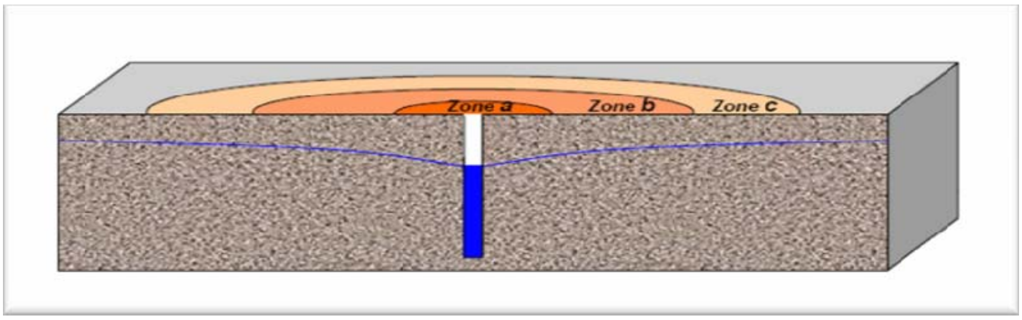


Figure 2.1: *Protection zones around a well according to Portuguese law.*

From a cost-benefit perspective, however, it is in the best interest of the public water supply to invest now in a proactive program of groundwater protection. Experience clearly indicates that the cost and hardships associated with remediating or perhaps losing a groundwater source as a result of contamination far exceeds the cost of implementing a preventative program **(http://www.deq.state.or.us, 2008).**

Oregon department of environmental quality recommends the following TOT zones be delineated within the WHPA:

- **6-Month TOT:** Emphasis placed on viral and microbial contaminants as well as the risk of direct contamination from other sources. Evidence is accumulating that some viruses (e.g., Hepatitis A and Echovirus) and micro-organisms (e.g., cryptosporidium) can survive in groundwater for extended periods of time. If possible, sources of these organisms should be kept at a distance of a 6-month TOT from the wellhead. It is recommended that chemicals capable of contaminating a system's groundwater neither be used or stored within the 6-month TOT because of the inability to respond to a contamination event should one occur. Because of potential changes in gradient direction, the state is requiring that a circular area, with a radius equivalent to the 6-month TOT be added to the well's WHPA.
- **5-Year TOT:** Within the 6-month to 5-year TOT travel zone, a greater emphasis on identification and control of potential contaminants can occur. Pollution prevention and risk reduction should be emphasized. Areas within this zone may be prioritized through the use of a susceptibility analysis.

- **10-Year TOT:** The area within the 5- to 10-year TOT boundaries represents the communities' water supply in the near future and should be treated accordingly. Again, a susceptibility analysis will help prioritize activities within this region **(http://www.deq.state.or.us, 2008).**

The steps in developing Wellhead Protection Plan in the Burlington City in United States are: **Phase I** defines the area to be protected and managed for wellhead protection. This is the subsurface area surrounding a well that supplies a public water system, through which contaminants are likely to move through and reach the well. The boundaries are scientifically calculated. **Phase II** is to create a contaminant source inventory with the purpose to identify potential sources of contamination which may impact the public water supply well. **Phase III** of the plan is through zoning and land use management. The City will incorporate essential elements of its wellhead protection plan into its zoning ordinances and land use planning as shown **Figure 2.2**. Residents and businesses within the wellhead protection area will be notified by mail and informed of the importance of preventing the release of pollutants within the areas **(Wilson, 2007).**

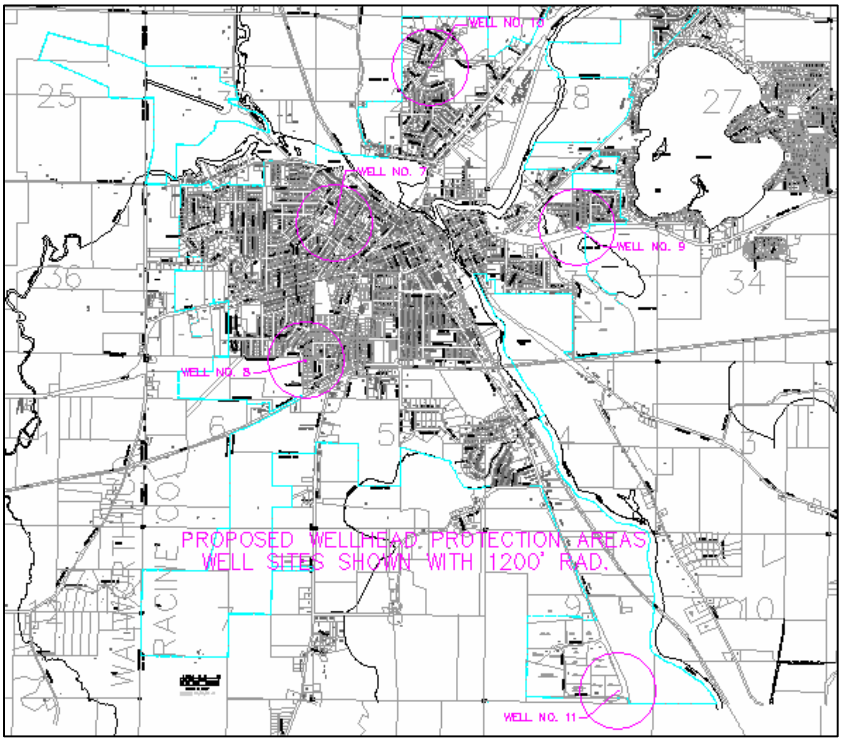


Figure 2.2: *Wellhead protection areas in Burlington City.*

2.3.2 Wellhead Protection (WHP) Plans in Gaza Strip

General framework WHP plans were recommended by PWA in report titled "Groundwater Pollution Control Wellhead Protection Plane Guidelines "the plans included:

- Defining the institutional roles of the involved authorities and other stakeholders.
- Establishing criteria for delineation of the Wellhead Protection Areas (WHPAs).
- Identifying potential sources of pollution and contaminant (prohibited activities and substances).
- Develop management approaches and action plans.
- Formulate contingency plans.
- Address the sitting of new wells.
- Public participation and hearings as required.

And it was said also about wellhead protection management strategy may consist of at the following items:

- Regulatory ordinance concerning zoning approach and the related prohibited activities and substances.
- Land-use restrictions in sensitive areas.
- Traffic control restrictions in sensitive areas.
- Plans to strengthen and enforcement of existing activities that may represent a potential pollution hazard to the groundwater resources.
- Other non-regulatory approaches.

The management techniques employed will need to be tailored to the specific needs and resources of the water authorities and utilities. This is dependent on the availability of qualified people to accomplish the management tasks, the level of local support, the legal authority to employ regulatory controls, and the money available to accomplish the management goals. Education of the users of the supply as well as those in the wellhead protection zone is strongly encouraged **(PWA, 2005).**

Therefore, the WHP plans should emphasize that a wellhead protection zone is not designed to eliminate existing businesses, land-uses and activities, but rather to ensure that such activities and interests within the wellhead protection zone are carried out in a manner that will minimize the risk of groundwater pollution by managing the potential contaminants in the best way possible.

Wellhead protection plans are considered the use of regulated substances, transportation, storage, and use of these, as well as spill response notification and contingency planning. In addition, plans will include public education and participation, proposed local ordinances, proposed zoning changes and other institutional controls. The plans will also include provisions for monitoring and periodic updating.

In principle, each owner of a well with a capacity of given capacity should be responsible for developing the wellhead zoning plans and proposals for a planned new well installation, however, in practice in Palestine, where wellhead zoning plans in most cases will over-lap due to the many existing wells, a more relevant and practical approach may be that PWA in close coordination with EQA, MoA and the well owner, or utility, will be responsible for developing the necessary wellhead protection plan **(PWA, 2005).**

2.3.2.1 Delineate Wellhead Protection Areas (WHPAs)

Zoning Concept

Zoning boundaries are restrictions designed to control the land use in the catchment area to a well. Several approaches to zoning are possible, such as: revision of existing zoning regulations or enactment of new zoning, overlay zoning which can target areas where protection is most vital, and/or defining conditional uses within a zone based on a set of requirements. Water pollution control regulations can be used to restrict certain high-risk land uses within the wellhead protection area. Zoning divides the wellhead protection area into specific regions for residential, commercial, and industrial use. Zoning can also be used to control lot sizes in un-sewered areas **(PWA, 2005).**

Zoning can control the type of land use, development density, placement, and placement of structures on lots, street frontage, and placement of parking areas, and roads with special traffic restrictions. For purposes of environmental protection, land use control is the most effective zoning function. Zoning may be used for existing wells, but are normally initiated with the establishment of a new major well. Land uses in existence before new zoning ordinances are established are usually permitted to continue as non conforming or grandfathered uses, however, new or additional restrictions and bye-laws to reduce the present level of groundwater pollution, and/o the risk of accidental pollution may be put in place. Even if land-use regulations are not implemented, the zoning concept can be useful, particularly in geologically complex areas, to better target voluntary pollution prevention efforts in the wellhead area.

Zoning constitutes an important component of groundwater pollution regulations, also providing a crucial basis for implementation of other provisions, including considerations to be carried out in conjunction with, for example, the licensing of pollution generating activities and issuing of waste discharge permits **(PWA, 2005).**

Criteria for Delineation of Zones Bounders

In general, distinction needs to be made between the protection of the groundwater resources, and protection in connection with a well, because abstraction of the groundwater will have an impact on the groundwater flow, and alter the natural flow regime in an aquifer. Wellhead protection zones will vary in size and shape. The size of the zone is strongly influenced amongst others by the well pumping rate, aquifer porosity, the hydraulic conductivity of the aquifer media, the groundwater gradient and the flow direction, and the natural recharge from precipitation and surface water run-offs **(PWA, 2005).**

Classification of Zones

Although the magnitude of the different zones depends on the type of flow, zones are defined provisionally for the most critical type of flow (porous flow or diffuse flow), however, the underground conditions with conduit flow it is difficult to define the areas, and the time of travel (TOT) is often very short.

Within the scope of regulations for pollution protection control for groundwater the following three zones are defined by PWA:

Zone I constitutes the accident prevention zone (inner source protection). This zone is located immediately adjacent to the groundwater source. It is designed to protect against the human activity which might have an immediate effect upon the source. **Zone II** is the attenuation zone (Outer Source Protection). This zone is larger than Zone I. This zone is established to protect a well from contact with pathogenic micro -organisms (e.g. bacteria and viruses), which can emanate from a source (e.g. septic system, latrines, sewers, animals etc.) located or held (animals) close to the well, as well as to provide emergency response time to begin active cleanup and/or implementation of contingency plans.

Zone III is defined as the remedial zone (Source Catchment). This zone covers the complete catchment area of groundwater source. All groundwater within it will eventually discharge to the source. It is defined, as an area needed to support an abstraction from long-term annual groundwater recharge (effective rainfall) as shown in **Figure 2.3 (PWA, 2005).**

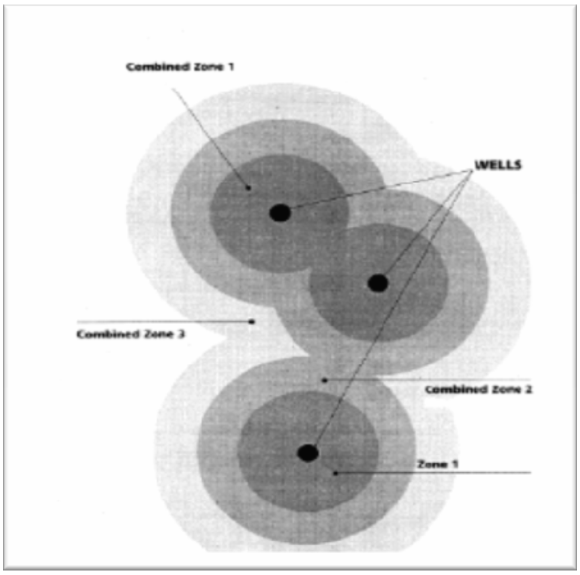


Figure 2.3: Criteria to delineate WHPAs by PWA.

2.4 Methods of Determining the Zoning Dimension

The Washington State Department of Health (WSDOH) defined four methods for delineating wellhead protection areas around public supply wells. These methods, in ascending order of complexity and cost, are the calculated-fixed-radius (CFR) method, the analytical method, hydrogeologic mapping, and numerical flow/transport flow mode **(Miller, 2003).**

2.4.1 Fixed-Radius Methods

Fixed-radius method addresses the distance criterion. One principal advantage of this method is their ease of application. Identification of a WHPA simply consists of identifying the WHPA radius and drawing a circle of that radius around a wellhead. They involve application of simple analytical equations that incorporate some of the physical processes taking place in the vicinity of a wellhead. Accordingly, they require some knowledge of local hydrogeologic conditions. Items of information typically required to calculate the radius of the WHPA include well pump age rate, various aquifer properties (hydraulic conductivity, saturated thickness, storativity, and porosity), and a time component. The time component is the time-of-travel, which is generally specified in terms of years.

The disadvantage of fixed-radius methods is that they ignore, or vastly simplify, the hydraulic behavior of wells in their specific hydrogeologic settings. In addition, they do not account for the effects of nearby pumping wells. In a hydrogeologic environment such as the sand and gravel aquifer, these methods can identify WHPAs inappropriate for local conditions. WHPAs identified by these methods may be either too large or too small, resulting in wellhead overprotection or under protection. If the radii are too large, more land use activities may require regulation than necessary to protect effectively the selected wells. In an area of high local recharge, little or no real protection will be afforded by protective measures undertaken within radii that are too small **(Richards et al., 1997).**

Intrinsic susceptibility to contamination is to be evaluated by considering the thickness and permeability of the material above the water supply aquifer. The thickness of the overlying formation is important, since any contaminants that are applied, deposited, or spilled on or near the ground surface will be less attenuated and will reach an aquifer more quickly where formations are thin **(OMOE, 2001).**

Water systems affected for water systems serving a population of 500 or less, and deriving their drinking water from a well or well field, a calculated fixed radius (CFR) is an acceptable delineation technique. It should be understood that this technique uses only minimal site specific data and does not account for some important aquifer characteristics (e.g., permeability or hydraulic gradient, which control how fast and in which direction groundwater is flowing). As a result of the limitations of using the (CFR) a TOT of 15 years is used for this technique. If the pre-plan assessment indicates a significant number of potential contaminant sources in the vicinity of their wells, a more site specific technique should be considered **(http://www.deq.state.or.us, 2008).**

Fixed radius approaches are used in a number of countries for defining a protection zone around the immediate vicinity of the wellhead, chiefly designed to protect the wells from pollution by short cuts. For example, in Germany this zone is set at a minimum of 10 m for wells, 20 m for springs and 30 m for wells in karst aquifers. The Swiss, Danish, and Austrian protection schemes also use an innermost zone of 10m radius. In Australia the wellhead protection zone is a concentric area comprising the operational compound surrounding for the well and is often, but not always, defined as a 50 m radius within which the most stringent controls on land use and materials apply **(Chave et al., 2003).**

2.4.2 Analytical Methods

The simplified, variable shapes and analytical methods address the drawdown and TOT criteria by incorporating generalized aquifer hydraulic conditions and time into WHPA identification. Application of these methods results in WHPAs that reflects the effects of the regional hydraulic gradient, aquifer flow boundaries and the average hydraulic conductivity on well capture zones. Analytical methods involve site-specific application of analytical equations describing flow to a well. They require the site-specific values of the hydraulic conductivity as required for the calculated radii method, as well as information on the magnitude and direction of the regional hydraulic gradient, location of up gradient flow boundaries, and specification of a TOT of interest. Simplified, variable shapes are a derivative of analytical methods.

For representative sets of hydrogeologic parameter values, "standardized" WHPA footprints are prepared using analytical methods. These standardized footprints are then applied to wells with similar hydrogeologic parameter values. The advantage of these analytical methods is that they better incorporate local hydrogeologic data and hydraulic behavior than do fixed radius methods. One disadvantage of these methods is that fixed hydraulic parameters (such as hydraulic conductivity and gradient) must be applied uniformly to the vicinity of the well when these parameters may, in fact, vary over the region. Another disadvantage is the inability to incorporate effects of nearby pumping wells. Compared to fixed-radius methods, application of analytical method is technically more involved **(Richards et al., 1997).**

WHPAs derived by analytical methods are typically asymmetric, having a long and short axis. The long axis is oriented parallel to the regional flow gradient, hence the requirement that this gradient direction be known. The pumping well is located near the down gradient end of the WHPA, which extends up gradient towards the nearest flow boundary. The length of the WHPA is a function of the specified TOT; the longer the TOT, the longer the WHPA. If the TOT is sufficient, the WHPA will extend to the nearest up gradient groundwater divide **(Richards et al., 1997).**

Estimations of values of porosity and hydraulic conductivity for aquifers always have wide ranges. The equation is quite sensitive to small changes in these parameters, thereby creating a certain uncertainty in the output. Distance of travel is computed for flow in the aquifer, while possible pollutants first have to enter the aquifer by passing through the unsaturated zone. In this methodology, it is assumed that the time for a pollutant to enter the aquifer from the surface is negligible on a time scale of 50 days. The methodology cannot be used to calculate the travel distances of pollutants in a certain time before entering a well. The travel time of pollutants in the aquifer is influenced by effects of dispersion, diffusion, adsorption/absorption, and retardation**.** The use of the equation is for delineating protection areas around the wells, with the objective of allowing the attenuation of pollutants in the aquifer, or providing a monitoring zone. The presented examples of protection areas with a symmetric shape are simplifications. In reality, the area could well be much more asymmetric **(Krijgsman and Ferreira, 2001).**

The main complication with the input parameters is the usual scarcity of field measurements. For a good assessment of groundwater protection zones, reliable data is needed for the entire studied area. In reality, this is rarely the case. Therefore, many simplifications have to be made. For instance, hydraulic conductivity 'K' values are normally scarce since they are hard and expensive to obtain, and for porosity, one normally picks an average from a range of typical values for the concerned lithology. In reality, values of hydraulic conductivity and porosity are never constant within an aquifer and vary considerably after small distances (heterogeneity), a reason to validate the reliability of the used input data. Other parameters that could be mentioned as having an influence on the estimation of the protection area are groundwater recharge and anisotropy **(Krijgsman and Ferreira, 2001).**

The analytical groundwater method is best if we consider both reliability and cost at the same time. Analytical groundwater flow is used for the demarcation of wellhead protection area around water well situated at Nachole Upazilla of Chapai Nawabganj District of Bangladesh **(Rahman and Shahid, 2004).**

2.4.2.1 Wellhead Analytic Element Model (WhAEM2000)

The U.S. Environmental Protection agency (EPA) Wellhead Analytic Element Model, WhAEM2000 for Windows (98/NT/2K/XP), is a groundwater geohydrology computer program. WhAEM2000 is a public domain, groundwater flow model designed to facilitate capture zone delineation and protection area mapping in support of the State's Wellhead Protection Programs (WHPP) and Source Water Assessment Planning (SWAP) for public water supplies in the United States. WhAEM2000 provides an interactive computer environment for design of protection areas based on radius methods, well in uniform flow solutions, and geohydrology modeling methods. Protection areas are designed and overlaid upon US Geological Survey Digital Line Graph (DLG) or other electronic base maps. Base maps for a project can be selected from a graphical index map for the State. Geohydrologic modeling for steady pumping wells, including the influence of hydrological boundaries, such as rivers, recharge, and no-flow contacts, is accomplished using the analytic element method.

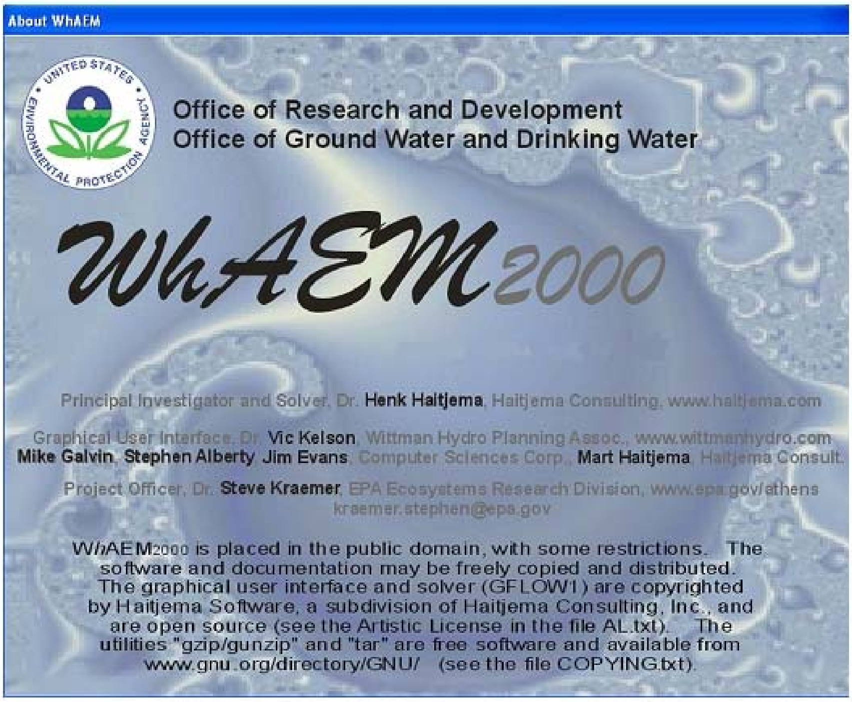


Figure 2.4: *WhAEM2000 splash screen.*

Program operation and modeling practice is covered in a series of progressively more complex representations of the wellfield tapping a glacial outwash aquifer for the city of Vincennes, Indiana.

WhAEM2000 has import and export utilities for DXF files and Shape files. WhAEM2000 has on-line help and tutorials. Install scripts and base maps are available for download from the EPA Center for Exposure Assessment Modeling web site **(http://www.epa.gov, 2007).**

2.4.3 Hydrogeologic Mapping

The hydrogeologic mapping method addresses the flow boundary criterion by incorporating local hydrogeologic information. In a hydrogeologic setting such as the sand and gravel Aquifer, application of this method would rely on identification of the aquifer potentiometric surface, regional flow gradient, up gradient groundwater divides, down gradient discharge boundaries and flow paths between up gradient and down gradient boundaries in the identification of capture zones **(Richards et al., 1997).**

2.4.4 Numerical Methods

Numerical methods are the most sophisticated of the four classes of methods. These methods can incorporate the effects of complex flow fields, complex hydraulic property zonation, boundary conditions, and well interference through the use of numerical computer codes which model groundwater flow. Computer models, which also simulate solute transport, can typically also address the assimilation criterion. The benefit of these methods is their ability to better incorporate spatial variability in hydrogeologic parameters, multiple well locations, and irregular boundary conditions than analytical methods. Because of the complexity of codes used to simulate flow and transport, WHPA delineation with this method requires a high degree of technical expertise. This approach will tend to be the most expensive but, if properly implemented, would yield the most realistic and precise representation of a WHPA, especially in the more complex hydrogeologic settings **(Richards et al., 1997).**

A conceptual hydrogeologic model is a three-dimensional portrayal of the groundwater system in the study area. Within the model, the distribution and geometries of the hydrogeologic units, their hydraulic properties, including variations in hydraulic head, the direction of groundwater flow, and the location(s) of hydrogeologic boundaries, and areas of recharge and discharge are displayed. The conceptual model provides the framework for decision making regarding the groundwater system in an area. It provides a vehicle for determining those hydrogeologic features that are especially important in controlling groundwater flow, it also provides for the testing of assumptions and recognizing where more data are needed. A well-conceived conceptual model is fundamental at developing a WHPA delineation that accurately reflects the groundwater system in the area as shown in **Figure 2.5 (Krijgsman and Ferreira, 2001).**

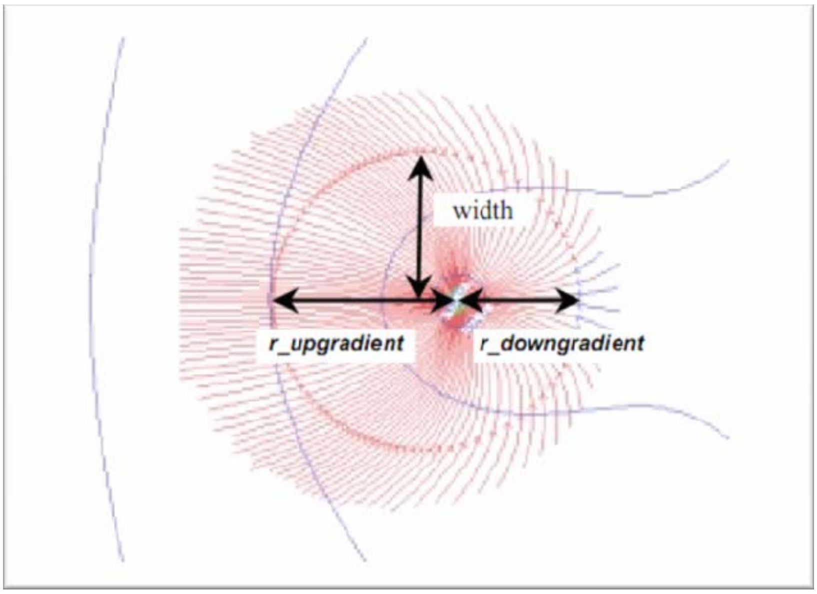


Figure 2.5: *Visual Modflow output showing the 50 day travel area.*

There are many countries used this method like the Palmela County on the Portugal and Goa city in India.

Numerical methods provide a high degree of accuracy and can be applied to almost all types of hydrogeologic situations. Accordingly, these methods are able to incorporate complex boundary conditions and variations in hydraulic properties within the aquifer. A large number of numerical models are presently available **(http://www.deq .state.or.us, 2008).**

2.5 Potential Contaminant Sources

Human activates can alter the natural composition of groundwater causing undesirable change in groundwater quality in the form of contamination or pollution. The difference between contamination and pollution terms is:

Groundwater contamination; the word "contamination" as used by Freeze and Cherry (1979) implies that human activities have increased the concentration of a constituent through no necessarily harmful.

Groundwater pollution refers to contamination levels that exceed acceptable limits results in pollution. Groundwater pollution is any physical chemical or biological change in groundwater quality that has a harmful effect on living organisms or makes water unsuitable for desired uses **(El-Naeem, 2007).**

Many types of industry, businesses, and land uses may have an impact on groundwater quality. These activities must be identified before effective wellhead protection management options can be instituted. At a minimum, the WHP plan team should identify, locate, and map the past, present, and proposed operations that may represent a source of groundwater contamination **(Nevada, 2007).**

Areas of commercial and industrial land use are located within most wellhead protection boundaries. Businesses that may contribute contaminants to the groundwater include dry cleaners, gas stations and other businesses with fuel storage tanks, auto repair shops, metal plating facilities, asphalt and concrete facilities, and machine shops. Wastes generated at these businesses include substances such a petroleum products, solvents, surfactants, heavy metals, and other organic materials. These wastes can potentially enter the groundwater system through inadequate disposal practices or accidental spills **(Gray and Osborne, 2002).**

Water systems are required to inventory potential contaminant sources in their wellhead protection areas. Potential contaminant sources include improperly abandoned wells, fertilizer and pesticide applications, and facilities such as gas stations and dry cleaners. You must complete the inventory within one year of delineating the system’s wellhead protection areas. An update is required every two years or, more often, if large changes in growth or land use occur.

When inventory the area is complete, prioritize the potential contaminant sources to help focus on whom to work firstly to reduce risks. You can do this by ranking the hazard relative to the potential for groundwater contamination and the impact it would have on your system's source of drinking water **(WSDH, 2006).**

In order to assess the risk for groundwater pollution a list of potentially polluting activities can be developed. The PWA established initial classification of activities is based on the most common and relevant activities in a Palestinian context, as shown in **Table (2.1)**. The ranking should take into account:

- The type of materials commonly used and stored for an activity.
- The potential risk of accident, or mal-practice, causing pollution of groundwater resources.
- The types and quantity of wastes or pollutants that commonly may generate by the activity.

Table 2.1, lists activity categories, typical activities within each category, and the most common pollutants associated with these activities. Industries, commercial establishments, facilities, etc. that fall within these categories and activities should not be allowed in Zone I, and only in Zone II if special remedial actions or precautions are taken to avoid pollution, and to minimize the risk of accidental pollution .

Activity categories listed in Table 2.1 may be permitted in Zone III based on careful environmental impact and risk assessments, and if actions are imposed that will limit the pollution to acceptable levels, and special remedial actions are taken to minimize the risk of accidents.

Potential polluting activities and developments outside Zone III will be permitted based on EQA and PWA's normal environmental impact and risk assessments **(PWA, 2005).**

Table 2.1: *Activities and pollutants (PWA, 2005).*

Activity Categories	Activities	Pollutants
Water and Wastewater	Treatment Plant Sewerage sludge landfill Septic tank effluent Treated wastewater infiltration basins	Heavy metals, high organic, nutrients (P, K, N), Faecal bacteria, viruses, protozoa
Solid waste disposal	Municipal landfill Industrial landfill Open dumps	Sulphate, chloride, ammonia, TOC, TDS, Biological contaminants, fatty acids, lactates
Waste Treatment Disposal	Storage of hazardous waste Waste handling	Hazardous substance
Storage and Transport	Storage of hazardous materials Fuel storage Oil and grease discharge	Hazardous materials, Petrlouem, hydrocarbons, benzene, ethylbenzene
Agricultural productions	Cropping practices	Pesticides, herbicides, nitrate, TDS, heavy metals, High nitrogen, phosphorus loads and biological contaminants.
Electricity generation	Fly ash ponds and landfills Waste briquettes, tars	Sulphate, heavy metals, TDS, Se, Ge, petroleum hydrocarbons, PAH
Mining and mineral industries	Mine water disposal Storage of fuel and hazardous chemicals Tailing dams Heap leaching	High TDS, iron, sulphate, heavy metals, organic flocculants, mercury, cyanide, vanadium pent oxide, acidic water, Petroleum hydrocarbons and hazardous materials
Manufacturing	Food processing	Nutrients, nitrogen, K, P, TDS

	Paper manufacturing	Organics such as lignins, organo-chloride, sulphates, organo-sulphur
		Organic solvents, petroleum hydrocarbons
	Automotive industry	Organic solvents, resin making compounds, heavy metals
	Paint and printing	Arsenic , chromium, cresols , phenols, pesticides compounds nutrients, sulphides, TDS
	Timber mills and preserving Tanneries	

2.6 Concluding Remarks

This chapter is focused on the international attempts for groundwater protection and ground protection in Gaza Strip, then Wellhead protection in international level and Gaza Strip. This chapter also defined four methods for delineating wellhead protection areas around public supply wells. These methods, in ascending order of complexity and cost, are the calculated-fixed-radius (CFR) method, the analytical method, hydrogeologic mapping, and numerical flow/transport flow mode. It presented the potential contaminant sources and the types of pollutants that commonly may generate by the activity.

Finally I will use three methods are the CFR method, the analytical method, and wellhead analytic element model (WhAEM2000) to delineate the WHPA for municipal supply wells in study area that will be described it in chapter four .

Chapter (3)

Legislative Frameworks for the Water Sector in Palestine

3.1 Introduction

A comprehensive and effective legislative framework is essential for the smooth operation of the water sector and for it to meet its goal of providing an adequate water supply. The key principle that should underlie the legislative structure of the drinking-water sector should be to protect and improve public health through the sustainable provision of drinking-water of adequate quality in sufficient quantities to all the population continually at a price which is affordable. Legislation should be flexible and dynamic and respond to developments within the sector rapidly and coherently.

Legislation is a tool to incorporate water policy within the national political-legal framework and should aim to protect both individual and communal water rights issues. Water quality is therefore only one aspect of water legislation which should cover aspects such as quantity of water supplied, access assurances, continuity provisions and limits set on costs charged to consumers. The legislation will empower the surveillance bodies, both financial and health-based, to closely monitor the water supplier to ensure that they met statutory functions which guarantee the supply of wholesome drinking-water **(Novonty and Olem, 1994).**

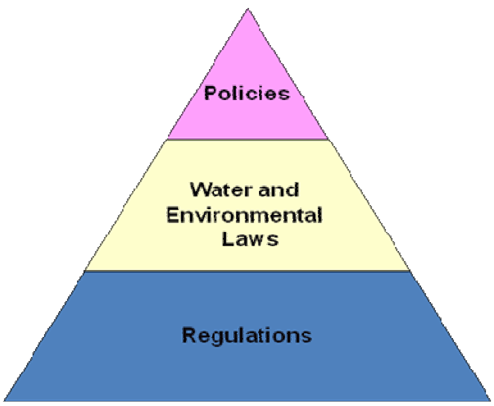


Figure 3.1: *Legislation framework.*

3.2 Key Elements of Legislation

3.2.1 Policy Statement

The policy statement should also clearly highlight source protection, minimum treatment requirements and water supply monitoring that is expected from the different institutions. The policy statement should also clearly state the difference but complementary roles of the supplier and the surveillance agencies. It should be made clearly that independent, health based surveillance is essential and entails the routine monitoring of suppliers performance with respect to nationally and regionally accepted norms of practice.

The policy statement should also clearly state the underlying health related rationale for water supply in the country and the primacy of drinking-water supply in use of water resources. This should also clearly state the need for source protection and distribution maintenance as well as outlining the need for minimum treatment requirements for water supplies of all types **(Novonty and Olem, 1994).**

The Palestinian Authority (PA) has formulated a national water policy to address the increasing scarcity of water resources in Palestine. This policy includes the set of principles to govern policy and planning for the water sector that are shown alongside. The PWA has formulated a strategy for institutional reforms towards a sustainable water sector which forms the basis for the analysis.

3.2.1.1 Policy Instruments

- Public awareness and applying polluter pays principle;
- Adopting affordable tariff structure;
- Capacity building for all levels of stakeholders;
- Monitoring and evaluation of groundwater quality;
- Initiating a comprehensive water related data bank;
- Strengthening the cooperation with international development donors;
- Improving water resources management systems through:
    - Adopting a water demand management approach;

- Encouraging users' participation in water management;
- Coordinating the Palestinian water resources on the national level, and carried it out on the appropriate local level;
- Separating the institutional responsibility for policy and regulatory functions from the service delivery functions;
- Continuing the effort to obtain the right of water resources shared with other countries;
- Institutional strengthening of the different water related entities; and
- Co-ordination between PWA and other ministries (**Abu-Zeid, 2005).**

3.2.1.2 Palestinian Water Policy

The Palestinian Water Policy, as set out in the following principles is the basis decisions on the structure and tasks of water sector institutions, and the water sector legislation.

- All sources of water are public property.
- Water has a unique value for human survival and health, and all citizens have a right to water of good quality for personal consumption at costs they can afford.
- Water supply and domestic, industrial, and agricultural development must be compatible with the available water resources and based on sustainable development.
- Water has social, environmental, and economic values.
- Development of Palestinian water resources must be coordinated on the national level, and carried out on the appropriate local level.
- The national water sector management should be carried out by one responsible.
- Public participation in water sector management should be ensured.
- Water management at all levels should integrate water quality and quantity.
- Water supply and wastewater management should be integrated at all administrative levels.
- Consistent water demand management must complement the optimal development of water supply.

- Protection and pollution control of water resources should be ensured. The "Polluter pas" principle will be applied to guarantee environmental protection.
- Conservation and optimum utilization of water resources should be promote and enhanced.
- Pursue Palestinian interests in connection with obtaining the right of water resources shared by other countries on the principle of equality.
- The Government will co-operate with regional and extra-regional parties to promote the optimum utilization of water resources to identify and develop new and additional supplies, and to collect and share relevant information and data **(PHG et al., 2006).**

3.2.2 Institutional Roles

The different institutions, their remit, and responsibility should be clearly defined within the legislative framework. Failure to provide this will lead to long-term problems within the sector from overlapping responsibilities, duplication of effort, unclear reporting lines, and difficulties in enforcement. During the occupation the role and responsibilities were scattered fragmented and unclear.

The organization of the Palestinian Water Sector theoretically envisages a clear separation between policy formulation, regulation, and service delivery functions. The National Water Council (NWC) establishes by By-Law No.2 (1996) is theoretically the policy making body while the Palestinian Water Authority (PWA) should only act as the regulator and the **Figure 3.2** shown the PWA regulatory framework **(Klawitter and Barghouti, 2006).**

3.2.2.1 The Current Structure and Main Actors of the Palestinian Water Sector

The Palestinian Natural Water Council (NWC)

According to Article 14 of the Palestinian Water Law (Law No.3 of 2002) the NWC theoretically consists of 11 members, which are appointed by the Palestinian National Authority (PNA). The NWC is chaired by the President of the PNA and consist of five ministers, six other members representing government and non-government organizations and the head of the PWA as the secretary of the NWC. The head of

PWA serves as liaison officer between PWA and NWC.

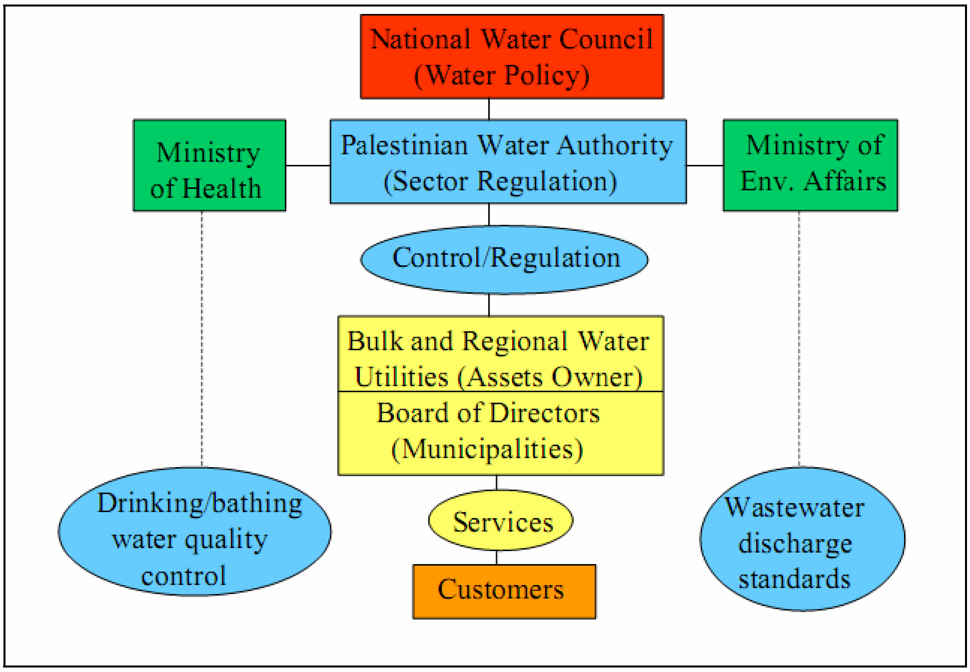


Figure 3.2: *The PWA regulatory framework* ***(Ghbn, 2003).***

Responsibilities of the Palestinian Water Council

- Reviewing and approving the national water policy.
- Reviewing and approving water quotas by means of development and utilization of water resources and their different uses.
- Ratifying plans and aimed at organizing the usage of water, preventing wastage, and directing consumption.
- Confirming the allocation of funds for investment in the water sector; Ratifying water pricing and tariff policy.
- Approving periodic reports concerning the activities of the PWA and its work.
- Examining all central water projects and approving their implementation.
- Approving PWA guidelines and confirming international regulations which govern administration and operation.

- Confirming the appointment of Board of Directors of regional utilities.
- Approving the annual budget of PWA and presenting it to the Council of Ministers to confirm.
- Implementing financial regulations prevailing in the PWA.
- Any other tasks which are delegate to the NWC according to the provision of the law **(Klawitter and Barghouti, 2006).**

Palestinian Water Authority (PWA)

The Palestinian Water Authority (PWA) is the central public authority in the water sector established under the Presidential Resolution No. 90 of 1995, acting under the direct responsibility of the President of the Palestinian National Authority (PNA). PWA's responsibility is to act as the main regulatory body for water resources management and development and infrastructure planning in Palestine.

PWA has been through a difficult process of establishment and consolidation and at the same time has been and is still involved in needed infrastructure planning and implementation. In recent days the institutional framework is still suffering from significant overlaps in roles and responsibilities, the investment, and regulatory frameworks are still works in progress **(Klawitter and Barghouti, 2006).**

Objectives of the PWA

- Execution of the national water policy as approved by the National Water Council.
- Ensuring the most efficient management of available water resources in Palestine.
- Ensuring reliable water supply through optimal planning and management of water resources and exploring further resources to ensure balanced management between supply and demand.
- Setting of standards and establishment of technical specifications to assure quality control of water works.
- Licensing the exploitation of water resources including the construction of water projects.

- Consolidation of co-operation between PWA and other relevant parties, especially international donors and NGOs **(Klawitter and Barghouti, 2006).**

The PWA prepared the National Water Plan of 2000 which is the strategic plan for the water sector. It sets the direction until the year 2020 and proposes actions to achieve the goals. The plan describes the role of the service providers and shifts the functions of the PWA to regional utilities in terms of operations, maintenance, repairs, waster water collection and treatment, bulk water supply, water reuse, allocation for industrial and agriculture use. Regional water utility assets will remain government owned with community representations on their boards (**Husseini, 2004).**

Ministries

PWA is interacting with most of the Palestinian ministries. **Figure 3.3** shows subjects to be coordinated by PWA and related ministries with the different ministries as agreed upon.

Local and international NGOS

Several non-governmental organizations are engaged in the water sector including UN agencies, international and local NGOs. Prior the establishment of the PA and due to the absence of central water organizations, NGOs had been playing a significant role in a multitude of areas in the water sector and gained remarkable influence and economic power.

Today, most of the local NGOs are engaged in the highly competitive field of infrastructure development and applied water research. No formal coordination mechanisms exist in order to avoid duplication and make better use of funds available to the sector. PWA is claiming with only limited success that any NGO activity needs its approval before starting, a claim that contradicts the definition and purpose of any NGO. Within the Palestinian water sector there is almost no room given for non-governmental opposition while the relationship between PWA and NGOs working in the water sector is often more competitive then cooperative. There is still a duplication of work and ongoing power struggle over political support and international funding. Nepotism and corruption on both sites hinder coordination and cooperation between governmental institutions and NGOs working in the water sector **(Klawitter and Barghouti, 2006).**

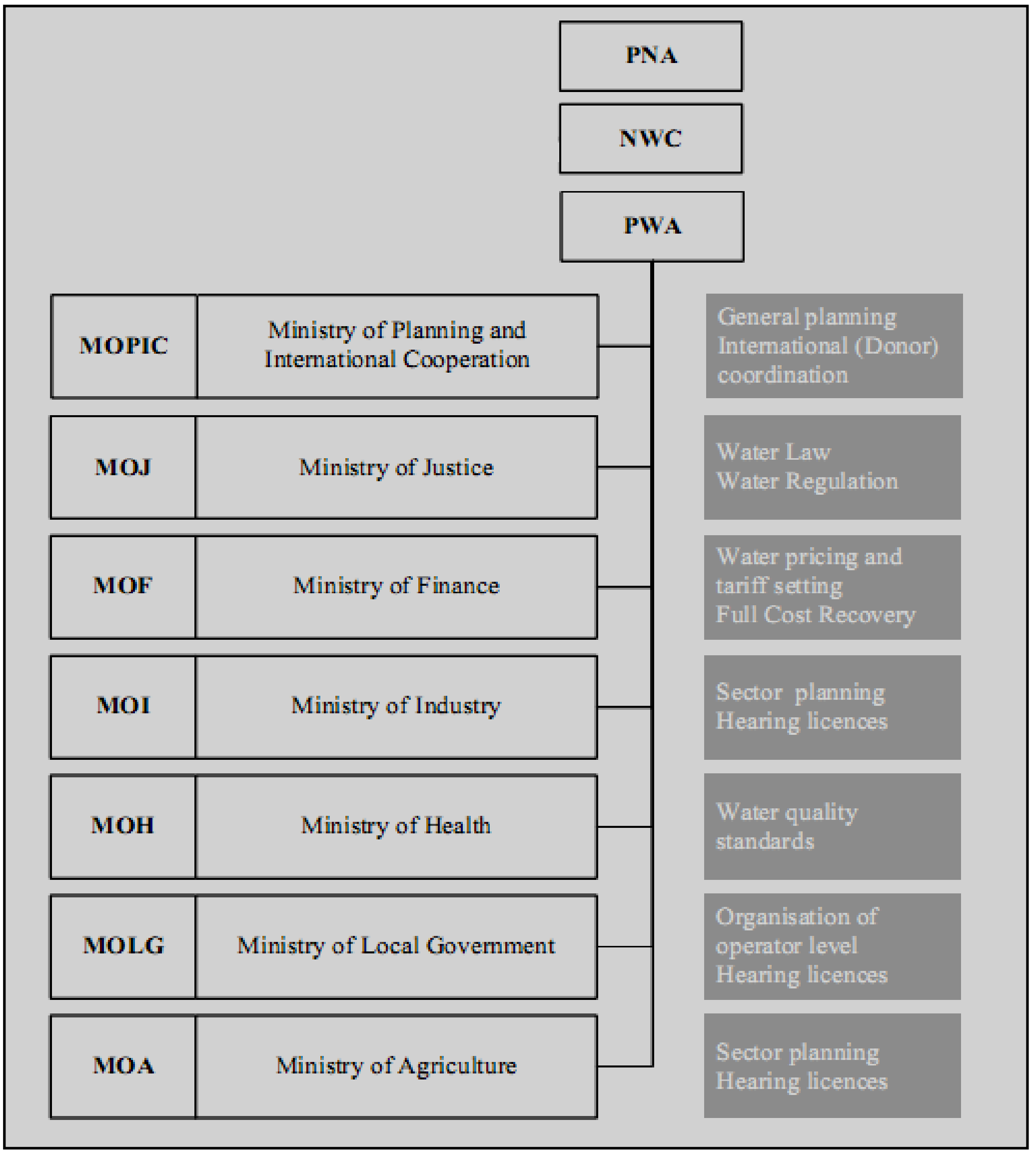


Figure 3.3: *Inter-ministerial coordination of the water sector* ***(Klawitter and Barghouti, 2006).***

3.2.3 Palestinian Water and Environmental laws

3.2.3.1 Palestinian Water Law

It is common to find that much of the water legislation in a country has historically been incorporated within other laws and elements of legislation, such as Public Health Laws or Natural Resources Laws. Whilst these may address water, it is limited to specific impacts and fails to provide a comprehensive framework for the sector. It is therefore desirable that all water legislation be brought under an umbrella Water Law which has an array of associated addenda, regulations, and codes of practice **(Novonty and Olem, 1994).**

Legal Framework Governing Water and Water Institutions Various Governments ruled Palestine and imposed their legal systems, rules, and laws. Water related laws in Palestine date back to the Ottoman Empire period, followed by the British, Jordan/Egypt, Israel, and now the Palestinian Authority. Each ruling power enacted new laws and created different water related institutions.

The process of law making and governance over the sector remained a key goal of the PWA. The PWA prepared a comprehensive law on water in 2000-2001 that it was enacted by the Palestinian Legislative Council in 2002. The Law No. 3 of 2002 encompasses the whole water sector issues and it aims to develop and manage the water resources, increase capacity, improve quality, preserve and protect against pollution and depletion. The Law establishes a Water Council chaired by the President of the PA and membership of water user association, various ministries, academicians, regional utilities that it sets the policies for the water sector and ratifies PWA plans and reports (**Husseini, 2004).**

Sharia Law

- Water is God's property and as such is free for all and thus belongs to all.
- Rights to use water were acceptable (drinking and irrigation).
- Payment was not clear (**Husseini, 2004).**

Objectives of the Water Law No. 3 of 2002

- Secure sustainable development.
- Provide and satisfy social and individual needs in an optimal and equitable way.
- Protect water resources from pollution.

Key Elements of Water Law

- Establish water authority and water council.
- Acknowledge water is public property under the administration of the water authority.
- Identifies national water plan as the guideline.
- Authorizes the establishment of utilities.
- Establish the basis of water regulations.
- Authorizes development of unified tariff structure **(PWA, 2002).**

3.2.3.2 Environmental Law

The law of Palestinian environmental will guarantee the right to every individual to live in a sound and clean environment and enjoy the best possible of health care and welfare. Protection of the country's natural fortunes and economic resources, the preservation of its historical and cultural heritage without any harms or side effects that are likely to occur sooner or later as a result of the variant industrial, agricultural or constructional activities, with an impact on the quality of life and basic ecosystems such as air, water, soil; marine resources, animals and plants and the objectives of Palestinian environmental law are:

- Protection of the environment against all forms and types of pollution.
- Protection of Public health and welfare.
- Insertion of the bases of environmental protection in social and economic development plans; and encouragement of sustainable development of vital resources in a manner that preserves the rights of future generations.
- Protection of bio-diversity and environmentally sensitive areas, as well as improvement of environmentally harmed areas.

- Encouragement of collection and publication of environment-related information to raise public awareness of environmental problems **(MEnA, 2000).**

3.2.4 Regulatory Framework

The regulatory matters in the water sector were transferred to PWA and in 1997; Presidential decree No. 66 established the regulations of the water sector, its rules, and procedures. The water utilities are operated within a regulatory framework developed based on governmental requirements at different levels.

Regulation is sets of commands issued by governments, which are designed to control behavior, with accompanying ‘police forces’ and penalties that it aims to improve access to services, ensure the quality of service and promote efficiency in the production and consumption of services, in addition to protection of the customer. It deals primarily with issues related to the cost and quality of services, as they are perceived by the individual consumer. The regulation should apply equally to all water service providers regardless of whether they are private or public sector entities **(Ghbn, 2003).**

Regulation plays a critical role in influencing the performance of utility industries, and hence the quality and coverage of services available to citizens. It does so in two main ways:

- By addressing concerns over possible misuse of monopoly power or other forms of market failure, regulation can protect important consumer interests and encourage efficiency.
- By influencing the opportunities, risks and incentives faced by service providers, regulation can determine the volume and composition of investment, the required level of consumer tariffs, and the responsiveness of firms to consumers **(Ghbn, 2003).**

The Objectives of water regulation

- Ensure the quality standards.
- Ensure the continuity and reliability of water and wastewater service.

- Protect consumer interests and encourage water efficiency.
- Promote social interests.
- Control water resources pollution.
- Conserve and maintain water resources **(Ghbn, 2003).**

The Regulator Responsibility

- Promoting efficiency and competitiveness.
- Developing policies.
- Issuing, awarding, and cancelling licenses.
- Defining and establishing detailed quality and technical standards.
- Monitor and enforce the water regulation.
- Monitoring and enforcing compliance with norms and standards.
- Ensuring the planned approach for future provision of water services.
- Conciliating disputes between customers and providers **(Ghbn, 2003).**

The Process of Regulation

- Creating water laws (Bylaws).
- Authorized certain bodies to create and enforce water regulation.
- Putting the law to works.
- Creating water regulation.
- Developing standards.
- Carry out the law and enforce water regulation (Enforcement).
- Monitoring and evaluations **(Ghbn, 2003).**

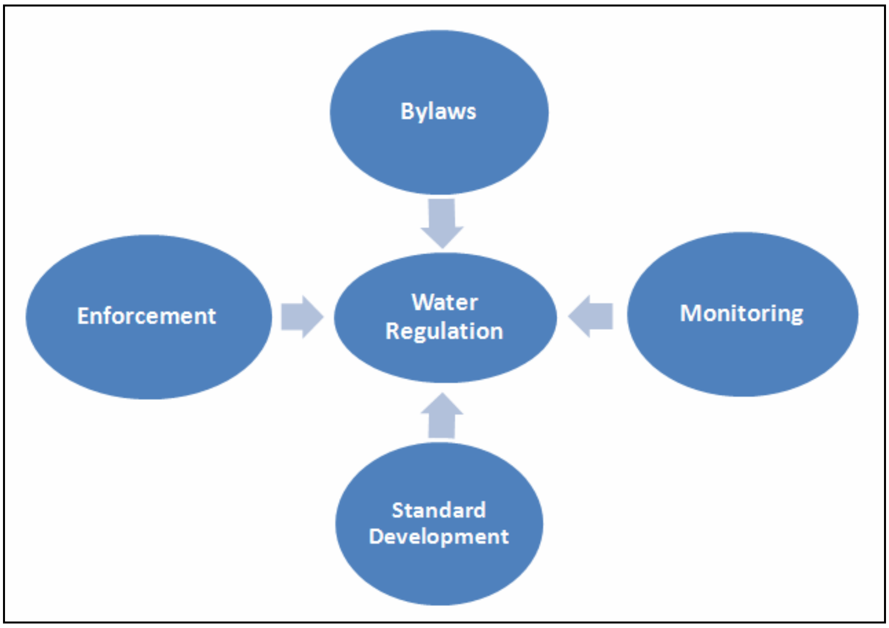


Figure 3.4: *The water regulation elements.*

3.2.4.1 Groundwater Monitoring Systems in the Gaza Strip

The general definition of monitoring is to follow the temporal change of system variables in order to provide information about the evaluation of these variables to support goals for the policy of decision making. Therefore, monitoring is only one tool for collecting information for water system management **(Mogheir, 2003).**

The objective of monitoring systems is designed for different sectors, including groundwater quality, the marine environment and air quality.

In general terms, the PWA has the responsibility for all water resources actions from monitoring and assessment up to the controlled use and protection of the water resources. From the point of view of water quality protection it is important to stimulate the implementation of the needed actions and to keep track of the planning and implementation processes and further to monitor the effect of the measures on the water quality:

1. Results of the monitoring efforts should be evaluated and if necessary the measures should be adjusted.
2. Additionally, to eliminate the depletion of the water resources it is essential that the PWA is fully controlling the exploitation of the water resources.
3. A Pollution Index (PI) is needed to assess the pollution level and the action required - time wise - for any measures to minimize the rapid rate of deterioration of water resources (quantity and quality).
4. Control and inspection of the results of monitoring programs, using selected contaminants must be regulated and assigned to the EQA **(EQA, 2004).**

Groundwater Quality Monitoring

Water quality is an important pillar for any water management program. Water quality monitoring is defined as "integrated activity for evaluating the physical, chemical and biological character of the water in relation to human health, ecological conditions and designated water use" **(EQA, 2004).**

One of the most important environmental issues that facing Palestine, is the degradation of groundwater quality, hence, to insure the quantitative future of the Palestinian's groundwater, the management of groundwater must be dealt within very effective ways, and data must be therefore provided on regular intervals. In other words, a reliable groundwater quality monitoring system must be established. The groundwater quality in Gaza city is considered as one of the worst **(EQA, 2004).**

The objectives of the monitoring system for groundwater quality are:

- To assess the quality of local aquifers by sampling public (municipal) and private (agricultural) wells for selected contaminants.
- To establish a reliable monitoring system for groundwater quality in Gaza governorate.
- Building the relevant database system to enable good management of the water resources and to provide the relevant data in a convenient format for data exchange.
- Putting into practice the Palestinian Environmental Strategy (PES) and the National Environmental Action Plan (NEAP), as well as other major national activities, plans

and policies including the national development plan **(EQA, 2004).**

Current groundwater monitoring in the Gaza Strip

Aquifer monitoring, by definition, implies that a particular baseline situation or a set of conditions is quantified and evaluated in time. The pre-requisite of efficient monitoring is that the baseline aquifer conditions are well defined and understood. Thus, an efficient monitoring in the Gaza Strip aquifer requires an understanding and quantification of the following major parameters:

1. Aquifer geometry and lithology;
2. Aquifer hydraulic characteristics;
3. Water quality of the aquifer;
4. Inputs and outputs from the aquifer basin (i.e., all sources of recharge and pumping);
5. Water managements practices in areas surrounding the Gaza Strip that may affect the water availability and use within the Gaza borders;
6. External factors, such as land use changes, water demands (by sector), industrial development, etc **(Mogheir, 2003).**

Table 3.1 illustrates the summary of the current monitoring activities in the Gaza Strip. From this table it can be noted that the groundwater monitoring network consists of:

1. Groundwater depth (level);
2. Municipal wells;
3. Groundwater quality.

Table 3.1: *Summary of the existing groundwater monitoring networks in the Gaza Strip.*

Variables	Number of wells [1] (Approximate)	Sampling Frequency	Data record since (Year)[7]
Groundwater level	133 [4]	Monthly	1970
Chloride and EC	1128 [2] 366 [3]	Twice per year	1970
Nitrate	1128 [2] 366 [3]	Twice per year	1993
Major ions [5]	97 [6]	Twice per year	1976

Notes:

1 95 % of monitoring wells are shallow, penetrating less than 30 m of the aquifer.

2 Per Ministry of Agriculture, 1128 wells were originally sampled.

3 Per Ministry of Agriculture, 366 wells have been sampled since 1999.

4 Per Palestinian Water Authority (PWA), 2000.

5 TDS, Cl, NO], pH, Ca, Mg, K, F, S04, Hardness and Alkalinity.

6 Wells exist today. In 1999, only 71 were sampled.

7 Time series for most data not complete; some years are missed.

The total number of wells used in the three networks and presented in Table 3.1 is 1455. These wells are used to collect information that describes the groundwater quality and quantity status. It can be realized that the monitoring is conducted by the Palestinian Water Authority (PWA), Ministry of Agriculture (MOA), and the Ministry of Health (MOH).

Recent surveying of all the groundwater well coordinates (including the monitoring wells) was undertaken by PWA and suggested that the total number of active wells in the Gaza Strip could total more than 3800 wells **(Mogheir, 2003).**

3.2.4.2 The PWA Regulation

PWA has recently developed some regulations as an output of water laws. These regulations are described in the following text.

Water quality Regulation (Safety Regulation)

The following items summaries the content of safety regulations:

- Procedure of sampling.
- Method of analysis.
- Reporting and data processing.
- Penalties and fines due to non-compliance/violation.

Environmental Regulation

The following items summaries the content of environmental regulations:

- Licensing of water abstraction for all demand sectors, domestic, industrial, agricultural, and recreational and also licensing for land use.
- Issuing of licenses related to disposal and/or reuse of treated wastewater and the disposal of industrial wastewater including the brine of desalination plants.

Economic Regulation

The following items summaries the content of Economic regulations:

- Customer service and public relations.
- Establishment of a proper billing and collection system.
- Proper implementation of the capital investment program.
- Application and tariff approvals.
- Efficient operation and maintenance.
- Compliance with service standards.
- Infrastructure and Project Follow up.

- License and Permit.
- Monitoring.
- Quality Assurance **(Ghbn, 2003).**

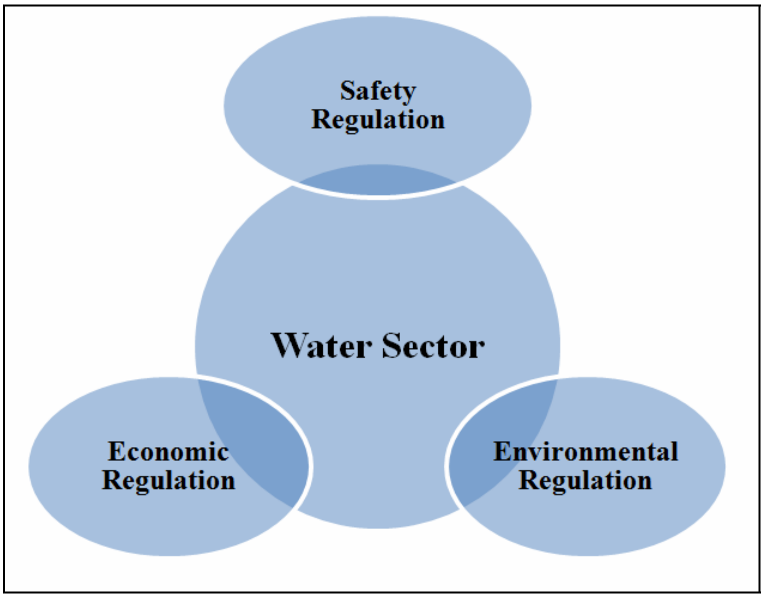


Figure 3.5 : *PWA regulations.*

3.3 Concluding Remarks

- The challenge of implementing water policy in Palestine is mainly constrained by the Occupation.
- Palestinians were already established their polices and strategies regarding water management and conservation while the enforcement of regulations is still very weak due to the sovereignty issue over land and water.
- Appropriate Regulatory frameworks need to be developed to accommodate best management practices in water management.
- Stakeholder participation and the creation of Water User Associations are needed to improve water management efficiency.
- Roles and responsibilities in the water sector in Palestine are still scattered fragmented and rather unclear what have led to often inefficient management and uncoordinated investments in new infrastructure and capacity building.

- It is important to define roles and responsibilities of the various institutions dealing with water management.
- The available monitoring networks should be reviewed and updated by reducing or extending the number of monitoring stations.
- This research focuses on Wellhead protection area which is an important part of PWA regulations (environmental regulations) and it will help PWA and EQA to grant license for environmental sound land use.

Chapter (4)

Description of Study Area

4.1 Geography

4.1.1 Location

Gaza Strip is the southern part of the Mediterranean Coastal Plain of Palestine with total area of 365 km^2 and a form of long and narrow rectangle. The study area is Gaza Governorate of Gaza Strip which located between longitude 34° 23 to 34° 30 and latitude 31° 26 to 31° 33. Its boundaries are Mediterranean Sea from the west, the 1948 Palestinian occupied areas to the east and North Governorate to the north and Wadi Gaza to the south. It covers an area of about 74 Km^2 with a length along the coast about 12 Km and width ranges from 6 Km in the south to 8 Km in the north.

4.1.2 Topography

A topographic map for the Gaza Governorate of Gaza Strip is shown in **Figure 4.1.** This area is characterized by narrow elongated ridges and depressions extend parallel to the shoreline (NNE-SSW).

The surface land elevation is ranging from zero at the shoreline to about 80 meter above mean sea level (MSL) in some places in the eastern side of the study area. The ridges and depressions show considerable vertical relief in some places up to 60 m. Surface elevation of individual ridges range between 20 m and 80 m. Sand dunes are dominant along the shoreline with elevations up to 50 m above MSL.

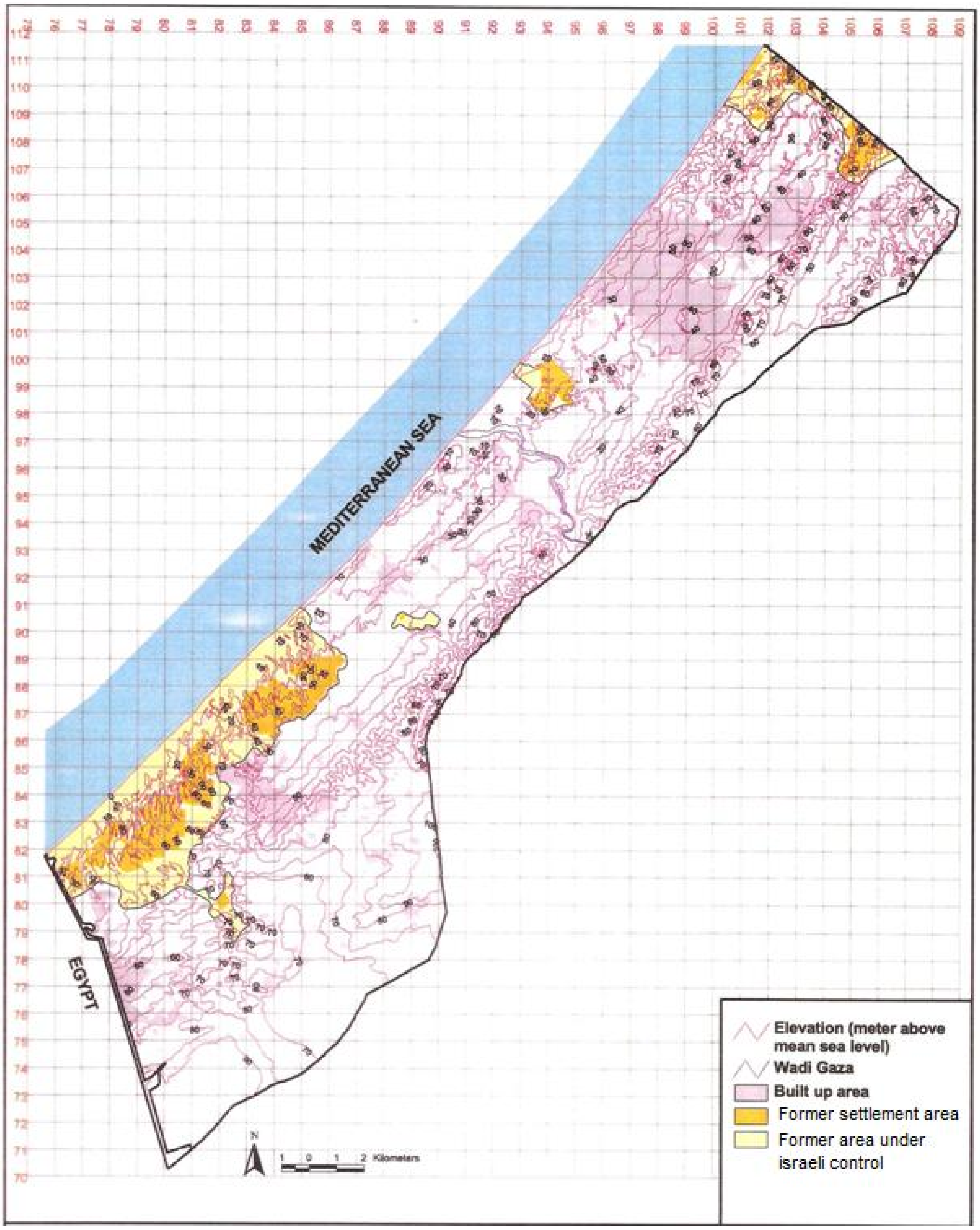


Figure 4.1: *Topography map of the Gaza Strip* ***(PWA, 2000a).***

4.1.3 Population

The Gaza Governorate of Gaza Strip is considered as one of the most densely populated areas all over the world where at year 2006 more than 409,680 inhabitants are crowded into an area of about 74 Km^2.The population densities in Gaza Governorate at year 2004 more than 6700 per square kilometer. The population situation here is strongly influenced by political developments which have played a significant role on the growth rate and population distribution. According to the Palestinian Central Bureau of Statistics, the natural rate of growth of population in Gaza strip is estimated at 4% per year **(PCBS, 2004).**

Gaza Governorate has experienced a 37.5 % increase in population from 1997 to 2004. The increase in population is as a result of natural growth and the Palestinians returning to their homeland. This high population growth rate in the study area has proved to be a serious challenge in the provision of essential services like water, sanitation, and health care.

4.1.4 Climate and Rainfall

The study area has a characteristically semi-arid Mediterranean Sea climate. It is located in transitional zone between a temperate Mediterranean climate to the west and north, and the arid Negev and Sinai deserts to the east and south and there are two distinct seasons; cool and relatively wet season (October-March), and hot and dry season (April-September). The average daily temperature in the Gaza Strip ranges from 26°C in summer to 12°C in winter with the average daily maximum temperature range from 29°C to17°C ,and the minimum temperature range from 21°C to 9°C, in the summer and winter respectively. The daily relative humidity of this coastal area ranges from 65% to 85%in summer and from 60% to 80% in winter in the day time and at night respectively **(GMS, 2005).**

The mean daily evaporation is variable during the year, where it ranges from about 2.1 mm/d, in December to 6.3 mm/d in July. The high potential evaporation is primarily related to high solar radiation incident over the strip at 190 kg-calories/cm^2/year **(U.S. National academy of Sciences, 1999)**. The generally cloudless summer months (April through September) and consequently open water evaporation is high in the summer, accounting for as much as 70 % of the annual total evaporation **(GMS, 2005).** More water is potentially lost through evaporation than added by precipitation.

The rainfall occurs in the winter period, which is between Octobers to March; and the mean annual rainfall in the Gaza Governorate varies 350-400 mm/year. The period for June to September is dry with no rainfall therefore the rainfall is the main source of almost all water in this area **(GMS, 2005).**

4.1.5 Soil

Soil media refers to the upper part of the phreatic zone. Soil media is an important factor in terms of movement of pollutants. All the infiltration processes took place in the upper part of soil. The soil varies in the study area. It is mainly composed of three types; sand, clay and loess as shown in **Figure 4.2.** Along the shoreline there is a zone and of sand dunes with varying in thickness from two meters to about 50 m and extends up from 4 km to 5 km in land. This area is wider in the north than in the south of the study area. The dunes have relatively high permeability. Moving eastward, the soil type change and becomes less sandy with more silt, clay, and loess **(EQA, 2005).**

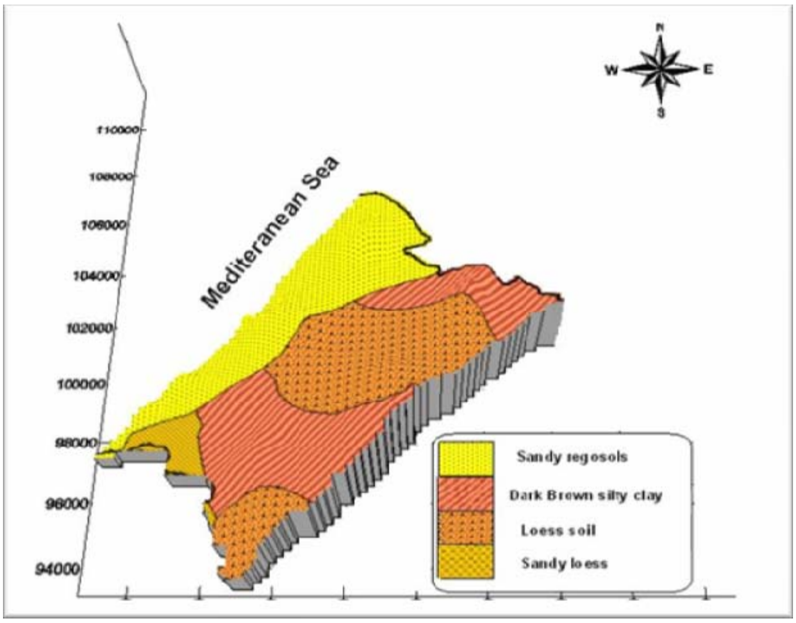


Figure 4.2: *Soil map of the Gaza Governorate (**EQA, 2005).***

4.2 Geology

Geology of the Gaza Strip was obtained from oil and gas exploitation logs up to depth of about 2000 m drilled by Israelis and from wells drilled during the Coastal Aquifer Management Project (CAMP). Geology of the study area consists of a sequence of geological formations ranging from upper Cretaceous to Holocene. This sequence is gradually sloping westwards **(PWA, 2000a)** as shown in **Figure 4.3 and Table 4.1** summarizes the geological history of the area. The formations of this sequence are:

1. Tertiary Formations

The Tertiary formations consist of Saqiya group (upper Eocene to Pliocene) underlined by Eocene Chalks and limestones**.** The Saqiya group composed of shallow marine impervious sediments of Shale, Clay, and Marl. The thickness of this group ranges from 400 m to 1000 m. This group wedged out rapidly to the east **(PWA, 2000a).**

2. Quaternary Formations

The Quaternary deposits throughout the Gaza Strip are overlain the Saqiya group, while at the east they overlain the Eocene Chalks and limestones. The thickness of the Eocene deposits reach to about 200 m **(PWA, 2000a).**

Quaternary formations are represented by the coastal plain aquifer of Palestine. These formations extend from the foothills of Mount Carmel (north of Haifa) southwards to the Gaza Strip and northern Sinai. The coastal aquifer composed of loose sand dunes (Holocene age) and Kurkar group (Pleistocene). The Kurkar group composed of marine and aeolian calcareous sandstone (locally known as "kurkar") reddish silty sandstone ("hamra"), silts, interlayers of clay deposited during the Last Glacial stage and during the Holocene, unconsolidated sand and conglomerates. The surface morphological features of the Kurkar group are three elongated hills known as "kurkar ridges," located in clusters extends parallel to the shoreline. These belts extend about 15-20 km inland. They unconformably overlie Eocene limestones and chalks deposits to the east and upper Eocene-Pliocene age of the Saqiye group to the west throughout the Gaza Strip. The transition from Kurkar group to the Saqiye group is sometimes obscured by the presence of a thin basal conglomerate. The calcareous sandstones are interbeded with irregular layers and pockets of uncemented sand and thin red brown sands and silty sands (Hamra) and especially at greater depths, marine silts and clays **(Zilberbrand et al., 2001).**

During the Quaternary period, four transgressions and regressions of the Mediterranean Sea occurred in the Coastal Plain. According to **(Zilberbrand et al., 2001),** deposition occurred partly in marine settings, partly in terrestrial environments, in lagoons, in stable and unstable marshes, and in some cases, in coastal environments. Each younger transgression penetrated inland less than the preceding one and the latest transgression seems to be represented by the Coastal Ridge. Close to the present shoreline, the sequence of the Kurkar Group attains an average thickness of 200 m in the south and around 120 m in the north, wedging gradually out towards the foothills of the Judea and Samaria Mountains in the east **(Zilberbrand et al., 2001).**

The Holocene deposits are found at the top of the Pleistocene formation with a thickness up to 25m. These deposits can be divided into four different types:

Sand Dunes:

These dunes extend along the shoreline, and originate partly from Nile River sediments. The thickness of these dunes is about 15 m, and their width is small in the south of the study area, increasing northward up to 3 km.

Sand, Loess, and Gravel beds:

This formation is small in thickness (about 10 m) and it is the main formation of the Wadi Gaza area (near surface)

Alluvial Deposits:

These deposits spread in the area around Wadi Gaza and have a thickness of about 25m.

Beach Formation:

This formation is composed of a relatively thin layer of sand with shell fragments. It is mainly unconsolidated, and in some places it is cemented due to the precipitation of calcium carbonate.

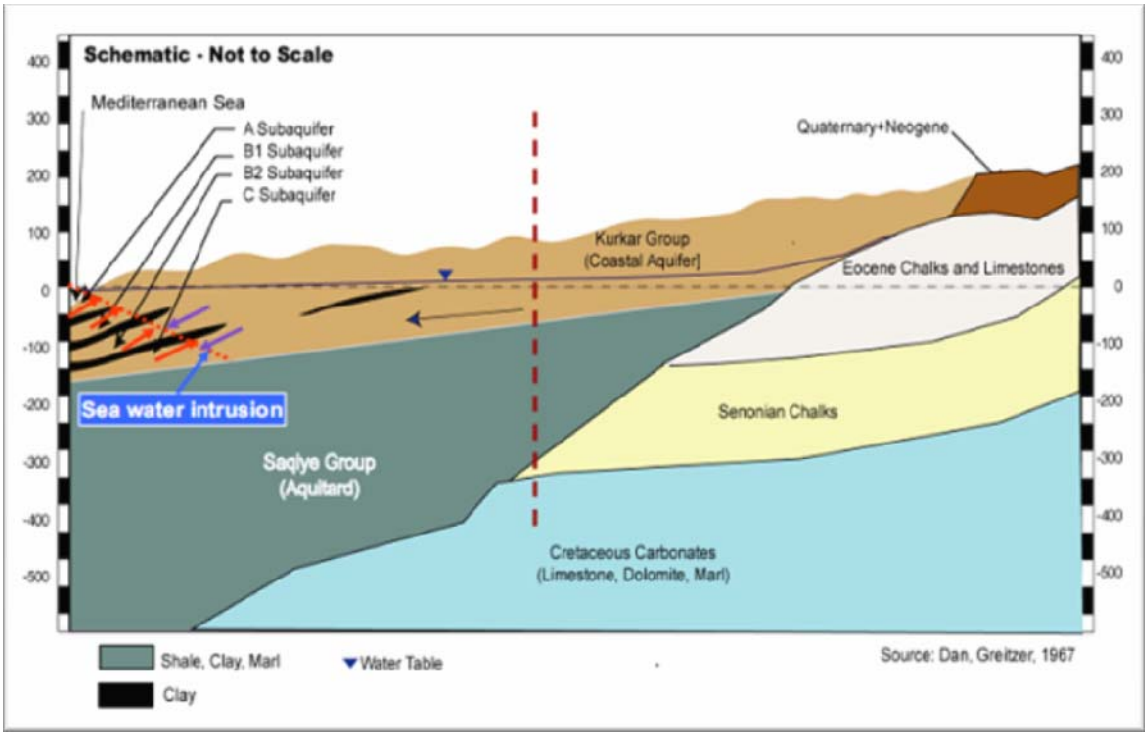


Figure 4.3: *Typical schematization of geological cross section of Gaza Strip* ***(PWA, 2000a).***

Table 4.1: *A summary for the geological history of the area* ***(PWA, 2000a).***

Time-rock Units								
System	Series	Stage & Substage		Groups	Formation	Symbols	Lithology	Hydrogeological Classification
Quaternary	Pleistocene	Holocene		Kurkar		Qk	Sandstone	Aquifer
		Upper	Post-Tyrrhen					
		Middle	Tyrrhenian					
		Lower	Sicilian					
			Calabrian					
Neogene	Pliocene	Placenzian		Saqiya	Yafo	Qy	Clay/Marl	Aquiclude
		Tabianian						
	Miocene	Late	Messinian					
			Tortonian					
Paleogene	Oligocene	Bormidian			Beit Govrin	Tub	Marl/Limestone	Aquitard
		Latto.-Chatt						
	Eocene	Upper (Auvers-Bartonian)						
		Middle (Lutetian)		Hashephela	Zor'a	Tlz	Marl/Limestone	Aquifer
		Lower (Ypresian)						
	Paleocene	Landenian			Taqiya	Tlt	Chalk	Aquiclude
		Danian						
Cretaceous	Upper	Maastrichtian			Ghareb	Kug	Chalk	Aquiclude
		Senonian	Campanian		Ein Zetim	Kuez	Chalk	Aquiclude
			Santonian					
			Coniacian					
		Turonian Cenomanian		Judea		Kj	Limestone	Aquifer

Legend

Hydrogeological Classification	Dominant Lithology	Notes:
Aquifer	Sandstone	Not to Scale
Aquitard	Clay/Marl	Israeli terminology used for Groups and Formations
Aquiclude	Marl/Limestone	Source: Adapted from: Rosenthal, Vinokurov, Donen et.al. Journal of Contaminant Hydrology, 1992
	Chalk	
	Limestone	

4.3 Hydrology

Precipitation falling on land is either returned directly to the atmosphere by evaporation, flows along the land surface to become surface water or percolate into the round. Water that infiltrates into the ground is either drawn into plants and returned to the atmosphere by transpiration or continues infiltrating and becoming groundwater.

4.3.1 Surface Water Hydrology

The surface water system in the study area is Wadi Gaza. Wadi Gaza that located at the southern boundary of study area is the bigger in Gaza Strip. It runs in the central part of the Gaza Strip and discharge into the Mediterranean Sea Wadi Gaza length is about 9 km in Gaza and it extends into the armistice border for about 95 km where it collects the water from a big catchment area (3600 km^2) from the Hebron Mountains and the Northern Negeve. This main stream was diverted by the Israelis to an adjacent area where it's been stopped their and collected at basins located 6km east of Gaza **(MWCP, 2001).**

Wadis are ephemeral streams, characterized by short duration floods that occur after heavy rainfall, while most of the time they are completely dry. Freshwater flows into them in the winter season. Israel has retained and changed the course of the two Wadis and they become dry since the early seventies, this means that fresh surface water resources are negligible.

4.3.2 Groundwater Hydrology

The coastal aquifer underlies the Coastal Plain of Palestine and runs parallel to the Mediterranean Sea coast. The coastal aquifer is an underground phreatic reservoir varies in width from 7 km in the north to 20 km in the south; its thickness decreases eastwards from 200 m near the coastline to a few meters in the eastern margins **(Figure 4.3) (PWA, 2000a).** The aquifer (the Kurkar Group of Pleistocene age) consists of sand, sandstone, and silt interbedded with marine clays, and it overlies the impervious marine clays of upper Eocene to Pliocene age (the Saqiye Group). The aquifer is basically phreatic, but clay layers divide it vertically into several subaquifers. The hydraulic connection between groundwaters in the different subaquifers and the sea is not well understood. While Bear and Kapuler (1981) considered that all subaquifers are connected to the sea, Kolton (1988) argued that the lower subaquifers are disconnected **(Oren, et al., 2004).**

In the central and eastern areas the aquifer is uniform and phreatic. The calcareous sandstone (arenites or "kurkar") is composed of several minerals: quartz, feldspar, calcite, aragonite, and iron oxides **(Vengosh, et al., 1996).**

4.3.2.1 Lithological Cross Sections

In literature 20 cross sections of the Gaza Strip were collected. Among them 5 sections were located in Gaza Governorate as shown as **Figure 4.4.** These cross sections show the distribution of impervious to semi-impervious layers and lenses alternating with predominantly permeable sand and calcareous sandstones. These sections represent the upper part of Kurkar Group (costal aquifer) since the depths of the available wells are limited .Clay layers divide the aquifer vertically into four sub-aquifers as mentioned before A, B1, B2 and C . The upper subaquifer "A" is unconfined, whereas subaquifers "B1, B2, and C" become increasingly confined towards the sea .These sections helped to know depth of aquifer for each well.

The presence of clay with silty clay, sandy clay and sandy silty clay on the surface will retard the movement of contaminate to travel very slowly until reach to groundwater. The section number of aquifer was identified for each well, according to the nearest section of the well and with identification of the distance far from the sea and determination the total depth for each well, and then measured the depth of aquifer which helps account WHPA.

Kurkar Group

Sub-aquifer A

Sub-aquifer (A) occurs in the uppermost and westernmost part of the sequence extends from the shoreline to the east up to 2 km. It is mainly composed of variously cemented concretionary calcareous sandstone mixed and interlayered with loose sand, of both

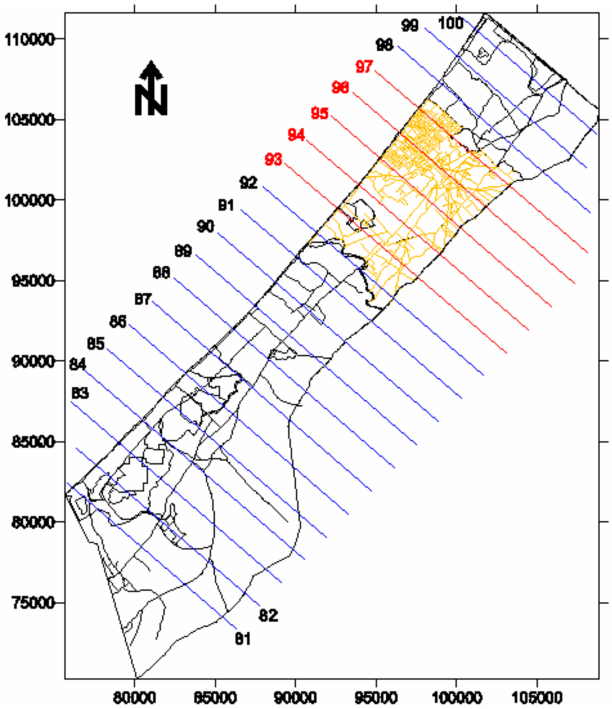
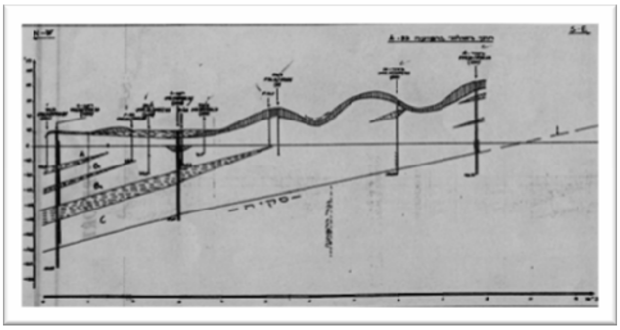
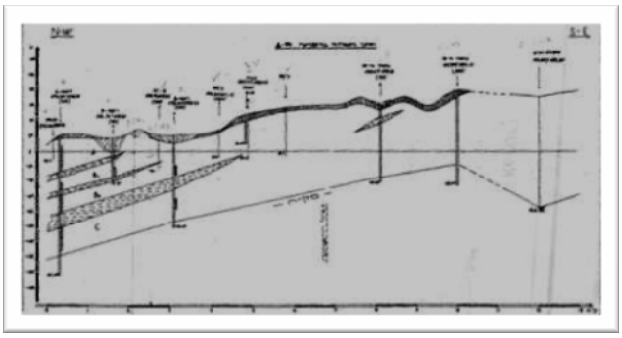


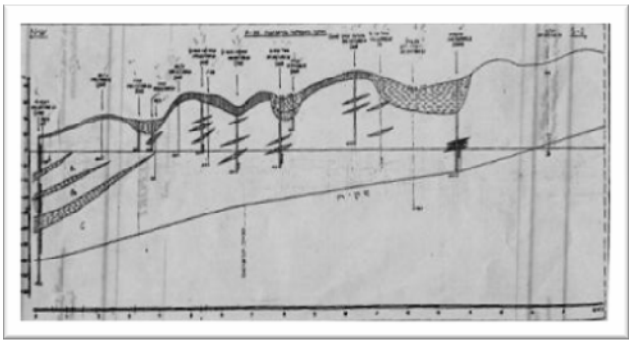
Figure 4.4: *Cross sections for Gaza Strip Aquifer (PWA, 1991).*



Geological cross section number 93.



Geological cross section number 94



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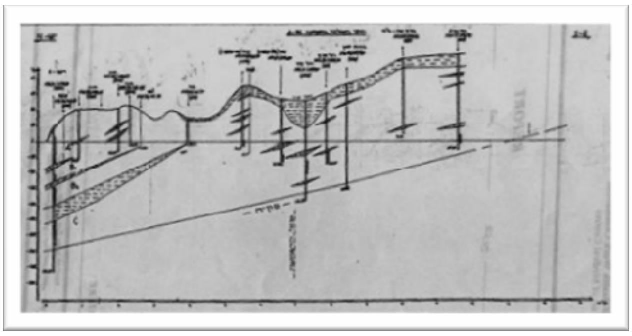
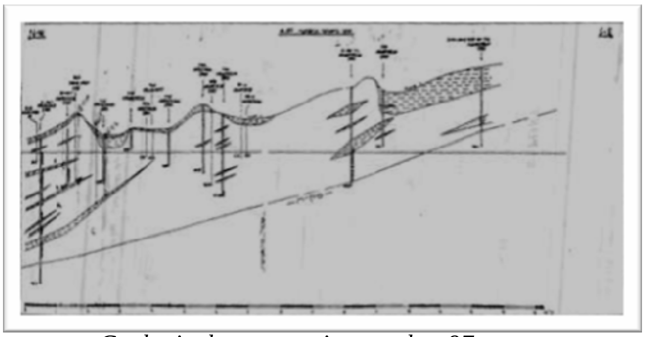


Geological cross section number 95.



Geological cross section number 97.

continental and littoral origin. This aquifer is bounded from the top by the water table and at the bottom partly bounded by the first aquitard of silty clay. In the study area, it is 25m thick in the east to about 60-m in the west. This aquifer unit overlies continental-estuarine clay or loam extending eastwards and upwards, reaches in thickness to 15 m. However, the clay-rich base layer of sub-aquifer A is not always continuous and therefore, the hydrogeological and hydro stratigraphical separation between sub-aquifer A and underlying subaquifer B does not always exist or can be clearly identified. Sub-aquifer A may contain thin interlayers of clay, sandy clay and silty clay, which act as aquitards.

Sub-aquifer B1:

Based on Israel studies of Ecker 1999 sub-aquifer B1 is mainly from Kurkar and micro-conglomerate deposited in a more littoral environment, the cementation of which is harder than in the overlying sub-aquifer A and having a lower proportion of loose sand. The base of this sub-aquifer is formed by marine to lagoonal-estuarine clays. Further eastwards, these base layers turn into continental clays and loarns and extend 6-7 km east of the shoreline.

Sub-aquifer B2

The calcareous sandstones of this unit are predominantly products of a high-energy littoral depositional environment, such as conglomerates and beach rock overlying a marine clay horizon. Based on Israel studies sub-aquifer B2 is 20-40-m thick. Near the coastline, sub-aquifer B2 occurs between elevations of (- 120) and (- 150) m below MSL **(Zilberbrand et al., 2001).**

Sub-aquifer C

Between the shoreline and 3-4 km inland, the lithology of this sub-aquifer is of a marine type, with no indications of shallower facies. It is characterized by interlayering of clay, silt, and silty sand, 10-20-m thick. Generally, the occurrence of calcareous sandstones increases eastwards on account of silty-clayey beds. The hydraulic conductivities of this unit are significantly lower than in the overlying sub-aquifers. Sub-aquifer C overlies impervious layers related to top of the Saqiye Group. Their occurrence is usually marked by thin streaks of chalky and marly sandstone, yellowish chalky marl, and clays. The top of the Saqiye occurs at elevations of -150 to -160 m below MSL, close to the shoreline **(Zilberbrand et al., 2001).**

The Saqiye Group

The Pleistocene Coastal Plain aquifer system (the Kurkar Group) overlies a very thick complex of shales and marls related to the Plio-Pleistocene Saqiye Group that wedges out gradually eastwards. In the study area its maximum depth reaches 1900 m near the coastline, wedging out in the eastern parts of the Coastal Plain. The top of the Saqiye Group dips 1-2% westwards **(Zilberbrand et al., 2001)**.

4.3.2.2 Aquifer Hydraulic Properties

Transmissivity:

From results of aquifer tests carried out in Gaza Strip, transmissivity values range between 700 and 5000 square meters per day (m^2/d).corresponding values of hydraulic conductivity K are mostly within a range of 20-80 meters per day (m/d).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 sub-aquifer **(PWA, 2000b).**

Effective Porosity:

Groundwater velocity is inversely proportional to effective porosity. Thus, a reduction in effective porosity implies in an increased velocity and hence faster migration of a particular contaminate. The base case calibration value is 25%.three sensitivity runs were carried out 15%, 20%, and 30% **(PWA, 2000b).**

Specific Yield and Specific Storativity

Specific yield values are estimated to be about 15-30 percent while specific storativity is about 10^{-4} from tests conducted in Gaza. Concerning the specific yield values is asking only about the porosity so the porosity values are consistent with the specific yield values (effective porosity 25%) for the sand and gravel **(PWA, 2000b).**The table 4.2 represent the horizontal and vertical conducting in Gaza subaquifers (A, B1, B2, C) in addition, it shows the related values of specific yield and specific storativity.

Table 4.2: *Aquifer hydraulic properties* ***(PWA, 2000b).***

Stratigraphic Unit	Horizontal Hydraulic Conductivity (m/d)	Vertical Hydraulic Conductivity (m/d)	Specific Yield	Specific Storativity' (m^{-1})
Subaquifer A	30.0	3.00	0.25	0.1 E-04
Subaquifer B 1	30.0	3.00	0.25	0.1 E-04
Subaquifer B2	30.0	3.00	0.25	0.lE-04
Subaquifer C	30.0	3.00	0.25	0.lE-04
Coastal Clays / Aquitards	0.20	0.20	0.10	0.lE-04
Undifferentiated Aquifer East of Coastal Clays	5.0 - 30.0	0.5 - 3.0	0.25	0.lE-04

4.4 Land use

There is land scarcity for all kinds of uses (urban, industrial, and agriculture). Most of the study area is categorized as agricultural and urban but it includes small industry located on site. The agricultural land is considered dominant and economic sector. Urban and agriculture expansion is concentrated in the western coastal zones of Gaza Strip. There is overcrowdness and related housing problems, especially in the refugee camps areas. Also there are inappropriate design of wastewater treatment plant (WWTP) and disposing of untreated wastewater in Wadi Gaza. Consequently, there is a huge bad impact on the groundwater quality situation in the study area. Taking into consideration the rate of population growth and the expected economic expansion, groundwater quality problems will rapidly increase **(MOPIC, 1998).**

4.5 Groundwater Situation in the Study Area

Groundwater from the coastal aquifer is the only source of water for the people of Gaza Strip and they rely mainly on it to fulfill all needs. Other minor sources are surface water occurrences and collected rainwater. Depletion of the fresh groundwater resources is already a severe problem in Gaza **(EQA, 2004).** The aquifer is presently being overexploited, with total outflow exceeding total inflow **(PWA, 2004a).** This deficit in the water balance leads to steady lowering of the groundwater level. The water level contour map which has been drawn in 1935 by British Government showed a high water level declined from east to west in lines parallel to seashore line. This level dropped by 8 meters within 1935-1969 **(PWA, 2000b)** clearly in the north as a result of extensive exploitation of groundwater, in addition to the sudden increase in population in year 1948 **(Qahaman, 2004).** The continuation in declination led to formation of depression cones, mostly in the heavily populated areas. Consequently, the hydraulic gradients have been significantly reversed from the sea in these areas and the resultant washing of salts into the sea has been reduced.

Also, the main causes of depletion of groundwater resource are high losses in the water supply systems and inefficient water use, particularly in the agricultural sector **(EQA, 2004).** Also, due to normal population growth, water demand for different purposes is expected to rise from the current level of 145 Mm^3/year to about 260 Mm^3/year by the year 2020 **(PWA, 2000a).** The freshwater resources will be ultimately completely exhausted, when groundwater pumping will increase at the same rate, while the brackish water resources will become increasingly saline **(PWA, 2000a).** Israeli wells around the border of Gaza Strip and the over-pumping of Israel wells within the settlements disengagement in 2005 have accelerated the increase of salinity of the groundwater. Also, Israel has retained and changed the course of the two main Wadis in the study area as a sources of freshwater that recharge the aquifer and they became dry Wadis since the early seventies **(MWCP, 2001).**

Qualitatively, numerous sources of pollution are present especially in major urban centers. In the same time, the aquifer is highly vulnerable to pollution especially the western part which covered with sand dunes. Human activities including agriculture (intensive and excessive use of agrochemicals) and inadequate waste management (collection, treatment, and disposal of wastewater and solid waste) have affected the groundwater quality parameters and presently they exceed WHO standards.

A slow, but continuing decline in groundwater levels has been observed in most areas of Gaza, since the mid-1970s**.** While some 2,800 to 3,000 agricultural wells are scattered throughout the Gaza Strip, the greatest densities of wells is near Gaza City. Total municipal pumping is also highest in this area and major cones of depression have formed with water levels up to 2 meters below sea level for the year 1998 **(PWA, 2000a).**

El-Nakhal and Abu Heen 1997 studied and evaluated the changes in groundwater quality in Gaza Strip during the last three decades before 1994 for domestic and irrigation purposes. The results of the evaluation shows that the chemical characteristics of water samples for the period 1964 and 1994 are better than for 1984. They found that the suitability of the water wells for domestic use for the years 1964, 1984, and 1994 are 25%, 5%, and 18% respectively.

According to Abu Heen and Lubad, (2005) decreasing of water quality is a function of time. Chemical analysis the quality of water for eighteen domestic wells in the Gaza City from 1994 to 2004 shows that for the years 1994, 1999 and 2004 about 33%, 44% and 67% of the samples respectively are unsuitable for drinking based on World Health Organization (WHO) and Palestinian standards.

4.5.1 Salinity Problem

Since the beginning of the 1970s, many studies have described the hydrological situation of the Gaza strip. Parallel to the long term water shortage, saline water replacing freshwater in many parts of the Gaza Strip **(Weinthal et al., 2005).** The existing network of wells is only adequate to identify shallow water quality situation **(PWA, 2000a).** Generally, most of the pumped water from wells comes from the upper 30-40m of the aquifer **(PWA, 2004b).** Chloride concentrations for the shallow portion of the coastal aquifer are generally better in the north of the Gaza Strip than in the south **(Al-Jamal, and**

Al-Yaqubi, 2001). Few boreholes have penetrated the deeper parts of the Gaza Strip coastal aquifer. Trapped water with higher salinity than sea water was found in the deeper aquifer, mainly in its western portion up to (2 km) from the sea**.** The deepest sample showed brine with a chloride concentration with approximately of 2 times of seawater. (60,300 mg/l) **(PWA, 2004b).** However due to the low exploitation of the deep subaquifers in the west, this trapped saline water is still inactive and does not appear to affect as yet the quality of the aquifer as far as its chlorides content is concerned **(Melloul and Collin, 1994).**

Groundwater salinity increases with water depth and away from the sand dunes area, where ground surface is covered by clay and silt. Salinity increased from 500 to 10,000 mg/l with depth. Wells of the major pumping center in Gaza City and Jabalia display a gradual increase in chloride with time. This suggests that brackish water from eastward is flowing toward the northern well fields in Gaza City and Jabalia. For the year 2004, the chloride content in most of the wells in Gaza Strip fluctuates from 300 to 600 mg/l which is double the recommended value be the WHO as shown in **Figure 4.5.** In the deepest sub-aquifers, high levels of chloride may be related to different sources of salinity e.g. seawater of possibly poor quality fossil water **(PWA, 2004 b)**.

The high concentration of chloride in the groundwater in Gaza aquifer is due to many different water sources. Those sources include inflow of groundwater from occupied areas, soil water interaction in the unsaturated zone due to recharge and return flows, mobilization of deep brines, sea water intrusion or up-coning of brines. The seawater intrusion and up-coning of brines in some areas may be due to water imbalance in the aquifer, since the rate of water extraction exceeds the rate of groundwater replenishment **(PWA, 200l).**

Additional sources of groundwater salinity in this area are: (1) the flux of saline water Coming from the Eocene aquifer in the east; and (2) pollution sources on the ground surface, such as effluent irrigation, domestic land-use effluents, solid waste, etc. Chloride concentrations up to 2,000 mg/l have been measured in wells that tap the Eocene system **(Vengosh et al., 1996).** The chemical and isotopic data show that most of the salinity phenomena in the Gaza Strip are derived from the natural flow of saline groundwater from the eastern part of the aquifer towards the Gaza Strip **(Weinthal et al., 2005).**

Saltwater intrusion varies with depth and different sub-aquifers exhibit varying degrees of seawater penetration. Salty water intrusion presently poses the greatest threat to municipal supply and continued urban and industrial growth is expected to impact water quality **(Qahaman, 2004).** Seawater intrusion has resulted in salinization of groundwater in the western part of the aquifer, but the geochemical and isotopic data indicate that the extent of seawater intrusion is limited **(Weinthal et al., 2005).** Seawater intrusion occurs along several kilometers of coastline in the Gaza Strip Modeling results, combined with surface geophysical surveys, indicating that seawater intrusion extends 1-2 km inland in areas of heavy pumping, and may extend up to 2-3 km inland in the deepest part of the aquifer within Gaza City **(PWA, 2004b).**

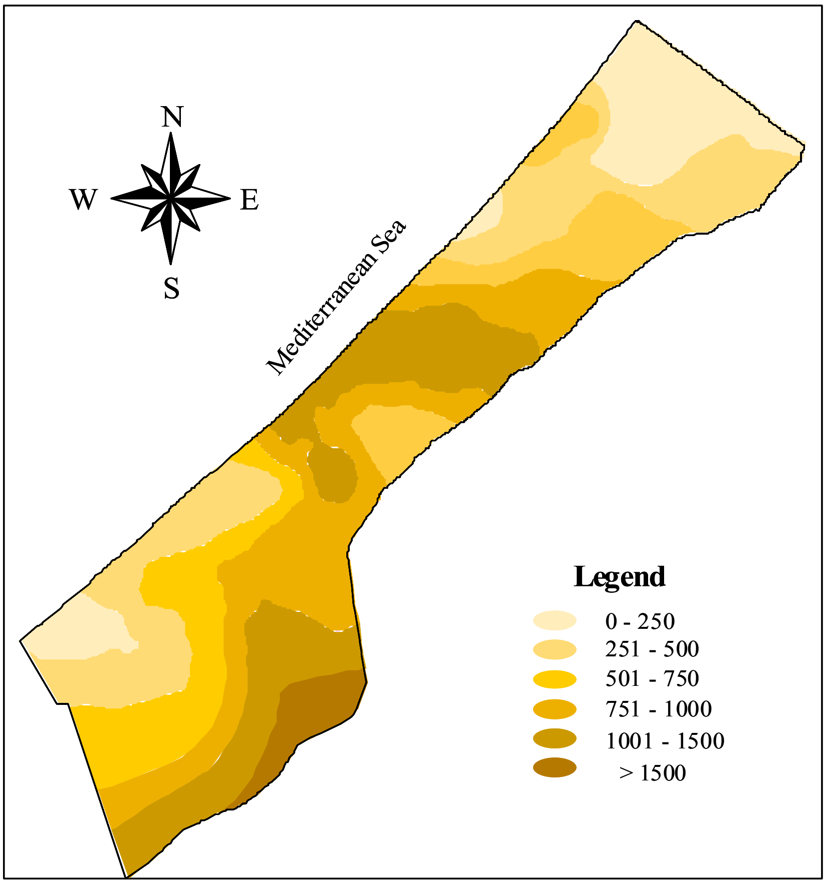


Figure 4.5: *Chloride concentration in the Gaza Strip* ***(EQA, 2005).***

4.5.2 Nitrate Problem

An additional source of water quality deterioration in the Gaza Strip is the nitrate which is used as indicator of pollution, especially when salinity is low. Nitrate pollution of groundwater in Gaza, has particular concern due to environmentally sensitivity of the area and the large number of people in city and rural areas relying on groundwaters for drinking. Large amounts of N-fertilizer and poorly managed irrigated systems may lead to nitrate leaching and pollution of groundwater.

The groundwater quality in the Gaza Strip with respect to the nitrate pollution is not constant depending on many factors, like the pollution sources, the intensity of pollutant, soil type and sensitivity of the aquifer. Increasing trends may be caused either by the accumulation of nitrates in the groundwater from continued land use practices or by changes in land use to more intensive agricultural activities or increased rates of wastewater effluent application. Decreasing trends may also be caused by changes in land use to less intensive agriculture or reduced waste disposal rates. In the case of a deep aquifer, decreasing trends could also be caused by increased abstraction rates, which would increase the hydraulic gradients around the well and could cause more water to be drawn from areas with lower nitrate concentrations **(Almahallawi, 2004).**

The level of nitrate contamination has been rising so rapidly that most of the Gaza's drinking water wells are no longer adequate for human consumption. Few wells in Gaza remain unaffected by high nitrate levels, and only about 10% of the municipal water supply remains below the WHO drinking water standard **(PWA, 2000a).** In most wells and urban areas, nitrate concentrations are increasing at rates up to 10 mg/l per year. Now nitrate level in most of the wells between 100 and 150 mg/l as shown in **Figure 4.6**. This value exceeds the recommended value by WHO which only 50 mg/l **(PWA, 2004b).** More than 50% of the domestic municipal wells in Gaza Strip have nitrate concentrations that exceed WHO guidelines of 45 mg/l **(Vengosh et al., 2005).**

There are numerous sources of nitrate contamination, including agriculture fertilizers, waste dumping, and especially direct discharge of raw sewage to wadis and soil. This contamination is believed to be primarily related to wastewater return flows in urban areas through leakage from septic tanks and municipal pipe systems. Contamination of the water of wells is caused by sewage and abundant use of agricultural fertilizers and pesticides contributes to rise in the nitrate level especially in and around areas of arable land. The contribution of fertilizers in agricultural areas cannot be ruled out, although this has never been quantified (i.e., quantities applied vs. levels in groundwater) **(PWA, 2000b).** The threat of groundwater contamination increases under irrigation on sandy soils which have lower adsorption capacity, where nitrate is more easily leached with the irrigation return flow.

Almahallawi (2004) showed that in the northern area, the nitrate concentrations decrease in a north-eastward direction. The water flow direction is from north-eastward to south-westward. This means that water comes from outside the Gaza Strip especially in the northern part has almost nitrate concentration less than 50 mg/l. Since this water mixed with the local aquifer the quality of water regarding nitrate contamination decreases. Two reasons are believed to explain the phenomena of the nitrate concentration less than 50 mg/l compared to the high concentration in the rest of the areas of the Gaza Strip. First, parts of these areas are kept low by dilution; second, large parts of this aquifer are deep in depth in the range of 50-120 meter.

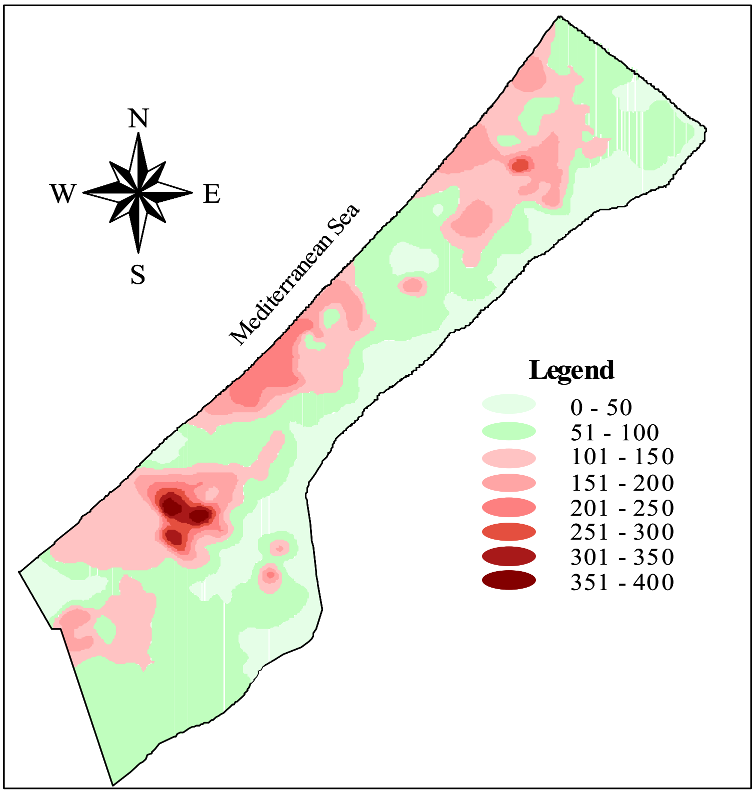


Figure 4.6: *Nitrate concentration in the Gaza Strip* ***(EQA, 2005).***

4.6 Available Data in the Study Area

4.6.1 Data Collection

In May 1994, Gaza Strip area became under the responsibility of the Palestinian Authority (PA). In 1995 the Gaza water department prepared a summary data report of available water levels, water quality lithology, and meteorology data.

Groundwater quality in Gaza Strip is monitored by different institutions. The Ministry of Health (MOH) monitors all of domestic water-use wells twice a year in summer and winter for the major anions and cations, and nitrates, to insure that the drinking water is safe. Each summer and winter, Ministry of Agriculture (MoA) also tests agriculture water-use wells for concentration of chloride and nitrate.

Pumped withdrawal quantity for municipal water-use wells was measured monthly by LEKA (lyonnaise des Eaux and Khatib and Alami) and the Ministry of Health (MOH). New wells have recently been constructed.

All data on water levels, water quality, withdrawal, and all data related to drinking water wells were transferred to the PWA, Water Resources Department, Gaza Water Data Bank Section, for quality assurance and entry into hydrologic database.

The collected data may have some errors. Most risk in data errors is associated with a human error during written transcription of data from laboratory notebooks or during ‘‘Keying-in’’ via computer keyboard. These input errors can be reduce through careful and integrated design of raw data recording forms and computer entry template and when data are handled by electronic means for interpretation and reporting procedures.

Also, individuals responsible for data entry in many organizations, have little or no knowledge of water quality .So, it is important to have the database checked periodically by an expert for omitting obvious errors.

4.6.1.1 Drinking Water Wells Data

The data have been collected from PWA. These data were concerned with drinking water wells that lie within the Gaza Governorate and the number of existing drinking wells is 47 wells as shown in **Figure 4.7.** The data include the name and coordinates and the number of operating hours to each well, mean value of abstraction, sections of groundwater, water level, porosity, and permeability some of these data are presented in **Table (4.3).** These data were used in the delineation of WHPA.

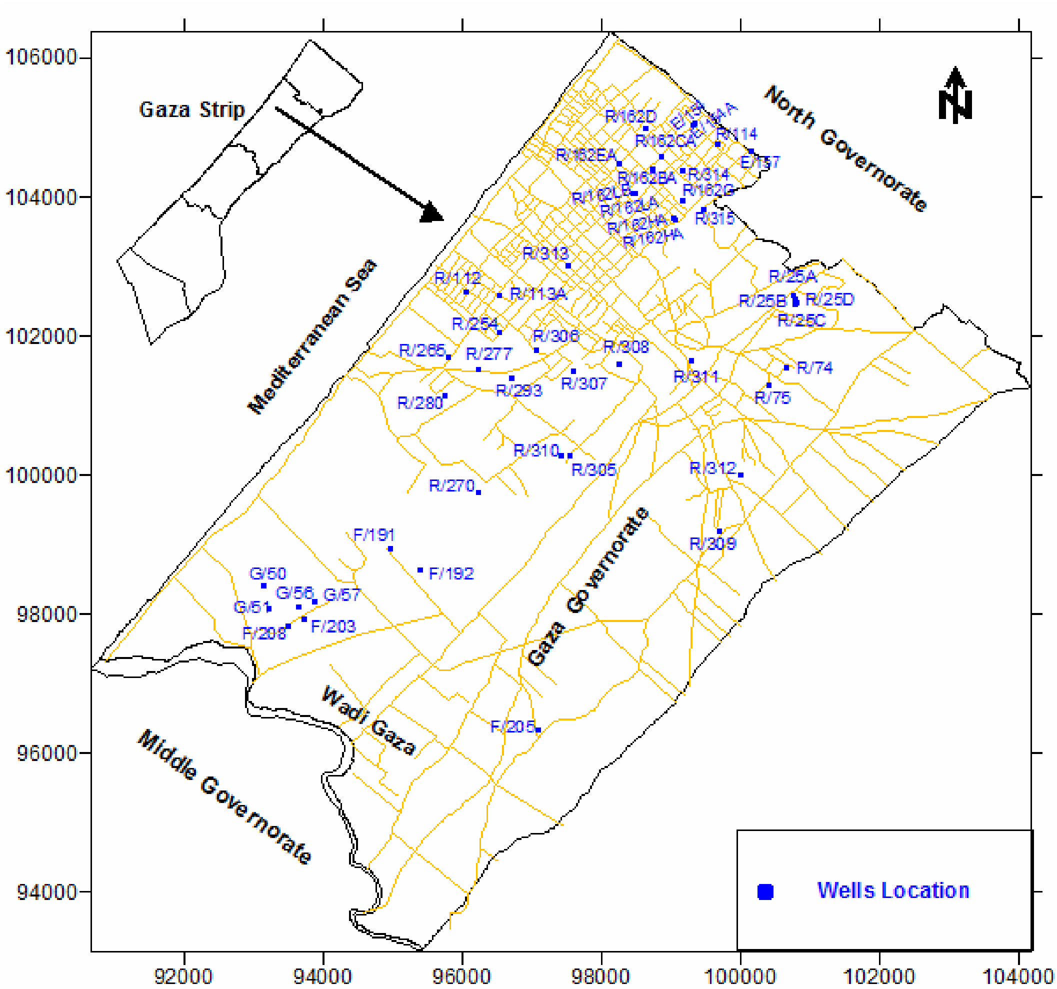


Figure 4.7: *Location map of drinking water wells in the study area (2008).*

Table 4.3: *The data related to drinking water wells* ***(PWA, 2008).***

No.	Well No.	Total Depth (m)	DTW (m)	Screen Interval (m)	Operating hrs (hr/day/s)	Mean Value Q (m3/hr)
1	**E/154**	102	48.4	47	24	150
2	**E/154A**	66	48.4	47	24	140
3	**E/157**	85	26	47	24	180
4	**R/162G**	100	36	46	24	210
5	**R/162LA**	101	59	28	24	125
6	**R/162LB**	96.5	59.83	20	24	170
7	**R/162EA**	68	40.3	21	24	60

No.	Well No.	Total Depth (m)	DTW (m)	Screen Interval (m)	Operating hrs (hr/day/s)	Mean Value Q (m3/hr)
8	**R/162BA**	70	55.49	16.5	24	50
9	**R/162CA**	71	53.5	12	24	60
10	**R/162D**	60	42	16	24	60
11	**R/162H**	103	34	45	24	200
12	**R/162HA**	85	35.5	31	24	120
13	**R/314**	73.5	49.92	11	15	60
14	**R/315**	56	26.92	11	24	50
15	**R/114**	65	41.96	10	24	60
16	**R/25B**	62	35	22	24	180
17	**R/25A**	95	35	40	24	160
18	**R/25C**	55	35	16	24	100
19	**R/25D**	60	35	23	24	180
20	**R/308**	59.5	27.93	9	10	60
21	**R/311**	70	47.71	12	10	60
22	**R/313**	62	40.27	12	10	60
23	**R/75**	72	41	25	24	120
24	**R/74**	55	40	20	9	100
25	**R/309**	91	73.18	10	10	60
26	**R/305**	60	39.55	9	10	60
27	**R/310**	63	38.69	9	10	60
28	**R/306**	61	42.22	9	10	60
29	**R/312**	106	84.23	9	10	60
30	**R/112**	45.12	19.49	9	24	70
31	**R/254**	72	33	26	24	60
32	**R/265**	66	39	27	24	45
33	**R/113A**	47	38.56	7	10	65
34	**R/277**	70	38.14	25.5	24	65
35	**R/280**	70	38	20	12	60
36	**R/293**	67	40.75	15	24	60
37	**R/307**	55.5	37.77	10	10	60
38	**F/191**	64	31.2	15	10	100
39	**F/192**	50	20.1	15	10	100
40	**R/270**	85	43	15	6	55
41	**G/50**	40	9.7	20	6	60
42	**F/203**	50	22.6	9	15	65
43	**F/205**	82	64.12	9	10	45
44	**G/57**	36.5	18.15	8	10	50
45	**G/56**	43.5	17.67	7	10	60
46	**F/208**	51	19.87	13	8	50
47	**G/51**	40	9.7	20	6	60

4.6.1.2 Pollution Activities Data

The Pollutants have been identified and the extent of the danger to the environment and groundwater due to industrial activities were selected in industrial installations manual 2005. This manual was adopted by the Environmental Quality Authority (EQA) and the activities are divided into three categories according to the dangerous of each industrial installation as follow:

A category (A): a group of industries of less dangerous waste on human health and the environment such as Paper and Carton Industry.

A category (B): a group of industries of medium dangerous waste on human health and the environment such as Block Industry.

A category (C): a group of industries of high dangerous waste on human health and the environment such as Asphalt Industry.

The category (C) industries were chosen because they produce high dangerous waste. This category consists of 157 facilities as shown in **Table 4.5.** These facilities were classified into 14 types and these types were divided into four groups according to article pollution. It is important to note that Gaza waste landfill and Gaza water treatment plant were added to category C as a group five.

Site visits were conducted to each facility. The exact positions of these facilities were located by Global Positioning System (GPS). It was found that some of the facilities have been closed due to the recent economic and political reasons.

Summary of the industrial facilities that located in the study area is presented in **Table 4.4** and **Figure 4.8.**

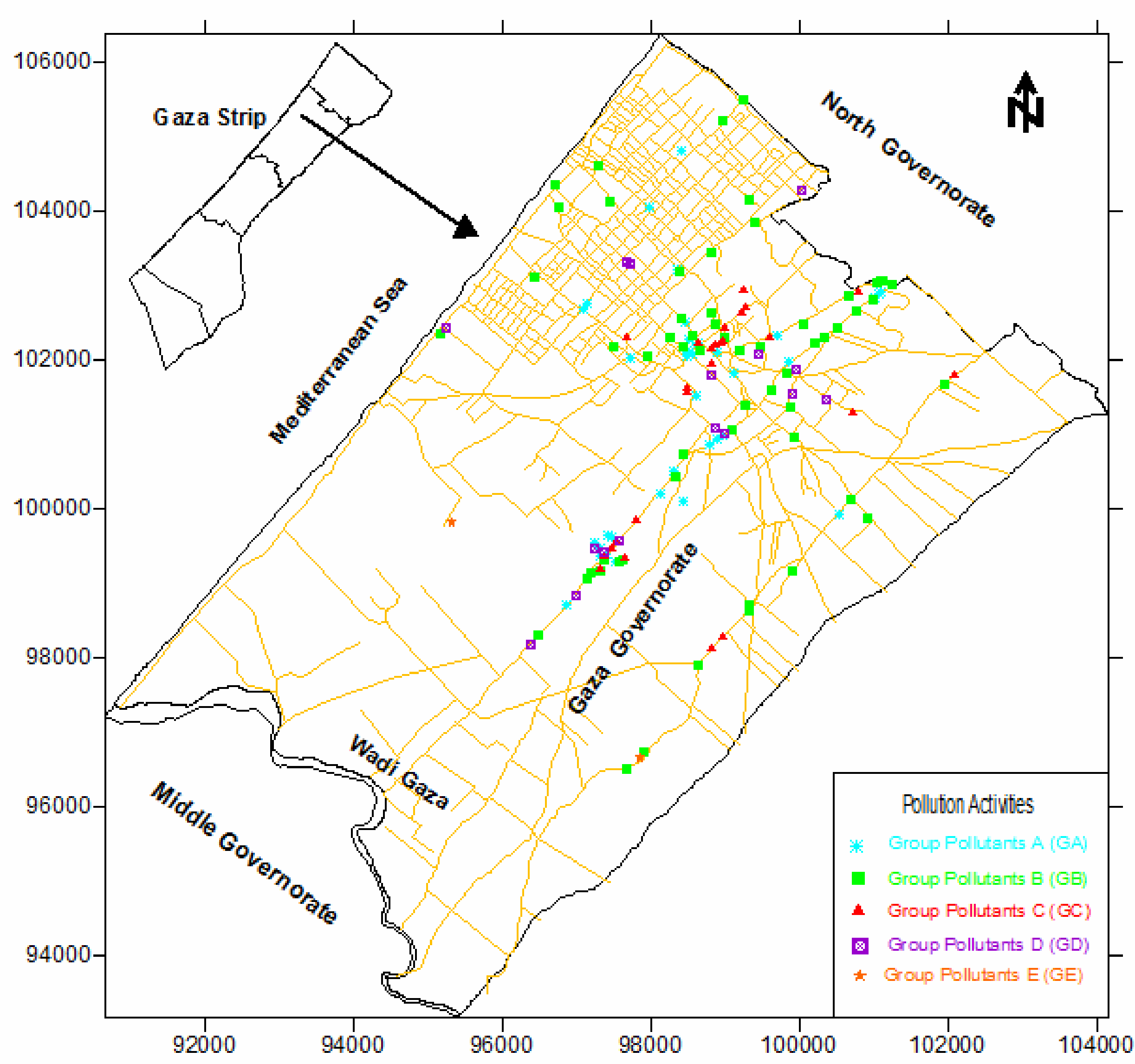


Figure 4.8: *Location map of pollution activities in the study area.*

Table 4.4: *The groups of category C.*

ID of industrial installations	Category	Number of industrial installations
Group Pollutants A (GA)	Printing &Painting Workshops	37
Group Pollutants B (GB)	Fuel Station, Asphalt Industry ,Plastic Industry, Textile Industry, Fiberglass Industry	60
Group Pollutants C (GC)	Tiles Industry ,Marble Industry, Ceramic Industry, Concrete Industry	26
Group Pollutants D (GD)	Chemical Industry, Jeans Cleaner ,Battery's Industry	16
Group Pollutants E (GE)	Landfill, Treatment Plant	2

Table 4.5: *Pollutants activities, category C groups (2008).*

Num.	ID of industrial installations	Category	Title of industrial installations
1	GA1	Printing Workshops	AL- Watan
2	GA2	Printing Workshops	AL-Khateb
3	GA3	Printing Workshops	AL- Taweel
4	GA4	Printing Workshops	AL-Gsean
5	GA5	Printing Workshops	Abo Sharaf
6	GA6	Printing Workshops	AL- Thabt
7	GA7	Printing Workshops	Dar AL-Arkam
8	GA8	Printing Workshops	Dar AL-Manar
9	GA9	Printing Workshops	AL- Rantese
10	GA10	Printing Workshops	AL-Garah
11	GA11	Printing Workshops	AL- Wataneya
12	GA12	Printing Workshops	Adnan Abo Watfa

Num.	ID of industrial installations	Category	Title of industrial installations
13	GA13	Printing Workshops	AL-Hytham
14	GA14	Printing Workshops	Elwan
15	GA15	Printing Workshops	AL-Wala
16	GA16	Painting Workshops	Ashoor
17	GA17	Painting Workshops	Yaseen
18	GA18	Painting Workshops	AL-Hales
19	GA19	Painting Workshops	Shaban
20	GA20	Painting Workshops	Abo Kmael
21	GA21	Painting Workshops	Jarada Yaseen
22	GA22	Painting Workshops	Kishko
23	GA23	Painting Workshops	Kozaat
24	GA24	Painting Workshops	Salah AL- Deen
25	GA25	Painting Workshops	Abo Zoor
26	GA26	Painting Workshops	AL- Gamal
27	GA27	Painting Workshops	Gabayen
28	GA28	Painting Workshops	AL-Masree
29	GA29	Painting Workshops	Abo Deya
30	GA30	Painting Workshops	Zohde Ashoor
31	GA31	Painting Workshops	Dababesh
32	GA32	Painting Workshops	AL-Waleed
33	GA33	Painting Workshops	Hillies
34	GA34	Painting Workshops	Basal
35	GA35	Painting Workshops	Yaseen
36	GA36	Painting Workshops	Abo Raas
37	GA37	Painting Workshops	AL-Sharef
38	GB1	Fuel Station	Shaat
39	GB2	Fuel Station	AL- Barbare
40	GB3	Fuel Station	Atalah
41	GB4	Fuel Station	Temraz
42	GB5	Fuel Station	Abo Asee
43	GB6	Fuel Station	Quraysh
44	GB7	Fuel Station	Jerjawe
45	GB8	Fuel Station	AL-Shawa
46	GB9	Fuel Station	Sabra
47	GB10	Fuel Station	Yafa
48	GB11	Fuel Station	Dalool
49	GB12	Fuel Station	AL-Tarazi 1
50	GB13	Fuel Station	Bahlol 1
51	GB14	Fuel Station	AL-Helo
52	GB15	Fuel Station	Akila
53	GB16	Fuel Station	Bahlol 2

Num.	ID of industrial installations	Category	Title of industrial installations
54	GB17	Fuel Station	Gaza
55	GB18	Fuel Station	Rajab
56	GB19	Fuel Station	Abo Joba
57	GB20	Fuel Station	AL-Gsean
58	GB21	Fuel Station	Bahlol 3
59	GB22	Fuel Station	Eabead
60	GB23	Fuel Station	AL-Sanafor
61	GB24	Fuel Station	AL-Goal
62	GB25	Fuel Station	AL-Tarazi 2
63	GB26	Fuel Station	Erhaym
64	GB27	Fuel Station	AL-Shawa
65	GB28	Fuel Station	Abo Joba
66	GB29	Fuel Station	Fatooh
67	GB30	Fuel Station	Abo Ras
68	GB31	Fuel Station	Eshtawe
69	GB32	Fuel Station	AL-Shawa
70	GB33	Fuel Station	Daban
71	GB34	Fuel Station	Abo Joba 1
72	GB35	Fuel Station	Abo Joba 2
73	GB36	Fuel Station	Moshtaha
74	GB37	Fuel Station	Abo Joba
75	GB38	Asphalt Industry	Norko
76	GB39	Asphalt Industry	Rezag
77	GB40	Plastic Industry	AL-Godwa
78	GB41	Plastic Industry	Tlmisko
79	GB42	Plastic Industry	Ehgazi
80	GB43	Plastic Industry	Abd AL-Fatah
81	GB44	Plastic Industry	AL-Rdase
82	GB45	Plastic Industry	AL-Rdreas
83	GB46	Plastic Industry	Deeb
84	GB47	Plastic Industry	AL-Quods
85	GB48	Plastic Industry	Esleem
86	GB49	Plastic Industry	Yhya Skiak
87	GB50	Plastic Industry	Waeal Esleem
88	GB51	Plastic Industry	Tal Al-Zohor
89	GB52	Plastic Industry	Telmisko 2
90	GB53	Plastic Industry	Nahawnd
91	GB54	Plastic Industry	Moshtha
92	GB55	Plastic Industry	AL-Rdease
93	GB56	Textile Industry	Jehad Oda

Num.	ID of industrial installations	Category	Title of industrial installations
94	GB57	Textile Industry	Esleem
95	GB58	Fiberglass Industry	kerjlass
96	GB59	Fiberglass Industry	Hsona
97	GB60	Fiberglass Industry	AL-Salam
98	GC1	Tiles Industry	Jadallh AL-Kozndar
99	GC2	Tiles Industry	Hashem AL-Kozndar
100	GC3	Tiles Industry	Healmi AL-Hayek
101	GC4	Tiles Industry	Fares Al-Ashram
102	GC5	Tiles Industry	AL-Ahlia Company
103	GC6	Tiles Industry	AL-Hayek 1
104	GC7	Tiles Industry	AL-Hayek 2
105	GC8	Tiles Industry	AL-Amana
106	GC9	Tiles Industry	AL-Hayek 3
107	GC10	Tiles Industry	Fadil Sons
108	GC11	Tiles Industry	Eareaz Company
109	GC12	Marble Industry	Noaman Ashoor
110	GC13	Marble Industry	Abd AL-Aal
111	GC14	Marble Industry	AL-Horany
112	GC15	Marble Industry	Abead
113	GC16	Marble Industry	Ehjazy
114	GC17	Marble Industry	Abo Galuon
115	GC18	Marble Industry	AL-Yazge
116	GC19	Marble Industry	Nabeel Egraab
117	GC20	Marble Industry	Rashad
118	GC21	Marble Industry	AL-Hadad
119	GC22	Marble Industry	Abo Shady
120	GC23	Ceramic Industry	Sabri Atalah
121	GC24	Concrete Industry	Masood Company
122	GC25	Concrete Industry	AL-Safady
123	GC26	Concrete Industry	Tafesh
124	GD1	Chemical Industry	AL-Haj Esmaeel
125	GD2	Chemical Industry	Zaharna Company
126	GD3	Chemical Industry	Karam Company 1
127	GD4	Chemical Industry	Karam Company 2
128	GD5	Chemical Industry	Haboosh
129	GD6	Chemical Industry	Ehjazy
130	GD7	Chemical Industry	Shorab Company
131	GD8	Chemical Industry	AL-Noor
132	GD9	Jeans Cleaner	Dry Clean
133	GD10	Jeans Cleaner	AL-Shanty

Num.	ID of industrial installations	Category	Title of industrial installations
134	GD11	Battery's Industry	Shaher AL-Helo
135	GD12	Battery's Industry	Battery's Company
136	GD13	Battery's Industry	Ryashe 1
137	GD14	Battery's Industry	Ryashe 2
138	GD15	Battery's Industry	Ryashe 3
139	GD16	Chemical Industry	Styel Company
140	GE1	Landfill	Gaza Landfill
141	GE2	Treatment Plant	Gaza Treatment Plant

4.6.1.3 Tools for Data Analysis

As a foundation for water resources decision making data must continue over space and time. Computer systems now offer the possibility of handling and manipulating very large databases in ways which were not previously practical options.

The data were analyzed using software programs involving the use of:

1. Excel for drawing graphs, tables, and making statistics for data.
2. **Surfer (Version 8)** is a contouring and 3D surface mapping program that runs under Microsoft Windows. It quickly and easily converts data into outstanding contour, surface, wireframe, vector, image, shaded relief, and post maps. Virtually all aspects of maps can be customized to produce exactly the desired presentation.
3. **AutoCAD 2009** is a CAD (Computer Aided Design) software application for 2D and 3D design , drafting , and architectural drawing.
4. **Global Positioning System (GPS)** is a system of satellites that provides navigation and timing information to military and civilian users worldwide. GPS satellites, in one of six medium earth orbits, circle the earth every 12 hours emitting continuous navigation signals on two different radio frequencies. GPS receiver units acquire the satellite signals and translate them into precise position and timing information. The GPS should be picking up 4 to 5 satellites at any one time to triangulate any position and it has an accuracy of about 10 meters **(http://www.wmi.org., 2008).**
5. **WhAEM2000** to be used in next chapter 5.

Chapter (5)

Application of the Methods

5.1 Introduction

Three classes of methods were used to delineate WHPA boundaries are identified in this research and this chapter will explain and clarify how to use each method. These methods vary considerably in input data requirements, difficulty of application and cost. There are many specific technical approaches to identify WHPAs. The classes are as follow:

- Calculated fixed-radius circles (CFR)
- Analytical methods
- Wellhead Analytic Element Model (WhAEM2000)

Regardless of the method used in WHPA delineation, certain basic hydrogeologic data are required to implement delineation. Actual data requirements are determined by the specific method applied. These data can include the following:

- **Transmissivity (m^2/day):** the rate of flow of water through a vertical strip of aquifer which is one unit wide and which extends the full saturated depth of the aquifer under hydraulic gradient.
- **Hydraulic conductivity (m/day):** A measure of how easily water moves through a geologic medium. The horizontal hydraulic conductivity (K_h) is a measure of how easily water can move in the horizontal direction and the vertical hydraulic conductivity (K_V) is a measure of how easily water can move in the vertical direction. Due to the stratified nature of geologic materials, the horizontal hydraulic conductivity if typically higher than the vertical hydraulic conductivity by one or more orders of magnitude.
- **Saturated thickness (m):** the saturated depth of an aquifer. For a confined aquifer, the saturated thickness at any point in the aquifer is equal to the aquifer thickness. For an

unconfined aquifer, the saturated thickness at any point is the distance from the top of the water table to the bottom of the aquifer.

- **Hydraulic gradient (magnitude and direction):** the rate of change of hydraulic head per unit of distance of flow at a given point and in a given direction.
- **Location of flow boundaries:** Demarcation of recharge areas or other hydrological features which control groundwater flow.
- **Storativity (dimensionless):** The volume of water given up per unit horizontal area of an aquifer and per unit drop of the water-table or potentiometric surface.
- **Porosity (dimensionless):** The ratio of the volume of void or air spaces in a rock or sediment to the total volume of the rock or sediment.

5.2 Methods of Determining the Zoning Dimension

5.2.1 Calculated Fixed-Radius Method (CFR)

Calculated Fixed Radius method also known as the "cylinder method", is easy to use and is based on simple hydrogeological principles that require limited technical expertise. However, this method tends to overprotect down-gradient and under protect up-gradient areas because it does not account for regional gradients. Calculated fixed radius capture zones are circular areas whose radius is determined using equation (5.1) **(Krijgsman and Ferreira, 2001)**:

$$r = \sqrt[2]{\frac{Qt}{\pi b n}} \qquad \text{———} \qquad \underline{5.1}$$

Where:

r = radius (distance from well) in meters

Q = maximum approved pumping rate of the well (m^3/day)

t = saturated travel times for each well capture zone (50 days,2 years,5 years)

b = saturated thickness of screened interval

n = porosity

π = 3.14156...

Where an aquifer characterization study is not being undertaken, the intrinsic susceptibility to contamination of the aquifer supplying water to municipal wells should be assessed to at least 500 meters beyond the limit of capture Zone 3. Intrinsic susceptibility to contamination is to be evaluated by considering the thickness and permeability of the material above the water supply aquifer. The thickness of the overlying formation is important, since any contaminants that are applied, deposited, or spilled on or near the ground surface will be less attenuated and will reach an aquifer more quickly where formations are thin **(OMOE, 2001).**

Example: An excel sheet was developed to compute the WHPA dimensions using equation 5.1. An example of the calculation used well name is Al-Daraj 1, Well number R/311 , With flow Q = 60 m^3/hr, Operating hours = 10 (hr/day) Porosity n = 0.25 (25%) and the saturated thickness of screened interval b = 12 m, time of travel TOT = 50 days, 2 years (730 days), 5 years (1825 days).

The mean flow per day = 60 × 10 = 600 m^3/day

From equation 5.1

The Radius for TOT 50 days $r_{50days} = \sqrt[2]{\frac{600\times50}{3.142\times12\times0.25}}$ **= 56.42 m**

The Radius for TOT 2 years $r_{2years} = \sqrt[2]{\frac{600\times730}{3.142\times12\times0.25}}$ **= 215.85 m**

The Radius for TOT 5 years $r_{5years} = \sqrt[2]{\frac{600\times1825}{3.142\times12\times0.25}}$ **= 340.86 m**

Figure (5.1) represent the zones boundary of well number R/311 at travel of time 50 days, 2 years, and 5 years. This figure shows that two industrial installations (GA10, GB8) fall in zone 3 at 5 years TOT.

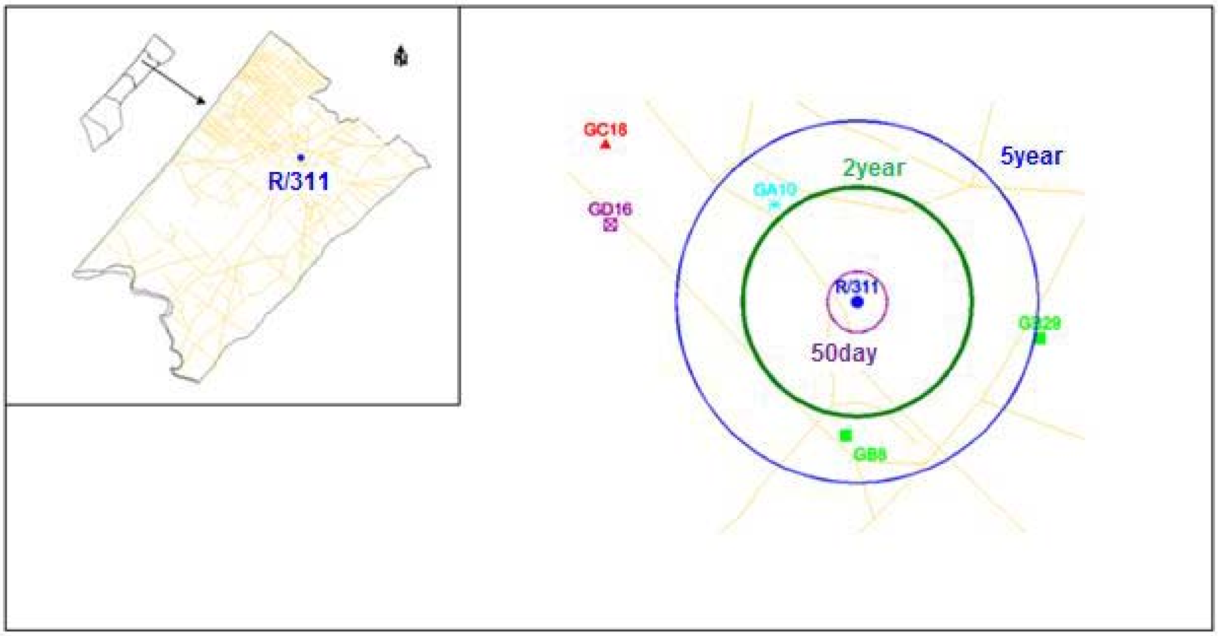


Figure 5.1: *Composite time of travel capture zones with 50 days, 2, 5 years for the well number R/311 using the Fixed-Radius Method.*

The limitation of this method is that it does not take into account regional groundwater flow, causing a hydraulic gradient. It thus can only be applied in situations where a horizontal initial (before pumping) water table is present. The depression cone due to pumping will then be a circle around the well **(Krijgsman and Ferreira, 2001).**

This method was applied for all municipal wells in the study area boundaries and Table 5.1 represents the results of CFR method for determining the zone boundary at 50 days, 2 years and 5 years TOT for each well. Figures (5.2, 5.3, and 5.4) represent the zone boundary at 50 days 2 years and 5 years TOT for each well in Gaza Governorate boundaries respectively.

The average of the radius of 50 days zone is about 71 m, for 2 year is about 217 m and for 5 year is about 429 m. From these results it can be recommended that by using CRF method any industrial insulation should be prohibited in any distance less than 430 m from the well.

Table 5.1: *The radius (m) for WHPA at TOT (50 Days, 2Years, 5Years) for each well in Gaza Governorate by using Calculated Fixed Radius Method (CFR).*

No.	Well No.	Mean Value Q (m^3/hr)	Operating hrs (hr/day)	Mean Flow (m^3/day)	Screen(m)	Porosity	Z0NE 1	Z0NE 2	Z0NE 3
							r_{50days} (m)	r_{2years} (m)	r_{5years} (m)
1	**E/154**	150	24	3600	47	0.25	69.83	266.82	421.88
2	**E/154A**	140	24	3360	47	0.25	67.46	257.77	407.57
3	**E/157**	180	24	4320	47	0.25	76.49	292.29	462.15
4	**R/162G**	210	24	5040	46	0.25	83.52	319.12	504.57
5	**R/162LA**	125	24	3000	28	0.25	82.59	315.57	498.96
6	**R/162LB**	170	24	4080	20	0.25	113.96	435.44	688.50
7	**R/162EA**	60	24	1440	21	0.25	66.07	252.46	399.17
8	**R/162BA**	50	24	1200	16.5	0.25	68.04	259.99	411.09
9	**R/162CA**	60	24	1440	12	0.25	87.40	333.97	528.05
10	**R/162D**	60	24	1440	16	0.25	75.69	289.23	457.31
11	**R/162H**	200	24	4800	45	0.25	82.41	314.87	497.85
12	**R/162HA**	120	24	2880	31	0.25	76.91	293.85	464.62
13	**R/314**	60	15	900	11	0.25	72.17	275.77	436.02
14	**R/315**	50	24	1200	11	0.25	83.34	318.43	503.48
15	**R/114**	60	24	1440	10	0.25	95.75	365.85	578.45
16	**R/25B**	180	24	4320	22	0.25	111.81	427.22	675.49
17	**R/25A**	160	24	3840	40	0.25	78.18	298.71	472.30
18	**R/25C**	100	24	2400	16	0.25	97.72	373.39	590.38
19	**R/25D**	180	24	4320	23	0.25	109.35	417.82	660.64
20	**R/308**	60	10	600	9	0.25	65.15	248.93	393.59
21	**R/311**	60	10	600	12	0.25	56.42	215.58	340.86
22	**R/313**	60	10	600	12	0.25	56.42	215.58	340.86
23	**R/75**	120	24	2880	25	0.25	85.64	327.22	517.38
24	**R/74**	100	9	900	20	0.25	53.52	204.51	323.36
25	**R/309**	60	10	600	10	0.25	61.80	236.15	373.39
26	**R/305**	60	10	600	9	0.25	65.15	248.93	393.59
27	**R/310**	60	10	600	9	0.25	65.15	248.93	393.59
28	**R/306**	60	10	600	9	0.25	65.15	248.93	393.59
29	**R/312**	60	10	600	9	0.25	65.15	248.93	393.59
30	**R/112**	70	24	1680	9	0.25	109.01	416.53	658.60
31	**R/254**	60	24	1440	26	0.25	59.38	226.89	358.74
32	**R/265**	45	24	1080	27	0.25	50.46	192.82	304.87
33	**R/113A**	65	10	650	7	0.25	76.89	293.78	464.51
34	**R/277**	65	24	1560	25.5	0.25	62.41	238.46	377.03
35	**R/280**	60	12	720	20	0.25	47.87	182.92	289.23
36	**R/293**	60	24	1440	15	0.25	78.18	298.71	472.30
37	**R/307**	60	10	600	10	0.25	61.80	236.15	373.39

No.	Well No.	Mean Value Q	Operating hrs	Mean Flow	Screen(m)	Porosity	Z0NE 1	Z0NE 2	Z0NE 3
							r_{50days}	r_{2years}	r_{5years}
38	**F/191**	100	10	1000	15	0.25	65.15	248.93	393.59
39	**F/192**	100	10	1000	15	0.25	65.15	248.93	393.59
40	**R/270**	55	6	330	15	0.25	37.42	143.00	226.10
41	**G/50**	60	6	360	20	0.25	33.85	129.35	204.51
42	**F/203**	65	15	975	9	0.25	83.05	317.32	501.73
43	**F/205**	45	10	450	9	0.25	56.42	215.58	340.86
44	**G/57**	50	10	500	8	0.25	63.08	241.02	381.09
45	**G/56**	60	10	600	7	0.25	73.87	282.26	446.29
46	**F/208**	50	8	400	13	0.25	44.26	169.11	267.39
47	**G/51**	60	6	360	20	0.25	33.85	129.35	204.51
Calculated Fixed Radius methods				Average			71.07	271.56	429.37

Table 5.2 shows all industrial installations that fall in the three zones (50 days, 2 years, and 5 years TOT). The location of the industrial installations and the three zones are presented in Figure (5.5).

Table 5.2: *Summary of the results of CRF method.*

TOT	Well field	ID of industrial installations
50 Days	R/25A,R/25B,R/25C,R/25D	GB53
	R/315	GB 57
2 Years	R/25A,R/25B,R/25C,R/25D	GA28,GB10,GB12, GB21,GC20
	R/308	GC11,GC17
	R/309	GB34
	R/74,R/75	GC18,GD11
	R/114,R/314,R/315,E/154,E/154A,E/157,R/162BA, R/162CA,R/162EA,R/162LA,R/162LB,R/162D,R/162G, R162H,R/162HA	GB4
5 Years	R/112, R/113A,R/254,R/265,R/277, R/280,R/293,R/306,R/307,R/308	GA19,GB25
	R/313	GD9,GD10
	R/25A,R/25B,R/25C,R/25D,R/74,R75	GA26,GA27,GB20,GB27, GB28, GB44 ,GB45,GB59
	R/311	GA10,GB8
	R/114,R/314,R/315,E/154,E/154A,E/157,R/162BA, R/162CA,R/162EA,R/162LA,R/162LB,R/162D,R/162G,R162H,R/162HA	GA9,GA12,GB3, GB13,GD8

5.2.2 Analytical Method

In the handbook Groundwater and Wellhead Protection **(USEPA 1994)**, equation (5.2) is used to compute the time of travel in x axes.

$$t_x = \frac{n}{ki}\left[r_x - \left(\frac{Q}{2\pi Kbi}\right)\ln\left\{1 + \left(\frac{2\pi Kbi}{Q}\right).r_x\right\}\right] \quad \text{———} \quad \underline{5.2}$$

t_x = time of travel (days)

n = effective porosity (fraction)

K = hydraulic conductivity (meters per day)

r_x = distance over which groundwater travels in t_x before entering a pumping well (m), being negative (–) if down gradient and positive (+) if up gradient

Q = pumping rate from the well (cubic meters per day)

b = aquifer thickness (meters)

i = hydraulic gradient before pumping

Equation (5.2) can be used to calculate travel time from point 'x' to a well, in case of a sloping hydraulic gradient, for both up- and down gradient points. To calculate the distance as a function of time't', this equation should be written for 'r' as a function of 't', 'n', 'K', 'Q', 'b', and 'i'. Krijgsman and Lobo-Ferreira (2001) developed approximate solutions using Taylor-series besides developing a computer program.

To calculate the distance as a function of time't', this equation should be written for 'r' as a function of 't', 'n', 'K', 'Q', 'b', and 'i'. Krijgsman and Lobo-Ferreira (2001) developed approximate solutions.

Krijgsman and Lobo- Ferreira (2001) equations 5.3, 5.4, and 5.5 developed by using Taylor-series besides developing a computer program (Modflow) for the new method aiming at the delineation of groundwater wellheads protection: upstream, downstream, and perpendicular to the flow lines.

For the up gradient protection distance, equation (5.3) is used to compute the maximum gradient protection distance (r_{max}).

$$\mathbf{r_{max}\,(m) = (0.00002\,\gamma^5 - 0.0009\,\gamma^4 + 0.015\,\gamma^3 + 0.37\,\gamma^2 + \gamma)\,/\,F} \qquad \underline{\mathbf{5.3}}$$

With $\gamma = 2Ki\sqrt[2]{\frac{\pi.b.t}{Q.n}}$ **(dimensionless)** and $F = \frac{2\pi Kbi}{Q}$ **(m^{-1})**

For the down gradient protection distance, the minimum distance (r_{min}) is calculated by using equation (5.4).

$$r_{min}\ (m) = (0.042\ \gamma^3 + 0.37\ \gamma^2 + 1.04\ \gamma) / F \qquad \underline{5.4}$$

For the protection distance perpendicular to the direction of flow (r_p), equation (5.5) is used as follows:

$$r_p = \sqrt[2]{\frac{Qt}{\pi b n}} \quad (m) \qquad \underline{5.5}$$

(Krijgsman and Ferreira, 2001).

Krijgsman and Lobo-Ferreira specified number of limitation to the application of their method. These limitations can be classified as follows:

- **For computing up gradient protection distance (r_{max}),**

Combinations of input parameters resulting in a value of $\gamma > 18$, should not be used this method. Visual Modflow models were run with combinations of input parameters that give a maximum value of γ up to 18. Values of r_{max} for γ larger than 18 are not found.

- **For computing down gradient protection distance (r_{min}),**

A minimum protection distance of 25 m, should be applied if $\gamma < -3.5$ because the values of r_{min} become very small. In addition equation (5.4) should be not applied with values of effective porosity smaller than 0.1 (10%).

- **For computing protection distance perpendicular (r_p) to the direction of flow; and**

If r_{max} is more than four times r_{min}, the possible calculation error can be more than 15%. Since this only leads to overprotection, it should not be a serious limitation. An error of 15% probably is irrelevant concerning the uncertainty of the input data.

5.2.2.1 Aquifer Depth (b)

The aquifer depth was computed by selecting the section number, far from sea and the total depth. After that the sections from Figure (4.4) were used to determine the aquifer depth as shown Table (5.3). It can be seen that the range of aquifer depth is between 32 m and 150 m when the average of aquifer depth is 77 m.

Table (5.3): *Aquifer depth for each well in Gaza Governorate.*

No.	Well No.	Total Depth (m)	Section no.	Far from sea(m)	Aquifer Depth(m)	No.	Well No.	Total Depth (m)	Section no.	Far from sea(m)	Aquifer Depth(m)
1	**E/154**	102	97	1730	40	25	**R/309**	91	95	5631	108
2	**E/154A**	66	97	1726	40	26	**R/305**	60	95	3281	68
3	**E/157**	85	97	2631	96	27	**R/310**	63	95	3152	68
4	**R/162G**	100	97	2298	110	28	**R/306**	61	95	1929	70
5	**R/162LA**	101	97	1718	36	29	**R/312**	106	95	5344	104
6	**R/162LB**	96.5	97	1694	36	30	**R/112**	45.12	95	613	48
7	**R/162EA**	68	97	1240	36	31	**R/254**	72	95	1347	72
8	**R/162BA**	70	97	1655	40	32	**R/265**	66	95	978	36
9	**R/162CA**	71	97	1652	40	33	**R/113A**	47	95	1030	36
10	**R/162D**	60	97	1203	32	34	**R/277**	70	95	1425	74
11	**R/162H**	103	97	2399	108	35	**R/280**	70	95	1314	74
12	**R/162HA**	85	97	2335	108	36	**R/293**	67	95	1899	72
13	**R/314**	73.5	97	2003	52	37	**R/307**	55.5	95	2540	88
14	**R/315**	56	97	2588	92	38	**F/191**	64	94	2220	64
15	**R/114**	65	97	2173	112	39	**F/192**	50	94	2755	32
16	**R/25B**	62	97	4445	150	40	**R/270**	85	94	2639	48
17	**R/25A**	95	97	4396	150	41	**G/50**	40	93	1064	40
18	**R/25C**	55	97	4478	150	42	**F/203**	50	93	1835	52
19	**R/25D**	60	97	4503	150	43	**F/205**	82	93	5455	120
20	**R/308**	59.5	96	2988	88	44	**G/57**	36.5	93	1848	52
21	**R/311**	70	96	3773	100	45	**G/56**	43.5	93	1665	56
22	**R/313**	62	96	1574	76	46	**F/208**	51	93	1761	52
23	**R/75**	72	96	4919	140	47	**G/51**	40	93	1335	40
24	**R/74**	55	96	4956	140						

5.2.2.2 Hydraulic Gradient

The hydraulic gradient (i) is computed by using equation (5.6):

$$\mathbf{i} = \frac{\Delta h}{F} = \frac{(Z - DTW)}{F} \qquad \underline{5.6}$$

i: Hydraulic Gradient

DTW: depth to water

Δh: deference between Z coordinate and DTW

F: far from sea

Table (5.4) shows the hydraulic gradient for all wells in the study area. The maximum of hydraulic gradient is 0.0028 where the average value of the hydraulic gradient is 0.0008.

Table 5.4: *Hydraulic Gradient for each well in Gaza Governorate.*

No.	Well No.	Z (m) Coord.	DTW (m)	Δh	Far from sea (m)	Hydra. Gradient (i)	No.	Well No.	Z (m) Coord.	DTW (m)	Δh	Far from sea (m)	(i)
1	E/154	43.486	48.4	-4.914	1730	-0.0028	25	R/309	74.152	73.18	0.972	5631	0.0002
2	E/154A	43.486	48.4	-4.914	1726	-0.0028	26	R/305	39.703	39.55	0.153	3281	0.0000
3	E/157	26.033	26	0.033	2631	0.0000	27	R/310	39.274	38.69	0.584	3152	0.0002
4	R/162G	34.648	36	-1.352	2298	-0.0006	28	R/306	42.399	42.22	0.179	1929	0.0001
5	R/162LA	57.712	59	-1.288	1718	-0.0007	29	R/312	84.663	84.23	0.433	5344	0.0001
6	R/162LB	57.87	59.83	-1.96	1694	-0.0012	30	R/112	20.861	19.49	1.371	613	0.0022
7	R/162EA	39.945	40.3	-0.355	1240	-0.0003	31	R/254	36.073	33	3.073	1347	0.0023
8	R/162BA	52.83	55.49	-2.66	1655	-0.0016	32	R/265	39.127	39	0.127	978	0.0001
9	R/162CA	50.834	53.5	-2.666	1652	-0.0016	33	R/113A	38.987	38.56	0.427	1030	0.0004
10	R/162D	39.727	42	-2.273	1203	-0.0019	34	R/277	39.93	38.14	1.79	1425	0.0013
11	R/162H	32.967	34	-1.033	2399	-0.0004	35	R/280	36.201	38	-1.79	1314	-0.0014
12	R/162HA	34.378	35.5	-1.122	2335	-0.0005	36	R/293	41.706	40.75	0.956	1899	0.0005
13	R/314	46.239	49.92	-3.681	2003	-0.0018	37	R/307	38.907	37.77	1.137	2540	0.0004
14	R/315	22.466	26.92	-4.454	2588	-0.0017	38	F/191	31.262	31.2	0.062	2220	0.0000
15	R/114	37.399	41.96	-4.561	2173	-0.0021	39	F/192	20.962	20.1	0.862	2755	0.0003
16	R/25B	33.179	35	-1.821	4445	-0.0004	40	R/270	44	43	1	2639	0.0004
17	R/25A	32.316	35	-2.684	4396	-0.0006	41	G/50	10.921	9.7	1.221	1064	0.0011
18	R/25C	34.527	35	-0.473	4478	-0.0001	42	F/203	24.111	22.6	1.511	1835	0.0008
19	R/25D	34.29	35	-0.71	4503	-0.0002	43	F/205	65.8	64.12	1.68	5455	0.0003
20	R/308	26.76	27.93	-1.17	2988	-0.0004	44	G/57	18.294	18.15	0.144	1848	0.0001
21	R/311	46.05	47.71	-1.66	3773	-0.0004	45	G/56	18.269	17.67	0.599	1665	0.0004
22	R/313	39.101	40.27	-1.169	1574	-0.0007	46	F/208	20.828	19.87	0.958	1761	0.0005
23	R/75	41.907	41	0.907	4919	0.0002	47	G/51	11.23	9.7	1.53	1335	0.0011
24	R/74	42.666	40	2.666	4956	0.0005							

Example: An excel sheet was developed to compute the WHPA dimensions using equation (5.3, 5.4, 5.5). An example of the calculation used well name is Al-Daraj 1, Well number R/311 , With flow Q = 60 m^3/hr, Operating hours = 10 (hr/day) Porosity n = 0.25 (25%) and aquifer thickness b = 100 m, hydraulic conductivity k = 30 m/ day , Depth to water = 47.71 m , Z Coordinate = 46.05 m, Far from well to sea = 3773 m, time of travel TOT = 50 days, 2 years (730days), 5 years (1825days).

The mean flow per day = 60 × 10 = 600 m^3/day

Aquifer depth (b) = 100 m **(Table 5.3)**

The hydraulic Gradient i = (46.05-47.71)/3773 = -0.00044 **(Table 5.4)**

For TOT = 50 days

$$\gamma_{50day} = 2*30*0.00044\sqrt[2]{\frac{\pi*100*50}{600*0.25}} = 0.27 \text{ dimensionless}$$

$$F = \frac{2\pi*30*100*0.00044}{600} = 0.01382\ m^{-1}$$

For the up gradient protection distance,

r_{max} = (0.00002*0.27 ^{5} – 0.0009*0.27 ^{4} + 0.015*0.27 ^{3} + 0.37*0.27 ^{2} + 0.27) / 0.01382 =

r_{max} = 21.72 m

For the down gradient protection distance,

r_{min} = (0.042*-0.27^3 + 0.37*-0.27^2 + 1.04*-0.27) / -0.01382 = 18.44 m

For the protection distance perpendicular to the direction of flow,

$$r_p = \sqrt[2]{\frac{600*50}{\pi*100*0.25}} = 19.55\ m$$

For TOT = 2 years (730 days)

γ_{2year} = 1.0319 dimensionless

F = 0.01382 m^{-1}

r_{max} = 115.08 m , r_{min} = 52.51 m , r_p = 74.7 m

For TOT = 5 years (1825 days)

γ_{5year} = 1.6316 dimensionless

F = 0.01382 m^{-1}

r_{max} = 236.13 m , r_{min} = 64.73 m , r_p = 118.11 m

Figure (5.6) presents the zones boundary of well number R/311 at travel of time 50 days, 2years and 5 years. This figure shows industrial installations are located out of the three zones but when the zones are calculated with CFR method, fall in zone 3 at 5 years TOT two industrial installations (GA10, GB8).

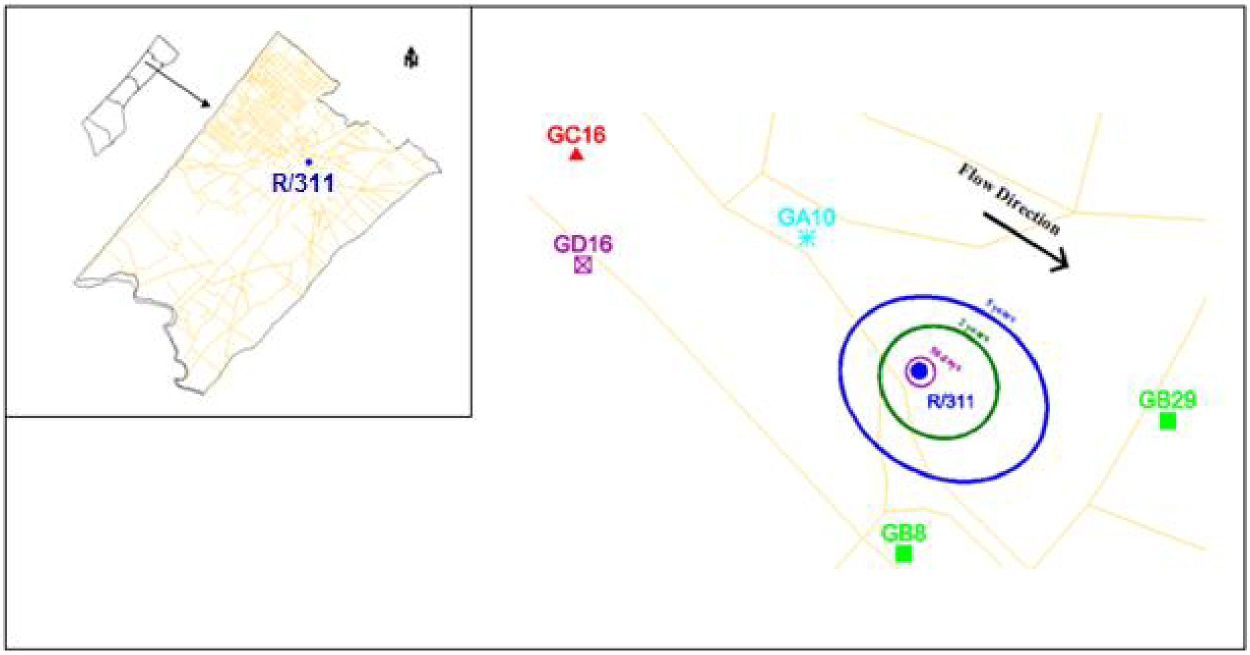


Figure 5.6: *Composite time of travel capture zones with 50 days, 2,5years for the well number R/311 using the Analytical Method (Krijgsman and Lobo- Ferreir approach).*

The advantage of these analytical methods is that they better incorporate local hydrogeologic data and hydraulic behavior than do fixed radius methods. One disadvantage of these methods is that fixed hydraulic parameters (such as hydraulic conductivity and gradient) must be applied uniformly to the vicinity of the well when these parameters may, in fact, vary over the region. Another disadvantage is the inability to incorporate effects of nearby pumping wells. Compared to fixed-radius method, application of analytical a method is technically more involved **(Richards et al., 1997).**

The analytical method using equations (5.3, 5.4, and 5.5) was applied for all municipal wells in study area boundaries. Table (5.5) represents the results for determining the zone boundary at 50 days TOT for each well. The boundary of 50 days TOT and the industrial installations are shown in Figure (5.7). Table (5.6 and 5.7) represent the zone boundary at 2 years and 5 years TOT for each well in Gaza Governorate boundaries respectively. The WHPA for 2 years and 5 years are shown in Figure (5.8, 5.9).

The average of the ellipse radiuses of 50 days zone r_{max}, r_{min}, and r_p are about 42 m, 31 m, 37 m respectively, for 2 years are about 328 m, 91 m, and 140 m respectively and for 5 years are about 862 m, 149 m, and 222 m respectively. From these results it can be recommended that by using analytical method any industrial insulation should be prohibited in any ellipse radiuses r_{max}, r_{min}, and r_p less than 862 m, 150 m, and 223 m respectively around the well.

Table 5.5: *WHPA dimension for 50 days TOT of each well in Gaza Governorate by using Analytical Method.*

No.	Well No.	F	$\gamma_{max50day}$	$\gamma_{min50day}$	Z0NE 1 (50days) (m)		
					r_{max}	r_{min}	r_P
1	E/154	0.005861333	0.443780126	-0.443780126	90.38	66.94	75.71
2	E/154A	0.00628	0.459356071	-0.459356071	87.89	64.29	73.15
3	E/157	0	0	0	0.00	0.00	53.54
4	R/162G	0.002419189	0.130688933	-0.130688933	56.77	53.61	54.02
5	R/162LA	0.001694942	0.123485055	-0.123485055	76.35	72.49	72.86
6	R/162LB	0.003493493	0.296817042	-0.296817042	95.41	79.34	84.96
7	R/162EA	0.001348427	0.068062476	-0.068062476	51.78	51.23	50.48
8	R/162BA	0.010093535	0.441218875	-0.441218875	52.12	38.68	43.71
9	R/162CA	0.008445561	0.404417485	-0.404417485	56.22	42.96	47.89
10	R/162D	0.007910468	0.42350508	-0.42350508	63.36	47.69	53.54
11	R/162H	0.001825297	0.097116362	-0.097116362	55.19	53.44	53.21
12	R/162HA	0.007933375	0.326958407	-0.326958407	46.86	38.06	41.21
13	R/314	0.020004449	0.664196156	-0.664196156	43.55	26.99	33.20
14	R/315	0.024858414	0.716506779	-0.716506779	38.68	22.96	28.82
15	R/114	0.03075649	0.880155047	-0.880155047	41.24	21.37	28.62
16	R/25B	0.002679949	0.114781794	-0.114781794	44.73	42.75	42.83
17	R/25A	0.004493304	0.181441203	-0.181441203	43.29	39.34	40.38
18	R/25C	0.001243764	0.039705268	-0.039705268	32.40	32.73	31.92
19	R/25D	0.001031442	0.044176492	-0.044176492	43.54	43.85	42.83
20	R/308	0.010819759	0.225476898	-0.225476898	22.74	19.98	20.84
21	R/311	0.013815001	0.27007024	-0.27007024	21.72	18.44	19.55
22	R/313	0.017723644	0.397440414	-0.397440414	26.25	20.17	22.42
23	R/75	0.009482291	0.343238266	-0.343238266	41.43	33.23	36.20
24	R/74	0.057158644	1.156616353	-1.156616353	32.93	13.52	20.24
25	R/309	0.00585375	0.1101154	-0.1101154	19.61	18.81	18.81
26	R/305	0	0	0	0.00	0.00	23.71
27	R/310	0.003956081	0.093785682	-0.093785682	24.56	23.84	23.71
28	R/306	0.002039616	0.047656843	-0.047656843	23.79	23.89	23.37
29	R/312	0.003464811	0.066418448	-0.066418448	19.65	19.47	19.17
30	R/112	0.012038984	0.568426125	-0.568426125	59.43	39.81	47.22
31	R/254	0.021490468	0.767027684	-0.767027684	48.96	27.87	35.69
32	R/265	0.000815501	0.035648012	-0.035648012	44.30	44.89	43.71
33	R/113A	0.047745259	1.619145434	-1.619145434	67.44	18.69	33.91
34	R/277	0.048855179	1.790223387	-1.790223387	78.35	18.77	36.64
35	R/280	0.026510378	0.65995828	-0.65995828	32.59	20.27	24.89
36	R/293	0.004742243	0.169257921	-0.169257921	38.08	34.93	35.69
37	R/307	0.012369128	0.257764753	-0.257764753	23.03	19.74	20.84
38	F/191	0	0	0	0.00	0.00	31.55
39	F/192	0.001886325	0.084157287	-0.084157287	46.05	45.02	44.61
40	R/270	0.010384099	0.217297801	-0.217297801	22.76	20.12	20.93
41	G/50	0.02402218	0.575153615	-0.575153615	30.22	20.14	23.94
42	F/203	0.008273857	0.285929413	-0.285929413	38.64	32.40	34.56
43	F/205	0.015472631	0.239127743	-0.239127743	16.95	14.74	15.45
44	G/57	0.093896603	2.32371779	-2.32371779	65.80	10.07	24.75
45	G/56	0.006326016	0.16525783	-0.16525783	27.83	25.60	26.12
46	F/208	0.013323871	0.294923176	-0.294923176	24.84	20.69	22.13
47	G/51	0.087810237	2.102405959	-2.102405959	58.25	10.72	23.94

**** (The data of (Q) and (n) from Table 5.1, (b) from Table 5.3, i from table 5.4).***

****(Hydraulic Conductivity (K) =30m/day).***

Table 5.6: *WHPA dimension for 2 years TOT of each well in Gaza Governorate by using Analytical Method.*

No.	Well No.	F	$\gamma_{max2years}$	$\gamma_{min2years}$	Z0NE 2 (2years) (m)		
					r_{max}	r_{min}	r_P
1	E/154	0.005861333	1.6956815	-1.6956815	594.36	154.30	289.30
2	E/154A	0.00628	1.7551971	-1.7551971	588.84	145.33	279.49
3	E/157	0	0	0	0.00	0.00	204.57
4	R/162G	0.002419189	0.4993617	-0.4993617	252.25	178.70	206.42
5	R/162LA	0.001694942	0.4718357	-0.4718357	336.25	243.52	278.38
6	R/162LB	0.003493493	1.1341363	-1.1341363	523.09	218.94	324.64
7	R/162EA	0.001348427	0.2600664	-0.2600664	213.38	182.57	192.87
8	R/162BA	0.010093535	1.685895	-1.685895	341.73	89.46	167.03
9	R/162CA	0.008445561	1.545277	-1.545277	352.53	104.03	182.97
10	R/162D	0.007910468	1.6182106	-1.6182106	406.65	112.77	204.57
11	R/162H	0.001825297	0.3710811	-0.3710811	235.40	184.69	203.30
12	R/162HA	0.007933375	1.2493063	-1.2493063	266.86	101.30	157.47
13	R/314	0.020004449	2.5378899	-2.5378899	366.80	47.13	126.87
14	R/315	0.024858414	2.7377686	-2.7377686	343.61	37.65	110.13
15	R/114	0.03075649	3.3630677	-3.3630677	427.45	29.60	109.34
16	R/25B	0.002679949	0.4385806	-0.4385806	194.92	144.96	163.65
17	R/25A	0.004493304	0.6932859	-0.6932859	204.95	124.00	154.29
18	R/25C	0.001243764	0.1517136	-0.1517136	129.25	120.13	121.98
19	R/25D	0.001031442	0.1687981	-0.1687981	174.57	160.17	163.65
20	R/308	0.010819759	0.861546	-0.861546	113.83	59.91	79.63
21	R/311	0.013815001	1.0319369	-1.0319369	115.08	52.51	74.70
22	R/313	0.017723644	1.5186177	-1.5186177	163.21	49.27	85.68
23	R/75	0.009482291	1.3115116	-1.3115116	240.84	86.72	138.31
24	R/74	0.057158644	4.4194249	-4.4194249	424.85	25.00	77.32
25	R/309	0.00585375	0.4207504	-0.4207504	84.97	64.10	71.88
26	R/305	0	0	0	0.00	0.00	90.58
27	R/310	0.003956081	0.3583546	-0.3583546	104.33	82.68	90.58
28	R/306	0.002039616	0.1820965	-0.1820965	95.74	86.96	89.28
29	R/312	0.003464811	0.2537845	-0.2537845	80.83	69.50	73.25
30	R/112	0.012038984	2.1719532	-2.1719532	451.47	78.39	180.41
31	R/254	0.021490468	2.9308087	-2.9308087	457.09	43.15	136.38
32	R/265	0.000815501	0.1362109	-0.1362109	175.91	165.42	167.03
33	R/113A	0.047745259	6.186746	-6.186746	1146.33	46.45	129.58
34	R/277	0.048855179	6.840434	-6.840434	1442.91	66.41	140.01
35	R/280	0.026510378	2.521697	-2.521697	273.31	35.58	95.12
36	R/293	0.004742243	0.6467336	-0.6467336	177.53	111.59	136.38
37	R/307	0.012369128	0.9849177	-0.9849177	120.16	57.04	79.63
38	F/191	0	0	0	0.00	0.00	120.54
39	F/192	0.001886325	0.3215645	-0.3215645	193.39	157.75	170.47
40	R/270	0.010384099	0.8302937	-0.8302937	112.75	60.91	79.96
41	G/50	0.02402218	2.1976589	-2.1976589	231.32	39.31	91.48
42	F/203	0.008273857	1.0925348	-1.0925348	208.92	90.57	132.05
43	F/205	0.015472631	0.9137058	-0.9137058	86.37	43.52	59.05
44	G/57	0.093896603	8.8789132	-8.8789132	1475.60	100.79	94.56
45	G/56	0.006326016	0.6314493	-0.6314493	129.09	82.16	99.82
46	F/208	0.013323871	1.1268999	-1.1268999	135.85	57.21	84.58
47	G/51	0.087810237	8.0332819	-8.0332819	1213.92	71.18	91.48

**** (The data of (Q) and (n) from Table 5.1, (b) from Table 5.3, i from table 5.4).***

****(Hydraulic Conductivity (K) =30m/day).***

***Table 5.7:** WHPA dimension for 2 years TOT of each well in Gaza Governorate by using Analytical Method.*

No.	Well No.	F	$\gamma_{max5years}$	$\gamma_{min5years}$	Z0NE 3 (5years) (m)		
					r_{max}	r_{min}	r_P
1	E/154	0.005861333	2.681107831	-2.681107831	1396.95	160.05	457.42
2	E/154A	0.00628	2.775210262	-2.775210262	1398.23	148.77	441.91
3	E/157	0	0	0	0.00	0.00	323.45
4	R/162G	0.002419189	0.789560196	-0.789560196	452.10	252.63	326.37
5	R/162LA	0.001694942	0.746037797	-0.746037797	598.24	346.55	440.16
6	R/162LB	0.003493493	1.793226984	-1.793226984	1098.91	262.59	513.30
7	R/162EA	0.001348427	0.411201014	-0.411201014	359.06	272.92	304.95
8	R/162BA	0.010093535	2.665633978	-2.665633978	801.81	93.00	264.09
9	R/162CA	0.008445561	2.443297531	-2.443297531	806.30	111.87	289.30
10	R/162D	0.007910468	2.558615674	-2.558615674	942.67	119.11	323.45
11	R/162H	0.001825297	0.586730733	-0.586730733	407.77	269.17	321.44
12	R/162HA	0.007933375	1.975326731	-1.975326731	575.05	117.77	248.99
13	R/314	0.020004449	4.012756341	-4.012756341	972.29	46.45	200.59
14	R/315	0.024858414	4.328792175	-4.328792175	931.02	39.24	174.14
15	R/114	0.03075649	5.317476946	-5.317476946	1225.70	44.97	172.89
16	R/25B	0.002679949	0.693456848	-0.693456848	343.74	207.94	258.76
17	R/25A	0.004493304	1.0961812	-1.0961812	386.59	167.08	243.96
18	R/25C	0.001243764	0.23988029	-0.23988029	211.65	183.93	192.87
19	R/25D	0.001031442	0.266893294	-0.266893294	287.07	244.33	258.76
20	R/308	0.010819759	1.362223863	-1.362223863	224.13	77.29	125.90
21	R/311	0.013815001	1.631635561	-1.631635561	236.13	64.73	118.11
22	R/313	0.017723644	2.401145396	-2.401145396	371.40	53.34	135.48
23	R/75	0.009482291	2.073681877	-2.073681877	525.87	99.14	218.69
24	R/74	0.057158644	6.987724285	-6.987724285	1302.01	61.78	122.25
25	R/309	0.00585375	0.665264723	-0.665264723	149.14	92.33	113.65
26	R/305	0	0	0	0.00	0.00	143.22
27	R/310	0.003956081	0.566608355	-0.566608355	180.13	120.86	143.22
28	R/306	0.002039616	0.287919913	-0.287919913	157.95	132.26	141.16
29	R/312	0.003464811	0.401268583	-0.401268583	135.80	104.03	115.81
30	R/112	0.012038984	3.434159503	-3.434159503	1142.72	75.50	285.25
31	R/254	0.021490468	4.634015384	-4.634015384	1262.60	49.02	215.63
32	R/265	0.000815501	0.215368282	-0.215368282	286.97	254.13	264.09
33	R/113A	0.047745259	9.782104356	-9.782104356	3752.09	294.94	204.88
34	R/277	0.048855179	10.81567574	-10.81567574	4800.37	431.99	221.38
35	R/280	0.026510378	3.987153119	-3.987153119	723.10	34.96	150.40
36	R/293	0.004742243	1.02257562	-1.02257562	330.83	152.14	215.63
37	R/307	0.012369128	1.55729168	-1.55729168	243.83	71.22	125.90
38	F/191	0	0	0	0	0	190.59
39	F/192	0.001886325	0.508438181	-0.508438181	330.67	232.54	269.54
40	R/270	0.010384099	1.312809658	-1.312809658	220.27	79.22	126.42
41	G/50	0.02402218	3.474803784	-3.474803784	587.56	37.82	144.65
42	F/203	0.008273857	1.727449118	-1.727449118	434.75	109.86	208.78
43	F/205	0.015472631	1.444695757	-1.444695757	172.27	55.38	93.37
44	G/57	0.093896603	14.03879444	-14.03879444	5090.06	616.49	149.51
45	G/56	0.006326016	0.998408977	-0.998408977	239.59	112.44	157.83
46	F/208	0.013323871	1.781785145	-1.781785145	284.92	68.75	133.73
47	G/51	0.087810237	12.70173393	-12.70173393	4133.52	450.78	144.65

**** (The data of (Q) and (n) from Table 5.1, (b) from Table 5.3, i from table 5.4).***

****(Hydraulic Conductivity (K) =30m/day).***

Table (5.8) summarized the industrial installations locate in the zones at 50 days, 2 years and 5 years TOT where these are shown in Figure (5.10).

Table 5.8: *Summary of the application of Analytical Method.*

TOT	Well field	ID of industrial installations
50 Days	NO Well field	NO Symbolic Figure
2 Years	R/25A,R/25B,R/25C,R/25D	GB53
	R/75	GD11
5 Years	R/265,R/277,R/293	GB26
	R/74	GA11,GD2
	R/25A,R/25B,R/25C,R/25D	GB12
	R/114,R/314,R/315,E/154,E/154A,E/157,R/162BA, R/162CA,R/162EA,R/162LA,R/162LB, R/162D, R/162G,R162H,R/162HA	GB3,GB4,GB13,GD8

5.2.2.3 Sensitive Analysis for Analytical Method

Generally, sensitivity analysis is used for testing the degree of sensitivity of a system or model's variables by applying incremental changes. The "system" can be physical or notional and represent the whole project or major element. The analysis determines which variables is the most significant having the most impact on results and so helps the selection of the optimal settings or best solution.

The equation for the up gradient protection distance r_{max} has been tested for if such anomalies do show up with special combinations of parameters. For each parameter a range of values from the upper to lower extremes are filled in, after which it is seen if the calculated value of r_{max} still follows a trend as expected. Equations 5.3, 5.4, and 5.6 are used to carry out the sensitive analysis. No values resulting in $\gamma > 18$ have been used, since the equation is derived only over the interval $0 < \gamma < 18$.

Also for the down gradient protection distance research r_{min} has been done on possible limits on the ranges of the input parameters, by filling in some extreme values of each parameter, since it could be possible that anomalies in the output arise when using very small or large values of one of the input parameters. The equation has been tested for anomalies with every parameter by filling in extreme values and seeing if the calculated value of r_{min} still follows the trend as expected. With every parameter, some variations of the other parameters have been looked at, since certain combinations might result in anomalies, while with other combinations errors might not show up.

Apart from the minimum and maximum distance, there is also the width of the ellipse, which is the protection distance perpendicular (r_p) to the flow direction. This distance will be in between the values of r_{max} and r_{min}.

a) Hydraulic Gradient (i)

The rest of data are kept constantly in equation 5.2, 5.3, and 5.4. For this analysis hydraulic gradient varies between 0 – 0.1. Figure 5.11 shows the relation between the hydraulic gradient (i) and maximum, minimum, and perpendicular radiuses $r_{max,}$ r_{min}, and r_P respectively.

Up gradient protection distance is increasing with increasing slope. Down gradient protection distance is increasing with increasing slope, except with very small hydraulic gradients which it depends on the combination of other parameters. Perpendicular protection distance is not affected by hydraulic gradients. Eventually the protection zone should be a perfect circle when a gradient is approaching zero.

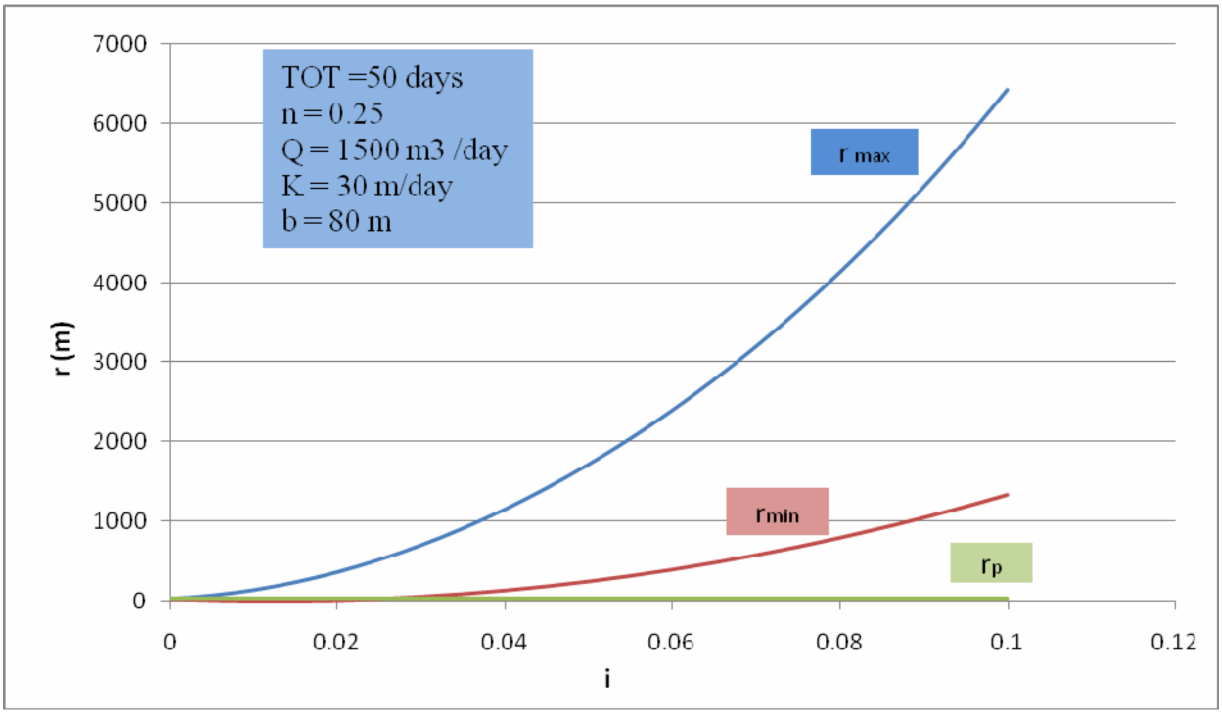


Figure 5.11: *The relation between hydraulic gradient (i) and* r_{max}, r_{min}, *and* r_P.

b) Extraction Rate (Q)

The rest of data are kept constant in equation 5.2, 5.3, and 5.4. For this extraction rate varies between 10 – 10000 m^3/day. Figure 5.12 shows the relation between the extraction rate (Q) and maximum, minimum, and perpendicular radiuses r_{max}, r_{min}, and r_P respectively.

Up gradient, down gradient and perpendicular protection distance is increasing with increasing extraction rate.

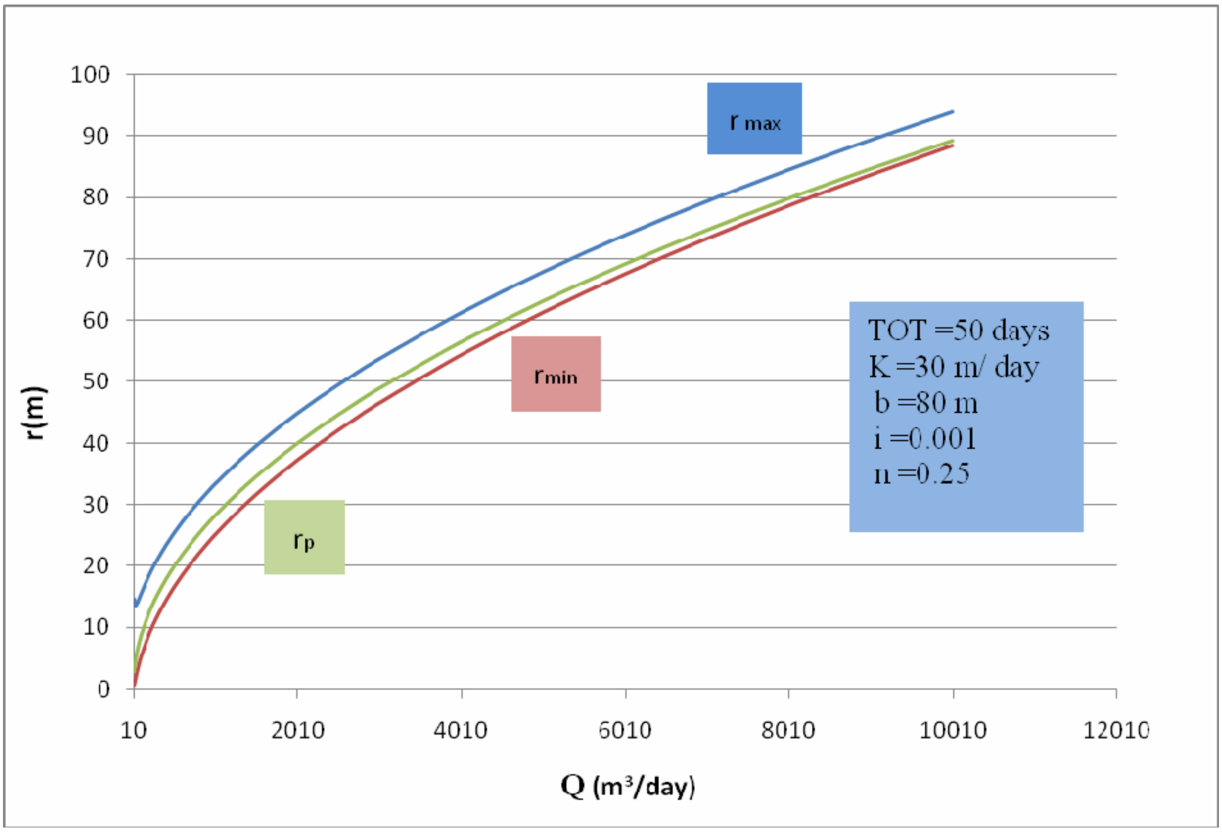


Figure 5.12: *The relation between extraction rate (Q) and r_{max}, r_{min}, and r_P.*

c) Hydraulic Conductivity (K)

The rest of data are kept constant in equation 5.2, 5.3, and 5.4. For this hydraulic conductivity varies between 0.001 – 100 m/day. Figure 5.13 shows the relation between the hydraulic conductivity (K) and maximum, minimum, and perpendicular radiuses r_{max}, r_{min}, and r_P respectively.

Up gradient protection distance is increasing with increasing hydraulic conductivity. Down gradient protection distance is decreasing with increasing hydraulic conductivity. Perpendicular protection distance is not affected by hydraulic gradients.

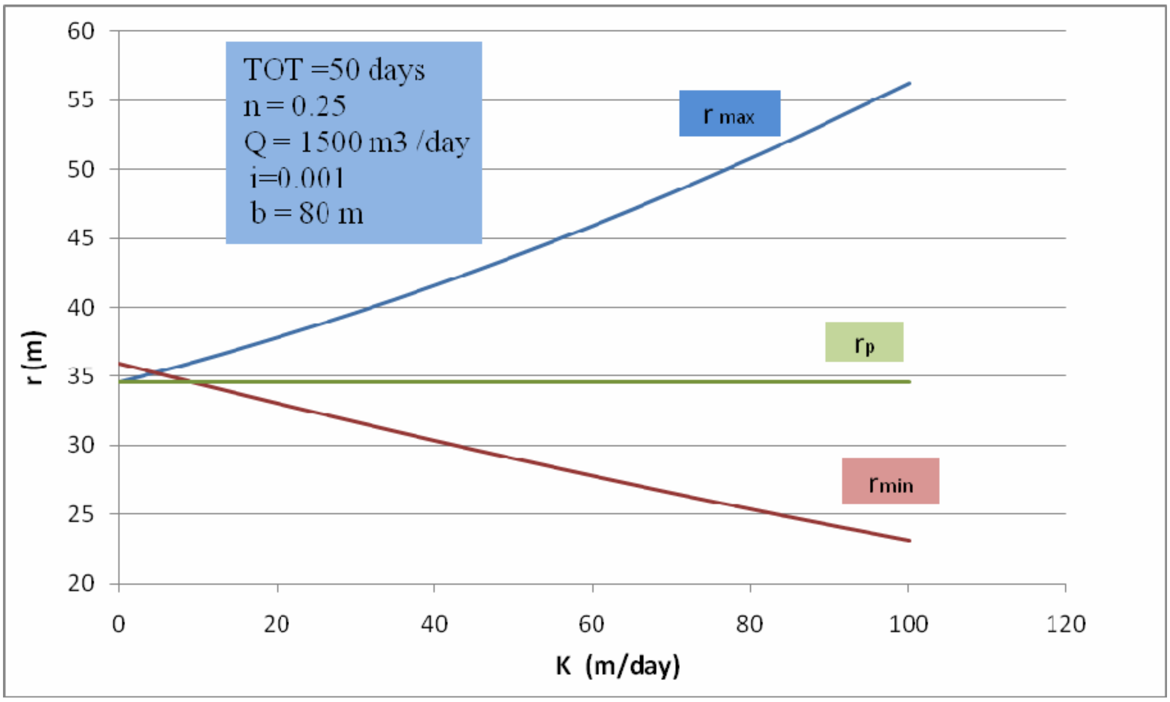


Figure 5.13: *The relation between hydraulic conductivity (K) and* r_{max}, r_{min}, *and* r_P.

d) Aquifer Thickness (b)

The rest of data are kept constant in equation 5.2, 5.3, and 5.4. For this aquifer thickness (b) varies between 0.1 – 1000 m. Figure 5.14 shows the relation between the logarithm of aquifer thickness and maximum, minimum, and perpendicular radiuses r_{max}, r_{min}, and r_P respectively.

Up gradient, down gradient and perpendicular protection distance is increasing with decreasing aquifer thickness.

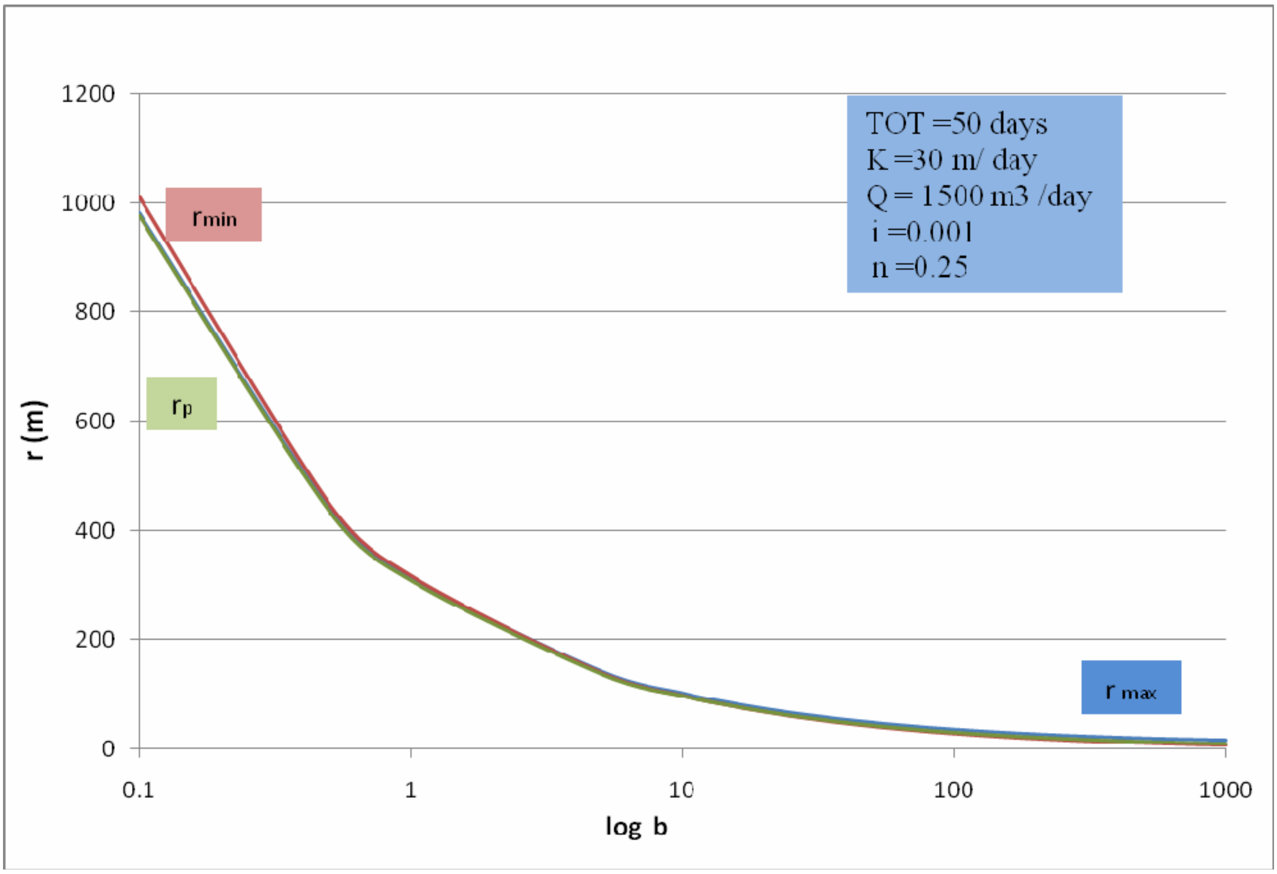


Figure 5.14: *The relation between aquifer thickness (b) and r_{max}, r_{min}, and r_P.*

e) Effective Porosity (n)

The rest of data are kept constant in equation 5.2, 5.3, and 5.4. For this effective porosity (n) varies between 0.01 – 0.5. Figure 5.15 shows the relation between the effective porosity and maximum, minimum, and perpendicular radiuses r_{max}, r_{min}, and r_P respectively.

Up gradient, down gradient and perpendicular protection distance is increasing with decreasing porosities.

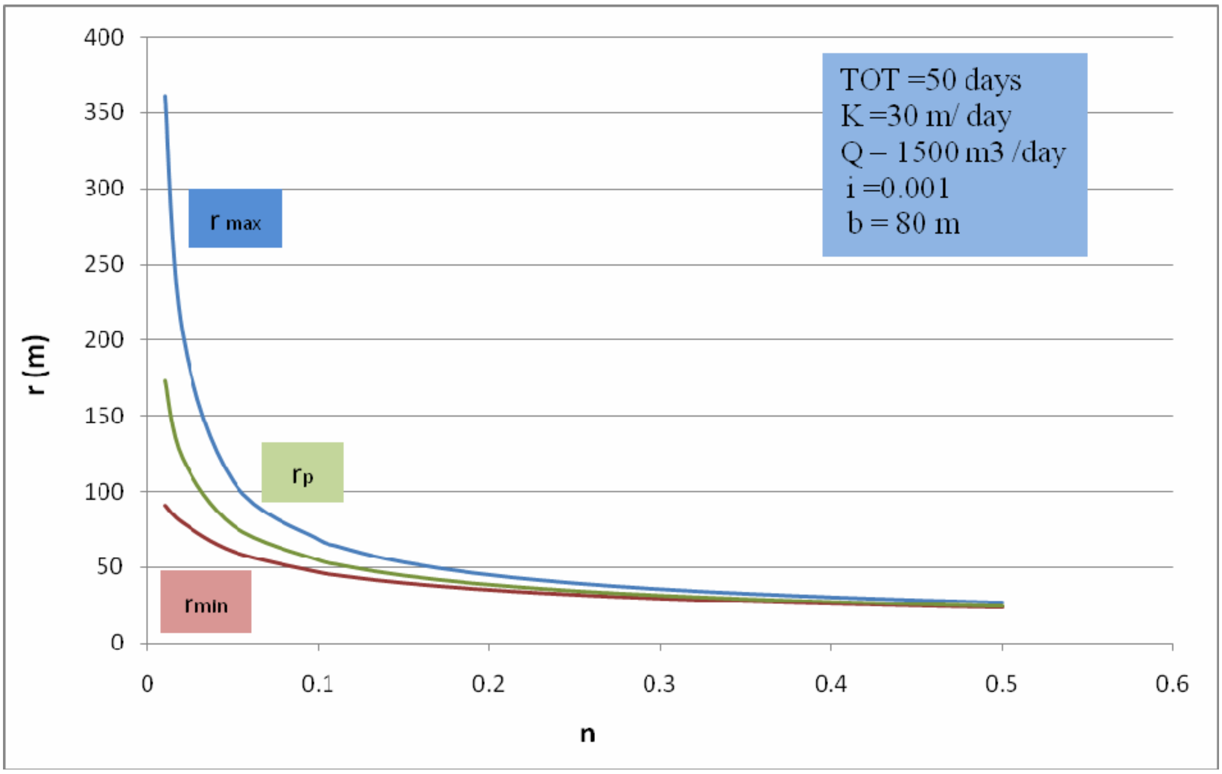


Figure 5.15: *The relation between effective porosity (n) and* r_{max}, r_{min}, *and* r_P.

Regarding the results of sensitive analysis for analytical method showed that there are no upper or lower limits on values of gradient, extraction rate, hydraulic conductivity, and aquifer thickness. The only witnessed anomalies are immediately on using low values of effective porosity. Without using effective porosities smaller than 0.1 however, the calculation of r should be correct. Effective porosities smaller than 0.1 are uncommon for aquifers.

5.2.3 Wellhead Analytic Element Model (WhAEM2000)

The U.S. Environmental Protection agency EPA's Wellhead Analytic Element Model, WhAEM2000 is a computer tool to support step-wise, progressive modeling, and delineation of source water areas for pumping wells. Each solution was conceptually more sophisticated, and it is assumed that the corresponding calculated capture zones were progressively more realistic. The emphasis of the WhAEM2000 project on “ease-of-use” and computational efficiency does not release the modeler, from responsibilities in justifying the conceptual models, and defending the reasonableness of the solutions. The uncertainties are emphasized in conceptualization of the boundary conditions in this study, but uncertainties in parameterization are also important.

WhAEM2000 is public domain and no-cost software, and while it is intended to capture the basics of groundwater modeling in support of USA efforts in source water assessments and wellhead protection, it is also intended to stimulate innovation in software design and modeling practice in the private sector **(http://www.epa.gov, 2007).**

The calculations of WHPA dimensions using WhAEM2000 depend on several parameters, including the magnitude and direction of the ambient flow near the well or well field, which is challenging to characterize. The magnitude of the uniform flow is denoted by Q_o (m^2/day), and can be estimated from the hydraulic gradient i [-] and the aquifer transmissivity kH (hydraulic conductivity k times saturated aquifer thickness H) (m^2/day) **(Kraemer et al., 2007).** The magnitude of the uniform flow rate is calculated as

$$Q_o = kHi \qquad \textbf{5.7}$$

The flow Q_o is the total amount of water in the aquifer integrated over the saturated thickness, per unit width of the aquifer.

The shape and size of a simplified time-of-travel capture zone can be related to a dimensionless travel time parameter, Ť, defined as

$$\check{T} = \frac{T}{T_0} \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \quad \underline{5.8}$$

Where T is the time-of-travel and T_o is a reference time defined as:

$$T_0 = \frac{nHQ}{2\pi Q_0^2} \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \quad \underline{5.9}$$

Where n is the aquifer porosity [-], and Q (m^3/day) is the pumping rate of the well.

When $\check{T} \leq 0.1$, the radius (R) centered on the well, including a safety factor for a non-zero ambient flow field, is given by

$$R = 1.1543\sqrt{\frac{(QT)}{(\pi Hn)}} \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \quad \underline{5.10}$$

When $0.1 < \check{T} \leq 1$, the R is given by

$$R = L_s[1.161 + \ln(0.39 + \check{T})] \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \quad \underline{5.11}$$

Where L_s is the distance from the well to the stagnation point down gradient from the well given by

$$L_s = \frac{Q}{2\pi Q_0} \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \quad \underline{5.12}$$

And where the eccentricity δ is the measure of the deviation from center of circular to center of well given by

$$\delta = L_s[0.00278 + 0.652\check{T}] \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \quad \underline{5.13}$$

When $\check{T} > 1$, a uniform flow envelope, the so-called boat-shaped capture zone, can be defined as

$$X = y/\tan\,(y/L_s) \qquad \text{5.14}$$

Where y is bounded by

$$-\frac{Q}{2Q_0} < y < +\frac{Q}{2Q_0}$$

And clipped at the up-gradient distance Lu given by

$$L_u = L_s[\check{\mathrm{T}} + \ln(\mathrm{e} + \check{\mathrm{T}})] \qquad \text{5.15}$$

And where (e = 2.718) **(Kraemer et al., 2007).**

This calculation sequence and results are illustrated in Figure (5.16).

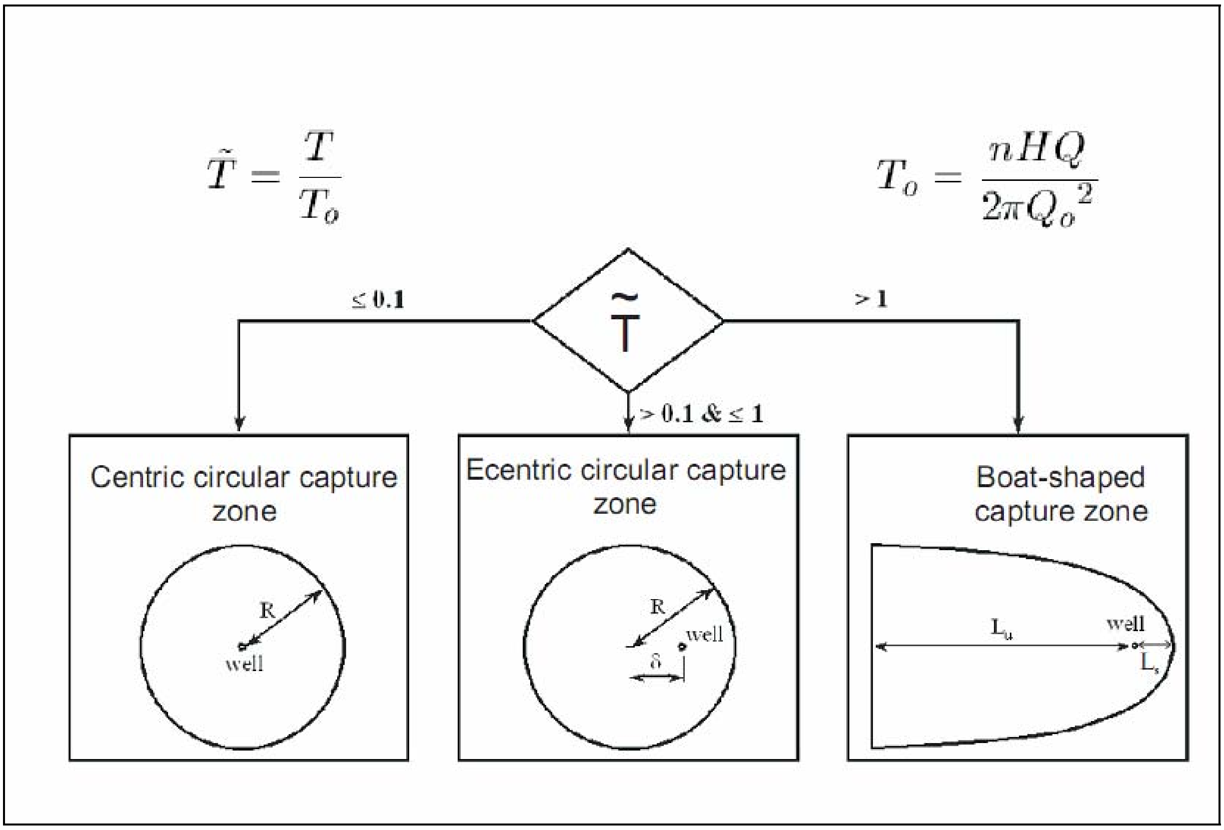


Figure 5.16: *Simplified delineation techniques for a well pumping at rate Q, in an ambient flow field Q_o, with aquifer saturated thickness H and porosity n, and time of travel capture zones of time T* ***(Kraemer et al., 2007).***

Example:

An excel sheet was developed to compute the WHPA dimensions using equation (5.7, 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14, and 5.15). An example of the calculation used well name is Al-Daraj 1, Well number R/311, With flow $Q = 60\ m^3/hr$, Operating hours = 10 (hr/day) Porosity n = 0.25 (25%) and aquifer thickness b = 100 m, hydraulic conductivity k = 30 m/ day , Depth to water = 47.71 m , Z Coordinate = 46.05 m, Far from well to sea = 3773 m, time of travel TOT = 50 days, 2 years (730 days), 5 years (1825 days).

The mean flow per day = $60 \times 10 = 600\ m^3/day$

Aquifer depth (b) = 100 m **(Table 5.3)**

The hydraulic Gradient i = (46.05-47.71)/3773 = -0.00044

The ambient flow $Q_o = 30*100*0.00044 = 1.32\ m^2/day$

The reference time $T_o = \frac{0.25*100*600}{2\pi*1.32^2} = 1370.1356$ day

For TOT = 50 days

$Ť = 50 / 1370.1356 = 0.0365$ **$Ť \leq 0.1$**

$R_{50day} = 1.1543 \sqrt[2]{\frac{600*50}{\pi*100*0.25}} =$ **22.56 m**

For TOT = 2 years (730 days)

$Ť = 730 / 1370.1356 = 0.5328$ **$0.1 < Ť \leq 1$**

$L_s = \frac{600}{2\pi*1.32} = 72.343$ m

$R_{2year} = 72.343(1.161 + \ln(0.39 + 0.5328)$ = **78.177 m**

$\delta = 72.343(0.00278 + 0.0652 * 0.5328)$ = **25.33 m**

For TOT = 5 years (1825 days)

$\check{T}$ = 1825 / 1370.1356 = 1.3318 **$\check{T} > 1$**

$-Q/2Qo < y < +Q/2Qo \rightarrow -227.27 < y < +227.27$

Y_{max} = **227.27 m**

L_s = **72.343 m**

L_u = 72.343(1.3318+ln(2.718+1.3318) = **197.53 m**

Figure (5.17) represents the zones boundary of well number R/311 at travel of time 50 days, 2years and 5 years. This figure shows industrial installations are located out of the three zones.

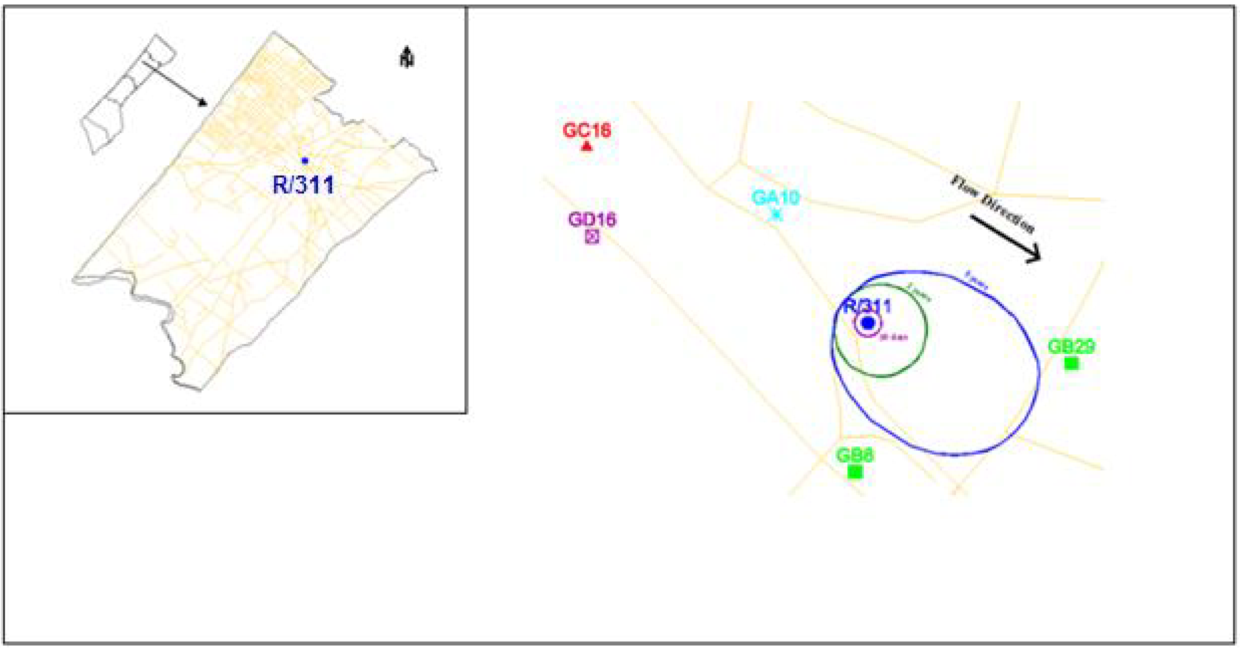


Figure 5.17: *Composite time of travel capture zones with 50 days, 2,5years for the well number R/311using the Wellhead Analytic Element Model (WhAEM2000).*

The WhAEM2000 method using equation (5.7, 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14, and 5.15) was applied for all municipal wells in the study area boundaries. Table (5.9) represents the results for determining the zone boundary at 50 days TOT for each well. The boundary of 50 days TOT and the industrial installations are shown in Figure (5.18). Table (5.10 and 5.11) represent the zone boundary at 2 years and 5 years TOT for each well in Gaza Governorate boundaries respectively. The WHPA for 2 year and 5 year are shown in Figure (5.19, 5.20).

The average of the travel time parameter ($\check{T}$) of 50 days is 0.0626 (dimensionless), 81% from values $\check{T}$ is less than 0.1 and the average of radius (R) is about 43 m, 19% between ($0.1< \check{T} < 1$) and the average of radius (R) and the average of eccentricity (δ) is about 36 m, 7 m respectively and no value of $\check{T}$ more than 1. For 2 year ($\check{T}$) is 0.9065, 34% from $\check{T}$ values is less than 0.1 and the average of radius (R) is about 156 m, 34% between ($0.1< \check{T} < 1$) and the average of radius (R) and the average of eccentricity (δ) is about 136 m, 32m respectively and 32% from $\check{T}$ values is more than 1 and the average boat shaped radiuses L_u, L_s and Y_{max} are about 276 m, 79 m, 250 m respectively. For 5 year ($\check{T}$) is 2.2664, 23% from $\check{T}$ values is less than 0.1 and the average of radius (R) is about 242 m, 32% between ($0.1< \check{T} < 1$) and the average of radius (R) and the average of eccentricity (δ) is about 254 m, 69 m respectively and 45% from $\check{T}$ values is more than 1 and the average L_u, L_s and Y_{max} are 454 m, 79 m, 250 m respectively.

From these results it can be recommended that by using WhAEM2000 method any industrial insulation should be prohibited in any boat shaped radiuses L_u, L_s and Y_{max} are 454 m, 79 m, and 250 m respectively around the well.

Table (5.12) summarized the industrial installations locate in the zones at 50 days, 2 years and 5 years TOT when these are shown in Figure (5.21).

Table 5.9: *Summary of the application of Wellhead Analytic Element Model.*

TOT	Well field	ID
50 Days	NO Well field	NO Symbolic Figure
2 Years	R/25A,R/25B,R/25C,R/25D	GB53
	R/114,R/314,R/315,E/154,E/154A,E/157,R/162BA, R/162CA,R/162EA,R/162LA, R/162LB,R/162D,R/162G,R162H,R/162HA	GB4,GD8
5 Years	R/75	GD11
	R/114,R/314,R/315,E/154,E/154A,E/157,R/162BA, R/162CA,R/162EA,R/162LA,R/162LB,R/162D,R/162G ,R162H,R/162HA	GB57

Table 5.10: *WHPA radius at 50 days TOT for each well in Gaza Governorate by using WhAEM2000.*

No.	Well No.	Ť	(Ť ≤ 0.1)	(0.1<Ť≤1)		
			$R_{50\ day}$	$R_{50\ day}$	δ	WHPA Direction
1	E/154	0.098520262	87.37359301			
2	E/154A	0.106512		73.3469952	11.4951066	150^0
3	E/157	0	61.78246011			
4	R/162G	0.008621389	62.34158879			
5	R/162LA	0.007697123	84.07527907			
6	R/162LB	0.013479986	98.04778156			
7	R/162EA	0.00233838	58.249062			
8	R/162BA	0.09826702	50.44516744			
9	R/162CA	0.082558058	55.25991225			
10	R/162D	0.090535075	61.78246011			
11	R/162H	0.004760849	61.3999025			
12	R/162HA	0.009881093	47.56015997			
13	R/314	0.222685702		33.5303983	7.39316466	150^0
14	R/315	0.259143444		29.3071603	6.90529183	150^0
15	R/114	0.39103712		29.6979555	8.37565523	150^0
16	R/25B	0.006650367	49.42596809			
17	R/25A	0.016617721	46.5992496			
18	R/25C	0.000795785	36.8399415			
19	R/25D	0.000985104	49.42596809			
20	R/308	0.025662781	24.04878998			
21	R/311	0.03649274	22.55976471			
22	R/313	0.079734022	25.87782488			
23	R/75	0.001886072	41.77256722			
24	R/74	0.051369458	23.35157498			
25	R/309	0.006120625	21.70814371			
26	R/305	0	27.35773317			
27	R/310	0.004439895	27.35773317			
28	R/306	0.001146437	26.9640762			
29	R/312	0.001298634	22.12166932			
30	R/112	0.163097641		47.2208793	9.05927242	-30^0
31	R/254	0.296976235		36.534656	9.1347058	-30^0
32	R/265	0.000641461	50.44516744			
33	R/113A	0.01086256	39.13491262			
34	R/277	0.085417178	42.28685435			
35	R/280	0.219853094		25.1269716	5.50917313	150^0
36	R/293	0.014460977	41.18830674			
37	R/307	0.033538735	24.04878998			

No.	Well No.	Ť	(Ť ≤ 0.1)	(0.1<Ť≤1)		
			$R_{50\ day}$	$R_{50\ day}$	δ	WHPA Direction
38	F/191	0	36.40566375			
39	F/192	0.003575058	51.48538343			
40	R/270	0.023834732	24.14878538			
41	G/50	0.166981103		23.9563859	4.64550547	-30^0
42	F/203	0.041268367	39.88040652			
43	F/205	0.028864202	17.83505999			
44	G/57	0.000720636	28.55895229			
45	G/56	0.013785538	30.14675366			
46	F/208	0.043905348	25.54390347			
47	G/51	0.166548062		23.9551069	4.6397782	-30^0

(The data of (Q) and (n) from Table 5.1, (b) from Table 5.3, i from table 5.4).

(Hydraulic Conductivity (K) =30m/day).

Table 5.11: *WHPA radius at 2 years TOT for each well in Gaza Governorate by using WhAEM2000.*

No.	Well No.	Ť	(Ť ≤ 0.1)	(0.1<Ť≤1) 2 year			(Ť ≥ 1) 2year				
			R(m)	R (m)	δ(m)	WHPA Direction	L_u(m)	L_s(m)	WHPA Direction	-Q/2Q0<y<Q/2Q0	Y_{max} (m)
1	**E/154**	1.438395831					488.22	170.52	150^0	535.71	535.71
2	**E/154A**	1.54113839					475.91	159.15	150^0	500.00	500.00
3	**E/157**	0	236.07								
4	**R/162G**	0.124744195		205.30	34.75	150^0					
5	**R/162LA**	0.111370845		277.50	44.45	150^0					
6	**R/162LB**	0.195043971		324.74	67.52	150^0					
7	**R/162EA**	0.033834379	222.56								
8	**R/162BA**	1.421840514					281.47	99.023	150^0	311.09	311.09
9	**R/162CA**	1.19454514					302.81	118.34	150^0	371.79	371.79
10	**R/162D**	1.309965824					341.55	126.35	150^0	396.94	396.94
11	**R/162H**	0.068885454	234.60								
12	**R/162HA**	0.142971039		156.54	28.26	150^0					
13	**R/314**	3.222073425					250.01	49.96	150^0	156.97	156.97
14	**R/315**	3.749586053					225.82	40.20	150^0	126.32	126.32
15	**R/114**	5.65797579					252.94	32.49	150^0	102.09	102.09
16	**R/25B**	0.096225181	188.85								
17	**R/25A**	0.240444337		155.63	35.490	150^0					
18	**R/25C**	0.011514338	140.76								
19	**R/25D**	0.01425362	188.85								
20	**R/308**	0.3713187		82.05	22.62	150^0					
21	**R/311**	0.532716536		78.17	25.33	150^0					
22	**R/313**	1.153683737					141.40	56.39	150^0	177.16	177.16
23	**R/75**	0.027289862	159.61								
24	**R/74**	0.743272532		81.53	30.90	-30^0					
25	**R/309**	0.088560252	82.94								
26	**R/305**	0	104.53								
27	**R/310**	0.064241519	104.53								
28	**R/306**	0.016587971	103.02								
29	**R/312**	0.018790133	84.52								
30	**R/112**	2.359884667					330.82	83.02	-30^0	260.82	260.82
31	**R/254**	4.29699448					290.45	46.50	-30^0	146.11	146.11
32	**R/265**	0.009281397	192.750								
33	**R/113A**	0.157172046		128.93	24.32	-30^0					
34	**R/277**	1.235914186					232.43	89.03	-30^0	279.70	279.70
35	**R/280**	3.18108799					186.85	37.70	150^0	118.44	118.44
36	**R/293**	0.209238078		136.76	29.33	-30^0					

No.	Well No.	Ť	(Ť ≤ 0.1)	(0.1<Ť≤1) 2 year			(Ť ≥ 1) 2year				
			R(m)	R (m)	δ(m)	WHPA Direction	L_u(m)	L_s(m)	WHPA Direction	-Q/2Q0<y<Q/2Q0	Y_{max} (m)
37	**R/307**	0.485277081		83.05	25.79	-30^0					
38	**F/191**	0	139.10								
39	**F/192**	0.051728057	196.72								
40	**R/270**	0.344868382		82.097	21.91	-30^0					
41	**G/50**	2.416075074					168.59	41.60	-30^0	130.71	130.71
42	**F/203**	0.597118301		138.68	47.36	-30^0					
43	**F/205**	0.41764054		61.19	17.76	-30^0					
44	**G/57**	0.010426997	109.12								
45	**G/56**	0.199465049		99.927	20.98	-30^0					
46	**F/208**	0.63527318		88.96	31.27	-30^0					
47	**G/51**	2.40980934					168.50	41.66	-30^0	130.88	130.88

**** (The data of (Q) and (n) from Table 5.1, (b) from Table 5.3, i from table 5.4).***

****(Hydraulic Conductivity (K) =30m/day).***

Table 5.12: *WHPA radius at 5 years TOT for each well in Gaza Governorate by using WhAEM2000.*

No.	Well No.	Ť	(Ť ≤ 0.1)	(0.1<Ť≤1) 5year			(Ť ≥ 1) 5year				
			R (m)	R (m)	δ(m)	WHPA Direction	L_u(m)	L_s(m)	WHPA Direction	-Q/2Q0<y< Q/2Q0	Y_{max} (m)
1	**E/154**	3.595989578					927.43	170.52	150^0	535.71	535.71
2	**E/154A**	3.852845976					912.83	159.16	150^0	500	500
3	**E/157**	0	373.26								
4	**R/162G**	0.311860488		333.41	85.16	150^0					
5	**R/162LA**	0.278427113		447.09	108.69	150^0					
6	**R/162LB**	0.487609928		535.48	166.65	150^0					
7	**R/162EA**	0.084585947	351.91								
8	**R/162BA**	3.554601284					533.81	99.02	150^0	311.09	311.09
9	**R/162CA**	2.986362851					559.49	118.35	150^0	371.79	371.79
10	**R/162D**	3.27491456					640.03	126.35	150^0	396.94	396.94
11	**R/162H**	0.172213636		320.40	63.01	150^0					
12	**R/162HA**	0.357427598		256.11	69.43	150^0					
13	**R/314**	8.055183562					521.23	49.96	150^0	156.97	156.97
14	**R/315**	9.373965133					477.12	40.21	150^0	126.32	126.32
15	**R/114**	14.14493948					551.48	32.50	150^0	102.09	102.09
16	**R/25B**	0.240562952		261.01	59.53	150^0					
17	**R/25A**	0.601110842		256.27	87.80	150^0					
18	**R/25C**	0.028785846	222.57								
19	**R/25D**	0.03563405	298.61								
20	**R/308**	0.92829675		132.78	56.17	150^0					
21	**R/311**	1.331791339					197.53	72.34	150^0	227.29	227.29
22	**R/313**	2.884209342					259.82	56.39	150^0	177.16	177.16
23	**R/75**	0.068224655	252.37								
24	**R/74**	1.858181329					214.23	63.40	-30^0	199.17	199.17
25	**R/309**	0.22140063		114.23	25.12	-30^0					
26	**R/305**	0	165.28								
27	**R/310**	0.160603797		142.56	27.16	-30^0					
28	**R/306**	0.041469927	162.90								
29	**R/312**	0.046975332	133.65								
30	**R/112**	5.899711669					668.62	83.02	-30^0	260.82	260.82
31	**R/254**	10.7424862					620.53	46.51	-30^0	146.11	146.11
32	**R/265**	0.023203492	304.77								
33	**R/113A**	0.392930115		211.71	59.84	-30^0					
34	**R/277**	3.089785464					431.72	89.03	-30^0	279.71	279.71
35	**R/280**	7.952719974					389.09	37.70	150^0	118.44	118.44
36	**R/293**	0.523095195		225.54	72.47	-30^0					

No.	Well No.	Ť	(Ť ≤ 0.1)	(0.1<Ť≤1) 5year			(Ť ≥ 1) 5year				
			R (m)	R (m)	δ(m)	WHPA Direction	L_u(m)	L_s(m)	WHPA Direction	-Q/2Q0<y<Q/2Q0	Y_{max} (m)
37	**R/307**	1.213192702					208.65	80.81	-30^0	253.86	253.86
38	**F/191**	0	219.95								
39	**F/192**	0.129320143		267.99	46.15	-30^0					
40	**R/270**	0.862170955		133.39	54.37	-30^0					
41	**G/50**	6.040187686					341.60	41.61	-30^0	130.71	130.71
42	**F/203**	1.492795752					354.00	120.80	-30^0	379.51	379.51
43	**F/205**	1.044101349					153.04	64.60	-30^0	202.94	202.94
44	**G/57**	0.026067493	172.54								
45	**G/56**	0.498662623		164.79	51.81	-30^0					
46	**F/208**	1.588182951					228.66	75.02	-30^0	235.67	235.67
47	**G/51**	6.024523349					341.32	41.66	-30^0	130.88	130.88

***** *(The data of (Q) and (n) from Table 5.1, (b) from Table 5.3, i from table 5.4).***

(Hydraulic Conductivity (K) =30m/day).

5.3 Evaluation of Methods

In this section, advantages and disadvantages of the used three methods are described.

The advantages of Calculated Fixed Radius (CFR) method that it is simple, low cost, and does not require significant amount of data acquisition, however **the disadvantages** consist of generally not representative of the groundwater system, prone to legal challenges, tends to over protect downgradient and under protect upgradient, and often yields larger area than other methods.

The advantages of Analytical Method are incorporates hydrogeologic characteristics of the aquifer, groundwater flow and hydrogeologic boundaries into the model, provide for a defensible delineation of the WHPA, and are based on site-specific information. Often produces a WHPA that is smaller than the one produced using CFR however **the disadvantages** consist of assumes a uniform aquifer (note that some exceptions to this do exist), requires significant expertise, and is moderately costly.

The advantages of WhAEM2000 method are the geohydrology computer model of groundwater flow, provides a more accurate delineation of the WHPA. The method accounts for variation in hydraulic parameters and boundary conditions. It often produces a smaller area to manage than other methods. However, **the disadvantages** consist of costly relative to other methods, requires significant amount of data collection and high level of expertise to set up the grid of the model.

Map 5.22 represent the difference between three methods at 50 days TOT and Figures 5.23, 5.24 represent the difference between three methods at 2, 5 years TOT.

Chapter (6)

Evaluation and Monitoring

6.1 Introduction

The problem of hazardous waste pollution is a serious one and is expected to worsen in the future. This is because generation of hazardous waste is increasing rapidly from various activities throughout the world including from industry, agriculture, communities, businesses, services, ports, hospitals, and laboratories.

In the Gaza Strip the improper industrial practices and the industrial may impose a real threat to the environment in the future. The main polluting industries include the textile dyeing, jeans washing factories, car washing workshops, electroplating, painting, foaming industries, etc. Most of these industries; could be hazardous, are located in the area that has the best fresh groundwater.

Most of the factories in Gaza Strip discharge their wastewater without proper treatment or even without any treatment to the municipal sewerage system or surrounding dunes. Furthermore, the solid waste, which may include hazardous waste, is badly managed and is dumped without separation in the municipal landfills or open areas and more than 15,526 tons/year of solid waste is generated from the industries in the Gaza Strip. Also the gaseous emissions from some industries are not monitored, and no treatment is used which endanger the public health of the workers and the people living at close proximity to these industries **(MEnA, 2001).**

This chapter describes the existing conditions related to hazardous materials and waste in Nahawnd Plastic Industry and also evaluates the potential significant hazard through operations activities. This industry was selected since it falls in the 50 days TOT zone of WHPA. It may induce a pollution to well that fall in the same zone.

6.2 Hazardous Material and Waste

The hazardous material defined as any material that because of its quantity, concentration, or physical or chemical characteristics, poses a significant present or potential hazard to human health and safety or to the environment if released into the workplace or the environment. Hazardous materials include, but are not limited to, hazardous substances, waste, and any material which a handler or the administering regulatory agency has a reasonable basis for believing would be injurious to the health and safety of persons or harmful to the environment if released into the workplace or the environment. A number of properties may cause a substance to be considered hazardous, including toxicity, corrosivity, or reactivity.

The hazardous waste defined as a waste or combination of waste which because of its quantity, concentration, or physical, chemical, or infection characteristics, may cause or significantly contribute to an increase in mortality or an increase in serious irreversible or incapacitation-reversible illness; or pose a substantial present or potential hazard to human health or the environment, due to factors including, but not limited to, carcinogenicity, acute toxicity, chronic toxicity, bio-accumulative properties, or persistence in the environment, when improperly treated, stored, transported, or disposed of or otherwise managed **(CEO, 2004).**

6.3 Evaluation

The Purpose of evaluation is to assign relative significance of predicted impacts and to determine the order which impacts could be avoided, mitigated or compensated.

The method for evaluating the potential waste management impacts during construction and operation phases include the following:

- Estimation of the types and quantities of wastes generated.
- Assessment of potential secondary environmental impacts from the management of solid waste with respect to potential hazards, air and odor emissions, noise, wastewater discharges, and traffic.

- Impacts on the capacity of waste collection, transfer, and disposal facilities.

If not properly managed, the handling and disposal of waste materials may cause environmental nuisance and impacts **(http://www.epd.gov., 2008).** It evaluation may also induce a critical remedial actions.

6.3.1 Remedial Action

Remedial action can take several forms:

1- Avoidance or Prevention:

Avoidance is generally the most wanted. If an impact can be avoided or prevented, then mitigation and monitoring expenses are also avoided. This is the main objective of development WHPA and all other prevention of isolation the waste material.

2- Mitigation:

Application of design, construction, or scheduling principles and practices to minimize or eliminate potential adverse impacts and, where possible, enhance environmental quality

3- Compensation:

1. Compensation is often associated with residual impacts that remain after mitigative options.
2. Compensation measures generally involve monetary payments for damage caused by the project.
3. Because cumulative effects involve several different projects, mitigation of these effects requires that impact mitigation and/or compensation should occur at a regional scale, not project scale **(Afifi, 2006).**

6.3.1.1 Mitigation Measures

Mitigation includes measures to avoid the impact altogether by not taking a certain action or parts of an action or to minimize potential effects by limiting the degree or magnitude of a proposed action and its implementation.

The mitigation measures have to be implemented in relation to circumventing or ameliorating those impacts that have been assessed as having a 'moderate adverse impact', or a 'major adverse impact'. The six (6) main developmental issues requiring specific mitigative responses are: dredging, domestic effluents, solid wastes management, energy generation, potable water sourcing, and socio-economic concerns **(http://www.doe.gov., 2008).**

Mitigation measures are required to eliminate / remediate / reduce significant negative environmental impacts.

Mitigation Measures includes:

- Avoiding undesirable impacts altogether by not taking a particular action;
- Minimizing the impacts by limiting the magnitude of the action;
- Rectifying impacts by repairing or restoring particular features of the affected environment;
- Reducing impacts over time by performing maintenance activities during the life of the action; and
- Compensating for impacts by providing additions to or substitutes for the environment affected by the action.

Mitigation measures must be subjected to periodic review and capable of readjustment to ensure that the objective of avoidance is indeed achieved **(USAID, 2005).**

6.4 Monitoring

The monitoring defined as an activity undertaken to provide specific information on the characteristics and functioning of environmental and social variables in space and time.

The purpose of an environmental monitoring program at a low-level waste disposal facility is to protect both people and the environment**.** Monitoring goes hand-in-hand with making impact predictions and proposing prevention, mitigation, or compensation measures. Monitoring involves generating, collecting, analyzing, and evaluating data. To monitor effects, suitable baseline (pre-project) data must also be available for comparison. Therefore, the monitoring program must also include a program for collecting baseline data, as necessary **(Afifi, 2006).**

Monitoring results can be used to:

- Ensure the accuracy and relevance of predictions.
- Judge the effectiveness of remedial measures and make appropriate adjustments if necessary.
- Ensure compliance with all regulations, standards, and environmental operating criteria.
- Monitoring results can also be used to improve the planning and outcomes of subsequent similar projects **(Afifi, 2006).**

6.5 Case Study:

6.5.1 Introduction:

Nahawnd Company is the one of the Gaza Strip industrials for manufacture of plastics which specializes in manufacture of Alafatyl rubber. These Alafatyl rubber used for the edges of the windows and doors to protect and preserve it from damage. This company licensed by the Environment Quality Authority and it was classified as a high-risk industrial installation.

Figuer 6.1: *Aerial photos from Google Earth to the Nahawnd Company.*

Nahawnd Company is among the Group Pollutants B and identified with Symbolic Figure GB53 which located in WHPA for the well field (R/25A, R/25B, R/25C, R/25D) by using CFR method at TOT 50 days as shown in Figure 5.2.

6.5.2 Field Visit

A filed visit was carried out to Nahawnd Company. The visit was to see contents of the industry from inside and outside. It was found that the industry contains four machines as shown in appendix. These machines work to manufacture Alafatyl rubber.

Through the visit, the director of the company Mr. Abdel Fattah Mashharawi assured that the factory was closed three years ago because of lack of raw materials due to the closing crossings. This factory was producing 4-5 tons of Alafatyl rubber each week before it has stopped recently.

Mr. Abdel-Fattah explained how the works of machines that manufacture rubber. Through this explanation it is clear that all waste (solid plastics waste) which is disposed in waste dumped site directly and also clear that all machines work by Electricity. There are no stores for hazardous materials within the factory, such as gasoline.

Figuer 6.2: *Nahawnd field visit to company.*

6.5.3 Evaluation

Through the visit to the Nahawnd Company, the following assessment remarks can be outlined:

- The generated waste from the industry is plastic solid waste which is collected and dumped outside the industry. Therefore, it does not influence the groundwater and doesn't have an impact on the municipal well fall in the same WHPA zone.
- It was investigated that there are no spills of hazardous materials within or outside the industry.

6.5.4 Mitigation Measures

Since the collection of solid waste is outside the industry and no spills of hazardous materials within the WHPA zone, no mitigation measures have been identified as necessary to reduce the anticipated groundwater impacts of the factory.

Chapter (7)

Conclusions and Recommendations

7.1 Conclusions:

Safe drinking water is vital to communities, economy, and health. If groundwater becomes contaminated, it may be lost forever as a water supply or may require very expensive treatment to remain usable. The best way to ensure a safe water supply, now and for the future, is to protect the area nearest a community public supply well from potential hazards**.** This research aims at delineation of WHPA for municipal wells in Gaza Governorate. From this research the following conclusions remarks can be outlined:

- Forty seven drinking water wells were located in Gaza Governorate boundaries and used by Palestinian Water Authority PWA as a main municipal water supply. The wells coordinates are identified by PWA.
- One hundred and forty one facilities those which affect the groundwater and identified by Environment Quality Authority EQA signed on maps by using handheld Global Positioning System (GPS).
- These facilities were classified into 14 types and these types were divided into four groups according to pollution.
- WHPA delineated to all 47 wells by three methods :

1. Calculated Fixed-Radius Method (CFR)

- The average of the radius of 50 days zone is 71 m, for 2 years is 217 m and for 5 years is 429 m. From these results it can be recommended that by using CFR method any industrial insulation should be prohibited in any distance less than 430 m from the well.

- By this method it was found that two industrial insulations in WHPA at 50 days TOT, 13 industrial insulations fall in WHPA at 2 years TOT, and 32 industrial insulations in WHPA at 5 years TOT.

2. Analytical Method

- The average of the ellipse radiuses of 50 days zone r_{max}, r_{min}, and r_p are 42 m, 31 m 37 m respectively, for 2 years are 328 m, 91 m, and 140 m respectively and for 5 years are 862 m, 149 m, and 222 m respectively. From these results it can be recommended that by using analytical method, any industrial insulation should be prohibited in any ellipse radiuses (r_{max}, r_{min}, and r_p) less than 862 m, 150 m, and 223 m respectively around the well.

- By the application of this method for all drinking water wells in the study area boundaries, it was found that no industrial insulation fall in WHPA at 50 days TOT but 2 industrial insulations were fallen in WHPA at 2 years TOT, and 10 industrial insulations in WHPA at 5 years TOT.

- It is clear from the results of sensitive analysis for analytical method showed that there are no upper or lower limits on values of gradient, extraction rate, hydraulic conductivity, and aquifer thickness. The only witnessed anomalies are when using low values of effective porosity. If not using effective porosities smaller than 0.1 however, the calculation of r should be correct. Effective porosities smaller than 0.1 are uncommon for aquifers, so this lower-limit shall not often be encountered.

3. Wellhead Analytic Element Model (WhAEM2000)

- The average of the travel time parameter (Ť) of 50 days is 0.0626 (dimensionless), 81% from values Ť is less than 0.1 and the average of radius (R) is about 43 m, 19% between (0.1< Ť < 1) and the average of radius (R) and the average of eccentricity (δ) is about 36 m, 7 m respectively and no value of Ť more than 1. For 2 year (Ť) is 0.9065, 34% from Ť values is less than 0.1 and the average of radius (R) is about 156 m, 34% between (0.1< Ť < 1) and the average of radius (R) and the average of eccentricity (δ) is about 136 m, 32m respectively and 32% from Ť values is more than 1 and the average boat shaped radiuses L_u, L_s and Y_{max} are about 276 m, 79 m, 250 m respectively. For 5 year (Ť) is 2.2664, 23% from Ť values is less than 0.1 and the average of radius (R) is about 242 m, 32% between (0.1< Ť < 1) and the average of radius (R) and the average of eccentricity (δ) is about 254 m, 69 m respectively and 45% from Ť values is more than 1 and the average L_u, L_s and Y_{max} are 454 m, 79 m, 250 m respectively.

- By the application of this method for all drinking water wells in the study area boundaries, it was found no industrial insulation fall in WHPA at 50 days TOT but 3 industrial insulations were fallen in WHPA at 2 years TOT, and 5 industrial insulations in WHPA at 5 years TOT.

- WhAEM2000 method is the best method because it is the geohydrology computer model of groundwater flow, provides a more accurate delineation of the WHPA. It often produces a smaller area to manage than other methods.

- CFR method is the weakness method because it does not take into account regional groundwater flow, causing a hydraulic gradient. WHPAs identified by these methods may be either too large or too small, resulting in wellhead overprotection or under protection.

- Nahawnd Company is one of the Gaza Strip industrials for manufacture of plastics which was used as a case study. Nahawnd Company falls in WHPA at 50 days TOT by using CFR method. Through the field visit it was found that the generated waste from this industry is solid materials. Therefore, the waste does not affect the groundwater and also there are no spills of hazardous materials within and outside the factory. It follows that no mitigation measures have been identified as necessary to reduce the anticipated groundwater impacts of the factory.

7.2 Recommendations:

The rapid rate of population growth in the Gaza Strip and dependence upon groundwater as a single water source present a serious challenge for future political stability and economic development. So, hard effort should be applied to prevent the increase of deterioration of water quality in the area. Accordingly, the following recommendations should be considered:

1. The produced WHPA maps are recommended to be used by Palestinian Water Authority for licensing the new wells, and by Environment Quality Authority for give the licenses to any new industrial installations in Gaza Governorate.
2. Allow for licensing and registration of groundwater through regulation by applying a modest registration fee for unlicensed wells.
3. Wellhead Analytic Element Model is recommended to be used for all wells, because it provides a more accurate delineation of the wellhead protection area. The model is available for PWA and EQA use.
4. Calculated Fixed Radius method is recommended to be used to calculate the wellhead protection area rapidly where less information and data are required.
5. It is recommended to apply the three methods for all wells and industrial installations in Gaza Strip.
6. It is recommended to study and apply of wellhead protection area before the construction of any new urban area.
7. The Wellhead Protection Plan should be revised, reviewed, and appropriately updated at least once a year by PWA and EQA.
8. To reduce the extension of wellhead protection area in critical areas, the rate of pumping wells should be reduced.

9. All industrial installations that fall in the 50 day or 2 years or 5 years TOT, should be visited and evaluated by EQA. The evaluation may result in recommending mitigation measures to prevent the pollutions to the nearby municipal wells.
10. For storage, spill prevention, emergency response, transport, and disposal of hazardous substances, hazardous wastes, liquid industrial waste, or potentially polluting materials shall be not allowed without approval from Environment Quality Authority.
11. Disposal waste of industrial installations should be monitored periodically to preserve groundwater from any pollutants.
12. Increase public awareness to knowledge of the importance of preserving the groundwater.
13. The research may be further tackled using by modeling approach.

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APPENDIX

A filed visit was carried out to Nahawnd Company. These are some photos to industry from within and outside.

Figuer 1: *A picture for the Nahawnd Company from outside.*

Figuer 2: *A picture for the first machine at the industry.*

Figuer 3: *A picture for the second and third machine at the industry.*

Figuer 4: *A picture for the fourth machine at the industry.*

Figuer 5: *Image for Alafatyl rubber output from the industry.*